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EXPLOSIVES,

THEIR USE FOR

MILITARY ENGINEERING LAND OPERATIONS

—AND—

ELECTRICAL MEASUREMENTS,

COMPILED BY

CAPTAIN H. R. SANKEY, R.E.,

Instructor in Fortification, etc., R. M. C. of Canada.

FOR THE USE OF THE GENTLEMEN CADETS.

KINGSTON:
PRINTED AT THE DAILY NEWS STEAM PRINTING HOUSE.
1882.

PREFACE.

The following is a compilation based on the works quoted below, and was undertaken because no text-book could be found which exactly suited the requirements of the Course at the Royal Military College of Canada.

The book has been divided into two distinct parts. The first part treats of the qualities and capabilities of Explosives, of the Construction of Magazines, and of the manner of using explosives, including Testing, so far as is necessary for Military Engineering Land operations. In the second part, the more usual methods of making electrical measurements have been treated in a general manner. This part is, however, principally intended as an appendix to the first part.

Prior to undertaking the present portion of the Course of Military Engineering, the Gentlemen Cadets go through a course of Chemistry and Electricity. An acquaintance with the chemical composition of explosives, with the chemical action that takes place in an explosion, and with the electrical laws involved, is therefore assumed.

I must here return sincere thanks to numerous friends for the assistance given to me, but more especially to Professor Bayne, Ph. D., Professor of Chemistry and

Physics, etc., at the R. M. C., Canada, and to Sergeant-Major Birtles, Royal Engineers, whose great practical knowledge of explosives has been invaluable.

H. R. S.

R. M. C., KINGSTON,
CANADA, March, 1882.

List of works consulted.

Instruction in Military Engineering, S.M.E., Chatham. Part IV, Mining.

Rough Notes of a Course of Lectures on apparatus used in Military Telegraphy and Firing Mines, S.M.E., Chatham.

Ganot's Physics, translated by Atkinson.

A Physical Treatise on Electricity and Magnetism, by J. E. H. Gordon, B.A., Camb.

An introduction to the Theory of Electricity, by Linnæus Cumming, M.A.

Electricity and Magnetism, by Fleeming Jenkin, F.R.S.S., M. and E., M.I.C.E., etc.

Blasting and Quarrying stone, by Sir John Burgoyne (Weale's Series.)

The recent history of explosive agents, by Prof. Abel, F.R.S., Professional Papers of the Corps of Royal Engineers, Vol. XXII, 1874.

Notes on Gunpowder and Guncotton, by Major Wardell, R.A.

Spon's Dictionary of Engineering.

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Journal of the Royal United Service Institution.

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Abbreviations used.

R. U. S. I.	Royal United Service Institution.
R. E. I.	Royal Engineer Institute.
I. M. E.	Instruction in Military Engineering.

Errata.

Page 22, footnote* for § 127 read § 126.
" 52, line 10 from bottom for § 204 read § 203.
" 53, " 19 " " " § 242 " § 241.
and dele "and § 243."
" 55, line 13 from top for 0.08 read 0.8.
and for 0.8 read 0.08.
" 66, the tables relating to metal lined wood cases and to barrels for ammunition have been extracted from "Aide Memoire for the use of Officers of Royal Engineers," by Col. Cooke, R.E.
" 92, line 3 from bottom for 10 read 10^8.
" 103, " 3 " " dele "to."
" 127, " 5 " " for ρx read ρ_x.
" 140, " 6 " " for t'' " t''^2.

PART I.

EXPLOSIVES,

THEIR USE FOR MILITARY ENGINEERING LAND OPERATIONS.

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PART I.

EXPLOSIVES.

THEIR USE FOR MILITARY ENGINEERING LAND OPERATIONS.

INTRODUCTION.

1. The purposes for which explosives are used in Military Engineering Land operations are numerous, and the effects to be produced vary considerably. The Military Engineer must, therefore, be acquainted not only with the methods of using the various explosives, but also (in order that he may be able to select the explosive best suited to each particular case) with their qualities and capabilities. This shows that the subject divides itself naturally into two distinct parts; the first is the inquiry into the qualities and capabilities of the various explosives, and the second is concerned with the methods of preparing explosives for use and of igniting them, which includes the methods of testing adopted in order to minimize the risk of failure. To this must, however, be added a third consideration, namely, the storage of explosives.

The study of the above will be greatly assisted by a knowledge of the manufacture of explosives, but more especially by an acquaintance with the chemical composition of the various explosives and with the changes produced by their ignition. These questions are, however, treated of in other Courses*, and will therefore not be considered here.

*In the Artillery and Chemistry Courses respectively.

CHAPTER I.

QUALITIES AND CAPABILITIES OF EXPLOSIVES.

2. When, owing to chemical decomposition and recombination, a large volume of gas and a large increase of temperature are very rapidly produced, an explosion ensues.

3. The explosive effect depends on the rate at which the chemical action proceeds, that is, on the time taken to convert the explosive into gas; and the shorter the time the greater and more violent the effect. In the special case when the conversion is almost instantaneous the explosion is called a *detonation*, and the effect produced is that due to an impulsive force or a blow.

The rate of explosion is influenced by the following circumstances:

(1.) By the physical condition of the explosive. For instance, fine powder burns much more rapidly than pebble powder owing to the difference in the size of the grains.

(2.) By the mode of ignition. Thus dry compressed guncotton will, if lit by a match, simply burn very rapidly but will not detonate, and gunpowder can be *detonated* under suitable conditions.

There are two methods of igniting an explosive.

(a) By the direct contact of a heated body.

(b) By the previous explosion by heat, percussion or chemical action* of a small quantity of a sensitive composition (such as the mercