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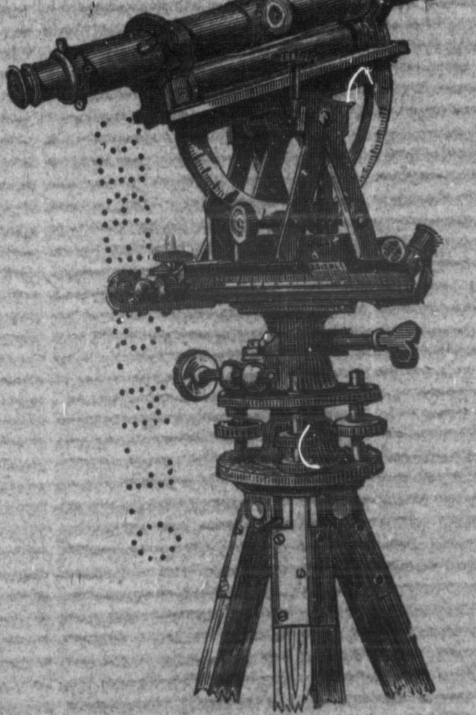

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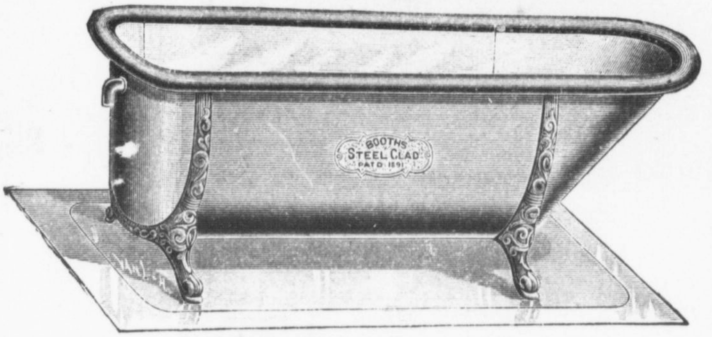

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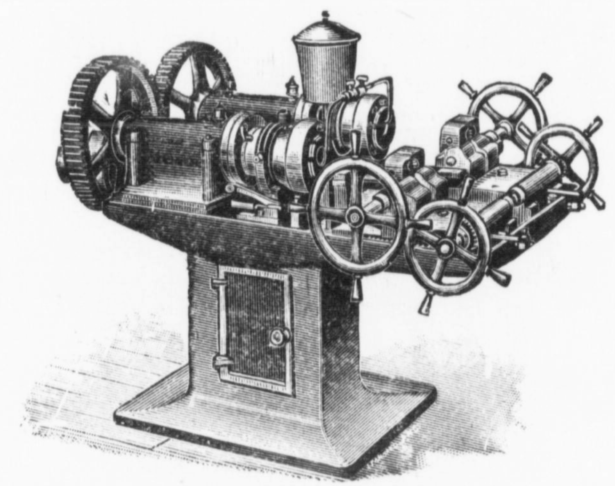

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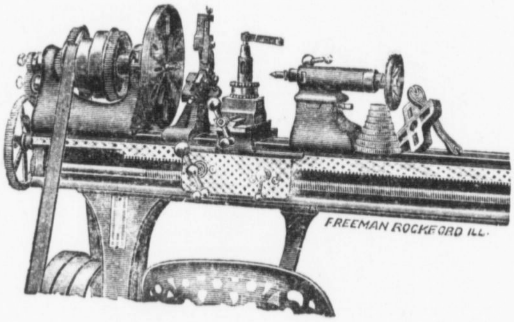
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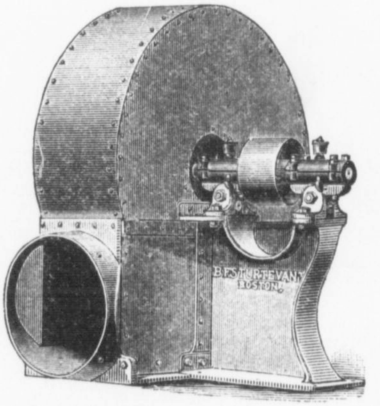

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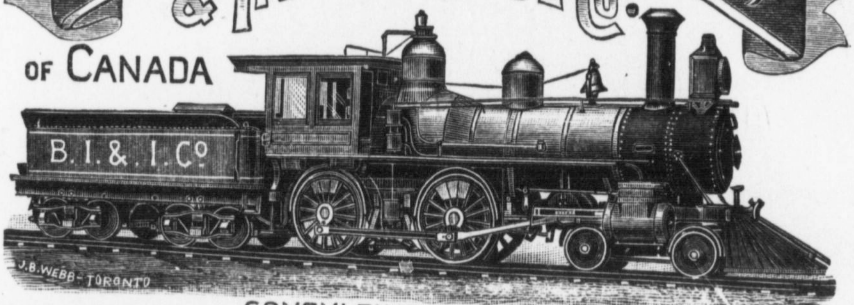

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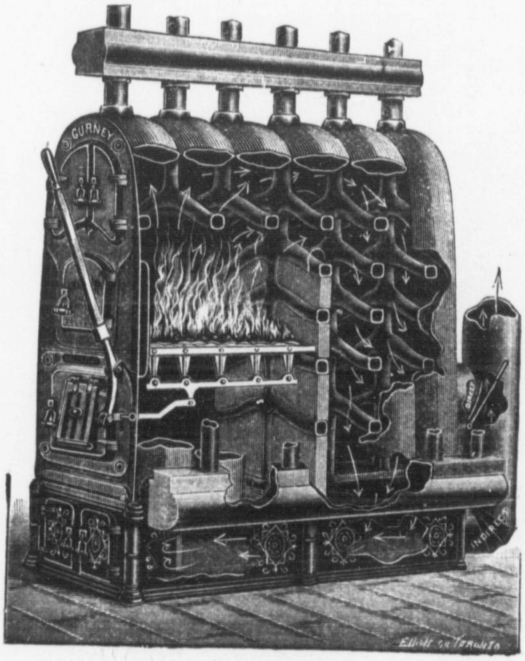

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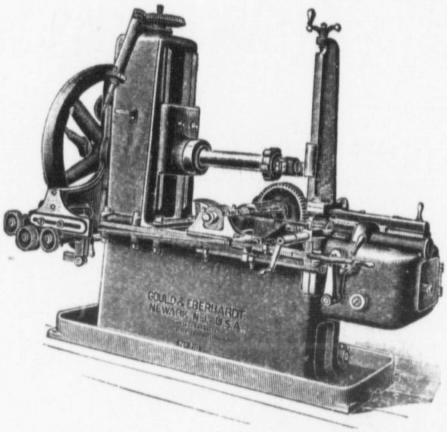
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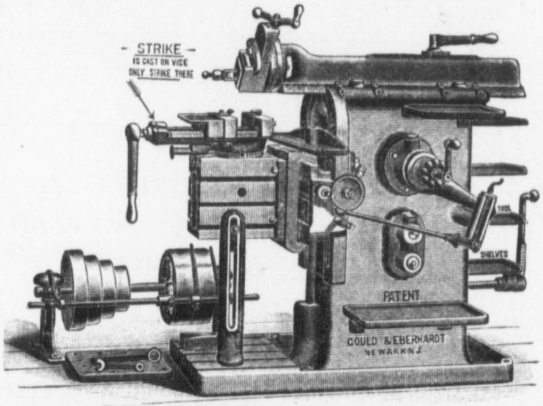
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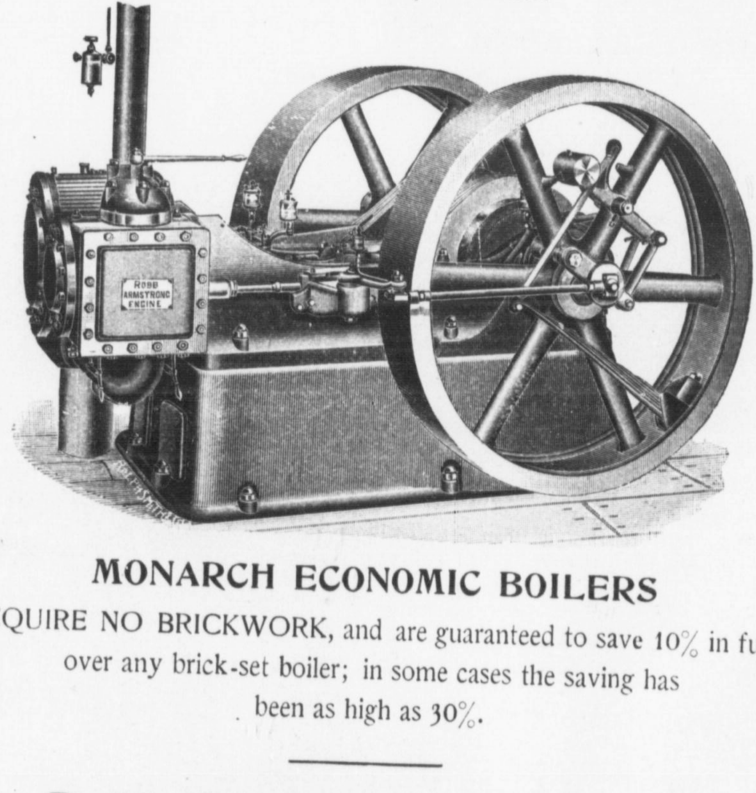

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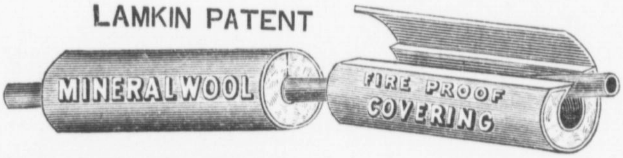

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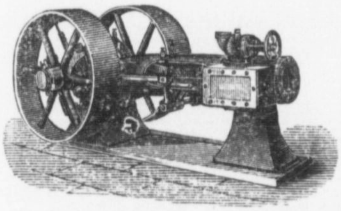

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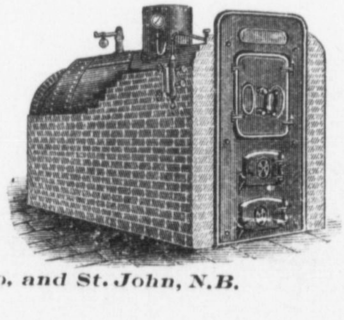

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PREFACE.

The present number contains papers read before the Engineering Society of the School of Practical Science during the session 1894-95.

The Society was organized in the year 1885 by the students then in the School, and has gradually grown since that time. Every alternate Wednesday afternoon during the session is set apart from the regular time of the course for the meetings of the Society, so that students may thus take advantage of them without sacrificing any of their time.

This number shows a marked increase, both in size and in the general character of the papers contained in it, over all previous ones, which is, no doubt, due to the larger number of graduates, but more particularly to the encouragement offered by the Faculty of the School to students writing papers, as a good proportion of our undergraduates have contributed.

A valuable addition is the discussion which has been printed at the end of papers. This discussion has been obtained in most cases by having printed, some weeks before the presentation of a paper, a large number of copies of same, which have been distributed amongst the members and others interested in the subject dealt with. The present number shows that this method of obtaining discussion and thus greatly increasing the value of papers is very satisfactory.

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1,500 copies constitute the present edition, and these will be widely distributed amongst the members and others interested.

April, 1895.

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ENGINEERING SOCIETY

OF

The School of Practical Science

TORONTO

PRESIDENT'S ADDRESS

GENTLEMEN,—It is impossible for me to find words to fully express my thanks and appreciation of the honor you have conferred upon me in electing me president of your Society, for, by so doing, you have made me the recipient of the highest office to which an undergraduate of our school is eligible.

And, if it were not for the support you have given me in the very able committee you have seen fit to elect, I would be unable to undertake, with any degree of assurance, the responsibilities connected with the position, especially as I am expected to fill the place just vacated by one of the best presidents, as well as the most able chairman, the Society has as yet had at its head.

With the assistance of the committee, however, I will do my utmost to give the Society no cause to regret having elected me to fill the chair for the present year.

I am pleased to see that we have with us to-day a number of new members, and it gives me great pleasure, on behalf of the Society, to welcome them to our meetings.

I must also congratulate these gentlemen of the first year upon their choice of a profession, for, undoubtedly, we have before us a greater field for our labors than has any other professional man.

It will not be necessary for me to dwell upon the object of our Society, as copies of the constitution, containing this and other information relating thereto, can be had from the librarian.

Thanks to the untiring efforts of the last committee, our Society is in a first-class financial condition. In addition to this, the roll of last year shows a greater number of members, and greater average attendance, than in any previous year. These facts, I must say, gentlemen, reflect great credit upon the committee of 1893-4.

We cannot expect to be able to make a better showing, financially, for the current year, but I sincerely hope that our average attendance will show another increase.

The time for our meetings, as most of you are aware, has been granted by the council from our regular school hours, and the attendance at these meetings is considered as part of our college course. Apart from this, however, as coming engineers, we should not throw away a chance of hearing valuable papers read and participating in the discussion thereon.

Although the paper before the Society may not be in our own special line of engineering, that is all the more reason we should want to hear it; for, undoubtedly, the broader we are in our studies, the better will be our ability to become thorough as specialists in any of its branches.

Again, as every engineer has, very often in his career, to speak before an assembly of some kind, we should not lose an opportunity to gain confidence in speaking, and also of being able to express our views clearly.

For this purpose, discussions are entered into after every paper is read, thus giving each member a chance to ask questions and state his ideas on the subject under discussion.

This is a golden opportunity, gentlemen, and one that should be grasped by every one of us; for, remember, we are here among friends but three short years, and after that time will have to speak before strangers, who will not (if you will pardon my use of a slang expression) "call us down" when we make a mistake, but will mentally, or perhaps through the press, note the fact. I therefore repeat what I have already said—do not miss a chance to become a speaker.

To make the discussion of papers more general, and also to make our yearly pamphlet more interesting and complete, it was decided at a general meeting, held towards the end of last year, to adopt the plan of having about 150 proof sheets of each paper struck off and distributed among the engineers and specialists on the subject throughout the country, asking them to discuss the paper in writing and send it in to the Society.

The paper and discussions thereon will then be read at the next meeting of the Society, and afterwards printed for the pamphlet.

This plan of securing discussions is, at the present time, working very satisfactorily in a number of American societies, the discussions, in many instances, being as valuable as the papers themselves.

The work of the editor and publishing committee will, under this new system, be less arduous, as it will spread out over the whole year, and will not, as heretofore, be limited to a few weeks. It will also enable the committee to have each year's pamphlet ready for distribution at the end of that year, instead of, as at present, the middle of the next.

I fully believe, therefore, that in the adoption of the preceding scheme, which is due to Mr. C. H. C. Wright, the Society has taken a decided step in the proper direction, and I am looking forward with interest to see the idea carried through successfully this year.

At the first meeting of the present committee last spring, the question of obtaining papers from the undergraduates was brought up, and, after carefully considering the subject from all points, it was decided to petition the council to grant a bonus in the way of marks for these papers. This was done, and as there was not going to be another regular meeting of the council before the examinations Professor Galbraith very kindly called a special meeting of its members to consider our request, the result being that your present committee is authorized to award marks to every student writing and reading a paper before the Society. These marks are not to exceed 100, and are to be awarded according to the value of the paper. All marks over 50 will be considered by the council in granting honors.

Some of you will, no doubt, say that as you do not intend to try for honors, it is no use your thinking of writing on any engineering subject. This, in my opinion, is very poor argument, for you must remember that we are here to become engineers, and should avail ourselves of every opportunity to forward our own interests, as well as those of the Society; and the writing of a paper would be of very great assistance to each one of us. I see, therefore, no reason why we should not have a paper from every second and third year man in our school, as well as a few from the first year; for by so doing we will not only benefit ourselves, but will show the faculty that we fully appreciate the interest that they take in us as a Society.

The library, which is under the control of the Society, is being increased every year, new books on scientific subjects being continually added to it by the faculty, as well as by ourselves. These books are carefully selected, and are the best that can be procured on mining, civil, mechanical, and electrical, as well as architectural work. All members have not only the use of the library, but also the privilege of borrowing, for a certain number of days, any book contained therein.

I hope you will all take an individual interest in any business that may be brought up throughout the year; for, remember, that every motion adopted or rejected will have its effect in forwarding or retarding the advancement of the Society. You should therefore give every matter of business your careful consideration before voting upon it, and by no means hurry a motion through without carefully discussing its effect on the Society.

Finally, I must ask you to watch carefully the work of the committee you have appointed to transact the business of the Society. Give them your instructions and see that they are carried out, for by so doing you will show them that you are interested in their doings, and consequently in the welfare of the Society.

Before sitting down, I wish to refer to the recent appointments made in our school, and in the first place to that of Mr. J. A. Duff, B.A., to the position of lecturer in applied mechanics.

Mr. Duff, as you are all aware, has been intimately connected with our Society for a number of years, and has, perhaps, done more to further its interests than has any other individual member.

The Society has been further honored in that three of its most prominent members have been granted fellowships. I refer to Mr. A. T. Laing, Fellow in Civil Engineering; Mr. K. W. Angus, Fellow in Electrical Engineering; Mr. J. Keele, Fellow in Architecture.

It gives me great pleasure, on behalf of the Society, to congratulate these gentlemen and wish them every success.

A. E. BLACKWOOD.

October, 1894.

GRADING

W. L. Innes, O.L.S., C.E.

The "grading" referred to is for railroad purposes, but the remarks will hold true, to a certain extent, for all kinds of grading. For the sake of economy, the banks are usually formed of the material excavated from the cuttings, side ditches, etc. In some cases, however, it is cheaper to "spoil," or waste, the material, and make up the embankment from "borrow pits." For instance, suppose the cuts and fills for some particular locality of the line do not balance—that is, suppose it would be necessary to haul the excavated material a very long distance to make up a fill—it would probably be cheaper, under these circumstances, to dump it anywhere convenient to the cut, and make the fill from material near at hand to the proposed embankment, as the contractor is usually allowed a certain amount per yard for additional haul over a specified distance. The cuts and fills, under ordinary circumstances, should about balance, care, however, being taken to add about 10 per cent. to the calculated number of cubic yards of filling, as it would take, ordinarily, about $1\frac{1}{10}$ cubic yards of earth, as found in the natural bed, to measure 1 cubic yard in an embankment properly made up.

The contractor is generally paid so much per cubic yard for excavating, and, unless in special cases (an instance of which has already been referred to), he is required to deposit it in an embankment; so that the work is only paid for as either an embankment or an excavation, and not as both. In making up quantities this should be remembered, and the sum of the cuts and fills should not be taken as the total, but either of them, if they are about balanced, the greater always.

The quantities should always (except in special cases) be measured in excavations, because of the uncertainty of the exact allowance that should be made for shrinkage, if measured in embankment. It varies a great deal with different kinds of material, and even considerably with the same kind, depending upon how it has been compacted. Trautwine's Engineers' Pocketbook gives it to be as below on the average:—Gravel or sand, 8 per cent.; clay, 10 per cent.; loam, 12 per cent.; loose vegetable surface soil, 15 per cent.; puddled clay, 25 per cent.; and this is confirmed by

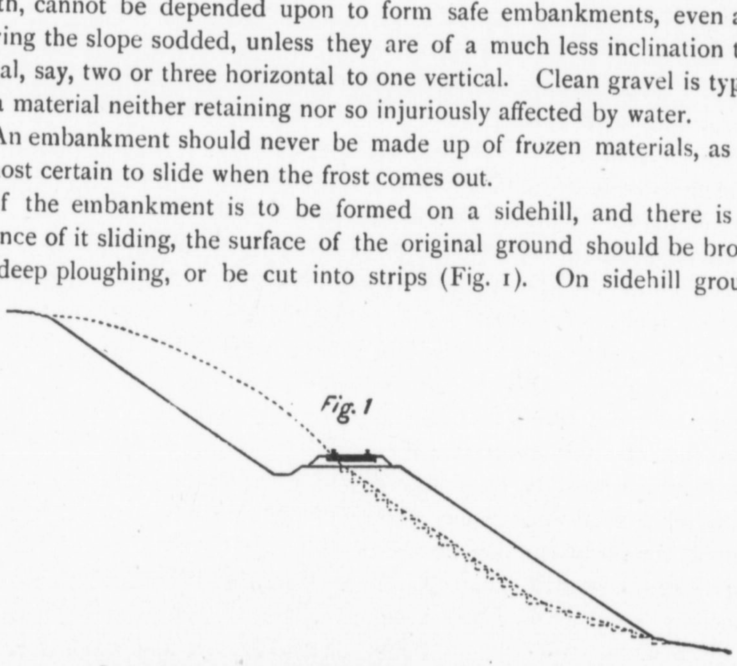
Mr. Q. A. Gilmore, in his book on "Roads, Streets, and Pavements," familiar to you all.

The materials best adapted for embankments are those that will form themselves into a firm, compact, and permanent mound in the shortest time after being deposited in place. Any kind of earth that is free from water, that will be but little affected by water, and that will not retain it long—that is, that will allow of the water that falls on it being drained away quickly—will answer for this purpose very well. Some earths, notably certain clays, seem to retain about them a large amount of water, and when exposed in slopes of either embankments or cuttings, especially the latter, will be washed down more or less by every rain, and every time a frost comes out. Thus new surfaces are being continually exposed, and in slopes of this kind of material it is a very long time before they will be covered by a growth of grass or other vegetable matter, unless specially treated by one of the methods to be described later. The greatest difficulty is always experienced in cuttings, as embankments always afford better drainage of the materials. Some other materials of a sandy appearance, and of such a nature that, when cut, act more like a liquid than an earth, cannot be depended upon to form safe embankments, even after having the slope sodded, unless they are of a much less inclination than usual, say, two or three horizontal to one vertical. Clean gravel is typical of a material neither retaining nor so injuriously affected by water.

An embankment should never be made up of frozen materials, as it is almost certain to slide when the frost comes out.

If the embankment is to be formed on a sidehill, and there is any chance of it sliding, the surface of the original ground should be broken by deep ploughing, or be cut into strips (Fig. 1). On sidehill ground,

Fig. 1



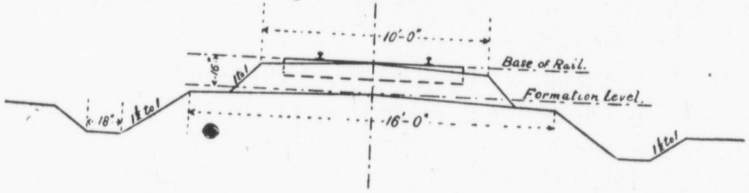
when it is wet and spongy, or likely to be affected by water, it should be thoroughly underdrained, so that no water will lodge between the old and new banks. This may be done by means of trenches cut longitudinally and transversely to a depth of about three or four feet, or to the source of the springs, with open joint tiles placed in the bottom, and the trench filled with a material that will allow the water to drain away quickly, or by any form of convenient blind drain.

When a new line is being built, it is frequently, for various reasons, more economical in first cost, besides being much quicker, to build a trestle over a ravine, then an embankment. At the end of the life of the trestle, it may be desired to make a permanent embankment, after first providing suitable openings for any waterways or undercrossings that may pass under the bridge. Under these circumstances, the material would be hauled to the top of the bridge, on either flat or dump cars, and unloaded there. In this way the bulk of the material would fall about the centre of the dump, and unless spread out would form a very unstable embankment, as the layers would be approximately parallel to the finished slope. The sides of embankments should always be kept a little higher than the centre, in order to retain the rainfall, and consequently hasten the consolidation of the whole mass.

The slopes should be less than that which they will naturally assume, in order to give them greater stability. Usually, $1\frac{1}{2}$ horizontal to 1 vertical is found to answer very well for earth. Sometimes, however, it is necessary, owing to the nature of the earth, to decrease this to 2 or 3 horizontal to 1 vertical. It will be noticed that the inclination at the upper end of an old slope is always steeper than at the lower end. Something as shown in Fig. 7. This being the case, it would be worth while making them conform more to this shape than to the rigid $1\frac{1}{2}$ to 1 slope. If done in the first place it will save trouble from this source later, as it is almost certain to assume this form eventually, and the extra material required at the foot of the slope must be made up from that sliding down from the top, thus narrowing the top of the embankment and allowing part of the ballast to be lost, unless prevented in the first place as suggested. The width of the embankment at the top or formation level (Fig. 2) should be enough to prevent the ballast from sliding down the slopes and being lost. It should not be less than 16 feet for a single track.

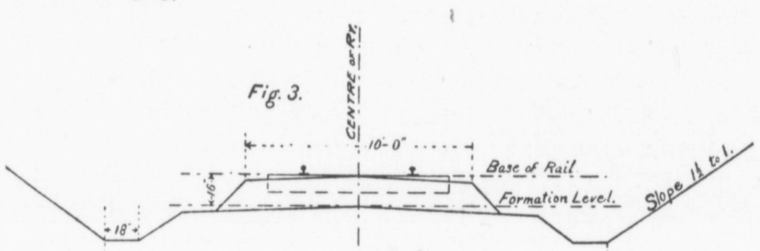
In finishing up the top of an embankment, it should be made a little higher in the centre than at the sides, so as to hasten the escape of the water that falls on the roadbed and settles through the ballast (Fig. 2). It is indeed a fortunate thing for all concerned in the welfare of the railroad, but particularly so for those who have to do with the keeping up of the roadbed, if all the cuttings come in dry, porous material; but it is equally unfortunate if, on the other hand, they are in wet, spongy material, easily affected by water and containing springs.

Fig. 2.



For a single track the cutting should not be less than 22 feet wide at the bottom (Fig. 3).

Fig. 3.



The slopes should be about the same for a cutting as for an embankment, that is, ordinarily, 1½ to 1, and the same remarks regarding lighter slopes and giving them a concave shape will apply here with equal force as in the case of an embankment, even though it is usually the aim of the contractor to give them a convex shape in cuttings to save work.

In any case, side ditches should be provided, and with as good a fall as possible, so as to carry away the water that collects in them quickly, and not allow it to soak into the substratum under the ballast, or, if the substratum is wet and spongy, to provide it with as good drainage as the circumstances of the case will permit. If the substratum remains soft and wet, it will allow the ballast to be sunk down into the mud (for a soft and wet substratum will amount to, in time, practically nothing more) by the action of passing trains, and the mud to work up about the ballast and cross-ties, making a soft, springy roadbed which can neither be kept in line nor in surface, and which, if proper drainage is not procured, will cause endless trouble and expense. For the reasons just mentioned, besides others, long level crossings are very objectionable.

Drainage about the roadbed is very important, but particularly so in cuts. Every time a train passes over a soft, wet roadbed, similar to the kind just mentioned, it will shove the ties further down into the mixture of mud and ballast, until finally they will be completely buried and the place becomes impassable, if not remedied. Two great mistakes are sometimes committed in making cuts: first, the cuts are not wide enough at the bottom to allow of good side ditches; the second, the slopes are made too steep. These two points should be carefully looked into at each cut, or, at the least, for cuts in all the different kinds of material.

If the material of which the slope is composed is wet and contains springs, it is not only very likely to slide in cut matter, but even more so when the frost comes out. It is very difficult sometimes to know what is best to be done under these circumstances, and no rule can be laid down to cover all cases, as each must be treated somewhat specially. Some advocate sodding the slopes, but this will probably prove of no avail, unless at the same time stakes about 2 or 3 feet long are driven into the slope at fairly close intervals; then it is claimed that this will effectually stop sliding in cuts. Instead of sodding, a thin layer of loam may be spread over the surface of the slope, and then seeded down with grass seed; of course it will be just as necessary now, if not more so, to use stakes as before. Anything of this kind greatly improves the appearance of the cuts, besides probably making a permanent improvement; but, as a rule, it is a difficult matter to get the management of a railroad to expend money in this way, although they apparently have no objection to sending out a train with a large gang of men each spring and fall to clean out cuts of the material that has slid down during the half year from the slopes, and this is only a temporary relief from the difficulty. It must be remembered, however, that unless the slopes are made up approximately in accordance with the shape which they will naturally assume in time, and as indicated in Fig. 7, and it is very doubtful if sodding or anything else will prevent sliding in cuts of certain wet materials, when acted upon by heavy rains or frosts, unless the slopes are very slight, which, generally speaking, is not the case.

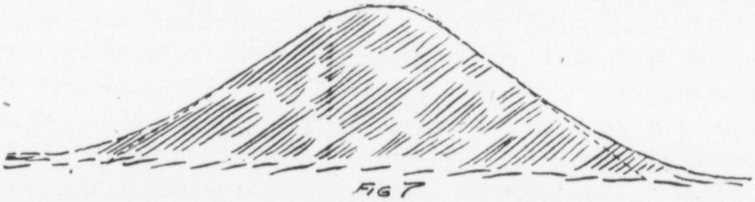


FIG 7

A variety of frost works have been designed and used for retaining the foot of slopes in cuts, only a few of which will be mentioned. Dry stone retaining wall, or "rip rap" (Fig 4). The stones should be large, and the spaces between the stones should be sufficient to allow the water to escape into the side ditches and thus carried away. If cement is used, drip holes should be provided; otherwise water will collect behind the wall, and, when it freezes, break the wall. Piles driven about 6 to 8 feet centres, and backed up with old bridge timber (Fig. 5), make a good retaining wall for the foot of slopes in cuts, provided that the wall does not exceed about 5 feet in height. Perhaps the best plan for this purpose is shown in Fig. 6. It has proved to be very effectual in answering the purpose for which it was designed. It is built entirely of old bridge timber, and, the construction being simple, it is not costly.

FIG. 4.

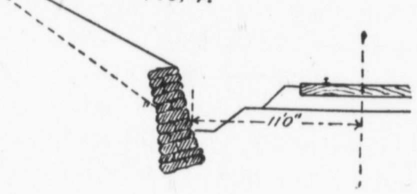


Fig. 5.

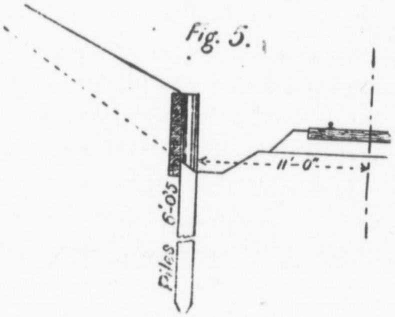
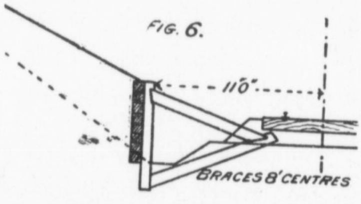


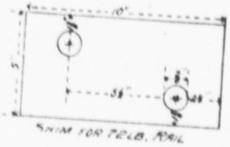
FIG. 6.



Ties settling into the mud during wet weather, caused, indirectly, by poor drainage in cuts, or a substratum of water-retaining material, is only part of the trouble. When the cold weather sets in, "heaving" of the track will commence, and continue until the frost has reached its maximum penetration into the ground. In some cases the track will be shoved up as much as 6 and even 8 inches, and, in an extraordinary case, it has heaved as much as 14 inches; but the ordinary maximum is 4 to 5 inches. The writer, in speaking with an experienced section foreman, some time ago, on this subject, was informed that he had, on one occasion, dug down at the ends of the ties when the track was badly heaved. After passing through the ballast, which, of course, was frozen, he found that there was intermingled layers of sand, ice, and air spaces, varying in thickness from about ½ inch to about 1½ inches. The substratum in this case was quicksand. The foreman thought that water was the cause of all bad heaving—in fact, of all heaving—and stated that, in a number of cases of bad heaving investigated by him, he found that, invariably, there was always considerable water present in the substratum. A certain amount of heaving is likely to take place anywhere along the line, but no really bad heaving occurs except in cut places. The greatest trouble is generally experienced at the ends of cuts. Heaving is seldom the same for any considerable distance along the line, and this is what causes the trouble. Sometimes one rail may be pushed up and the opposite one remain as it is, or one end of the same rail will be heaved up, while the other end remains unmoved. The amount of heaving seems to depend directly upon the amount of water contained in the ballast and substratum within the range of frost. The more water, the more heaving. This is explained, no doubt, by the well-known property of water—expanding when transformed into ice; each additional penetration of the frost adding its quota to the heave. This also explains, or seems to explain, the appearance of air spaces and layers of ice and sand, as found in a frozen roadbed mentioned above. The frosts might reach deeper in certain spots than others, thus including more water and causing more heaving, leaving spaces under the other spots when the frost did not reach down so far. These spaces might then be filled, or only partly filled, with water, which, when reached by the frost, would form an air space and a layer of ice, or an air space, a layer of ice, and a layer of sand, according to the increase of the depth of the frost, etc. These would, in their turn, probably be heaved up, and a similar process continue until the frost had reached its maximum penetration. A remarkable case of an air space being found under a track has been related to the writer by a roadmaster of wide experience. The space in this case, to use his own words, "was large enough to let a rabbit run under the roadbed." The heave in this case was extraordinary, being about 14 inches. In order to keep the two rails level, or at the proper elevation, if on a curve, or to take the ups and downs out of the track, since the ties are frozen in and cannot be either raised or lowered, it becomes necessary to use shims. Adzing the ties should never be allowed. Shims are simply pieces of hard, tough wood, varying in size to suit the weight of rail, with two holes, $\frac{7}{8}$-inch diameter, bored through them for the spikes to pass down, and so placed that the spikes will fit close to the flange of the rail. Figs. 8, 9, and 10 are plans of shims for the different weights of rails; and Figs. 11 and 12 show the method of using them.

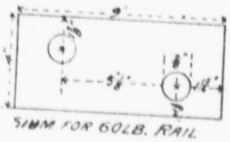
SCALE, ¼ SIZE.

FIG 8.



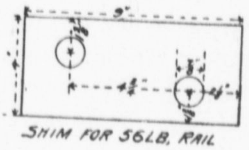
SHIM FOR 72LB. RAIL

FIG. 9.



SHIM FOR 60LB. RAIL

FIG. 10.



SHIM FOR 56LB. RAIL

Fig. 11

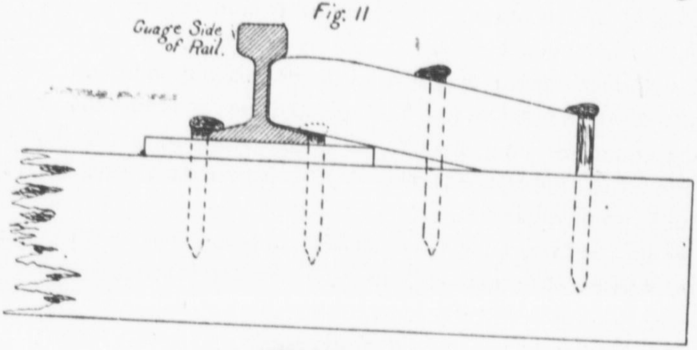
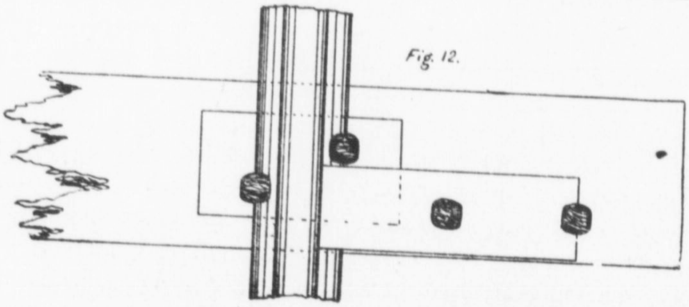


Fig. 12.



Shims are generally supplied the sectionmen machine-made, of various thicknesses, varying from $\frac{1}{4}$-inch up to 3 or 4 inches. For anything less than $\frac{1}{4}$-inch, the foreman should have a block of tough hardwood on his hand car, from which he may chip off the desired thickness of shim. When thick shims are used, the ordinary track spike, which is about 6 inches long, is too short to hold well, and spikes 8 and 10 inches long, but otherwise of the same dimensions as the ordinary, are used. At first the upheaval is very slight, but becomes more marked as the weather grows colder and continues till the dead of winter. However, this is not always the case, as frequently the track will heave once and remain undisturbed until the frost goes out. When the upheaving continues, it is necessary to commence with thin shims, and gradually replace them with thicker ones as the change proceeds. Similarly, when the frost is going out, it is necessary to continually change them and reduce the thickness until the last shim is out.

It will be noticed that drainage in cuttings, soft springy roadbeds, heaving, shimming, etc., have been considered under the head of grading. This was done for the purpose of bringing out the intimate relationship existing between them. Very often, at the time grading is going on, by using proper precautions, a great deal of soft roadbed and bad heaving, and consequently the dangers and expenses appertaining thereto, may be avoided

The cost of excavation, of course, will depend upon the nature of the materials to be excavated, the locality, the price of labor, and also upon the circumstances generally; so that no one price can be given to cover every case, but the price per cubic yard for earth usually ranges in the neighborhood of 20 cents.

Trautwine gives some very useful tables for cost of excavation on page 742 of his Pocketbook.

Peterborough, Oct. 13th, 1894.

DISCUSSION.

MR. C. H. MITCHELL. – Mr. Innes' paper supplies a valuable part to our preceding papers on railroad work. We have previously had considerable information on earthworks and track-laying, but this paper very aptly closes the gap between them. Mr. Innes has presented us with a considerable amount of valuable concise general information on the question of grading, but that which I consider the most valuable is his clear and complete treatment of the frost question, and in view of the climatic conditions in this country it is most important to the engineer. In view of the fact that Mr. Innes' paper is the outcome, for the most part, of his personal experience in railroading, his paper is doubly valuable.

In reference to the drainage of cuttings, where the soil is springy, the most effectual way to prevent trouble is to strike at the root of it and gather the water into drains of some kind before it gets to the roadbed, or surface of the cut. If the springs are near the surface of the original ground, they can be tapped by wells situated back of the crown of the slope, and filled with loose stone. An ordinary drain leading from the bottoms of these wells would carry the accumulated water to any desired place. If the water comes out on the slope of the cut or near the roadbed, blind intercepting drains of loose stone, not necessarily deep, and running diagonally down the slope, would gather the water and convey it down the slope to the side ditches, which, if sufficiently deep, would protect the roadbed.

MR. JAMES MACDOUGALL.—I am glad to see a paper on grading having a place in the proceedings of our Society, as it, and other forms of earthwork, hold such an important place in the various matters that an engineer is likely to have to deal with; in fact, it may almost be said to form an important part of every engineering work. As a friendly criticism, I might say that the paper, in my opinion, lacks definiteness in some particulars.

My experience has been that the young engineer sometimes lacks a knowledge of the customary methods of calculation. One case in my own experience was that of extra haul. The specifications generally contain something similar to this: "Extra haul will only be paid for when it exceeds one thousand feet, and then at the rate of one cent per cubic yard per additional one hundred feet up to two thousand five hundred feet total haul."

The reason for limiting total haul to two thousand five hundred feet is evident, as then the extra haul would amount to fifteen cents per cubic yard, and when that price is reached it would be about as cheap to borrow nearer at hand if the excavation price is under twenty cents, as is frequently the case. Methods of calculating extra haul are numerous. When one is in a hurry, and complicated methods are forgotten, it is perhaps as well to take the profile and work each way from grade by station lengths, or shorter if the notes permit, until the haul reaches the beginning of extra haul, allowance being made for shrinkage. Then you have a certain fill between two sections and a certain cut between two sections. If they balance, the extra haul is simply the half length of the prism in cut added to the half length of prism in fill. If they do not balance, the balance either comes from the next prism in cut to fill up same prism in fill, or comes from same prism in cut to next prism in fill. This method is pursued until either cut or fill is gone through. Making thus a table, with the various quantities and corresponding distances of extra haul, multiplying out, adding, dividing by 100, and multiplying by the price per 100 feet, the total value of extra haul is arrived at. This, of course, is an approximation, the assumption being that the centre of gravity of each prism is at the centre of length, which is seldom true in fact.

I have tested Trautwine's percentages as to shrinkages in fills in some instances, notably in gravel, and have found them to check out closely when applied to the cuts from which the material was taken. The young engineer should verify these and similar results of experience as often as he possibly can.

As regards the material of which embankments should be made, I may say that an engineer seldom has much choice. I have made embankments which we afterwards had to cover with clay to prevent their being burnt up. These were made by piling up black muck in long swamps where no solid material was obtainable, until the track was got through. When it dried, it was quite inflammable. I have also used large quantities of frozen material, as the exigencies of railway building sometimes do not allow for weather. These matters, however, are easily rectified after the track is once laid, when large cuts and borrow pits can be cheaply run out. Mr. Innes' remarks as to depositing the earth in layers are to the point, and the importance of doing embankments in this way is too much underrated in practice.

Mr. Innes has not quite brought out the idea of the agreement of a twenty-two-foot cutting with a sixteen-foot embankment. If you will take a twenty-two foot cutting and allow eighteen inches as the width of the table drains at bottom and six inches for depth, and give their sides the usual slope of $1\frac{1}{2}$ to 1, you will find you have a small middle embankment left which is exactly sixteen feet wide, and is, therefore, continuous with the embankments at either end of the cut. This, I assure you, looks even better on the ground than it does on paper. The fact is, cuts should be taken out to widths suitable for leaving this width of grade, and providing for any size of table drains that the nature of the ground may require.

Blue clay in cuttings should not be left exposed if top soil of any kind is handy. In damp weather the clay cracks vertically and falls forward, filling up the table drains. I had a large cut which was taken out by steam shovel. The cuts, of course, were nearly vertical, and were taken out to about midway between the bottom and top widths. I found that there was scarcely any more trouble after the top soil had fallen down and covered up the hard blue clay. Previous to that, even a misty atmosphere would start the cracking of the clay.

One of the frost works described by Mr. Innes—shown in Fig. 6—could, I think, be improved on by laying in a horizontal sill of rough timber just below the level of the table drain and extending to the centre of the track. On this erect your vertical post with mortice and tenon at the foot, and put in the brace as before, but with the foot below the ballast on the top of the sill. I have seen these remain in place until they have rotted out.

In wet sand cuts, a box drain with sides of square timber, resting on cross sills every six feet, floored with plank, and open at top, except for cross ties, is frequently very efficient.

Mr. A. T. Laing.—Is it not preferable to avoid the use of wooden structures for retaining walls, and would it not be advisable to dispense with walls altogether, if possible, by widening the cut, even though this involved the expense of procuring more land?

Mr. James MacDougall.—Wooden structures are objectionable, of course, but in the case of new construction it answers the purpose for the time being, and facilitates the progress of the work. At the end of ten or twelve years it will need repairing, at which time it may be replaced by stone. With reference to widening the cut, this in many cases is the more permanent way of overcoming the difficulty, but in some kinds of soil no reasonable width of cutting will prevent sloughing; also in long, deep cuts it would be found very expensive to remove the material. In such cases it would be preferable to construct retaining walls.

Mr. A. T. Laing.—In the case of shimming, I think it would be better to use shims without holes. These may be placed diagonally underneath the rail between the spikes, thus facilitating the labor both of placing and removing the shims, and it will be found less injurious to the tie, as the spikes need only be partially drawn.

THE MAINTENANCE OF ENGLISH ROADS

By Sidney M. Johnson, Grad. S.P.S., Stud. Can. Soc. C.E.

In this short paper I do not intend to touch upon the construction of new roads, nor will it be necessary to point out to you the advantages of well-maintained roads, but my object is to bring before you as concisely as possible the system by which the English roads are maintained under County Councils, and also the cost of this method.

But before entering upon the subject of maintenance, I must give you some of the history of these roads.

The earliest roads of England about which anything certain is known are those laid down by the Romans during the time they occupied the country. These are characterized by their straightness from point to point, and by the solidity of their foundations, which in many cases consisted of carefully constructed pavements, sometimes cement being used, and upon these the roads were constructed. Many of these roads still exist, or form the foundations of the present roads.

The roads laid out after the Roman occupation are by no means characterized by their straightness, but were laid out without regard to system, attention being paid only to the requirements of the traffic, and as to where the best road could be built at the least expense. Thus we have the road following the brow of a hill, a valley, the course of a stream, or else constructed to suit the convenience of the owner of the land, and these causes produce the pretty winding roads and lanes which add so much to the beauty of the country, as contrasted with the regular concessions and sidelines of our own.

This method has advantages more important than that of picturesqueness, for by deviating the road, instead of cutting through hills, it may be kept upon nearly the same level, and a much better bed thus selected. Another advantage is in the matter of bridges. In parts of England there are a great many deep winding sluggish streams and rivers, and the roads have been laid out so as to have as few bridges over these as the convenince of the traffic would allow, thereby greatly lowering the cost of maintenance.

The system of maintenance, until the latter part of last century, was very similar to that in vogue in Canada at present. The law then required each parish to repair its own roads, which they did by statute labor.

Early in this century turnpike trusts were formed, but these were conducive of very little improvement.

In the year 1819, and those following, greater interest was aroused by the keen competition for favor between the rival systems advocated by McAdam and Telford.

These men both, for the first time, advocated the thorough drainage of the foundation and the breaking of the material to a certain gauge, but differed in that Telford advocated a pavement upon which to build the road, while McAdam maintained that this was unnecessary.

In 1835 the "General Highways Act" was passed, by which highway rates were substituted for the statute labor, and paid surveyors were authorized for parishes or highway districts. This Act, with slight modifications, continued in force until the County Councils were constituted by Act of Parliament in 1889, when the present system was called into use.

Under the present system the roads are divided into two classes, viz., County and Parish roads, the former including all the old turnpike roads and many of the other main roads, whilst all other roads come under the latter heading, and the parish in which they are situated is responsible for their maintenance.

The details of the system adopted vary slightly in different counties under the County Councils, depending greatly upon the engineer, but are very similar upon all major points.

The outline of the chain of responsibility or system of maintenance which I am going to detail is that followed in the County of Norfolk, one of the large counties on the east coast, and which possesses very good roads.

Here, as in other counties, the county roads are placed by the council under the supervision of an engineer, who is known as the County Surveyor.

If the parish authorities think that the traffic upon any of the roads under their supervision is more than local, or that it should be classed as a main road and the county made responsible, they must apply to the council for relief, at the same time setting forth their claim. The county surveyor is then instructed to examine into the case and report. In case it should, in his estimation, be classed as a main road, the parish must first bring it into as efficient a state as the county roads, and they may be relieved of its care, it then becoming a county road.

The county surveyor appoints his own assistants, who are known as Overseers or Local Surveyors. These men should have previous experience, as they have, on an average, the supervision of one hundred miles of road, devoting their whole time to the care of their section. Their first duty is to inspect their section, and this they must do personally at least once a fortnight, and send a written report to the county surveyor.

The engineer also convenes a meeting of these local surveyors once a month, when their successes and failures are reported and discussed, and thus they severally profit by the experience of each one.

In the county I have mentioned there are, in round numbers, twelve hundred miles of main or county roads under the charge of twelve local surveyors, each having about one hundred miles in his district.

The local surveyor has under him a laborer, who is known as a Gauger, for every four to six miles of his district, according to the amount of labor required upon that part of the road.

These gaugers devote their whole time to their section, except that during August they may be granted leave by the local surveyor to help in the harvest, if their section is in a satisfactory condition. They are responsible to the local surveyor for the maintenance of their section, and are visited at least fortnightly by him.

During the autumn and early winter, when the work on the roads is heaviest, they are granted extra help, sometimes having as many as four or five men under them.

PARISH ROADS.

The vestry of the parish at present have had the management of the parish roads, but by the "Parish Councils' Act," lately passed, the supervision is this autumn transferred from the vestry to the parish council.

The number of miles of road in each parish varies from four to seven, and the system of maintenance is similar to that under the county, but upon a smaller scale.

The vestry appoints a parish surveyor, who is generally a small farmer or tradesman in the parish, and he is responsible for the maintenance of all roads within the parish boundaries, other than main roads. He does not devote his whole time to the roads, but continues his calling, whatever it may be, and inspects his section systematically, directing his assistants where to bestow their labor. He must also keep careful account of all moneys expended and received on account of his roads, and for these duties is paid a fixed sum annually.

The amount of labor required on the parish roads varies, as in the case of the main roads, and the surveyor engages men as he requires them.

WIDTH.

The metalled surface of the road should always be of sufficient width to accommodate the traffic being less in the country than near an important town, the minimum being twelve feet and the maximum about forty.

Between the sod borders the width should in no case be less than that necessary to allow two vehicles to pass comfortably, for this purpose fifteen feet being sufficient. Where the width is less than this people cannot pass without turning out upon the sod, and thus cutting up the border, filling the side channel, and carrying soil from the side on to the metalled surface of the road, all of which should be avoided.

Whatever widths are selected for the county and important parish roads they are uniformly preserved, except where a hill or some other local cause makes an additional width advantageous. The borders are well defined by straight lines or curves, the sod being cut back, side channels cleaned, and outlets opened at least yearly. This, besides giving the road a neat and finished appearance, facilitates and lessens the cost of maintenance.

CROSS SECTION.

A good cross section is one of the most important, and at the same time one of the most difficult, things to attain upon a road.

The slope towards the side should be such that the rain flows freely towards the side channels, as the effect of water standing on the road is ruinous, for it not only adds greatly to the wear of the metal, but also permeates and weakens the crust of the road and subsoil.

The effect of too great a slope is almost as bad as the other extreme, for where there is a perceptible pitch the traffic confines itself to the centre of the road, as the only place where the vehicles can run horizontally, and thus grooves which retain the water are worn by the wheels and horses' feet.

By constant attention the English roads have attained an easy curve, principally of a flat elliptical form, and thus, aided by the smoothness of surface, sheds the water with ease.

The amount of fall from the centre towards the sides is greater on hills than at other portions of the road, so as to shed the water rapidly, and thus prevent it running down the hill upon the road and scouring the surface. The fall is least where there are easy grades on the road, and upon the level the fall on a road thirty feet wide is generally about six inches, and should never exceed nine, while for the narrower roads a fall of three or four inches is given.

METAL.

The metal used upon the roads varies greatly, according to the locality and fitness of local supply, if any. Those in most common use are the igneous rocks, the granite being the principal, iron sandstones, flint, flint and chert gravel, the harder limestones, and in the iron district the slag and furnace refuse are used.

In choosing a road material the four properties considered are its hardness, toughness, its power to withstand the action of the weather, and the degree with which it binds. No one metal possesses all these qualifications. Thus, although granite is hard, it is often brittle if containing too much felspar, and of itself does not bind well. Flint also is very hard, but is brittle and is not cohesive, while, on the other hand, limestone from the mortar-like detritus formed by its wearing binds well, but is not of sufficent hardness for roads on which there is heavy traffic.

Returning to the county which we have especially under consideration, there is no local supply of igneous rocks. Where the rocks do outcrop they are chalk, with which is associated flint, and there are also deposits of flint and chert gravel, while upon the seashore large quantities of flint may be procured.

Besides the local materials, a great deal of granite is imported for use upon the county roads.

When gravel is used, it is from pits sanctioned after inspection by the county engineer, and is screened and broken to a certain gauge; being in this condition contracted for per load of twenty-four bushels either in the pit or delivered on the roads. The usual price of this gravel is from $1.10 to $1.20 a load delivered, or 75c. a load in the pit.

The flints are of two classes: first, those gathered off the land, and, secondly, those from the seashore. The former are gathered during the autumn and winter by children off the fields, the children being paid 2c. per bushel, and the landowner sells them at 5c. per bushel, or about $1.40 a load delivered on the road.

The flint from the seashore is not so good a road material as the land flint, the salts of the sea having the effect of softening it, so that when used it should be broken and left standing in heaps or metal depots at least one year before being placed upon the roads. The ordinary flint also improves by standing in heaps after being broken.

Upon the most important county roads granite from Guernsey or Belgium is used. This granite costs according to proximity to a seaport, and on the east coast costs from $3.00 to $3.75 a ton. This is double the cost of the local material, but after careful investigation it has been estimated by good authorities to stand three times the wear and traffic, and is therefore cheaper in the end. It is, on these grounds, favored by experienced men for use on the principal county roads where the traffic is heavy.

SIZE OF METAL.

The most advantageous size to which the metal may be broken depends greatly upon its toughness, and how it is to be laid, but the pieces should be as nearly cubical as possible. The recognized standard for the metal since early in the century has been its ability to pass through a 2½ inch ring, or a cube of about 1½ inches.

A hard material may, with advantage to the road, be broken smaller than a softer one, and if but light repairs are to be made a smaller gauge is an advantage, as the material binds better, covers more, and gives a smoother surface. When the metal is to be rolled, it gives a better and stronger surface if the pieces are large.

In all cases the metal is broken as nearly cubical as possible, and should pass the gauge in every way. When the harder descriptions of metal are used, it is important that they should be as near the same size as practicable, which will give a smooth surface to the road and reduce the wear and crushing.

The granite is delivered broken, being crushed by machinery, while the local material is broken by hand during the summer by the man in charge of the road, or is delivered broken upon the roads.

LAYING THE METAL.

The laying down of the metal to the greatest advantage is an art learned only after long practice, and especially is this the case with light repairs. The tendency of the roadman is, for the sake of appearance, to lay it in long narrow rows, where the horses—whose habit it is to follow in the same track—have worn a hollow, or in the wheel tracks. This causes the traffic to be diverted to the side of the road. The only way to avoid this is to lay the material, where necessary, in short lengths at a time.

The metal should be laid on one stone thick, and close enough so as to touch those on all sides of it, thus forming a sort of mosaic work. Each cube then gives and receives support from its neighbor, and the binding is greatly facilitated.

When the roadbed is thick and strong, it is sometimes an advantage to pick the surface before laying on the new metal, so as to help the binding, but it should never be more than half an inch deep, and is only advisable where a hard metal like granite is to be used, and where the surface has worn unevenly.

A more common plan of aiding the consolidation of old and new materials is by the use of a binding material, marl being now greatly used, especially where the subsoil is of a light or sandy character. After laying the metal the marl is spread over it in the proportion of about 1 to 7.

The use of steam rollers upon the roads is growing rapidly, the county engineer now having four at his disposal, and hopes soon to have twelve, or one for each district of one hundred miles. These rollers are capable of consolidating one thousand two hundred superficial yards of new material per day, but their use is only advantageous where extensive repairs are being made upon roads with strong foundations, and where some thickness of metal is to be laid down.

WIDTH OF WHEELS.

The width of wheels and their loads has been the subject of statutes and by-laws since early in the century. Under the "General Turnpike Act" in the reign of George IV. a premium was put upon broad tires with countersunk rivets by charging them but two-thirds of the ordinary toll. At the same time conveyances with heavy loads and narrow tires were charged additional.

At present there are no regulations bearing upon this subject which are enforced, but wheels upon all vehicles and carts are much wider than those in use upon our roads, and which, especially in soft weather, do so much harm. Upon the carts, which replace our buggies, the wheels average two inches in width, or about twice as wide as those on the corresponding conveyance in use here, while upon the carts and wagons used for farm purposes the width varies from four to six inches.

There is a growing feeling that some measure should again be introduced and enforced, and authorities place the maximum allowable load for a wagon at one ton of vehicle and load per inch of tire, that is, five hundred weight per wheel.

DISTRIBUTION OF LABOR.

The great difficulty in this respect is that the heavy work is concentrated unavoidably into a short time, whilst at other times the road surface itself requires little or no attention.

During the summer months the man in charge should clean out the side ditches, which are too wet at other seasons. He should also take advantage of any soft weather to cut back the sod bordering on the road, thus giving the road surface a uniform width throughout. This keeps the road of the proper cross section, and forms a channel for the storm water between the side ditch and the footpath or metal heaps, and from which it is led at intervals into the side ditch. This should all receive attention before the wet weather sets in. On roads where flint is used and delivered unbroken, it is broken to the proper gauge during the summer.

During the early autumn, or as soon as the rains make it necessary, the roads are scraped to remove the mud produced by the summer's wear of the metal.

Having cleaned up the sides and scraped the surface, the new metal should be laid on, the first care being bestowed upon those places which are naturally low and damp. After these are attended to the remainder receives its coating, and it should all be laid before the beginning of the new year

The new metal being laid, the work upon the road for the remainder of the winter is light, and any extra help which may have been necessary is dispensed with. The regular man's time is occupied in attending to any weak places which may need additional metal, raking the loose metal so as to facilitate its binding, and scraping where necessary.

When the rains of spring, with the wear, tend to again make the road muddy, the gauger's time is taken up with scraping the detritus off the surface, and any spare time should be spent upon the side ditches.

METAL DEPOTS.

To facilitate the metalling in the autumn, the road material, when delivered by the contractor or otherwise, is laid in heaps by the roadside, if its width be sufficient to admit of same. These heaps vary in size and distance apart, according to the importance of the road, in some cases being as close as twenty yards, but should never be more than one hundred yards, which leaves the gauger but fifty yards at most to wheel his material when metalling the road. Upon narrow roads, where this method cannot be adopted, recesses have been constructed on the side, and here the material is stored without inconveniencing the traffic. These stores of road material are known as metal depots.

COST.

The cost to the county for the main roads was last year £35, or about $170, per mile. Of this thirty to forty per cent. is chargeable to manual labor, about ten per cent. to salaries and management, and the remainder to materials. This money is raised by a general rate over the whole county, with the exception of the county boroughs of Norwich and Yarmouth, which maintain their own roads, etc., themselves. The cost of the parish roads is from $60 to $75 a mile per year, and this is raised by a rate upon the incomes of the parishioners.

Having detailed to you the points which most forcibly struck me regarding the English system of maintenance, I think you will agree with me that in many points we may, with advantage, follow their example, after allowing for climatic and other variations of condition.

The three things to which these roads owe their superiority are, first, the stability of their foundations ; second, the constant and not spasmodic attention bestowed upon them ; and last, but not least, the fact that they are under competent authorities in the county engineers and local surveyors.

ISCUSSION.

MR. ALAN MACDOUGALL—This is a useful addition to the literature of good roadmaking, and is presented at a fitting time. The conference held in the Canadian Institute last February resulted in the formation of an association for the improvement of roads, under the name of The Ontario Good Roads' Association, which held a meeting in Toronto in September during Exhibition week. The Provincial Government is taking so much interest in the subject that it is not likely to be neglected, and from what I can learn it is likely to be a prominent subject of discussion at meetings of farmers' institutes this season. There is a danger that the present craze for electric railways will blind rural constituencies and hinder the growth of road improvements; it becomes the duty of those of us who know the value of roads to the advancement of the country to combat the idea that it is not necessary or advantageous to improve sidelines. The country can no more exist without good roads, and sidelines too, than we can breathe without lungs.

I have already pointed out to you that there is a good field for the exercise of your talents in this field of engineering, and I hope it may not be long before many of you are engaged in improving our roads. You are kind enough to ask me to address you once more; I daresay I might be able to do so early next year, and I shall have pleasure in so doing, if I can arrange for a subject.

MR. P. K. HYNDMAN—Having already written a paper on the subject, which appears in the first report of The Good Roads' Association of Ontario, printed by order of the Government, it will be unnecessary to repeat here any of the views or statements which are there given. Suffice it to say that it is satisfactory for me to find that the main features of the English system, as described so fully and clearly by Mr. Johnson, but of which I was ignorant, are identical with what I proposed should be adopted in Ontario. These are (1) a special road tax, instead of tolls or statute labor; (2) the administration by county and parish municipalities, with the consequent necessary classification of the roads under each; and (3) the appointment of a competent engineer for each county.

Our road allowances being all laid out, it is necessary, with some exceptions, to adhere to them. Fortunately, the topography of western Ontario, at least, renders it possible to do this, so that alignment has not to be considered, as in Great Britain.

The width of sixty-six feet, also, gives plenty of space for making carriage and foot ways, as well as room for shade trees and stacking "metal" for repairs. I have already described how, in my opinion, this width, which should be fully utilized, may be divided up.

In India, the repairs were carried out by miles, which facilitated the periodical renewal of the upper metal coat. Therefore, I consider it necessary, in the first instance, to mark out all the main roads, at least, by mile posts, or divide them into sections, extending from one cross-road to another, which is generally a distance of 1¼ miles. This is a much better arrangement than renewals in short pieces.

Repairs in India consisted of what were called "annual" and "petty" repairs, the first being the laying down of an entirely new coat of metal every three or four years, or as often as required over the whole mile. The metal for this was brought in and stacked in one continuous heap on one side of the road. For the second, which consisted in patching holes which would appear in the coat, after the first year, the metal was stacked in short heaps, distributed over the mile on the other side of the road.

This work of collection of metal, laying the new coat, and making up the earthen berms was carried out by contract, the patching being done by gangs of monthly-paid laborers, who attended to this, making up the earthen berms and slopes, when and where required.

Mr. Johnson has accurately described the qualities of the different materials used for road metal. Trap-rock is the best. It is used extensively in Scotland, where it is called "whinstone." In Ontario there is not much variety, beyond the ordinary pit gravel. In India, a material much used is an earthy nodular limestone called "kunkur."

This material, after being broken and screened off the earth embedded in the cavities, is laid down and consolidated by iron hand-rammers, plenty of water being used in the process. It binds well, and makes a very smooth road, but is deficient in hardness.

Thirty-five miles of the roads in my division were metalled with sandstone, broken up from large boulders which were brought down every season by the torrents from the Himalayas. A little earth or clay was scattered over this, and dibbled in with light strokes of a pick, and the coat consolidated by a large heavy stone roller six feet in diameter (of which there are several on the road), pulled by about forty coolies or laborers, water being also used in this work. The patching was done by hand-ramming. This road was not nearly as smooth or pleasant to drive over as the "kunkur" roads.

In Central India there is kind of red laterite called "moorum," which is used as a road metal. It is not capable of being blasted, and is very difficult to break up with the pick. It makes a smooth road like "kunkur," but, like it, wears rapidly.

Broken, overburnt, or vitrified brick is also used as road metal, but it is friable, and apt to work loose, unless some binding material, better than clay, is used. Still, if procurable, it forms a fair material for road metal.

I have found the best width for metal was twelve feet, as ten feet caused the traffic to travel in the same track, which wore into two deep hollows or ruts. This was not the case where the metal was twelve feet wide. Near large centres of population the width of metal was increased to sixteen feet. The total width of the carriage-way was thirty feet, as the roads were main trunk roads. The thickness of a coat of metal was taken at four and a half inches, and was laid down according to a wooden "template" laid across the road, the central thickness being about six inches and the sides three inches.

The metal was carefully spread for lengths of about one hundred yards. Before consolidating, as already described, I found it better to repair and bring up the surface on which the new coat was to be laid to a hard, even, and smooth condition, the loosening of it by picks making it too soft, and the new coat adhered perfectly to it. Whilst a length was being consolidated, the traffic was turned aside to the berms, which were afterwards made up to the new level, and not until the new surface was perfectly dry was the traffic allowed to pass over it. Similarly, the patches were cut out in a rectangular form, and filled in with fresh metal, which was rammed and watered, and brought flush with the existing surface.

The practice in Scotland, which was in vogue before the introduction of the steam roller, of spreading the metal over all hollows, and allowing the traffic to consolidate it, was most unscientific and wasteful, as fully half the metal was pulverized before that part of the road became smooth again.

Small patches should be hand-rammed, where the extent of the petty repairs does not warrant the employment of the steam roller.

The Telford system of road surface, providing an underlayer of large stone, has the defect of not giving a firm and even bed for the upper coat of broken stone to rest on.

On laying metal for the first time on a road, it is desirable, besides providing proper drainage, to ram or roll the earthen surface till it is quite hard. It is better that this surface should be flat and not rounded. In India, a new road received two coats, one being consolidated before the second one was laid down. The second coat might consist of stone broken to a larger size, say, to pass though a two and a half inch ring, the upper either two or one and a half inches, the latter being preferable.

Gravel, when used, should be screened and broken to two inches, and one and a half inches in *two* thicknesses or layers for the second coat (the first or under coat two and a half inches), the coarse sand remaining to be spread thinly over each layer, to assist in binding.

After a new coat has been consolidated, very fine gravel or stone dust should be spread over the upper surface to a thickness of half an inch, as "blinding," which makes the new coat smoother to travel over, besides preserving it till it has got quite hard.

Drains should not be *under* the carriage-way, as they may cause subsidence. The edges of the carriage-way should be kept even and trim, and every facility given for the storm water to run off into the side gutters. Where there are slopes, these should be grassed to prevent their being cut up into channels by the rain water.

The general form of cross-section is a central curve of about one hundred feet radius, the side berms sloping off at one in forty tangents.

The planting of trees, and provision of, at least, one footway at the side, and keeping the whole width trim and neat, are very important matters to be attended to.

The time for carrying out the renewals and heavier repairs must be fixed at the most convenient and favorable season of the year, it being borne in mind that where repairs are required to a small extent these should be carried out at once.

The County Engineer should have charge of all the roads, as tending to a uniform system. He should have a sufficient number of assistants and road overseers, according to the extent and importance of the work.

He might also be given charge of the various drainage works in the county carried out under the Drainage Act, and might act as consulting engineer to the municipalities of the smaller towns and villages in the county which could not afford to employ an engineer, but could pay the salary of a street or town overseer. All county and township buildings might also be put in his charge to carry on the necessary periodical repairs. In this way, his time would be fully occupied.

For the guidance of the staff in their duties, a specification and set of rules and regulations, embodied in a code, should be carefully drawn up, printed, and a copy furnished to each member of the staff. These rules can be amended from time to time.

MR. W. F. VAN BUSKIRK—Mr. Johnson's paper gives us much information of a character not readily obtainable in this country, and which should be of value to all interested in road improvement.

Quantities and prices of material and labor on completed works and the maintenance of them are always interesting to engineers, and it is not often we get them in detailed form.

As Mr. Johnson has made a pretty extensive study of the English roads, it is probable that he can give us a little more information on some few points. For instance, it would be of interest to know what the county and other surveyors are paid for their services, and the manner in which they get over their respective sections of road; what their duties are in regard to buying material and payments therefor. What about the management and care of water after it leaves the surface of roadways?

The drainage of the subsoil foundations of roads and the removal of storm waters is, of course, the most important feature to be looked after in the maintenance of a road, and I am sorry to say is the feature most neglected in our own attempts at roadmaking. This neglect of the first necessity of a good road is perhaps excusable in the case of the ordinary citizen, as he does not generally think why a road is good or bad; but an engineer should know that it is not by chance that the large amount of water delivered on a roadway is removed without doing serious damage. When we consider that some forty thousand tons of water fall annually upon each mile of roadway in this country, the problem of its immediate removal begins to assume some importance, and any hints we may be able to obtain in regard to the practice, in countries having good roads, are of value to us in dealing with our own.

MR. J. F. BEAM—Undoubtedly the first step in this important problem should be the adoption of some suitable plan or system by which, when once in force, good roads would result, and add materially to the comfort and welfare of the people of our province. How can this object be attained with more ease and thoroughness than by taking advantage of the experience of countries which have already worked out this question?

This paper of Mr. Johnson's plainly shows that we can look to our motherland, England, more especially with profit and advantage in regard to road management, as well as in many other respects in which she stands so pre-eminently foremost among nations in the science of government.

Having observed and studied this question for years, my conviction is that before any system is crystallized into law we ought not only to avail ourselves of England's experience, but the experience of all other leading countries and of the foremost states of the American Union where improved modern methods have been adopted should first be obtained, and placed as far as possible before our people by the aid of public meetings, which should be held in every county and township to discuss the most suitable method for each locality, and upon the result of these a general system may be devised. Caution, however, is very necessary, as this matter should not be hastened until public opinion is quickened, and the agriculturists especially become ready to handle it in earnest.

Such a movement, I am glad to state, has already been planned by the executive board of The Ontario Good Roads' Association, where it was proposed at the meeting held lately in Toronto to send the best available speakers on this subject to address the farmers' institutes in January.

I am well aware that at present the farmers generally are adverse to adding any further burden of taxation, and it must be fully shown that a better system need not prove heavier, but rather less burdensome, than the present wasteful and inefficient statute labor system, more especially if the English income tax method were adopted, as the man who has the smaller income need not pay so much as the man with a larger one, who also gets proportionately with his large business more benefit from improved roads.

During the summer the clay roads of this district are excellent, but they are almost impassable during the rainy seasons of spring and fall, and also during an open winter.

MR. S. M. JOHNSON—Mr. Van Buskirk's questions touch upon some important matters which have received but little notice, or been omitted in the paper.

Regarding the salary of the county surveyor no fixed rule is followed in England, as the size of the counties and responsibilites vary, and he is paid for his services according to the work he is called upon to perform. Passing to the local surveyors, it must be remembered that these men are not surveyors in our sense of the word, but are simply inspectors, or overseers, who have received a thorough knowledge through practise of road building and maintenance. These men are paid about $500, a year, and in many counties they receive an allowance for the maintenance of a horse and cart, as it is in this way that they inspect their district.

As to the respective duties of surveyors in purchasing material, etc., the county surveyor prepares an estimate each year showing quantities of material and labor required for the following year, and appropriation necessary to carry this out. When sanctioned by the council, tenders are called for the material and cartage, and, as required, the county surveyor orders from the accepted tenderer.

In regard to the management of water after leaving the road surface, in the open country a well-kept open ditch is maintained upon one side of the road, at least, and this empties into the natural watercourse at the most convenient point. The "General Highways Act" of 1835 granted the authorities power to seek an outlet through the adjoining property to the watercourse, the owner being compensated for any damage caused. The same act also provides that if any watercourse be obstructed the surveyor shall order the occupier of the land to clear it, and if he does not comply the work may be done by his own men. As the road approaches a village or town, covered drains take the place of the open ones.

Where the subsoil requires drainage beyond that given by the side ditches, drains are laid with open-jointed pipes, these often taking the form of mitre drains; that is, they meet in the centre in the form of a V, and run with an inclination of about 1 in 100 towards the side ditches in the direction of the fall in the road.

VICE-WORK

By G. M. Campbell, '96.

Under this heading will come all operations by the machinist which are not included in the work done by machine tools.

The man who performs vice-work is generally known as a vice-hand or fitter; he should have a good mathematical education, and should, of necessity, be a man of good natural ability, for new classes of work, new ideas, original designs, are being continually brought forward, and for these the workman has always to be prepared.

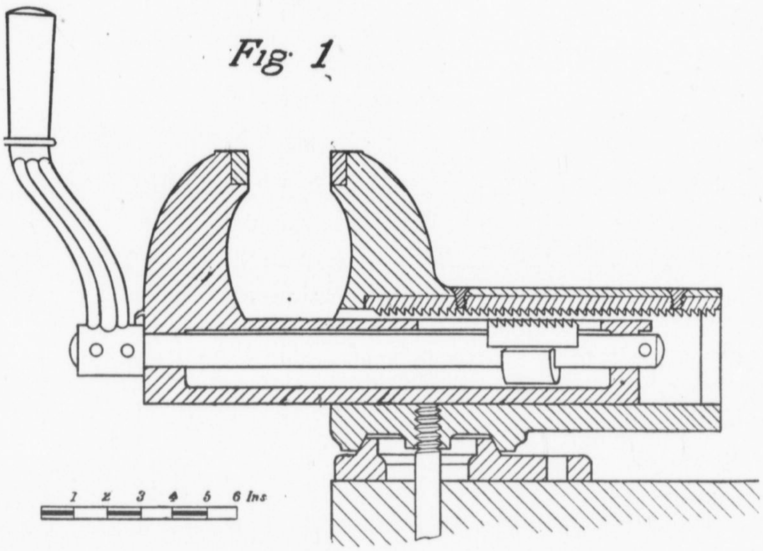
The number and variety of tools that a fitter requires is quite limited, but the number it is advantageous to have is not. Among the necessaries are an ordinary two-foot rule, a twelve-inch scale, divided on one edge into sixty-fourths, two or more pairs of outside, the same of inside, callipers, compasses, surface gauge, spirit level, scriber, and try-square. Other handy tools are a pair of compass-callipers, or, as workman say, a pair of "morphodites," bevel, centering, box, and T squares, bottoming gauge, thread gauge, pair of trammels, plumb-bob, and many others. In addition to these tools a fitter should have or have access to a bench-vice, hand-vice, hammers, chisels, punches, drifts, files, file-card, scrapers, hacksaw, taps and dies, reamers, surface plates, straight-edges, etc.

It is thus easily seen that the term "vice-work" is of the widest significance. It includes, besides the direct treatment of the work by chipping, filing, scraping, polishing, etc., the proper use of all the various hand tools and instruments mentioned; the lining and marking off of articles of every description, to prepare them for further manipulation; the final fitting and erecting into one symmetrical whole the various parts of the simplest or most complex machine. But of these various requirements the present paper will take up vice-work in its most limited sense, the writer deeming it better, in such a short paper, to touch somewhat definitely on a few main points than to skim vaguely over the whole wide subject. Attention will therefore be mainly directed to the form and general use of the vice, hammer, chisel, file, and scraper.

VICE.

Of necessity, the first thing that has to be looked to is the vice. One of the best forms in the market to-day is that patented by Entwisle and Kenyon, Fig. 1. These vices are on a swivelling base, so that they can be swung round and locked in any position, usually by a large winged nut underneath the bench. The jaws are steel-faced and are parallel in all positions; the front jaw is part of a sliding box which may be easily hauled out and in when the handle, or rather lever, is vertically upward. The locking device is quite simple; in the body of the vice above the sliding box is a rack with fine teeth, eight to the inch, pointing to the back; the handle is fastened to a rod, extending the length of the sliding box, pinned at the back end to prevent its abstraction and to prevent it making more than three-quarters of a turn, and on this rod toward the back end is an eccentric running spirally or screw-wise around it; on the eccentric rests a short toothed steel piece, the saddle, shaped beneath to fit the slant sides of the eccentric. When the handle is up, the saddle, the teeth of which point to the front, is just clear of the rack teeth; as the handle is lowered, the saddle is raised, the teeth engage, then the screw motion of the eccentrics hauls the jaw firmly to its grip. The usual closure is about one-eighth of an inch. To grip any article, raise the handle with the right hand, haul out the sliding box with the left, place the work in position, push in the jaw till it presses against the work, then

Fig 1



rapidly lower the handle and the work is firmly and quickly gripped. For rapidity and ease of action and firmness of grip this vice has no equal, for with one-half turn of the handle an article of any size, large or small, can be securely seized.

The height of the vice from the floor depends much on the class of work that has to be operated upon ; if heavy, it should be low ; if light, high. A good average height is to have the jaws of the vice on a level with the workman's elbow ; usually, however, the height depends solely upon the height of the bench, which should be about thirty-three inches.

Of the ordinary vices, those with a sliding box are better than leg-vices where the front jaw is long, acting with hinge motion ; therefore, its jaws are parallel and vertical in one position only. For heavy irregular-shaped work the latter, however, acts very well.

To prevent injury to the surface of the work from the hard and rough jaw vice-clamps are used, made of copper, for holding iron, and of leather or lead for brass or any delicate piece of work. The copper clamps should be of one-sixteenth inch annealed sheet copper, shaped by the hammer to fit neatly over the vice jaws ; the jaw part of the lead clamp being about one-half inch thick. For holding articles of special shape various attachments are used ; thus, for holding a taper cotter, a piece of iron, straight on one edge and rounded on the other, is pivoted to a piece of copper which fits over the back jaw of the vice (Fig. 9), the cotter beds itself against the forward jaw and the straight side of the vice-strip, which then readily adjusts itself against the fixed jaw by reason of the rounded side. An excellent way of holding small screws or other articles is made by connecting two pieces of iron or copper by a spring (Fig. 10), the pieces being provided with a flange to rest on the top of the vice jaws, and having in the face of each, vertically, round and square grooves of different sizes. The spring keeps the pieces slightly apart until the jaws of the vice tighten upon them.

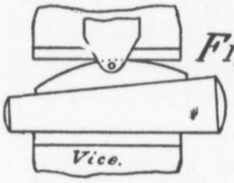
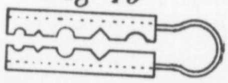


Fig 9

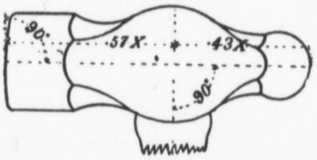
Fig 10



HAMMERS.

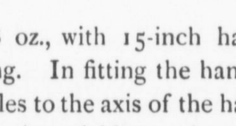
Hand hammers are divided into two classes, (*a*) chipping and riveting, and (*b*) pening. In the former (Fig. 2), one end is cylindrical in shape, the other, hemispherical; the first for chipping or driving, the second for riveting; while in pening hammers the round knob is replaced by a long narrow edge, either straight or rounded in its length, the edge being either at right angles or parallel to the line of the handle, the former being much the better. Hammers vary in weight from 6 to 30 oz., according to requirements. One for general work should weigh about 21 oz., having a handle 13½ inches long, inside the head. The proper dimensions of a hammer of about that weight are: length over all, 4⅛ inches; length of face end, ¾ inch; diameter of face, 1¼ inches; length of eye, 1½ inches; thickness at eye, 1⅛ inches; the pene, ⅞ inch in diameter. The face of the hammer should be slightly convex, with rounded corners.

Fig 2



A hammer weighing 28 oz., with 15-inch handle, is very serviceable for heavy chipping or driving. In fitting the handle, it is most important to have it stand at right angles to the axis of the hammer head (see Fig. 2), and to have its oval true with the axial line, otherwise erratic hammering is sure to result, with injury to the hammer, the work, or the workman's fingers. The operation of pening is much resorted to to straighten articles which have become bent, or to bend pieces of work to give them a different shape, as shown in Fig 3. It consists in hammering the skin of the metal, thereby lengthening it. If a straight piece be hammered all over one side, it becomes convex on that side; if a curved piece be hammered on the convex side all over the surface, the curve bends to a smaller radius, but, if hammered on the inside, to a larger radius. Ham-

Fig 3



mering in one place, instead of all over the surface, will produce a sharp instead of a uniformly curved bend. The amount that cast iron can be bent is considerable. The hammer should not, in general, exceed 8 oz. in weight; and, in hammering, most of the motion should come from the wrist, as much more depends on the number than the force of the blows. When pening cast iron, it is best to rest it on a narrow surface of iron, always taking care to have the article bedding well when being pened. Articles of other material are best done when resting on wood. When any article has been pened, as little of the surface as possible should afterwards be removed, for, otherwise, the results of the pening may be destroyed.

Riveting is generally performed by the machinist upon cold metal, and can best be described by an example. A crank pin has to be riveted to the crank (Fig. 4), the crank first being countersunk on the back (a narrow and deep countersink will hold much better than a wide and shallow one), and the pin, which should be slightly longer than the thickness of the crank, should be recessed. Stretch nearly the whole end of the pin, deliver the hammer blows in a slanting direction from the centre to the circumference, thus forcing the metal outward. The pin should be hammered symmetrically, *i.e.*, first on one side of the centre, then on the other, which will prevent its being thrown out of true. The round pene of a light hammer should be used, but the weight of hammer varies with the weight of the article operated upon. The article to be riveted should rest firmly on a solid bed, such as an anvil, a piece of copper being interposed if the work is liable to be injured by the contact.

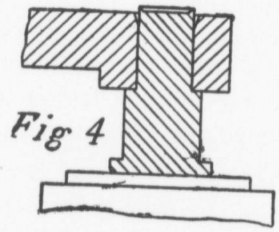


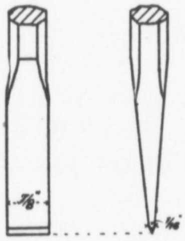
Fig 4

Hammers are used for driving, straightening, and stretching. In driving, a sharp, rapid blow is much more effective than a slower one with the same momentum; for example, in loosening a key from its seat, unless the blow produces the desired effect, it simply makes matters worse by swelling the end of the key; in stretching, as in pening and riveting, slower "dead" blows act better, while in straightening the kind of blow depends on circumstances, slow blows with a fairly heavy giving good results. When using a hammer, to get a maximum amount of work from it, hold it, at the end of the handle, somewhat freely, by no means grip it, give plenty of motion to the wrist and fingers, so that when the hammer is drawn back the pene all but strikes the workman's elbow; let the force of the blow be mainly derived from the forearm.

CHISELS.

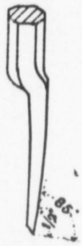
Chisels are of all sizes, from a small one driven by a four-ounce hammer to a large one driven by a fourteen-pound sledge; but for all ordinary sizes and shapes three-quarter-inch octagon steel is used. These chisels are of various shapes—flat, side-cutting, cope or crosscut, keyway, round-nosed, cow-mouthed, diamond-pointed, oil-groove, and draw-chisels, and many others. The greatest of care should be exercised in tempering chisels, for the work required of them is considerable, the temper extending for half an inch or more from the cutting edge, and being in color from a yellowish brown, for light cuts on hard steel or iron, to almost a blue, for heavy cuts on wrought iron; a dark red makes a very serviceable tool. However, the Society is to receive, soon, a paper on the subject of tempering, when the matter of tempering will be fully dealt with.

Fig 5



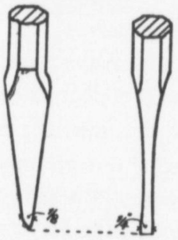
The flat chisel (Fig. 5) is the one most used, and should be made shorter than is usually the case, $6\frac{1}{2}$ or 7 inches being quite long enough. It is tapered for from 3 to $3\frac{1}{2}$ inches of its length, and is about $\frac{1}{16}$ or $\frac{3}{32}$ of an inch thick near the point, and about $\frac{7}{8}$ of an inch wide. The facets forming the cutting edge should be flat, not rounding, so as to form a guide to maintain a proper depth of cut. The angle of the facets to one another depends on the material and on the heaviness of the cut; the lighter the cut, the more acute the angle; the tougher the metal, the greater the angle. In general, 65° to 60° for cast steel, 60° to 55° for wrought iron, 55° to 45° for cast iron, and 45° to 35° for brass and copper; the facets being ground at an equal inclination to the axis of the chisel. The cutting edge should be very slightly rounded in its length, nearly straight in the middle, slightly more rounded close to the corners. The rounded edge gives increased strength, as the corners are not so apt to break off; but, if the edge is quite straight, better and smoother work can be done; a chisel with a straight edge is, therefore, used to advantage whenever there is clearance to its corners. The edge should be carefully ground parallel to the flats, and perpendicular to the length of the chisel; for, if not, in the first case, the chisel would cut deeper at one side than the other, and, in the second, it would be apt to jump sideways after each blow.

Fig 6



A side-cutting chisel (Fig. 6) is a slightly altered form of flat chisel; the taper is all on one side, as is also the grinding for the facet angle, while the other side of the chisel is nearly straight, being bevelled very slightly only for about ½ of an inch from the cutting edge. This tool is used very much for cutting down the side of holes, such as the cotter holes in a connecting rod.

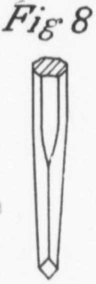
Fig 7



The cope or crosscut chisel (Fig. 7) is for cutting narrow channels across any surface; it is, in length, about the same as a flat chisel, drawn out somewhat heavier, *i.e.*, the taper is shorter. The cutting edge is usually about ¼ of an inch wide, and the cutting angle slightly greater than in the case of the flat chisel, the bottom facet being at a less angle than the top to the axis of the chisel. It should be widest at its cutting edge, decreasing very slightly the first $\frac{1}{4}$ of an inch, and, after that, more. The first $\frac{1}{4}$ of an inch guides the chisel, yet, at the same time, allowing it enough motion sideways to permit its being properly directed. It is even more particular in the case of this chisel that the cutting edge be ground properly, as it should be at right angles to the flat sides and to the line of the chisel.

Keyway chisels are special sizes of cope chisels, and are of fixed widths, usually $\frac{1}{64}$ of an inch less than the width of keyway required. The greatest width that may be used to advantage is about $\frac{39}{64}$ of an inch, *i.e.*, for a $\frac{5}{8}$-inch keyway; keyways of greater width being made by two or more cuts of a narrower chisel.

Fig 8



The diamond-pointed chisel (Fig. 8) receives its name from its shape. The steel is drawn out till almost square at the point, then bevelled from corner to corner, the point being usually on a line with a side of the tool, and the two sides forming the cutting angle should be about 85° to each other. This chisel is used for cutting out square corners in a round hole, for cutting a heavy iron pipe in two, or a thick sheet of metal, etc.

The other chisels are governed in shape by the same general principles; their use is known from their general appearance; for example, the oil-groove chisel is a round-nosed narrow chisel, curved in its length, which adapts it for use on the curved surface of bearing brasses, etc. When any article has to have a cut taken off one surface, the operation should be performed as follows:—Mark the line to which the cut has to be taken, and bevel the edges all the way round with a chisel, finishing to the line with a file, which will prevent the metal breaking away at the edges; next groove the surface, almost to the lines, with a crosscut chisel, leaving $\frac{3}{4}$ of an inch between the channel, and then remove these ridges with a flat chisel, in at least two cuts if on cast iron, for, in taking a heavy cut on that material, the iron is apt to break away below the line of cutting. On wrought iron, use a little oil on the end of the chisel.

When taking a light cut or using a narrow chisel, hold the chisel well to its cut, *i.e.*, keep its cutting edge always against the metal and the shaving; but in heavy chipping, with a flat chisel, a "rebound motion" is best, *i.e.*, after every blow of the hammer draw the chisel back a little, then forward again before the next blow, just as if it rebounded under the force of the blow; in this way one can watch better the cut being taken, and can always ensure the cutting edge being properly placed in regard to the chipping.

When chipping stand well in front of the work, so that the hammer acts as nearly as possible in a vertical plane. Hold the chisel loosely; a beginner has to be told this but once, for he soon finds out by experience that if he grips the chisel like a handspike and happens to miss the end of it with his hammer onerous consequences follow, while if he held it freely the hand would give before the hammer, and little damage would result.

FILE.

After the chisel naturally follows the file, the proper use of which is of the greatest importance. Files are either hand cut, *i.e.*, cut by hammer and chisel, or machine cut, the former being much superior. The objection to machine-cut files is an odd one, the teeth are too regular, thus causing the file to cut in grooves. A file is fully described when its length, "cut," fineness, contour, and cross-section are known.

The *length* is measured exclusive of the tang. Hand files are rarely less than $1\frac{1}{2}$ inches or more than 20 inches long; their length does not, in general, bear any fixed relation to their width or thickness.

In "cut," *i.e.*, the way in which the teeth are placed, a file is single, double, or rasp (the last is but little used, and so need not be taken account of). The single-cut file is one in which the tooth extends the full width of the file, being cut by a single course of chisel cuts each parallel to the preceding, all inclined at an angle to the central line, varying from 5°, on brass, to 20°, on harder metals. Double-cut are those having two courses of chisel cuts, one crossing the other; the first, the "over-cut," is inclined at from 30° to 50° to the central line, up to the right; the second, the "up-cut," at from 5° to 30° to the left, the lesser angle giving the better satisfaction; the up-cut is usually slightly finer than the over-cut. Single-cut files are used in all lathe work, and at the vice in filing any narrow edge, and for draw filing on soft metals. Half-round files are usually single-cut on the round side, as are also round files, the edges of flat files, etc.

Double cut are by far the most used; they cut faster, easier, and smoother, and are suitable for any description of vice-work. The teeth on a double-cut file are, approximately, diamond pointed,

In *fineness*, files are divided into six grades, rough, middle, bastard, second-cut, smooth, and dead-smooth; the distance between the teeth in each case altogether depending on the size of the file, the teeth of some dead-smooth files being so fine that the eye finds it difficult to distinguish the lines; and yet these are cut by hand, the finest coming from Switzerland.

As to *contour*, *i.e.*, the general outline, files are parallel, equalling or bellied, and taper. Parallel files, *i.e.*, those of the same diameter or thickness from end to end, are but little used; occasionally long square parallel files are of service, as, for example, in filing out a long keyway; but the great trouble with these, and, in fact, all files, is to keep them from warping in the hardening; the variation from straight is more noticeable, however, in parallel files. Equalling or bellied files are by far the best for general purposes, for, as these files are slightly thicker and wider at the middle than at either end (the more even the curvature, the better the file), it is comparatively a simple matter to obtain a flat surface. Nearly all "flat" files are equalling. Taper files are those which have a marked difference in thickness and width at the centre as compared with the ends, especially the point, and in this class are included most round files and many half-round and square, and also all triangular files.

In *section*, files are flat, square, triangular, round, and half-round. A flat file is one of any rectangular section other than square. The other terms are self-explanatory. Square files are usually double-cut and well bellied, one edge usually being made a safe edge. The square files and round, generally used, are bastard-cut. Small round files, $\frac{1}{4}$ of an inch and under, are called rat-tails.

There are many other specially shaped files other than those mentioned, but they do not come much into use in a machine shop.

The flat bastard file is the general-purpose file of the shop, any coarser grade being used on soft metals alone or on very large work. For heavy filing, a 14-inch file is used, while for lighter work a 12-inch one is quite large enough. Unless the work has to be polished, the bastard file will usually answer, for any good workman can file quite smoothly with it; a second-cut is, however, used in preference to a bastard when the material is unusually hard, the two finer grades of files being used chiefly for polishing. When the surface to be filed is wider than the length of the file, a surface handle is used which fits over the top of the file, the tang fitting into a dovetailed groove in the back end of the handle (see Fig. 11).

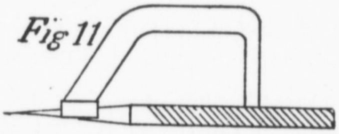


Fig 11

Whenever it is necessary to use a file in a corner, one side of which must not be injured, a "safe edge" is put on the file, *i.e.*, the teeth are ground off; in this way a good square corner may be obtained. Sometimes the edge is left uncut, but in that case also the safe edge should be reground. When the file is pushed end-wise the operation is called "cross-filing"; and when it is moved in a line at right angles to its length, it is termed draw-filing. In heavy cross-filing the file should be held so that the handle presses against the palm of the right hand, thumb on top, while the left hand presses down on the point of the file, the ball of the hand on top, the fingers underneath. If, however, the file is thin, the point should be held with the thumb and one or two fingers, the fingers being nearer the point than the thumb, which exerts a downward pressure, an upward pressure being applied by the fingers underneath, thus tending to make the file convex on the bottom side. As any file can cut on the forward stroke only, remove all pressure from it on the return stroke; otherwise the teeth are apt to break off. For heavy cross-filing the workman should stand well off from his work, feet wide apart, left foot forward, and with each stroke of the file relieve the left foot of all pressure, lean forward, and thus make the weight of the body aid in pushing the file. At the end of the stroke the left foot should receive the weight of the body till the workman has regained his position ready for the next stroke. In all cross-filing, no matter for what purpose, the file should be given considerable lateral as well as forward motion, better results being obtained when it is from right to left, for the file cuts better, and there is less injury to the teeth, but the file marks should cross and recross each other every few strokes. In filing any narrow surface the file should be applied very diagonally. The beginner will find it an exceedingly difficult matter to file *flat*, for, despite his best efforts, he will find that he has, even on a surface three inches wide, considerable curvature. The reason of it is evident: certain pressures are applied at each end of the file, therefore as the file advances, if the pressures are maintained, the resultant of all the forces is continually changing its position, thus causing the file to dip first on one side, then on the other, the result of which will be a curve which by no means conforms to the equation $y = mx + c$. To counteract this, the pressure exerted by each hand must be continually altered, the one decreasing as the other increases. No amount of explanation can, however, make a man file flat. It is an accomplishment in which one can become proficient only after considerable experience.

Draw-filing is employed for two purposes: first, to ensure a much better fit than can be obtained by ordinary cross-filing; and, secondly, to finish the surfaces more smoothly, so that they may be polished. Before draw-filing any article, first cross-file it with a file not coarser than a second-cut. The greater accuracy obtained from draw-filing arises from the fact that it is possible to remove metal just where desired; the curved form of the file allowing it to rest just where it is wanted, and strokes of the proper length can, of course, be given. Thus choose a well and evenly-bellied file, run your eye along the edge, noting the place of greatest curve. Apply that part to the work, grasping the file at each end, independent of the handle. Use short strokes, and when draw-filing in preparation for polishing use light pressure, relieving the file entirely from pressure on the return stroke. Very great care has to be taken to prevent the file "pinning," *i.e.*, getting the cuttings locked in the teeth, and thus causing scratches. As a cause for pinning, long strokes and failure to remove the pressure on the back stroke are most conducive; therefore avoid such. Keep the file flat on the work, not tilted to one edge, except for rapid first touches, or when perfect freedom from scratches is not a necessity. After every few strokes clean the file by lightly tapping it on the back of the vice, and occasionally with a file card, and at the same time blow off the filings from the work, or wipe them off with a *clean* piece of waste, but by no means use the hand for the purpose, for it puts a scale on the iron which it is difficult to make any but a new file touch. As another preventive of pinning, the surface of the file is rubbed with chalk; this causes the file to cut smoother, but not nearly so rapidly; the file has to be as frequently cleaned as before and re-chalked. The file card is brushed along the line of the teeth, so that the wire may reach the bottom of the grooves. To remove any pins which may get in the file teeth, use a piece of sheet brass, or wire flattened out, which, after being shoved over the file a few times, gets teeth cut in it, which easily dislodge the objectionable cuttings or dirt.

When draw-filing in preparation for polishing, it is best to make the file marks cross and recross each other, and, if possible, across the grain of the iron. The subject of polishing is a wide one, and cannot be entered upon here, but, in general, for very fine work proceed as follows: After preparing the work with a bastard or second-cut, cross-file, then draw-file it with a smooth file, then repeat the operations with a dead-smooth one which has been considerably used, and then finish the surface with emery cloth, either dry or with oil.

When it is necessary to use a round or half-round file, choose one well tapered or bellied, and of a curvature in cross-section less than the curve to be cut. When cross-filing with either of these files give them a side sweep as well as a forward motion, this is given by gradually twisting the wrist; the sweep should be first from right to left, and then from left to right. Avoid, as much as possible, draw-filing with a half-round file, for the teeth are rarely cut accurately enough, and scratching is sure to occur; but if draw-filing is resorted to, slightly rotate the file at each stroke, and give it a little end motion, the marks crossing and recrossing.

Hold all work as close to the vice jaws as possible, and in such a position that the file acts in a horizontal plane.

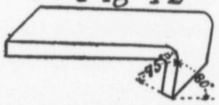
To get a maximum amount of service from a file, it should be used first for copper or brass, then, when too dull for these, on wide to medium surface of cast iron, then on wide to medium surface of wrought iron, and, finally, for any other purpose. Also, to increase the life of a file, be careful always to use first an old file until the hard scale is removed; on any hard spots use the edge of the file.

Well, so much for the files and filing; let attention be next directed to

SCRAPERS AND SCRAPING.

Scraping is the third graded step in localizing abrasive action, and with the use of the scraper an almost perfect surface or bearing can be produced. Scrapers may be divided into two classes: those for flat surfaces, and those for round or curved surfaces. Of the first class there are two main forms, each claiming superiority; they are, first, the ordinary straight scraper, straight throughout, made from a flat piece of steel; and, secondly, a scraper with the cutting edge on a part at right angles to the rest of the tool, Fig. 12. Of these two the writer prefers the former; it will cut faster, truer, and, if carefully ground, just as smoothly as the

Fig 12



other; its operations are much more easily watched and guided, and it can be made and sharpened with far less trouble, and for one sharpening presents two cutting edges, while the second form has but one. As good a scraper as desired can be made from an old flat file drawn out, from which the teeth have first been carefully ground, for otherwise it would be apt to crack in the hardening or scratch afterwards. Scrapers should, of course, be made as hard as fire and water will make them, and for not more than $\frac{1}{4}$ of an inch from the point. The width of the straight scraper at the point should be about $\frac{7}{8}$ of an inch, its thickness $\frac{1}{16}$ of an inch, thickening gradually up to the butt, and its length should not exceed 7 inches exclusive of the handle, for which an ordinary file handle will answer. The end of the scraper should be sharpened on the side of an emery wheel, being made almost straight in the length of the cutting edge. Each cutting edge, which at first contains an angle of 90°, should be carefully oil-stoned to contain an angle of about 95°; this is done to prevent the scraper "chattering," as it otherwise would do. The scraper bent at the point has the front face at an angle of from 80° to 90° with the top of the scraper, and the bottom face at a considerable angle, say 75°, with the front; the angular projection should not exceed $\frac{1}{4}$ of an inch. (See Fig. 12.) When scraping, grasp the scraper firmly, for considerable pressure has during the first processes to be used, and, as in the case of the file, relieve the pressure on the back stroke. Short strokes crossing and recrossing each other should be employed. When planer or file marks have to be removed, scrape diagonally across them, and it is advisable always to give lateral as well as forward motion, as the scraper will cut faster and smoother.

When work has to be scraped flat, a surface plate is necessary; it should be of a comparatively thin plate of cast iron, heavily ribbed, and should be supported at three, and only three, points. To use the plate, "marking" is required, which is usually red lead, mixed to a thin paste with lubricating oil. (Venetian red is better, but is more expensive.) The marking is usually applied with an old rag rolled over and over, and tied with a string so as to form a kind of brush; but when the coating has to be very thin, the palm of the hand should be used. The amount of marking required depends upon the fineness of the work, varying from a thick coating for testing chipping to an almost imperceptible amount for fine scraping; if much red lead is employed for scraping, it is impossible to obtain a true surface. So by no means believe in the maxim, "Much red lead makes a good bearing." Have the marking evenly spread over the surface of the plate. If the work is large, the surface plate should be applied to the work; but, if not, the work should be applied to the surface plate. Take the article which is to be operated upon, and plane or file it to as flat and smooth a surface as possible by planing, or cross-filing. If a file is used, the work could be frequently tested with a straight-edge, applied to various parts, and then the work is laid on the surface plate to see if there is any "rocking," which should be removed with a file. Next, with a scraper remove the surface of the metal almost to the bottom of the file or tool marks, using short strokes, as mentioned before, crossing and recrossing each other; then laying the work on the surface plate, and holding it somewhere near the centre, move it lightly about, rotating it at the same time. The higher spots will be marked with the red lead; the darker the spots the harder the work bore upon the plate. Scrape the work when necessary, *i.e*, whenever the marking shows, removing most metal where the spots are darkest; again lay it on the plate, and again scrape where required. These operations have to be repeated over and over, till the job is complete. Any well-scraped article presenting about 12 square inches of surface should be able to lift up by surface contact alone a 45 lb. surface plate, each having been rubbed with the hand until almost quite dry.

If the work is held in the vice, be most careful to so hold it that the pressure of the vice jaws does not throw it out of true, and it is remarkable how little pressure is needed to bend even massive castings; for example, a surface plate supported at *four* points can easily be proved to bend in several ways, merely from its own weight, according to which three of the four feet are acting; of course the deflection is small, but still quite perceptible; this is a fact not generally noticed.

If work has to be scraped where a surface plate cannot be conveniently applied, other methods have to be adopted; for example, in a valve seat, first scrape the valve to a perfect surface, and then true the valve seat, using the valve as a surface plate.

When scraping wrought iron, steel, or brass, use a little water, by which scratches or chattering are greatly avoided. With brass the cutting edge of the scraper should contain an angle of about 100°.

When it is desired to scrape the inside of a hole or the inside of any curved surface a half-round scraper is employed, which is made usually from a half-round file drawn out to a point, and then slightly and evenly curved on its flat side, having a little more curve than a well-tapered ten-inch square file; too much curve will cause chattering. The cutting edges are along each side, and form an angle with the flat side of about 75 or 80 degrees. The scraper should be hardened "right out," then carefully ground and honed. The scraper should be given a twisting motion, under considerable pressure, and at the same time end motion either inwards or outwards.

The triangular scraper, usually made from a three-cornered file, ground to a point, is used in holes of small diameter or on other small curves, and is worked similarly to a half-round scraper.

THE COUNTRY ROADS OF ONTARIO

By John A. Duff, B.A., Grad. S.P.S.

The following paper has grown out of what was originally intended as a discussion on Mr. Johnson's excellent paper on "The Maintenance of English Roads." My object was to supplement his paper by showing to what extent the system which has produced such good results in England would be applicable to the conditions prevailing in Ontario, and how nearly we may expect to approach in our own country roads the perfection of the English highways.

It was thought, however, that as this was a subject of personal interest to all the members of the Society, it would be well to give full opportunity for discussion by publishing these remarks as a separate paper. This decision having been arrived at, I have incorporated some new matter and recast the whole, but without losing sight of my original purpose; and, as every paper must have a title, this has been called

THE COUNTRY ROADS OF ONTARIO.

At certain seasons of the year, most of our country roads are very bad; some of them are bad at all seasons. Being nearly all earth roads, with no more grading than was incidental to the construction of side ditches, the quality of the road in each case depends in a great measure upon the nature of the soil and season.

This is a very primitive state of things; and it is not surprising that travellers, and especially wheelmen, who have walked through sand ankle deep, or toiled through clay which only needed underdraining, or jolted over some neglected corduroy, should complain of the condition of our roads and demand their improvement.

But, all things considered, are they not much better instead of worse than might have been expected? It is not many years since they were hewed out of the forest. The road allowances went up and down hill, over swamps and streams, following the lines run by the surveyors, without any regard for the two cardinal principles of road location—economy of construction and convenience of travel. This great mistake made the construction of the roads exceedingly difficult in many localities, and has added enormously to the cost of maintenance, to say nothing of the comfort and the beautiful picturesqueness which a level winding road affords. This system of road allowances may have been convenient in the arrangement of farms, but in the hilly country it was fatal to the interests of good roads. And would it not have been a more sensible plan to have laid out the farms with regard to the configuration of the land, instead of having them contain a fixed number of acres? How often do we see a narrow strip of land separated by nature from the rest of the farm, which would be much more valuable if belonging to the adjoining property!

If a more scientific system of road location had been adopted, the problem of road improvement would be much less difficult and less urgent than it is to-day.

Much could yet be done to retrieve the blunder by closing up unnecessary roads, opening out new roads, and making deviations in difficult places.

On these road allowances the pioneers were left to build and maintain roads in the intervals between the clearing of their fields. The roads were only beginning to show the labor which had been done upon them when the era of railway construction began, and they were called upon to build railways instead of highways to connect them with the world outside. They could not well do both. They chose to develop the railways in preference to the highways, but the liberality with which the railways were bonused shows that the farmers appreciate the advantages of good avenues of transportation, and will not be content with bringing the world's market to the nearest town, but will complete the work by bringing it to their own doors.

Now that the province is well supplied with railways, public attention is turning towards the highways, and a few years will see a great improvement in them, unless the electric railway promoters persuade the farmers to build trolley lines instead.

The agitation for the improvement of the roads has already taken definite shape, and in February last the Ontario Good Roads' Association was formed. The report of their meeting, published by the Ontario Department of Agriculture, shows that, though few definite conclusions were arrived at, some valuable papers were read, and much profitable discussion took place.

The feature of the meeting was the vigorous attack made upon the statute labor system. It was called antiquated and unscientific, obsolete and semi-barbaric; but the association did not agree upon any better system, nor upon the kind of road which is both desirable and possible in Ontario.

The latter question should be decided first, because the system of maintenance best adapted to one kind of road may not be the best system for some other kind.

In most localities in Ontario the choice will be between Earth, Gravel, and Broken Stone or Macadam roads.

EARTH ROADS.

The most prominent characteristic of earth roads is their infinite variety, ranging all the way from a wagon track across a common to a road as carefully graded and drained as for Gravel or Macadam, though without a metal covering.

Nearly all the country roads in Ontario are Earth roads, and very few of them are as good as they might be, the chief cause being that little or no attention is given to underdraining.

An instance which has come under the writer's observation is that of a place near the foot of a hill, which had a very unpleasant habit of "breaking out" every spring. Some years ago, under the direction of the pathmaster, the road at this place was paved with field stones, lightly covered with earth. Last spring it was impassable, and a sign had to be put up to warn travellers. It had "broken out" in a fresh place. A few rods of tile drain, at a cost of three or four dollars, would have disposed of this soakage water, and made the road permanently firm and good.

Such attempts at roadmaking are like trying to make a field dry by closing up the spring holes. Water cannot be corked up in the ground as in a bottle; it will ooze out somewhere. A soil saturated with water is never firm, and the only way to insure a firm roadbed is *to keep it dry* by providing for the immediate discharge of all water which may fall upon it or sink into it. For the proper maintenance of any kind of road, there is nothing so important as that the foundation should be *firm* and *dry.* A firm, dry roadbed supports and drains the surface, keeps it firm, and hinders the formation of ruts and holes, and (what is perhaps of greater importance in a climate like ours) almost entirely prevents the destructive action of the frost known as "heaving."

If the subsoil be clay, or not naturally dry, it must be thoroughly underdrained. Deep side ditches will partially underdrain a narrow road, but deep ditches are dangerous. A single drain of three-inch tile laid down the centre of the road will generally be sufficient. The trench in which the tile is laid should be filled in with gravel, sand, small stones, or other loose material, since there is a danger of the clay becoming so compacted as to be almost impervious to water, and thus prevent the proper action of the drain. The cost of a rod of such a drain may be estimated as follows:

Tile	20 cts.
$\frac{1}{2}$ cubic yard gravel	40 cts.
Labor	15 cts.
Cost of drain per rod	75 cts.

It would soon pay for itself in the difference in the cost of maintenance, apart from any improvement in the condition of the road.

The advantages of easy grades are better appreciated than good drainage, and many of our roads are well graded, though very few are properly drained.

The work of grading has been rendered much more difficult by the bad system of road location already referred to, and much time and money has been spent in grading which might otherwise have gone towards draining and metalling.

GRAVEL AND MACADAM ROADS.

These roads should be graded and drained the same as Earth roads. In fact, the only difference between Earth, Gravel, and Macadam roads is in the character of the wearing surface.

For the economic maintenance of a metalled road, it is of great importance that the foundation be made firm and dry by thorough underdraining; otherwise the metal will be continually sinking into the subsoil, and will require frequent renewal.

Gravel or Macadam roads dry more quickly than Earth roads, because they are harder, smoother, and yet more porous, and the water runs into the side ditches or filters to the underdrains more readily.

Broken stone is a harder and more unyielding material than gravel, especially when the latter is moist, so that the Macadam road is better for heavy traffic or wet weather. But if heavy loads in wet weather make ruts in a Gravel road, the ordinary traffic fills them in when the road is dry; whilst if ruts form in a Macadam road the subsequent traffic only makes them worse, and they must be filled in by day labor. This is an important consideration when comparing the cost of maintenance of a Gravel and a Macadam road.

A Macadam road is harder on the horses' feet than gravel, and unless in good repair is very rough and hard on vehicles, and much inferior to a well-conditioned Gravel road.

Macadam roads are more expensive in construction and maintenance than Gravel roads; but where there is heavy traffic, or much wet weather, and where ample provision will be made for thorough maintenance, they are more satisfactory in the end.

THE BEST ROAD FOR ONTARIO.

In determining the road best adapted to any locality, the decision will chiefly depend upon:

1. First cost.
2. Cost and convenience of maintenance.
3. Climate and soil.
4. Nature and amount of traffic.
5. Number of people directly benefited, and amongst whom the cost is to be distributed.
6. The average wealth of the community.

As a district increases in wealth and population, the traffic on the roads becomes heavier, requiring a more durable, if more expensive, road metal, while the cost of construction and maintenance becomes less burdensome, and is not such an important factor in the calculations. England is frequently cited as the country to be imitated in the matter of roads, and it is argued that because the English have good Macadam roads our roads should also be Macadamized. The weakness of this argument consists in the fact that it can easily be shown that the conditions upon which road construction depends are quite different in England from what they are in Ontario.

In the first place, the climate is very different. The English climate is wet, so wet that an English engineer, speaking of asphalt pavement, says, "Its one great fault of slipperiness, which requires it to be sanded every morning, is made up for by its being clean, healthy, and durable."

This shows the influence of the English climate on the roads better than any tables of rainfall or humidity.

In England there is little frost and no sleighing. In Ontario there are four winter months, during which the roads are frozen hard or covered with snow, and five summer months, so dry that even an earth road is in good condition. The traffic on the English roads is much heavier than in Ontario, and a material which would not stand their traffic might serve admirably for ours.

England is populous and wealthy, and the cost of construction and maintenance are of minor importance. In Ontario, where each farmer on one hundred acres is required to build and maintain about a quarter of a mile of road, the first cost and the cost of maintenance are very serious considerations.

In short, the English roads are in commission all the year, the climate is wet, the traffic is relatively heavy, and the country is populous and wealthy. Accordingly, the cost of construction and maintenance of a Macadam road would be counterbalanced by its adaptability to wet weather and heavy traffic. In Ontario the conditions are quite different. A wet-weather road is needed only three months in the year, the traffic is light, except in the vicinity of towns, and the population is so sparse that the cost of construction and maintenance may prove a heavy burden. In most cases the question will not be, "What is the best road that might be made?" but, "What is the best that may be made with the resources at our disposal?'

In a paper on "The Improvement of Country Roads," read before the Ontario Good Roads' Association, Mr. A. W. Campbell estimates the cost of converting our present earth roads into good, well-drained Macadam or gravel roads as follows—the material in each case being obtained within five miles:

	COST PER MILE
Gravel, width 8 ft., depth 9 in.	$1,334 00
Gravel with flake stone foundation, width 8 ft., depth 9 in	1,396 00
Broken stone, width 8 ft., depth 7 in	1,596 00

He does not refer to the cost of maintenance except in the following paragraph, which must be quoted full in order to be duly appreciated:

"To illustrate how the above figures would apply to township municipalities, I have prepared an estimate of the cost of improving 175 miles, being the road mileage at present maintained in the township of Yarmouth, adjoining the city of St. Thomas.

175 miles, cost $1,800 per mile	$315,000 00
Equal annual payments, 4 per cent., thirty years	$18,216 45
Maintenance $20 per mile	3,500 00
Total yearly payment	$21,716 45
Present maintenance, including statute labor at $1 per day	$ 9,000 00
30 years' actual extra rate	12,716 45
	$21,716 45

"Total acreage in township, 70,000.

"Assessed value, $2,700,000; per 100 acres, $3,850.

"Estimated actual value, $4,000,000.

"Extra rate required for annual payment, 4¾ mills.

"Estimated increase in value of property, 10 per cent., $400,000.

"In constructing 175 miles of stone road 50 per cent., or $157,500, would be expended for labor that could be performed by the ratepayers this would be equal to $225 per each 100 acres.

"The roads would cost $315,000, of which $157,500 would be spent in the township. The property would be increased in value $400,000. Taking these figures into consideration, the township would be benefited to the extent of $242,500 over and above the cost of construction of the roads."

The annual cost of maintenance of a first-class Macadam road at $20 per mile!!

With wages at $30 per month, it would require the appropriation for twelve miles of road to pay the wages of one man for eight months of the year, so that, according to *this* estimate, one man, working eight months in the year, would be expected to rake and roll the road, fill in ruts and holes, replace worn-out culverts and road metal, keep the drains and ditches clear, etc., etc., on twelve miles of road, and make the material as he went along.

Even with this estimate for maintenance, Mr. Campbell derives his large profit from a ten per cent. rise in the value of the land. Judge

Woods does better. He calculates how much cheaper it would be to *build* a gravel road than to *maintain* an earth road for fifty years.

The following is from his paper read before the Ontario Good Roads' Association:

"Here are some figures that I have put together, and you can judge of the result:

"Let us take the case of the statute labor account of John Smith, a ratepayer on a 200-acre farm, based on an assessment of 22 days, as may be found in one of the adjoining townships to this town, applied as at present on the ordinary earth road for 50 years, as against the borrowing of, say, $90,000, wherewith to make 45 miles of gravel road the first year, on the assessment of $1,000 for a 200-acre farm:

JOHN SMITH		DR.
To 22 days' work for 50 years	$ 1,100	
50 years' interest at 6 per cent	1,683	$ 2,783
Say there are 100 ratepayers, and they are, like John Smith, giving 22 days each, and you have at the end of 50 years, with only the ordinary earth road		278,300
Cost of 45 miles of gravelled roads made in 1889 by borrowing	90,000	
Interest at 6 per cent. for 50 years	135,000	225,000
Balance in favor of gravel road		$53,300

But if the assessment be low it may get as high as 30 days, as it has done. Let us put it in another way:

Statute labor as above	$278,300
Proportionate annual instalment on debentures for 90,000 upon the 100 owners of 200-acre farms at the rate of $1,000 at 6 per cent., $12.63, to give good gravelled roads in 1889, each $634.00	63,400
Balance in favor of debentures and instalment	$214,900

with the use of a good gravelled road in 1889.

"The London *Free Press* says of these figures: 'Judge Woods places the matter of bettering our roads in a clear, intelligent light, on purely mathematical and financial principles.'"

The arithmetic is correct so far as the writer has tested it. But would not even a good gravel road cost *something* for maintenance in fifty years? What would his good gravel road be like at the end of that time?

A false argument never benefits a good cause. Sooner or later, it will be exploded; and, if not, it does greater injury by giving rise to hopes which never can be realized. There is no doubt that good roads pay, and that municipalities cannot spend money more profitably than in judicious road improvement; but the advocates of good roads must depend upon more substantial arguments than the "purely mathematical and financial principles" quoted above.

With the exception of underdraining, which hinders the formation of ruts and holes, and the destruction of the road by frost, the benefits of road improvement are not to be found in a decreased cost of maintenance. These benefits are none the less real, but are derived from other sources, such as increased economy in the marketing of produce and the transaction of business, ability to do marketing at any season of the year, and thus take advantage of high prices, the increased value in farm property which always follows increased profits, and the pleasures and comforts which good roads provide.

The cost of maintenance is much more difficult to estimate than the cost of construction. There are so many contingencies, such as storms and floods, variation in traffic, and durability of material, that a close estimate on maintenance is nearly impossible. It will also depend upon whether the road is to be kept continually in as good condition as when first constructed, or to be allowed gradually to deteriorate and be renewed periodically. All estimates on maintenance should be based upon information showing what has actually been expended upon similar roads, whenever such information is obtainable.

In the county of York, some of the leading roads are Macadamized to a width of ten feet, and maintained by tolls. The following is an abstract of the expenditure on account of maintenance on two of these roads for the years specified:

EXPENDITURE ON MAINTENANCE.

Year.	Yonge Street (28½ miles).	Kingston Road (13 miles).
1884	$ 6,833	$ 3,473
1885	7,275	3,530
1886	9,710	3,442
1887	9,550	3,709
1888	7,546	3,994
1889	8,897	5,531
1890	16,170	4,295
1891	12,077	3,591
1893	11,994	5,816
	$90,052	$37,381
Average annual maintenance	$10,005	$4,153
Average per mile	$351	$319

The expenditure for 1892 was not obtained, but it is improbable that it would materially affect the result.

There is probably more traffic on Yonge Street and the Kingston Road than on other leading roads in Ontario, and the cost of maintenance on other roads would perhaps be less. But, in view of the above figures, the severity of our climate, and the cost of labor, $200 per annum seems to be a low estimate of the cost of maintaining a mile of Macadam road. If the original cost of construction were $16,000 per mile, and if half the cost of maintenance went towards renewals, this would provide for the renewal of the road metal once in sixteen years.

If all our roads were Macadamized to a width of eight feet, the owner of one hundred acres would be required to pay about $400 on construction and $50 per annum on maintenance. This is more than the average farmer can afford, and accordingly the roads would be ill-maintained and go to ruin, like many of the Macadam roads which now exist in parts of Ontario.

A gravel road does not require that constant attention and experienced labor which are so essential to the proper maintenance of a Macadam road. Being composed of a more yielding material, the ordinary traffic rolls it smooth, more especially if the heavy traffic is carried on wide tires; as it wears smoothly, and if it wears out it is because the gravel is pulverized or sinks into the soil. It never becomes rough and unendurable like a neglected Macadam road, and is generally better for driving on than the earth at the sides.

Mr. Campbell's estimate of the cost of construction of a gravel road is for a depth of nine inches. This depth would not be required, except where the traffic was heavy, as on a leading road near a town. One and a half cubic yards of gravel to the rod, spread to a width of eight feet and a depth of about four inches, is common practice, and is sufficient for most of our country roads.

If the road has not already been underdrained, this should be done before the gravel is applied; if not, the gravel will sink into the subsoil and be lost.

The following is an estimate of the cost of draining and gravelling a mile of road which has previously been ditched and graded:

3 in. tile drain, at 75 cents per rod..................	$165 00
330 cubic yards of gravel, at 80 cents per yard........	264 00
Spreading and rolling gravel......	15 00
Cost per mile for draining and gravelling	$424 00

The draining would not require renewal. Assuming that one-half the cost of maintenance went towards renewing the road metal, this road could be maintained and renewed once in fourteen years at an annual cost of about $40 per mile.

If all our roads were of this description, they would cost the owner of a hundred-acre farm about $100 on construction and $10 per year on maintenance. In this calculation it is assumed that our country roads are already graded and ditched, but not underdrained.

Ten days is the regular amount of statute labor on an assessment of $2,500. Reckoning this at $1 per day, and a hundred-acre farm as assessed at $2,500, the road just described could be maintained by the ordinary statute labor tax.

Such a road might not be so good as a carefully maintained Macadam road, or a deeper gravel road, and it is not recommended where the traffic would be heavy; but it is not beyond our resources, and if all our roads were no worse there would be little reason for the outcry for "better roads."

In the construction of a road there are three distinct operations: (1) grading and ditching; (2) underdraining; (3) metalling. The first two operations are permanent in their character, and when once properly performed do not require to be repeated, except at very long intervals, but the metalling is only temporary, and requires constant attention and frequent renewal. If all three operations cannot be performed at once, they should be carried out in the above order, for the underdraining cannot be made permanent until the grades are fixed, and any alterations in the underdrains disturbs the road metal. But draining should follow ditching and grading as soon as possible, in order that the latter may not be destroyed by frost and wet. Thus, in opening out a new road, the first thing necessary is that it should be properly graded and ditched, next that it should be thoroughly underdrained, and, lastly, that the surface be improved by the application of whatever road metal the nature of the traffic may require. Most Ontario roads have scarcely reached the first stage of construction—proper grading and ditching.

Returning to the kind of road which is both desirable and possible in Ontario, the roads may be divided into three classes :

1. Those on which there is heavy traffic.
2. " " " moderate "
3. " " " very little "

Roads of the first class are in the vicinity of large towns, and their mileage is comparatively small. The second class would include the roads connecting villages and lying along the favorite routes of travel, and whose maintenance is of general interest to the community. The third class would include the less frequented and purely local roads, many of which might, with advantage, be closed up altogether.

The first class of roads should be gravelled to a width of 8 or 12 feet, and a depth of 6 or 8 inches, or, if the traffic is very heavy, should be Macadamized. The second class should be light gravel roads, as described in this paper ; and the third class should be well drained and graded earth roads, with a light covering of sand or gravel where the soil is heavy clay.

These roads would not be too heavy a burden on the people, and could be well maintained. It must never be forgotten that the first requisite of a good road is proper maintenance, and an expensive road should never be constructed without the assurance that it will be properly maintained.

If an increase in the wealth or population of a district made a better road desirable, the only expense involved in the conversion of a third-class road into a second-class road, or a second class into a first class, would be the cost of applying the necessary road metal.

SYSTEM OF GOVERNMENT AND MAINTENANCE.

With few exceptions, the country roads of Ontario are maintained by the statute labor system, by which each resident or property owner in a township is required to contribute a number of days' labor (or in commutation thereof a money payment), proportionate to the assessed value of his property. The council of each township has authority to pass by-laws regulating the manner in which this work shall be performed, and appointing overseers or "pathmasters" to superintend its performance.

It has been the fashion to condemn the statute labor system as the chief cause of the unsatisfactory condition of our country roads. But the system has never been fairly tested. Apart from being badly administered, the statute labor has been required to do work for which it was never intended. It was intended for the maintenance of the roads, but it has been chiefly employed in works of construction—in grading and ditching. Can the system, then, be condemned if the little statute labor which was not diverted to works of construction has proved inadequate for the work of maintenance?

The following are the arguments most frequently made use of by those who condemn the statute labor system:

1. It places work requiring skill and superior intelligence under the direction of those who may possess neither.

2. All the work of roadmaking and repair is usually done in about one week, and during the very worst part of the season for such work—the end of July or the beginning of August.

3. Pathmasters undo year after year what their predecessors have done.

4. It is a lax system, and some may avoid performance.

5. It gives people the selfish idea that they are interested in roads only in their immediate vicinity.

6. Transient labor cannot be so systematically directed as can the labor under a contractor.

7. By it the roads are not only not properly made or repaired, but are absolutely being destroyed.

It does not require much ingenuity to expose the hollowness of arguments such as these.

The first three refer to the method of supervision of the road work, and not to the question at issue, which is: Would it be better to have the farmers pay their road taxes in money instead of in labor?

As to the fourth, no one can avoid performance if the overseer does his duty.

If the fifth has any weight, it can be easily overcome by making the road divisions larger.

The sixth may be valid, so far as *construction* is concerned, but would any one seriously consider letting out the *maintenance* of a road by contract? and the maintenance of the road is the proper province of the statute labor.

In view of what has already been accomplished under this system, the seventh needs no refutation.

It will be observed that all these arguments have reference to the manner in which the work is done, and are not valid until it has been shown that it is impossible or difficult to have the statute labor efficiently performed. Another objection seldom mentioned is that the statute labor system is applicable only where most of the work may be performed with horses and with laborers not specially skilled in roadmaking. Accordingly, the statute labor system, though applicable to a gravel or earth road, is inapplicable to a Macadam road, and in any case it should be supplemented by a few workmen constantly employed.

The fact that very few take advantage of the opportunity to commute their statute labor indicates that the majority of farmers find it more convenient to pay the tax in labor than in money. This is because the horses and men necessary for the work on a farm are not busily employed throughout the whole season, and it is an advantage to be able to avoid a money payment by letting them work upon the road at a time when they are not required in the fields.

If the farmers are to work upon the roads at all, it is simpler and more natural that each should do his share as statute labor than that they should pay taxes, part of which, after passing through several hands, would be paid back in the form of wages.

The statute labor system has this further advantage, that, when not particularly busy, the farmers often give some extra days' work when they would not vote money for the improvement of the roads.

The great drawback to this system is the manner in which it is administered. In the first place, the road divisions are too small. A few farmers, with an easy piece of road, have little to do; a few others, close beside them, on a difficult section, have more than they can properly perform. But the chief difficulty is with the "pathmasters"; there are too many of them, when so few of them know their work. The system of rotation of pathmasters, thus letting each man in the township have a try at the roads, is absurd.

The system is good in itself, but the manner in which it is ordinarily administered is indefensible.

How, then, can statute labor be properly administered? By dividing the Township into districts about five miles square, and placing each under the direction of an overseer appointed by the Council, and holding office during their pleasure. This overseer, who should be one of the most intelligent farmers in the community, would be expected to make himself familiar with all the most improved methods and machinery for road construction and maintenance, and would receive so much per day for each day employed upon the roads. He would have complete control of expenditure of the statute labor, and of the commutation or other road money to be expended in his district, and could order the work to be done in any part of the district. He should frequently examine and report upon the condition of the bridges, culverts, etc., and would have under him a small gang of laborers who would be constantly employed upon the roads. He would also have authority to appoint foremen, in case the statute labor could not all be performed under his personal supervision.

The township overseers should consult from time to time with the county or township engineer, and should carry on their work under his general direction. The leading roads which are of general benefit to the county should be placed under the immediate control of the county engineer, and maintained out of the general county rate. This should be done gradually at first, and, if found to work well, other roads could be added to those maintained in this manner.

The question rests with the Township and County Councils.

It would not be necessary to ask for fresh legislation, the present Assessment and Municipal Acts giving all necessary powers.

Under such a system the statute labor would be intelligently and efficiently performed; and, while giving satisfactory results, would be more economical and less burdensome to the farmers than the payment of road taxes in cash.

CONCLUSION.

In conclusion, there is no doubt of a well-founded demand for better roads, but the surest way to obtain them is not by a revolutionary change in the road system, but by improvements in the system which we have, according to the natural laws of growth and development.

And while it may not be advisable to imitate the English by building Macadam roads, and consequently abolishing statute labor, it *is* necessary to imitate them in "the three things to which the English roads owe their superiority," which are: "First, the stability of the foundations; second, the constant, and not spasmodic, attention bestowed on them; and last, but not least, the fact that they are under competent authorities in the county engineers and local overseers."

DISCUSSION

Mr. T. R. Deacon.—Mr. Duff's paper on "The Country Roads of Ontario" gives good evidence of a careful investigation of the subject, as well as experience in the matter. Good country roads are absolutely essential to the farming community to make the most out of the capital invested in their farms. I am well acquainted with parts of the country where the residents of one-half of a township must always sell their commodities at from 20 per cent. to 50 per cent. lower than those in the other half, because of difficulties in getting to market, when a good road might easily be built if the conservatism of the community could only be got over, and the benefits shown in such a logical way as to excite their slow powers of credibility.

With regard to Mr. Duff's remarks about the laying out of the original road allowances, I differ strongly from his opinion, as I do also from his suggestion about laying out farms to suit the configuration of the ground. I am surprised at Mr. Duff making such a suggestion, as I know he has had experience in laying out new townships. Who would undertake in a heavily timbered country to lay out land in such a way that when the land was cleared and drained it would be seen to have been laid out in the best possible way? Much better, in my opinion, to lay out the land, as is now done, in rectangular blocks, and then make the roads in the best place for them, only making them conform to the original survey lines when it is practicable to do so, and at other times as nearly so as is *economically* practicable. I think with Mr. Duff that in many parts of Ontario the "pathmaster" system cannot be got over for some time yet, but that that system can be much improved in the newer parts of the province, in the manner suggested by Mr. Duff. In the older and wealthier portions of the province, I believe better results could be obtained from the expenditure of the same amount of labor skilfully directed by a competent road builder than in the desultory and haphazard way in which my experience leads me to believe the "road work" is commonly done.

Mr. J. R. Peddar.—There is some question as to whether it is advisable to follow Mr. Duff's specification, where he says, "The trench in which the tile is laid should be filled in with gravel, sand, small stones, or other loose material," etc.

Filling the trench in this manner will cause the water collecting in the trench to quickly run in the joints of the tiles from tops and sides, which will, in most cases, carry sand with it.

Does not a tile drain act in the same manner as the crest of a dam in regard to taking off the water ?

In wet land the water rises and rises until it finally oozes out on the surface of the ground, whereas, if a tile drain be put in, the water will soak the ground until it reaches the bottom of the tile, when it is carried away, and the height of the water in that part of the ground is kept as low as the tile drain.

If this be so, is it not, then, as some authors contend, advisable to pack clay in the trench immediately above the tile ? thus preventing sand being carried in the top of the tile, which will eventually block the drain.

I might also add, in regard to materials for good roads, that the best road in this part of the township is formed of 8″ or 10″ of the refuse of brick kilns, brick bats, etc., covered to a depth of 9″ with the cinders which are raked out from beneath stationary boilers. This road, although continually subject to the passing of wagons loaded with bricks, does not wear out, nor allow ruts to form as quickly as the gravel roads. The cost of the materials is nothing, as, if the pathmaster did not make use of them, the proprietors would be at an expense in hauling them to a suitable dumping ground. The cinders from two 75 horse power boilers are more than ample for keeping a half mile of road in repair.

Although the above materials can hardly be quoted as general materials for road construction, there are a great many places where they can be had, where they are not made use of, but are allowed to be wasted.

MR. W. F. VAN BUSKIRK.—I am by no means satisfied that there is a demand in Ontario for better roads. There are any number of complaints, both on account of roads and taxes, but I cannot discover anything that could be called a demand for improvement among the great mass of the people in the western district. The average citizen thinks that we have as good roads as possible for the money expended, and cannot see that anything is to be gained by investing more money. Any one wishing ocular demonstration of this has only to look at the average driveway from roadway to barn.

I am, therefore, of opinion that improvement will come through the action of the Provincial or Dominion Government. This is in accordance with the experience of Great Britain, France, Germany, etc. The Provincial and Dominion authorities will, however, take no action in regard to improvement until such time as the public are sufficiently educated in the matter to submit to interference with the existing state of affairs. Some time ago, I wrote to *The Canadian Engineering News*, suggesting that the government undertake the instruction of the public in roadmaking in a similar way to that in which butter and cheesemaking is being taught.

I am convinced that one mile or so of properly made earth road in each county or township will do more to educate the public than all the papers we may write in the next few generations.

This method has been lately adopted by the State of Massachusetts, where three miles of Macadam road are being built in each county.

The assumption that "our country roads are already graded and ditched" is entirely unwarranted. At the present moment, I cannot think of a single piece of road that does not require a large amount of work in grading and ditching to put it in a fit condition for either macadamizing or gravelling. The failure to recognize this is the great cause of waste under the present system. Gravel and stone are piled on roads year after year, and as quickly sink into the wet ground beneath.

In order to form a good foundation for a road, the ground must be made and kept dry to a depth of at least four feet, and must be thoroughly compacted by rolling with a roller weighing not less than five tons, all hollows being filled as they appear under the roller. Steam rollers weighing about ten tons will do better and cheaper work than horse rollers in consolidating the earth of newly-graded roads, but are a little heavy for rolling gravel.

Tile drains are not always necessary, as in many cases the side ditches (not gutters), if made of sufficient depth, will dry out the subgrade in addition to carrying the storm water.

Drainage requires much more skill than is generally supposed. The ordinary farmer cannot lay tile drains properly, the said farmer to the contrary notwithstanding. I strongly object to filling in trenches over tile with gravel, sods, or any loose material whatever. Water enters tiles through joints from sides by gentle flow or movement horizontally along top of water table when drains are working properly; and any loose material above tiles permits water to flow direct from surface and fill up drains with sand, etc. My practice is to lay tiles in a trench cut with a drainage scoop to the exact shape of the lower half of tile, and to fill the trench with earth or clay well rammed over pipes, so as to leave the ground in, as nearly as possible, the same condition as before cutting the trench.

I agree with Mr. Duff, to some extent, in the belief that the statute labor system can be made to work, but am of opinion that the gangs must be in charge of permanently employed, skilled foremen who would be directly responsible to engineers trained in roadmaking. The ordinary township engineer is generally a surveyor, knowing no more about scientific roadmaking than the ordinary pathmaster.

Mr. Duff seems to have lost sight of the fact that good roads have a cash value to all persons using them, and that they will, undoubtedly, increase the value of farm lands, so that it would be possible to spend more money upon them than is done at present.

I am of opinion that the only question that should be considered in determining the nature of road to build in any locality is No. 4 on Mr. Duff's list, "Nature and amount of traffic." All other considerations must be subordinate to this in order to keep the road good.

No doubt properly-constructed earth roads, with a little gravel on the surface, will answer in most cases; but wherever the traffic is heavy, as upon main roads between town and through townships, the roads should be macadamized, and kept up in the most approved manner.

Mr. Campbell's idea of cheap, and therefore nasty, Macadam roads, maintained at a cost of $20 per mile, is rather amusing, but does not merit consideration among engineers.

I do not expect much improvement under present management and methods, and am of opinion that any change short of thorough reorganization will only cast discredit upon the promoters and the movement for reform.

That untrained troops require the most highly-trained and efficient officers is a well-known principle among military men, and applies equally well to men employed upon engineering works.

MR. JAMES McDOUGALL.—The subject of road improvement is one of deep interest to me.

I think the writer is on the right tack in advocating good gravel or earth roads which can be more easily maintained than Macadam roads. Still it is not going far enough to keep up an agitation in favor of good roads. There are portions of the province, such as parts of the counties of Essex, Kent, and some others, where gravel is very scarce and the cost of laying it down on the roads almost prohibitive, owing to long haul. Such conditions should also be discussed. It is most important that the roads be well maintained. In this connection Mr. Duff very properly laid great stress on the influence of thorough underdraining. I might mention a case which has occurred in my own practice. I had been superintending the cutting down of a hill on the Kingston Road, where the ground showed indications of springs. I had two tile drains laid down the road about eight feet apart. These thoroughly drained the hill, which is hard and firm even in the wettest weather, and the Macadam over the drains does not require nearly so much repair and renewal as on other undrained parts of the road. From my experience with municipal councils, I feel safe in saying that it would take a great deal of argument to persuade the farmers to raise money by debentures for road improvement. The railway bonuses proved such a heavy burden that they are not likely soon to repeat the experiment. In the county of York, some of the townships have been making good roads. In Vaughan township, where the soil is very heavy clay, many of the roads, especially the trunk roads, are well gravelled, a policy inaugurated some years ago by a newly-elected reeve. Previous to that time about $2,500 had been spent on the roads annually. The first year of his term of office the expenditure was raised to $3,000, and afterwards this amount was raised, till it has reached an annual expenditure of $6,000, and during last year but $5,000 was expended. The policy was so acceptable to the people that the reeve, after several elections by large majorities, was returned by acclamation until his policy had been fully carried out, when he retired, after securing the wardenship of the county. The townships of Markham and Georgina had also done extensive work on gravelling roads, Georgina especially being mentioned, owing to the excellent supply of gravel in the township. I think that great encouragement and impetus could be given to road building and improvement by a judicious system of bonusing, as in the case of public schools, where government grants have immensely improved the material conditions and efficiency of such institutions. With this end in view, I would suggest that the roads of the province should be considered under three heads :

(1) Roads of provincial importance in which traffic is through more than one county. Such roads as, for instance, Yonge Street, Dundas Street, the Kingston Road, the Governor's Road, the Toronto and Sydenham Roads, and others throughout the province.

(2) Those of county importance, where the traffic crossed more than one township ; as, for instance, in the county of York, the Weston and Vaughan Roads on the west, and the Markham Road on the east.

Those of only local importance within the townships.

While the management and expenditure of all moneys should be vested in the local authorities, roads of provincial or county importance should receive provincial or county aid, to be granted only on condition that the road be kept at a certain fixed standard of excellence.

These roads would require to be inspected periodically by a provincial and county inspector respectively, on whose recommendations the grants would be made, as in the case of schools obtaining government grants. The local authorities, in order to obtain these grants, would see that the roads were efficiently maintained, and a spirit of emulation would be inaugurated, even should the grants be comparatively small.

I am in accord with a great deal that Mr. Duff had said in reference to statute labor. Its proper rôle is the maintenance of roads, and not their construction. In Vaughan it is used to great advantage in this way, teams being employed to work the road machine to level down ruts and round up the crown of the roads after the spring rains and traffic has put them out of shape.

MR. S. M. JOHNSON.—We are greatly indebted to Mr. Duff for his clearly stated views upon this important subject. We are all interested in the advancement of this movement for better roads, but we must recognize that there is nothing which in the end retards a needed reform more than overestimating the advantages to be derived, or stating the increased cost at too low a figure, and thereby causing disappointment and a reaction against the movement.

The tables regarding the cost of the macadamized roads of the county of York are very interesting, although their cost does not compare favorably with the English roads. It must, however, be remembered that if the system were to be extended the cost per mile would be lowered, as these roads are situated where the greatest traffic, and, therefore, the greatest wear, occurs. I would like to ask Mr. Duff at what season of the year the metal is placed upon the York roads. We all know that upon our average road under the statute labor system the material (when any is added) is laid on in the early summer, and just at the season when the roads are naturally at their best, which, instead of improving the roads, diverts the traffic to the side.

In my experience I have only seen one attempt to obviate this, and in that case the gravel was placed upon the road just as the frost left the ground in the spring, and when the roads are generally at their worst. The result was that the traffic soon had the new material compact, and in the summer a good road resulted, and there is no doubt, had the road been first scraped, the advantage would have been still greater. I am of the opinion that could a system be devised whereby gravel could be placed upon the roads after scraping in the spring and fall a great advance would be made.

The thorough drainage of the roadbed is an important part of the construction of any road, and especially is this the case in Canada, where the frost, by its "heaving" action, does so much damage, this being greatly aggravated by the presence of water. The English roads are underdrained in many places, but these drains are not intended to carry off the surface water, but to cut off all water from the subsoil, their aim being to make the road surface impervious, and thus shed all surface water towards the side ditches.

MR. DUFF.—I do not think that my remarks on the location of roads would bear the interpretation placed upon them by Mr. Deacon; it certainly was not intended that they should. The basis of all land subdivision should be rectangular, and I never thought of the surveyor's lines being run other than as they are. It was not proposed that the original surveyor should divide the township into irregular blocks, but that the settler should have more freedom in purchasing any portion of a lot or of two adjoining lots, so that the lands which naturally lay together should belong to the same farm. What I did object to was the practice of blindly "following the lines run by the surveyors" in those cases where better roads and more compact farms would have been obtained by deviating from them. I am pleased to note that Mr. Deacon's views on this subject are very similar to my own.

I am indebted to Messrs. Van Buskirk and Peddar for pointing out the mistake which occurs in the description of the filling in of a tile drain. The sentence should have read, "*The upper part* of the trench in which the tile is laid should be filled in with gravel," etc. When tile are laid they should be covered with three or four inches of clay, well rammed in about the tile; this will prevent any loose material from working into the joints. When clay is not available for this purpose, sods, hay, or straw, or similar materials, are sometimes used, but these are only necessary in the case of quicksand.

My theory of the action of a tile drain is somewhat different from theirs. The pores of the soil form so many channels through which water may flow. But water will not flow except down grade or under a pressure head higher than its level, and if the flow is obstructed the grade must be steeper or the pressure greater. In every case of underdraining there will be a surface separating the soil from which the water is drawn off from that which is below the influence of the drain. This surface may be called the *water table.* In sandy, porous soils, through which water flows freely, it will be practically horizontal; but in clays, where the flow is impeded and is not along horizontal lines, the water table is inclined. The inclination for ordinary heavy clay is about one vertical to ten horizontal;

so that the water table to a drain three feet deep would intersect the surface at about thirty feet on either side. If the clay is made more porous or the flow of water facilitated in any other way, the water table will be more horizontal and the influence of the drains extended.

One way of accomplishing this is to fill the upper part of the trench over the tile with gravel, thus making a large trench to which the water will flow, and then filter through the few inches of clay to the drain underneath.

The object of underdraining is not merely to carry off the water which oozes into the subsoil under pressure from a distant head. No matter how hard and smooth the surface may be, the rain water will not be all shed into the side gutters, some will sink into the subsoil. An important function of the underdrain is to carry this water off rapidly, and prevent it from rendering the roadbed soft and yielding, or subject to the influence of frost. This beneficial influence of the underdrain is more noticeable in earth and gravel roads, where a larger proportion of the rain water is retained by loose earth, ruts, etc., until absorbed into the soil.

I am much pleased to observe the unanimity of opinion with regard to the necessity for underdraining in order to secure a firm, dry roadbed, which is the most important requisite in a good road. Yet this is the very condition which in practice is most neglected, perhaps because the destruction occasioned by a wet subsoil goes on gradually and unseen. If the government adopts Mr. Van Buskirk's suggestion, and gives public instruction in roadmaking, the first lesson to be taught is the necessity of a firm subsoil, and that if the subsoil is not naturally very dry it must be underdrained.

It is said that the assumption "that our country roads are already graded and ditched" is entirely unwarranted. If the writer had considered that they *were* properly graded and ditched, it would have been stated as a *fact*, and not as an *assumption* made merely for the purpose of facilitating the calculation. In counties of York and Simcoe (with which I am most familiar) a great many roads are well graded and ditched, whilst on the others the amount of grading and ditching done is so variable that it would be difficult to make a general estimate of the cost of completing the work. It was simply to avoid making this estimate that I assumed that the roads were ditched and graded, and I do not consider such an assumption misleading or unwarranted.

I concur in Mr. Van Buskirk's opinion of Mr. Campbell's cheap Macadam roads. Such erroneous ideas do no harm amongst engineers, but where they are widely disseminated amongst the farmers (who are, after all, the men who decide what kind of roads we are to have) then every engineer is in duty bound to expose the error, especially in such a case as the present, where Mr. Campbell's position as City Engineer of St. Thomas may give to his opinions a prestige they might not otherwise possess.

In the case of Judge Wood's "figures," I regret having taken up space with such misleading and ridiculous "calculations."

Although the nature and amount of traffic is the most important consideration in determining the kind of road which *should be* built, and the essential condition of the road to be thoroughly maintained, yet necessity knows no law, and the vital question for us in Ontario is: *What is the best road that we are able to maintain?*

One of the objects I had in preparing this paper was to call our road reformers down from quixotic discussions on the theoretically best road, and induce them to grapple with the conditions which actually do exist in Ontario. Would a man spend his time planning how to erect a castle, when he has only an axe and a few nails with which to build a cabin?

Scientific roadmaking is not necessarily the work of a surveyor, and many a good surveyor may know nothing of making roads. But the education of a surveyor is such that he can easily learn the science of roadmaking, and should he be township engineer, and it be made a part of his duty to superintend the roads, he could make himself proficient, or, if not, could be dismissed as incompetent.

In answer to Mr. Johnson's question, I would state that the new metal is placed on the York roads in the spring and fall. The difference between the cost of maintaining these roads and English Macadam roads is no doubt due in some measure to the cause mentioned by Mr. Johnson. Other causes which may be mentioned are the severity of our winter frosts, the difference in the price of labor, the character of the soil, which is nearly all heavy clay, and the fact that they are imperfectly underdrained.

I think very favorably of Mr. McDougall's plan of provincial and county subsidies, provided that they are expended, as he suggests, by the local authorities. This might be combined with the writer's suggestion, that the township councils divide the township into about four divisions, and place the roads in each under the supervision of an intelligent farmer, who would make a special study of roadmaking, and personally superintend the expenditure of all road money and statute labor in his division. This I believe to be the best practical solution of the road question in Ontario.

AERIAL MECHANICAL FLIGHT

C. H. Mitchell, B.A.Sc.

The following paper is, for the most part, a compilation of prevailing theories and ideas advanced by different writers, together with the results of observations and experiments which have up to the present been made in this new field of science. It is well recognized that until recently the subject of mechanical flight has been the object of considerable ridicule, but the fact that the scientific world is rapidly turning its attention to aerodynamical research warrants us in making haste to acquaint ourselves with the progress in this direction.

I wish it to be distinctly understood that I am not a disciple of any particular method or theory of flight, and that I have interested myself in the subject for no other purpose than to become familiar with the underlying scientific principles.

I have attached this title to the following paper chiefly for the purpose of discriminating against what has up the present been known as aeronautics, but which is now referred to as aerostation. Within the past five years there has come forcibly before the eyes of the world a new branch of aeronautics—that now known scientifically as aviation, and which shares with the former the chances of aerial navigation. Heretofore "aerostation" has won all the fame which has been conferred on aerial invention, and the disciples of that branch of the subject have looked down with a commiserating eye from their lofty vantage on their struggling brethren of the aviation family. A well-known writer very tersely puts the discrimination in this way: "There were two roads to possible success—the one broad, beautiful, smooth, and bordered with flowers, but, after all, leading to no result—it was that of aerostation, of balloons, lighter than air; the other way was contrariwise, a rough, narrow, rugged path, bristling with difficulties, but still leading to something—it was that of aviation, of rapid transit by machines heavier than the air."

I do not propose at this point to discuss the question of balloons *vs.* mechanical flight (that will come in further on), but I desire to point out that this paper will deal exclusively with the newer branch, its history, its aims, designs, and possibilities. Owing to the fact that the subject is in its merest infancy, that no literature of a responsible nature of a date previous to 1881 is obtainable, and that the greater part of it is in periodical form of a very recent date, particularly since the aerial congress at Chicago in 1893, the compilation of a comprehensive paper is somewhat unsatisfactory unless all information is thoroughly trustworthy.

I consider that this new branch of science which has so suddenly and forcibly thrust itself upon us is one which we as engineers should at once make ourselves sufficiently acquainted with, so as to be prepared for its actual development, which is assuredly not far distant. With this view, I have taken time by the forelock, and have endeavored to give to the members of the Engineering Society the benefit of my reading and observation in the subject during the past year.

If there is one haunting predominant conception more than another which to-day infests the mind's fancy, it is that we may possibly before long be soaring the air, partners with the feathery tribe which have since the beginning held universal sway in the realms of Æolus. Unhappily, some of our fellow-men have fallen dire victims to the conception, and, if they have *lived* long enough in the possession of it, have been looked at askance with pitying contempt, and dubbed "cranks," perhaps too persistently. Now, however, this dream of the enterprising inventive genius is drawing near to its realization; he no longer stands before the finger of ridicule, no longer is he classed with the seekers after the elixir of life and perpetual motion; the past few years have been more lenient, and his innings has come.

Perhaps the cause of the ridicule which has been so ludicrously hurled at the disciples of the "flying machine" during the past may be summed up in a few words. Heretofore our attention has been called to mechanical devices for the most part designed and built by mechanics, without a thorough scientific basis—in fact, with no other recommendation than that "they *ought* to fly." Of course the results could have been foretold. Now, however, we find scientific men of the very highest reputation delving into the previously existing data, making new deductions, performing all kinds of preliminary experiments and tests, but proceeding in the most cautious and logical manner, content with "making haste slowly"; their fondest hopes being that in a few years a machine that will raise itself off the ground may be constructed. The scientific world has acquired confidence in these men, and has ere this proceeded to offer assistance in a very tangible manner, so that now we find scientific societies, clubs, and single experimenters all combined in a grand race for the goal not far distant.

Much of the experimentation so far concluded may be said to be based upon the work of the early physicists, notably Newton, Gay Lussac, and Hutton, though the results of these men have been greatly modified—in fact, sometimes have they been found entirely at variance with nature. As before intimated, these results were not made use of for any aeronautical purposes, all the attention being bestowed on the balloon, with the result that no particularly successful method of aerial navigation was forthcoming. I do not mean to say that no advantage was gained, for the balloon has been most valuable in all scientific directions, and by its means we have discovered some of the idiosyncrasies of the upper air currents, a thorough knowledge of which, by the way, is an absolute necessity for successful navigation. But the balloon has so far demonstrated one important thing, and that is that for rapid and complete aerial flight for all purposes we must look not to the gas bag—lighter than the air—but to the fully-equipped heavy machine, with inherent capabilities, as it were, of sustaining and propelling itself in all conditions of wind and weather. It is needless to point out how this has been brought about, for the very circumstances of ballooning are against it as a means of navigation. Balloons are costly, clumsy, easily damaged, and with difficulty repaired; they are dependent, for the most part, on fair weather, perfectly helpless in a wind storm, and, above all, are slow. The great war balloon "La France" accomplished only fourteen miles per hour. There are balloons now under construction by the same experimenters (the French Government) which are to attain twenty-five miles per hour. This will be, if successful, a truly great accomplishment, but when we remember that such balloon trips are limited necessarily to a few hours, and that the maintenance commercially is enormous, while there is only a thin piece of silk between success and complete collapse, we are in this age of business enterprise slow to consider it advantageous.

It seems almost absurd for men of our scientific age to look toward the gas bag as a means of aerial suspension, for what is there in nature to warrant such? What parallel is there? All birds are much heavier than their enclosing fluid, and motion is accomplished by the purely mechanical effort of their muscles and organic members. We have heretofore considered the birds as beyond our powers of imitation, or else have entirely ignored them. We have almost with ridiculous contempt passed over the everyday principles underlying the kite, the boomerang, or the skater on thin ice. We have discovered the uselessness of the gas bag, and have sought to replace it by some mechanical device of wondrous intricacy, a galaxy of propellers and screws, *a la* Jules Verne, forgetful of the fact that there are scores of birds which for hours together soar in the air almost without dynamic effort, using only the wind currents, and that in the simple kite of our juvenile days is the secret of their movement. These things are now fully recognized by the scientific world, and the current of research has accordingly veered around in the new direction, so that, in place of intricate mechanical creations, we find the much-talked-of "aeroplane."

The result of all this is that we have now, out of a multitude of designs and principles, hit upon what, as far as we know, is going to lead to something substantial—a single line of experiment only, toward which all energies are being bent.

The basis of these investigations may be divided into three distinct parts, which it will be necessary to consider in the abstract before we touch upon the principles of the flying machine. This division may be made as follows:—(1) The flight of birds; (2) observations on the principles of the kite and other similar contrivances; (3) abstract experiments in the "laboratory." These constitute our data, and their value as such will be in proportion to their reliability. Having discussed these divisions, it is the province of this paper to consider the generally accepted theories of the ideal "flying machine." It will then be in order to review what has actually been done in the experimental world with reference to aerial navigation, which means a résumé of the different machines now constructed and on trial.

Bird flight, after years of close study by naturalists and physicists, still remains very much an enigma. It may appear easily, or with difficulty, accounted for, according as one looks at it. It is one of the few unsolved everyday problems which have been so prolific of discussion during the past years in the scientific world. Perhaps the most insurmountable difficulty which presents itself for pursuing investigation in this direction is that of the inaccessibility for experiment and observation. Could we spend our time side by side with the birds, we might soon discover their secret. Those to whom we owe our present knowledge in this subject have obtained their information with great difficulty, and, even then, it is, for the most part, very incomplete, and does not furnish us with any real precise data. Were it possible to domesticate the birds we are most interested in, and place them under close scrutiny in the laboratory, the task would be simpler, perhaps, but the results not as valuable.

Before considering the flying process, let us examine into the anatomy of the bird with reference to flying. For our purposes, the bird consists of three parts, the body, the wings, and the tail. Theoretically considered, the two wings and the tail form the supporting members, though the function of the latter, in this regard, is very much restricted. The centre of gravity is, of course, situate within the body of the bird, though it can be shifted by means of the movement of the wings. The body proper and the tail serve, generally, to obtain steadiness and equilibrium ; in some birds, having a deep breast bone, the body acts like the keel of a ship. The wing consists, essentially, of three parts, having two joints, by means of which the whole can be contracted or extended. The peculiar joint system, and the strong muscles, permit of movement of the wing in almost any direction with very great rapidity. The general structure of the wing is a marvellously exquisite contrivance, combining strength, flexibility, and lightness. With the quills hollow and tapering, and the web composed of overlapping feather vanes, closely clinging and fitting into each other, the whole comprises an exceedingly light aeroplane, impermeable to air under certain conditions. The quill of the feather, as we all know, is nearer to the forward edge of the plane surface, which edge is turned downwards, and the forward feather underlies the next one back. From this it is seen that the wing, on an up stroke, can be made to permit the free passage of air *downwards*, while, on a down stroke, it would be impermeable. The wing bones are all situated on the forward edge of the wing plane, so that a flapping motion partakes, partially, of a rotation of the plane about this forward axis, and the ends of the strong wing feathers (primaries) flex upwards on the down stroke.

The wing and its action is, to us, the most important. It has two distinct functions : that of a propeller, and that of a sustaining aeroplane, though the relative use of each varies exceedingly in different species. Insects and small birds use their wings almost entirely as propellers, beating the air and flapping, sometimes, with great rapidity. Large birds, having wing surface of great expanse, resort, to a very great extent, to soaring and gliding by means of their wings as aeroplanes. There are, essentially, two kinds of wings : the one, long, and the other, short. It can be easily understood that a bird with long and wide wings is well prepared for soaring, an adaptability which increases with mass ; also, that the bird with long and narrow wings can fly in great winds, that short and narrow wings can attain great speed, while short and wide wings produce but ordinary flight. By these considerations, we may enunciate the law that velocity is in inverse ratio to wing surface. Though we speak of birds' wings as aeroplanes, it is only to a few of the smaller birds and the insects that such can be really applied, for most wings are concave on the underside, a fact that, though known, has not been greatly recognized by investigators until recently.

In Plate 2 are shown three positions of the wings of a bird, to illustrate the mode of changing the centre of gravity; no explanation is necessary.

The tail of the bird serves, to some degree, three functions—to sustain, to direct, and to preserve equilibrium, though it is not a necessity to flight, for many birds have little tail, and all birds, when deprived of their tails, can manage to fly. The size of the tail has no apparent effect on the flying qualities, though very large tails denote feeble flight. The tail is most valuable in acting as a rudder, and swift birds utilize a very powerful tail in changing direction quickly, so that the law might be stated, that the aptitude for changing direction of flight is in direct proportion to the size and power of the tail. It may also be used to shift the centre of gravity forward or backward, and, in some cases, to serve as a third supporting plane.

Curious explanations of bird flght have been presented by some investigators, in which they attribute much of the unexplainable to the fact that the bones of the bird are porous and contain spaces presumably filled with rarefied air. Such, certainly exist, but the explanation is considered very weak, for, by actual experiment, it is found that the specific gravity of the bird without its feathers is about unity, the same as that of man, mammals, and fishes. Even a water bird, if deprived of its feathers, will sink. It has been urged that there is some property in the feather covering which assists flight. This, apparently, can be true in only one sense, viz., that it forms an elastic cushion, frictionless in the air, displacing more of that fluid, and, hence, lowering the specific gravity, though to a small degree only. Strangely, however, it is found that a bird, when stripped of his body feathers (thus leaving him his wings and tail intact), will still be able to fly with apparent ease, though, perhaps, awkwardly at first.

Hence, then, if we are to attribute the flying powers of the bird to its actual organism, we must look to other quarters. We see that the bird is much heavier than the air, for it immediately falls to the ground when shot. We know that birds can fly under nearly all conditions of weather, that they can fly with body feathers stripped, with tail cut, and with wings clipped, also that they can still fly if artificial wings are substituted. What, then, can we do but consider the bird as a machine, a highly organized mechanical creation, sustaining itself through the reactions produced by muscular effort, "not as a balloon floating in the air, but as a stone glancing along the water, or a skater gliding over thin ice"?

Our study of birds now takes two courses as regards aviation, the one that of flapping, and the other that of soaring flight. Flapping flight, as far as the bird is concerned, is easily explained, and requires but brief attention. The following description is that presented by Mouillard in "L'Empire de l'Air":—Presuming that the bird is on the ground and ready to fly, he is crouching to spring upwards, his wings hanging loosely, the position, then, of the three parts of the wing is such as to offer little resistance to an upward thrust, the feathers being "edge on." The bird makes the jump, and, at the same time, the upstroke, the whole wing being contracted and close in towards the body, so as to present the least possible surface, and yet quickly and easily execute the movement. Then comes the down stroke. The wing is fully extended and stiff, all feathers completely overlapping, and forming a surface concave on the underside. The "down stroke" is downwards and backwards, and this accomplishes not only an upward, but a forward movement. The effect is easily seen by reference to Figure 1, Plate 1. The wing is then again contracted, moved forward and upward, then extended, and ready for another down beat. Flapping flight is used by certain birds continually, while other birds alternate it with soaring, and others use it only on occasions such as when rising quickly from the ground, on a calm day, or when surprised. The angle of rising motion is seldom greater than 45°, and a vertical rise is rarely seen, being at best a most difficult manœuvre. This method of flight apparently requires great power and endurance on the part of the bird, and it is generally found that all the small and light active birds use it.

Soaring or sailing flight, though simpler in appearance perhaps, is much more difficult of explanation, and, in fact, is not yet explained to the satisfaction of the investigator. In it there appears to be the very secret of aerial flight we are so desirous of discovering, but even now, though it yet remains a mystery, we are assured that by copying the soaring birds as far as we are able we are pursuing the most natural and logical course toward the desired end. We are all now pretty well aware that there are many birds which sail on the air without apparent muscular propulsion, utilizing some subtle inherent force either of the air or themselves. The principal of these are to be found in the tropics, and are, in

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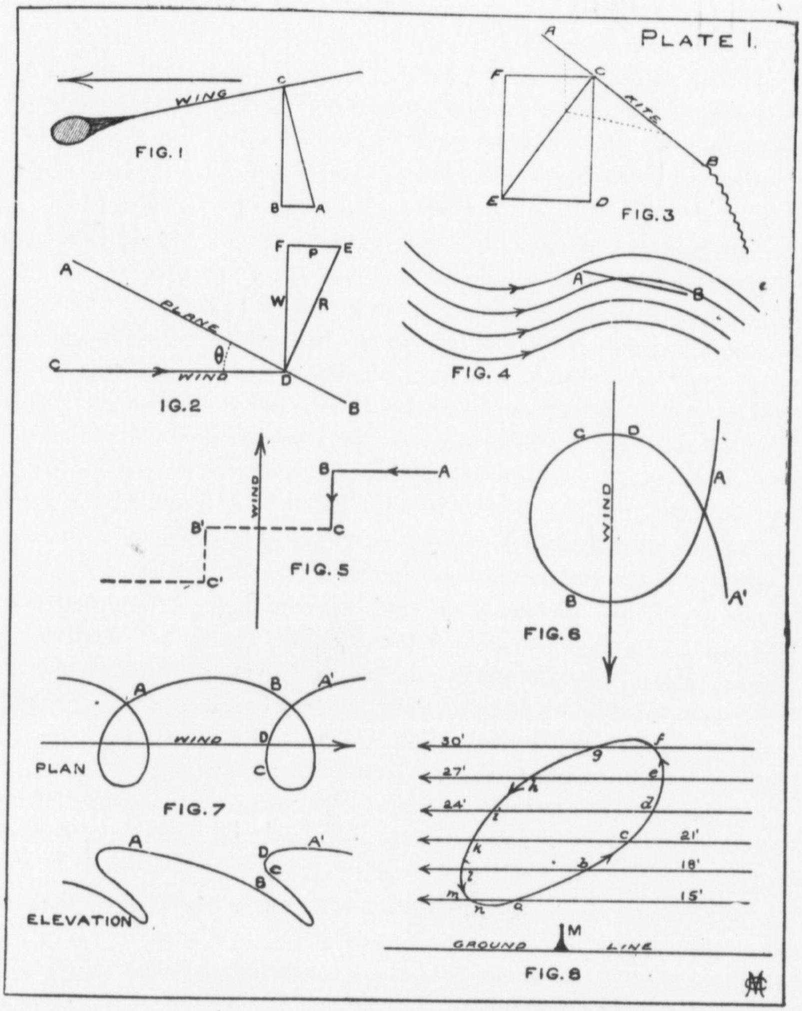
PLATE I.
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FIG. 1
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KITE
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FIG. 3
F
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E
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C
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FIG. 4
WIND
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FIG. 5
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FIG. 6
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B
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WIND
D
C
PLAN
FIG. 7
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ELEVATION
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GROUND LINE
FIG. 8

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general, large birds, while a few smaller species inhabit more northern latitudes. The gull, petrel, albatross, hawk, kestrel falcon, the pelican, kite, buzzard, and vulture, are the representative members of the soaring class.

The discussion of soaring requires a thorough knowledge of the behavior of the air currents passing over the earth's surface, and this is just where we are at a loss, for we know comparatively little of anemometry. Perhaps a thorough exposé, as it were, of the antics of the winds, particularly with reference to local disturbance, would solve the question of soaring flight.

No better way of explaining soaring flight can be presented than by describing that indulged in by a representative bird, and for different reasons we will take the great tawny vulture (*Gyps fulvus*) as our teacher. I will again refer largely to Mouillard, as he has perhaps been the greatest student of this bird. This vulture, as is well known, is at home in the east, and has been watched most closely at Cairo, Egypt. As a flyer he is most successful, and when we couple with that fact another one, namely, that he is the laziest bird created, we must conclude that he sustains himself with the least expenditure of force, and hence flies with the utmost science. His weight is very great, and his wings large and powerful, two facts which at once mean momentum and sustaining power. He weighs, probably, sixteen pounds, and spreads his wings eight feet or more, with perhaps eleven square feet within his contour—a truly magnificent aeroplane. The bird himself has a forbidding and repulsive look, but his bright eye and powerful movement invite us to a closer inspection. He is certainly lazy, for he will rest in his rocky eyrie during the gray dawn and far into the forenoon, until the land breeze springs up, when he flaps his wings and limbers up, yawns, as it were, and with a jump and three or four beats of his wings he launches forth for his day's work. He descends, perhaps, thirty yards on rigid wings, gaining momentum, and is soon in full soaring flight, with wings extended and tipped slightly backwards. Now comes the interesting series of manœuvres; he commences a series of circlings, of a helicoidal nature, and we discover him climbing up into the heavens, without a single wing beat; higher and higher he goes, his wings always rigidly extended, changing their position only when he turns abruptly. When he has gained an elevation from which he can survey the surrounding country for his meal, he proceeds to pursue his usual pastime, that of waiting. He glides in great circles, now against the breeze, now with it, he makes long, but graceful descents, and rises again in some mysterious manner to his former altitude. He may remain aloft in this way for hours, gently sailing on the breeze, when suddenly he descries from afar the meal for which he is in search, and he commences a long, steady, majestic descent, swift, but dignified, which soon lands him at his prey. During the whole morning's work he has scarcely flapped his wings once. True, there has been a breeze, but almost imperceptible. "When we watch a martin flashing through space, we think of high speed mechanism; when it is a snipe or a partridge which flies off, we are reminded of the action of a released spring; a gull suggests perpetual motion, but the view of the great vulture in sailing flight inspires at once the desire for imitation: it is a dirigible parachute which man may hope to reproduce."

Let us turn our attention to other similar instances of bird flight. A typical case is related by M. Bretonnière as he saw it at Constantine, Algeria. Storks commonly performed a series of circular orbits, similar to that shown in Figure 7, Plate 1. From A to B the bird, with a certain momentum, descended in the direction of the wind, then he glided across and upward against the wind to C, crossed it at D, thence to A, whence he commenced a long but slight descent, repeating the operation as before. The series of movements is of course made without flapping. The same gentleman finds that a bird can hold itself head on to the wind and remain practically in the same position in space. He finds that certain birds will precipitate themselves from a height of, say, a hundred feet in order to raise themselves, *against* the wind, to a greater altitude. He also tells us of instances of birds sailing downwards in a gentle wind which, when arriving at a certain exposed place, encountered a very strong wind from a side direction; they immediately headed against the wind and rose twenty or thirty yards very rapidly, whence they commenced circling.

Mr. E. C. Huffaker has made a number of valuable observations on vultures in the mountains of Tennessee. He finds that in a wind of thirty miles per hour the vulture cannot make any soaring headway against it, but resorts to a system of vertical tacking. The bird can, by exposing the underside of his wings properly to a strong wind, rise vertically, though being drifted backward. By sailing *across* the wind a very swift flight may be attained horizontally, in which the bird, however, heads so as to make a slight angle with the wind, also the swift flight may be stopped by facing the wind. The same writer tells of the following instance of a buzzard soaring about fifty feet above a level, open field, when, by reference to neighboring high trees, not even a slight breeze was noticeable. The flight was elliptical and of a velocity of twenty-five feet per second, requiring about five seconds to complete its orbit. It made some twenty

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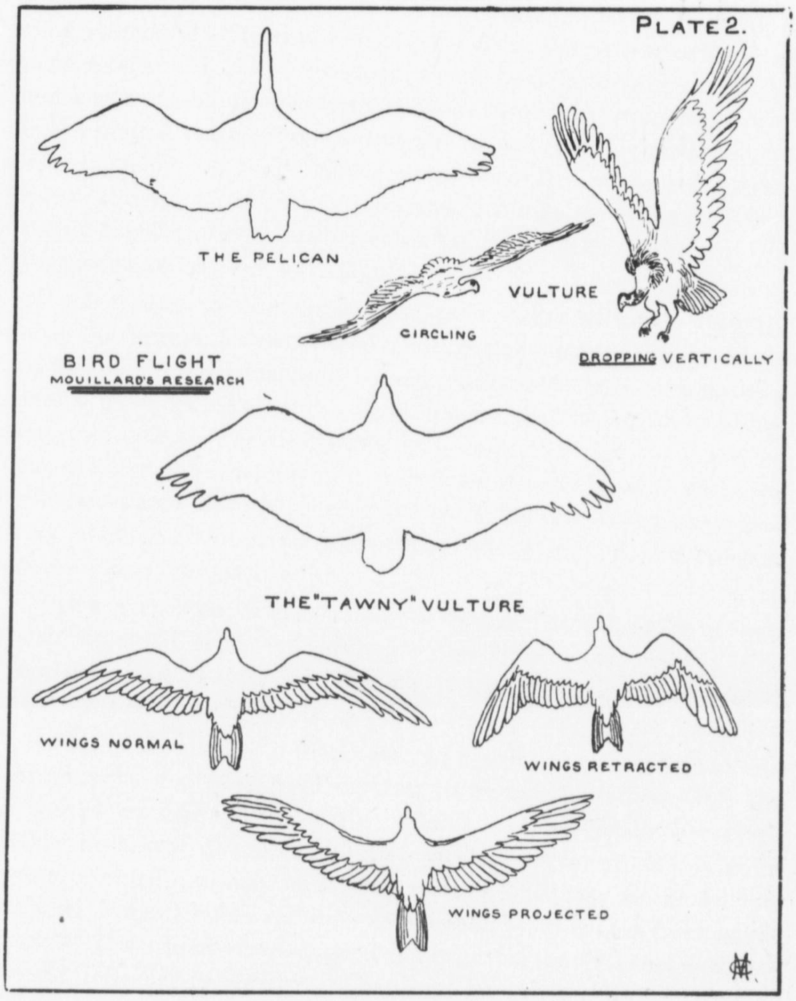

PLATE 2.

BIRD FLIGHT
MOUILLARD'S RESEARCH
THE PELICAN
VULTURE
CIRCLING
DROPPING VERTICALLY
THE "TAWNY" VULTURE
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revolutions in a horizontal plane, so that in about a minute and a half it progressed some five hundred feet, having maintained its original elevation and velocity, and not flapped its wings. He says that in the above case of horizontal soaring, a slight increase of velocity could be detected as the bird passed the vertices of the ellipse. This is most noticeable in the common mode of flight. "Instead of moving in horizontal circles, the bird consumes such energy as it may possess by gliding upwards. Having lost its velocity it hangs for a moment almost motionless, turns backward, sweeps suddenly downward like a wheel with the outer wing greatly elevated; then with a single powerful stroke brings the wings and body into a horizontal position and speeds away with a velocity due to a fall of twice as many feet as it has taken."

Mr. Lancaster, the well-known naturalist, finds that frigate birds are able to go at the rate of one hundred miles per hour on fixed wings, and also that they can live for a week on the wing. Professor Le Conteu gives us numerous examples of albatross flight, notably that of following a boat against the wind. The bird skims the surface behind the boat, but of course falls behind rapidly; he then rises quickly *against* the wind, wheels and swoops downward *with* the wind, until he has gained a great velocity, after which he turns again toward the wind, and, skimming the water, overtakes the boat.

I have given these brief examples of bird flight for the sake of showing concisely what evolutions birds are capable of accomplishing. To explain them and to apply the principle to man flight is another matter, and a discussion of such will be now in order.

Before proceeding with that, however, it will be of advantage to look briefly into the matter of wind currents as regards bird flight, and also into general consideration of flight of birds. Wind usually blows in a generally horizontal direction, and may vary in uniformity, that is, come in gusts or squalls, or may change in velocity. It may be blown into undulating currents either vertically or horizontally, as is seen from smoke ascension. It is also affirmed on good authority that the air is stratified, as it were, with reference to velocity. That is to say that the farther up we go the greater velocity there is. That such is so on occasions we know from simple experience, and we recognize the fact that the earth's surface, be it ever so level, must exert a retarding influence on the wind. In this regard we have yet to discover that on what we call a calm day there is a stiff "sailing" breeze up where the birds manœuvre. Unevenness of the earth's surface exerts, of course, a tremendous effect upon the air currents. The intensity of wind on the brow of a hill may be much more than on its side, because there may be a strong upward pressure along the sidehill, the result of the upward diverted current; this would create an upward sustaining breeze at the brow. There are many other cases also where an upward current may be encountered. Downward currents are also frequently formed. The observations on thistledown, smoke, snowflakes, and sand show the varying moods of our "enclosing envelope."

For every pound weight of bird pressing downwards there must be an equivalent upward pressure to insure suspension alone, without propulsion. This upward pressure can be produced in only two ways, either by some natural pressure of previously existing air currents, or by an effort expended by the bird in giving a downward motion to air previously at rest. The former acts only on occasions, as we know when there is an ascending current of air. Generally speaking, then, the bird must set up a downward current by some means at every point of his route, and the greater volume of air he displaces, and the quicker he does it, the better suspension he obtains, and, if he is moving horizontally, the greater his velocity; that is to say, the more air he will pass *over* and force downward in a given time. The soaring bird's wing is curved concave on the underside, as previously stated, which teaches us a very important thing. We all know that the impulse derived by a surface on which a moving fluid is impinging is proportional to the change of direction of motion caused by such surface. This is the principle on which the blades of a screw propeller, a turbine, or a windmill are constructed. Consider a plane (Figure 2, Plate 1). Suppose a wind current is acting on it obliquely. A particle of air striking the forward edge at A would be deflected, and would pass downwards along the plane to B. The effect is the same for every point on the surface, and when the particle once strikes its work is done, as it passes off the plane without doing work. Some particles of the air current lower down may, perhaps, never reach the plane to do work. If, however, the surface is slightly curved, with the greatest curvature at the forward end, the particle of air striking at the point A has, during its passage to B, its direction continually changed, and it consequently does work till it passes off at B. In this, then, the curved surface has the advantage over the plane, and this is the reason that birds were created with concave wings. Looking again to Figure 2, Plate 1, let CD be a horizontal current of air impinging in the plane AB at D. The direction of the force created by such will be normal to the plane, viz., DE. Let DF be the direction and intensity of the lifting effort; then EF will represent the horizontal motion or "drift." This is the general diagram for the aeroplane under air pressure.

The full significance of this is not quickly realized, particularly when the angle ADC is slight. As an illustration, hold a stiff fan outside the window of a railway car moving at, say, thirty miles per hour. It is very surprising how great the uplift is when the angle is small. In the figure let ADC be θ, R the normal pressure, W the uplift, and P the resistance to horizontal motion. Then we have $W = R \cos \theta$, and $P = R \sin \theta$. Then $P = W \tan \theta$. But horse power exerted would equal VP when V is the velocity. So that with V in feet per second we have $HP = \frac{VW \tan \theta}{550}$ If, therefore, we could discover the weight, velocity, and angle of wings of a sailing bird, we could compute the horse power he is using. It is to be noticed that the extent of surface does not enter, though it is of considerable importance, depending altogether upon weight. If it is small, great velocity and angle are required for sustentation; if large, it becomes cumbersome and heavy. In either case power is consumed. With a given sustaining surface and angle there is some velocity of wind which would just overcome the force of gravity and air resistance, and the bird would then sail horizontally against the breeze. Should the wind drop, or should the bird enter a sheltered space, or increase the angle of wings, he will descend by force of gravity. If the wind increases, or the bird increase his velocity by any means, or decrease the angle of wings, he will rise (against the wind). We learn all these points from the foregoing figure.

Rather than outline the different theories in explanation of soaring flight, I will discuss several of them very briefly, though, as yet, no one has satisfactorily explained the problem. It is practically admitted by all, despite certain trustworthy observations, that soaring cannot be done in still air. The very laws of nature forbid such. All considerations eliminate the air resistance of the bird, and admit the soaring process to be accomplished by some adjustment of the wings in conjunction with a natural knowledge of the wind currents and their several effects. (It has been pointed out that the noise made by buzzards, when flying, may be caused by a continuous flapping of their strong pen feathers at the tips of the wings, a motion not capable of detection.)

There are numbers of problems for solution. How can a soaring bird sail with the wind at a faster rate? How can he rise above his starting point against a wind? How can he travel at a certain rate against a strong wind? and many others. All can be answered by the solution of one problem, which may be stated as, "How can a bird sail indefinitely in a horizontal breeze, retaining his altitude, and using his wings only as aeroplanes?" Such sailing, usually, takes the form of circling, whether progress is made or not.

M. Bretonnière points out how limited are the chances of sailing flight in a truly horizontal path, and shows that such can be accomplished under only two conditions: the one, that of ascending currents, and the other, that of squalls or gusts of wind; the advantage of the latter will be explained later. Generally, then, this writer shows that the bird transforms the ordinary horizontal currents into "relative squalls" by two artifices, viz., the zigzag path and the spiral. The former may be explained in its simplest form by reference to Figure 5, Plate 1. We will suppose the bird to be at the point A, and, for convenience, have no initial velocity. Let it perform a downward glide in the direction AB *across* the wind, thus acquiring a velocity V at the expense of an altitude h. Suppose now, neglecting resistance, shock, and other causes of loss, the bird turns to the *left against* the wind (BC) and proceeds to transform its kinetic energy into work again. Suppose the wind is blowing in the direction indicated, at a velocity v', then, when the bird turns against the wind, he has a velocity of $v+v'$. Now, the altitude $h=\frac{v^2}{2g}$, and a kinetic energy of $\frac{1}{2}mv^2$ is required to procure it. When the bird is passing from B to C his kinetic energy would be $\frac{1}{2}m(v+v')^2$, and the corresponding altitude obtained $H=\frac{(v+v')^2}{2g}$, subtracting :—$H-h=\frac{(v+v')^2}{2g}-\frac{v^2}{2g}=\frac{2vv'+v'^2}{2g}$, which is the additional height which may, under these circumstances, be obtained by the bird. With the spiral, the same reasoning applies. In Figure 6, Plate 1, the bird plunges downward from A to B across the wind, and from B to C up against it (having his wings inclined above the horizon, of course), while from C to D he may rise somewhat further, across the wind, by a proper adjustment of his wings, then a gentle downward glide at will towards A′ to resume the same operation. The last part of the manœuvre covers a great distance if the bird is travelling, but is short if he is ascending. Should the bird desire to travel against the wind, an angle of wing can be found which will carry him forward and downward at the most economical rate, when he can rise at pleasure to any elevation, though with loss of distance. Thus Bretonnière emphasizes the motion downward *across* the wind and *upward* against it.

Mr. William Kress, of Vienna, Austria, deduces a solution depending on the increasing velocity of air currents as we ascend. Without going into his elaborate explanation, I will present a copy of his figures and diagram, showing how a bird, without muscular effort, can perform a vertical orbit and gain in speed. Let Figure 8, Plate 1, represent an orbit traced in air currents of varying intensity, as shown. Let M be a reference point on the earth. Let the bird attain a velocity of 45 feet per second with respect to the air. The following table will explain the process of the flight. The argument is that the bird loses no relative speed when working against the air, but gains when flying with it, due to gravity.

Velocities.	a	b	c	d	e	f	g	h	i	k	l	m	n
Speed of wind	15	18	21	24	27	30	30	27	24	21	18	15	15
Absolute speed of bird	30	27	24	21	18	15	72	72	72	72	72	72	39
Relative speed of bird	45	45	45	45	45	45	42	45	48	51	54	57	54

Thus the bird has completed the orbit and increased its speed by nine feet per second. The preceding result, is perfectly possible on the hypothesis that the air currents are varying, a fact which is already partially proven by experiment.

Professor Langley has suggested a theory of soaring which, though faulty, may have some value. It depends on the law of wind pulsation, which he has investigated. There is no doubt that wind currents are more or less undulating, which can be seen by the ducking of a kite at periodical times, of smoke, etc. By reference to Figure 4, Plate 1, in which the arrows show the direction of the currents, and AB the aeroplane at a small angle to the horizon, a sustaining and upward motion is given to the latter in the position shown, while additional speed can be attained by a downward glide in the intervals between "the gusts." A general tendency, then, would be upwards, a result which could also be obtained if moving against the wind, though not as rapidly.

A consideration of any of these solutions would serve to explain the phenomena of soaring flight. But how, we ask, does all this lead to the solution of man flight? Simply in this: supposing we were thoroughly acquainted with the laws of aerial currents, and possessed the knowledge of turning them to our use, we could by adjusting to ourselves a sufficient aeroplane and a mechanical device for individual propulsion be enabled to sustain ourselves in the air under similar conditions. From research which has already been made, it seems as if man would be unable to sustain himself in the air by means of an aeroplane pure and simple, but that some means of propulsion must be utilized. By reference to the table on Plate 3, this will be recognized. The results are taken from Mouillard, and show figures on sixteen well-known birds. The original figures were in the gram meter system. The last column, deduced from the preceding ones, is the one in which we are immediately interested. It shows the relative surface required to sustain the weight of a man and light apparatus, in respect to the different birds. It will be seen that the wild duck furnishes the example of the lowest, but we cannot look to that bird for our model. The vulture is the heaviest bird given, and presents the most promising model in every respect, showing some 135 square feet of aeroplane required for man. We will see later on how this agrees with actual experiment. All the other birds present too great relative surface for practical use.

We will leave the subject of bird flight at this point and look briefly into the next division of our data—that of the kite. We have all flown kites, and know something of their behavior. They are of many shapes and sizes, and may be built of almost any material, and flown in many ways, but the principle of sustentation is the same. When held by a single string, the surface is perpendicular to it, which shows that the thrust of the air is normal to the kite. We remember, too, that there is always a particular point at which the string must be tied which gives the best flying results, and this point is *above* the centre of gravity. This shows roughly that the centre of pressure is not coincident with the centre of gravity of an aeroplane. A similar diagram of forces may be constructed for the flying kite as for the bird's wing. Thus in Figure 3, Plate 1, let AB be the kite, and C the centre of pressure where the string is attached. Construct the parallelogram of forces where CF represents the drift and CD the lift. If to the lift we add the weight of kite tail and string, we get the total carrying power; and if from the drift we subtract the drag of the tail, we get the power required to hold the kite, or otherwise to *propel* it through the air. This is the ordinary kite with which we are familiar. We have frequently heard of types of kites which are flown in the East, notably by the Chinese, Malays, and Javanese. These are tailless kites, and are flown in the most sluggish breezes, in fact, almost in a calm. I had the opportunity of seeing one in the Javanese village at the World's Fair in 1893. A type of such kites is shown in Figure 2, Plate 8, and was constructed by Mr. W. A. Eddy, of Bayonne, N.J. He has flown it in an exceedingly slow breeze and can fly it in a calm by walking at the rate of a couple of miles an hour. He

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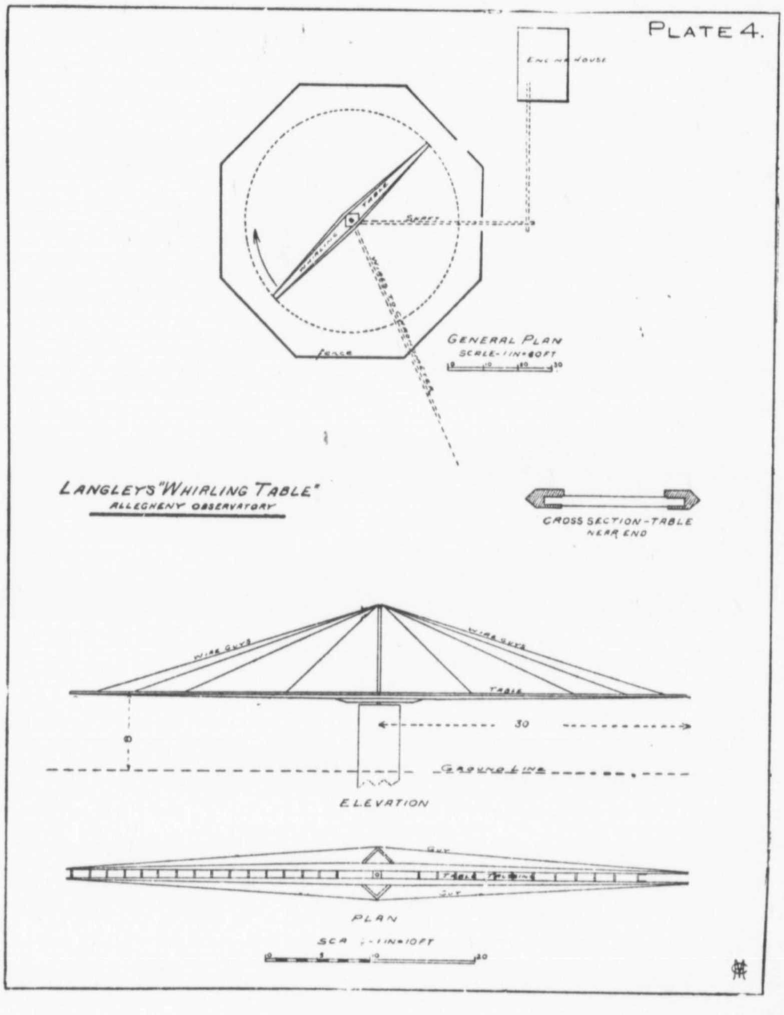
PLATE 3.

COMMON NAME.	WEIGHT OF BIRD. POUNDS.	SURFACE WITHIN CONTOUR. SQ. FEET	SPREAD OF WINGS. (A) FEET.	MEAN WIDTH OF WING (B) FEET.	PROPORTION. A/B	ONE LB. OF BIRD'S WEIGHT SUSTAINED BY SQ. FEET.	ONE SQUARE FOOT SUSTAINS POUNDS.	RELATIVE SURFACE REQUIRED TO SUSTAIN 200 LBS. SQ. FEET.
WATER FOWL....	1.309	1.031	2.28	0.518	4.40:1	0.787	1.270	157.4
GOSHAWK........	0.638	1.109	2.36	0.525	4.48:1	1.738	0.575	347.6
NIGHT HAWK....	0.136	0.434	1.70	0.262	6.36:1	3.191	0.313	739.2
GULL............	0.510	1.175	3.10	0.427	7.27:1	2.304	0.434	460.8
PETREL..........	1.540	1.283	4.10	0.410	10.0 01	0.833	1.200	166.6
WILD DUCK	2.035	0.901	2.36	0.360	6.54:1	0.442	2.26	88.4
WILD GOOSE.....	4.444	2.627	4.49	0.623	7.26:1	0.591	1.692	118.2
PELICAN	14.575	10.750	9.19	1.279	7.17:1	0.737	1.355	147.4
SCREECH OWL....	0.671	1.519	3.08	0.541	5.69:1	2.264	0.442	452.8
NIGHT HERON ...	1.353	1.949	3.41	0.656	5.20:1	1.441	0.694	288.2
STORK...........	4.708	6.620	6.82	0.984	6.93:1	1.406	0.711	281.2
KESTREL FALCON.	0.398	0.990	2.43	0.410	5.92:1	2.480	0.402	496.0
KITE	1.408	3.090	4.36	0.721	6.04:1	2.195	0.456	439.0
FISH HAWK......	2.794	3.542	5.08	0.787	6.45:1	1.270	0.789	254.0
TAWNY VULTURE.	16.500	11.250	8.24	1.460	5.64:1	0.682	1.466	136.4
NUBIAN VULTURE	17.934	11.980	8.75	1.509	5.76:1	0.667	1.497	133.4

PLATE 4.



LANGLEY'S "WHIRLING TABLE"
ALLEGHENY OBSERVATORY

ENGINE HOUSE
WHIRLING TABLE
SHAFT
FENCE
GENERAL PLAN
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0 10 20 30
CROSS SECTION–TABLE NEAR END
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8
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has found that just previous to a reverse of the breeze, the kite partakes of a rocking motion from side to side, as if beating the air like a bird. When the wind ceases the tension on the string is released, and it hangs downward ; the kite then slowly descends in a slanting direction, but when the wind comes up from another quarter the descent ceases, the kite catches the wind, backs away, and ascends again.

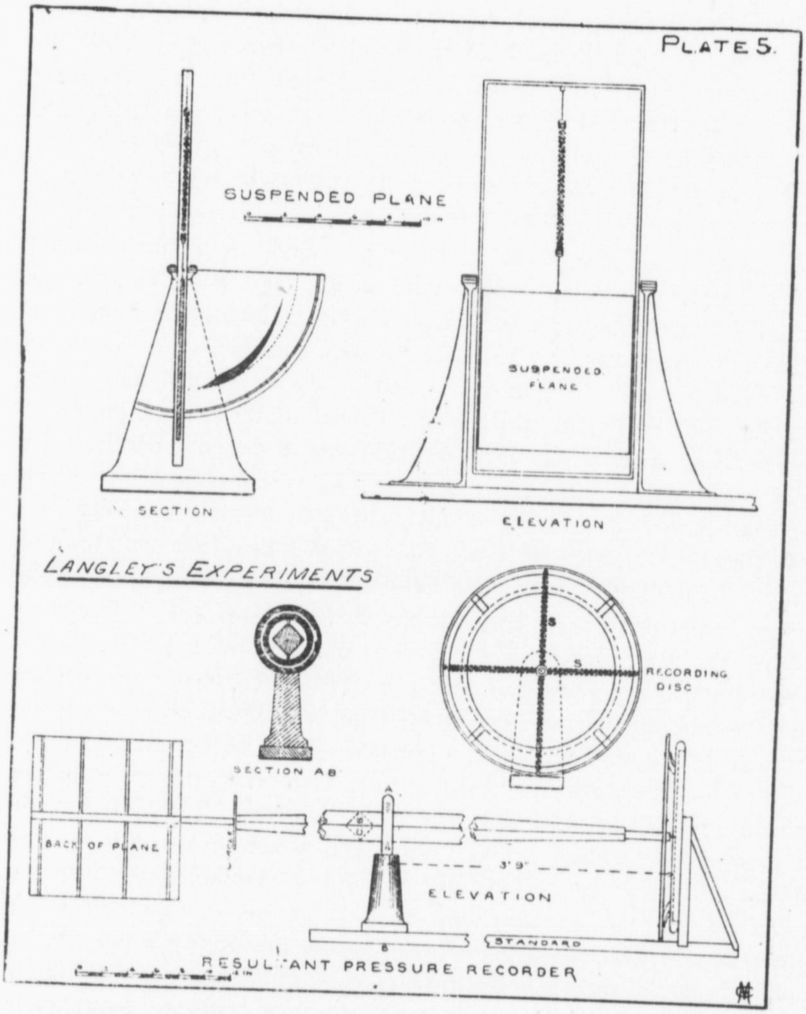
No little attention has been directed to the singular kites constructed by Mr. Lawrence Hargrave, of Australia. A type of these is shown in Figure 1, Plate 8. The principle involved depends on two well-known facts: "The necessary surface for supporting heavy weights may be composed of parallel strips, superposed, with an interval between them" (see Wenham and Langley); and "two planes, separated by an interval in the direction of motion, are more stable when conjoined." The construction partakes the form of a cellular pigeon-hole box on the underside of the compartments of which the wind acts. The angle at which they float is very small, and as a consequence the kite may take up a position almost in the zenith. It is found that a kite with surfaces concave on the underside pulls about twice as strongly on the string as a similar one with plane surfaces.

Investigations "in the laboratory" form one very reliable source of information in regard to the sustaining powers of the aeroplane. Prof. S. P. Langley, of the Smithsonian Institute, Washington, has without doubt furnished us with the most valuable information on this subject. He made his experiments at Alleghany Observatory, and I will briefly review a few of these for the purpose of showing important laws governing the pressure of the air on moving planes. His elementary apparatus consisted of a "whirling table," as shown in Plate 4. This table consisted of a very light wooden trussed structure sixty feet long, and pivoted on a shaft at the centre. By suitable gearing this vertical shaft and the table could be made to revolve at any speed, power being supplied by a small steam engine. One end of the table was arranged for attaching certain apparatus for testing purposes, the balance of each arm being retained. By an electric circuit and a chronometer attachment, the complete behavior of the table could be recorded. The arms revolved at a height of eight feet from the ground, and the whole was protected from winds by a high board fence. The outer end of the table could be made to travel at any rate up to 100 miles per hour, and the motion was at such a radius that it could be considered practically linear.

His first experiments were made with the suspended plane, as shown in Plate 5. This consisted of a plane suspended in a frame, and free to slide up or down under the balanced impulse of a spring. The whole frame was free to revolve on a horizontal axis, the lower part, having the plane, being heavier, however. A graduated circle was attached together with a pencil recorder. The whole instrument was placed on the end of the arm of the whirling table, and the table revolved, the plane and frame being exposed to the direction of motion. The pressure of air caused the lower part of the frame to swing backwards, while the plane travelling forward at an angle on to new air released the tension of the spring, and consequently rose in the frame, the pencil recording the amount of rise. In the figure the records of the pencil are shown shaded. The significance of this experiment is easily seen.

The next experiment in logical order was that of the resultant pressure recorder. When a plane is advancing on the air at an angle above the horizon, the resultant pressure varies in intensity and direction according to that angle. This apparatus was constructed to investigate this. An arm, shown in Plate 5, was hung at the centre in gimbal joints in a support and standard, which was attached to the end of the table. The arm was about seven feet and a half long, and at one end carried a pencil and at the other (outer) a plane of any convenient size which might be inclined to the horizon at any angle, a circle being attached for reading such. The arm was nicely balanced, and the pencil fitted through a collar which was attached to four calibrated springs (SS), and played on a paper disc placed in a support. When the apparatus was set in motion on the table, the plane being placed at any desired angle, the pencil recorded on the paper not only the intensity of the pressure (as reduced from the calibration of the four springs), but the direction or "excursion of the trace" in reference to co-ordination. This "excursion" could be made in *any* direction with equal facility. In this way a law of the resultant pressure could be deduced. Newton's law in this instance made the pressure on a plane moving in a fluid vary as the square of the sine of the angle between the plane and the line of motion. Mr. Langley's researches have shown that this is quite erroneous, and, though his apparatus was constructed more for an approximation to the quantitative pressures than for precision, the discrepancy is sufficiently great to entirely change the complexion of the previous law. As an instance, for an angle of 10° the theoretical vertical pressure would be $\sin^2 10^\circ \cos 10^\circ = 0.030$ of the pressure on a *normal* plane moving with the same velocity. According to these experiments under similar conditions, it is 0.30 of the same pressure, or ten times greater. Rather than give any tables of Langley's results, I have plotted a curve representing in general the rate of variation

PLATE 5.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LANGLEY'S EXPERIMENTS

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of the pressure; that is, the ratio of the total normal pressure P on an nclined plane to the pressure P_n on a normal plane at the same velocity. In the diagram, Figure 1, Plate 7, the abscissæ are the angles of inclination to the horizon, and the ordinates the ratio or percentage of the pressures ($P \div P_n$). I have also plotted a curve showing the Newtonian law within the same limits. The inferences from this diagram will hardly need explanation. The practical experiments show that the lifting effort increases much faster with the angle than was hitherto supposed, a fact which is surprising and most important.

Probably the most important experiment made by Mr. Langley was that with what he called the "plane dropper." Its construction was simple. It consisted merely of a frame and standard, to be attached to the end of the table, provided with a set of vertical guides in which moved anti-friction rollers attached to a set of two horizontal planes. (See Plate 6). The planes being held by a catch at the top were released electrically, and fell some four feet, passing vertically down the guides and striking on a spring cushion at the bottom. The planes were capable of being inclined to the horizon at any angle up to 45°. Five pairs of planes were experimented on, ranging from 6 x 12 inches to 18 x 4 inches each, end weighing an average of 120 grammes per pair. The additional weight of the falling piece was 350 grammes, or a total of about one pound. The time of fall from the breaking of contact at the top to the making of it again at the bottom was recorded on the chronograph. This record, together with that of the rate of the table, the angle of inclination, and size of the planes, afforded a means of determining the sustaining power of the air with regard to speed and area. Mr. Langley made his experiments with a view to three results: first, to show that the supporting power of the air increases with the horizontal velocity, be the planes either horizontal or inclined; second, to determine what particular speed is necessary to produce for different angles of inclination a lifting effort sufficient for sustentation; third, to investigate similar facts with superposed planes.

No doubt, the easiest way to show the truth of the first is to furnish a diagram with the plotted results of the experiments; see Figure 2, Plate 7. The abscissæ are the horizontal velocities of translation in meters per second, and the ordinates the times of fall in seconds. These were made with two horizontal falling planes (18 × 4 inches), advancing long edge on to new air. The theory of this is similar to that before quoted of the skater on thin ice. Should the plane be at rest, only one unit of air serves to sustain; but, while in motion, a number of units act. These experiments show the great value of speed for the sustaining of a moving aeroplane. Mr. Langley has found that better results are obtained with the longer edges of the planes foremost; the reason is obvious, for the back parts of the planes are not acting on previously used air.

The relation of angle, speed, and lift is the very essence of the soaring aeroplane. It is evident that if the first law above is true, then there is an angle for each speed of translation which will continually maintain the aeroplane in the air. Mr. Langley actually made such experiments. He placed different planes at different angles, and then ran the whirling table at increasing speed until the planes were just merely supported. He was enabled, from the results, to calculate the respective horse powers acting. Figure 3, Plate 7, shows the plotted results of two sets, 18 × 4 inches and 8 × 9 inches, moving at different inclinations. The abscissæ are the angles of inclination of the plane, and the ordinates the velocities in meters per second. In regard to the third case of investigation, it was found that the closeness with which the planes could be set was a function of the speed; the greater the speed, the greater the relative proximity. The air seems to be disturbed under the aeroplane for only a slight depth, and this is the air which really might be said to do the work. The minimum distance with Mr. Langley's planes was four inches. At two inches, a decided diminution in the lifting power was experienced.

A result of prime importance is logically deduced from the preceding—this is that, with heavy inclined planes in motion of translation, the higher speeds are accomplished by less actual power than are the lower ones. This is surprisingly paradoxical, and the fact led Mr. Langley to continue his experiments directly for this purpose. He arranged an automatic apparatus, called a component pressure recorder, to be used in conjunction with a "dynamo-meter chronograph," for recording the speed, times, resistance to forward motion at the instant of soaring, the horse power, and other phenomena. The latter instrument was placed *on* the recorder, and was provided with an air screw propeller actuated electrically, and recorded its own work. The recorder was a combination of the resultant recorder and plane dropper, and was capable of recording the instant of soaring flight of its plane, the location of the centre of pressure on the plane, and the intensity of the horizontal and vertical components. The propeller was calculated to so actuate the whole recorder as to counteract the air resistance to the arm of the recorder on which it was situated. Knowing the power or pressure required to make the plane of the recorder soar itself, and reproducing this by means of the dynamometer, the power expended for different speeds, etc., was found. Thus the paradox was demonstrated experimentally.

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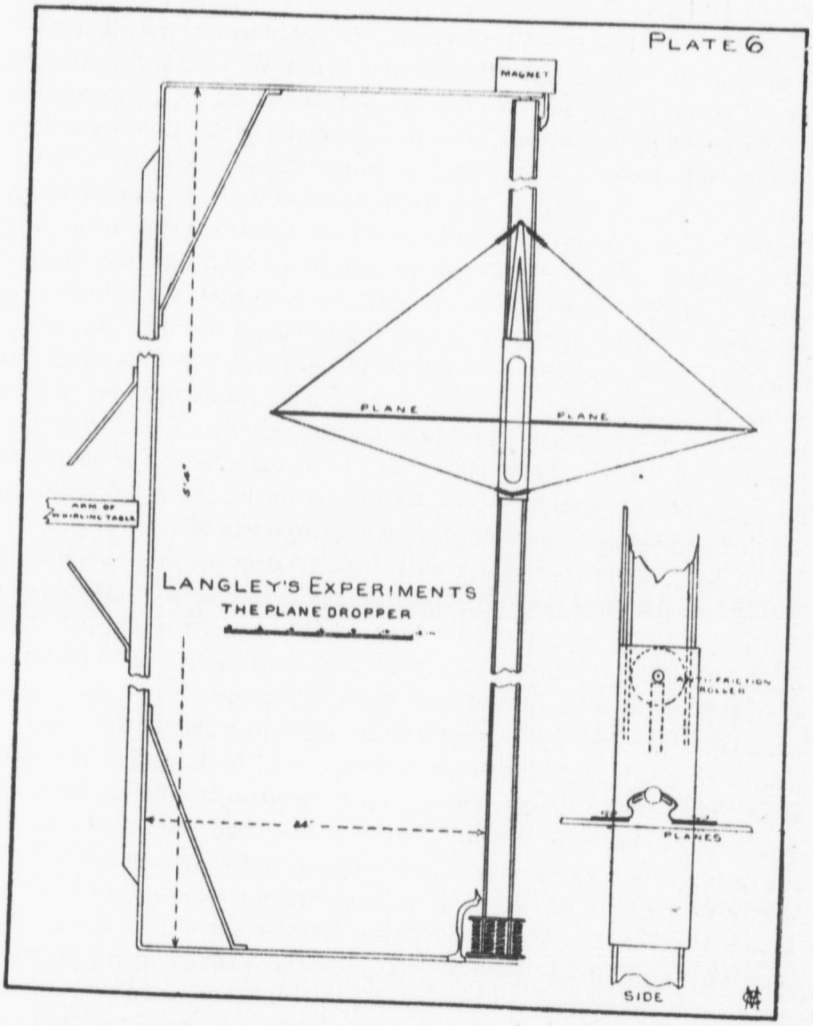
PLATE 6

LANGLEY'S EXPERIMENTS
THE PLANE DROPPER

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PLANE
5' 6"
ARM OF WHIRLING TABLE
ANTI-FRICTION ROLLER
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Similar experiments were conducted by Mr. H. S. Maxim at Bexley, England, and, it might be said, took up the work where Mr. Langley left off. Mr. Maxim also provided a whirling table similar to Mr. Langley's. The circumference described was 200 feet, and power was supplied electrically through the pivot to the end of the table. To briefly outline Mr Maxim's experiments: On the end of the whirling arm he mounted an aeroplane and an electric motor actuating a screw propeller, which caused the table to revolve. In connection he had mounted on the arm different dynamometers, so that he obtained a record of the thrust of the screws, the horse power exerted, the velocity of rotation, and the lifting effort on the aeroplane. He tested about fifty different kinds of screws, and also aeroplanes ranging from 3 × 24 inches to 3 × 12 feet. He concluded that long narrow planes, long edge on, slightly concave on the underside, and at inclinations of from 5° to 10°, gave the best results. Screws with two narrow blades of small pitch and with high velocity were the best. He was able, with the aeroplane running at 60 miles per hour, to lift 133 pounds per horse power.

The late Mr. C. W. Hastings has compiled the results of a number of experimenters into tables and diagrams which are too extensive to touch here. Some of his results may be mentioned, however. If the the area of the supporting plane is constant, the horse power required and the angle of inclination decrease with an increase of speed. If the angle is constant, the speed increases directly as the horse power, and inversely as the area. If the power remain constant, the speed increases with the decrease of both area and angle. The smallest angle is, therefore, desirable. "If the smallest angle which can be safely used be 5°, we see that if the speed be decreased from seventy miles per hour to forty, then the area required will be increased from 0.36 square feet per pound to 1.10, or more than three times; while the power required will decrease only from 0.015 to 0.009 (per pound weight), or considerably less than one-half. This shows the advantage of high speed.

I have reviewed thus briefly the outline of the principal laboratory data which is the basis of aerial sustentation. In a paper of this kind it is well-nigh impossible to present any complete collection of information, and the foregoing must suffice.

We now come to the consideration of the theoretical and ideal flying machine—the requisites for its sustentation, propulsion, and stability. Such a discussion must be based, of course, on the foregoing data, and hence must be, in part, somewhat a conjecture, for with the exception of the renowned Maxim machine we have no actual working data at hand.

The requisites for a flying machine may be summed up as follows:

(1) Its various parts and members must be of the lightest construction compatible with strength and stiffness, and the factor of safety must be large.

(2) Its general configuration must be economical for space and convenience, and present the least possible resistance to the air.

(3) It must be capable of rising gently, but swiftly, and supporting itself in the air in storm or calm, for a length of time.

(4) It must have stability and be incapable of upsetting.

(5) Should be easily steered in any direction.

(6) Provided with a means of rapid and powerful propulsion.

This enumeraton may appear highly idealistic, but the practical possibility is much clearer than is generally supposed.

Taking the first division above—that of its mechanical construction in regard to strength and weight. Just where the useful limit of the compromise between these two conditions is remains to be determined for the greater part experimentally. The basis of such, however, would rest on the primary comparative value, weight for weight, of different materials. Let us first look at different working machines in this regard. A man will exert about one horse power for 1000 pounds weight, or, working continually, can put out about one-sixth of a horse power. Animal muscle is seldom subjected to more than 100 pounds per square inch tensile, and in ordinary 20 pounds. Thus the factor of safety must be very high. A draft horse weighs 1,500 pounds per horse power, a marine engine about 300 pounds, a locomotive about 150 pounds per horse power. Birds, as far as can be learned, exert one horse power for perhaps 20 pounds. Anything better than the latter in mechanical construction would have been thought impossible a few years ago, but it is already surpassed by actual results. Munro's yacht "Norwood" is run by boilers and engines of nineteen pounds per horse power. Langley has built an engine at the rate of twelve pounds per horse power, and Maxim has an engine of 300 horse power, which with boilers and all apparatus weighs not more than six pounds per horse power. Hence it is seen that the problem of the weight of the propelling machinery is solved even beyond our hopes, for it has been previously predicted that could we design a motive power at twenty pounds per horse power the success of aerial flight is all but a fact. Mr. Maxim's engine is built of the very finest tool steel, and all possible parts are made hollow, with the very best workmanship and the greatest care. It is to be noted, however, that he states his engines to have cost their weight in silver.

Professor Thurston says:—"The reduction of weight may be accomplished by advances in either or all of three directions: (1) Reduction of weight of material by improved design and proportions; (2) increase of ratio of strength of the materials used to their density; (3) increased velocity of motion of the moving parts of the machinery transmitting energy." Much has been claimed the past years for the new aluminum. Aeronautical research has shown a great part of this to be a fallacy; the reasons are well known without detail here. In regard to the relative value of materials, we have the following table compiled from Langley, Hunt, and Hall:—

Metal.	Weight of one cubic foot.	Tensional strength per square inch.	Length of bar that just supports its own weight.
Cast Iron................	444 lbs.	16,500 lbs.	5,351 feet.
Ordinary Bronze...........	525 "	36,000 "	9,874 "
Wrought Iron	480 "	50,000 "	15,000 "
Hard Struck Steel.........	490 "	78,000 "	22,922 "
Aluminum................	168 "	26,000 "	22,285 "

This clearly decides for hard steel in construction where combined strength and lightness is required; which means, then, that all framing of a machine requires hollow steel rods, steel wire guys and bracing. Castings and drop forgings of steel are, apparently, better than any kind of alloyed aluminum yet made. Piano wire steel has been drawn to a tenacity of even 300,000 lbs. per square inch. Certain alloys of aluminum, with copper and nickel, have been very successful in regard to strength, but there yet remains the difficulty of working the metal. Wood may be used under circumstances, but, in such occasions, attention is directed to the increased air resistance which might arise. It is needless to point out that the factor of safety, under all conditions, must be large.

There is not much to be said on the subject of configuration outside of the air resistance. Our best models for such are the bird and fish. Each of these present a very small forward resistance. Their lines and surface friction are such that the resistance may be almost zero. This is the reason that most aeronautic constructions built for speed are elongated, or "cigar" shape, as we know it. The balloon "La France" measures 165 feet in length, and 27.5 feet diameter, the maximum transverse cross-section being at about 40 per cent. of the length from the front. For a flying *machine*, however, the circumstances would be much altered from those of a balloon. If the sustaining apparatus be a rigid aeroplane, the forward resistance will be limited, for the greater part, to the car and machinery section, although, by the way, the resistance of bracing, etc., has been found to be surprisingly great. In such a machine, then, the orward part of the "deck" might be protected by a light construction of fine lines which would cut the air with the least resistance, and divert the wind current from all deck apparatus but the propellers. In such, however, the division of the currents should not be great enough to effect the efficiency of the propellers, aeroplanes, or steering apparatus. As for the economy of space, that would necessarily take care of itself in the economic mechanical construction.

We now consider a requisite which is of vital importance, and which will require a lengthy discussion—that of the supporting power. In this we will merely consider the theories in regard to the "soaring" machine. The controlling conditions of such aerial support are quite dependent on each other. They may be summarized as follows: (1) The weight of the machine; (2) the area and character of the supporting surface; (3) the angle of the supporting surface; and (4) the velocity of forward motion, and, consequently, the power.

In considering the supporting power of an aeroplane, we must always bear in mind the fact that the upward impulse is directly dependent upon the thrust of the new air on the underside of the plane. We have seen how the laws of such pressure are deduced. It is true that they have been made on a small scale on small planes, but the concordance of the experiments leads us to infer that they are similarly applicable to larger areas. The air is such a very light and mysterious substance that not only does difficulty of experimentation arise, but it will be a long time before man will realize that its supporting power is something quite material. Those who have really been up in the air in a free machine tell us that we "cannot imagine what a delightful sustaining power there is" in the air. We have seen how the sustaining power depends on the angle of inclination of the moving aeroplane, and the velocity with which it is propelled. If we follow out the principle presented in the table on soaring birds, we could arrive at a series of tables for the weight which would be sustained by one square foot of aeroplane moving at a known rate and angle. We have seen, in Plate 7, how the sustaining power is a function of the normal pressure, and how the power increases with small

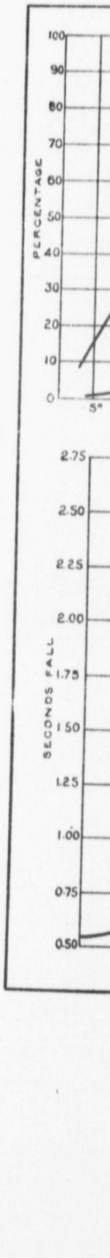

PLATE 7

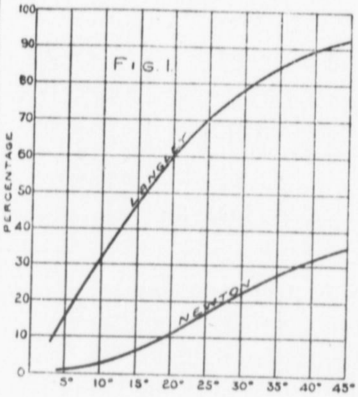

FIG. 1

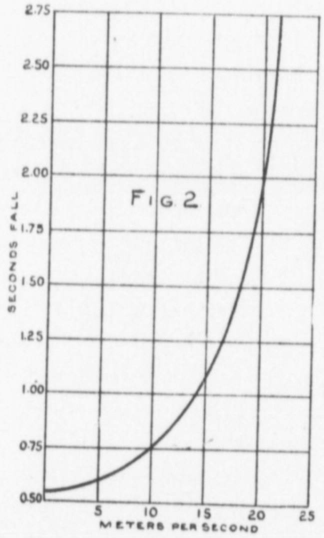

FIG. 2

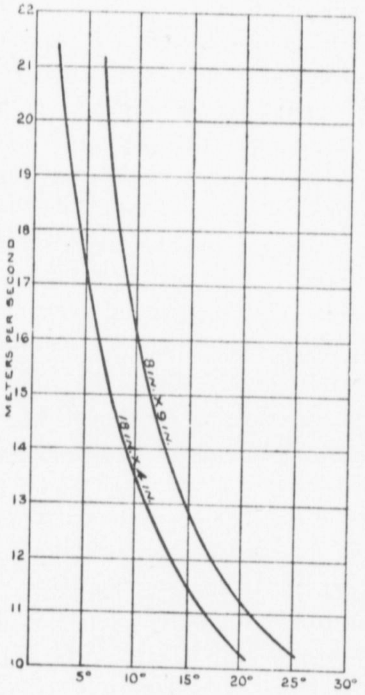

FIG. 3

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PLATE 8.

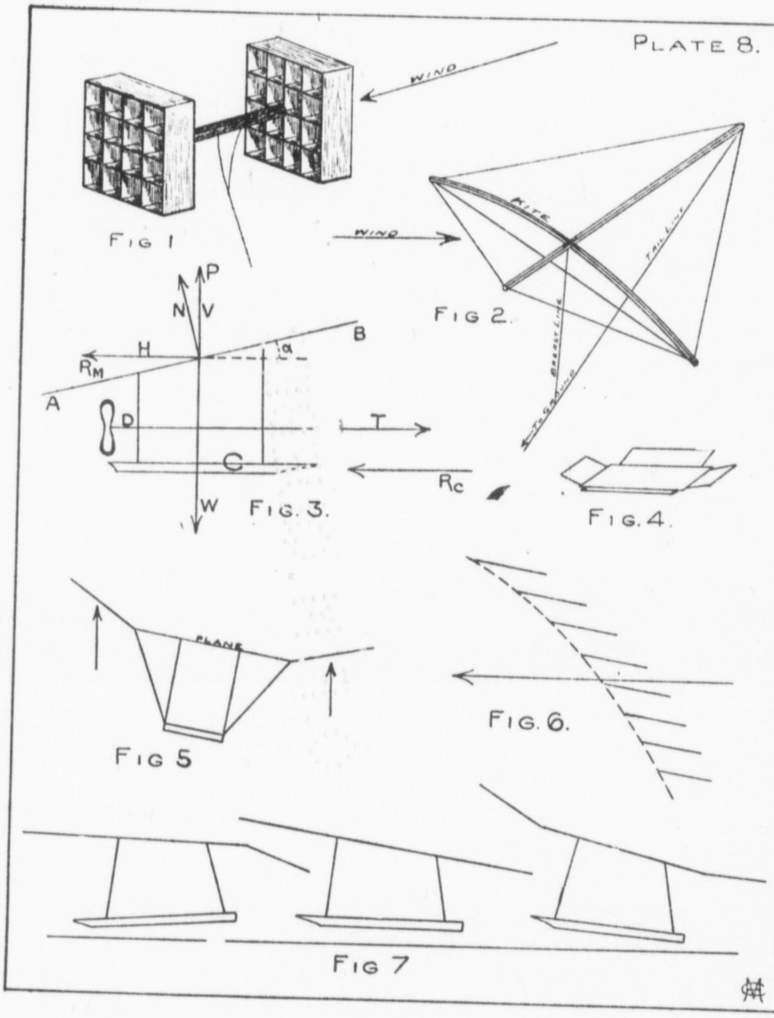
WIND
FIG 1
WIND
KITE
TAIL LINE
BREAST LINE
TO GROUND
FIG 2.
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FIG. 3.
FIG. 4.
PLANE
FIG 5
FIG. 6.
FIG 7

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angles and high velocities. Experiments have led us to believe that inclinations of from 5° to 10° are the most serviceable. True, better results might be obtained by smaller angles, but the stability of the machine in a longitudinal direction would then be endangered. Let us look at the mathematical considerations for an aeroplane, with car, etc., attached, passing through the air. In Figure 3, Plate 8, let AB be the aeroplane, C the car and apparatus, and D the propelling machinery. Suppose R_c be the air resistance of car and attachments, W the weight of the machine, and a the angle of plane. Then we have $N \cos a = P =$ the vertical sustaining force where N is the normal pressure of the air caused by the velocity. $N \sin a = R_m$, the horizontal resistance to motion of aeroplane. If L be the thrust of the air on the underside of the plane, then $L \cos a = V =$ vertical part of wind pressure, and $L \sin a = H =$ horizontal part of wind pressure. Let $T =$ the thrust required for propulsion. Then we have the following conditions of equilibrium and motion of the machine: $P + V$ and W must act through the centre of pressure of the plane. The centre of gravity must be below the centre of pressure or lift. The thrust T must $= R_c + R_m$, and when $P + V = W$ the machine will proceed horizontally. When $P + V$ is greater than W the machine will rise, and when less it will fall. With increased velocity or T the machine will rise, and *vice versa.*

By means of the Langley formulæ and diagrams, together with those of De Louvrie and Duchemin, we have a definite formula for the ratio of up lift and forward motion with regard to the normal pressure on an aeroplane of known inclination. For instance, where the normal pressure on an inclined plane is expressed as a percentage of that on a vertical plane, we have with an angle of, say, 8° the normal pressure 0.260, the lift 0.257, and the resistance to horizontal motion or "drift" 0.036, by the De Louvrie formulæ. By this means we can arrive at the extent of the supporting surface to carry a given number of pounds. Let us look at the number of square feet per pound required under different conditions. Referring to the accompanying table of birds, we see that the rate varies from 3.191 square feet per pound for the night hawk to 0.442 for the wild duck. Good soaring birds, such as the petrel (0.833), pelican (0.737), stork (1.406), and tawny vulture (0.682), lead us to believe that we ought certainly to fly with a machine carrying one square foot of sustainer for every pound weight. It is with this assumption that experiments have been actually made, and we will see further on how this rate has been much surpassed.

It has been pointed out how we may consider the support by means of an aeroplane as being obtained by driving the *new* air downwards. Considering the subject in this way, we will see it much clearer. Suppose we take the formula $\frac{WV}{g}$, so well known, where W is the weight of the mass of fluid acted upon in pounds per second, V the downward velocity in feet per second, and g as 32.2 feet per second. To illustrate this, let us consider the power expended to do the work. Take two machines each weighing, say, 1000 pounds. Let one be capable of being run so as to act on, say, 2000 pounds of air per second. Then $2000 \div (32.2 \times 1000) = 16.1$, which is V or downward velocity. If now we determine the horse power to accomplish this alone, we have $W \frac{V^2}{2g} \div 550$, or $\frac{2000 \times 259.21}{64.4} \div 550 = 14.64$ horse power. Suppose, now, we double the quantity of air acted upon, we have $V = 8.05$ feet per second, and $\frac{4000 \times 64.8}{64.4} \div 550 = 7.32$ horse power. The significance of this is apparent, that much is to be gained by acting on a large quantity of air. Such can be accomplished in two ways, either by velocity (which fact we have seen before) or by large aeroplanes. The figures as given above refer, of course, to propulsion as regards the aeroplane alone, and not to car resistance.

It cannot be too strongly urged that the aeroplane must be driven on to new air previously undisturbed, that this air must be driven downwards, and that at a fast rate. As has been before intimated, the lifting effort with regard to the thrust is found to be very much greater than was hitherto supposed. The figures from the De Louvrie formula above will show this. The lift is seven times the drift or thrust horizontally; that is to say, if the propellers of a machine gave a clear thrust of one foot, the lifting effort produced would be seven pounds, with an aeroplane at an angle of eight degrees. This fact has been already borne out experimentally.

From the foregoing, it can be readily seen that the problem of actual flying is very easy of solution; that a machine, once up, can be propelled with a minimum amount of power, provided the velocity be sufficiently great. The power is required at the rise, and that is where the difficulty will always present itself—to say nothing of the descent. If the angle of an aeroplane be rigid, and the machine be constructed so as to rise by a forward thrust, the angle, when rising, will be much greater than when proceeding in horizontal flight, the speed cannot be so great, and there is an additional effort required against gravity, so that a great deal of power is consumed. By any scheme of aeroplane it is a practical necessity to rise in this way by a forward impulse—riding *up* on the air, as it were. Some experimenters have suggested screws revolving on vertical axis, expecting thereby to raise the machine vertically, so as to avoid the horizontal running start, as they call it. They forget that with rigid aeroplanes such a procedure is very difficult. If it were possible to automatically collapse the aeroplanes, the case would be different, but a direct rise otherwise would require a very great displacement of air. Professor C. V. Riley has suggested propellers moving on shafts which can be turned through a quadrant, from vertical to horizontal, at will. The consensus of opinion, however, leads us to expect that rising will be effected by a gentle forward and upward progress. Suppose, we will say, that the rise, after leaving the ground, will be at an angle of 20°, then our aeroplane is encountering the air at an angle of, say, 28°. In such a case, by reference to De Louvrie, the normal pressure is 0.751, the lift 0.662, and the drift 0.354, so that only about two pounds could be raised per one pound horizontal thrust. If rising at an inclination of 10°, the upward thrust would be over three pounds. If it were possible to arrange a system of aeroplanes which could be adjustable to such circumstances, much power might be saved.

Much ridicule has been hurled at the flying machine in regard to its ability to descend to earth—very much like the Irishman who didn't mind the falling, but objected to the sudden stop. In reality such difficulties are, perhaps, more imaginary than real. Suppose we have a large aeroplane, and that we have wings, as it were, on each side at an inclination, as shown in Figure 4, Plate 8; and suppose our propelling power is suddenly stopped in mid-air. The whole would *settle* to the earth like a parachute, and would land with little shock. Landing under such circumstances would soon become a matter of practice. This will be spoken of further on under stability.

Altogether, it appears to be generally conceded that the aeroplane system offers the best supporting power, the swiftest and gentlest method of ascension, with the simplest attachments, therefore, that has as yet been investigated.

Let us look now, briefly, into the character of the supporting surface. Hitherto we have been treating the subject of the aeroplane as if it were one plane upon which the wind was acting. This was done for simplicity. It may be said that there are two systems of aeroplanes which are advocated. The one, that of the very large aeroplane alone, with the necessary side planes and rudders, of course; the other that of a series of long narrow planes arranged to advance long edge on the air at the necessary angle. The first system has the advantage of being very simple, and offering, probably, a more stable and safe support, due to its parachute properties. Maxim is the leading disciple of this system. The second system has grown out of Langley's experiments, which show that the best results to be obtained for soaring are with the narrow planes. It will be remembered that Langley made his experiments on real planes for simplicity. It is to be desired, of course, in the aerial construction, that all supporting planes be concave on the underside. This is more easily accomplished by the series of narrow planes than by the single large one. The large plane must be so placed as to not interfere with the action of the propellers or steering apparatus in shutting off the air or creating an adverse current. It has been suggested to arrange the narrow planes in a superposed series similar to that shown in Figure 6, Plate 8. Each narrow plane thus gets new air, which does its work quickly, and passes off at the back end. There is less loss at the sides, too. The intervals between planes should be considerable, at least the same as the width of the planes. One objection to this method is that the propellers, etc., if situated behind the planes, are not efficient, and, if before them, render the planes inefficient, while, if below, would make a cumbersome construction.

As to the materials for aeroplanes, experience seems to point to light balloon cloth or "gold beaters' skin" for exceedingly light construction. This can be stretched upon the very light metal or wooden framework of the plane. It has been urged, however, that this material is too frail, and that something stronger is preferable. Oiled linen weighs about 2.6 oz. per square foot, and makes good material. A new material is suggested, and has been found very satisfactory—a wire woven web made of very light aluminum wires is varnished, and the interstices filled with a light elastic varnish, which altogether makes an impermeable web about one-fiftieth of an inch thick and weighing 3 ounces per square foot.

Sections 4 and 5, as mentioned in the requisites for the flying machine, might be treated together under the head of steering and stability. Steering horizontally is probably most easily accomplished by the use of twin screws, as in sea vessels. The steering vertically is where our difficulty lies. We must remember that in aerial navigation we have all forces resolved into three directions, whilst in marine navigation there are only two. Vertical guidance can be effected in part by speeding the propellers —as pointed out in the conditions of equilibrium and motion. This, however, is limited, and vertical rudders, revolving on horizontal axes, must necessarily be used. In Figure 7, Plate 8, is shown the effect of the rudders, as illustrated by the Maxim machine. Here there are fore and aft rudders, each with its work to do.

The matter of stability is of vital importance. As previously intimated, the centre of gravity should be as far below the centre of lifting effort of the machine as possible. This is easily obtained with a machine of the Maxim type, the former being down near the deck and the latter up in the aeroplane. There is one fault which we are, perhaps, likely to overlook in our idea of the ideal machine, and that is an extreme in weight. If the machine is *too* light, it will be clumsy, and will have small momentum; its stability will be lessened, and it will be liable to topple over in the first gust of wind. The air is so subtle and light that we must expect great difficulty in providing a steadiness of motion. We know the birds retain their equilibrium intuitively; it is affirmed that they sleep on the wing; and our balancing apparatus, then, must be something of the same sort. It is frequently suggested to provide some automatic electric balancing agent to accomplish this, but so far no success has been attained. Recourse to additional planes seems to be the only solution.

For transverse stability—that is, the prevention of side rocking and tipping—an imitation of the bird's wings seems to be preferable. The bird can preserve his equilibrium by placing his wings at a diedral angle from his body. This is such that if the body tends to rotate about a longitudinal axis, the wing which descends receives additional pressure from the air on account of its position, whilst the upper wing, being very much inclined upward, receives so much less. This principle is followed in several designs of machines now being tested. If side planes were projected, as shown in Figure 5, Plate 8, from each side of the main aeroplane system at an angle with it, they would attain this end. This condition is observed in boat building, but, besides, the boat has a keel—why not the air ship? Such would tend to prevent the rocking motion, though it would not help the supporting members. If the machine were sustained by the compound aeroplane system, the matter of transverse stability is simpler on account of their arrangement. Now comes the stability about a vertical axis, the prevention of a tendency to move in a horizontal circle or oscillate horizontally. This might be caused in a ship with twin screws, or where one side is heavier than another, or by a side wind. A couple is formed about the centres of pressure and gravity, and the ship may advance, perhaps broadside on. A keel and a controlling screw speed or a rudder for horizontal steering ought to prevent such; at any rate an attentive hand "at the helm" is required.

As for longitudinal stability—that is, the prevention of a fore and aft motion—it appears to be the most serious problem in this connection. There is less opportunity for experiment, which, with the fact that the fore and aft motion is limited in the aeroplane machine, renders our chances less. A number of things endanger longitudinal stability—the speed of propellers, head winds, sudden shifting of centre of gravity, and rudders. Much has been written upon this part of the subject, but as yet no definite information is at hand. Some advocate a horizontal keel like the fins of a fish, others a judicious manipulation of fore and aft rudders (see Plate 8), an automatic shifting of the centre of gravity, or the speeding of the screws. All of these have objections, and it is hardly likely that the problem will be solved until practical mid-air trials are made. In the Maxim ship with large aeroplane, although there has been no opportunity to make actual tests, it is observed that this stability is preserved in part automatically by the shifting of the centre of pressure, which, with the centre of gravity, forms a turning movement tending to right the ship.

The last requisite, but by no means the least, for the ideal machine is the propelling apparatus. I do not propose to go into this at any length, for it would require much space. All propelling apparatus can be divided into three parts: (1) The propeller proper; (2) the motor; and (3) the agent actuating the motor. Of propellers, there may be three kinds: The feathering paddle, similar to the marine one; the wing or oscillating fin, similar to the flapping birds; and the screw. For obvious reasons, the screw receives by far the greatest attention, and appears to merit it. The screw is capable of marvellous things in the water, and similarly should give the best results in air. To go into the theory of the screw is not the intention here, but the peculiarities of its action in air should be pointed out. The greatest drawback to the efficiency of the air screw is the very great "slip." The tendency is, of course, for the screw to become nothing else than a blower or centrifugal fan, forcing the air backwards. It is imperative that the screw advance upon fresh, undisturbed air, and that it act upon as much of it as possible with the least amount of disturbance. We know that a motion of translation imparted to the screw will decrease its efficiency. We also know that the pressure on the screw blades will vary as the square of the speed, and consequently the efficiency will vary inversely as the speed. The efficiency will vary also inversely as the angle of pitch, and directly as the square root of the area. The thrust of the screw will vary directly as the area and speed. Hence, we may infer that large screws with small pitch and velocity should give the best results. This seems to be correct in experiment, except in the velocity.

As for the motor much also might be written. Three kinds are suggested—the steam, the gas and the hot-air engine, and electric motor. The first may be of two divisions—the ordinary steam engine and the steam turbine. It is toward a suitable motor that, perhaps, the greatest energies have been bent in striving to solve the problem of flight. Success appears to be at present resting on the ordinary steam engine. Electric motors are not yet perfected, and storage batteries are out of the question on account of their weight. Hot-air and gas engines are also too heavy. This leaves us the two steam motors. Much is expected of the steam turbine, but as yet very little progress has been made with it; there is no doubt it will form a most efficient motor for aeronautical purposes. The steam engine forms, then, our most reliable motor. It is a machine which we know much about, and is reliable and powerful, and can be constructed of comparatively small weight. Closely allied with this is the agent actuating the motor—in this case the steam boiler. Research in the steam engine has also included this. It is needless to point out that the boiler must be of special pattern and construction; it must work under high pressure, make steam quickly, use a minimum amount of fuel —liquid, of course—and, like the marine boiler, work equally well in unstable conditions. With the steam plant goes the condensing apparatus, the pump and injector system, and the fuel feeding apparatus, together with the fuel and water storage reservoirs.

In speaking thus far of the propelling apparatus, we have been considering only the conditions affecting a large machine, and we have not paid any attention to the single or individual machine, the parallel of the bicycle—the former may be likened to the railway train. There is no doubt that the time is coming when we will have machines of one-man power navigating the air. The power will probably be supplied by the foot pedal similar to the bicycle, though a man cannot generate more than 0.2 horse power for any time. We may find perfected gas engines of simple construction which, by the aid of chemicals, will furnish small powers for propulsion.

We have now come to the consideration of the progress made thus far in the flying of actual machines. To describe the varying fortunes of these would probably quite comfortably fill a large book. Langley and Hargrave have each designed and successfully flown model machines, but I do not propose to present the principles of these in this connection. I would direct attention to the two great types of machines which are now before the world seeking success, which, it may be said, appears to be not far distant. These are the Lilienthal soaring machine and the Maxim flying machine.

Herr Lilienthal has, since 1890, been performing direct experiments on an apparatus to be attached to the body of a man, by which he is enabled to soar or gently descend from a high elevation to the earth. Previous to that time he had directed his attention to the solution of certain problems of construction and to experimenting upon the supporting power, especially of curved surfaces. During the year of 1893 he attained considerable success with his machine, and astonished the scientific world with his marvellous feats. These were nothing more or less than a gentle gliding downwards against the wind at the least possible angle to the horizon; that is, covering the greatest horizontal distance. Lilienthal believed that the only way to successfully solve the flight problem was to follow a purely tentative method, and having hit upon a simple contrivance of supporting surface similar to that of the soaring bird he proceeded to try his wings, as it were, in a very humble way. He succeeded in soaring downwards on a hillside against the wind, passing only a few feet above the surface. This simple beginning has been the stepping-stone to great things, and he is now enabled to ride long distances on the air in a gentle breeze.

His apparatus consists essentially of three members—the wings, or aeroplanes, a vertical rudder, and a horizontal rudder. The framework is so contrived that the wings can be elevated, lowered, or folded backward. The rudders are manipulated by the operator directly; the horizontal one being immediately behind him, between the wings; and the vertical one further back still. The horizontal rudder serves to act as a sustainer also, and closes the space back of the wings. The operator rests on a cross-arm, between the wings, either by grasping it, or placing it under his arms; in some cases he has arranged a seat. The wings and other sustainers are built of a very fine muslin, washed with collodion to make it impermeable to air, which is stretched on a very light but strong framework of split willow or bamboo. In the apparatus which gave the best results, the wing surface was about 150 square feet, having a total spread of 23 feet, and a width of wing of 8.2 feet. The whole weighed some 44 pounds, which with Lilienthal's weight placed the total at 220 pounds. The concavity of the wings is a point on which he lays unusual stress; it certainly would have been impossible for him to accomplish his feats had the wings been planes. He points to the birds, of course, for his proof. Just here it may be mentioned that Lilienthal was among the first to insist upon the concave sustainer. He was somewhat ridiculed, but of late the experimenters have been looking favorably on it. It is unfortunate that Langley has not given us any data on curved surfaces, but that fact does not signify that he has no belief in their value. The great value of concavity is its power of stability, which is exemplified in the Lilienthal experiments. The sustainers were given a concavity to conform with the parabolic curve so common in the bird.

The relation of weight to surface can be pointed out by reference to the above figures. We see that he sustains in gliding flight alone one pound for every 0.68 square foot of sustainer. This is the same as the tawny vulture previously given, and shows the possibilities to which we may attain.

Herr Lilienthal gives special emphasis to the stability of his apparatus, and no wonder, for we can imagine how little there is between the passenger and a broken head. The framing is very rigid, and when once in the air and gliding forward descent is easy, unless a gust of wind comes to disturb the poise. When anything of that sort happens, requires quick and thoughtful action—a change of the centre of gravity, a movement of the rudders and wings, and that very carefully. The movement of the body—the head, arm, or foot—will suffice to alter the centre of gravity sufficiently to obtain the equilibrium. Lilienthal describes as follows:—"You run down hill against the wind with lowered wings; at the proper moment you raise the carrying surface up a little, so that it is approximately level; and then, springing forward, you try by a proper position of the centre of gravity of the apparatus to give it such an inclination that it will glide along rapidly and drop as little as possible." The legs hanging from below the apparatus are kept well in front, which tends to keep the wings on the wind. This part of the stability is assisted by the horizontal rudder, which prevents the whole machine from tipping forward, a motion which is quite possible with arched wings. In landing, he throws the upper part of the body directly backward, which tilts the wings strongly against the wind; in nature this is most noticeable when a heavy bird, such as a wild goose, alights. The rudders must be so arranged as to not prevent a rapid backward tilting of the machine when landing. Both the starting and alighting must be made dead against the wind, as in the case of birds.

The shifting of the centre of gravity by the movement of the body requires much practice; it must become almost automatic. Lilienthal says a beginner is too apt to move his feet or body to the wrong side when attempting to right the machine. Perhaps the operator soon becomes well used to his position when working against the wind, and he then tries to pass across it. It is here that nothing but practice avails—like bicycle riding. While in the air one has no time to consider just how scientifically he is manœuvreing, but the preserving of his equilibrium obtains all his attention. Altogether, this mode of flight is very much a matter of diligent practice, and success is to be obtained only by failure.

The science of the soaring machine is very simple, being identical with the soaring bird. There is very little mathematics, and that has been all discussed previously.

The greatest velocity of wind in which Lilienthal dared to start was about 16 miles per hour. Of course, the stronger the breeze, the least angle of "aeroplane" and flight will suffice. In a wind of, say, 10 miles per hour he could glide downwards at an angle of 8° with the horizon; in a calm he has even glided at an angle of 10°. In such a case, the wings are very slightly tilted, and he estimates the uplift to be 80 per cent. of the pressure, if normal. He attained about 30 feet per second, so that with a surface of 150 square feet he obtained a total uplift of 260 pounds; whereas all that was necessary was 220. With a wind of, say, 15 feet per second, and a gliding of 8°, the drop would be 2.1 feet per second, or the work by the ideal machine would be 0.8 horse power. Lilienthal is now testing a small steam engine of about 2 horse power, and weighing, all told, 44 pounds. By utilizing this, it will be seen that he will be enabled to accomplish *horizontal* flight against the wind. There are no reports of the trials yet to hand, but there is no doubt that success will be attained.

In Figure 1, Plate 9, is shown an elevation of gliding lines. The course A D was made in a strong wind, and at the culmination the apparatus stood for several seconds inert until the downward course was commenced. This was quite similar to the flight of birds already explained.

During the past few years the eyes of the world have been very attentively fixed upon Mr. Hiram S. Maxim, of Bexley, England. Without describing the events and experiments which led up to the construction of an actual flying machine, I will endeavor to describe some of the salient points of his air ship, which has won for itself such an enviable reputation. So much has been written in the papers and magazines that a detailed description seems hardly necessary, and I will leave the members of the Society to look up the subject, if they have not done so already.

PLATE 9

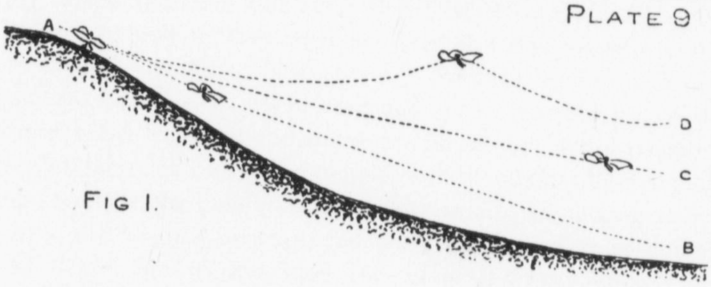

FIG 1.

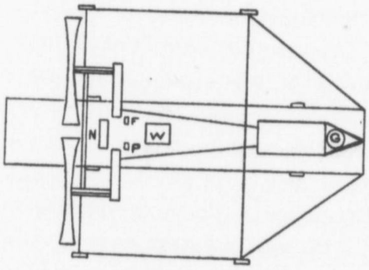

FIG. 2

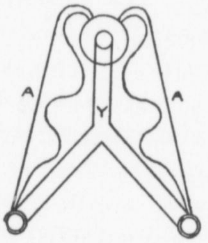

FIG. 3.

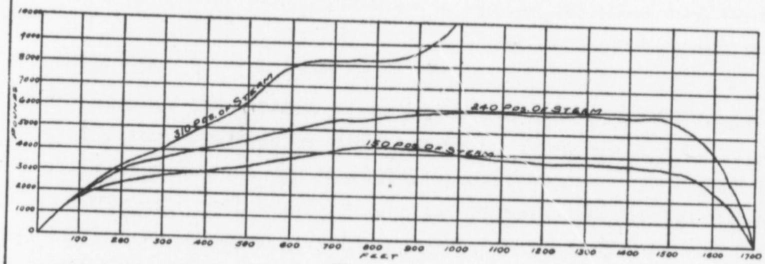

FIG. 4.

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In his extensive park, Mr. Maxim has built a steel track 1,800 feet long, of 9 feet gauge, and outside of this a wooden *inverted* track, which may be known as an outrigger track, of 3 x 9 Georgia pine. It is upon these tracks that Mr. Maxim tests his machine. The body of the machine is a platform about 8 feet wide and 40 feet long, which rests on four steel wheels on the inner track. Upon this platform are mounted the engines, boiler, and all apparatus, together with the supports for the aeroplanes, etc. The main aeroplane is 50 feet wide and 40 feet long in the centre, and about 22 feet above deck. The framework of this is supported by means of hollow steel tube construction, thoroughly guyed and rigid with the deck. Fore and aft of the main plane are the rudders, hinged horizontally, and acting as shown in Figure 7, Plate 8; the forward one being 18 feet wide and 30 feet long, and the aft one 18 feet wide and 23 long. On each side of the whole structure extend side planes or wings for transverse stability, as well as for support. These are hung from the structure near amidships, and are superposed, their longer sides being transverse to the centre line of the machine. As these wings are 27 feet in length, the whole clearance width of the machine is 104 feet, and the total length would be about 93 feet. Aft of all the deck machinery are the propellers. The shafts are about 19 feet apart, are mounted 11 feet above the deck, and are run directly from the engines, which are placed at the same level. The boiler is at the forward part of the deck, and forms a windbreak for other apparatus. On each side of the platform extends an outrigger wheel system, which runs under the *under* side of the outer track, giving a vertical play of the whole machine of several inches. The centre of gravity of the machine is five feet back of the boiler and seven feet above the deck. (See Figure 2, Plate 9, for plan.

The engines are marvels of strength and lightness, weighing themselves only two pounds per horse power. They are a pair of high pressure compounds of one-foot stroke, and pistons of five and eight inches diameter. Each engine weighs 320 pounds, and the two together have exerted as much as 363 horse power, though only for a short time. The cranks on each propeller shaft are placed at 180°. The engines are placed transversely to the deck, the steam pipes being led in at the inner ends, while the propeller shafts are at the outer. Directly below the engines are the feed pumps and reservoirs, the one set for fuel naphtha and the other for feed water. The naphtha reservoir N and pump P supply the liquid fuel to the gasoline boiler G at a pressure of fifty pounds per square inch, being run by a belt from the port engine. In the gasoline tank the naphtha is heated, by products of combustion, to gas, and is fed automatically to the jets of the furnace. The feed water pump F and reservoir W are run by means of the other engine, and force the water into the boiler system at a pressure of about 330 pounds by means of an injector. There is also a device by which the rate of feed can be observed.

Not the least marvellous part of the apparatus is the boiler. It is essentially a water tube boiler of a remarkable type, resembling both the Thornycroft and the Yarrow, but much lighter. Figure 3, Plate 9, shows a diagram in section. The cold water comes in at the outer tubes (A) of the boiler (which form the feed water heater), at a pressure of 330 pounds, or 30 pounds more than that in the boiler. This difference is utilized in forcing the water (then at 250°) down through the steam drum by means of an injector, in which it carries downwards through the down-take Y the heated water in the bottom of the drum. This is carried directly to the heating tubes near the burners, and soon becomes steam. The outside tubes are of pure copper, and are $\frac{3}{16}$ inch inside diameter, and $\frac{1}{80}$ inch thick. The inside or real boiler tubes are also of copper, $\frac{3}{8}$ inch in diameter and $\frac{1}{80}$ inch thick, and are made to stand a bursting pressure of 1,650 pounds per square inch. Maxim says he has been enabled to get a horse power out of three of these tubes. There are about seven hundred tubes in the boiler, aggregating a heating surface of about 800 square feet. The furnace consists of some 7,600 gas burners, burning naphtha gas under a pressure of 50 pounds. Great difficulty was experienced in preventing the jets from blowing out. The boiler has been run up to 410 pounds pressure, but seldom is above 300, at which the engines easily exert 300 brake horse power. The motor requires 600 pounds of water and 200 pounds of naphtha for about one hour's run.

The boiler proper weighs 1,009 pounds, which together with 200 pounds of water inside, and the engines, gas generator, and pumps, puts the total weight of the motor up to 2,040 pounds (not including fuel, feed water, or condensers), with a total horse power developed of 363. The weight per horse power, then, is 5.6 pounds.

Mr. Maxim at first designed an extensive system of surface condensers, which was, in reality, nothing but the interiors of all the hollow tube construction in the flying machine, and most particularly that exposed to the air in the wings and planes.

After considerable testing of different screw propellers, a type was decided upon which appeared to give the maximum thrust with the minimum slip. These screws are two-bladed, 17 ft. 10 in. in diameter, and built of light American pine of the least thickness. The face at the periphery is 5 ft. 2 in. wide, and the pitch 16 feet. They are mounted on hollow shafts of 5 inches diameter, 5 feet long and $\frac{1}{8}$ inch thick. These screws are capable of driving the machine on the rails at 40 miles per hour, with 375 revolutions per minute. Mr. Maxim has estimated that out of the 363.63, 150 horse power is wasted in slip, 133.33 expended in uplift, and 80.30 in overcoming horizontal resistance when running at 40 miles. The horizontal thrust at that rate has been measured at 2,000 pounds, though it may be much greater before starting. On account of the great loss in slip, it is seen that the diameter of the screws is not great enough. Mr. Maxim thinks it should be at least 22 feet, and he is also making alterations in the framework to reduce the loss in resistance from 80 to 30 horse power. He has experienced no difficulty in the fan blower action of screws, for he found that his screws actually *drew in* air at the periphery, discharging it in a longitudinal direction. The first screws he built were of a pitch of 24 feet, which was found to be too great.

The aeroplanes were necessarily very carefully built. They were made of Spencer's balloon fabric tightly stretched upon a framework on both the upper and under sides. The underside was re-stretched a number of times, until it was as tight as a drumhead, and was unaffected by heat or cold. The upper one was not so tight, and permitted a certain circulation of air between. The fabric was lightly varnished with boiled oil. The main aeroplane was at an angle of one in eight in most tests. The upper side planes are hinged to the sides of the main one; whilst the other four on each side are attached to the bracing, one above the other. A very great supporting power is obtained with the side planes, though in the tests there were only several on each side. The total sustaining surface spread in the experiments aggregated 4,000 square feet. All the "aeroplanes" are true planes and not concaved; Mr. Maxim gives no very particular reason for this, though there is no doubt that better results might be obtained with the curved sustainer. He also departs to a certain extent from the teaching of experiment in exposing a very large main plane to the air instead of narrow ones. He claims, however, that one large one is a necessity, for stability's sake, but admits that the "narrow wings are found to be much more efficient than the main aeroplane itself." The rudders are directly controllable by levers at the engineer's hand, and these with the respective throttles of the engines place the steering gear in easy command.

In different parts of the machine are dynamometers for measuring the power exerted. Between the platform and wheels are calibrated springs in connection with a dynagraph, which records the uplift of the whole machine from the track. Indicators on the engines and dynamometers on the shafts record the horse power. There is also a speed indicator.

The weight of the whole machine, with water, fuel, and three men on board, was a little less than 8,000 pounds.

The Maxim machine exemplifies the true flying machine, accomplishing flight by motive power actually aboard, and not depending upon the wind. Mr. Maxim, however, does not wish his machine to be known as a flying machine as yet. He says:—"I don't call this an air ship, or anything else. To me, it is merely a machine for making experiments in aerial navigation." Nevertheless, this machine has actually flown. On July 31st, 1894, it raised itself, not only off the inner track, but from beneath the outrigger track, completely freeing itself. This is the first time any machine has ever actually lifted *itself* free from the earth, and, though an accident, marks an epoch in aerial flight.

No better description of the action of the Maxim ship can be presented than by reviewing the facts of the above accident of July last. Several previous runs had been just made with steam pressures of from 150 pounds to 240 pounds, and the machine was pushed back over the track to the starting place, at the workshop, and was tied up to a post and dynamometer. The screws were set going at an increasing rate, until they attained a speed of 375 revolutions per minute, and were exerting a horizontal thrust of 2,100 pounds. The pump was delivering 5,000 pounds of water to the boiler, and the safety valve was blowing off slightly at 310 pounds pressure. At this juncture the signal was given to let go, and the huge machine, with three men and all apparatus on board, shot forward at a frightful speed of thirty-five miles per hour. The steam was blowing off at 320 pounds pressure, and the speed of the screws increased. Having run about 500 feet, the machine was lifted entirely from the lower rails, and was running on the upper ones, the outriggers bearing all the additional uplift. When this occurred, the machine had lifted its own weight—8,000 pounds—and was really flying. At the 900-foot mark the rear axles (two-inch tubing) buckled, and set their outrigger wheels free, which allowed the aeroplanes to *decrease* their angle of motion, and consequently increase the uplift. Steam had already been shut off, but at the 1,000-foot point the uplift became so great that the left hand forward wheel left the safety track, and immediately afterwards the right wheel crushed the other outrigger rail, and the débris became entangled in the deck. The machine swerved to the right and landed fairly on the ground, imbedding the wheels in the earth, and did not move after it struck which showed that if the machine had been in the air it would have fallen directly.

Figure 4, Plate 9, shows a diagram of the lifting effort for three runs. The diagrams were made with the dynagraphs, and in the last run it will be seen that the pencil ran completely across the paper. The abscissæ show the distance travelled in feet, and the ordinates the uplift in pounds.

Mr. Maxim's device for stopping his air ship on the track is novel. At the end of the run the machine strikes against a series of ropes stretched across the track and connected with capstans in gear with revolving fans. These soon bring the ship gently to a standstill.

Upon the run in which the accident occurred the lift amounted to at least 10,000 pounds, though it could not be measured. The sustaining area was 4,000 square feet; the sustaining power was, therefore, 2.5 pounds per square foot of surface—a fact which is surprising in the extreme, as we have no record of any flying creature of equal capabilities.

The fact that there is now a machine capable of surpassing nature in its *power* to fly or raise itself from the ground compels us to admit that the mechanical considerations, if not already successfully disposed of, are not far from realization. And yet, when we consider the relation of mechanical invention to similar natural machines, the surprise fades somewhat. Man has solved marine navigation in an altogether different method from that provided by the Creator, and he has attained, we may say, greater relative speed, perhaps; at any rate, from the standpoint of power generation, he has surpassed the fishes. So on land. We have seen how the locomotive, the bicycle, and the electric car can surpass any natural means of locomotion, weight for weight. Why, then, is it to be wondered at that we should look for similar success in the other natural element—air?

Nothwithstanding this, however, the consummation of successful flight is still some way off. Man has made for himself a machine with which, we grant, he *may* fly, but it is not to be expected that he will be immediately able to manipulate it. No one would expect even the maker of a bicycle to be able to ride it upon the first trial. The fortunes of a flying apparatus depend on a purely tentative procedure, and in that direction only are we to expect success. Many persons have pointed out a means whereby this may be accomplished. Lilienthal takes a most practical way about it; Mouillard suggests a very similar method; whilst Mr. A. P. Barnett proposes a procedure somewhat like Maxim in riding an aeroplane attached to a bicycle on a level platform. Mr. C. E. Duryea gives us the novel suggestion of tying our machine below a captive balloon, and thus practising. Much might be learned also, theoretically, by the experiments on models by Hargraves. An idea has occurred to me which may also be of assistance in such safe experimenting, especially in our northern countries—that of running a machine such as Maxim's on the ice, similarly to an ice boat. This would greatly widen the field for practice. I have failed to see any similar suggestion, and have been somewhat surprised that it has not been made.

The perfection of aerial flight will come gradually, as did other perfected inventions which have revolutionized the whole world. We cannot look for any one man to thoroughly solve the problem, but it will be evolved from many sources, and these will at last contribute to the one long-desired end. At any rate, the age of blind and unscientific trial is now past; we look to science to solve the remaining part of the enigma, and we no longer expect signal failures of hopeful aviators who, like Icarus, venture too far.

Niagara Falls, Canada,
January 22nd, 1895.

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Jeremiah Head. . —"Locomotion in Air," address British Assoc., 1894.
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J. D. Fullerton . . —"Design of Flying Machines," July, 1894.
William Kress . . —"Theory of Sailing Flight," June, 1894.
F. H. Winston . . —"Secret of Soaring," Oct., 1893.

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J. Bretonnière. . . —"Gliding Flight."
G. C. Taylor . . . —"Gliding or Soaring Devices."
A. M. Wellington . —"Theory of Sailing Flight."
A. F. Zahm . . . . —"Stability of Flying Machines."
Lawrence Hargrave—"Experiments in Flying Machines."
F. H. Wenham . . —"Suggestions and Experiments."
R. H. Thurston. . —"Materials."
C. E. Duryea . . . —"Learning How to Fly."
A. P. Barnett . . . —"Methods of Experimentation."

DISCUSSION.

PRINCIPAL GALBRAITH.—The author is to be complimented on the excellence of his paper. It shows a very large amount of research in connection with a fascinating subject. It was the fashion not long ago to pooh-pooh work of this kind, but lately so many respectable people have taken an interest in aerial locomotion that it is no longer advisable to do so. The older attempts in the construction of aerial ships were based on what might be termed the fish idea. A fish is practically a body floating in a fluid of its own specific gravity, and capable of automatic motion. The former air ships were balloons floating in the air, and propelled by screw-fans. The more modern idea is to imitate the bird, viz., a body heavier than its surrounding fluid, and maintaining flight by utilizing the reaction due to swift motion. One of the difficulties in imitating bird flight arises from the fact that in the bird the supporting wings are also the propellers. In machines like Maxim's, on the contrary, the support is derived from aeroplanes, which are simply set like the sails of a ship, while quickly-revolving and comparatively small fans are depended on to produce the motion. If both functions could be combined in the same organ, there would be great gain in compactness.

MR. DUFF.—Mr. Mitchell has presented to us in a concise and interesting form all that has as yet been accomplished in aerial navigation. I feel that individually, as well as a society, we are greatly indebted to him for such a valuable paper, which will open up for many of us a new and interesting field for thought.

One question which occurs to me, and upon which I have been unable to arrive at any conclusion, is: Would the perfecting of aerial navigation be in the best interests of humanity and civilization? I know of no possible invention which would make so great a change in the life of the individual, or in the customs or organization of communities, as would the successful navigation of the air. The change would be so great that it is impossible to estimate its effects, and that they would be, in the main, beneficial is, to me, very doubtful.

However, it is a question which we need not as yet consider seriously.

Though much progress has been made in the construction and operation of flying machines, the greater part remains to be accomplished. The danger from sudden squalls, the necessity of moving at a high velocity, the uncertainty of the sustaining force, and, above all, our profound ignorance of the real course of air currents, seem to indicate that the successful operation of a flying machine is far more difficult than its construction. Icarus made himself wings, but he flew too near the sun and the wax melted. Maxim may build an air ship, but can he sail it? Bret Harte has a very amusing poem on this subject, entitled "An Aerial Retrospect," in which he describes his boyish attempts and experiments in ballooning, kite-flying, etc., and, amongst other things, how he

> "Launched from attic tall,
> A kitten and a parasol;
> And watched their bitter, frightful fall."

With the permission of the Society, I will read a short extract from the *Popular Science Monthly*, which explains itself.

AN EARLY DREAM OF AIR SHIPS.

"An essay by Roger Bacon, published in 1618, has been brought to attention by M. de Fonvielle, which contains dim predictions of steam power and the navigation of the air. 'Instruments,' the author says in this essay, 'may be made for navigating, without any men pulling the oars, with a single man governing, and going quicker than if they were full of pulling men . . . Wagons can also be made that, without any horse, they should be moved with such a velocity that it should be impossible to measure it . . . It is possible also to devise instruments for flying, such that a man being in the centre of revolving something by which artificial wings are made to beat the air in the fashion of birds . . It is also possible to devise instruments which will permit persons to walk on the bottom of the sea . . . All these things have been done in old times and in our times, except the instrument for flying, which I have not seen, and I have not known any man who saw it done.'"

MR. EDGAR J. LASCHINGER.—Mr. Mitchell, in his admirable paper on "Aerial Mechanical Flight," has opened up a field for wide and varied discussion.

Aerial navigation, the art of holding in subjection the powers of the air, of exercising perfect control over the motions of apparatus resting upon, and gliding over, its invisible yet sure support, has to this day existed only in the vivid dreams or pictured imaginations of its devoted disciples.

To navigate successfully, the mariner must adequately understand not only his vessel as to its capabilities, strength, and power, but also his ship's native element, the ocean, in its various moods and aspects, so that he may adapt the one to the other under all its varying conditions, with safety to himself and profit to the world at large.

Faith *grows* with knowledge, and knowledge with experience, aided by observation and reason; but practical demonstration *begets* faith, reason or no reason. The generality of mankind has no faith in aerial navigation, because no practical demonstration has been presented; on the contrary, the subject has been, and is, greatly ridiculed because of the many unsuccessful attempts by disciples of false doctrines of the art and disastrous consequences to ignorant, short-sighted, and reckless devotees. Although the subject has now for some years engaged the attention of scientists, very little is known either of the action of the air on the supporting surfaces of birds, which afford us our only successful models at present; and in spite of eighty years of history of ballooning, the laws governing the motions of our aerial sea, with its billows, currents, and counter-currents, are not understood.

The sciences of anemometry and aerodynamics being thus in their undeveloped state, principles are advanced with trepidation, and most of them lie in the realm of conjecture; this dearth of reliable data precludes the manufacture of any machine with a reasonable expectation of approaching success. The tentative method pursued by Herr Lilienthal is therefore commendable, and lies on the highway to success if supplemented by the application of experimentally determined data and established principles.

Since rapid locomotion on land has been affected by a departure from nature's methods, and since the screw propeller has no analogue in all her wide domain, the problem of aerial navigation will, in all probability, require, for its ultimate successful solution, instruments of propulsion, or even sustentation other than wings, but learners should study objectively.

Many theories have been advanced to explain bird flight, more especially soaring flight, which the bird accomplishes with such grace and ease, but which presents a harder problem and darker enigma than the quick, complicated actions of flapping flight, so tiring to the bird. No two theorists agree perfectly, but the following statement is fact: *an aeroplane absorbs energy only from a variable wind.* In a theoretically steady breeze (no wind is absolutely uniform either in velocity or direction), the necessary change of wind velocity acting on the surface may be obtained by changes in direction of flight, such as "circling," etc., to the formation of "relative squalls."

The amount of energy absorbed from a variable wind increases with the mass and spread of the plane, large, heavy planes being much more efficient than small or light ones. The shape of the plane also greatly affects the amount of energy transferred from the wind to the plane, more especially where the plane is much inclined to the direction of the wind. Prof. Langley has also pointed out that the *power expended during flight decreases as the speed increases*, which is surely a revelation, and appears paradoxical, as was pointed out in the paper. His experiments also furnish data by which we can show the strikingly analogous action exerted by planes on water and air, respectively.

The pressure on a plane disposed at right angles to the current is obtained theoretically by assuming it produced by the destruction of the momentum contained in the mass of fluid that would, if unhindered, pass through the boundaries of that plane per second.

$$P = mv = \frac{Wv}{g} = \frac{Av}{V} \cdot \frac{v}{g}$$

$$= \frac{Av}{\frac{RT}{p}} \cdot \frac{v}{g} = \frac{Ap}{gRT} \cdot v^2$$

When

P = pressure in pounds.
M = mass of air reacting.
W = weight " "
g = acceleration due to gravity.
V = volume of a pound of air.
T = absolute temperature of air.
p = barometric pressure reduced to pounds per square foot.
R = a constant for air.
A = area of plane.
v = velocity of current.

Assuming ordinary values for the quantities,

$A = 1$ sq. ft., $p = 14.7$ pds. per sq. in., $T = 62° + 461°$.
$g = 32.19$, $R = 53.2$.

We have

$$P = k \times 0.00235 v^2$$

when k is a correction co-efficient applied because the assumed conditions do not obtain exactly. From Langley's experiments on air we take the average result,

$$P=0.00153v^2$$

$$\text{and } k=\frac{153}{235}=0.615$$

which is practically the same co-efficient as that experimentally determined for water. Seeing that these results are so nearly identical for the two cases, let us consider the aeroplane as the vane of a turbine or centrifugal pump, and anticipate a like action of air on this surface as that of the water on the vane. The pressure acting on the surface depends upon the mass passing per second, and the angle through which its motion is deflected by the resisting surface. Since the aeroplane is stationed in an unlimited stream, the mass acting is governed by the size of the plane and the configuration of its boundary, while the effective pressure per unit of mass of fluid depends solely upon the angle of deflection; the efficiency of the whole system of transmission of desirable pressure depends upon the shape, which should have a smooth curvature to avoid sudden changes of direction, because a fluid as mobile as air is easily thrown into energy-absorbing whirls.

This theory, however, when applied to air, may need essential modification, since air being perfectly elastic and easily compressible the effects of impact, instead of being harmful, as in the case of water, may, when properly applied to fitting apparatus, become of immense utility, and form an essential feature of the future flying machine.

In calling attention to the statements regarding the Maxim motor, it is clear that a mis-statement has crept in. The heat required to furnish 300 horse power per hour, assuming a thermodynamic efficiency of 15 per cent., and 42.5 thermal units per minute as the equivalent of one horse power, is

$$\frac{300 \times 42.5 \times 60}{0.15}=5,100,000, \textit{ B.T.U.}$$

The total heat above 32° F. of 1 pound of steam at 320 pounds gauge pressure is 1212.5 thermal units, and the heat supplied per hour is

$$1212.5 \times 600=727,500 \textit{ B.T.U.},$$

or only about 14 per cent. of the amount required to produce that power.

Further, also, 200 pounds of naphtha, assuming that 15,000 thermal units of heat are received by the water per pound of combustible consumed, would furnish only 59 per cent. of the heat required to produce the power.

Attention might also be directed to the marvellous inefficiency of the Maxim machine as a whole, only 80 out of a total output of 363 horse power being useful as a transporting agent—efficiency, 22 per cent.

MR. MITCHELL.—With reference to the point raised by Mr. Laschinger as to the six hundred pounds of water required by the Maxim boiler for an hour's run, I may say that the present wording was due to a misconception on my part. The statement should have read: "The motor requires 600 pounds of water and 200 pounds of naphtha for an ordinary run." As a matter of fact, the Maxim engine at 300 horse power is calculated to use some 5,000 pounds of water and 300 pounds of naphtha for one hour's run.

HIRN'S ANALYSIS OF HEAT DISTRIBUTION IN THE CYLINDER OF A STEAM ENGINE

EDGAR J. LASCHINGER, B.A.SC.

Watts' original improvement on the "atmospheric engine" of Newcomen consisted in condensing the working steam in a separate vessel, and not in the cylinder itself. He knew that a tremendous amount of heat was wasted by allowing steam from the boiler to enter the cylinder which had the moment before been chilled by a cold-water injection, this loss occurring at every stroke, and he, therefore, provided a separate condenser, and arranged a mechanism whereby a communication was opened with the cylinder during the return stroke of the piston. His other improvements of excluding the air from the upper end of the cylinder by covering it and introducing steam to force the piston down, making the cylinder double-acting, using the expansive power of steam, changing reciprocating into rotary motion, etc., all followed in quick succession.

G. A. Hirn* seems to have been the first one to call attention to the fact that the walls of the containing vessel, even though not in direct contact with the cold condensing water, exercised a very great influence upon the action of the steam in its passage through the cylinder. He made experiments on an actual engine, and the results calculated from data thus afforded showed that this action is inimical to conditions of economy; so he immediately set about to study more closely this phenomenon, in order to determine means of decreasing the loss. In this work, Hirn was assisted by Hallauer, Leloutre, and others, reports and discussions being published from time to time in the "Bulletin de la Societe industrielle de Mulhouse." Professor V. A. E. Dwelshauvers-Dery, of Liege University, investigated more fully this complex action of the steam, and deduced formulas, so that with data obtained from certain measurements the "heat exchanges" between the walls and the working fluid during a complete stroke of the piston could be traced. The attention of engineers and men of science was now strongly attracted to this subject, and much experimental work has since been done. Chief among those who have furnished important facts and additions are Prof. Zeuner,[*] Major English,[†] and Mr. Bryan Donkin.[‡]

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*Hirn's first publication of his theory appeared in 1855.

Without entering into speculations (which is beyond the province or scope of this paper), the action going on in the interior of the cylinder of an ordinary steam engine may be briefly described as follows:

Steam, saturated or slightly wet, is admitted at the beginning of the stroke into a space enclosed by metallic walls, a space that had the instant before contained vapor of a much lower pressure and temperature, the exhaust of the previous stroke; thus a part of the entering steam met by chilling surfaces is rapidly condensed, the water of condensation covering them as a film, or whirling about as mist with the eddying currents of steam. During all this time the walls have steadily abstracted heat from the steam.

Now, however, the admission valve closes, and as the piston travels forward the steam enclosed completely begins to expand, and as it expands its temperature rapidly falls with the decreasing pressure, so that the walls are now hotter than the fluid, consequently heat travels from them to the interior, the water on the surfaces evaporates, and this new-made steam does work by augmenting the pressure acting on the moving piston. During expansion, therefore, heat travels from the walls to the fluid.

Near the end of the stroke the exhaust valve opens, and the steam finds relief either to a condenser, a low-pressure cylinder, or to the open air, as the case may be. The steam escapes at a low pressure and temperature during the return stroke, and the walls, still being very hot, an energetic exchange of heat goes on, the water on these interior surfaces being converted into steam. During the process of exhaust, therefore, there is a serious waste of heat, because the steam made by the heat absorbed from the walls is incapable of performing any positive work on the piston.

When the exhaust valve closes near the end of the return stroke, the steam enclosed is compressed in the space behind the piston, and its temperature rises; during this operation, therefore, the walls, rendered cold by their long exposure to the exhaust, may receive heat from the steam, but, unless the compression is considerable, the exchange of heat in this case is very slight and of little account.

The end of the stroke is now reached, and on admission a new cycle of operations similar to the one just described begins again.

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[*] Zeuner's Thermodynamik.

[†] Transactions Institution of Mechanical Engineers, September, 1887.

[‡] Transactions Institution of Civil Engineers, Vols XCVIII., C., and CXV.

Tracing now the effects of the exchanges of heat for one complete stroke: During admission, the pressure is practically that of the boiler steam, but owing to condensation due to the heating of the walls more steam enters than is necessary to do the work; while expansion is going on, part of the condensed steam is re-evaporated, and thus increases the pressure, doing work; during exhaust, all the heat contained in the water present at release, together with all the heat furnished by the walls to evaporate that water, is absolutely thrown away.

The steam engine is a prime mover, using heat as the available and convertible energy, and is now treated as a heat engine by all investigators. The true method of engine testing is by heat measurements, and since the cylinder is the only essential part of the machine, thermodynamically considered, attention confined to it alone includes all that is necessary for a perfect knowledge of its efficiency as a converter of heat energy. As a Hirn's analysis includes a knowledge of all the quantities necessary for a complete test, it has been very appropriately called by Gustav Schmidt, "The calorimetric method of engine testing."

The data to be obtained for such an investigation consists of:

(1) Measurement of steam supply and its quality, to obtain the total heat furnished; this includes steam used in the jackets, if there are any.

(2) A record of the cycle of operations going on inside the cylinder; obtained by taking the indicator diagram.

(3) Observations to determine the heat rejected; by measuring the condensing water used, observing its temperature before entering and on leaving the condenser, and taking the temperature of the condensed steam. The heat dissipated from the cylinder externally is included under the head of heat rejected. In an engine with steam jackets, this loss is obtained by observing the amount of condensation taking place in them when the engine is at rest.

In Fig. 1, which represents the indicator diagram, the events of the stroke are designated as

(0) Representing the point of admission.
(1) " " cut-off.
(2) " " release.
(3) " " compression.

and the parts of the stroke as

(*a*) representing the admission,
(*b*) " expansion.
(*c*) " exhaust.
(*d*) " compression.

p_0, p_1, p_2, p_3, represent the pressures of the steam at the points indicated.

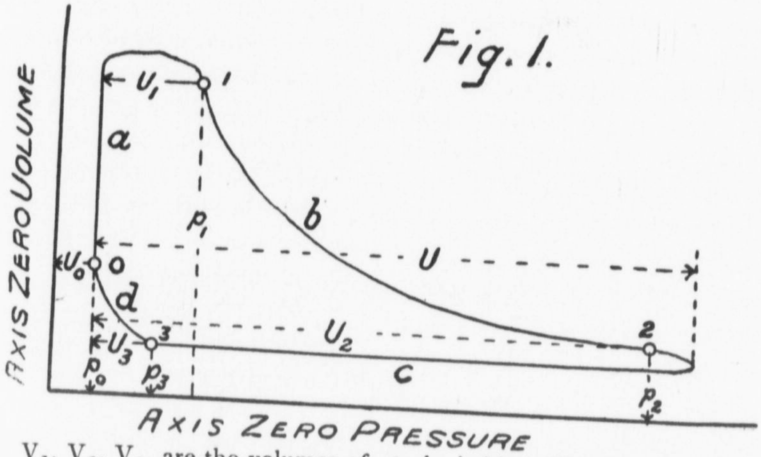

Fig. 1.

V_1, V_2, V_3, are the volumes of stroke behind the piston at the principal points in the cycle. Since there is no pre-admission shown on this diagram, the volume V_0, at admission, is identical with that of the clearance which is the space behind the piston when at the back end of its stroke.

Let W_a, W_b, W_c, W_d, be the absolute work done during the different parts of the stroke.

I_0, I_1, I_2, I_3, are the intrinsic energies of the fluid in the cylinder at the several points.

Now, let Q_a, Q_b, Q_c, Q_d, represent the heat exchanges between the working steam and the walls.

Applying the theory of the conservation of energy—

$$Q_a = I_0 + Q - I_1 - AW_a \tag{1}$$

when Q is the total heat brought in by the working fluid and AW_a is the heat equivalent of the work done during admission, A being the reciprocal of the mechanical equivalent of heat.

$$Q_b = I_1 - I_2 - AW_b \tag{2}$$

$$Q_c = I_2 + AW_c - Mq_4 - G\,(q_k - q_i) - I_3 \tag{3}$$

when M is the weight of the working fluid, and q_4 its heat of liquid corresponding to t_4, the observed temperature of the condensed steam; G is the weight of condensing water, and q_k, q_i, the heats of liquid corresponding to the temperatures t_k, t_i, of the water on leaving and entering.

$$Q_d = I_3 + AW_d - I_0. \tag{4}$$

Now Q, the heat supplied by the working fluid, is found from the equation

$$Q = M\,(xr + q) \tag{5}$$

when x is its quality, and r and q the heat of vaporization, and heat of liquid corresponding to its observed pressure p.

If the steam is superheated

$$Q = M\,[r + q + c_p(t_s - t)] \tag{6}$$

when t_s is the observed temperature, and t that corresponding to its pressure; $c_p = 0.4805$ the specific heat of superheated steam.

Now

$$I_0 = M_0(x_0 n_0 + q_0) \tag{7}$$

$$I_1 = (M + M_0)\,(x_1 n_1 + q_1) \tag{8}$$

$$I_2 = (M + M_0)\,(x_2 n_2 + q_2) \tag{9}$$

$$I_3 = M_0(x_3 n_3 + q_3) \tag{10}$$

where x with the reference subscripts represents the quality of the steam at the points, n refers to the internal heat of vaporization, and q the heat of liquid corresponding to the pressures as taken from the indicator diagrams. M_0 is the weight of steam compressed, which is not known.

We have also

$$V_0 = M_0(x_0 u_0 + v) \tag{11}$$

$$(V_0 + V_1) = (M + M_0)\,(x_1 u_1 + v) \tag{12}$$

$$(V_0 + V_2) = (M + M_0)\,(x_2 u_2 + v) \tag{13}$$

$$(V_0 + V_3) = M_0(x_3 u_3 + v) \tag{14}$$

u refers to the change of volume which one pound of water, volume v, undergoes when converted into saturated steam, volume s.

Now, since we have four equations and five unknowns, it is necessary to make an assumption in order to arrive at a result. For this purpose we may suppose, for the case of considerable compression at a low speed (a case rarely met with)

that $x_3 = 1$

$$\text{then } M_0 = \frac{V_3}{u_3 + v} = \frac{V_3}{s_3} \tag{16}$$

In other cases assume $x_0 = 1$

$$\text{then } M_0 = \frac{V_0}{u_0 + v} = \frac{V_0}{s_0} \tag{17}$$

$$\text{also } x_1 = \frac{V_0 + V_1}{(M + M_0)u_1} - \frac{v}{u_1} \tag{18}$$

$$x_2 = \frac{V_0 + V_2}{(M + M_0)u_2} - \frac{v}{u_2} \tag{19}$$

$$x_3 = \frac{V_0 + V_3}{M_0 u_3} - \frac{v}{u_3} \tag{20}$$

The intrinsic energies and the dependent quantities Q_a, Q_b, Q_c, Q_d, then become known. These are all assumed as positive in the equations, but if heat given by the steam to the walls is called positive heat furnished by them will be negative, and the quantities expressing that heat will appear in the result with a minus sign.

The only defect in this method of investigation as presented lies in assuming the steam dry, either at compression or admission. Observations, however, have shown that the assumption is practically true. Dwelshauvers-Dery calculates the heat rejected from the cylinder due to the action of the walls by making it equal to the internal heat of vaporization of the water in the cylinder at release,* thus assuming the steam caught at compression as dry; and he says that calculations thus based agree with actual measurements within the limits of experimental error.

As a check on the results, however, the following equations are applied

$$W = W_a + W_b - W_c - W_d \tag{21}$$

where W is the indicated work

$$Q_e = Q_j + Q_a + Q_b + Q_c + Q_d \tag{22}$$

$$Q_e = Q + Q_j - G(q_k - q_i) - Mq_4 - AW \tag{23}$$

Q_e is the heat dissipated from the cylinder by external radiation, and Q_j is the heat furnished by the jackets.

By combining equations (3) and (23) we obtain

$$Q_c = I_2 - I_3 - Q - Q_j + Q_e + A(W + W_c) \tag{24}$$

in which case the quantities depending on the condenser do not appear.

Since a graphical representation always gives a clearer view of the relative proportion of quantities than a mere statement, or an array of figures, Diagram No. 2 is drawn to show the results of a Hirn's analysis of the Brown engine in the School of Practical Science. The heat quantities are plotted as areas on equal bases, and their heights, therefore, represent their relative values. The engine is 50 horse power nominal, 12-inch cylinder, 30-inch stroke, 86 revolutions per minute. Fig. 3 is a copy of an average indicator card. Exhaust takes place practically at the end of the stroke, there is very little compression, and steam is cut off at 8 per cent. of stroke, the steam then being 32 per cent. wet, while at exhaust, owing to cylinder re-evaporation, there is present only 21 per cent. of moisture. Though the time of admission is so very short, still the heat lost by the entering steam is very great, showing how very rapid and energetic the interchange must be.

The item of chief interest is the heat rejected by the walls during exhaust, the magnitude of which Hirn proposed as a measure of the performance of an engine, but, as Prof. Peabody† points out, this is an unjustifiable use of that quantity.

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*Proceedings Institution of Civil Engineers, Vol. XCVIII., 1888-89.

†Thermodynamics of the Steam Engine, p. 192.

The hurtful influence exerted by the walls of the cylinder is due to the fact that they are of metal, which, being a good conductor of heat, the part in contact with the steam absorbs energy at the beginning, and parts with it during the latter part of the forward stroke, and all through the return stroke, thus acting simply as a vehicle of unconverted heat. A series of experiments carried on by Bryan Donkin, jr., show that only a certain depth of metal is affected, and for uncovered cast-iron walls one inch thick this "periodic portion" was found to be $\frac{2}{5}$ inch deep, steam being introduced at 48 pounds per square inch pressure, at 35 revolutions per minute. The outside metal remained at a constant temperature. When working condensing, there was a very slight increase in the depth the temperature fluctuations penetrated. Were it possible to have a cylinder and piston constructed of absolutely non-conducting materials, presumably there would be no initial condensation of steam.

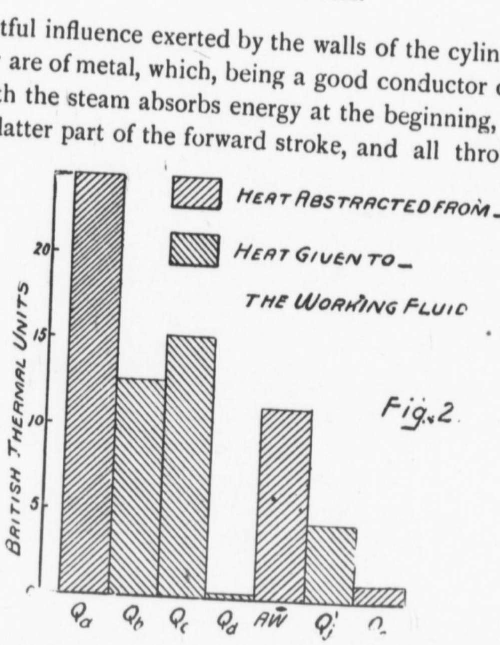

Fig. 2.

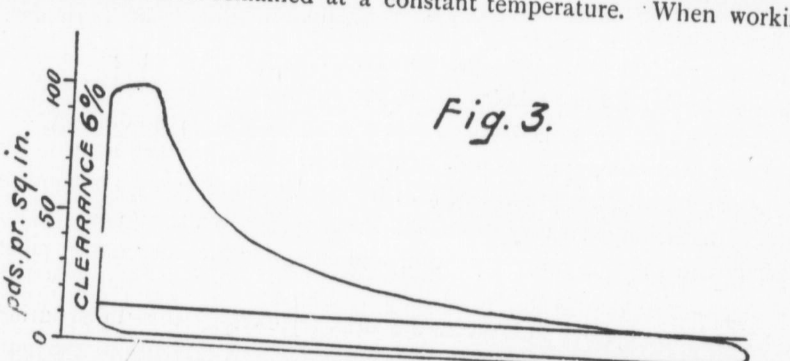

Fig. 3.

There are three methods of increasing the thermodynamic efficiency of an engine, in so far as it is affected by the material of the cylinder:

(1) By superheating the steam supplied.
(2) By jacketing the cylinder with steam.
(3) By increasing the rotative speed.

If the entering steam were sufficiently superheated, there would be no initial condensation, and therefore the steam being dry at release, "water, that powerful vehicle of heat," being absent, and dry gases (of which superheated or dry steam is a type) absorbing heat but very slowly and indifferently from heated surfaces, very little heat would be carried off.

Steam-jacketing induces a flow of heat from the outside to the interior of the cylinder walls, and decreases the thickness of the periodic portion, consequently there is less initial condensation, and, if sufficient heat penetrated, the interior surfaces would be dry at release, and practically no heat would be rejected by them during exhaust.

Since the heat absorbed by a body varies with the time of contact with the source of heat, it is plain that the shorter the time of communication the less heat is transmitted, and the greater the speed the less the depth the temperature fluctuations will penetrate the walls, and the less heat exchanged. The walls may in this respect be looked upon as a kind of heat pendulum of ample capacity swinging between the limits of the temperatures of admission and exhaust. This pendulum takes a charge of heat from the entering steam, proportional somewhat to the time of contact, swings with its freight to the exhaust temperature, and discharges heat as long as it is allowed to remain in contact with the issuing steam. Mr. Willians* made many careful experiments which prove conclusively that, within the limits of his engine trials (maximum speed 400 revolutions per minute), economy resulted, and, according to Dwelshauvers-Dery's calculations on those tests, the heat exchanges were all greatly decreased with increased speeds.

Other considerations beside those of thermodynamics, however, limit the application of the methods of increasing economy just stated, but a statement and discussion of their practical value, more especially in the many specific and widely varying uses to which steam engines are put, is waived in this presentation.

Engineering Laboratory, School of Practical Science,
Toronto, Jan. 24th, 1895.

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* Proceedings Institution Civil Engineers, Vol. XCIII., 1888.

THE VENTILATION OF SEWERS

By W. F. Van Buskirk, A.M. Can. Soc. C.E.

Sewer ventilation has received much attention in many works on sanitary engineering; therefore I do not propose going into an extensive history of the subject, nor to weary you with a long list of chemical smells. Smells may be very nice in the laboratory, but I must confess that I do not appreciate them in a sewer, and generally keep out of their sphere of influence as much as possible.

Were it possible to put in house connections, plumbing, and fixtures that would remove the household wastes, and at the same time prevent admission to the house of any gases or contaminated air from the sewers, the necessity for ventilation would not exist, and the much-abused manhole grating would be banished from the streets. This is becoming recognized as an impossibility in practice, however, and the shallow **S** trap of the text-book, whose only fault was that it sometimes refused to swallow a dishcloth, is in danger of losing its reputation as a defender of the household. It will, no doubt, be some little time yet before our old friend is returned to its proper station in society. It was only the other day that I discovered a touching example of architectural faith in the old S trap. Cellar drains with gratings in floor at upper ends were shown on plans as discharging into house drain on sewer side of cut-off trap.

The best modern practice aims at making sewers so perfect in alignment and grade that sewage will be kept moving at a nearly uniform rate of flow from the house drain to the main outlet, without depositing solids in any part of the system, and will reach the outlet before decomposition sets in.

Owing, however, to the impossibility of making perfectly smooth joints, etc., and of maintaining a uniform depth of flow at all times, a certain amount of the solids in suspension will be deposited in the system; and when decomposed or partially dried upon the walls of pipes will form gases, and impregnate the air with bacteria.

To mitigate this evil, flushing at frequent intervals and the admission of large quantities of fresh air to the sewers must be resorted to.

Automatic flush tanks located at the heads of all branch sewers liberate large volumes of water at once, filling or nearly filling the smaller-sized sewers and scouring the walls and bottoms of pipes. The air in front of these volumes of water is, of course, forced out at manholes, etc., and fresh air is drawn in through all openings both in main sewers and house systems immediately in rear of them. It will be seen, therefore, that unless fresh-air inlets are provided on sewer side of cut-off traps on house drains, the seals of traps will be broken, and a clear way will be provided for foul air and bacteria from street mains to interior of houses.

Exactly similar action takes place in each house system whenever a large quantity of water is discharged from a fixture, so that it is necessary to provide ventilators for the admission of air upon the sewer side of all traps in use. These ventilators should all be carried above roof line, since they will both admit and discharge air with every change in density of air in pipe system. Manholes with perforated covers will, if built at short intervals on line of sewer, admit and discharge a sufficient amount of air for ventilating purposes; and as they are generally located in the centre of streets at intersections are far enough removed from dwellings to prevent any injurious contamination of air.

It is important that any deposit on the walls of sewers be not allowed to dry before removal by flushing, for the reason that the number of bacteria and their spores that can be taken up by air from dried sewage is much greater than that from sewage in the liquid state.

In order to prevent deposits becoming at all dry, flush tanks should be timed to discharge after the period of maximum daily flow, since it is not advisable, owing to the large quantity of water required, to discharge them more frequently than once in twenty-four hours.

I am aware that my contention in regard to the danger of disease germs being carried by sewer air is at variance with the opinions of many engineers; but, on the other hand, I am supported by the great mass of the medical profession, whose opinions are worthy of consideration, although they are much inclined to blame "sewer gas" for "all the ills that flesh is heir to." In the discussion of this question, engineers generally have in mind sewers of the most approved construction, accurate grades and alignment, smooth walls, etc.; while doctors have in mind the sewer as it unfortunately is in many cases. As an example of the article which the doctor has in mind, I quote the description of a sewer recently examined by me:—

"A badly-constructed, foul-smelling stone box drain, located below the centre of the roadway, and having its outlet in the heart of the business part of the town.

"The box drain is constructed of stone, with open joints, has rough flag top and bottom, is two feet wide, and two and one-half feet deep, but is now nearly half filled with gravel and dirt. This drain is connected directly to cellars, sinks, etc., without traps, and has no openings for ventilation, and is never flushed except by heavy rainfalls."

Another, not in the same town:—"A ten by twelve box, made of two inch oak plank, no bottom; side planks kept in place by means of short lengths of two-by-four plank nailed to lower edges. This sewer is connected to wooden box street gullies without traps, and to many cellars, water closets, and sinks."

Who will say that disease germs cannot escape from these "sewers"? Our friends, the physicians, have many cases on record in their numerous periodicals and reports which, upon examination, will convince almost any one that diseases are communicated by sewer air.

The want of a reasonable explanation as to the manner in which the organisms are carried from one point to another has been the stumbling-block in the way of engineers. The recent experiments with the bacilli of typhoid fever performed by David Arthur, M.D., King's College, London, will, I think, go far towards removing this block. After describing several experiments in a report to the recent sanitary congress, he says:—"This, in my opinion, is one of the principal ways sewage microbes find access to sewer air. The bacteria of the sewage may creep like those of typhoid up the walls of the damp nutrient sewers, so that they may be literally alive with them. Moulds here also grow with great proliferation. In their struggle for existence they will often be covered with bacteria, and in shooting forth their spore stalks must carry some bacteria with them. When the spore stalks are sufficiently long to project from the damp sewer walls, and have become ripe for dissemination, the clinging bacteria and their spores will become liberated, mould spores and bacteria and their spores will be wafted with every air current; many will gravitate to the sewage, others will stick to the damp sewer walls, others will be carried up the ventilators to the outside air, while others, again, may gain access to dwelling houses."

I am strongly of opinion that all wastes known to contain germs of contagious or infectious diseases should be burned immediately, and should in no case be discharged into sewers.

This precaution will not, however, make it any the less necessary to attend to the proper cleansing of sewers, as it will be found impossible to destroy by fire more than a very small percentage of the disease germs ordinarily reaching the sewers.

Stratford, Ont., January 10, 1895.

DISCUSSION.

MR. W. L. INNES.—Recently a very important sanitary case was argued in Peterborough. The town wished to discharge its sewage into the Otonabee River, and the townships farther down the river objected.

Some of the greatest sanitary engineers, bacteriologists, and chemists of Canada and the United States gave evidence, and the question was thoroughly threshed out.

To me one of the most startling announcements was that "sewer gas is remarkably free from bacteria"; that whatever other poisonous gases it contains, it is rarely a carrier of disease. I may have carried away an incorrect impression, but have simply stated what I believe was given in evidence before the court of arbitration.

THE CLEANING AND ANNEALING OF CASTINGS

H. L. McKinnon, '95.

The manufacture of iron is perhaps one of the simplest and oldest processes in existence, and yet the best grades of iron and steel in use at the present time require exceedingly great care and a thorough knowledge of the chemistry and metallurgy of iron and its ores in order to produce them.

History shows that for more than three thousand years human ingenuity has been at work on this metal, endeavoring to make it fill a place in the economy of man.

The first attempts were crude indeed. Imagine, if you can, a pit dug in some side hill and then fuel piled in and kindled, then ore and more fuel, and this kept up long enough to reduce the ore to a comparatively pure state; and, next, if you will go and examine some elaborately arranged smelting apparatus and compare the methods.

To examine into the reasons for these developments is scarcely within the scope of this paper, but I would like to drop a suggestion here, namely, that the luxuries of one generation become the necessities of the next. For example, in the early ages articles manufactured of iron were of necessity few, but as they became more common they might be regarded as essential.

While all men were only armed with bows and arrows a gun might be regarded as a luxury; but when one body of men came to battle armed with guns and protected with coats of mail and iron helmets, and met others who were still only provided with their bows and arrows, these latter might well consider that the guns and coats of mail were necessities which they could no longer afford to do without. Thus we see that as time rolls on new uses are found for this, the most useful of all the metals, and as a natural sequence it rapidly rises into commercial importance.

Iron is, with the probable exception of aluminium, the most widely distributed of all the metals. It occurs in a great variety of forms known as its ores, which contain, besides iron, quantities of oxygen, carbon, silicon, phosphorus, manganese, and sulphur, along with many other substances. The separation of iron from its impurities is accomplished by the process known as smelting, which consists essentially in roasting the iron in a stream of air or oxygen.

The immediate product of the smelting furnace is known as pig iron, and the particular brand of pig designates generally the proportions in which carbon, silicon, etc., are contained in it.

From various mixtures of the brands, all the cast iron in use is made by the process known as casting, with which we are all more or less familiar.

It is to the treatment of gray and white iron castings, between the time of casting and the time at which they are ready for use, that I wish to call your attention this afternoon. It has occurred to me that the processes used to change both the physical and chemical properties of iron castings would be of interest to engineering students. Many foundries simply brush the dirt from their castings, chip off fins and sprues, and then they are ready for use. For many purposes, and, in fact, for the greater part of the castings made, that is all that is necessary, but for mechanical and other reasons the above process is far from producing the castings in the condition frequently required. In foundries doing small work, or on castings which require to be cut with machine tools, we find that the practice is becoming more prevalent of changing the character of such castings by processes known as pickling, annealing, and rolling. Such foundries should be provided with a cleaning room, which should contain a pickling vat, washing vat, rolls, and an annealing oven.

The pickling vat is made like an open-topped wooden tank, inclined a little toward an opening in one end. The sides and bottom are lined with sheet lead, in order that it may not be affected by the sulphuric acid. The process is simple, consisting of covering the castings with a dilute solution of sulphuric acid, and allowing it to act until the sand, dirt, etc., peels off quite readily. The acid is then drained off into another similar tank, from which it may be dipped and used over again. The castings are washed in water, so as to remove the acid and scale mentioned above, after which they are dried. Where I saw this process in operation, the solution was composed of about two parts of water to one of commercial acid. The action seems to be that the acid attacks the metals, and in taking it away loosens the sand, etc., which has been set in the outside of the casting. This process is always attended by the loss of the outside crust of the iron, but in many castings strength is a secondary matter, as compared with a smooth and clean surface. Again, the removal of the outside crust is of advantage in castings used in motors and dynamos, due to electrical and magnetic considerations. We may take it as a general principle that soft iron is more suitable for electro-magnets than hard iron, so that by removing the hard crust we decrease the magnetic resistance.

The rolling process is one much used to give a smooth finish to castings. The most common method is to put the castings in metal cylinders, or barrels, of various sizes, commonly from three to four feet in length, and from eighteen to thirty-six inches in diameter, along with some chippings, sprues, and small scraps. The barrels are filled a little more than half full, and rotated at a moderate speed, about from twenty to fifty revolutions to the minute, the speed depending on the weight of the castings and on the size of the rolls.

Several kinds of rolls are used, those which I had the privilege of examining being made as follows: Two circular cast-iron heads were mounted on a shaft about two inches in diameter. At the outside of each of these there was a flange extending all the way round, and in these flanges bolt holes at regular intervals around the circumference. The sides of the rolls consisted of cast-iron staves about three or four inches wide, which were fastened to the heads by means of bolts passing through the flanges.

Emery powder and sawdust are materials sometimes used in rolls, the first to help wear away the surface, and the latter to prevent castings from wearing rapidly away or striking each other heavily.

Some of late have turned their attention to water-tight rolls. These have also metal cylinders, the main difference between them and the other style being that these will hold water. The cylinders are nearly filled with castings, and the rolls are then filled with water and rotated in a manner similar to the others. It is claimed that finer work can be obtained in this way, and as there does not seem to be any great difficulty in making rolls of this kind it would seem reasonable to suppose that in many cases the old-fashioned rolls would be displaced by water-tight rolls.

Annealing is the name given to the process of softening castings by heating them to cherry redness in a tight oven and keeping them hot for a period ranging from twenty-four to one hundred and twenty hours, then allowing them to cool slowly. Though the process is much the same for

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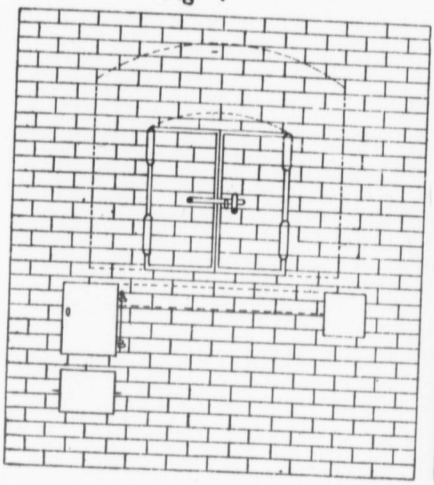

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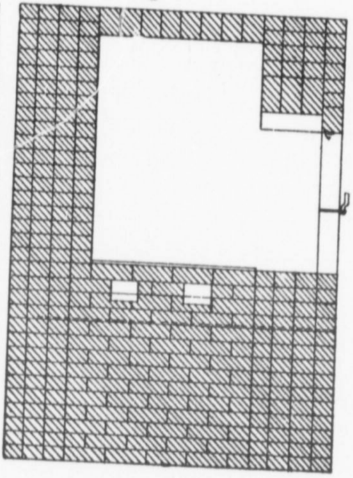

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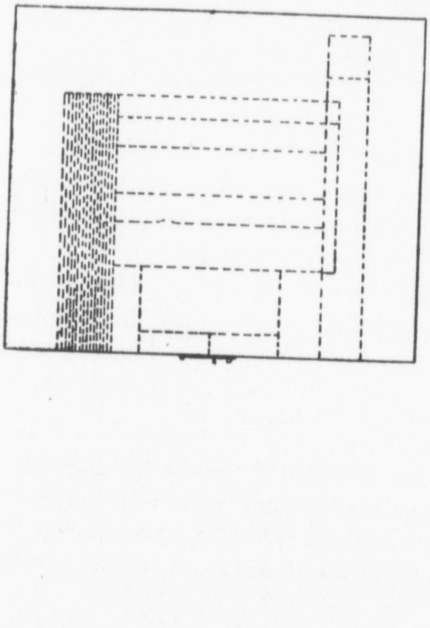

ANNEALING OVEN

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all castings, we will consider the treatment of gray and white castings separately.

The oven in which the castings are heated will here be described. I have seen but one, which is shown in the drawings Figs. 1, 2, and 3. This oven worked satisfactorily, and for this reason I have thought it advisable to take it as a type.

It is built of hard white brick, and is as far as possible solid, which gives it great stability and strength. It will be easily seen that strength and thickness of walls are very necessary on account of the long-continued heat to which the walls are exposed. To further increase its strength iron rods run across it, one on either side, which may be screwed up, the stress, by means of long washers, being spread over a considerable area of brickwork.

The outside measurements of the structure are six feet by seven feet six inches, and eight feet high. The door to the oven consists of two pieces, each fifteen by thirty inches, and is built of brick, inside a cast-iron frame. The main frame to which these doors are hinged is also of cast iron.

The inside dimensions of the oven proper are three feet by four feet six inches, the height varying from three feet four inches at the sides to four feet in the centre, on account of the arched top which supports the brickwork directly above the oven. The fire grate is shown at the left in Fig. 3; and Fig. 1 shows the door to the firebox, which is twelve by fifteen inches. Beneath the grate is shown the ashpan, and a damper to regulate the draft. This draft is quite indirect, the products of combustion being led from the fireplace by means of two flues which are built in the brickwork, three inches below the oven. These flues lead to a larger one, which is at right angles to both, and which runs into the chimney at the corner of the structure. On the brickwork bottom of the oven is placed a cast-iron bed with raised flanges crossing it in two directions, and dividing it up into hollow squares, of five inches a side. The thickness of metal throughout this piece is three-quarters of an inch, and the depth of the hollow squares a little more than one inch.

The gray castings to be annealed are, if small, put into wrought-iron pots, often rectangular in form, and of convenient size to be easily handled in placing in the oven and removing again, and are covered with sand, so as to exclude the air as much as possible, and also to prevent the castings from uniting with each other, while raised to the high temperature of from 700° to 800° C. It is usual to fill these pots first and to place them in the oven, where they will be exposed to less heat than the larger pieces, these being thrown in together, and covered with sand. When all the castings that are to be annealed at one time are placed in the oven, the doors are closed up and all joints are daubed with fire-clay, or sometimes with common clay.

The fire is now kindled, and in the oven described wood is always used, which seems to give better satisfaction than other fuels, since the flame enters the cross flues better, and gives out its heat to better advantage. Thus a continually increasing temperature is obtained in the oven until the desired temperature is reached, when the fire may be slackened, and a constant temperature kept up for any length of time. In the present case that period is usually about twenty-four hours, after which the firing ceases and the temperature is allowed to gradually fall until cool, when the oven is opened and the castings removed. These castings will then be much softer than before the treatment, especially on the outside, and the tensile strength is generally somewhat increased, and the brittleness modified.

The process as applied to white iron castings is very similar, except that in place of surrounding the castings with sand they are surrounded by iron rust, hammer scale, or some substance rich in the oxides of iron. The length of time during which the heat is kept up is also increased, sometimes being as much as four or five days. In this case the annealing has a much more marked effect than on gray iron, as it seems to completely change the properties of the iron. From being the hardest and most brittle of all castings, they are transformed into those so tenacious and ductile that they may be bent and hammered when cold without fracture. The temperature at which such castings are fusible is considerably increased, and when fused they do not possess fluidity in any marked degree, but form a sort of pasty mass. They can with difficulty be welded.

The changes that take place during the process do not appear to be very well known, and are no doubt partly physical and partly chemical. The molecular structure may be affected by the heating followed by slow cooling, just as, for example, the different amorphous forms of sulphur are derived by heating to various temperatures, and then cooling by certain well-known methods.

White cast iron, according to many authorities, amongst whom might be mentioned Roscoe, differs from gray cast iron chiefly in the way in which the carbon is contained in it. Most of the books which I have seen state that in the white iron the carbon is combined feebly with the iron, forming the carbide of iron, while in the gray iron the carbon is uncombined and is in the form of graphite. Turner, of Birmingham, writing in the "Dictionary of Applied Chemistry," disputes the above, however, and from this we are led to infer that this is an open question at the present time.

Mallet doubts whether decarbonization is the cause of softening, and states that by annealing white brittle cast iron in either hæmatite, chalk, or sand we obtain not so much a chemical change as a molecular change of the constituent parts.

If, as a number of writers assert, the carbon is combined with the iron in the carbide, it is possible that the following reaction takes place: $2Fe_4C + O_2 = {}^2Fe_4 + 2CO$, after which the CO burns away, the oxygen for this reaction being obtained from the oxides in which the castings are buried. In the case of the gray iron castings, it is hardly possible that the silicate will be broken up while the temperature is kept so low as red heat. It seems, therefore, more likely that the change in this case is of a physical nature, although it is possible that a silicate of iron is formed near the surface.

We know that wrought iron, which is iron in its softest form, contains a very low percentage of carbon, probably less than one-half of one per cent., and the various pig irons used in casting from three to six per cent., which naturally would lead us to believe that when iron is softened the carbon is reduced.

The order in which these processes are performed is not that in which they have been treated in this paper. Annealing is usually the first, which is followed by pickling, if that process is used, but as it materially increases the cost a great many of the castings are taken direct from the annealing oven, and treated in the rolls. If the castings are pickled, that precedes the tumbling in the rolls, or rattle barrels, as they are sometimes called.

It should be understood that castings treated by the above methods are only used where their extra usefulness counterbalances their increased cost. For instance, in sewing machine work, where there is a good deal of milling to be done, it is very important that the iron be soft, and all castings for such uses require also to be very smooth. Many points must, therefore, be considered before we can say whether or not these processes are profitable. Malleable castings are usually made to obtain greater strength than is possible from common gray iron castings, and where the shape desired is difficult to forge from wrought iron or steel.

Toronto, Nov. 19th, 1894.

THE CANADIAN DAWN ANIMAL

A. T. Tye, '95.

Eozoon Canadense, the Canadian Dawn Animal, is essentially one of the most ancient fossils with which the palæontologist has to do, and should Eozoon actually be what some claim it is, namely, a foraminifer, the primordial fossils which once demanded reverence as the hoary monuments of an immense antiquity become quite youthful and modern in their altered aspect. The discussion which has arisen in regard to the animal nature of Eozoon has directed the attention towards Canada of a great many European scientists, whose papers are to a greater or less extent inaccessible to the general public. It is for this reason, therefore, that the writer has endeavored to give a brief but accurate description of this remarkable fossil, which is but too little known. The amount of literature upon this subject is extensive, and this description has therefore been given from the works of the two great authorities—Sir William Dawson, F.R.S., F.G.S., and Dr. Carpenter, C.B., F.R.S., F.G.S., etc., of London. The principal works from which authority has been derived are "The Dawn of Life," "The Microscope and Its Revelations," "Notes on Eozoon Canadense," and will be found very interesting to those who should care to enquire into that period when life was introduced. Before proceeding, however, we might quote the words of Professor Leconte, of California University: "It is in precisely such almost amorphous masses of protoplasmic matter that, according to the evolution hypothesis, the animal kingdom might be expected to originate."

EOZOON CANADENSE.

This remarkable fossil has been discovered in strata much older than the very earliest that were previously known to contain organic remains. It occurs in beds of serpentine limestone of the Laurentian formation, discovered by Sir William Logan. The Lewisian or Ottawa gneiss is the oldest known stratified rock in Canada, which is wanting in

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limestones and organic remains; even quartzites, slates, and dolomites are absent, such as would indicate the ordinary disintegration of rocks under water, or the evidence of any distinction of land and water; thus it is termed a fundamental rock, and "may be a portion of the original crust of the earth," formed before the causes of the ordinary deposition of sediment were called into play. Above this is what Dr. Sterry Hunt calls the Grenville series, and contains, besides large masses of gneiss, beds of limestone, diorite, pyroxene rock, quartzite and magnetite. The limestones, which are continuous, occur in three great principal bands, which are traceable for long distances. These bands are of great thickness, and consist of crystalline limestone with dolomite, and serpentine, graphite, apatite, and mica. In the Grenville band, which is uppermost, is found the most perfect Eozoon. Above the Grenville, again, is found the Upper Laurentian of Logan, which has afforded no fossils, and it is thought that part of it is of igneous origin and indicates great earth disturbances near the end of the Laurentian age. This disturbance was accompanied by a great lapse of time, and it is represented locally by schistose rocks.

PRESERVATION.

Now, as to the manner of the preservation of Eozoon, it is only necessary to work upon the supposition that it was a marine organism and many difficulties may be explained.

Large masses, usually of indeterminate form, are found in the abovementioned beds which much resemble an ancient coral reef. These masses are formed of alternating layers of carbonate of lime and serpentine, frequently from fifty to one hundred in number. The great regularity in these alternations, and also the fact that it presents itself between other calcareous and siliceous minerals having caused suspicions that it was the product of an organic creature, very thin slices of the best preserved specimens were submitted to a rigid microscopic study by Dr. Dawson, of Montreal, who at once discerned the nature of a foraminifera. The *calcareous* layers had the characteristic appearances of a true *shell*, so arranged as to constitute an irregularly chambered structure, and frequently traversed by systems of ramifying canals corresponding to those of calcarina; whilst the *serpentinous* or other layers were regarded as the casts of that portion of the animal which the sarcode originally filled, caused by the infiltration of silicates. This action has occurred in various geological periods, and is going on at the present time, and is supported by an abundance of evidence.

Having taken up the investigation at the wish of Sir William Logan, Dr. Carpenter, of London, was not only able to confirm Dr. Dawson's conclusions, but to adduce new and important evidence in support of them.

The test or shell, which grew upon the floor of the ocean, was composed of a series of these calcareous laminæ, which, though not perfectly parallel, bent towards each other, forming flattened chambers, deeper near the bottom and becoming shallower in the upper parts, till at the top they become broken up into rounded cells, which constitute what is known as an "acervuline" mass. Now, when the chamberlets, which were formerly filled with the sarcodic matter of the animal, have become empty by reason of putrefaction, the space became filled with the infiltrations of mineral matter which were being deposited at the same time in the surrounding material. These minerals were especially pyroxene and serpentine. If well preserved, the calcareous laminæ are seen to be traversed with a multitude of canals, terminating in very fine tubuli. The usual form of Eozoon is that of a turbinate, or club shape, and these, by coalescence, form wide sheets or ununiform masses. In this case conical or cylindrical tubes or oscula may be observed to penetrate in the direction of their thickness. The sea-surface of these oscula is strengthened by the bending and coalescence of the laminæ. The walls of the animal have remained unchanged, except that they have become somewhat crystalline and assume the cleavage of calcite, which is common, however, in palæozoic shells and crenoids. Should the calcareous tests be broken up and scattered by the waves and currents, Dr. Dawson thinks that their fragments would consist of that which is found in the limestone, called archæospherinæ.

Assuming Eozoon to be a fossil animal of the above-described character, its mode of preservation in the ordinary serpentinous specimens is more simple than that of many fossils of later date. The chambers have been filled, and the canals and tubuli traversing the calcareous test have been injected with a hydrous silicate. This is a filling by no means infrequent in later fossils, and, as Dr. Carpenter has shown, it is going on in the modern oceans, in the case of foraminifera and other porous tests and shells injected with glauconite. Mineralization of this kind is not nearly so confusing as is the case of many fossil corals and fossil woods, the calcareous or woody matter being replaced by silica, oxide of iron, or pyrite. In a great many cases, in palæozoic fossils, the cavities have been filled with successive coats of different minerals, giving very complex appearances. That porous fossils, once infiltrated, are nearly indestructible should not be forgotten by the geologist. There is hardly anything, except fusion itself, that would cause the complete destruction of their structures, and these frequently remain in perfection even where the external forms have been totally lost. There is, therefore, nothing very strange in the preservation of Eozoon, except that it occurs in highly crystalline rock. But many palæozoic limestones are of a highly crystalline character, and yet retain abundant evidences of their organic origin; for example, the Chazy and Trenton limestones of Montreal have a perfectly crystalline fracture, yet, when sliced and studied under the microscope, they are seen to consist of organic fragments having their most minute structure preserved.

Many specimens of cœnostroma are found in the Silurian dolomite of Guelph, in Ontario, entirely replaced by perfectly crystalline dolomite, which not only shows the lamination, but even the fine canals. Corresponding appearances are found in the gray dolomite of Niagara. In places, stromatopora in masses can be seen dispersed through the rock in a similar manner to Eozoön in the Laurentian limestone. The mode of occurrence of these fossils resembles that of the Eozoon of Côte Ste. Pierre in every respect, except in the absence of hydrous silicates, and some of those who oppose the organic nature of Eozoon take the badly preserved examples of it as typical, and suppose that these are in the original mineral condition. Such a mode of argument would, however, dispose of all reasoning from the fossil structures, two of which are corals and woods. What seem to be a much more reasonable way would be to use the well-preserved specimens and portions as the means of interpreting the rest. Eozoon has, in common with other fossils, the independence of form, with reference to the mineral infiltration. This salient feature of the fossil attracted the notice of Sir William Logan, and caused him to believe in its organic nature long before its minute structure had been studied, and since then the argument has been much strengthened. The minerals, serpentine, pyroxene, and loganite, are found filling the chambers, while the first two, together with dolomite and calcite, fill the canals, which often have calcareous fillings in the finer ramifications when the main branches are filled with serpentine.

FORM OF EOZOON.

The shape of Eozoon in its general form is that of an immense confluent sheet or mass, which may be somewhat distorted by lateral pressure. But the fact has been established, from recent examples, that the normal shape of a young specimen is a broadly-turbinate, funnel-shaped, or top-shaped form, sometimes with a depression on the upper surface. These specimens also enable us to determine that there is no theca or outer coat, and that the laminæ pass outward without change to the margin of the form, where they seem to have a tendency to coalesce by bending. It is also evident, from the close study of sliced specimens, that there exist cylindrical depressions or tubes, sometimes filled with calcite or serpentine, crossing the laminæ vertically. These are noticed in the large confluent masses, and have no special arrangement, but their occurrence is by no means accidental, as they were designed for the admission of the sea into the lower portions of the structure. If Eozoon was an organism growing on the sea floor, it would be most probable that the waves would, in time, demolish the upper acervuline structure to some extent; then the currents would distribute these particles over the sea bottom, and in time we would expect to find them imbedded along with Eozoon in the rock. In fact, such fragments are found in the Grenville band, the Adirondack Mountains, Mass., St John's, and in the Alps. The Redpath Museum (McGill College) has sawn slabs of limestone which show irregular layers or bands, and these are evidently successively deposited layers, and when examined closely show the structure of Eozoon.

VEINS OF CHRYSOTILE.

As has been mentioned, there are veins of fibrous chrysotile which abound in the serpentinous limestones of the Laurentian, but these are of secondary aqueous origin, as they fill cracks or fissures, not merely crossing the beds of limestone, but passing through masses of Eozoon, and the concretions of serpentine which occur in these beds. These chrysotile veins must, therefore, have had their origin long after the Eozoon was buried, as it even occurs after the beds have been folded and crumpled. They, therefore, have no connection with Eozoon, which has been subject to the same bending and compression as the rocks themselves. These veins have been mistaken by some for the very finely tubulated portion of the fossil.

OTHER LAURENTIAN FOSSILS.

In the Ottawa district specimens are found of peculiar cylindrical or elongated conical bodies, which are from one to two inches in diameter, and occurring in connection with beds or nodules of apatite. These are composed of a thick outside cylinder of granular, dark-colored pyroxene, with an inner core of white felspar, and show no structure, except, perhaps, that the outer cylinder is sometimes marked with radiating bands of a rusty color, which indicates the decay of radiating bands or plates of pyrite. These bodies may be organisms, perhaps, of the nature of archæocyathus, but this is only conjectural, and is based upon nothing of very positive importance.

CRYPTOZOUM.

Very large laminated forms, which have been described as Eozoon, have been discovered by Professor Hall in the Potsdam *(sandstones)* formation of New York, and in that of Minnesota. Professor Dawson discovered fragments of these fossils in the conglomerates of the Quebec group, associated with middle Cambrian fossils, and he states that whatever may be their zoological relations it is evident that their mode of occurrence in the Cambrian is similar to that of Eozoon in the Laurentian. There are also found in the Laurentian limestones peculiar laminated forms which, though often referred to Eozoon, have thin continuous laminæ, with porous spongy matter between, like cryptozoum or loftusia. It is not, of course, yet known whether these are distinct structures or peculiar forms of Eozoon. Such structures, perhaps, suggested to Mr. Julian his objection to the animal nature of the fossil. In the American Association in 1884, he suggested that the structure of this fossil might be due to the alternation of mineral matter in layers, formed in the passage-beds, between concretions and other mineral masses and their enclosing matrix. But in contradiction to this there is to be noticed: (1) Laminated passage rocks and laminated concretionary rocks have only simple laminæ, whereas Eozoon has connected or reticulated laminæ. (2) Laminated passage rocks have no structure other than crystalline. Eozoon has beautiful tubulations in the calcareous walls, besides tubes or oscula. (3) The mineralizing agent may be pyroxene, serpentine, loganite, dolomite, or mere earthy limestones. It is impossible that all these minerals should assume the same forms, etc.

LAURENTIAN APATITE AND GRAPHITE.

At Grenville and other places the Chazy formation contains many phosphatic nodules; these hold fragments of lingulæ, such as also occur in the surrounding beds. These nodules also contain grains of sand, and when heated emit an odor of ammonia. These are regarded by Sir William Logan and Dr. Sterry Hunt as coprolitic, and are said to consist of "a paste of commuted fragments of lingulæ, evidently the food of the animals from which the coprolites were derived." (Geology of Canada, p. 125.) It has been brought forward that these animals may have been some of the larger species of trilobites. In the Cambrian and lower Silurian rocks of Canada, phosphatic deposits occur in many localities, though they are not large enough to compete with the rich Laurentian beds. If, then, we agree with Sterry Hunt that the iron ores of the Laurentian are of organic origin, "the apatite which occurs in them may quite reasonably be supposed to be of the same character with the phosphatic matter which contaminates the fossiliferous iron ores of the Silurian and Devonian, and which is manifestly derived from the included organic remains. If we consider the evidence of Eozoon sufficient to establish the organic origin, in part at least, of the Laurentian limestones, we may suppose the disseminated crystals of apatite to represent coprolitic masses, or the débris of phosphatic shells and crusts, the structure of which may have been obliterated by concretionary action and metamorphism." Further, the presence of graphite together with the apatite in both cases is probably not accidental, but may depend in both on the association of carbonaceous organisms, vegetable or animal. This is strengthened by the presence of phosphatic shells in great abundance during the primordial age.

The Laurentian apatite nearly always contains a trace of calcium fluoride, which salt also occurs in bones, especially fossil bones. No organic remains have been found in the lowest part of the Laurentian, and these beds are also poor in phosphate. As has been already mentioned, Eozoon is most abundant in the Grenville band, and, likewise, the phosphates are found in the overlying beds.

Graphite. The graphite of the Laurentian in Canada occurs both in beds and in veins, and it is evident that its origin and deposition are contemporaneous with the containing rock. Dr. Hunt has concluded that there had been a Laurentian vegetation upon chemical grounds alone; Dana upon various grounds; and Dawson insisted, as early as 1860, upon the probability of the existence of some of the lower forms of plants. The quantity of graphite in the Laurentian is enormous. In Buckingham, in strata 600 feet thick, there is at least 30 feet of pure graphite. It may be said that the quantity of carbon in the Laurentian is equal to that in similar areas of the carboniferous system, and it may also be assumed, without much fear of contradiction, that in this age, and in those geological periods with whose organic remains we are most familiar, there is no other source of unoxidized carbon in rocks than that furnished by organic matter, and that this has obtained its carbon in the first instance from the deoxidation of carbonic acid by living plants. That graphite is found with organic limestones, beds of iron ore, and metallic sulphides, greatly strengthens the probability of its vegetable origin.

EOZOON AS A FORAMINIFER.

In the "Microscope and its Revelations," Dr. Carpenter, the eminent authority upon foraminifera, makes some interesting statements in regard to Eozoon. He states that although the animal nature of it has been called in question, on the ground that some resemblance to its supposed organic structure is presented by bodies of purely mineral origin (Professors Rowney and King), yet it has been accepted not only by most of those whose knowledge of foraminiferal structure gives weight to their judgment, but also by geologists who have specially studied the micro-mineralogical structure of the older metamorphic rocks—amongst the former the late Professor Max Schulze, and amongst the latter Professor Geikie, of Edinburgh, and Professor Bonney, of Cambridge and London. Whilst essentially belonging to the nummuline group, in virtue of the fine tubulation of the shelly layers forming the "proper wall" of its chambers, Eozoon is related to various modern types of foraminifera. It agrees with polytrema in its indeterminate zoophytic mode of growth; it resembles carpentaria in its incomplete separation of its chambers; in the calcarina it is closely resembled by the high development of the "intermediate skeleton" and of the "canal system." The succession of the calcareous layers one above the other resembles the stories of a house; while the chambers on each floor usually open into each other, like apartments *en suite*, but occasionally being divided by complete septa. These septa are traversed by passages of communication between the chambers which they separate, as stolons connecting the segments of the sarcode body.

Each layer of shell consists of two finely tubulated or "nummuline" laminæ, which form the boundaries of the chambers above and beneath, acting as the ceiling of one and floor of the other; and of a deposit between the boundaries of homogeneous shell, which is termed the "intermediate skeleton." The tubuli of the "nummuline layer" are usually filled (as in nummulites) by infiltration of mineral matter, so that in transparent sections they have a fibrous appearance, but fortunately it so happens that in some cases they have not been infiltrated, and the tubulation is as distinct as it is even in recent nummuline shells, having quite a resemblance in its waviness to the crab's claw. The "intermediate skeleton" is sometimes traversed by larger openings, which establish connections between the different layers of chambers; it is also pierced by aborescent systems of canals, which are often so extensively and minutely distributed through the structure as to occupy nearly all the space. These canals arise from irregular laminæ, or interspaces between the outside of the proper chamber walls and the "intermediate skeleton," as in calcarina, the sarcode body which filled them having been formed by the coalescence of the pseudopodial filaments passing though the tubuli. Not only the chambers in Eozoon are filled with siliceous infiltration, which takes the place of the original sarcode body, but even the very smallest of the canal ramifications are filled with it. This is found to be the exact state of things in the green sand of Ehrenberg, the Challenger collection, and modern foraminifera studied by such as Carpenter, Parker, and Rupert-Jones.

When we subject a piece of this fossil to the action of dilute acid, its calcareous portion is dissolved away, leaving an "internal cast" of its chambers and canal system, which, though dissimilar in arrangement, has its analogies in textularia, rotalia, and polystomella. The cast thus obtained of the chambers and canals is simply a model in hard serpentine of the soft sarcode body which originally filled these spaces, and extended itself into the minute ramifying canals of the calcareous shell; and, like that of polystromella, it affords an even more satisfactory elucidation of the relation of these parts than we could have gained from the examination of the living subject. In spaces between the layers of serpentine which were originally occupied by the calcareous shell, we see the "internal casts" of the branching canal system, which give the exact models of the extensions of the sarcode body. In specimens where the nummuline layer constituting the "proper wall" of the chambers was originally well preserved, that layer is represented by a thin white film covering the exposed surface of the segments. When this layer is studied with a sufficient magnifiying power, it seems that it consists of extremely minute needle-like fibres of serpentine, which sometimes stand upright parallel, and almost in contact, like the fibres of asbestos. Now, these fibres, which are less than $\frac{1}{10000}$ of an inch in diameter, are the internal casts of the tubule of the nummuline layer. Thus these delicate and beautiful siliceous fibres represent those pseudopodial threads of sarcode which formerly filled the minutely tubular walls of the chamber.

The change which is observed from the regular lamellæ to the acervuline is common with many foraminifera, an irregular grouping together of the chambers being frequently found in the later growth of types, whose earlier growth was of a much more regular system. In a quite recent specimen which has been discovered, it seems that each successive "story" of chambers was limited by the closing in of the shelly layers at its edges, such as to give the whole mass much the appearance of a straightened peneroplis. Thus, from a comparison with recent foraminifera, it appears that the only peculiarity of Eozoon lay in its indefinite extension, so that the product of a single germ might attain to the magnitude of a massive coral. This, it will be noted, is simply due to the fact that its increase by gemmation takes place "continuously"; the newer segments simply successively budding off and remaining in connection with the original stock, instead of detaching themselves from it as in foraminifera generally. Thus the little globigerina forms a shell, in which sixteen is the limit to the number of chambers, any above this detaching themselves and becoming independent, but by the repetition of this multiplication the sea bottom of large areas of the Atlantic ocean has become covered with accumulations of globigerina, which, if fossilized, would form beds of limestone not less massive than those whose origin was the Eozoon growth. The difference between the two may be compared in their mode of increase to the difference between a plant and a tree.

SUMMARY BY DR. DAWSON, LL.D., F.R.S., F.G.S., ETC.

1. Eozoon occurs in masses in limestone rocks, just as stromatoporæ occur in the paleozoic limestone.

2. While sometimes in confluent and shapeless sheets or masses, it is, when in small or limited individuals, found to assume a regular rounded, cylindrical, or, more frequently, broadly turbinate form.

3. Microscopically, it presents a regular lamination, the laminæ being confluent at intervals, so as to form a network in the transverse section. The laminæ have tuberculated surfaces, or casts of such tuberculated surfaces, giving an acervuline appearance to those laminæ which are supposed casts of chambers.

4. The original calcareous laminæ are traversed by systems of branching canals, now filled with various mineral substances, and in some places coarse and in many others becoming a fine tubulated wall. The typical form of these canals is cylindrical, but they are often flattened in the larger stems.

5. In some specimens, large vertical tubes or oscula may be seen to penetrate the mass.

6. On the sides of such tubes, and on the external surface, the laminæ subdivide and become confluent, forming a species of porous epidermal layer or theca.

7. Fragments of Eozoon are found forming layers in the limestone, showing that it was being broken up when the limestones were in process of deposition.

8. The great extent and regularity of the limestones show that they were of marine origin, and they contain graphite, apatite, and obscure organic (?) fragments other than Eozoon.

9. The specimens of Eozoon have been folded and faulted with the containing limestones, showing that they are not products of any subsequent segregation.

Books of reference for further information.

1. "The Dawn of Life," Sir J. William Dawson, LL.D., F.R.S., F.G S., etc.
2. "The Story of the Earth and Man," 1873.
3. "Geology of Canada," pp. 48-49. Sir W. E. Logan, LL.D., F.R.S., F.G.S.
4. "The Microscope and Revelation," W. B. Carpenter, C.B., M.D., LL.D., F.R.S., F.G.S., F.L.S., etc.
5. "Notes on Specimens," Peter Redpath Museum, McGill College. Sir J. W. Dawson, F.R.S., etc.

Toronto, Jan. 11, 1895.

DISCUSSION

PROF. A. P. COLEMAN.—This paper is a very interesting and suitable one, taking up a question which all Canadians should know something of. However, it presents only one side of the question, *i.e.*, the side of Sir Wm. Dawson and Dr. Carpenter. Most European geologists do not believe Eozoon was an animal, but hold the opinion, as do many American geologists, that it is of purely mineral origin. On the whole, the prevalent feeling of geologists is against the organic origin of the Eozoon Canadense. It would be well if some one would present the other side of the question.

MR. A. T. TYE.—In reply to a letter to Sir Wm. Dawson, asking his opinion as to the animal nature of the Eozoon, I have received an answer from him, of which the following is an extract :

". . . . Zittel gives it (the Eozoon) a place in Volume I. of his 'Palæontologie,' although not definitely committing himself to it, and Carpenter, Parker, Rupert-Jones, Brady, Gumbel, Max Schulze, Reup, Hochitetter, and, in fact, all our best authorities on foraminiferal fossils, have accepted it.

"In this country I may mention Logan, Hunt, and Matthews, the principal opponents having been King, Rooney, and Mobius. As to the rank and file of geologists, not one in twenty has sufficient knowledge of fossil foraminifera and of the mode of preservation and microscopic examination in altered rocks to form an independent opinion, and they therefore follow authority as it appears more or less strong to them.

"I see that Gregory, of the British Museum, recently published a paper in the *Dublin Transactions* on some products of Mt. Vesuvius, which he compares to Eozoon. I have not yet seen the paper; but from what I learn, I believe the resemblance is merely accidental.

"I have no fear of the ultimate acceptance of Eozoon as a fossil, but at the present it labors under the disadvantage of lack of appreciative students, and of being isolated from the Canadian fauna. The new discoveries in Brittany and elsewhere are tending to fill the gap."

ON THE USE OF ASPHALTUM IN ENGINEERING CONSTRUCTION

FRANK N. SPELLER, B.A.SC.

HISTORICAL SKETCH.—The ancient historian, Herodotus,* in his description of the construction of the fortifications of Babylon, says that "When they had made a certain number of bricks they baked them in a kiln, then using boiling bitumen as mortar, and inserting mats of woven reeds between every thirtieth course of brick they built, first the borders of the moat, and next the wall itself in the same way." The remains of these works and many other vast structures have been uncovered and studied, but, owing to the inferior quality of much of their brickwork, many of these noble monuments have entirely disappeared, and no doubt those which remain to us owe a large part of their preservation to the bituminous cement with which they were built, which appears to be as good to-day as when laid over 3,000 years ago.

The former inhabitants of Chaldæa occupied a region of country about the Lower Euphrates, where very little stone or other natural building material was to be found, and, consequently they were forced to depend entirely on the manufacture of bricks for their building material. All the great structures in this country, of whose colossal size and grandeur history tells, and whose remains corroborate the tale, were constructed of these brick.

The bricks were of two kinds, baked and unbaked, the latter being invariably protected by the former, which were of excellent quality, and for this reason were always selected where extra strength was required.

The two cements in use as mortar in this district were stiff clay and bitumen, the former being chiefly used with unbaked bricks, while with the more durable form of brick, and in the more important parts of the structure, bitumen was prevalent.

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*I., 179.

The bitumen so frequently mentioned in ancient records as a cement is a natural asphaltum, obtained chiefly from Mesopotamia, where to-day springs are to be found, notably, at Hit, yielding a copious supply of maltha. As is usually the case in such regions, springs of crude petroleum are also found to some extent, and records exist to show that this was used, where found necessary, in the manufacture of asphaltic cement.

Among the ancient monarchies whose far-reaching influence centred in this district, in nearly every case we find the use of asphaltum to be characteristic of their civilization, although Assyria forms a notable exception in this regard, for, so far as is known, these people scarcely ever availed themselves of this resource so near at hand.

Besides as a mortar, bitumen was employed to prevent damp in floors, a very common form of pavement being one of baked brick imbedded in bitumen. On removing the débris from these floors, and taking up the large brick slabs, they are seen to be covered with inscriptions, the impression of which is seen to be accurately preserved in the bitumen when the brick is removed.

Another favorite use was in making concrete, which with them consisted of broken brick and asphaltic cement.

The above will suffice to give us an idea of the importance of this material at that time, and when we read of the palaces of Babylon, the hanging gardens and immense walls of that city, we must admit that they made good use of their resources.

Much of what has been said above might be repeated with regard to the ancient inhabitants of the southern part of our continent, the aborigines of California and Mexico, who applied the natural asphaltum found in such abundance in their country in building, in the manufacture and repair of domestic utensils, in weapons of war, in rendering their canoes water-tight, and in many other ways, as necessity and ingenuity suggested.

This will, perhaps, demonstrate that the application of asphaltum to engineering construction is not a new departure, but the revival of what is, perhaps, a long lost art, which has already laid the foundation for a great industry in our country.

It is with the object of setting forward the possibilities of this material, the peculiar properties which it possesses, and the manner and extent to which these properties have been taken advantage of so far by the engineer, that this paper is written.

In order to gather some idea of the value of asphalt as a cement in engineering work, it occurred to me to carry on a series of experiments to determine the adhesive and cohesive strength of this material, and to ascertain if in this way a practical test of the quality of an asphalt could be deduced, and, further, to investigate how the conditions under which the material was tested affected the results obtained.

The method chosen as being the most feasible and practical was somewhat similar to that used in determining the tensile strength of Portland cement. By selecting broken briquettes of the latter and cementing them together again with the asphalt to be tested, it was found that this material adhered to the Portland cement with great tenacity, and, as a rule, broke across itself with a clean fracture, providing, of course, that the Portland cement was sufficiently strong not to break of itself.

The difficulty found in obtaining a uniform quality of the necessary broken briquettes led to experiments in the use of brass or copper cast to the pattern of a Portland cement briquette cut in half. These were very carefully finished, to ensure an even bearing surface, but the ends to which the asphalt was intended to adhere were left rough, as cast, to give it a better hold.

This was a marked improvement, and gave more concordant results, when properly manipulated, which were also a little higher than those obtained with the former appliances. In most cases, especially where the tensile strength is high, the layer of cement, which should be not less than $\frac{1}{16}$ of an inch thick, breaks clean across itself; while if the cement be weak, it will partially or wholly pull away from the metal, leaving the latter with a clean surface. In this case the adhesion is less than the cohesion.

Most of the testing previously attempted in this line, so far as I have learned since starting these experiments over a year ago, consisted of attempts to mould the surface mixture of the asphalt pavement into briquettes while hot; this was subjected to a certain pressure, cooled, and broken in one of the standard testing machines. The proportions are generally within the following limits :

Asphaltic cement	12—16	per cent.
Limestone dust	10—15	"
Sand	78—69	"

The results obtained by this method have not been very satisfactory, owing to the numerous varying conditions, such as the temperature, pressure, proportions of ingredients, etc., which affect the accuracy of the results. The result, of course, varies widely with the pressure employed, and, so far, it has been found impossible to attain the same degree of density in the laboratory as is obtained on the street, owing to the peculiar efficiency of the heavy steam roller in this regard.

The method of testing the cement *per se*, as first described, has been carried on in the city engineer's laboratory of this city for some time, and I think that this simplifies and brings the experiment within the limits of a practical test of some value, which may, when better understood, retain the same relation to asphalt and other bituminous cements as the tensile strength test does to Portland cement.

To get satisfactory results, certain precautions must be taken in melting the asphalt and in heating the metals before putting the briquette together. The metals are best warmed by placing them in water at about 150° F., and leaving them there until they are heated throughout. Meanwhile, the asphalt is warmed and melted in a suitable vessel, care being taken to bring it to a convenient state of liquid viscosity without overheating at any point. The metals are dried and quickly dipped into the melted asphalt, then stuck together, placed securely in position, and allowed to cool *slowly* to the temperature selected for breaking.

The testing is conveniently done on a Fairbanks' machine, the stress being applied by shot falling at a uniform rate. The uniform application of the stress at a certain standard rate is a necessity to reliable testing, and is automatically obtained in a simple manner with the Fairbanks machine, but with a little practice the Riehle machine may be made equally useful in this regard. The highest rate of application of stress which I have been able to get on the Fairbanks machine is 1,000 pounds per minute, which has been used throughout these experiments; it is two and a half times the standard rate adopted in the Portland cement tensile strength test.

The following are a few characteristic results collected as averages from a large number of experiments:

Refined Asphalt.		Tensile strength.*
"Land" quality		330 pds. per sq. inch.
Standard Lake		518 "
"Lake" (Series No. 15), at a temp. of 60° F.		460 "
"Lake" (Series No. 15), at a temp. of 71° F.		430 "
"Lake" (Series No. 21)		460 "
"Lake" (Series No. 14), good quality ..		525 "
Bermudez, at	at 58° F.	330 "
Californian	at 40° F.	250 "

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* These figures are copied from the records in the books of the City Engineer's laboratory, with the permission of H. D. Ellis, Esq., Roadway Engineer.

It will be observed that the Trinidad asphalts give a much higher result than the purer varieties (Bermudez and Californian), although in each case the per cent. of bitumen petrolene is about equal, favoring the latter slightly. This apparent irregularity led to a question.

It has been stated that the adhesion of the asphalt to the metal is in nearly every case greater than the cohesion of the material in itself. This is a physical fact which may be demonstrated in regard to the adhesion of liquids and solids generally, and asphalt may be considered as a liquid, compared with the brass with which it is in contact. This led to the theory that the excess of fine inorganic matter * in the Trinidad asphalt (see analysis on page 11) brought into play this superior adhesive power possessed by the bitumen.

To test this the following experiment was arranged: the Californian asphalt above mentioned was taken, finely ground and mixed with kieselguhr—a very absorptive siliceous earth—the mixture having the proportions:

Bitumen	70.4	per cent.
Kieselguhr	25.1	"
Other inorganic matter	4.5	"

The organic matter non-bituminous was too small to be noticed.

The effect of this addition of mineral matter was to raise the breaking strength from 250 to 333 pounds per square inch; the material, however, partly pulled away from the metal, otherwise much higher results might be expected. Further experiments will be made soon, as this has opened up a very important field of research.

This points to the conclusion that the fine mineral matter is an advantage to the asphalt for certain purposes. I am not stating that the inorganic matter of the Trinidad asphalt is particularly advantageous, it is combined with too much organic matter and clay to be so; but may we not infer that the fine clean microscopic siliceous matter is a distinct advantage, and a thing to be provided, if possible artificially, when found wanting?

Where dealing with Trinidad asphalt alone, the tensile strength test affords us a ready means of comparison. A case in point is selected, a

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*This mineral matter appears, when all organic matter has been removed, as a reddish-brown impalpable powder, consisting of finely divided fragments of minerals, chiefly quartz mixed with a little clay. It is so intimately mixed with the bitumen as to almost form an integral part of the same.

few of the physical properties being added to further show the difference in nature of the asphalts. The "land" is evidently the least desirable.

	"Land"	"Lake"
Softens at	197° F.	178° F.
Flows at	230° F.	188° F.
Percentage of flow	32	100
Tensile strength	331	518 pds. per sq. in.

In dealing with refined Trinidad asphalts the temperature within ordinary limits has little effect on the results, especially the harder the asphalt becomes; this is illustrated in example, Series No. 15 above.

Another example is cited to show the ordinary degree of concordance to be expected between results obtained with the same material.

Refined lake asphalt on Riehle machine, temperature of test 65° F., tensile strength 520, 525, 540 pounds per square inch.

By obtaining cements of the same degree of penetration, made from different asphalts, it is easy, by following a course such as that outlined above for refined asphalt, to make a quick comparison of their strength; and, by varying the temperature, we get an idea of the variation of the strength with the temperature. As an example, the case of two cements of "lake" and "land" asphalts is selected, the penetrations being almost identical (60° and 56° respectively):

Temperature of Test.	"Lake."	"Land."
34° Fah.	450 pds. per sq. in.	395 pds. per sq. in.
57° "	368 "	310 "
68° "	215 "	215 "
78° "	182 "	182 "

As the figures are averages, and the "lake" cement of a rather inferior quality, this may account for the equivalence of the results for the two higher temperatures.

An attempt was made to compare Bermudez asphalt (an exceptionally pure variety from Venezuela, South America) with that from the "lake" in Trinidad. Two Bermudez cements were made in the laboratory. No. 1 contained 100 refined asphalt to 11 of oil; penetration, 87°. No. 2 contained 100 refined asphalt to 9 of oil, penetration, 71°.

A Trinidad lake cement of penetration 71° was used for comparison with No. 2 Bermudez, the average results being as follows:

Temperature.	Bermudez, No. 2.	Trinidad.
35° Fah.	430 pds. per sq. in.	468 pds. per sq. in.
55° "	325 "	309 "
64° "	270 "	253 "
68° "	157 "	212 "

As far as this test indicates, they seem to be on a par, although it must be remembered that the Bermudez cement is nearly pure bitumen, while the Trinidad contains about 30 per cent. inorganic mineral matter, besides far more residuum oil than is present in the former.

As an example of a "lake cement" of good quality, tested in this manner, the following will serve. Penetration, 80°.

Temperature.	Tensile strength.
35° Fah	477 pds. per sq. in.
40.5° "	400 "
50° "	298 "

As the temperature rises above 55°-60° the strength of the cement rapidly diminishes as the cement gets softer, and it becomes more difficult to get good results; therefore, it appears to be of more advantage to break the briquette below 50° Fah., this being easily attained by immersing the briquette in water of the desired temperature for fifteen minutes previous to breaking.

It may be premature at this stage to specify any standard, but, from a consideration of from 200 to 300 experiments made during the past year, it appears to me that a "lake asphalt cement" should (if the penetration is between 70°-80°) have a tensile strength, at 35° Fah., of over 450 pounds per square inch, and, at 50° Fah., at least 300 pounds per square inch, the experiments being made on a cross-section of at least one square inch, and with a rate of application of stress of 1,000 pounds per minute.*

Coal tar, and other products of destructive distillation of like nature, often have a tensile strength of 300-400 pounds per square inch at first, but are distinguished by generally diminishing in strength very rapidly when allowed to stand, especially when in water.

In considering this part of the subject, the nature of the material with which we are dealing must not be overlooked. It is not such a substance as iron, wood, or even Portland cement, which will withstand a stress of greater or less degree without yielding, for in the case of an asphaltic cement, although it may appear quite hard and brittle, yet it will always yield before even a slight stress continuously applied; therefore, while it is invaluable for certain purposes as a cement, yet its field of utility is limited, but nevertheless well defined. From this it will be seen how important the regulation of the rate of application of stress is in making experiments, and for this reason the above figures are necessarily somewhat arbitrary. However, they sufficiently illustrate the fact that asphalt and its products possess a wonderful degree of strength, combined with plasticity and absolute impermeability, which eminently fits them for certain important uses in engineering construction, a few of which will be briefly described.

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* The briquettes should be allowed to stand twenty-four hours after being made up, before breaking.

STREET PAVING.—In a paper which I had the honor to present before this Society last year on the subject of "Asphalt and Asphalt Paving," a brief history and outline of the industry was given. The facts in regard to the widespread and general popularity of this pavement are now better known, and it will, therefore, be unnecessary, even if we had the space, to give it more than a passing glance in this paper. Suffice it to say that in the short interval of twenty-five years, since this infant industry was first started on this continent, it has increased with such tremendous strides as now to employ millions of dollars of capital and a proportionate amount of skilled labor; and asphalt pavements have now been laid in ninety-two cities of this continent, requiring an average importation of 70,000 tons of asphaltum per annum from the island of Trinidad alone, to say nothing of the native material in use. The latest statistics, up to January 1st, 1894, show the total amount of asphalt paving in America up to that date as:

	Sq. yds.	Miles.
Trinidad asphalt...	13,900,000	911
Asphaltic limestone	151,000	10
Asphaltic sandstone and other asphaltic materials.	619,000	41
	14,670,000	962

The total area of asphalt pavement laid in Europe up to the same date was 2,323,413 square yards, or 151 miles, over half of which is in Berlin.

The subject of asphalt paving is so extensive that a mere outline of the technology and laboratory testing in connection with this work would require a few articles to itself, so we will pass on to some of those uses of asphaltum in engineering works which, while valuable, are not as familiar as the asphalt pavement, of which we are being constantly reminded in the new beauty lent to those of our cities in which this pavement has gained prominence.

Reservoir Lining.—During the last few years much of the lining of reservoirs on this continent has been done with asphalt, by the recommendation of some of the most eminent American engineers, and the results are such as to encourage its continued use.

~~The peculiar nature of asphalt~~ especially adapts it for this work, where strength, elasticity, and imperviousness to water are required; and in lining new embankments, where some settlement is to be feared which would be fatal to a concrete lining, the asphalt lining will, if properly laid, adapt itself to such changes in the foundation without injury. Nor is the ease with which this lining may be repaired an advantage to be overlooked, as new material may be made to unite perfectly with the old wherever a patch may be required.

To ensure a good, firm, and uniform foundation, the earth should be well rolled with a five-ton steam roller. The rolling of the slopes is accomplished by means of a heavy roller manipulated by a cable and drum connected with an engine on the bank, the whole being carried on a truck, which may be moved around the reservoir on a track of ten-foot gauge laid on the bank for this purpose.

In order to prevent dry earth from the slopes rolling down and mixing with the asphalt when being laid, it has been recommended that the surface of the slopes be covered with a layer of cement of lime and sand mortar, one-half to one inch thick, which, when dry, presents a clean and even surface for the laying of the asphalt lining.

The lining is best laid in three coats, consisting of a layer of asphaltic cement, one-quarter to one-eighth inch thick; on this is placed the body of the lining, which is a mixture of asphaltic cement and sand, the cement amounting to about 16 per cent., this layer being about one and a half inches thick when compressed; finally, a dressing of asphaltic cement is applied to the surface similar to the first layer.

To get an intelligent view of this matter, it will be necessary to discuss in brief the various kinds of asphalt on the market. These may divided into *two* classes, and the three most important examples which we have are:

(1) Trinidad asphalt.

(2) Bermudez asphalt, from Venezuela, S.A.; and California asphalt, from that state.

The first asphalt is well known in connection with street paving, to which it has proved itself to be well adapted.

On analysis,* an average example of refined Trinidad pitch lake asphalt will show :

Bitumen	Asphaltene	20.90 per cent.
	Petrolene	34.85 "
Inorganic matter		38.25 "
Organic matter (non-bituminous)		7.60 "

Nearly all "land" asphalt is of very much inferior quality to this, and should be guarded against. Although this asphalt has been so successful in street paving, yet the per cent. of bitumen is too low to make it desirable in works exposed constantly to water, the high per cent. of organic matter, other than bitumen, being also a disadvantage on the same account.

The second class of asphalts mentioned above are distinguished by their purity. This does not give them any advantage—so far as is known at the present time—over Trinidad asphalt in paving, but they are to be preferred and sought after for such work as reservoir lining. The following characteristic analyses speak for themselves :

		Bermudez.	Californian.
Bitumen	Asphaltene.	total bitumen . . 96.09 per cent.	29.73 per cent.
	Petrolene . .		61.46 "
Inorganic matter		2.76 "	5.79 "
Organic matter (non-bituminous)		1.15 "	2.49 "
		100.00	99.47

The Californian asphalt has been largely used, and is particularly valuable in this regard, as it is as good as any asphalt at present on the market, and, being mined in the country, is the cheapest, selling at $15 per ton of refined material at the refinery in California, although, in Toronto, it would cost $30 per ton, which is, however, still considerably below any other at our present scale of prices.

California also produces a natural asphaltic oil or maltha which dissolves the asphalt and forms the most efficient fluxing material known ; the objection to the residuum oil in general use in the east being that it does not dissolve the asphalt, but merely forms a mechanical mixture, which is also hard to make perfectly, owing to the great difference in specific gravity of the two ingredients.

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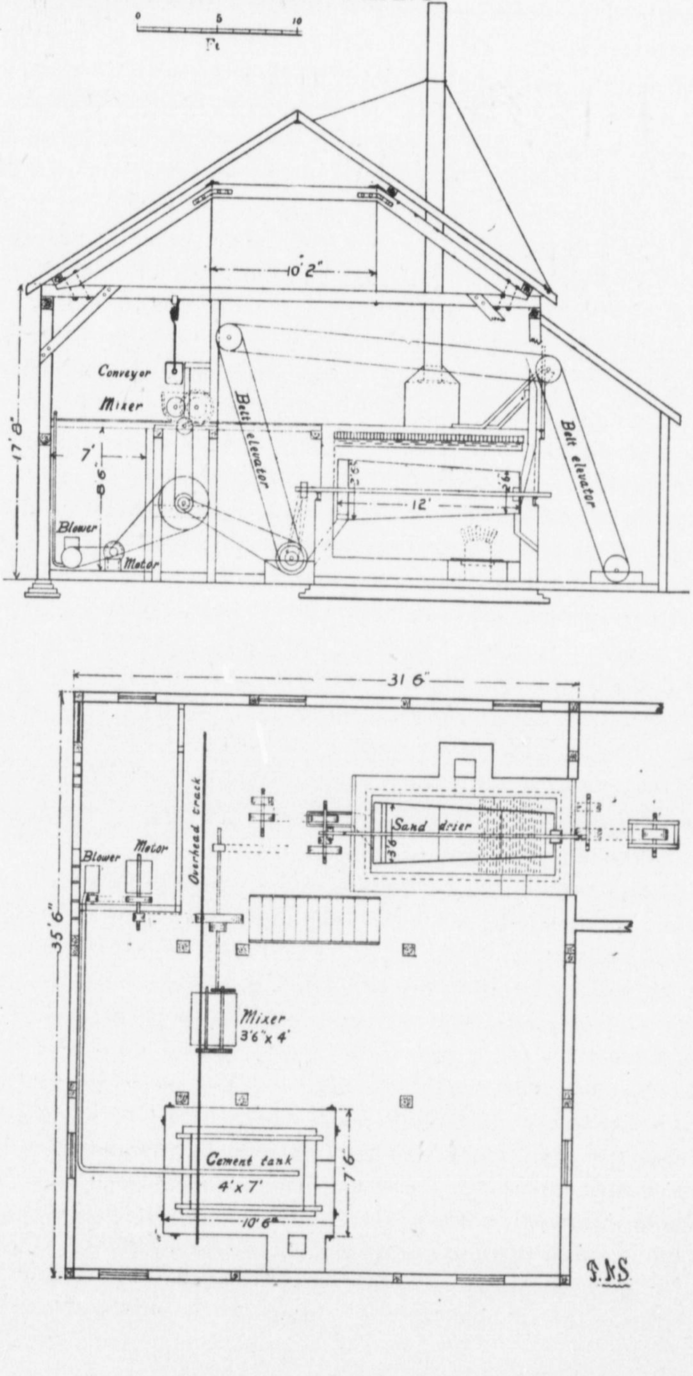
*All these analyses were made in the laboratory in connection with the City Engineer's Department of this city.

The plant in which the material is prepared for work is shown in the Plate, although for any extensive piece of work two or three kettles and as many sand drums would be necessary. The refined asphalt, which has been previously weighed, is placed in the cement tank, and the fluxing material (residuum oil or maltha) is added, preferably hot, until the proportion is arrived at which is most desirable for the work in hand. This must be varied with the circumstances and the object for which the cement is required. Thus in the case of our reservoir lining 15-18 per cent. by weight of fluxing material would be used for the cement in the second layer, while this proportion would be decreased for the final coat. The exact proportions, however, can only be fixed after an examination of the asphalt and oil in the laboratory. The bottom of the tank is protected against the direct action of the heat by a brick arch, the products of combustion being finally allowed to go around the tank before going up the flue. Agitation is provided by either direct mechanical means, as with paddles, or by means of compressed air escaping through a cast iron perforated pipe running along the bottom of the tank. The latter device is very satisfactory, for while it keeps up a thorough agitation the air escaping at the bottom of the tank helps to keep the contents from becoming unduly heated there, thus injuring the material. It has been objected to this method that the air may have a deteriorative effect on the asphalt by oxidizing the petrolene, but no fears need be entertained in this regard if the temperature does not rise above 325° F., and 300 degrees is quite enough for all ordinary conditions.

The preparation of the sand is next to be considered. In quality, it should be clean and free from all dirt. A considerable gradation in size is a desideratum, and if the sand does not contain 10 per cent. of fine, clean mineral matter, passing through a sieve of 100 meshes to the linear inch, this should be provided by substituting 10-15 per cent. of finely ground limestone for a part of the sand. The sand is raised by belt elevators, and dropped into the inclined revolving drums, in which it is dried. On coming out through a sieve of 10 meshes to the inch attached to the end of the drum to separate the large material it is elevated again to the mixing floor, where it should arrive at a temperature of 300° F. On this floor stands the mixer, a pug-mill with two horizontal shafts, to which are attached radiating blades, which work in and out among one another, producing a most thorough mixture. A conveyer running along an overhead track carries the sand (about 730 pounds) to the mixer, into which it is

ASPHALT REPAIRING PLANT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5
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Conveyor
Mixer
Belt elevator
Belt elevator
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7'
8' 6"
12'
Blower
Motor
31' 6"
35' 6"
Overhead track
Sand drier
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Blower
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Mixer
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Cement tank
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dumped. A similar vessel holding about 140 pounds of cement is run from the cement tank, and the cement is skilfully dumped into the mixer on top of the sand. In one and one-quarter to one and one-half minutes the mixing is completed, and by pulling a lever the sliding bottom is thrown back and the charge falls into the wagon waiting below. The above processes are similar to those in preparing the asphalt paving mixture, in which work the plant is fitted up with every convenience to facilitate the work and provide a large output in a short time. If an asphalt paving plant is available within two or three miles of the work, all the better; but, if not, a temporary plant may be cheaply rigged out, consisting of a mixer, two melting tanks, one or more sand driers, and a portable engine, to which the mixer and sand drums are geared. This will do the work in a satisfactory manner.

It is needless to point out that the most careful watch should be kept on all stages of the operation in the plant by some person thoroughly familiar with the technology of the subject. A laboratory for testing is an important adjunct to the plant, where systematic records of the work are prepared from tests made there. The consistency of the asphaltic cement may be controlled to a nicety by a liberal use of the penetration machine.

To proceed with the practical construction of the reservoir lining. The first layer of cement has been poured on and ironed with hot smoothing irons. On this the mixture above described is placed; this should not arrive on the site of the work with a temperature below 250° F., and it is a critical operation laying it with the temperature of the air below 45° F., as the material cools on the surface before sufficient compression can be applied. The work is carried on in strips 10 feet wide, the material being raked out, rolled with hot rollers, and then ironed as above, and finished with the steam roller where possible. Rows of anchor spikes (made of pieces of scrap iron 1″ x ⅛″ x 7″) are driven in at one-foot intervals through the warm material to bind it to the slope, each alternate spike being driven in flush with the surface, the others being left to support planks to enable the men to ascend to the work above. When the finishing coat of asphaltic cement is to be applied all remaining spikes are driven in, and any dirt which may have fallen on the surface is swept off. The cement is poured over the surface and well ironed into the layer underneath. When finished, this surface should present a bright glossy appearance, and be from one-eighth to one-quarter inch thick and of the consistency of leather. The cost of this lining depends largely on the situation in which the work is done, but should be between $1.00 and $1.25 per square yard.

If the soil contains water, this must be got rid of by suitable drainage, or it will seriously impede the progress of the work. A very ingenious method of removing this water is that devised by Mr. James D. Schuyler, M.Am. Soc. C.E., who has constructed a number of reservoir linings in this manner in the Western States; it consists in cutting deep drains as far up the slopes on both sides as any water is to be found, filling them with broken stones to a depth of one foot, and then covering with boards and filling up with earth again. These drains converge to wells in the bottom of the reservoir, in which sections of twelve-inch cast-iron pipes are inserted, with the bell end turned upward. These were kept bailed out while the work was in progress, the asphalt being brought up around each, and a tight connection made by means of the cement. When the work was completed, cast-iron tops were fitted to these pipes, in the centre of which was a flap valve about two inches in diameter of leather, weighed down by a disc of iron sufficient to sustain a pressure of a few ounces from the water confined in the well. By this means it is evident that the asphalt lining will not have to sustain any material stress because of the subsoil water when the reservoir is empty, and no leakage can take place when the pressure of the water in the reservoir exceeds that of the water underneath.

A method of lining reservoirs with an asphaltic concrete has been described* which, although resembling the above in principle, might be mentioned. The mixture consisted of twenty-five parts clean sand, seventy-five of gravel, and ten of asphaltic cement, the operations being carried on as usual, except that the concrete was tamped and then rolled with hot rollers. The thickness of this lining was on the bottom three and one-half inches, running down to two and one-half inches near the top of the slopes, the total cost being $1.15 per square yard.

An account of the magnificent system of waterworks which have been just completed for the city of Portland, Oregon, has recently come under my notice, and, as asphaltum played a very important part in the construction of the reservoirs, it might be interesting to give an outline of this work, and the manner in which the asphalt was used, as it is somewhat unique.

The water is led from the Bull Run River through a steel conduit (varying in diameter from 35″ to 42″) for twenty-four miles to the high service distributing reservoir at Mount Tabor, 400 feet above and six miles from the city. The system also includes three other reservoirs, two of which are located in the city parks, the combined capacity of all these reservoirs being 68,000,000 gallons. The head works at the Bull Run River are at an elevation of 710 feet above the level of the Willamette River at Portland. The surplus energy of the water due to this fall is utilized for the generation of electricity for lighting purposes.

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*"Asphaltum in Irrigation Works," by Mr. Purcell, in Trans. Inst. C.E., Vol. 90.

Three of these reservoirs referred to are lined with concrete, strengthened with twisted iron bars, and finished with pure asphaltic cement, while the remaining one is lined with a double course of brick laid in asphaltum. The construction of the latter is especially interesting. Each brick before being laid is dipped in asphaltic cement made, as above described, with pure Californian asphalt and maltha. When the first course was finished the surface was given a good coat of cement, on which the next course of brick was laid in the opposite direction, the surface being finished off with a final coat of asphaltic cement.

This reservoir has a capacity of 22,000,000 gallons, the slopes being one and a half to one. As an instance of the strength and quality of this lining the following case is instructive. A large boulder had been left in one of the slopes. As the surrounding earth had not been sufficiently compressed settlement occurred to the extent of eight inches about the stone, without, however, causing the least fracture, the lining being still perfectly tight.

All gate houses and water chambers in connection with this system are lined with asphaltum.

The extensive and elaborate nature of these works may be inferred when we consider that the estimated cost of the system complete amounted to $3,518,896. Mr. James D. Schuyler, previously referred to, who is one of the most eminent of American hydraulic engineers, had charge of the work.

Asphaltic Masonry.—Mr. W. C. Ambrose, M.Am. Soc. C.E.,* describes a very successful use of asphaltum in the construction of sea walls. The situation was on the Pacific coast, where a railway was built along the top of the bluffs facing the ocean for several miles. Owing to the unstable nature of the strata, the sea was gradually encroaching on the land, so that some method of protection against its force became imperative. Piling was impracticable on account of the bed rock, and the building of a concrete wall was beset with many difficulties, besides being expensive there. It was decided to build a wall of stone, cemented with asphaltum obtained from a mine in the locality.

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* Trans. Am. Soc. C.E., Vol. 24.

The wall was made six feet wide at the base, two feet wide at the top, and nine feet high, the back being built vertical and close up against the cliff. The mode of construction was simple. A layer of stone was laid, then melted asphalt was poured on, then another layer of stone was placed in position and more asphalt added to fill up all interstices and adhere to the layer below. The fact that no vibration is caused by shock in a wall like this may account for its success.

For many years, the use of asphaltic concrete as a foundation for heavy machinery has become prevalent in Europe, as it has been found to solve the question of vibration simply and absolutely. This it does, owing to its plasticity and entire want of vibration under heavy shock, and, therefore, in such cases, is very superior to ordinary concrete. The proportions adopted in a case of its application in New York as a foundation for heavy steam and drop hammers were :

Asphaltic cement	8½	per cent.
Lime dust	6½	"
Sand	36	"
Crushed limestone	49	"
	100	

Total quantity made at once, *i.e.*, one batch, weighs 820 pounds.

The foundation is encased in a wooden box, firmly braced with rods, and the material was deposited in layers four inches deep, each being firmly tamped before being covered by the next. With such a foundation, no shock can be felt in the adjacent buildings, with all the heavy machinery running right beside them.

In California, where the natural asphaltum is so abundant, it is further used in the foundations and walls of buildings. It has thus been used in building some of the finest mansions in the state. The object for which it is applied is to prevent damp from rising in the walls from the subsoil; a few of the lower course being laid in asphalt will effectually prevent this. It is coming more and more into use in the Western States, replacing Portland cement in many cases.

MINOR USES.—As a preserver of piling in the sea against the teredo and other such enemies, a coat of asphaltum is very efficient ; also it makes one of the best coatings for iron pipe, and is much used in this capacity in the numerous hydraulic works of California.

As a roofing material it is superior to coal tar, being more stable, and not losing its lighter oils, and becoming brittle on exposure to the weather.

A few of the well-known uses to which asphaltum is put in the arts will be merely mentioned, the most important of these being: in electric insulation, in the manufacture of fine varnishes, in photography, photolithography, and photo-engraving, in the lining of wooden flumes and vats, and in the protection of these from the action of chemicals.

Examples might be multiplied in which this invaluable material, whose possibilties are perhaps all too little known and understood by engineers generally, has been made to fill a few of the wants of this age of advance. The foregoing is intended as a simple digest of the principal uses to which this material has been put, with the object of placing these in such a form as to give the members of this Society a comprehensive view of the part which asphalt may take in engineering construction.

Toronto, Ont., Feb. 23, 1895.

DISCUSSION

Dr. Ellis.—When Mr. Speller began to work at asphalt, he found very little help from the published works of other chemists. Mr. Speller has done much careful painstaking work in this difficult field. The question what relation there is between the chemical composition and the physical properties of asphalt is one of great interest, but one of which next to nothing is known; indeed, our knowledge of the chemical composition of asphalt is of the vaguest.

Mr. Speller's work will help to solve these very interesting problems in applied chemistry.

Mr. C. H. Mitchell.—I consider Mr. Speller's paper on asphaltum of great value, particularly at this stage of its success as a matertial of engineering. True, the paper suggests mere possibilities, and does not pretend to do more than present a synopsis of the valuable uses to which the material can be put. We have been so apt to consider the use of asphalt to be relegated to only one department—that of paving—that the suggestions in Mr. Speller's outline have appeared quite novel. This has been caused for the most part, perhaps, through ignorance of the nature of the substance.

The result obtained in the tests which the author has presented are certainly interesting. I had always been of the opinion, with my own slight acquaintance with asphalt, that in our climate the use of the substance as a cement would be very hazardous, on account of the apparent difficulty of making secure and homogeneous joints to withstand extremes of temperature. From the tests which Mr. Speller quotes, however, it appears that with a large factor of safety the tensile strength should be sufficiently grea to permit of its limited use in masonry construction. In our climate, we are subject to temperatures of from, say, 20° below zero to 100° above, where masonry would be concerned. It would, no doubt, be difficult to make actual tests on asphaltic cement under these conditions, but it seems to me that before we can place very much faith in the general use of asphalt as a cement we must have tests under these temperatures. Then, too, it appears from rough observation that the rates of contraction of asphaltum by cold air are greater than those of stone or brick, which fact is not to be overlooked. Of course, the substance is very elastic, but it seems that this decreases at low temperature. I have found no figures giving these rates, and if the writer can give us such it would be acceptable as general information.

The use of asphalt in reservoir lining seems to have grown much in favor in the West, where, of course, it is cheaper. There is, indeed, much in its favor, especially the fact that it needs little foundation. As far as I can learn, literature on the details of the construction is not plentiful. Mr. Speller has given us a brief outline of such; if he could indicate references on the subject, it would be of value to us in familiarizing ourselves with it. Has there been as yet any objection found to this lining from a sanitary point of view? Would the organic matter have any action on the water, and would the taste be affected?

The roadway department of Toronto seems to have gone into the subject of asphalt to a great extent. Could Mr. Speller inform us as to the comparative results with other similar series of tests, in other places, in reference to tensile and crushing strength?

Mr. F. N. Speller.—In reply to Mr. Mitchell, I must say it would be certainly valuable to obtain tests at the extremely low temperature mentioned by Mr. Mitchell, in most cases, though I think that the masonry construction would be subjected to less extremes of temperature than those mentioned above. In the case of foundations, they would be protected from such extremes largely by the surrounding earth, and the poor conducting material with which they were built. The asphaltic cement must, of course, be manufactured for the particular conditions of temperature which it is required to stand, no one formula or penetration being applicable for every place and situation.

The elasticity doubtless decreases with the temperature, but it will be observed that the tensile strength increases at the same time, although the limit to this increase has not yet been found. A curious factor in the success of the sea wall described in the above paper seems to have been that although, when the tide was out, the wall was exposed to the severe rays of a California sun, which, of course, diminished the strength of the asphalt, yet when the water returned and strength was required the very would-be destroying agent supplied this resistance by cooling the wall. As to the contraction, the difficulties in obtaining the rate of the same are obvious, owing to the tendency of the material to flow. I have watched Clifford Richardson, U.S. Government chemist and expert in asphalt, in his laboratory at Washington, conducting experiments to this end with cylinders of asphalt eight inches long, and after taking every known precaution, and making numerous experiments, the results were small, but discordant, some actually showing an expansion on cooling, which, of course, means that the figures obtained were unreliable, and also that the rate of expansion is probably low. It is highly desirable that the co-efficient of expansion should be determined, and I intend trying an indirect method for the solution of this problem by careful determinations of the specific gravity (by the bottle) at different temperatures.

The literature on the subject of reservoir lining is exceedingly meagre in quantity. A paper by Mr. Schuyler, in Transactions of the American Society of Civil Engineers, Vol. xxvii., 1892, is the only thing I know of in that line. A large part of the information which I have endeavored to embody in the above imperfect attempt has been obtained by personal correspondence. As the Portland system of waterworks, to which I have briefly referred, is only just finished, we have heard little about it in the engineering papers so far, and I desire to express my thanks to Mr. J. S. Jackson, contractor for the asphalt work there, for a detailed account of the work, with which he was kind enough to furnish me.

One of the advantages of the asphalt lining, as I understand, is that it is perfectly sanitary, and imparts no taste to the water.

With regard to the last question of Mr. Mitchell, I would say that when the tests referred to were started no knowledge of any similar line of work was to hand, and from diligent inquiries since I find that very little seems to have been done in that line, which is surprising, as it seems to be a natural and practical mode of test. In order to draw out some information on the matter, the writer published a short account of his work in the *Paving and Municipal Engineering Journal* (November, 1894), and received, as a result, considerable correspondence on the matter of an inquiring nature. The only account of previous experiments was from a gentleman who recently had made such, using a breaking cross section of one-eighth square inch, applying the stress as quickly as possible, and who was surprised to obtain results twice as great as those given above.

It is needless to point out that standard uniform methods must be adhered to in this matter, or the results will be practically useless, except, perhaps, to the person making them.

HARDENING AND TEMPERING STEEL

E. F. Shipe, '96.

In presenting this paper to the Society, it is necessary to state that this is not a discussion of the subject in its broadest sense, but rather a view from the standpoint of a workman engaged in practical shop work.

In dealing with iron, in its various forms, there are no other two properties of such value as those steel alone possesses, namely, hardening and tempering, which enable us to work different materials into any desired shape, and a knowledge of the best methods of getting good tools from steel is a very important part of an engineer's education.

The terms, hardening and tempering, are used to describe the two principal operations in preparing steel for tools, closely connected with which are forging and annealing, the character and quality of the work often depending quite as much on the care given the steel before being hardened and tempered as upon the last-mentioned operations.

In forging steel that is afterwards to be tempered, it is not sufficient to hammer away until the required shape is secured, for in hardening there will be considerable straining in the steel, which must not be made greater by poor forging.

The grain in steel, or, at least, the line along which it flows easiest, is always lengthwise of the bar, and should be kept, as nearly as possible, straight, or in even curves, and not violently driven to one side at a sharp angle.

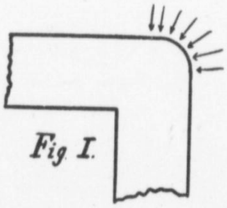

Fig I.

In giving a new shape to a piece of steel, it should be driven gradually into the desired shape, and the flow of the metal aided by proper hammering; for example, in bending a sharp corner, as in Fig. I., the hot steel is laid on the anvil, and the outer half forced down into its position by striking on the end only, the fibres of the steel being stretched at the outside, or compressed at the inside, the inside fibres, however, being cooled by contact with the anvil, the outside ones are compelled to stretch beyond their limit, and small cracks will be formed or started, which will rapidly develop when the piece is hardened. To prevent this straining of the steel, the hammer should be used on top and around the corner, by this means driving the fibres together and stretching them by the blows in the direction they are to assume. These blows should be evenly distributed over the surface, and during the time the heavier blows are bending the piece around.

If the piece be flat, and it is desired to have it square in the corner, work on the sides should alternate with that on the bend, and, when the piece is finished, the metal will appear somewhat rounded at the corner, as in Fig. II., the lines passing around in curves instead of making angles.

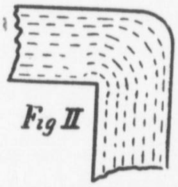
Fig II

Butt-ending or stoving—that is, striking a bar on the end to enlarge it—is a common but very poor way of treating steel that is afterwards to be tempered. There is little chance to keep the fibres compacted, and the chief part of the work falls on the centre, which becomes more dense than the remainder. Such treatment, if carried to any extent, almost invariably produces cracks or checks all around the end, as in Fig. III., and makes a piece it is impossible to harden without cracking.

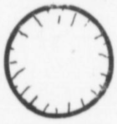
Fig III.

All pieces that are forged should receive practically the same treatment all over, in order that the density, which is increased by hammering, may be as uniform as possible. As a piece gets cooler on the anvil, the blows should get lighter, for when the steel is hot it is easily forced to flow from under the hammer, but, as it gets cooler, it resists this action, and the blows tend to compress the fibres, and will cause surface strains unless they are lighter. In forging small tools, as chisels, lathe tools, and the like, so much care is not needed, but it is best to hammer uniformly, keeping the stock as nearly square as practical, so that the effect of the blows will be even throughout the piece.

During the process of forging, great care should be used so as not to heat the steel too hot. Above a bright red heat, steel readily takes up inpurities from the fire, and, on hardening, it becomes quite granular, and entirely worthless for cutting tools, though it may look all right. In cases where steel has been "burned," as such overheating is called in the shop, the only safe plan is to cut off all that is injured.

No matter how carefully steel may have been forged, there will be certain strains in parts, and some places will be harder than others from contact with the cold anvil. To modify these conditions and make the piece more easily worked, it is generally annealed or softened, which is done by heating to a good red heat, covering with lime, ashes, or charcoal, and allowing it to cool slowly. If heated hot enough, any strains that may have been caused by the hammering will have a chance to adjust themselves.

If the piece be small and of a regular shape, a very good and quick plan is to "water anneal." This is done by quenching the steel in water after it has cooled from bright red until it just shows red in the dark. This method leaves the steel in a very "open" condition, so that it works nicely with a file.

After forging and annealing, nearly all tools, except the simpler ones, such as chisels and lathe tools, are machined to the proper shape before being tempered. Where it is possible, it is best to temper just as the work leaves the hammer, for the outer surface is close-grained from the working it has received, and the tool will do better service than if this thin layer be ground away.

Owing to the many grades of steel, it is difficult to describe exactly the processes used to harden them; but in general, for common tool steel, all that is required is that it be heated a good red and then suddenly cooled. Of course, there are many ways of accomplishing this, varying from heavy armor plate heated in reverberatory furnaces and chilled in immense shower baths down to the small drills used by watchmakers, which are heated in the flame of an alcohol lamp and chilled by waving in the air.

We may divide the work of hardening and tempering in the ordinary shop into three classes:

First, such tools as are hardened for only a part of their length, and the temper drawn by using the heat that remains in the rest of the tool. In this class are cold chisels, flat drills, lathe tools, etc.

Second, tools that are hardened all over, and tempered by applying heat from some outside source. In this class are milling cutters, reamers, twist drills, and dies for many kinds of work, as well as springs of various sorts.

The third class includes tools, dies, and parts of machines that are required to be as hard as water will make them, and in which the temper is not drawn at all, or else at the same time as the hardening.

The first class contains the greater part of the work in tempering done in the ordinary shop, and every mechanic should know the various ways of doing it properly.

Having first seen that the piece or tool is in the desired shape, the next thing is to heat it to a good red heat. This will vary in different classes of steel, but should never be more than just enough to harden in the particular quenching fluid it is intended to use. It is best to use a charcoal fire, but, where this cannot be had, a coal fire, well burned down and clean, may be used. The addition of a handful of common salt will keep the work free from scale, and aid in obtaining uniform results. The article should be drawn from the fire as soon as it is uniformly heated over the part it is desired to temper, as longer exposure to the fire gives more opportunity for injurious elements to combine with the steel. In heating a tool having a light point and a heavy body, as ordinary cold chisels or lathe tools, it is best to place the point well through the fire and heat the body of the tool first, then draw in until the point is at the required temperature. After heating properly, if the piece is to be hardened, it is drawn from the fire and plunged into some fluid which will cool it suddenly.

In the choice of quenching fluids there is much difference of opinion amongst those engaged in this kind of work ; but clear, cold salt water will harden about as hard as any fluid except mercury, which, of course, is not to be had in the average shop.

Different workmen advocate the addition of various substances to the water as an aid in hardening, but the general utility of these is open to question, since equally good results are obtained with clear water. For some work oil is used, its effect not being so marked as that of water, and work is less liable to crack, which is also often prevented by cooling in hot water.

In dipping a tool, suitable tongs should be provided, so that it may be held securely in any desired position, and that part of the tool which is to be the cutting edge should strike the water first. I here refer only to the common class of bench or lathe tools having a comparatively short cutting edge. Only as much should be hardened as will be used before the tool must be redressed, and, to prevent the line of hardening being sharply marked, the tool should be drawn in and out of the water for a short distance while it is cooling.

Practice alone can determine just how long to cool the hardened part, but it will be found best to cool so that the heat left in the body of the tool will be but little above that necessary to draw the required color, for the piece will be tougher if this be drawn slowly instead of rapidly, and the colors will occupy a wider space and give one a better chance to secure the exact temper required.

After dipping a tool to harden it, it is roughly brightened on the hardened part by rubbing with a piece of stone or emery cloth, which makes a bright clean surface, where the colors are easily distinguished from each other. These colors, as they appear on steel as it is heated, serve to indicate the temperature rather than the hardness, for they will show on a piece of polished iron as well as on hardened steel. We, therefore, must make sure that the tool was hardened before we attempt to draw the temper, or the tool will be worthless, so far as cutting qualities are concerned, although of the proper color. If quite hard and clean, steel has a mottled-gray appearance as it is taken from the hardening bath, but, if at all in doubt, it is best to try if an old file will cut it. If it will not, the piece is hard, and the drawing of the temper may be completed.

The colors, as they appear on hardened steel, change from light straw to dark straw, brown, purple, blue, blue tinged with green down to gray, when all the hardness has been practically removed. These colors are said to be caused by oxidation, and this being increased by heat, up to a certain point, we get the various colors. The fact is, however, of more importance to us than the theory.

In deciding upon any certain color for a tool, the work it is to do and the grade of steel used must be known by the operator to get the best results. It is best to use but one grade of steel for each class of tools—and this should be a good grade—in order that the men may become familiar with it, and find, by experiment, the particular temper best adapted for the work it is to do. In general, a tool should be left as hard as possible, and still stand the work without crumbling. For most steel, a good straw color is used for ordinary work in cast or wrought iron, while for working steel tools are left a light straw color.

In the case of thin tools, only the cutting edge should be hard, and the back or underside should be drawn well into purple or blue, in order that it may be tougher and more elastic. Cold chisels vary in color from dark-brown to blue, according to the work they are to do, and should be nearly uniform in color within about one-half inch of the end to allow for grinding.

Only by experience can one learn to have just the proper amount of heat in the body of the tool to do the drawing, although the heat may be easily increased by placing the tool over the fire or on a hot piece of metal. Very light work, in which the color is apt to run too rapidly, is best tempered by using a gas jet after hardening and polishing, by means of which one may have ample time to check the cooling at the proper moment.

In tempering tools of the second class—such as milling cutters, reamers, various sorts of dies, and the like—considerable difficulty is experienced in obtaining uniform results on account of the great variety of shapes.

Tools that are practically uniform in cross section as reamers or taps need to be evenly heated, which is best done by keeping them turning in the fire. They are dipped endwise to harden. After polishing, the temper may be drawn in melted lead, hot sand, or, very conveniently, in a piece of gas pipe kept hot in the forge fire, the progress of the work being easily noted in the last method, and it is convenient. The shanks of such tools are always drawn to a dark-blue, in order that they may not snap off under sudden strains. Long pieces of this class will spring, even under the most careful treatment, but may be straightened while at their tempering heat by placing between centres and applying pressure to the higher parts.

Milling cutters and pieces of similar shape are very liable to crack in hardening. If possible, avoid key seats in such tools, or, if they must be provided, have them round on the bottom, as this is not nearly so liable to crack as if square in the corners.

Tools of this class are often hardened in oil, the heat being just enough to insure their hardening. After polishing, they may be drawn in various ways, but a red-hot bar passed through the hole will give good results, and leave the centre soft and the tool less liable to crack than if of uniform hardness throughout.

Dies for cutting out various shapes often assume very complicated forms, and in the tempering of these will be found some very difficult work along this line. Owing to the peculiar shapes, great care is necessary in heating and dipping, so that unequal expansion or contraction may not distort the finished die. On account of the varying nature of this class of work, only a general summary of the points requiring care can be given here.

The selection of the steel is of first importance, and special brands made for such work should be used. The forging and first annealing should be carefully done, and, after rough dressing to nearly the desired shape, it is a good plan to anneal the second time. This will allow of any readjustment that the removal of the outer surface may have allowed, and aids the operator in getting out work that is true and not badly warped. After dressing to final shape, all sharp corners or holes should be filled with dry fire-clay, which prevents access of water to one part more than another, and, by causing uniform cooling, prevents cracking. If there should be a heavy part to the die, this is usually dipped first, in order that it may partly contract before the lighter parts are cooled.

The springing of this class of work often causes considerable trouble, and is often due to uneven heating rather than to the hardening. If a piece, as Fig. IV., be placed on the fire and heated rapidly on the underside, while the top remains exposed to the air and practically cool, it will assume a shape like Fig. V., on account of the expansion of the lower layers. This expansion is about one-eighth of an inch per foot in passing from a black to a red heat, and this must be accommodated in some manner. If thin, the piece bends to allow for part of this expansion, but, if heavy, the hot metal is not strong enough to bend the colder parts, but is forced to compress to relieve the expansion. If now the piece be cooled, this compressed part will contract the usual amount; and, when cold, the piece will be curved just the opposite way to that shown in Fig. V. This will show how needful is slow, even heating, and in this class of work great care is needed at every step.

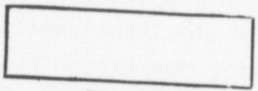

Fig IV.

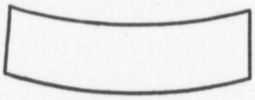

Fig. V.

Such tools or dies have usually only one cutting edge, and the writer has found the use of potassium cyanide (KCN) very beneficial. The addition of a very little causes steel to become hard when chilled at a comparatively low heat, and if the edges of a die be "flowed" over with KCN while at a low red heat it will spread over part in a glass-like film, and the die may be dipped at such a heat that it will harden only where the cyanide has been placed. The remainder of the die will remain soft, and this almost entirely overcomes the danger from cracking. The work is not nearly so liable to be distorted, since the heat and consequent expansion and shrinkage are not so great as when hardened without this treatment.

After having succeeded in hardening this class of work, it is polished, and then generally placed on a heavy piece of red-hot plate with the cutting edge up. The progress of the drawing of the temper is easily observed along the sides or on the top, and when the proper color is reached they are usually quenched in oil.

After hardening steel rings, they are usually found to be somewhat larger on the outside than they were before heating, while the holes are smaller. This is probably due to the outside layers being chilled while held in their expanded shape by the metal in the inside.

Springs of many kinds have their temper drawn by a process called "blazing," a heavy oil being poured over them after hardening, and they are then held over the fire until this burns off. Experience, however, is the only guide in this kind of work, which varies very much.

In the third division we have made are included dies for stamping coins, medals, and similar work, special spindles, and wearing parts of machines, as well as special tools for cutting chilled iron or steel.

The work done by dies in striking coin is very hard, and they are usually made of such a grade of steel as will allow of the dies being hardened without drawing the temper. In heating such work, the engraved surface must not be allowed to scale in the least, the medal dies being heated in charcoal or lead.

In hardening, they are first dipped for a moment in strong acid to thoroughly clean the face, and then placed in a stream of cold water, which strikes the face, such as that from a common water tap. Spindles and wearing surfaces are usually left large enough to be ground to size after hardening. Many different processes are used in doing this class of work, and scarcely two men will be found who use the same means for arriving at the same end. In making tools especially hard for cutting chilled iron, each workman or shop has some particular formula, but the greater part depends on the quality of the steel used rather than on the quenching fluid.

In a few cases it is possible to harden and draw the temper at practically one operation, or, in other words, harden to a less degree than the usual cooling in water produces. As examples of this, I might refer to tinsmiths who temper cold chisels by driving the hot chisel into a bar of lead, the only examples in the common shop being in the tempering of very small drills, chisels; and scribers by heating red-hot and forcing into a bar of soap. This gives a very durable point for this class of work, and is both quick and sure, but must be termed an accident rather than a process in tempering.

There may be many other short ways of tempering that are reliable, and, no doubt, many more are possible; which, therefore, offers plenty of room for the satisfaction of the desire for "original research." The entire subject is one of great practical importance, and will prove of much interest, should any of you decide to try to answer many of the questions that still remain unsettled.

Toronto, Jan. 8, 1895.

GEAR CUTTING

H. V. Haight, '96.

Before proceeding to consider gear cutting, it might be well to look at the different methods of making gear wheels.

Gears may be made in several ways :

(1) They may be cast with the teeth in them.

(2) They may be cast with mortises in them, into which the teeth are afterwards driven.

(3) The teeth may be cast on the gear, but finished by a machine.

(4) The teeth may be cut out of the solid.

Each of these methods has its advantages. When made in quantity, the gears with cast teeth are generally cheaper than those with teeth cut from the solid. I quote from the catalogue of Geo. B. Grant, a manufacturer of both cut and cast gears: "Cast teeth are cheaper only for gears in considerable quantity, unless they are list gears, as special patterns must be made for special gears." Cast teeth are usually stronger than cut ones, as the skin of the metal is the strongest part. Cast iron is the material generally used for cast gears, but those weighing less than half a pound can generally be made cheaper of brass. Where great strength is required, as in a punch or shear, the gears may be cast of mild steel.

In gears with inserted teeth, the teeth are often made of wood, and a gear with wooden teeth, meshing with one with iron teeth, will run with very little noise or friction. Such a pair is often used in mills or factories to connect lines of shafting. In a pair of gears like this the wooden teeth are often made a little thicker than the iron ones, in order that they may be of equal strength.

The third method referred to of making gears is that of casting them with the teeth in, and then finishing these with a machine. This method is only used, so far as I am aware, for heavy gearing, and would appear to be a good method for such, for in order to cut the teeth out of the solid it would be necessary to remove a large amount of metal.

Cut gears, by which is meant those with teeth cut out of the solid, are coming more and more into use all the time. Methods of making these have been so improved as to make them almost as cheap as cast ones. Cut gears have many advantages over cast, for the teeth are more nearly of the theoretical form, and the surfaces are much smoother; as a consequence, the teeth fit better and work with less friction. Another advantage is that they can be made of material which cannot be cast, such as forged steel, sheet brass, fibre or rawhide. The chief advantage of cut gears, however, is their greater accuracy, and in the trains of gearing in screw-cutting lathes, milling machines, clocks, etc., they have come to be a necessity.

In a screw-cutting lathe, for instance, if one gear is to run one-third as fast as the next one, it is not only necessary for it to have three times as many teeth, but at every instant the velocity of one must be three times that of the other. This constant velocity ratio can best be obtained by the use of cut gears.

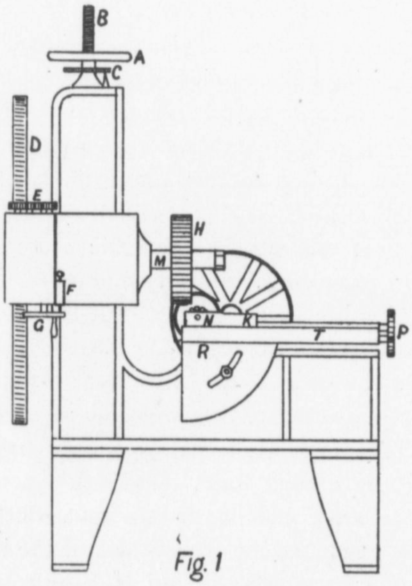

Fig. 1

Fig. 1 represents a gear-cutting machine of a somewhat common type. M is the mandrel upon which is placed the gear to be cut. Upon the same axis as M, and turning with it, is the worm wheel D of the dividing head, this head being for the purpose of dividing the circumference of the gear into parts, equal to the number of teeth required. It consists of the worm gear D, a worm in mesh with it and the change gears E, one of which is connected to the worm, and another to the plate G; the plate G can be turned by the handle, and can be locked after each revolution by the pin F. By placing the proper change gears at E, we may get any number of teeth we wish in the gear H.

The teeth are cut by a rotary cutter N. The saddle R, upon which the cutter spindle is mounted, works in the horizontal slide T, below the gear, and is moved along this slide automatically by a screw and the gears P.

The head which carries the work mandrel and the indexing mechanism is adjusted vertically by the hand wheel A, which turns like a nut on a screw, B, fastened to it. This screw has four threads per inch, and the circumference of the plate C attached to A is divided into 250 parts, so that one division on the plate corresponds to one-thousandth of an inch. This enables the gear to be adjusted vertically, so that the cut will be the exact depth required, which is very important, especially with cycloidal teeth.

In the machine described, the cutter is fed through the gear and stopped automatically, but it is necessary to pull back the slide and turn the indexing mechanism by hand. This type of machine is called half-automatic. The most improved machines are entirely automatic, requiring no attention from the time the gear is put on the mandrel until it is ready to be taken off, which is quite an advantage, as a large gear may easily take half a day to cut, and an entirely automatic machine would require no attention during that time.

Fig. 2 is a cut of an entirely automatic gear cutter, designed for cutting heavy spur gears only. I am indebted to Messrs. Gould & Eberhardt for their kindness in sending me the cut.

The cutters used to cut the teeth have clearance behind the cutting edge, but the shape of a cross section along any radius is the same, which enables the teeth of the cutter to be sharpened on the face without changing their form. The cutters are made in a special machine, which is said to give a theoretically correct form, that is to say, the curve is not a copy of the curve on some cam in the machine, which may itself be far from correct, but is generated by the motions of the machine.

The system of cutters most in use is Brown & Sharpe's, and, as many other manufacturers of gears and cutters follow this system, it may be well to give a short description of it. First, let us note some of the general terms used in describing gears. The curved outline of a tooth is often called its *profile*. That part of the profile which is above the pitch line is called the *face*, that part below the pitch line the *flank*. The whole of he tooth above the pitch surface is called the *point*, that below it the *root*,

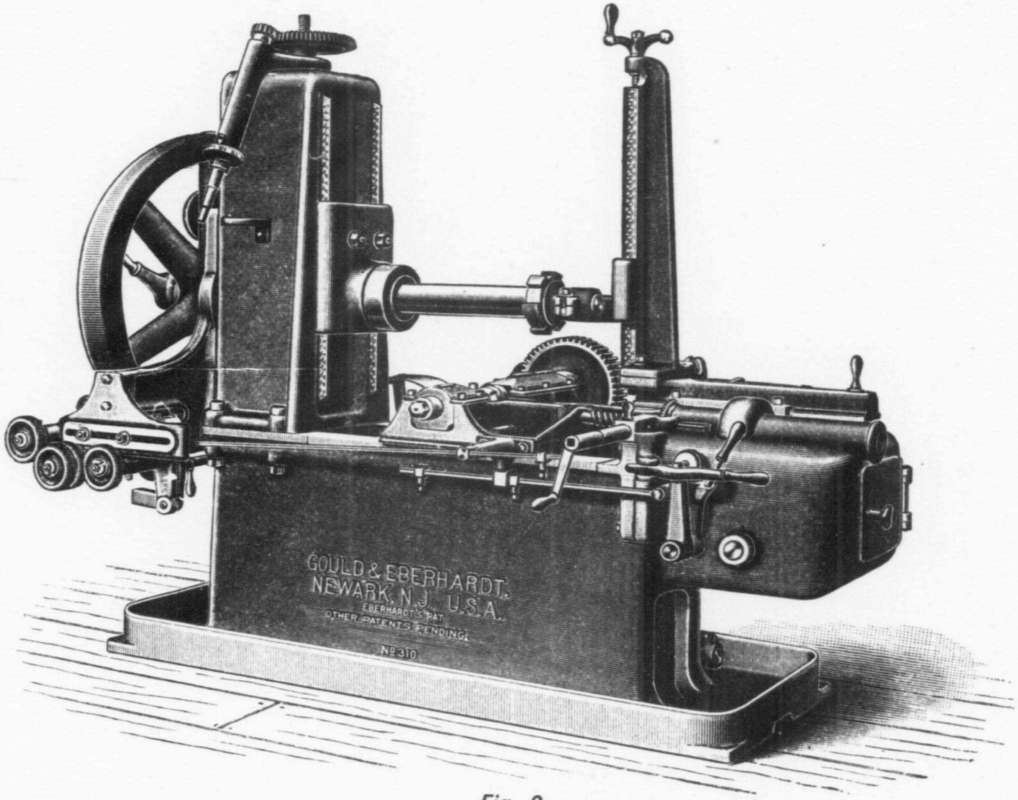
GOULD & EBERHARDT,
NEWARK, N.J. U.S.A.
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Fig. 2

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while the height of the tooth above the pitch line is called the *addendum*.

The size of gear teeth may be given in either *circular* or *diametral pitch*. *Circular pitch* (see Fig. 3) is the width of a tooth and a space at the pitch line, *measured along the pitch line* (if we measure in a straight line, we get what is called *chord pitch*). *Diametral pitch* is the number of teeth to each inch of the pitch diameter, and is evidently equal to 3.1416 divided by the circular pitch ($P = \frac{3.1416}{P^1}$). Note that the circular pitch is given in *inches*, while the diametral pitch is an abstract number.

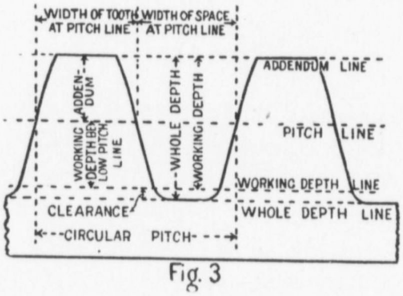

Fig. 3

In Brown & Sharpe's system of gearing, for cut gears, the addendum, or height above the pitch line, and the working depth below the pitch line (see Fig. 3), are each made equal to one inch divided by the diametral pitch, and the clearance at the bottom of the space $\frac{1}{20}$ of the circular pitch. Some manufacturers make the clearance $\frac{1}{16}$ of the working depth of the tooth, or about $\frac{1}{25}$ of the circular pitch. The width of the tooth at the pitch line is made equal to the width of the space at the pitch line.

In the Brown & Sharpe system the fewest number of teeth cut in a gear (either involute or cycloidal form) is twelve, the other extreme, of course, being a rack. For involute gears the angle of pressure is 14½ degrees, and eight cutters of each pitch are required to cut a complete set of gears, from a twelve-tooth pinion to a rack. For cycloidal gears, the diameter of the describing circle is equal to the radius of the fifteen-tooth gear, twenty-four cutters being required for each pitch.

Gears with involute teeth are used to a greater extent than those with cycloidal teeth (the manufacturers call them epicycloidal) for two reasons—first, involute gears require fewer cutters; second, they will run at different distances between centres and maintain a constant velocity ratio. In the change gears of a lathe, for instance, a pair of involute gears will run quite well when half out of mesh, while with a pair of epicycloidal gears in the same place there would be likely to be considerable noise, and the velocity ratio would vary. A disadvantage of involute gears is their tendency to crowd between centres, and for this reason the epicycloidal teeth are preferred for heavy gearing.

The following extract from a letter from a firm which manufactures gears may be of interest, as it shows methods in actual use by manufacturers:

"We have in our works both Brown & Sharpe and Gould & Eberhardt machines. All our gears are cut with Brown & Sharpe patent involute cutters. We believe this form to be far preferable for general requirements, and, indeed, in our judgment, it is very doubtful if the epicycloidal form possesses any points of real advantage.

"We measure the teeth on all gears with compound vernier calipers, especially constructed for gear teeth. These calipers enable us to measure the distance from the top of the tooth to the pitch line within one-thousandth of an inch, and at the same time to measure the exact thickness at the pitch line. All our gears are tested on special gear-testing machines. The Spur gear-tester carries two studs which are exactly perpendicular to the bed of the machine, and is provided with a vernier, which enables us to test the gears at exactly the correct centre distance. The Bevel gear-tester is provided with two spindles exactly perpendicular to each other, and the central lines of these two spindles are in the same plane.

"Very truly yours,

"Leland, Faulconer & Norton Co."

Large gears and racks are often cut by some form of planing process.

Fig. 4 represents a shaper arranged for cutting racks. This shaper is a large one (16 in. stroke, 66 in. travel) of the style in which the work remains stationary, and the feeding is done by moving the saddle in which the ram works. The principal change necessary to arrange this machine for cutting racks was some method by which the saddle could be moved to a distance just equal to the pitch of the rack, after cutting each tooth. This was accomplished by putting an index plate A on an arbor of one of the feed gears. The plate is stationary, and in front of it is an index arm, which revolves with the gear, every revolution of which moves the saddle one-quarter of an inch. Near the edge of the plate is a row of 250 holes, thus one division on the plate corresponds to .001 of an inch. The two arms D and E of the spacer may be clamped together in any position, and thus save the trouble of counting the holes every time.

Let us note briefly the process of cutting a rack on this shaper. Suppose it is three pitch, the circular pitch corresponding to this being 1.047 inches. This will take four complete turns of the index arm and 47 spaces, so we set the two arms of the spacer with 48 holes between them,

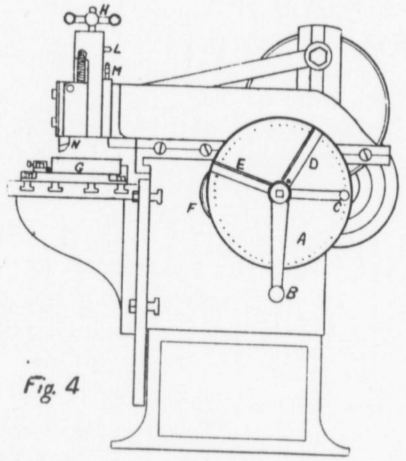

Fig. 4

and the micrometer screw M at the back of the slide for a depth of .719 inches, which is the whole depth of a three-pitch tooth. We put into the tool post a rib tool, as wide as the bottom of the space, and cut a straight groove the depth of the tooth. The index arm is then turned by means of the handle B through four revolutions and 47 spaces and another groove cut, and so on, until the whole rack is cut in this way; then we remove the rib tool and put in a special tool (Fig. 5) the exact shape of

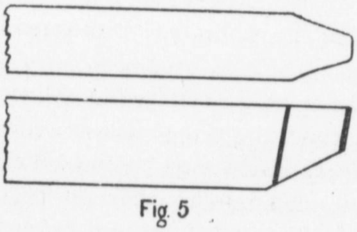

Fig. 5

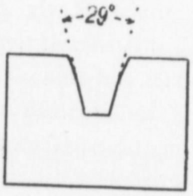

Fig. 6

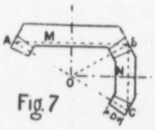

Fig. 7

the space, and cut through as before. This second tool is made by forging and then filing a piece of steel to fit a template like Fig 6. For involute teeth the flanks of the teeth are straight, and at an angle of 29° to one another, and the faces are rounded off slightly to prevent interference when working with a small pinion. This template is also used to set the tool perpendicular to the rack.

In making these templates, and also in laying out pattern gears, the curves are struck with a compass. This does not give the true curves, but it is probably as nearly correct as they could be drawn in any other way without special instruments.

Gears, also, may be planed out on a shaper, but not so readily as it is necessary to have some substitute for the dividing head of the gear cutter. There are, however, a number of gear planing machines made by different firms which are used chiefly for heavy gears and for bevel gears. It is usual, I believe, to cast the gears with the teeth in them and to finish the teeth in the machine; for this reason the machines are called gear-dressing machines.

The following is a short description of one form of gear-dressing machine: The dividing head and the mandrel for the gear are much similar to those in the ordinary gear cutter, while the slide for the tool block is at one side of the gear, about on a level with its axis, and is pivoted at a point in front and two or three feet from the gear. The other end of the slide rests on a cam or former, and as the slide is fed up towards the gear the cam gives the required curve to the tooth. By altering the distance between the cam and the pivot, the pitch can be changed. Some gear planers are provided with a circular saw, which can be put in place of the planer tooth for dressing the teeth of mortise gears.

One of the more difficult problems in gearing is that of cutting good bevel gears. These are usually made in pairs, and are intended to run with their axes at right angles and in the same plane; they are the only kind listed in gear catalogues. Where a pair of bevel wheels are the same size, they are called *mitre wheels.* Fig. 7 shows a pair of bevel gears, N is called the *bevel pinion*, M the *bevel gear*, AB is the *largest pitch diameter* of the pinion, BC that of the gear, D is the *face*, O the apex of the two pitch cones AOB and BOC.

In bevel gears the teeth, instead of being on the surface of a cylinder, as in spur gears, are on the surface of a cone, and if the teeth were theoretically correct their elements, if produced, would meet at the apex of this cone. The curve of the tooth, though similar throughout its length, is not the same size or curvature. I do not think I can do better at this point than to quote from Brown & Sharpe's catalogue (p. 161, 1893):

" The curve of teeth in bevel gears, when correctly formed, changes constantly from one end of the tooth to the other. Therefore, bevel gears whose teeth are produced with a cutter of fixed curve are not theoretically correct, the cutter usually being of a curve that will make the large ends of the teeth the correct form, and of necessity leaves the curves too large at the small ends of the teeth. Small bevel gearing is almost universally produced in this manner, which practically answers the purpose, except when the teeth are very coarse or the gears very small, in which cases their operation is not satisfactory.

"In place of cutting by changing the position of the cutter, etc., the teeth are often filed slightly to round them off to the curve required for their free running. On all bevel gears cut with a cutter of fixed curve it is necessary to cut through *twice*, owing to the necessity of making the thickness of the cutter at the pitch line about .005 inch thinner than the space between the teeth at the smallest *pitch* diameter. As the width of space between the teeth at the largest pitch diameter should be greater than the thickness of the cutter, it must be made so by passing the cutter through the second time."

Let us examine the usual method of cutting bevel gears with a rotary cutter. Fig. 8 represents a bevel gear with one cut made through it by a cutter. The cutter is supposed to be central and the slide at zero; that is, the path C, of the centre of the cutter, is in the same plane as the axis of the gear, in which case neither side of the tooth is in line with the apex of the pitch cone. To get one side of the space true, we may either set the cutter a little to one side, or turn the slide through a small angle.

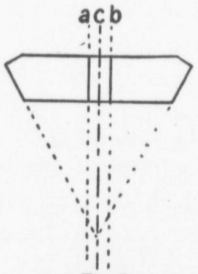

Fig. 8

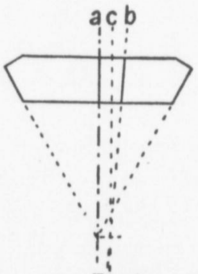

Fig. 9

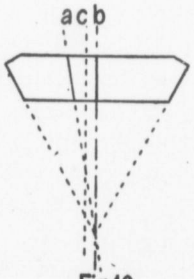

Fig. 10

In the first method we move the cutter to one side a distance equal to half its thickness at the pitch line, revolve the gear in the same direction until the cutter just enters the former cut at the small end of the tooth, and then cut through. This makes side A (Fig. 9) true. We then bring cutter and gear back central and roll the gear and move the cutter to the left, the same as we did before to the right, and cut through again. Fig. 10 shows this cut completed. Both sides of the space will now be true, that is, in line with the apex of the pitch cone, but the space may not be wide enough. The space should be at least as wide as the tooth. If it is not, we may revolve the gear a little more, without moving the cutter over.

In some gear cutters it is inconvenient or impossible to set the cutter over to bring the side of the cutter true, and in that case we may turn the slide through a small angle to bring one side of the cutter true. The gear is revolved as before.

In cutting bevel gears on a universal milling machine, either of the two methods may be used. The position of the cutter being fixed, however, we move the gear, instead of the cutter, to one side, or turn it through an angle.

There is still another point. At what angle (vertically) shall the slide be set? The angle of the pitch cone (COA, Fig. 11) is determined by the ratios of the two gears, the angle of the tops of the teeth, BOA, is a little greater than COA, and the angle of the bottoms of the teeth, DOA, is a little less than COA, by an amount which depends on the pitch of the teeth. The usual practice is to set the cutter to the angle of the bottom of the teeth, although machinists advocate setting the cutter at the angle of the pitch cone.* The reason is more apparent in the case of cycloidal teeth, for, as the faces are usually convex and the flanks concave, the curve changing at the pitch line, if the cutter is the right curve for the large ends of the teeth, and is set at the angle of the bottoms of the teeth (EOA, Fig. 11), then the line where the curve changes will not be along the pitch cone (FO, Fig. 11), where it should be, but along the line FH. This would make the small end of the tooth very bad shape (see Fig. 12). If the cutter slide is set to the angle of the pitch cone, the bottom of the tooth will be along the line EM, which will make the tooth too deep at the small end, but it will be better shape than the preceding.

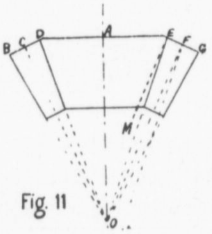

Fig. 11

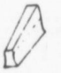
Fig. 12

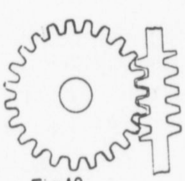
Fig. 13

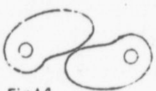
Fig. 14

Bevel gears of coarse pitch are better if cut by some form of planing process. The gear-dressing machine before described is quite suitable for this purpose, as the centre at which the slide is pivoted can be set at the apex of the pitch cone, and every cut of the tool will then be in line with the apex of the pitch cone, and the teeth will be the right curve throughout, provided the curve is correct at one place.

**American Machinist*, April, 1892.

Another subject in connection with gearing is that of worm gears. A worm gear and a worm form a sort of combination of a rack and pinion with a screw and nut. The section (Fig. 13) of a worm and worm gear shows the similarity to the rack and pinion.

The worm is turned in a lathe, the dimensions of the threads (in section) being the same as those of a rack. The tool for turning the worm thread should have its sides straight, and the angle between them should be 29 degrees. The width at the point is about two-thirds the width at the pitch line, and the corners are not rounded off as they are in a rack tool.

The worm gear is usually cut in a gear cutter and then "hobbed." The gear being hollow on the face, it is necessary to take what is called a "drop cut," *i.e.*, the cutter is brought under the centre of the gear and the gear fed down upon it. The cutter, of course, is set at an angle (horizontally), the tangent of this angle being the pitch or lead of the worm thread divided by the circumference of the worm. The teeth made in this way have not the real helical form, but for ordinary purposes they do quite well; but to give the teeth the exact form the gear must be "hobbed."

The hob for any worm gear is almost exactly like the worm for that gear, but is made of steel and has longitudinal grooves, a little deeper than the threads, to give it cutting edges. To hob a worm gear, the hob is put on a mandrel between the lathe centres, and the gear on a vertical mandrel in the tool block, where it is free to turn on its mandrel. The hob is put in mesh with the gear and is revolved; it turns the gear around, just as the worm would, and at the same time cuts out the teeth to the exact form required.

The teeth in the worm gear might be cut altogether by the hob; but unless there were some means of revolving the gear at the correct rate, the spacing would not be likely to come out well, although some gear cutters are so arranged that the worm gears can be cut by the hob alone.

There are other methods of making worm gears. Sometimes they are made just like ordinary spur gears, except that the teeth run at an angle across the face; this is called a straight angular cut. The worm has very little bearing surface on a gear cut in this way, yet these gears are said to work quite well, and as they are much cheaper than drop-cut and hobbed worm gears are used to a considerable extent for elevators.

The worm and worm gear of the dividing head of a gear cutter are made differently still. The worm thread is a sharp block V, and the worm gear is straight on the face, is drop-cut and not hobbed, as hobbing might affect the accuracy of the spacing.

Gears are sometimes made other shapes than circular, to give a varying motion. For instance, a pair of elliptic gears may be used to give a quick return. A pair of irregularly shaped gears may be seen at work on one of the large presses of the Methodist Book and Publishing Company of this city. Fig. 14 will give a rough idea of their shape; they are used to give a variable motion to a chain carrier which removes each paper as it is printed and lays it on the pile. The paper is caught by the forward edge, is carried quickly through the air (to keep it nearly horizontal), and is laid gently on the pile.

A practical example of the time required to cut gears might be interesting.

A certain street railway company cut their own motor gears. For the Edison motors which they use, the pinion has 15 teeth and the gear has 63 teeth, both three pitch, 6-inch face. The pinions are made of steel, the gears sometimes of steel and sometimes of cast iron. It takes about three hours to cut a pinion, five hours to cut a cast-iron gear, and ten hours to cut a steel gear. The gear cutter is of the type called half-automatic, and is somewhat antiquated. The results are very good, however, for this type of machine.

Compare this with the results obtained by the General Electric Company at Schenectady. They have five automatic gear cutters similar to Fig. 2, use duplex cutters in them, and each machine cuts from 10 to 13 cast-iron gears, 23-inch diameter, 4½-inch face, 67 teeth, 3 pitch, in 10 hours. A little calculation will show that the metal to be removed in each of these gears is about four-fifths as much as in the 63-tooth gears before mentioned; thus 10 to 13 of the 67-tooth gears would be equivalent to 8 to 10 of the 63-tooth gears, which is four or five times as many per day as the half-automatic machine could cut. As one man could probably attend to the five machines, he would cut from twenty to twenty-five times as many gears per day as the man with the half-automatic machine.

By methods such as these the cost of cut gears can be brought down nearly to that of cast gears.

Toronto, Ont., February, 1895.

DESCRIPTION OF THE FINLAYSON MARINE PIPE BOILER

ARTHUR E. BLACKWOOD, '95.

During the last few years water tube boilers (the reverse of the old style, wherein the water surrounded the tubes, and the heat passed through) have come prominently to the front. Experience has proved the pipe boilers to be economical of fuel, rapid steam generators, lighter in weight and smaller for equal capacity than any other boiler; they have also been proved to be non-explosive under the highest pressure.

In view of the above facts, the writer will endeavor to explain the construction of the Finlayson marine boiler, which has come under his notice during the past year.

The most important point to be considered in constructing water tube boilers is how to build them so as to get the water divided to as great an extent as possible, or, in other words, to get the greatest number of feet of pipe in the space. There is no doubt that Mr. Finlayson had carefully studied this point, as well as the action of heated particles in a liquid, before designing his boiler, as he has embraced in its construction all the advantages of the drop tube boiler without its disadvantages.

He has provided for the ready escape of steam from the generating pipes by placing them in a vertical position, and so connecting them that their water supply is from the bottom, the advantage of this being in not having the water descending and steam ascending in the game tube.

The fronts and backs of water tube boilers, as generally used, are laid up with fire-brick to about three-quarters the height of the boiler, but it is claimed by Mr. Finlayson (and, in the writer's opinion, very justly so) that the use of the brick ends is a mistake, for the following reasons:

I. The heat taken up by the fire-brick is absolutely wasted.

II. The fire-brick walls are just so much dead weight (which is an important consideration in some small boats).

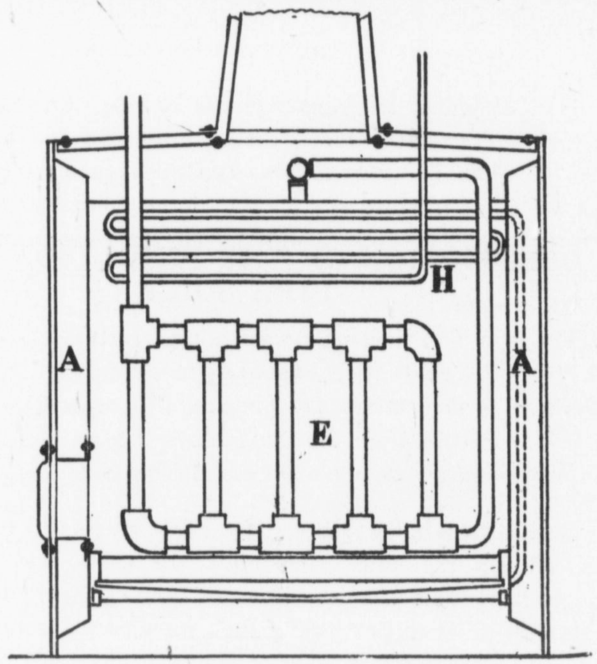

Fig. I.

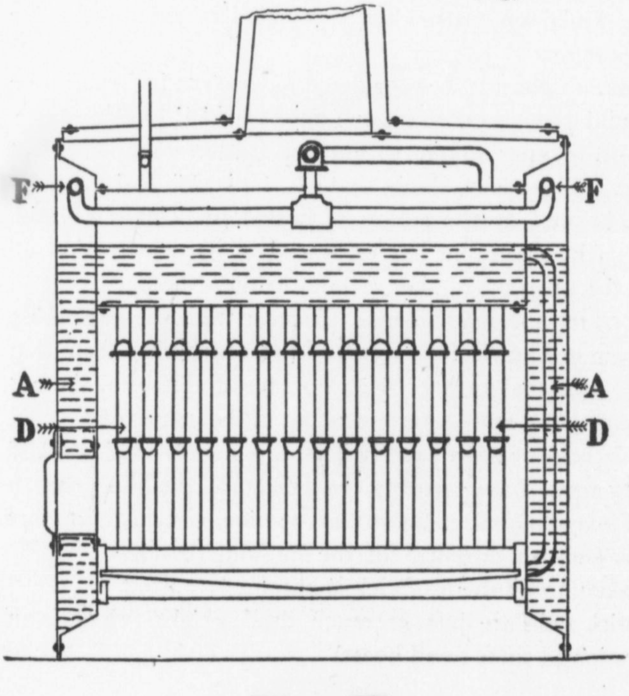

Fig. II.

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III. A sudden jar against a pier in landing or a sudden blow from a heavy sea will very often knock the brick wall into the furnace, and thus cause great liability to fire. On account of these objections to the fire-brick walls, and in order to utilize all the heat possible, as well as to secure a greater water space, thus assuring a constant water level, the boiler under consideration is always built with the water front and back, as shown by AA, Figs. I. and II.

The front and back are similar in construction, the outer plates being each cut from a single sheet of steel $\frac{5}{16}$ inch thick, and the inner or flanged plate from $\frac{1}{4}$ inch steel. The flanging is done by heating the plate red-hot to a distance in from the outer edge of about 8 or 10 inches; it is then placed on a flange block, and the required flange made by hammering. The inner plate is then drilled and riveted to the outer one, stay bolts being placed at regular intervals throughout the water space; the object of these being to strengthen the plates, which would, were the stays not used, be forced further apart by the great pressure they have to support.

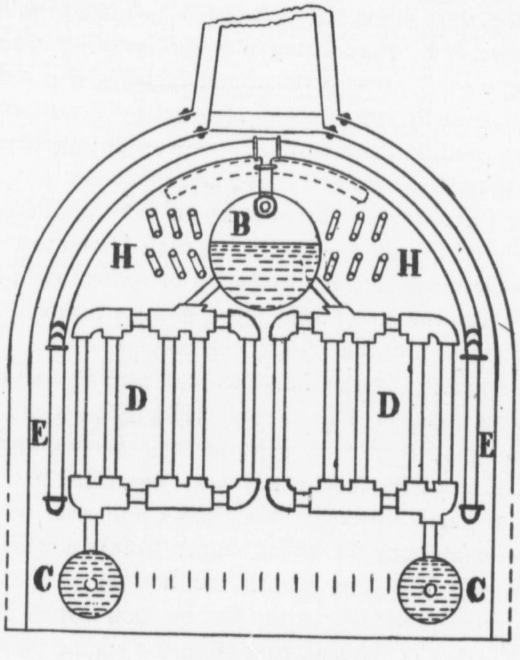

Fig. III.

After the front and back are built, they are fastened together by means of three horizontal steel pipes, which are threaded at both ends and screwed into flanges riveted on the inside sheets. One of these pipes, B, measures 10 inches in diameter, and the other two C, C, 4 inches in diameter. The 10-inch pipe is placed at the top and in the centre of the boiler, the other two being secured one at each side near the bottom, as shown in Fig. III.

The skeleton of the boiler being then complete, the steam-generating loops (D, D, Figs. II. and III.) are made and fitted. These loops consist of five vertical steel pipes connected together by malleable steel castings, manufactured specially for this work. The size of the pipe used in the loops varies according to the power of the boiler, although 1-inch pipe is the average size used.

After the loops are made, they are tested to a water pressure of 400 pounds per square inch before being placed in position in the boiler, the object in testing each of these parts separately being that a defective pipe can be much more easily removed and replaced by a good one before the loop is placed in position than it could be afterwards; besides, caulking at the joints is required in nearly every case, and this could not be done were the loops in their final place. From thirty to forty of these steam-generating loops are used in each boiler, that is, from fifteen to twenty on each side. They are fastened in place by means of vertical right and left hand nipples screwed into the lower side pipes, and by diagonal right and left hand nipples screwed into the 10-inch central pipe.

The next operation is the building and placing in position of the superheating coil. (E, E, Figs. I. and III.) This coil is made of a larger size steel pipe than that used for the generating pipes, and is placed at the side of the boiler and very near the fire. The object of this coil is to catch any water that may come over with the steam, should the boat containing the boiler happen to turn a little on to its side. This water would, of course, fall to the bottom of the coil, and, on account of its close proximity to the fire, be soon turned into steam, and then, rising to the top of the coil, pass off to the engine perfectly dry.

The steam is taken, by means of two bent pipes (F, F, Fig. II.), from as high a point as can be got, and, therefore, starts on its way to the engine as dry as it is possible to secure it at any point in the boiler. It then passes through the superheating coil, already described, and is further dried, so that finally it is received by the engines in a perfectly dry state. It will be noticed, then, that, on account of this coil, it is impossible for water to get into the engine by passing over with the steam.

The feed water coils, as shown by H, H, Figs. I. and III., are now next placed in position, namely, on each side, along the top of the steam-generating loops. This coil is made of a smaller-sized pipe than that used for the loops, and is constructed so as to cause the cold water injected to pass backward and forward five or six times before going into the boiler proper, the water is consequently quite hot when admitted. The feed water is discharged into the lower horizontal pipes, the reason for this being as before stated, that as the heat under the generating pipes causes the steam to rise in them a new supply of water is obtained without it having to come down the same pipe in which the steam is ascending.

The inside of the boiler then being complete, the jacket, or cover, is put on. This cover consists of two sheets of thin steel, packed between with asbestos, and the bottom is a plate of ¼-inch steel.

The necessary safety valves, try cocks, steam gauge, blow-off cocks, water gauge, etc., are then attached, and the boiler is ready for the inspector's test of 400 pounds per square inch.

[Note.—The piping used throughout is a grade of lap-welded steel pipe made specially for boiler work.]

Toronto, Jan. 23, 1895.

SEWAGE DISPOSAL IN ONTARIO

R. W. Thomson, B.A.Sc.

The subject of sewage disposal is becoming of such universal interest that a short sketch of the influences at work and the results accomplished in this direction in our own province may not be out of place here.

For years sanitarians in different parts of the civilized world, more particularly in Europe and America, have heen wrestling with the problem of "sewage disposal" as applied to the requirements of their particular country.

In a new country, where population is sparse and the accumulated wealth is not sufficient to warrant expenditure in the extravagances and refinements, or even the conveniences, of life, the question of sewage disposal is not forced upon the people; but as soon as the population has reached a point of development into towns and cities, so soon do the ordinary laws of health demand artificial means for the removal of the offensive products of civilization from the immediate vicinity of such town or city, and in such a way that its disposal shall not interfere with the rights or privileges of any other place, or even any individual.

In the case of seaport cities the easiest and most economical method is, doubtless, to run the sewage directly to the water, trusting to the diluting and purifying power of this to render it harmless. Even in the case of inland cities situated on lakes or other large bodies of water this method is often the most expedient, if not the most sanitary. However, so eminent an authority as Col. Waring, writing on this subject, says: "So firmly do I believe it to be wrong to wash the organic wastes of our lives into the sea that I should hesitate even to recommend such a course were it not for the greater wrong of keeping them in a putrescible form in the vicinity of dwellings."*

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*"Sewerage and Land Drainage," by Waring.

In the cases mentioned the greatest sufferer from any nuisance that might arise, such as the fouling of its water front or the contamination of its water supply, would be the community itself, and, so long as these unsanitary conditions did not become sufficiently marked as to be prejudicial to the health of the community, no exception should be taken to this method of disposal. But these are not the conditions that obtain in the majority of towns and cities in Ontario, which are situated on a river or other small stream, the pollution of which means the contamination of the water supply of, or the creating of a nuisance to, other places down the stream. This condition involves the question of the consideration of the rights of others, and to such an extent that we would expect to find legislation bearing on the matter. As long ago as 1888, the authority before quoted, writing in this connection, said: "The indications are clear that legislative control of this matter cannot long be delayed, and there is no more intricate or more interesting problem now presented to the sanitarian than the correct solution of this great question of the future." This statement has been strongly supported by subsequent evidence in the way of costly litigation between municipalities and others. Only a few months ago we had a case in point in Ontario, where the municipality of Peterborough issued an injunction to prevent the town emptying its sewage unpurified into the Otonabee River. The courts have not yet decided the matter.

At this date there is in Ontario no statute setting any direct restrictions on the method of disposal or on the quantity or quality of sewage discharged at the outlet, whether that outlet be a lake, river, small stream, or mud puddle. The power of regulating these details is vested in a Provincial Board of Health by the following statute (sec. 30, ch. 205, R.S.O., 1887): "Whenever the establishment of a public water supply or system of sewerage shall be contemplated by the council of any city, town, or village, it shall be the duty of the said council to place itself in communication with the Provincial Board of Health, and to submit to the said board before their adoption all plans in connection with said system.

"It shall be the duty of the Provincial Board of Health to report whether, in its opinion, the said system is calculated to meet the sanitary requirements of the inhabitants of the said municipality, whether any of its provisions are likely to prove prejudicial to the health of any of the said inhabitants, together with any suggestion which it may deem advisable, and to cause copies of said report to be transmitted to the Minister of the department to which the said Provincial Board of Health is attached, and to the clerk of the municipal council, and to the secretary of the local board of health of the district interested.

"No sewer or appliance for the ventilation of the same shall be constructed in violation of any of the principles laid down by the Provincial Board of Health, subject to appeal to the Lieutenant-Governor in Council."

Since, then, all questions of sewage disposal are to be governed by principles laid down by the Provincial Board of Health, it is well to know what those principles as now defined are. At a meeting of the Association of Executive Health Officers of Ontario, held in Trenton, August 20th, 1891, the report of a special committee on sewage disposal was adopted, which contains the following extracts relating to sewage disposal: "That in all places having or constructing systems of sewerage it is desirable that the sewage be delivered at its outfall separately from storm water, in order, among other reasons, that the economical and profitable utilization of it may be possible. Therefore, it is recommended that the separate system or the restricted separate system of sewerage be adopted whenever practicable.

"That the most desirable method of disposing of sewage is by land irrigation wherever this is practicable. This method is especially important for cities and towns situated inland, or on such rivers and streams as are or may be used for public water supplies.

"Inasmuch as it has at times been found necessary (especially in older countries where the land is expensive, and the best land for sewage farms is not always available) to concentrate the sewage, some method of precipitating the suspended organic portion of it has to be adopted.

"In every instance, however, where the town to which sewage disposal is applied is situated on a lake or river whose pollution may possibly affect a public water supply, it is found necessary with every precipitation method to cause the passage of the effluent from the precipitation works to a land area for filtration."

The above defines very clearly the stand at present taken by the Provincial Board of Health, and it is probable the tendency will be to incline to greater strictness as the Province develops.

In France, Germany, England, and the United States, the purification of sewage by application to land has been proved to be a success even in cases where the combined system of sewerage is in operation. There are a few isolated cases where its opponents claim it has been a failure, but, if a failure at all, the failure has been due to carelessness in attendance, or else it has been a case of putting fertilization before purification. It is most instructive to read instances of the purifying power of earth when under favorable conditions. At Gennevilliers, in France, experiments were made to ascertain this power. Large tanks were constructed, filled with earth to a depth of six feet, and underdrained. Sewage at the rate of 24,000 cubic metres per hectare in six months was applied, and out of this only 1,600 cubic metres reached the drains below, nearly $\frac{14}{15}$ being evaporated. The above quantity is equivalent to about 14,000 gallons per acre per day, or at sixty gallons per person per day is equivalent to 232 persons per acre. Of course, this by no means represents the total capacity of the land, other experiments at the same place having demonstrated that in permeable lands the yearly irrigation may reach 100,000 cubic metres per hectare, or, on the same basis as before, 500 persons per acre. At Breslau, where storm water is admitted, the proportion reaches 400 persons per acre.

An idea of the degree of purification reached by fiitration at Gennevilliers may be best obtained by comparing the following results of bacteriological analyses :

Sewage at outlet of main contained	per	cubic cent	 20,000	microbes
Water of Seine	"	"	 1,200	"
" Vanne (Paris drinking)	"	"	 62	"
Rain water	"	"	 35	"
Underdrainage of Gennevilliers	"	"	.... 13 to 24	"

An extensive series of experiments in sewage purification has been also carried on at Lawrence, Mass., under the direction of the Massachusetts State Board of Health. Space will not permit of our going into the details of these experiments, but we may note some of the conclusions to be deduced from them, which are :

(1) In order to get the best results, it is imperative that the sewage be applied to the land intermittently.

(2) That the capacity of earth to purify increases with use, under proper conditions, up to a maximum depending on the quality of the soil.

(3) That the application of sewage to land is at present the only practicable method of purification.

(4) That the process of purification is due to the work of minute organisms in the soil, which convert the organic matter of the sewage into harmless inorganic substances capable of sustaining plant life.

(5) That the process of nitrification or purification goes on between 32° and 130° Fahr., and is most active at about 100° Fahr.

In one experiment the necessity for intermittent application was shown most conclusively. While acting intermittently the filter removed 99.2 per cent. of the sum of the ammonias in the sewage, but when kept continuously saturated the sum of the ammonias in the effluent gradually increased until they exceeded those in the sewage, some of those previously stored in the filter escaping. The sewage was then applied intermittently as before, when the nitrates in the effluent began to rise, until they exceeded the ammonias in the sewage by fifty per cent., the impurities collecting during the continuous filtration becoming nitrified. After three months the effluent was again purer than the average drinking water of the state. In each case the amount of sewage treated was the same, the difference in purification being entirely due to the different methods of treatment. In speaking of the purity of the effluent treated by intermittent filtration, the amount treated being from 117,000 gallons to 60,000 gallons per acre, the report says: "We have found that the sum of the ammonias which have been taken to indicate the amount of nitrogenous organic matter has been reduced to 0.5 of one per cent. of those in the sewage, and is less than the sum of the ammonias of most of the public drinking water supplies of the state." One result of these experiments has been to bring the question of sewage purification more forcibly before the people, and to demonstrate, in response to the constantly increasing demand for some system of sewage purification, that the only practicable method where purification, and not simply classification is required, is to apply the sewage to land.

The stand taken by our Provincial Board of Health, together with the interest that is being aroused in local sanitarians, due to the imperative demand of our increasing population for some practical and economical method of sewage disposal, is being already felt.

We have at present only two filtration areas on any large scale in Ontario—one in connection with the Asylum for the Insane, London, and the other the Berlin sewage farm. Plans have also been prepared for a system at Waterloo, where the work is partly finished. Guelph and Galt are considering the putting in of sewerage systems, and will probably have filtration areas in connection. The system at the London Asylum was designed by Col. Waring, and is the Intermittent Downward filtration system. The sewage from the different buildings is collected in a large tank constructed of brick and lined with cement, having a capacity of rather more than 100,000 gallons. From the tank the sewage is pumped by a six-inch rotary pump to the filtration area, through an eight-inch spiral riveted steel pipe about 1,550 feet long. The filtration area comprises

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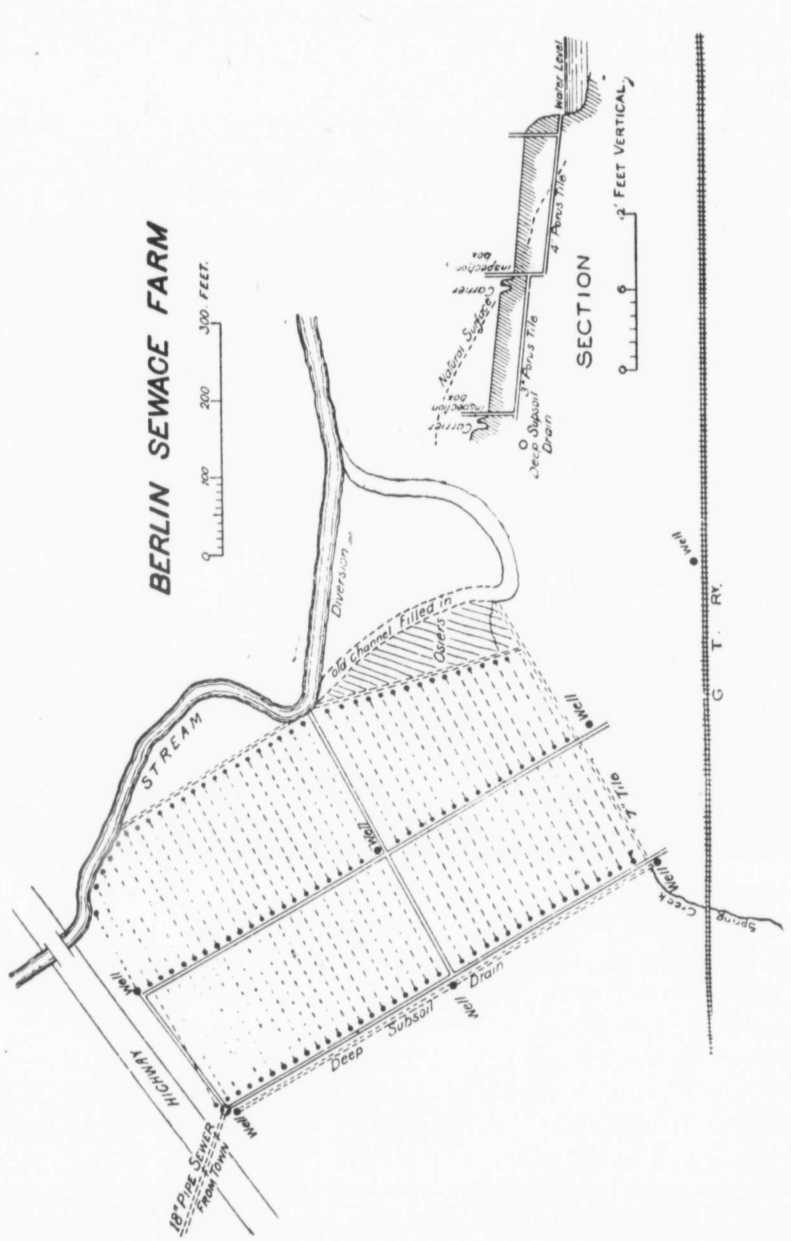

BERLIN SEWAGE FARM

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Old channel filled in
Osiers
Well
Well
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Well
4" Tile
Spring Creek
G. T. RY.
HIGHWAY
18" PIPE SEWER FROM TOWN
Deep Subsoil Drain
SECTION
Carrier
Inspection box
Natural Surface
Carrier
Inspection box
3" Porus Tile
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Deep Subsoil Drain
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about four acres, laid out in eighteen parallel ditches eight feet wide at top, two feet wide at bottom, and one and one-half feet deep, separated by beds ten feet wide at top. The bottoms of the ditches are all in the same horizontal plane. The sewage is conveyed to these by an eighteen-inch vitrified channel pipe running from the distributing well at one corner of the field in a line at right angles to the settling ditches, and connected to them by **T** channel pipes. The sewage can be turned into any one or all of the settling ditches at will, or can be all diverted to the broad irrigation tract below by inserting small wooden dams at different points in the carrier.

In reply to some questions on the working of the plan, Dr. Bucke, the superintendent of the asylum, writes: "Sewage disposal at this asylum is on what is called the Intermittent Downward filtration system. We use four acres of land for 1,200 persons, and it is ample. The system has been in use here five years, and has given the most complete satisfaction. The coldest weather gives us no trouble. The sewage in the tank never reaches a temperature lower than, say 50°, and when thrown into the trenches thaws the ground enough to let it through. We never see the effluent, and so know nothing about it; no doubt it again reaches the surface somewhere as *spring water*, and, no doubt, it is *pure spring water*.

"Using the sewage to irrigate, I grow on the beds between the trenches (*i.e.*, on about two acres of land) a crop worth from about $800 to $1,000 a year. The system is not only economical, but, I am satisfied, could be made to pay enormously if properly carried out for cities, towns, and villages."

The plant at Berlin was designed by Mr. Willis Chipman, C.E., and superintended by Mr. H. J. Bowman, town engineer. The system is Broad Irrigation. There are about twenty acres in the farm, only eight having been graded and underdrained. The sewage in this case is not collected in a tank, but runs directly to the irrigation tracts. These tracts are graded and underdrained to a depth of from three to four feet, this being the maximum attainable on account of the insufficient elevation of the tract above the watercourse into which the drains discharge. The drains are of agricultural tile, in parallel rows sixteen and two-thirds feet apart. Inspection boxes, six inches square, made of plank, are situated at each end and at the middle of each drain. Small wells have also been dug at different points on the farm for the purpose of observing the height of the subsoil water. The farm has been in operation since 1892. Writing under date of January 23rd, 1895, and referring to the Berlin farm, Mr. Bowman says: "This method works very well except in winter, when, on account of the beds having a fall away from the carrier, the sewage runs across the surface in channels.* During the past summer we have added new ends perfectly level."

Mr. Bowman has kindly sent me a plan of the proposed works at Waterloo, accompanied by the following description: "These beds are about 200 x 132 feet, perfectly level, and separated by embankments formed from the top soil. Tile drains will run across the beds and only ten feet apart, and vary from three to four feet below the surface. This depth is not sufficient to give the best results, but is enough for partial purification, which is all that is required, as the stream receiving the effluent is not used as a water supply."

The great objection to the adoption of sewage disposal by application to land in Ontario seems to be the idea that our climate is too severe in winter for the proper working of such a system, an objection more fancied than real, as the unqualified success of the plant at the London Asylum has demonstrated. The Berlin system must also be considered a success, since it is being followed by a similar one at Waterloo. However, it is only by trial that the details of the system best adapted to the varying conditions of our climate can be discovered. There is no doubt that the success of the London farm is in part due to the exceptionally favorable nature of the soil, but there is also reason to believe that a great element in its successful working in the winter season is the fact that the sewage is collected in a large tank and then discharged over the filtration area before it has time to become very much lowered in temperature, the amount of heat in the liquid due to its temperature above the freezing point being sufficient to thaw the ground and admit of its uniform filtration through the soil, and, were this point in detail adhered to in all cases instead of letting the sewage dribble over the soil as it comes from the outlet, there would probably be less cause to think that our Ontario climate in winter is too severe for successful sewage disposal by land application.

Toronto, March 5th, 1895.

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*For some reason the beds were constructed with a greater slope than intended by the designer. —R.W.T.

POWER SWITCHBOARD AND DYNAMO TENDING

ROBERT A. L. GRAY, '95.

If any of you expect, under the above title, a learned discourse on this subject, I fear you will be greatly disappointed; I will merely attempt to give a short description of the construction of a switchboard at which I worked, and, perhaps, give a few hints which may be of benefit to beginners.

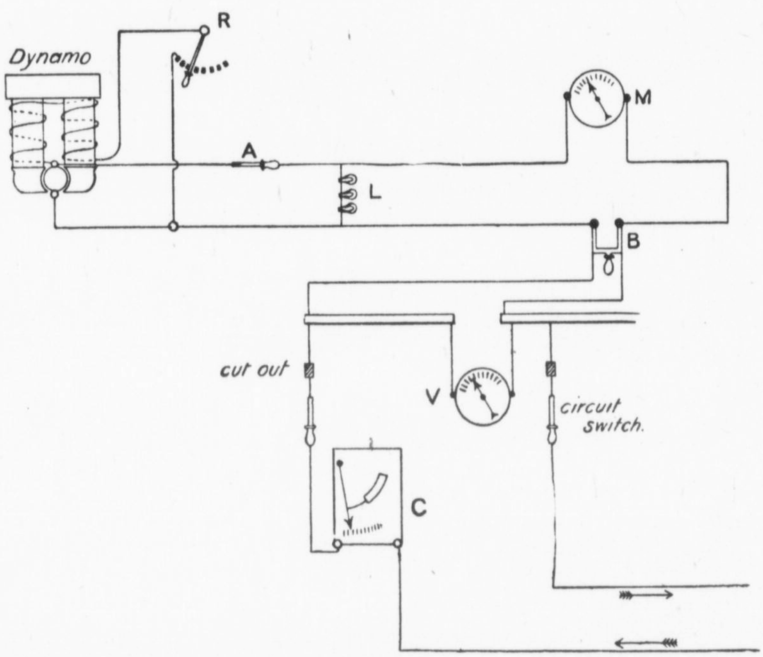
The switchboard was for the purpose of regulating six compound wound dynamos supplying power to motors for printing presses, elevators, etc.

These dynamos were connected in multiple, the positive and negative brushes being connected, respectively, to two heavy copper bars fastened to the switchboard.

The diagram shows the connections for a single machine, and the connections for one of the outside circuits. It will be seen that each machine has three incandescent lamps, L, in series with each other, across its terminals, and also that the dynamos, which are compound wound, are regulated by the Edison system, a rheostat being inserted in the shunt circuit to regulate the amount of current flowing through it. In series with each machine is also a single switch, A, and an ammeter, M, while, between the two copper bars is a voltmeter, showing about 250 volts between its terminals. The voltage of the test lamps will, therefore, aggregate 250 volts.

Leaving the dynamos for the present, we shall proceed to the outside circuits. There are five of these connected in multiple, each circuit having two switches, an ammeter, and two cut-outs in it. The switchboard, behind which a passage is left to allow of renewal of wires, etc., is a wooden framework with a shelf running along it, the switches and cut-outs on the board being mounted on slate and porcelain to obviate all risk of fire. In my opinion, it is best to have an open switchboard like this, because all the wiring is then in sight.

The ammeter C, for indicating current in the outside circuit, is of a very simple and effective type, and consists of a coil of very heavy insulated copper wire with a small armature connected to the index finger, which is pivoted at one end. The armature is pulled into the coil, a distance proportional to the current flowing, thus causing the index to move along a graduated scale.



WORKING IN A DYNAMO.

This operation must be performed with considerable care, or trouble is sure to result. First, put in the single switch and let the dynamo run for a little while, when the test lamps will gradually grow brighter and brighter, the resistance in rheostat being regulated until lamps are of proper brilliancy, showing that machine is developing a proper EMF. Test this also with the double switch. If a fairly large spark is made when this switch is closed a little and then opened, the machine may be safely worked in, and the switch be completely closed. The voltage and current to be given by each machine are now regulated with the rheostat, care being taken that each dynamo has, at least, enough to do, otherwise it will stop giving current, and then, suddenly, a current in the opposite direction will be produced, which is, of course, sure to make trouble. This dropping out and reversing is most liable to occur when the load is light, as at noon. Then all the factories will be closed down, and almost the only current taken from the mains will be that used for elevators, a current necessarily varying greatly, as a large amount will be taken off for a few moments, then this will suddenly drop to almost nothing when, the load being nearly all taken off the dynamos, they will tend to drop out and reverse. Of course, if there were only one dynamo running, this would not matter so much, but two are usually kept going at noon, so as to relieve each other.

TAKING OUT A DYNAMO

In taking a machine out of circuit gradually shift the load on to the other machines, and then, just when there is no current shown on the dynamo ammeter, open the double switch and slacken down the engine, then open the single switch.

If an accident happens to any of the machines, and the others are not able to supply the whole demand for current, so that one of the outside circuits has to be opened, be very careful which circuit you do open. For instance, if a machine supplying only a *small* amount of current has to be taken out, do not open an outside circuit, taking a *lot* of current, as the effect of this would be that the other machines would not have enough work to do, and would therefore commence to drop out and reverse. I believe switches are now being made which open when less than a proper amount of current is being supplied, and this will, of course, obviate a great deal of the trouble referred to.

Above all things, keep your wits about you, and, if any accident happens, be prepared to act promptly, so as to remedy the trouble as well as possible. I found it a good habit, while the load was steady, to think of what I should do in case of accident, and so was usually prepared.

CARE OF A DYNAMO.

Be sure always to keep the machines clean. This should always be attended to the first thing in the morning, when all oil and dirt should be carefully wiped off the base and other parts, for although the oil itself is not so injurious, yet it holds dirt, copper dust, etc., which is very liable to produce a short circuit. See that there is plenty of oil in the bearings and that the commutator is bright and clean, occasionally lightly swabbing it with oil of a character depending upon the material of which the brushes are made, castor oil being the best for copper brushes, as it does not make the commutator sticky or gummy. Always keep the brushes perfectly clean, and if of copper clip them quite often, to keep a good edge on them. This edge should be bevelled at an angle of about 45°.

The ordinary copper brush with which I had to do I shall now describe. It is usually made up of several thin sheets of copper placed together and folded in the middle, with a heavier piece over the top, the whole being then either soldered or riveted together. This makes a fairly flexible and springy brush, but it is very dirty, for the commutator, rubbing against it, wears the copper off and sends it flying in all directions. This dirt has to be all cleaned off, and takes considerable time, as the dust gets into any corners or chinks in the machine, and has to be got out with bellows and brushes. Another disadvantage of this brush is that, if anything should happen to produce sparking, the layers of the brush get fused together at the ends, necessitating clipping, which, besides taking considerable time, is very wasteful. In a certain large lighting station it takes two men working all day to clean up machines and clip the brushes, whereas one man could easily do the work of cleaning the machines. On the whole, I think carbon brushes are much to be preferred.

Slipping of belts is often a great source of trouble, and is sometimes caused by oil getting on them. This may often be remedied by throwing a little powdered resin on to the slack side of the belt just at the pulley. A new style of belting is now being advertised which has grooves running lengthwise of the belt, which are supposed to allow the escape of air sufficient to overcome the air-cushion, and thus allow the belt to be run very slack, as well as relieving a good deal of strain on the bearings. This belting should be of great benefit if it fulfils all that its manufacturers claim for it.

In concluding, I would say, never use sheet-iron oil cans. They are sure to cause trouble, and are very liable to get drawn in and caught in the armature when oiling the bearings, with results which I need not try to enumerate.

DYNAMO DESIGN

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The following paper is prepared in the hope that it may be a help to those engineering students who for the first time propose to consider the subject of designing a generator or motor for a specific purpose. It was suggested by the difficulty I myself had at first in picking out a definite path to follow in the labyrinth of principles and applications, of formulæ and usages, of electrical and mechanical considerations that appertain to the subject.

In the limits of this paper I cannot hope to give more than an outline, but my attempt shall be to provide a framework which any one who wishes to go fully into the subject may fill out for himself. There are a good many works written specially on this subject to choose from, but most of them are devoted to the design of particular machines, and would, therefore, not give sufficient help to design one for any purpose. For the engineering student Prof. S. P. Thompson's work is of great value, while the articles by Houston and Kennelly, and by Wiener in the *Electrical World*,* deserve special mention; the former on account of the clearness with which the principles are followed out in accordance with the most recent modes of considering them, and the latter on account of the results of examination and tests of actual machines of many types embodied in them.

In designing a dynamo, there are so many variables for fixing which a good deal of latitude is allowed that the great difficulty one has at first is to know how to adjust them, for the arbitrary fixing of the first may affect all that follows. One may be familiar with the general electrical principles, and yet will find himself at sea when he asks himself where he

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*Electrodynamic Machinery, Houston and Kennelly; *Electrical World*, Vols. xxiv. and xxv. Practical Notes on Dynamo Calculation, A. E. Weiner, *Electrical World*, Vols. xxiii., xxiv., xxv.

should begin, and whether he should settle one point before or after another. He feels the need of sufficient experience to enable him to decide these points—to select the best forms for a given purpose, and to know what allowances to make for points of secondary consideration, upon which points, however, the special value of the machine mainly depends. We have to consider fundamental principles, but we have also to consider the way of applying them to produce the most economic result. There are, to borrow from chemistry, the qualitative and the quantitative divisions of the work.

Let us now run over briefly the theory of the generator and motor, and afterwards consider the procedure in design. And if I start at the very beginning, it is because I believe that we cannot emphasize too much the importance of carrying in mind the connections between the definitions and axioms of a subject and the main deductions that follow from them.

THEORY OF THE DYNAMO.

1. As satisfying the results of numerous experiments, the following law is accepted as an axiom in the science of electricity:

The strength of field at any point due to an elementary length of conductor carrying current is inversely proportional to the square of the line joining the point and the element, and is directly proportional to the resolved part of the current in the conductor at right angles to that line. The direction of the magnetic force is at right angles to the plane of the element and line, and the sense is given by the familiar rule of the right-handed screw.

2. On this is based the definition of unit current*: *A current has unit strength (C.G.S. unit) when unit length (centimetre) of its circuit bent into an arc of unit radius exerts unit force (dyne) on unit magnet pole placed at its centre.* 1 ampere$=10^{-1}$ C.G.S. units. And from this:

Unit quantity of electricity is that quantity which is conveyed by unit current in one second. 1 Coulomb$=10^{-1}$ C.G.S. units.

Unit difference of potential or electromotive force, since potential is measured by work done on unit quantity of electricity, exists between two points when it requires the expenditure of unit work (erg.) to bring a unit of +ve electricity from one point to the other against the electric force. 1 volt$=10^8$ C.G.S. units.

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*These definitions are taken almost verbatim from Professor S. P. Thompson's Elementary Lessons in Electricity and Magnetism.

Unit resistance by the aid of Ohm's law is defined from unit current and unit EMF. 1 ohm $= 10^9$ C.G.S. units.

3. From the definition of unit EMF we deduce that a unit current (that is, a unit quantity of electricity per second) does unit work per second in a conductor between points at unit difference of potential, and from this the work done in any conductor per second is the product of the current flowing and the difference of potential between the points considered.

$$\begin{array}{llll} 1 \text{ C.G.S. unit current} & \times\ 1 \text{ C.G.S. unit EMF} & = 1 \text{ erg per sec.} \\ 10^{-1} \text{ C.G.S. units} \quad " & \times\ 10^8 \text{ C.G.S. units} \quad " & = 10^7 \text{ ergs per sec.} \\ 1 \text{ ampere} & \times\ 1 \text{ volt} & = 10^7 \text{ ergs per sec.} \\ & \textit{i.e.},\ 1 \text{ watt} & = 10^7 \text{ ergs per sec.} \end{array}$$

Now, since 1 horse power $= 745.94 \times 10^7$ ergs per sec., it must also $= 745.94$ watts, or 746 watts commonly used in practice.

$$CE = P \textit{ (power)}$$

Where the transformation of energy in a conductor is entirely into heat, we have $E = CR$ where R is the resistance between the points at difference of potential E, so that the equation for power is

$$C^2R = P$$

the rate of production of heat, or the energy expended per second in heating the conductor.

4. The application of these principles to the theory of the dynamo and motor is this: If E is the total EMF generated in the armature of a dynamo, and C the armature current at any time, then $EC = P$ the total power of the machine at the time. Any heat losses in the windings of the machine may be considered just as they would be if the energy were being used in the external circuit, armature and series field coils as in series circuits, and shunt fields as in parallel circuits. Following is a summary of the distribution of power in the generator and motor. The Roman letters are for the generator, the italic ones for similar quantities in the motor.

GENERATOR.		MOTOR.	
$\mathrm{EC} = \mathrm{P}$	total transformation mechanical to electrical.	$EC = P$	total transformation electrical to mechanical.
$\mathrm{EC} - \mathrm{C}^2\mathrm{r} =$	power given outside armature and series field.	$EC + C^2r =$	power received in armature and series field.

GENERATOR.	MOTOR.
$EC - C^2r - c_1^2r_1 = E_1C_1$ power given external circuit.	$EC + C^2r + c_1^2r_1 = E_1C_1$ power received from external circuit.
$\frac{E_1C_1}{EC}$ electrical efficiency of generator.	$\frac{EC}{E_1C_1}$ electrical efficiency of generator.

E_1 and C_1 and E_1 and C_1 are the EMF and current, as measured at the terminals of the generator and motor, respectively :

$$E_1 = E - Cr \qquad\qquad E_1 = E + Cr$$

5. *A unit magnet pole is one which placed at unit distance (centimetre) from an exactly similar one repels it with unit force (dyne).*

A magnetic field has unit strength ($\mathfrak{H} = 1$) at a given point when it acts upon unit pole with unit force at that point. *A unit line of force is therefore defined as having unit area of cross section in unit field.* With field strength $\mathfrak{H}$ the cross section of unit line becomes $\frac{1}{\mathfrak{H}}$. As there is unit field at unit distance from unit pole, there will be 4π lines from unit pole and $4\pi m$ lines from pole m.

6. From the first fundamental statement of the relations between a current and its magnetic field (sec. 1), we deduce, by a simple process of integration, the distribution of the magnetic field about a straight infinite current. $\mathfrak{H} = \frac{2C}{r}$ where C is in C.G.S. units current, and r is the distance of the point considered from the wire in centimetres.

If unit pole is carried in a circle around the wire, therefore, by the action of the current, the work done by the current will be

$$\mathfrak{H}L = \frac{2C}{r} \times 2\pi r = 4\pi C.$$

The work is seen to be independent of the radius of the path, and, as no work is done in carrying the pole to or from the wire, a little consideration will show that if the pole is carried in any path whatever around the conductor, if it start and end at the same point, the work will be the same.

7. In carrying the pole around the conductor, all its lines cut the conductor, so that the pole has $4\pi C$ units of work done upon it by the current while its 4π lines are cutting the conductor ; or, if a pole with one line or strength $\frac{1}{4\pi}$ were carried around, the work would be C for the cutting

of one line. Now, the circuit does C units work on the pole in virtue of the product CET, where E is an EMF, which would have to be added to that of the circuit to maintain C constant. E, therefore, when T is one second, must also be unity to give total work C. The EMF added to that of the circuit must be to counteract an EMF due to the cutting of the line through the circuit, since the current remains as before. It is, therefore, the natural inference that the line, in cutting the circuit in a second in the direction it does, produces a unit EMF in a direction opposed to that of the current.

This induced EMF is seen also to be independent of the magnitude of the current, and exists, therefore, when the current is zero, or becomes negative in sign, that is, reverses direction. In the latter case, the pole does work on the electric circuit, *i.e.*, increases the product EC in it.

From the above, we may deduce that the cutting of a conductor by unit line in one second (or of a unit line by a conductor) produces unit (C.G.S.) EMF, and by noting the directions of the magnetic lines, conductor, and motion of the lines or conductor, we may deduce Fleming's rule of the hand for determining their interrelation with the direction of the induced EMF.

8. The generator and the motor are the practical embodiment of the above principle. In both EMF is generated by conductors cutting magnetic lines, for the conductors of the armature cut through the magnetic lines of the field.

If a conductor in one second cuts unit line, it produces unit EMF.

If a conductor moves with unit velocity in unit width of unit field, it produces unit EMF.

If a conductor moves with velocity v in width l of field $\mathfrak{B}$, it produces EMF, vl $\mathfrak{B}$, and

If c of these conductors are united in series, the total EMF is $cvl\mathfrak{B}$, and in volts

$$E = 10^{-8} cvl\mathfrak{B}.$$

This is the equation for the EMF produced in the armature, whether of generator or of motor. As $\mathfrak{B}$ is directly proportional to the square of the linear unit, v, l, and $\mathfrak{B}$ may be taken either all in C.G.S. units, or all in the English system.

9. We now come to consider how the magnetic lines are produced. We have a field of average strength $\mathfrak{B}$, and cross-section S to provide, or a total flux $\phi = S\mathfrak{B}$—

As the work done by a circuit on a unit magnet pole (or *vice versa*) depends only on the current in that circuit and the EMF generated by the lines from the pole that cut the circuit, if all these lines cut the circuit once, then the work done is independent of the form of the circuit. So that the work done when unit pole is threaded through a loop with current C, and brought outside and back to the starting point, so that all its lines have been cut once, is $4\pi C$ units (the same as that given for the straight current in section 5); and if there are N loops each with current C through which the pole is threaded, then the work is $4\pi NC$ units. Furthermore, since $\mathfrak{H}$, the magnetic intensity or magnetizing force at any point of the field, is the force acting on unit pole at that point, the work done in carrying unit pole around the circuit is evidently equal to the line integral of the magnetizing force for the path pursued.

$$4\pi NC = \int \mathfrak{H} dl.$$

10. Now, by definition the magnetic permeability $\mu = \frac{\mathfrak{B}}{\mathfrak{H}}$

$$\text{so that } \Phi = S\mathfrak{B}$$
$$= S\mu\mathfrak{H} \text{ for any cross section of a magnetic circuit}$$
$$\text{or } \frac{\Phi}{S\mu} = \mathfrak{H}$$

and taking the line integral of this around the magnetic circuit, we get (as Φ is constant for all cross sections, and μ and S may vary).

$$\Phi \int \frac{dl}{S\mu} = \int \mathfrak{H} dl, \text{ and this becomes}$$

$$\Phi = \frac{\int \mathfrak{H} dl}{\int \frac{dl}{S\mu}}$$

which is the law for the magnetic circuit corresponding to Ohm's law for the electric. Φ is the total flux, $\int \mathfrak{H} dl$ is the magnetomotive force, and $\int \frac{dl}{S\mu}$ is the reluctance. We have shown that $\int \mathfrak{H} dl$ is equal to $4\pi NC$ (sec. 9), and, as magnetic circuits, as a rule, are made up of sections of length l, and constant cross-section S, throughout which the permeability μ may also be considered constant, we may write the equation in the form

$$\Phi = \frac{4\pi NC}{\Sigma \frac{l}{S\mu}} \quad \text{(all C.G.S. units)}$$

11. As the question with us now, however, is how to produce the required flux, the equation takes the form if C is in amperes

$$NC=\frac{10}{4\pi}\phi\ \Sigma\ \frac{l}{S\mu}$$

and if l and S are in inches it becomes

$$NC=\frac{10}{4\pi\times 2.54}\ \phi\ \Sigma\ \frac{l}{S\mu}$$

where NC is the number of ampere turns required to produce the flux ϕ in the circuit defined by the terms l_1, l_2, l_3, etc., S_1, S_2, S_3, etc., and μ_1, μ_2, μ_3, etc. The magnetic properties of the materials used in the circuit must be known in the forms of curves or tables, giving the relation between two of the three quantities $\mathfrak{B}$, μ, and $\mathfrak{H}$, so that to determine μ for any section we have only to determine $\mathfrak{B}=\frac{\phi}{S}$ for that section. The relation between N and C can be settled for any particular case.

PROCEDURE IN DESIGN.

12. To understand the foregoing principles of the dynamo, one needs only a slight acquaintance with the actual machine; but to apply these principles to the synthetic process of design or construction, he needs a very practical acquaintance with the make-up, in detail, of such machinery. The best training for this work is to be employed in turn in the different departments in works which build a good type or types of machines, to perform every operation possible in their construction, and to test them when completed. This experience should be supplemented in the repair shops, for there the weaknesses and defects of machines are soon made apparent. This is an invaluable training, if one is careful to understand the reasons for everything that he does or sees done.

Failing this, one should make himself acquainted with the best practice by studying the points of difference of several good types of machines; by partially dissecting them, if possible, to obtain the data necessary for recalculating them and comparing the results of calculation with actual results; and by obtaining access to machinery in process of construction or repair, and paying strict attention to the details of the work.

Tabulated results of best practice will be found of very great help in design.

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13. Before proceeding with the design of a dynamo, it is evidently necessary to ascertain as definitely as possible what is required of it. It is to be built for a given purpose. It is a generator, perhaps to do lighting or electro-plating, or to supply a power circuit, or it may be a motor to run a fan, a lathe, or a workshop, an elevator or a street car; a generator for a constant, or for a variable, pressure circuit; or a motor for fixed, or for variable speeds. We must obtain sufficient data for deciding:

(1) What circuit is it to supply or be supplied from?

(2) What power is required of it?

(3) What are the general conditions of use—such as the position that it is to stand or be suspended in, the limit of floor space, protection from dust, water, iron filings, and other sources of injury, the mode of driving, etc.

14. From the answer to the first question, we determine one of the factors of the power. It will decide the pressure to be obtained between the terminals if for parallel working, as for incandescent lighting, and for motors on constant pressure circuits, or the current to provide for in series circuits, as for arc lighting, and for motors on constant current circuits; it will help us in settling the question of open or closed coil armatures, and of series, shunt, or compound fields. The degree of constancy necessary in the pressure of generators and in the speed of motors will determine whether they are to be shunt or compound wound. We shall know also whether special design and regulation will be necessary to effect alterations of EMF in generators, or of speed in motors.

From the answer to the second, we determine the other factor of the power, for, as we know (sec. 3), electrical power is the product of current and EMF, and we have only to divide the required power—reduced to Watts—by the one given to obtain the other; usually, we are given the pressure and require to determine the current to be allowed. As we have before seen, power is lost in the various windings of a dynamo, so that this also must be considered. As to the effect of the power of a machine on the type, one may say, generally, that, for small powers, bipolar machines are preferable on account of their simplicity and economy in construction, while, for large powers, multipolar machines are most economical.

The answer to the third question will affect the general design, particularly the selection of the type.

15. There is an almost endless variety of different types of continuous current machines; they may all, however, be classed as bipolar and multipolar. The bipolar machines may be divided into those having single

or multiple magnetic circuits, and these, again, as having one or more exciting coils. Multipolar machines, in practice, never have more than one magnetic circuit per pair of poles, and often this is abridged; that is, two or more pairs of poles may have parts of their circuits in common. Multipolar machines may, therefore, be classed as having one exciting coil —half as many coils as poles, or as many coils as poles, etc.

16. The common types of armature are the drum and ring (Gramme). In bipolar machines for small armature diameters, the drum winding is the more economical in length (*i.e.*, resistance) of conductor, and the core more simple in construction; while, for large diameters and shorter cores, the ring type gives more economy in metal and winding, and offers much better opportunity for ventilation. Ring winding is done in distinct sections, so that it is much easier to insulate it and replace portions of it than in the case of drum winding, in which the sections all overlap. In ring winding there is one active conductor in each loop; in drum winding there are two.

In multipolar machines, both rings and hollow drums are used; and for these we have the ring, and lap and wave windings, with as many parallel circuits as poles, excepting for wave winding, for which there are always two. The cores of armatures may be smooth or slotted, the advantage, on the whole, lying with the smooth surface. The teeth in the slotted core form good driving horns, and somewhat decrease the magnetic reluctance of the circuit; they also allow the heat to escape more rapidly from the core, but their additional cost of construction, the heating of the pole pieces, due to their unequal distribution of magnetism, and the trouble they cause in sparking, tell heavily against them.

17. Let us now, to fix our ideas, suppose that we are to design a dynamo for constant pressure. In the first place, we know (sec. 4) that the terminal pressure for a generator is less, and for a motor is greater, than the generated EMF by a product Cr; so that if Cr is small, as it must be for economy, the same machine generates nearly the same EMF as a generator or as a motor with terminal pressures the same, and, therefore, as other conditions are unaffected, the speed must be nearly the same also, so that a generator and a motor to be used in the same circuit may be considered very nearly as the same machine.

18. As the EMF of a dynamo is generated in the armature, and the whole current used must flow through it (excepting for the shunt field of a motor), both factors of the power affect it directly; and as

the field provided by the magnetic circuit is only for the use of the armature, and must, therefore, be designed to suit it, the consideration of the armature is evidently the first and most important part of the design of a dynamo ; so that, after deciding the number of poles to be used, we should proceed to determine what is required of the armature, and select the type.

We know approximately the EMF that it must generate (sec. 4—$E = E_1 + Cr$, of which we know E_1 and Cr is small, and need not be considered at this stage), and the maximum current that must flow through it, allowing a percentage for the shunt circuit (sec. 14). The total armature current is divided between two parallel paths in bipolar dynamos, and between two, four, or more parallel paths in multipolar ones, so that the total current that the armature conductor has to carry is fixed, and from this, knowing the safe carrying capacities of conductors, we can fix the cross section necessary. From 400 to 800 circular mils per ampere for copper gives the common range of practice, the lower values when the machine is run intermittently, or when there is good ventilation, and the higher values for continuous running, or when the ventilation is poor.

19. We may now consider the application of the equation

$$E = 10^{-8}\, c\, v\, l\, \mathfrak{B}$$

The armature of a dynamo consists of the arrangement of a number of conductors (usually copper wire) on a core which is a good magnetic conductor, which is attached to a shaft, and revolves in a magnetic field, so that the conductors cut through the lines of that field as they pass from the poles of the dynamo across the gap—composed of clearance and space occupied by the conductors and their insulation—to the core. As we shall see later in considering the magnetic circuit, it is very important that the depth of this space between pole face and core should be as small as possible.

20. The cross section of the magnetic field is approximately the same as the pole face, and the distribution $\mathfrak{B}$ is fairly uniform in a good design, l is the length of a conductor that is actually cutting through the field $\mathfrak{B}$, and may be taken, therefore, as the length of the pole face, and the length of armature core is usually about the same. The linear velocity of the conductors, *i.e.*, the peripheral velocity of the armature, is v, and c is the number of effective conductors in series, *i.e.*, the number of those in series in which EMF is actually being generated, and which are, therefore, within the polar arcs.

As a means of decreasing the exciting power necessary for a given total magnetic flux (sec. 11) the intensity of magnetization, $\mathfrak{B}$, of the gap spaces is taken quite low, especially for smaller machines, as compared with the limits of saturation of the poles and armature core. The value in practice increases with the capacity of the machine, and is about 50 per cent. higher for wrought iron or steel than for cast-iron pole pieces. For bipolar machines, with cast-iron pole pieces, $\mathfrak{B}$ ranges from 2,300 for 1 kwt. capacity to 4,700 for 300 kwt., or from 15,000 to 30,000 per square inch.

The velocity v as an easily-produced factor of the EMF should be as high as possible. It is limited, however, by mechanical and electrical considerations, such as strain in the moving parts, vibration due to irregularities of balance, friction in the bearings and air friction in the clearance space; eddy currents also and hysteresis losses increase with the speed.* The hysteresis losses depend on the number of reversals per second and the intensity of magnetization of the core. In practice, the peripheral velocities of drum armatures range from 25 to 50 feet per second, increasing with the capacities; and those for ring armatures—on account of their better ventilation and the better hold of the conductors—reach double that amount.

21. We must now select values for $\mathfrak{B}$ and v. We then have c and l to determine, having the relation $cl = \frac{10^8 E}{v\mathfrak{B}}$ between them.

As a question of internal resistance, c and l may nearly balance each other, and it becomes a question then as to whether altering l increases or decreases the idle wire necessary in the particular winding used. But there are other conditions which limit the fixing of c, a consideration of which will help us in making the adjustment. c is the number of conductors in series—in one of the two or more parallel armature circuits—which are actually cutting the magnetic field at a given instant, at any of its two or more pole faces; its ratio to the total number of conductors on the cutting surface is approximately that of the polar arcs to the periphery of the armature space. The length of the polar arc, we find in practice, ranges between 50 and 100 per cent. of the total circumference, and usually lies between 70 and 80 per cent.; questions of magnetic leakage, sparking, etc., affect its length. Fixing this ratio now also fixes the relation between c (the effective) and the total number of *active* armature conductors.

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* *Electrical World*, xxiii., p. 867.

Again, the number of conductors around the circumference, and the number of layers, with a knowledge of the space required for insulation* (between conductors and core, between layers, between sections, and between individual conductors) and that needed for driving horns, will fix the circumference required for the armature and the depth of winding.

The radiating power of the armature fixes the limit of depth of conductors. The greatest current density allowed in practice, that is, the ampere turns per inch circumference, is fixed at about 800, or about 2,500 per inch diameter. The average would be about 600, or 1,900 per inch diameter, which corresponds to a rise of about 70° or 80° centigrade. The depth of winding varies, in practice, with the diameter of the armature, ranging with drum armatures from .25 to .8 inch for diameters of from 2 to 30 inches.

Another question affecting c is the number of sections that there are to be in the armature and in the commutator. Many sections increase the difficulty of winding and insulating, and increase the size and cost of construction of the commutator, while few sections give greater losses in the coils short-circuited under the brushes, causing sparking, and give greater variations in the total EMF generated. Thirty-six divisions cause only a variation of one-fifth of one per cent., so that this would be plenty for steadiness; but, besides this, the self-induction in the short-circuited coils require that the number of loops per section should be kept down, which would both tend to decrease the total number of conductors and to increase the number of sections. From 40 to 60 sections is good practice for pressures up to 300 volts on bipolar machines.

For high pressures, the effect of self-induction in the coils comes still more into play in increasing the number of sections, as also the necessity of keeping the pressure between adjacent segments low enough not to maintain an arc across the insulation between them.†

Let us, then, decide upon a number of sections for the commutator. Each commutator bar will begin one coil and end another, so that the number of armature and commutator sections will be the same.

22. We may now select a value for l, obtained from a similar type of machine in practice, and obtain c and the total number of conductors; then select the nearest number to this which will give the chosen number of sections, and correct the assumed value of l. Knowing now the number of conductors per section, we can decide, from considerations above

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* *Electrical World*, xxiii., p. 741.

† *Electrical World*, xxiv., p. 129.

given, and from convenience in winding and insulating, the form that the sections will take and how they will be placed and wound. The circumference of the armature is readily deduced from this, and, therefore, the diameter. We may now see if the length chosen and the diameter deduced bear reasonable proportions to each other; if not, a new value of l may be selected.

23. The selection of the type of armature need not be finally made until after a preliminary calculation of the dimensions, though, as we have seen, a higher value of v is allowed for ring than for drum armatures, which should be considered.

24. We now come to the consideration of the magnetic circuit which produces the fields for the armature conductors to cut. There are a great many different forms of magnetic circuits, and dynamos are classified by the forms and arrangements of these (sec. 15), and, since they can only be utilized for dynamos by conductors cutting through gaps in them, the rest of the circuit is, therefore, only of use as it provides the fields. Electric current circulating in a continuous direction, in coils which surround the material of the magnetic circuit, is necessary to produce and maintain the magnetic flux. *Energy is not necessary to maintain a field.* What is used in the exciting circuit is a more or less necessary waste, for it is all transformed into heat. The excitation is proportional to the product of two terms, the current and the number of times it encircles the flux or NC, and, since only the current involves energy, we have the power to reduce the energy waste by increasing N.

25. As they are interrelated, we may consider together the questions: How do we adjust the proportions of the magnetic circuit? what excitation will be needed for it? and how shall this be provided?

They are, in fact, the discussion of the equation (sec. 11)

$$NC = \frac{10}{4\pi}\Phi \ \Sigma \frac{1}{S\mu}$$

In this equation we have to fix the quantities Φ, and for each part of the circuit the term $\frac{1}{S\mu}$. To fix Φ we have already the intensity of the field $\mathfrak{B}$, its width, which is taken as the length of the pole face, and its depth is calculated from the ratio of polar arc and the circumference of the armature; so that we have the area of the pole face, which is taken as the cross section of the field S, and therefore $\Phi = S\mathfrak{B}$ is determined.

26. We shall now consider the terms $\frac{l}{S\mu}$ for (1) the air gaps, (2) the armature core, (3) the pole pieces, (4) the magnet limbs, and (5) the yoke or connecting pieces.

For the air gaps, we have already settled S; μ is unity, and l is the distance between armature core and pole face, which is made up of depth of winding and clearance. The depth of winding has already been settled. The clearance varies with the diameter, in practice, between $\frac{1}{32}$ and $\frac{7}{16}$ of an inch. The larger distances are for slotted armatures, being found necessary to prevent sparking; it should be as small as possible, but there should be assured safety, for the surface of the armature, from touching the pole face. The smallness of μ makes this the most important term in the calculation. The main reason for making S large or $\mathfrak{B}$ small is now apparent.

27. Let us now deal with the armature core. In the first place, it has to be well laminated, for the reason that iron is a good electrical conductor, so that if the core were made of solid iron, this, cutting the magnetic lines which pass through it, would have the same effect as though conductors on the surfaces were short-circuited, which would waste power if it did nothing worse. The current that would flow in it would be in the same direction as in the conductors; the lamination, therefore, is to effect discontinuity in this direction. If the lamination is too thick, there will still be formed circuits in it sufficient to cause serious loss, and the range of practice seems to be between 10 and 80 mils in thickness. Special insulation is not required between the plates; the coating of oxide formed by heating the iron is sufficient.

The radial depth of the core is fixed so that, after allowing for air space in the lamination, the total cross section is sufficient to keep the value of $\mathfrak{B}$ in it well within the limits of saturation. In bipolar machines the total flux has two paths to take about the centre. In multipolar machines, for each magnetic circuit, it has but one path in the armature. The value of S for the armature is now fixed, since we know the length and have corrected it for lamination already. We must determine μ from tables giving the relation between $\mathfrak{B}$ and μ for the intensity of flux decided on. The average length of magnetic path through the armature core is l, and may be estimated. The hysteresis losses in the core are proportional to the number of magnetic reversals and to the 1.6th power of the intensity of magnetization; for this reason $\mathfrak{B}$ should be lower as the speed increases, to keep down the heat and the heat losses.

28. The quantities l, S, and μ are readily estimated for the pole pieces—the pole face has already been fixed. The general design of the pole should be such as to prevent the unequal distribution of the field. They are often made of cast iron, especially in smaller sizes, when the intensity of the magnetic flux carried by them is not great, and therefore the permeability is large.

29. The magnetic limbs, on the other hand, should be of the best annealed wrought iron, for the cross section, as it affects the cost of winding, as well as the weight of metal, should be a minimum. It should also be circular, as this has the least circumference for a given area. The limbs are usually run pretty well up to saturation, so that $\mathfrak{B}$, and therefore $S = \frac{\Phi}{\mathfrak{B}}$, can now be fixed. For the present, the value of l will have to be estimated, which may be done by comparing similar machines, and it is decided later, when we find the space required for winding. μ is fixed by $\mathfrak{B}$. If the dynamo is to have field regulation for EMF or speed over any considerable range, then the value of $\mathfrak{B}$ chosen should correspond with the field needed for maximum pressure or minimum speed, so as to keep the field below saturation.

30. The cross section of the yoke or other connecting pieces between the limbs should, at least, be as great as the latter, if of the same kind of iron. It is better to have it somewhat larger, so as to bring $\mathfrak{B}$ and μ down. If of cast iron, the value of S, being decided by $S = \frac{\Phi}{\mathfrak{B}}$, would be considerably larger, as the permissible value of $\mathfrak{B}$ would be much smaller. l is again the length of the average path of the magnetic lines (not the length of the yoke over all).

31. We now have all the data for calculating the ampere turns NC necessary to produce the field for the armature conductors to cut. We should find, however, that if we took this value and designed the fields according to the cross sections, etc., above obtained, and provided windings and current accordingly, that the useful flux that we should actually obtain would perhaps be only $\frac{3}{4}$ or $\frac{2}{3}$, or, perhaps, even less, of the amount calculated upon.

The explanation is this: air is a magnetic conductor—not a good one, but still it has conductance, and magnetic lines, instead of passing around, and keeping within the bounds of the circuit, run out from the exciting coils, in more or less wide paths through the air, constituting magnetic leakage. The part of the total flux that does not go through the armature is considerable.

32. If we were to take a practical example of the magnetic circuit, and calculate the ampere turns, or the magnetomotive force necessary for each part of it, we should see that by far the greatest term would be that for the air gaps; so that if we consider the magnetomotive force about the magnetic circuit in the same way that we do EMF about the electric circuit, we see that the drop is proportional to the resistances. The air gap is to the magnetic circuit in a good deal the same relation that the space between plates suspended in acidulated water is to an electric circuit. The reluctance of the air gap is greater than that of the rest of the circuit, and, therefore, the greatest drop of magnetomotive force takes place over it. Wherever we have difference of magnetic potential in a magnetic conductor, we shall find magnetic lines. The pole pieces have great difference of magnetic potential. There are, we may say, two magnetic conductors between them, the air gaps and armature core as one, and the remaining possible paths as the other. Most of the lines will follow the former path, but only in proportion to its magnetic conductivity as compared with the other. In the same way there will be leakage between the limbs, and between the pole pieces and the yoke; although very little between the ends of the yoke. In all cases given the machine the magnetic conductivity of the air spaces is perfectly definite and can be ascertained, and, therefore, the proportion of the lines in a given case that leak though the air and those which are used in the armature can be ascertained.

33. As all the lines (or nearly all of them) will have to pass through the iron within the exciting coils, and through the yoke, we shall have to increase the cross sections of these as calculated, if we wish to keep the value of $\mathfrak{B}$ and μ the same—adding sufficient to them to take the leakage of the rest of the circuit at the same densities $\mathfrak{B}$, thereby retaining the flux ϕ for the armature.

Doing this will be seen not to affect the value of NC calculated; the increased flux is simply proportional to the increased conductance. The ratio of the total to the useful flux is called the co-efficient of leakage, and ranges from 1.1 in large machines of good design to 2 for very small ones.

The determination of the conductances of the air circuits is rather troublesome, so that if it is not necessary to have very accurate results at first a value for the co-efficient of leakage may be assumed by comparing those of similar types of machines; and an allowance may be made for increasing or decreasing the excitations when the machine is tested.

34. There are two more items to be considered in providing ampere turns, which, in bad construction or in bad design, may become of considerable importance: they are the effect of joints and the demagnetizing action of the armature. The former becomes of importance when there are too many joints in the circuit, or when their surfaces are not perfectly even and smooth. The latter is due to a certain number of turns in the armature between the pole horns, which actually surround the magnetic circuit, and have a current in the opposite direction to that of the magnet. It is due to the lead given the brushes to prevent sparking. The effect, evidently, varies with the armature current, *i.e.*, with the load, and can be allowed for, for some particular load, or may be counteracted by compounding.

35. If the field and speed can be kept constant in a generator, then the EMF generated will be constant; but the terminal EMF will drop as the load increases, as we see from the relation $E_1 = E - Cr$ (sec. 4). Now, as it is the terminal pressure that must be kept constant, since the speed cannot be very well increased with the load, the machine is compounded; that is, a winding is provided on the magnet which, by taking the armature current (or that, less the shunt field current), is designed to produce an additional flux, which will increase the EMF generated by the amount Cr over as wide a range of load as possible.

A motor is compounded to maintain constant speed when run on a constant pressure circuit. The series winding acts against the shunt, decreasing the counter EMF by the part Cr in the relation $E_1 = E + Cr$ (sec. 4) as the load increases. As the action of the armature turns, due to negative lead in the motor, is opposed to that of the field turns, just as it is in the generator, it may be made use of in the design of the motor to maintain constant speed, instead of providing a special series winding.

36. We may now decide the relations betweed the turns and current in the fields. We have for the shunt field

$$NC = k_1$$

where k_1 is the calculated value, we have also the relations

$$C = \frac{E}{R} \qquad \text{and}$$

$$R = k_2 \frac{L}{s}$$

where L is the total length, and s the cross section of the wire used, and k_2 is the resistance of unit length of copper conductor of unit cross section. If L is in feet and s in circular mils, then k_2 is the resistance of one foot of wire of one mil diameter = 10.381 ohms at 75° F. Again,

$$L = k_3 N$$

where k_3 is the average length of a turn. Now, if k_3 can be considered nearly constant for a fairly wide range of turns of a given wire, then knowing the excitation required must fix the gauge of wire to be used, for we derive from the above equations the relation

$$s = \frac{k_1 k_2 k_3}{E}$$

k_3 being estimated at first from the diameter of the spools on which the wire is to be wound, and is corrected by trial, as the space to be occupied by the windings is determined.

37. We may now select a value for the current to be used, which must be within the safe carrying capacity of the gauge of wire determined; and calculate the number of turns. The adjustment should be made by balancing running loss against cost of construction. As the field losses are rather a matter of absolute than of relative cost, we find that much larger percentages of the total output are used in field circuits in small than in large machines. They range from about 15 to .015 per cent.

38. In adjusting the excitation due to the series field of the compound winding, the principal necessity is the knowledge of the properties of the magnetic circuit above the degree of its magnetization by the shunt coils, if for a generator, or below, if for a motor, because if lines are added to those already in the circuit, or are taken away, it affects the values of $\mathfrak{B}$ and μ throughout, so that the ratio of the increase of $\mathfrak{B}$ per increase of the magnetizing force must be known.

SOLUTIONS

A. W. CONNOR, B.A., '95.

Within the last few years much has been written on the subject of solutions, and a great deal of work has been done, rendering what until recently was one of the most obscure branches of physics one of the clearest and best understood; and as in connection with this recent development many interesting problems relating to the voltaic cell have been solved, I propose in this paper to give an account of so much of the new theory of solutions as will be necessary for the proper understanding of its application to these cases.

A solution, in the modern sense of the word, may be defined to be a "gaseous, liquid, or solid mixture, perfectly homogeneous in all its parts"; this extended significance of the word including air, alcohol-water mixtures, and the various solid glasses, as well as those solutions of solids in liquids to which the term was originally restricted.

Liquid solutions, to a consideration of which this paper will be restricted, may be subdivided into:

(1) Solutions of gases in liquids, *e.g*, of ammonia in water.

(2) Solutions of liquids in liquids, *e.g.*, of sulphuric acid in water.

(3) Solutions of solids in liquids, *e.g.*, of salt in water; or resin in alcohol; but that this classification is merely one of convenience may be gathered from the fact that the physical state of the components of the solution varies with the temperature and pressure. Acetic acid, for instance, melts at 16.7° C.; above that temperature a one per cent. solution of the acid in water would come under head (2), below 16.7° C. under (3), although no change in the physical or chemical properties of the solution at that temperature gives indication of any real difference between the two subdivisions.

Another basis of subdivision has been sought in the circumstance that whereas some substances have the power of mixing in all proportions (*e.g.*, alcohol and water), others (*e.g.*, ether and water, carbolic acid and water, camphor and alcohol) can do so only to a limited extent, and still others are known which seem incapable of dissolving in each other at all — such, for instance, is the case with silver chloride and water, water and carbon disulphide, etc. These distinctions, however, like the former, have proved more apparent than real, the difference between the various classes turning out on investigation to be merely one of degree, not of kind: above 70° C., for instance, carbolic acid and water will mix in all proportions, below that temperature they will not*; while careful researches have shown that there is no such thing as a totally insoluble salt, and the solubilities† of silver chloride and barium sulphate in water, though very small, have been experimentally determined.

OSMOTIC PRESSURE.

The distinctive conception of the new theory of solutions is that of "osmotic pressure," developed by Prof. van t' Hoff‡ from data contained in a paper on the physiology of plants, published in 1877 by Dr. W. Pfeffer,§ now Professor of Botany in Leipzig.

He found that a porous clay cell on which a film of cupric ferrocyanide was precipitated was pervious to water, but not to sugar; that if aqueous sugar solution were enclosed in such a cell and subjected to pressure above a certain amount (depending on the concentration of the solution) pure water would filter through the pores of the cell; that, on the other hand, if the pressure were kept below this value and the cell were immersed in a vessel of water, the water would enter the cell from without. Other membranes have been discovered possessing similar properties, and solutions of various substances have been experimented on by their aid. The pressure at which equilibrium takes place has been named the "osmotic pressure" of the substance in solution, and has been found:

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* *Ostwald.* Lehrbuch der Allgemeinen, Chemie, I., 640, 1891.

†A solution is said to be saturated with reference to a certain substance at a given temperature if the solution can remain in contact with that substance without altering in composition, and the number of grammes of the substance dissolved in 100 grammes of the solvent under those circumstances is said to represent the solubility of the substance at the temperature specified.

‡*van t' Hoff.* Une proprieté generale de la matière diluèe, Sv. Vet. Ak.'s Handlingar, xxi., Nov. 17, 1886; *also* Die Rolle des Osmotischen Druckes in der Analogie Zwischen Losungen und Gasen, *Z. Ph. Ch.* (Zeitschrift für Physikalische Chemie), I., 481, 1887.

§*Pfeffer.* Osmotische Untersuchungen, Leipzig, 1877.

(1) Proportional to the concentration of the solution.

(2) Proportional to the absolute temperature.

(3) Equal for solutions of various substances, containing the same number of gramme molecular weights per litre.

(4) To have the same absolute value as the pressure which the same quantity of the dissolved substance would exert in the form of a gas enclosed in the same volume and at the same temperature.

In other words, this "osmotic" pressure varies according to

(1) The law of Boyle.

(2) The law of Charles.

(3) Avogadro's hypothesis; and

(4) In the equation

$$PV=nRT \qquad \ldots\ldots\ldots\ldots (1)$$

which is the algebraical expression of these three; the constant R has the same numerical value when P represents the osmotic pressure, T the absolute temperature, n the number of gramme molecules of the dissolved substance, and V the volume of the solution, as when these letters represent the (hydrostatic) pressure, temperature, number of gramme molecules, and volume of a gas.

The importance of these relations will readily be seen; Pfeffer's work furnishes a means of isothermally and reversibly separating solvent from solution, and the quantity of work involved may be calculated from the osmotic pressure by means of the ordinary gas laws.

OSMOTIC PRESSURE AND VAPOR TENSION.

Direct measurements of the osmotic pressure offer exceptional experimental difficulties; the relation, however, which subsists between (*a*) the alteration produced in the vapor tension of a liquid by dissolving another substance in it, and (*b*) the osmotic pressure of that substance in the solution so formed, offers us a ready means of indirectly determining this latter quantity. It has long been known that the boiling point of aqueous solutions of non-volatile substances, *e.g.*, salt, sugar, etc., is higher than that of pure water (or, in other words, that for the same temperature their vapor tension is lower); the quantitative theory of the phenomenon, however, is of comparatively recent date.

It follows directly from the second law of Thermodynamics that if a "reversible circular process" be carried on at constant temperature (isothermally), the quantity of work gained by the system must be equal to that lost (or done). Such a circular process is the following:

Suppose a solution consisting of solvent and dissolved substance in the proportion of N gramme molecules of the former to n of the latter, where n is small in comparison with N.

(1) From a quantity of this solution so large that its composition may be considered as remaining unchanged during the operation remove N gramme molecules of the solvent as follows:

Let A (Fig. 1) be an enclosed vessel containing the solution, and furnished with a cylinder, B, in which the piston, C, permeable for the solvent, impermeable for the dissolved substance, moves without friction. On forcing the piston in the direction of the arrow, water will be removed from the solution and a quantity of work will be done $=PV$, where P is the (constant) osmotic pressure of the substance in solution and V the volume of the N gramme molecules of solvent removed. The value of this quantity may be obtained from the equation

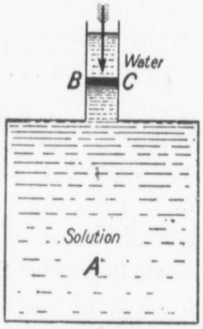

Fig. 1.

$$PV = nRT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(the mathematical expression of Boyle's, Gay Lussac's, and Avogadro's laws), in which R is a constant, P is the osmotic pressure, T the absolute temperature, and V the volume occupied by n gramme molecules of dissolved substance (very nearly equal to the N gramme molecules of solvent, the solution being dilute). The work done, then, in this first operation is

$$nRT$$

(2) The N gramme molecules of pure solvent so obtained may now be converted into vapor at the (constant) pressure p (the vapor tension

of the pure solvent at the temperature T), whereby a quantity of work Npv will be gained, where v is the difference in volume between one gramme molecule of the solvent in the form of vapor (at p, and T) and in the form of liquid; or, approximately, the volume in the form of vapor. Making this approximation, and assuming the applicability of the gas laws in their simplest form, viz., $pv = RT$ ....(1*a*), the quantity of work gained in the second operation will be

$$NRT$$

(3) These N gramme molecules of vapor are now allowed to expand from the pressure p to the pressure p_1 (vapor tension of the solution at temperature T), the quantity of work gained being

$$N\int_{p}^{p_1} pdv = NRT \ \log. \frac{p}{p_1} \ \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

or, approximately (since $p - p^1$ is small compared with p),

$$NRT\,\frac{p - p_1}{p} \ \ldots\ldots\ldots\ldots\ldots\ldots (2a)$$

(4) Lastly, the N gramme molecules of the vapor of the solvent are compressed into the solution whereby the pressure keeps constant $= p_1$, and the quantity of work done is (see operation 2)

$$NRT$$

The circular process has now been completed, each one of its four parts is reversible, and has been carried on at the constant temperature T; therefore, the sum of the four quantities of work involved, each taken with its proper sign (work done positive, work gained negative), is

$$nRT - NRT - NRT\frac{p - p_1}{p} + NRT = 0 \ \ldots\ldots\ldots\ldots (3)$$

Whence

$$\frac{p - p_1}{p} = \frac{n}{N} \ \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

or, "The relative diminution of the vapor tension of the solvent is equal to the ratio of the number of gramme molecules of dissolved substance to the number of gramme molecules of the solvent." And also

$$P = \frac{RT}{V} \cdot \frac{N}{n} \cdot \frac{p - p_1}{p} \ \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

an equation which connects the osmotic pressure with the temperature, the composition and density of the solution, and the vapor tensions of the solution and the solvent.

OSMOTIC PRESSURE AND FREEZING AND BOILING POINTS OF SOLUTIONS.

The very close connection that exists between the vapor tension of a solution and its freezing and boiling points (a relation by means of which we may with ease experimentally determine the ratio $\frac{n}{N}$) may readily be seen from the following considerations:

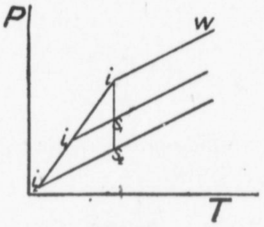

Fig. 2.

In the accompanying figure (Fig. 2), let the line *wi* represent the vapor tension curve for water (*i e.*, a line the ordinates of whose various points represent the pressures of steam in equilibrium with water of the temperatures given by the corresponding abscissæ); let the line $i\ i_1\ i_2$ be the vapor tension curve for ice, and the lines $s_1\ i_1$ and $s_2\ i_2$ the same for the two different salt solutions S_1 and S_2.*

The points i, i_1, and i_2 will then represent the freezing points of water and of the two solutions respectively.

The difference $p - p^1$ between the ordinate of the two lines *wi* and $s_1\ i_1$ at any given temperature is, according to the equation,

$$\frac{p - p_1}{p} = \frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

equal to $\frac{n}{N}p$, in which $\frac{n}{N}$ (which gives the composition of the solutions,) is constant for the line $s_1\ i_1$, and p may be treated as a constant for small variations of temperature. In other words, within the small limits

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*As the variations of temperature and pressure hereinafter to be considered are very small, the parts of the various vapor tension curves represented in the figure will be treated as *straight lines.*

represented in the figure, $s_1 i_1$ (and similarly $s_2 i_2$) may be considered as *parallel* to *wi*. Now, the distances is_1 and is_2 are proportional to the ratios $\frac{n_1}{N}$ and $\frac{n_2}{N}$; and, on the other hand, the lengths of these same lines, is_1 and is_2, are obviously proportional to the horizontal distances of the points i_1 and i_2 from the line $is_1 s_2$, that is, to the differences between the freezing temperatures of water and of the solutions s_1 and s_2 respectively.

From this it follows that the lowering of the freezing point of the solvent is proportional to the ratio:

$$\frac{\text{No. grm. mols. subst. dissolved}}{\text{No. grm. mols. solvent}}$$

or

$$-dT = k\frac{n}{N} \text{.......................} (5)$$

k being a constant whose value evidently depends on the angle which the lines *wi*, etc., make with the T axis; its numerical value has been found from thermodynamical considerations* to be $\frac{Q}{2T^2}$, where Q is the latent heat of fusion of solvent and T the absolute temperature. Introducing this value into (5) it becomes

$$-dT = \frac{Q}{2T^2} \times \frac{n}{N} \text{.......................} (5a)$$

A perfectly similar line of argument leads to an analogous expression for the raising of the boiling point.

MOLECULAR WEIGHTS OF DISSOLVED SUBSTANCES.

The relations obtained in the last two pages connecting the ratio $\frac{n}{N}$ with:

(*a*) The osmotic pressure of the dissolved substance,
(*b*) The diminution of the vapor tension ⎫
(*c*) The lowering of the freezing point ⎬ of the solvent,
(*d*) The raising of the boiling point ⎭

have been made use of in determining the molecular weights of dissolved substances, for a knowledge of the molecular weight of the solvent (in the

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**van t'Hoff, loc. cit.*, p. 496.

state of gas) and of the composition of the solution gives N, a determination of any one of the quantities (*a*), (*b*), (*c*), (*d*) above gives $\frac{n}{N}$, and the product of the two is n, or the number of gramme molecules contained in the (known) weight of the dissolved substance, hence the molecular weight of the latter.

The molecular weights obtained in this manner have in many cases proved identical with those expected from purely chemical grounds, sometimes, however, notably in the case of solutions of salts, strong acids, and strong bases, the number of molecules, as deduced from freezing point depression, etc., has been found to be two, three, or more times as great as can be accounted for if the molecular constitution represented by its chemical formula be assigned to the dissolved substance.

A similar discrepancy had years before been noticed in the molecular weights of certain gases. A density determination showed that the number of molecules contained in the vapor evolved on heating a given quantity of ammonium chloride was twice that calculated by the help of Avogadro's hypothesis* from the chemical formula NH_4Cl; the explanation suggested, viz., that the substance had undergone chemical decomposition ("dissociation") into ammonia and hydrochloric acid gas, although at first scouted as "contravening all the laws of chemical affinity," has since been confirmed by direct experimental evidence. The attempt, however, to account for the "abnormal depression of the freezing point" of water by salts, strong acids, etc., in a similar manner was balked by the difficulty of saying into what such a substance as sodium chloride (NaCl), for instance, *could* possibly be "dissociated."

ELECTROLYTIC SOLUTIONS.

The fact that these "abnormal" results were obtained chiefly with solutions of electrolyte, however, has led to a hypothesis which, originally put forward to explain a limited number of phenomena, has proved itself an invaluable assistance in all investigations into the nature of electrolytic solutions.

That aqueous salt solutions can conduct electricity was well known to Galvani and Volta; that chemical decomposition accompanies the passage of the current through them seems first to have been discovered by Nicholson and Carlisle (1800); but a quantitative investigation of the products of this decomposition was first undertaken by Faraday, who established the first and second of the following four general statements:

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*"Equal volumes of all gases at the same temperature and pressure contain the same number of molecules," or, as the atomic weight of hydrogen has been adopted as the unit, and the molecule of hydrogen contains two atoms, 22.327 litres at 0°C and 760 mm. (which would contain two grammes of hydrogen) will contain the molecular weight in grammes of any gas.

(1) The quantity of salt decomposed in a given time is proportional to the current.

(2) If the same current be passed through solutions of various salts, chemically equivalent quantities of these salts are decomposed. (Faraday's law.)

Apart from this decomposition, however, there has often been observed:

(3) An alteration of the concentration of the undecomposed electrolyte along the line of flow of the current. Thus, for instance, if electricity be passed through copper chloride solution between platinum electrodes copper will be deposited at the kathode,* and chlorine set free at the anode; but, besides this, at the end of the experiment, that half of the solution towards the anode will be found to contain more copper chloride than the half in the neighborhood of the kathode. The quantitative investigation of this phenomenon is due to W. Hittorff.†

(4) In all other respects, however, the conduction of electricity by electrolytes resembles that by metals, and is subject to the laws of Ohm and of Joule.

ION THEORY.

Faraday represented the passage of electricity through the solution as effected by the actual motion of translation of material particles (which he identified with the then recently invented "atoms" of Dalton), each one carrying an equal (positive or negative) charge, much as the pith balls in the familiar electrostatic experiments. Such of these particles as were positively charged would tend to move towards the (negatively charged) kathode, and were hence named "kations," the others (moving in the opposite direction) "anions." The electrical neutrality of the solution he explained by assuming the existence of equal numbers of these two classes of ions.

Thus in the electrolysis of a solution of sodium chloride, he imagined the sodium atoms, each with its appropriate charge of positive electricity,

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*The *anode* is that pole which is metallically connected to the positive pole of the source of E.M.F., the *kathode* to the other. According to the usual convention, the + current is supposed to enter the *electrolyte* (*i.e.*, the conducting solution) by the anode and leave it by the kathode.

†*W. Hittorff.* Wanderung der Ionen waehrend der Elektrolyse Pogg. Ann., LXXXIX., 177; XCVIII., 1; CIII., 1; CVI., 337 and 513; 1853-1859. Reprinted in *Ostwald's* Klassiker, Nos. 21 and 23, Leipzig, 1891.

as moving "down" towards the kathode, while the chlorine atoms were carrying their negative charges "up" to the anode. If the atoms of the various elements be supposed to carry charges proportional to their valency, we can deduce from Faraday's ion theory the second of the above general propositions. The variations in concentration may be accounted for by assuming that under similar circumstances (*e.g.*, the same difference of potential per centimetre) the various ions ($\overset{+}{K}$, $\overset{++}{Cu}$, $\overset{-}{Cl}$, $\overset{--}{SO_4}$, etc.) move at different rates; for in the electrolysis of copper chloride solution, mentioned above, if the chlorine ions move toward the anode quicker than the copper ions toward the kathode (the condition of electrical neutrality of the solution being maintained), the concentration of the copper chloride will become relatively greater in that part of the solution nearest the anode; and conversely experimental measurements of the alterations in concentration, brought about by the passage of a current, have led to the determination of the relative velocities of the various ions.

The next step in the development of this "ion theory" of electrolysis was taken by Kohlrausch, who found that the "molecular conductivity"* (μ) of *dilute solutions* of salts, and of some acids and bases, was an "additive" property, *i.e.*, might be measured in each case by the sum of two specific constants, one for the kation and one for the anion. In endeavoring to give a physical meaning to these constants, he was led to the conjecture that they might possibly represent the rates at which the various ions transport the electrical charge, and a careful comparison of his own results with those of Hittorff showed this hypothesis to be well founded. The result of his investigation he expressed in the formula

$$\mu_{\infty} = u + v \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

or, "molecular conductivity in extremely dilute solutions is equal to the sum of the velocities expressed in suitable units of the anion and of the kation."

The molecular conductivities of more concentrated solutions he found to be less than those of the dilute.

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*The conductivity (in reciprocal ohms) of such a quantity of the solution as contains a formula weight in grammes of the salt, when enclosed between electrodes one centimetre apart. It will be seen from this definition that the molecular conductivity may be obtained by multiplying the number of cubic centimetres of the solution that contain one gramme formula weight of salt *into* the "specific conductivity" of the solution, *i.e.*, the conductivity of a cube whose side measures one centimetre.

The following table* shows the extent of the agreement between the experimental results and those calculated by means of equation (7): the values are for 18° C. and for extremely dilute solutions.†

TABLE 1.

Values of u for $K=52$. $Na=32$. $Li=24$. $Ag=42$. $H=272$. $\frac{1}{2}Zn=24$.

Values of v for $Cl=54$. $I=55$. $NO_3=48$. $OH=143$.

	Molecular Conductivity, μ_∞		Transport of the Anion $\frac{v}{u+v}$.	
	Obs'd.	Calc'd.	Obs'd.	Calc'd.
KCl	105	106	0.51	0.51
$NaCl$	87	86	0.63	0.63
HCl	324	326	0.19	0.17
$AgNO_3$	89	90	0.53	0.53
$\frac{1}{2}ZnCl_2$	77	78	0.70	0.69
KOH	199	195	0.74	0.73

NOTE.—The "observed" molecular conductivities are from a paper by Kohlrausch; the "observed" transport values are from Hittorff's work.

This theory of ions, though admirably adapted to explain the phenomena of electrolysis, was looked on askance by the great majority of chemists, whose ideas of the true nature of things were inexpressibly shocked by the idea of sodium atoms—with or without a "charge of

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**Ostwald.* Lehrbuch II., 646 (in part).

†As the transport values vary markedly with the concentration of the solution, the following table of the relative velocities of the kations of a few common salts in "normal" aqueous solutions (which contain one gramme formula weight of the salt in one litre of the solution) will be of more practical use in the calculation of electromotive forces—as will appear further on:

TABLE 2.

Salt.	Ions.	Relative Velocity of Kation $\frac{u}{u+v}$
Hydrochloric acid	H,Cl	0.82
Sulphuric acid	$2HS,O_4$	0.82
Potassium chloride.........	K,Cl	0.48
Potassium sulphate........	$2K,SO_4$	0.5
Magnesium chloride.......	$Mg.2Cl$	0.26
Magnesium sulphate.......	Mg,SO_4	0.25
Zinc sulphate......	Zn,SO_4	0.28
Cadmium chloride	$Cd,2Cl$	0.26
Copper sulphate.	Cu,SO_4	0.276
Silver nitrate.............	Ag,NO_3	0.50

(The values are taken from *Ostwald*, Lehrbuch II.)

electricity"—existing in contact with a substance so violently acted on by metallic sodium as is water. The most they could allow was the existence of a few stray ions here and there, and one can easily imagine the stir caused by a paper of Sv. Arrhenius,* who assumed that in a *dilute* common salt solution *all* of the salt existed in the form of sodium ions $\overset{+}{\mathrm{Na}}$ and chlorine ions $\overset{-}{\mathrm{Cl}}$, and that in more concentrated solutions the fraction of the salt in the state of ions was given by the ratio between the molecular conductivities of the more concentrated and of the dilute solution, *i.e.*, α being the fraction of the salt in the state of ions,

$$\alpha = \frac{\mu_v}{\mu_\infty} \qquad \ldots\ldots\ldots\ldots\ldots (8)$$

where μ_v is the molecular conductivity of a solution containing one gramme molecule of salt in the total volume V; and μ_∞ the limiting value of the molecular conductivity in an extremely dilute solution.

IONS AND OSMOTIC PRESSURE.

This hypothesis of Arrhenius suggested to van t' Hoff, in answer to the question referred to on page 230, that the *dissociation products* of sodium chloride (needed to explain the "abnormalities" in freezing point, etc., of its solution) might be none other than these very *ions* which were introduced in order to account for the phenomena of electrical conduction of the same solution; and the fact, already mentioned, that the class of electrolytes furnished the most striking variations from the simple laws as to vapor pressure diminution, etc., served to render the assumption plausible from the first.

If the molecules in a sodium chloride solution are *not* NaCl, but $\overset{+}{\mathrm{Na}}$ and $\overset{-}{\mathrm{Cl}}$, there are obviously twice as many of them present in a given volume of the solution as was thought, and a depression of the freezing point twice that calculated on the assumption of NaCl molecules is at once accounted for. Speaking generally, if one molecule of the electrolyte (as expressed by its chemical formula) give rise to *m* ions (*e.g.*, NaCl two, $CaCl_2$ three., viz., $\overset{++}{\mathrm{Ca}}$, $\overset{-}{\mathrm{Cl}}$, $\overset{-}{\mathrm{Cl}}$), and if α be the fraction of the salt

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**Sv. Arrhenius.* Sur la conductibilité galvanique des electrolytes. Bihang till K. Svenska Vet. Akad. Handlingar—Band. 8, No. 13, 1884. *Also*, Ueber die Dissociation der in Wasser gelösten Stoffe, *Z. Ph. Ch.*, I., 631, 1887.

in the state of ions,[*] then for every formula-weight in grammes of salt in the solution we have $1-\alpha$ gramme molecules of undecomposed salt and α decomposed, yielding $m\alpha$ ions, or, in all, $1-\alpha+m\alpha$, or $1+(m-1)\alpha$ gramme molecules, counting the ions as independent molecules; and the depression of the freezing point will be $1+(m-1)\alpha$ times "too great," while the molecular electrical conductivity will be $\alpha\Sigma(u+v)$ where $\Sigma(u+v)$ represents the sum of the velocity constants of the various ions involved. By means of these relations, electrical conductivity and freezing point (similarly the boiling point, vapor tension, etc.) are connected, and one being experimentally determined the other may be calculated. The remarkable success of calculations of this nature has very materially contributed toward the general acceptance of a theory that furnishes a link between two branches of physics so dissimilar.

IONS AND THE MASS LAW.

The success attending this first venture at treating the ions as full-fledged molecules, natuarally soon led to a second, viz., an application of the law by which, in the case of gases, the dissociation may be expressed in terms of the concentration. The quantitative expression of this relation is contained in the equation of Guldberg and Waage[†] (the so-called "Mass law").

$$\frac{C_1^{n_1}\cdot C_2^{n_2}\cdot C_3^{n_3}\ \ldots}{C}=\text{Const.}\ \ldots\ldots\ldots(9)$$

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[*] Value of α for "normal" solutions of various electrolytes at ordinary temperatures:

(1) Salts of the alkalis, of ammonium, and of silver, with monobasic acids, about 0.75 to 0.8.

(2) Zinc sulphate, copper sulphate, etc., dissociating into two ions with double charge, about 0.25.

(3) Monobasic acids and monacid bases; all values from about 0.8 for "strong" acids and bases, *e.g.*, HCl and KOH down to about 0.01 for acetic acid and ammonia, and even less for many of the weaker organic acids and bases.

[†] This important equation, whose relation to the fundamental principles of thermodynamics has been clearly shown by Prof. W. Gibbs (Transactions Connecticut Academy, III., 231, 1876), was first deduced by Guldberg and Waage, 1867, from considerations as to the velocity of chemical reactions. Wilhelmy had shown as early as 1850 that in many cases the quantity of chemical change taking place in a given time is proportional to the concentration of the reacting bodies, or that the "velocity"

$$v=KC_1C_2\ \ldots$$

In case the reaction be "reversible," *i.e.*, if the products of the chemical action of two (or more) substances can recombine to form the originals, as, for example, in the case

C being the concentration (gramme molecules per litre) of the undecomposed substance; C_1, C_2, etc., the concentrations of the various products of dissociation; and n_1, n_2, etc., the number of molecules of each of these latter formed from one molecule of the original substance. For example, in the case of phosphorus pentachloride, which on heating decomposes as follows:

$$\mathrm{PCl_5 = PCl_3 + Cl_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

one molecule of phosphorus trichloride and one of chlorine being formed from one of phosphorus pentachloride, the Guldberg and Waage's equation takes the form:

$$\frac{\text{Concentration } (\mathrm{PCl_3}) \times \text{Concentration } (\mathrm{Cl_2})}{\text{Concentration } (\mathrm{PCl_5})} = \text{Const.} \ldots (11)$$

If the "dissociation" of sodium chloride in solution into sodium ions and chlorine ions

$$\mathrm{NaCl} = \overset{+}{\mathrm{Na}} + \overset{-}{\mathrm{Cl}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

be subject to the same law, the following relation must hold good:

$$\frac{\text{Concentration } (\overset{+}{\mathrm{Na}}) \times \text{Concentration } (\overset{-}{\mathrm{Cl}})}{\text{Concentration } (\mathrm{NaCl})} = \text{Const.} = \mathrm{K} \ldots\ldots\ldots (13)$$

or (from the definition of "concentration" given above)

$$\frac{\mathrm{M}(\overset{+}{\mathrm{Na}}) \times \mathrm{M}(\overset{-}{\mathrm{Cl}})}{\mathrm{M}(\mathrm{NaCl})} = \mathrm{KV} \ldots\ldots\ldots\ldots\ldots (13a)$$

where $\mathrm{M}(\overset{+}{\mathrm{Na}})$ denotes the mass of sodium ions expressed in gramme

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$$\text{Alcohol} + \text{Acid} \qquad \text{Ether} + \text{Water},$$

the change actually observed will be only the difference between the quantity of alcohol and acid which are used up in the reaction, and the quantities that are re-formed by the reaction, and when equilibrium is reached, *i.e.*, when no further change in the relative quantities of the four reagents takes place,

$$0 = v_1 - v_2 = K_1C_1C_2 - K_2C_3C_4$$

$$\text{or } \frac{C_3C_4}{C_1C_2} = \frac{K_1}{K_2} = K$$

Equation (9) above gives the relation in its most general form.

molecular weights, and similarly with $M(\overset{-}{Cl})$, etc. ; V is the total volume occupied by the solution, in litres.

In the special case that the solution contains but one salt, the chemical equation of decomposition furnishes a relation between the masses of the various dissociation products. In the example selected, it follows from (12) that $M(\overset{+}{Na})$ and $M(\overset{-}{Cl})$ are equal, and (13*a*) takes the form :

$$\frac{M^2(\overset{-}{Cl})}{M(NaCl)} = \frac{M^2(\overset{+}{Na})}{M(NaCl)} = KV \ldots\ldots\ldots\ldots\ldots (13b)$$

Representing the fraction of the salt in the state of ions by a (as on p. 234), then the one formula-weight of salt dissolved has given rise to a gramme molecules of (each) $\overset{+}{Na}$ and $\overset{-}{Cl}$ and $1 - a$ gramme molecules NaCl ; so that (13*b*) may be written

$$\frac{a^2}{1 - a} = KV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13c)$$

which, on substituting for a its value from (8), becomes

$$\frac{\mu^2_v}{\mu_\infty(\mu_\infty - \mu_v)} = KV \ldots\ldots\ldots\ldots\ldots\ldots (13d)$$

an equation connecting the molecular conductivity of the solution with the concentration of the dissolved substance, which obviously holds not only for the special case here considered, but also wherever one molecule of an electrolytic substance gives rise on dissociation to equal quantities of two ions. This is true for all monobasic acids, *e.g.*, acetic acid

$$CH_3COOH = \overset{-}{(CH_3COO)} + \overset{+}{H}$$

for all monacid bases, *e.g.*, potassium hydrate

$$KOH = \overset{+}{K} + \overset{-}{(OH)}$$

and for many salts, *e.g.*, silver nitrate and zinc sulphate

$$AgNO_3 = \overset{+}{Ag} + \overset{-}{(NO_3)}$$
$$ZnSO_4 = \overset{++}{Zn} + \overset{--}{SO_4}$$

The accuracy of this relation, and therewith the applicability to the case of dissociation in solution, of a quantitative law originally obtained for the dissociation of gases was immediately tested* by careful comparison with the experimentally determined conductivities of over two hundred organic acids in solutions of varying concentration. The remarkable agreement between the experimental values and those calculated by equation (13*d*) attracted great attention, and contributed largely to create confidence in the new theory of solutions. Since this time, many other applications of the law of Guldberg and Waage to the case of solutions have been made with equal success. Of these but one need be considered here. A reference to equation (9) shows that if the concentration of any one of the dissociation products be increased (by addition from without), the quantity of undissociated substance in the solution will also necessarily increase; thus the dissociation of the acetic acid† in aqueous solution

$$CH_3CO.OH = CH_3C\overset{-}{O}\cdot\overset{\cdot}{O} + \overset{+}{H}$$

would be diminished by the addition of (*a*) any salt of acetic acid (*i.e.*, the ion $CH_3.\overset{-}{CO}.O$), or (*b*) any "strong" (much dissociated) acid (*i.e.*, $\overset{+}{H}$). Thus, speaking generally, the total number of ions contained in the (separated) solutions of two substances possessing a common ion will be diminished on mixing the solutions, and, hence, the specific conductivity of the mixture will be less than the average of the conductivities of the solutions before mixing. This relation, also, has been reduced to quantitative form, and tested by experiment, with satisfactory results.

ELECTROMOTIVE FORCES.

The most recent triumphs, however, of the new solution theory have been in connection with calculations of the E.M.F. of cells. Previous attempts at such calculations had been made by H. v. Helmholtz§ and by Sir Wm. Thomson‡ who, acting on the assumption that all of the

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*[*] *Ostwald.* Zur Theorie der Lösungen, *Z. Ph. Ch.*, II., 36, 1888. Dissociationstheorie der Elektrolyte, *Z. Ph. Ch.*, II., 270, 1888.

[†] *Sv. Arrhenius.* Gleichgewichtsverhältnisse zwischen Elektrolyten, *Z. Ph. Ch.*, V., 1., 1890.

[§] *H. v. Helmholtz.* Erhaltung der Kraft, 1847. *Ostwald's* "Klassiker," No. 1, Leipzig, 1889.

[‡] *W. Thomson.* *Phil. Mag.*, (4) 2, 429, 1851.

energy set free by the chemical action in the cell could be converted into electrical energy, equated the mechanical equivalent of the "heat of reaction" for the chemical change taking place in a given cell to the product of the quantity of electricity transferred during these changes into the E.M.F.

REVERSIBLE CELLS.

The results obtained from calculations based on this assumption were soon found to differ widely from the results of experiment; and simultaneously, the science of thermodynamics, now undergoing rapid development at the hands of Clausius and others, tended to cast grave suspicion on the fundamental hypothesis underlying the calculations themselves. A period of thirty years, however, elapsed before these problems were attacked again from the more modern point of view; this time, again, by v. Helmholtz.*

A large number of galvanic cells are "reversible machines" in the thermodynamical sense; that is, not only will the chemical decomposition produced in the cell be reversed by a change in the direction of the current,‡ but the E.M.F. which must be opposed in order to produce this change in direction need be greater than the E.M.F. of the cell itself by but an infinitesimal amount.

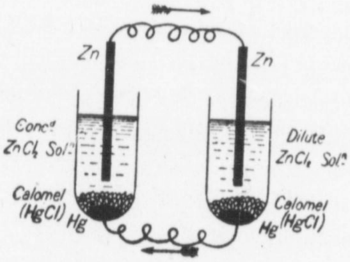

Fig. 3

Such a cell, for instance, is the combination

Amalgamated zinc | Zinc chloride solution | Mercurous chloride | Mercury

two of which are represented in opposition in Fig. 3. When the electrodes of one of the so-called "calomel cells" are metallically con-

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*v. *Helmholtz.* Monatsbericht der k. pr. Akad d. Wiss. zu Berlin, 1877, p. 713.

‡Which, for instance, is approximately true in the case of the storage battery.

nected, the zinc of the zinc electrode dissolves, forming zinc chloride with the chlorine of the calomel, while the mercury of the latter is deposited at the other (mercury) electrode. The E.M.F. at 15° C. of a cell filled with zinc chloride solution of s.g. 1.409 is 1.000 volts, and, if it be opposed by an external E.M.F. of any higher value, the zinc will be precipitated on the zinc electrode and the surface of the mercury electrode will be attacked with the formation of calomel. But although the decompositions produced in the cell by its own action are those expressed by the chemical equation

$$Zn + 2HgCl = ZnCl_2 + 2Hg \ldots\ldots\ldots\ldots\ldots (14)$$

there is, in addition, a change taking place which is not represented there, *viz.*, an increase of concentration in the zinc chloride solution; and if two "calomel cells" be set up in opposition, as in Fig. 3, and a current pass in the direction of the arrows, this latter change is the only net effect of the operation; for just as much zinc is precipitated in the left-hand cell (cell No. 1) as is dissolved in the other, and the quantity of calomel decomposed in cell No. 2 is precisely equal to that formed in No. 1, the whole effect of the passage of the current being merely to increase the concentration of the zinc chloride solution[*] in No. 2 and to decrease it in No. 1.

APPLICATION OF THE SECOND LAW OF THERMODYNAMICS.

An apparatus, then, such as the one under consideration (Fig. 3) furnishes an electrical means of isothermally and reversibly bringing about alterations in the concentration of a zinc chloride solution, and must require the same quantity of work to effect this result as would be required to effect the same result by means of any other isothermal reversible process; otherwise these two processes could be combined (the first operating in one direction and the second in the reverse) to form an isothermal cycle, yet capable of supplying any desired quantity of work, the only source of which could be the heat of the surroundings; a proposition directly at variance with the fundamental conceptions of the second main principle of thermodynamics, according to which a difference of temperature is absolutely necessary in order that heat may be converted directly into work.

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[*] As there is solid calomel present in the cell, the concentration of the mercurous chloride dissolved remains constant.

The application of this theorem to the cases in point is simple and direct. The electrical work that must be done in order to bring about a certain alteration of concentration in the two electrolytes is obviously the integral of the quantity of electricity passed through the cells into the resultant electromotive force of the combination at each instant: if, then, any other reversible method be known, by means of which this same effect can be produced, and if the work necessary in this latter case be known, an expression equating these two quantities of work* furnishes a means of calculating the E.M.F. of the cell combination in question.

In the paper of v. Helmholtz before referred to, he selects as his second means of altering the concentration of the electrolyte the method of directly evaporating the water at a pressure equal to its vapor tension over the solution, and thus by expressing the vapor tension of aqueous zinc chloride solutions of various concentrations in terms of these concentrations, he was enabled to perform the remarkable feat of calculating the E.M.F. of an electrical battery from entirely independent data.

RELATION TO OSMOTIC PRESSURE.

It will readily be seen by those who have carefully read the earlier part of this paper that the vapor tensions in Von Helmholtz's formula for the E.M.F. may be replaced by expressions containing the osmotic pressure of the dissolved substances.† The first attempt, however, to attack this problem from the point of view of the modern theory of solutions was made by Prof. W. Nernst in an important paper published in 1889.‡

Starting, as did v. Helmholtz, from the theorem that the work to be obtained by the passage of a system from one state to another by any isothermal reversible process is independent of the special nature of that process, he equated the work which would be done by the osmotic forces during the passage of the zinc chloride from the stronger to the weaker solution§ to that obtainable by the electrical process which leads to the same result; that is,

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* In conjunction with Faraday's law, connecting current and amount of chemical change produced.

† The vapor tensions of solutions being known functions of the osmotic pressures of the dissolved substances; see page 229.

‡ *W. Nernst.* Elektromotorische Wirksamkeit der Ionen, *Z. Ph. Ch.*, IV., 130, 1889.

§ As in the case of a gas, the work done in bringing one gramme molecule from pressure p_1 to p_2 is $\int_{p_1}^{p_2} pdv$, from which by substituting for p its value from equation (1) the expression in (15) is obtained.

$$4.18 n_i RT \log. \frac{p_1}{p_2} = n_e \varepsilon \pi \ldots\ldots\ldots\ldots\ldots\ldots (15$$

Where

4.18 is the mechanical equivalent of heat (in Joules).

n_i the number of gramme ions contained in the solution of one gramme formula weight of salt.

p_1 and p_2 the osmotic pressures of the zinc chloride in cells (1) and (2) respectively.

n_e the number of electrical equivalents represented by one atom of the dissolved metal (for zinc $n_e = 2$).

ε the quantity of electricity which on passing through a salt solution decomposes one gramme equivalent of the salt, viz.: 96,540 coulombs.

π the E.M.F. of the combination.

T the "absolute" temperature.

R the constant of equation (1)——$RT = 2T$ cal.

Whence

$$\pi = 4.18 \frac{n_i}{n_e} \frac{R}{\varepsilon} T \log. \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (15a)$$

or collecting the constants and substituting Briggs' logarithms for natural

$$\pi = 0.0002 \frac{n_i}{n_e} T \log._{10} \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (15b)$$

This quantity π, the electromotive force of the combination represented in Fig. 3, is, evidently, equal to $\pi_1 - \pi_2$, the difference between the E.M.F. of cells (1) and (2). If the concentration of the solution (and, therefore, the E.M.F.) of cell (2) be kept constant, while that of cell (1) is arbitrarily varied, then the E.M.F. of cell (1)

$$\pi_1 = \pi + \pi_2 = 0.0002 \frac{n_i}{n_e} T \log._{10} p_1 + (\pi_2 - K) \text{ volts} \ldots\ldots (15c)$$

(Where $K =$ the constant quantity $0.0002 \frac{n_i}{n_e} T \log._{10} p_2$)

and as the osmotic pressures are, at all events in dilute solutions, proportional to the concentrations, this expression shows the relation between the E.M.F. of a cell and (1) the concentration and (2) the state of dissociation of the electrolyte.

Another example of the facility with which the theory of osmotic pressure lends itself to the solution of problems of this nature was shortly afterwards furnished by V. v. Türin.* In the case of a cell whose electrodes are composed of zinc amalgam of different concentrations (Fig. 4), the electrolyte being the solution of a zinc salt, the electromotive force may be arrived at by setting the electrical work gained during the transference of an elementary mass of zinc from the stronger to the weaker amalgam to that which might be obtained by its passage under the influence of the osmotic forces from its more concentrated to its more dilute solution in mercury; or,

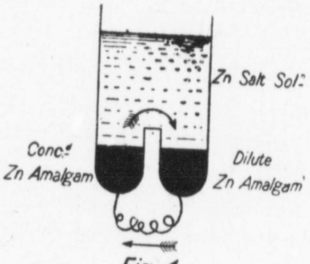

Fig. 4

$$n_e \varepsilon \pi = 4.18\, n_i RT \log. \frac{p_1}{p_2} \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

an equation identical in form with (15), but in which p_1 and p_2 represent the osmotic pressures of the zinc in the zinc amalgam electrodes of cells (1) and (2) respectively. Whence, as before,

$$\pi = 0.0002 \frac{n_i}{n_e} T \log._{10} \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (16a)$$

in which $\frac{p_1}{p_2}$ may be set equal to $\frac{c_1}{c_2}$, the ratio of the concentrations of the zinc in the two amalgam electrodes; $n_e = 2$; and n_i has been found to be unity by experiments on the freezing point of solutions of zinc in mercury.

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[*] *V. v. Türin.* Molekulargewichte der Metalle, *Z. Ch. Ph.*, V., 340, 1890. See also *G. Meyer*, Bestimmung des Molekulargewichtes einiger Metalle, *Z. Ph. Ch.*, VII., 477, 1891.

The case of the combination represented in Fig. 5 is of peculiar interest. This, as will be observed, differs from the arrangement in Fig. 3, in that the circuit is completed by direct communication of the

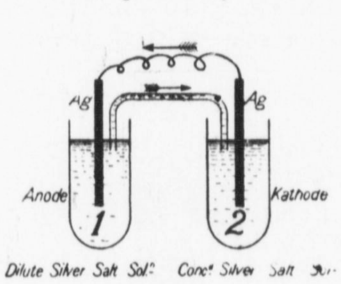

Fig. 5.

electrolytes (through a siphon)* instead of by means of the mercury electrodes and metallic connection of the latter. Under these circumstances, while one equivalent of silver is dissolving at the anode, the quantity

$$\frac{u}{u+v}$$

passes through the siphon towards the kathode, and the resulting increase of concentration in cell (1) is only

$$1-\frac{u}{u+v}=\frac{v}{u+v}$$

with which factor the expression (15*b*) must be multiplied, giving

$$\pi=0.0002\,\frac{v}{u+v}\,T\,\log._{10}\frac{c_1}{c_2}\text{ volts}\ldots\ldots\ldots\ldots(17)$$

as the electromotive force of the combination in question.

INDIVIDUAL ELECTROMOTIVE FORCES.

This last example leads directly to a consideration of the cases in which an E.M.F. is produced through the contact of two electrolytes.

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*Simultaneously with the reversible motion of the ions under the influence of the electrical forces, there takes place a non-reversible diffusion through the siphon, tending to equalize the concentration in the two cells. Owing to the comparative slowness of the diffusion, however, the effect produced by it during the small time necessary to make an E.M.F. measurement may be neglected.

While a quantity of positive electricity corresponding to one gramme molecular weight passes through the siphon in the direction of the arrow (Fig. 6), the quantity $\frac{u}{u+v}$ of the kation moves out of cell (1) into cell (2). Suppose the solution in cell (1) to be more concentrated than in cell (2), this transference would yield (in reversible osmotic piston and cylinder apparatus) the work

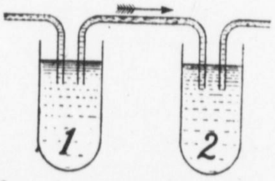

Fig 6.

$$4.18 \frac{u}{u+v} n_i RT \log. \frac{p_1}{p_2}$$

but during the same time the quantity $\frac{v}{u+v}$ of the anion has gone from the (dilute) cell (1) to the (concentrated) cell (2); which second transference could be effected by the osmotic pressure apparatus only by the expenditure of the work

$$4.18 \frac{v}{u+v} n_i RT \log. \frac{p_1}{p_2}$$

a gain, on the whole, of

$$4.18 \frac{u-v}{u+v} RT \log. \frac{p_1}{p_2}$$

which, as all processes here considered are isothermal and reversible, may be set equal to the electrical work $n_e \varepsilon \pi$.

From this relation it follows, collecting constants, etc., as before that the E.M.F. in the siphon*

$$\pi = 0.0002 \frac{u-v}{u+v} T \log._{10} \frac{p_1}{p_2} \text{ volts} \ldots\ldots\ldots\ldots (18)$$

---

*Silver is selected as the type of a monovalent kation; for divalent, etc., kations (*e.g.*, zinc) the formulæ are somewhat more complicated. The general expression for the E.M.F. at the contact of two solutions of the same salt of different concentrations is

$$\pi = \frac{\frac{u}{n} - \frac{v}{m}}{u+v} \cdot \frac{RT}{\varepsilon} \log. \frac{p_1}{p_2} = \frac{\frac{u}{n} - \frac{v}{m}}{u+v} 0.0002 \, T \log._{10} \frac{p_1}{p_2} \ldots\ldots\ldots (18a)$$

where n is the valency of kation, m that of the anion.

an expression of very considerable interest, furnishing, as it does; the first example* of the calculation of an "individual" E.M.F. For it will be seen that π in equations (15*c*), (16*a*), and (17), referring to Figs. 3, 4, and 5, is the algebraic sum of several of such "individuals"; for instance, the E.M.F. of the cell-combination represented in Fig. 3 is the resultant of:

(1) EMF between zinc and electrolyte in cell (1).
(2) " electrolyte and mercury in cell (1).
(3) " mercury and (platinum) wire in cell (1).
(4) " platinum and mercury in cell (2).
(5) " mercury and electrolyte in cell (2).
(6) " electrolyte and zinc in cell (2).
(7) " zinc and wire in cell (2).
(8) " wire and zinc in cell (1).

Professor M. Planck (*Wied. Ann.*, xl., 561, 1890) has deduced a formula for the still more general case, where the two solutions contain a number of different electrolytes which are not necessarily the same in each. The equation runs:

$$\pi = 0.0002\ \mathrm{T} \log. x \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \ldots\ldots(18b)$$

in which x is defined by the relation

$$\frac{x U_2 - U_1}{V_2 - x V_1} = \frac{\log. \frac{c_2}{c_1} - \log. x}{\log. \frac{c_2}{c_1} + \log. x} \cdot \frac{x c_2 - c_1}{c_2 - x c_1}$$

$$\text{and } U = up + u^1p^1 + \ldots. \qquad V = vq + v^1q^1 + \ldots.$$

u, v, p, and q being the velocities and osmotic pressures of the various kations and anions, and the quantities U_1 and V_1 referring to one of the solutions, U_2 and V_2 to the other. c_1 and c_2 are the total concentrations (gramme molecules per litre) of all positive ions in the two solutions respectively.

The formula has been applied to calculate the E.M.F. between two equally concentrated solutions of different electrolytes. The values are mostly small, as may be seen from the following examples:

Normal solutions of	π obs'd.	π calc'd.
HCl, KCl	0.0285	0.0282
KCl, NaCl	0.0040	0.0052

*Historically, the first individual E.M.F. to be determined was that existing at the contact of two different metals. It was calculated, at Edlund's suggestion, by equating the heat given off (or absorbed) per second at the junction while a current passed to the product of current and F.M.F. at the junction. Electromotive forces of this nature are usually very small, as may be seen from the annexed table, giving their value in volts for the following metals against copper:

Table 3.

Antimony	—0.0060
Iron	—0.0031
Cadmium	—0.00061
Zinc	—0.00044
Bismuth	+0.024

The table is taken from *Ostwald*, Lehrbuch, II., 919.

Of these, Nos. (3) and (4) are obviously equal in magnitude, but of opposite sign, and the same is true for Nos. (7) and (8). The possibility of computing the values of the remaining quantities (Nos. (1), (2), (5), and (6), which represent, in each case, individual E.M.F. between metals and electrolytes, has now to be considered.

E.M.F. BETWEEN METALS AND ELECTROLYTES.

It will be readily seen that no process of addition or subtraction of the E.M.F. of various cells will lead to the desired quantities. If, on the other hand, the total E.M.F. of the cell No. (1) (Fig. 3) be known, and, in addition, the individual E.M.F. between the mercury and the electrolyte, then that between the zinc and the electrolyte can be determined by subtraction; and that similarly by measuring the E.M.F. of suitable cells having mercury (with calomel) for one electrode, any other individual E.M.F. of the kind under consideration may be at once determined; or, in other words, that a knowledge of one such individual renders possible a determination of all the rest.

The importance, then, of arriving, by some means, at a measurement of some one individual electromotive force of this nature is apparent: the method suggested is due to the development, by Prof. Ostwald,* of a theorem of H. v. Helmholtz respecting the alteration of the surface tension of mercury by an electrical charge. If a drop of mercury in a watch glass (Fig. 7) be covered by dilute sulphuric acid (to which a trace of potassium bichromate has been added), and an iron wire be passed through the acid so as to touch the mercury, the latter will at once contract, the drop becoming more rounded and its surface correspondingly less. That this phenomenon (increase of the surface tension of the mercury) is brought about by an alteration of the electrical condition of the mercury may be concluded from a modified form of the experiment, the apparatus for which is indicated in Fig. 8.

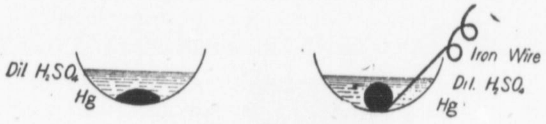

Fig. 7.

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*Ostwald. Lehrbuch, II., 931, 1893 (first published in the first edition of the "Lehrbuch," Vol. II., p. 487, 1887).

This consists essentially of an upright tube, drawn out to a capillary at one end and filled to a certain height (depending on the diameter of the capillary) with mercury, which does not, however, fall through, being supported by reason of its surface tension at the meniscus. Electrical connection is obtained by means of the wire A, and the tube so prepared dips into a beaker of dilute sulphuric acid (one part of acid to six of water). By means of this apparatus any variation of the surface tension of the mercury at C may be very readily observed; an *increase* causing the meniscus to rise in the tube, a *decrease* to lower. It has been observed that the application of an external E.M.F., raising the potential of A relatively to B, causes the meniscus to fall; if, on the other hand, the potential of B be raised with reference to A, the meniscus rises until the potential difference reaches 0.97 volt, after which any further increase causes it to fall.

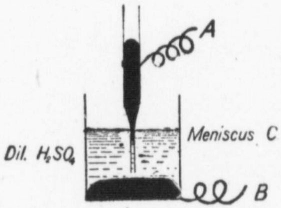

Fig. 8.

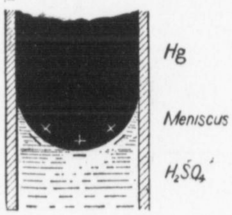

Fig. 9.

H. v. Helmholtz's explanation may be understood by a reference to Fig. 9, which represents a magnified image of the meniscus C of Fig. 8.

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*_H. v. Helmholtz._ Gesammelte Abhandlungen, I., 855 and 925, originally published in _Wied. Ann._, VII., 337, 1879.

As the passage of electricity from mercury to sulphuric acid, or *vice versa*, involves the decomposition of the sulphuric acid, which cannot be effected with less than about 2 volts, the surface of separation between mercury and electrolyte under the conditions of the experiment (E.M.F. less than 2 volts being made use of) acts the part of a dielectric, and the charges produced by the (individual) E.M.F. between the mercury and the sulphuric acid collect on the two sides of the meniscus, as in the case of an ordinary electrostatic condenser. The presence of this charge tends to increase the surface of the mercury, *i.e.*, decreases the observed surface tension (*cf.* theory of gold leaf electroscope), and a removal of the charge by means of an external E.M.F. of opposite sign and equal intensity will cause the apparent surface tension to reach a maximum. The observed value 0.97 volt is then the positive potential assumed by mercury in contact with sulphuric acid of the strength employed. Similar measurements with hydrochloric acid as the electrolyte give + 0.560 for the potential of mercury against a solution of 36.5 grammes HCl in a litre of water.

If v.Helmholtz's theory of these electro-capillary phenomena be accepted, it furnishes the first individual E.M.F. between a metal and an electrolyte; the E.M.F. of other metals *in contact with normal solution of their salts* (calculated as indicated on page 247) are given in the following table (for a temp. of 15° C.):

Table 4.*

Magnesium	—1.22 Volt
Zinc	—0.51
Aluminium	—0.22
Cadmium	—0.19
Iron	—0.06
Lead	+0.10
Copper	+0.60
Mercury	+0.99
Silver	+1.01

The accurate determination of these values (those given in the table have a probable error of about one or two hundredths of a volt) is of the same importance to electrochemistry as is the determination of the atomic weights to analytical chemistry; the table itself is the modern quantitative form of the old "Electrochemical Series" of Volta.

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*[*] *Ostwald.* Lehrbuch, II., 946, 1893.

As the individual electromotive forces of all ordinary voltaic batteries occur at the junction of

(*a*) Metal with metal;
(*b*) Metal with electrolyte;
(*c*) Electrolyte with electrolyte,

it is possible from the data given above to calculate the E.M.F. of a large number of cells. For example, in the Daniell's element, the total E.M.F. is made up of

(1) Zinc – Zinc sulphate solution.
(2) Zinc sulphate solution – Copper sulphate solution.
(3) Copper sulphate solution – Copper.
(4) Copper – Zinc.

(1) Of these the first depends on the concentration of the zinc sulphate solution. If this contains 161 grammes $Zn\,SO_4$ per litre ("normal solution"), the E.M.F. will be 0.51 volts with the zinc negative [Table 4], which number will be greater if the electrolyte be more dilute, and conversely. The quantitative relation is given by equation (15*c*):

$$\pi = 0.0002\frac{n_i}{n_e}\,T\,\log._{10}c + \text{constant}$$

(c being the concentration of the zinc sulphate in solution) the change in value of variable term on the right-hand side being obviously the quantity in question. Thus, diluting the electrolyte with an equal volume of water would change the E.M.F. to

$$0.51 + 0.0002 \times \frac{1.25}{2} \times (273 + 15)\,\log._{10}2 \quad = \quad 0.51 + 0.0108$$

or about 0.52 volts, the zinc negative, as before.

(2) The second, on account of the approximate equality of the velocities of copper and of zinc [Table 2], will be negligible if the copper and zinc solution has the same concentration; if not, its value may be obtained from equation (18*b*).

(3) The third is similar to the first, for normal copper sulphate solution amounting to 0.60 volts, the metal positive; increase in concentration of the electrolyte increases this value, and conversely, according to the equation (15*c*), just quoted for zinc sulphate.

(4) The value of the fourth E.M.F. is given in Table 3. It may be neglected in comparison with the others, being less than the thousandth of a volt.

Addition of these four quantities gives 1.11 volts as the E.M.F. at 15° C. of the cell

Zinc | Normal zinc sulphate | Normal copper sulphate | Copper.

and the effect on this quantity of alterations in the concentration of the electrolytes may be calculated as described under heads (1), (2), and (3).

"ABNORMAL" E.M.F.

In contrast to the case of the Daniell's cell, where the total E.M.F. is practically the sum of the two individuals of Table 4, examples may be quoted where the allowance for difference in concentration of the electrolyte (in the case just calculated a mere correction) constitutes by far the largest term. Such, for instance, is the case in the combination*

Ag | 0,1 normal $AgNO_3$ | normal KCl | AgCl | Ag,

whose E.M.F. has been found to be 0.51 volt. This comparatively high value for a cell whose two electrodes are formed of the same metal depends on the fact that the osmotic pressure of the silver ions in the silver nitrate solution is very considerable; while in the silver chloride solution it is extremely small, both on account of the slight solubility of that substance, and because the dissociation of what silver chloride does dissolve is much reduced by the presence of the potassium chloride (see p. 238). When the cell is closed, the effect of the passage of the current is simply to remove silver ions from that solution in which their concentration is great to that in which it is small, and the E.M.F. of the cell will be

$$\pi = 0.0002 \text{ T} \log._{10} \frac{C_1}{C_2}$$

Where C_1, the concentration of the silver ions in the $AgNO_3$ solution, may be set (assuming complete dissociation) 0.1; while C_2, their concentration in the silver chloride solution, which, in the absence of potassium chloride, has been found† to be approximately 1.1×10^{-5}, is reduced by the presence of that salt to $(1.1 \times 10^{-5})^2 = 1.21 \times 10^{-10}$. Substituting these values, the calculated E.M.F. of the silver cell at 15° C is

---

* *W. Nernst.* Thereotische Chemie, Stuttgart, 1893, p. 569.

† *Kohlrausch and Rose*, Loeslichkeit schwer loeslicher Koerper, *Z. Ph. Ch.*, XII., 234, 1893, have estimated the solubility of silver chloride in water by determining the electrical conductivity of its solution, and calculating m (the quantity of salt dissolved) from the known velocities of the ions $\overset{+}{Ag}$ and $\overset{-}{Cl}$ by means of the equation:

Conductivity m = (u + v). See page 232.

$$\pi = -0.0002 \times 288 \times \log._{10}(1.21 \times 10^{-9}) = 0.52 \text{ volts}$$

a result which agrees sufficiently well with the observed value 0.51 volts.

An analogous explanation may be offered for the "abnormal" behavior of silver in a solution of silver potassium cyanide.* In a cell of

Silver | Silver-potassium cyanide | Lead nitrate | Lead

not only does the E.M.F. observed bear no apparent relation to that of silver against lead in a solution of their nitrates, but its very sign is changed; and whereas in the latter case the lead is negative with reference to the silver, in the cyanide cell it is the silver that dissolves. "Abnormal" cases such as this, which have contributed largely to the overthrow of the older electrochemical theories, and which seemed to argue against the possibility even of a definite order for the metals in the "Electrochemical Series," may, by means of the methods explained in this paper, be brought under the same category as the others, and their E.M.F. may be calculated without the introduction of any new hypotheses.

In this paper, an endeavor has been made to show how the introduction of the conception of "osmotic pressure" in conjunction with the first and second main principles of thermodynamics has led to the evolution of a theory of solutions, which includes a quantitative account of the relations existing between phenomena so diverse as are the vapor tension, freezing and boiling points of solutions, their electrical conductivity, and its dependence on dilution, and the alteration in their concentrations produced by the passage of a current, and which lends itself to the solution of problems in connection with the E.M.F. of various voltaic batteries in a manner as accurate as it is simple and straightforward. It must not be supposed, however, that more than a mere sketch of the subject has been attempted, or that even the points of contact between the new theory and the electrical phenomena have been extensively reviewed; the temperature

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*Such a solution contains extremely few $\overset{+}{\text{Ag}}$ ions. See *Leblanc and Noyes*, Ueber vermehrte Loslichkeit, *Z. Ph. Ch.*, VI., 397, 1890.

the form

co-efficient[*] of the E.M.F. of cells, electrical conduction and electrolysis[†], in mixed salt solutions, the phenomena of galvanic polarization[‡], and the common experiments[§] grouped by Ostwald under the title of "Chemical Action at a Distance," have been, and are at present, subjected to a searching and successful investigation by the aid of this modern scientific instrument, the product of a fortunate combination of wide-reaching experimental generalizations with the rigid laws of Energetics—of the genius of Faraday with that of Clausius.

I desire to take this opportunity of expressing my thanks to Dr. W. L. Miller and Mr. T. R. Rosebrugh for much valuable assistance in writing this paper.

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[*] For many cases this may be determined by the differentiating formulæ for π given in this paper; for example, equation (15*b*).

[†] *W. Hittorff*. Pogg Ann., ciii., 45, 1858 (Electrolysis of mixture of K Cl and KI). *H. Freudenberg*, Neues Prinzip der Elektrischen Trennung von Metallen: Ber. d. deutsch. Chem. Ges., 1892, 2492.

[‡] *M. Le Blanc*. Die Elektromotorischen Kräfte der Polarization, *Z. Ph. Ch.*, VIII., 299, 1891.

[§] *W. Ostwald*. Chemische Fernewirkung, *Z. Ph. Ch.*, VIII., 541, 1892.

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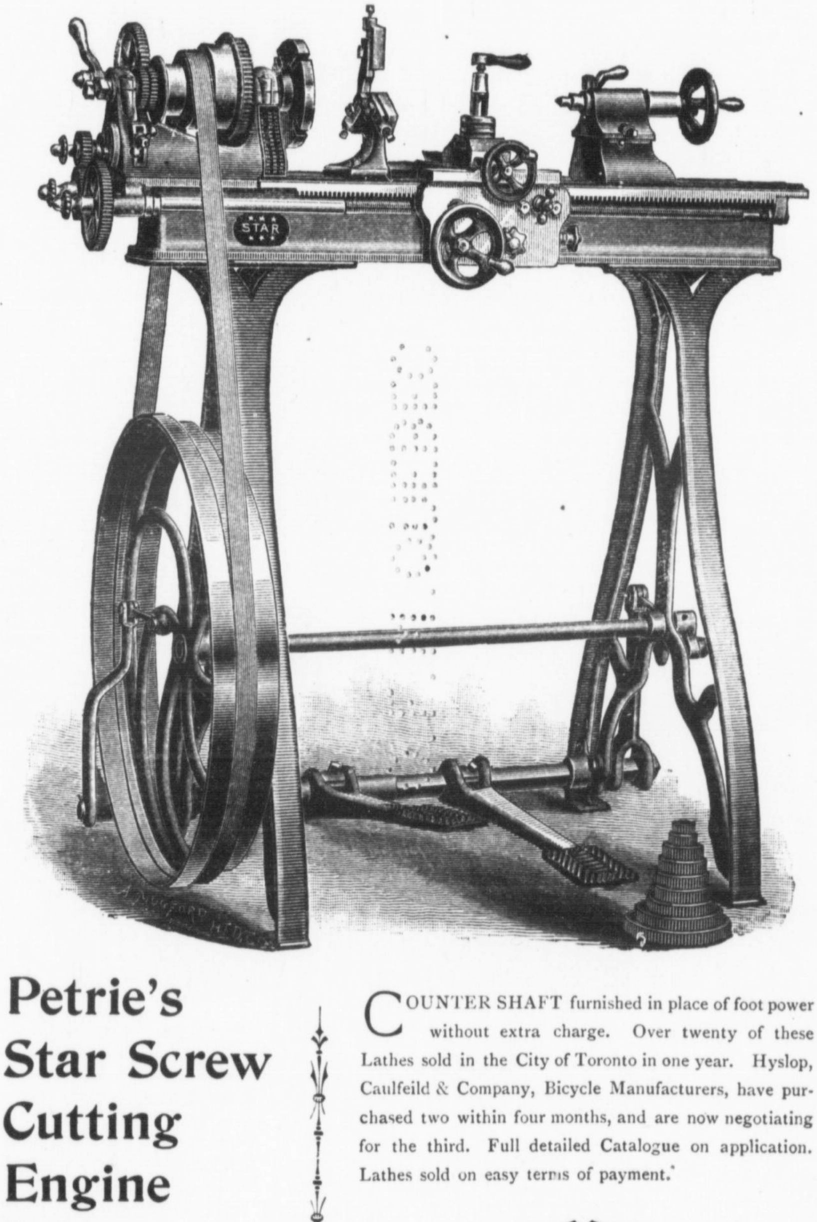

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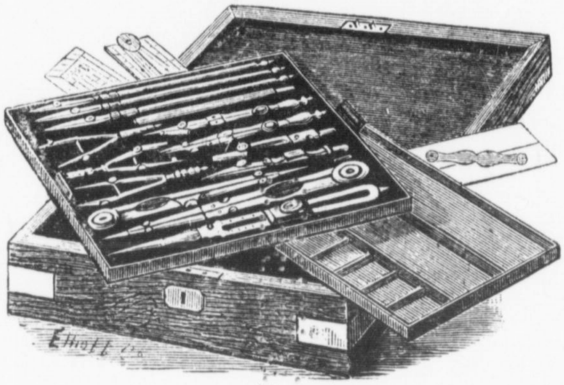

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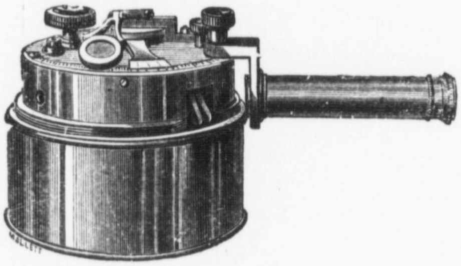

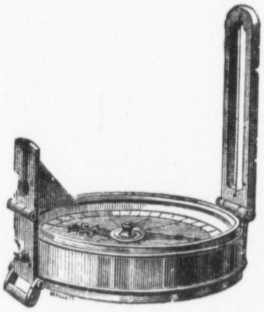

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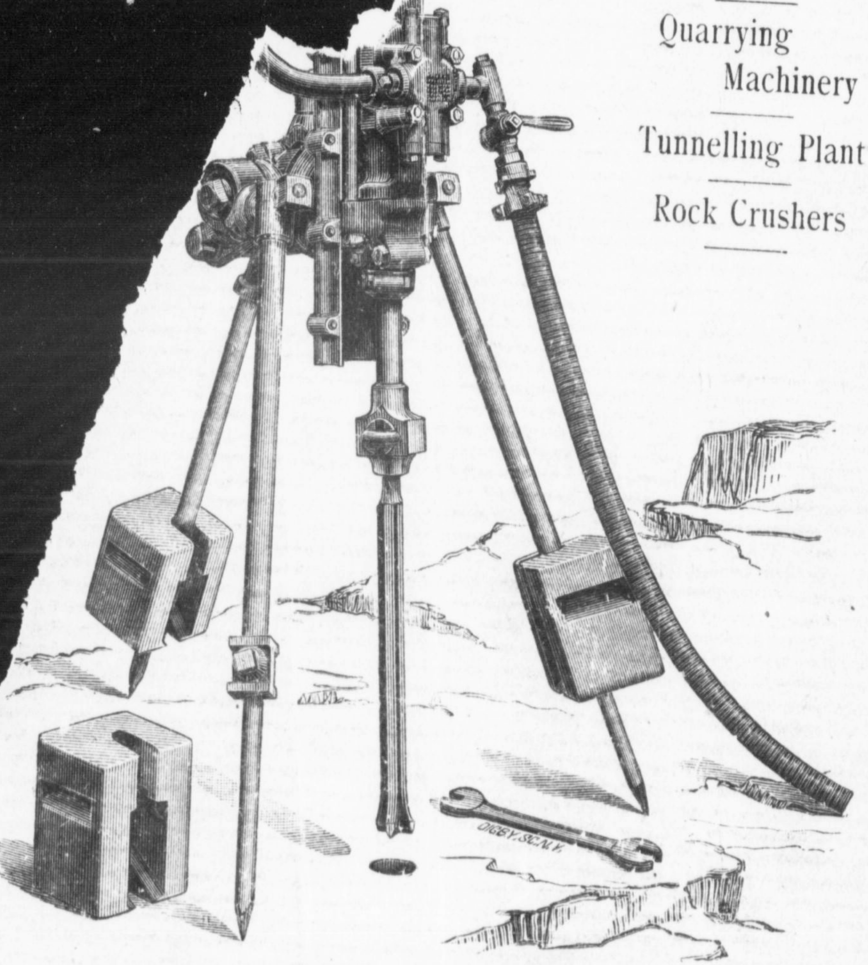

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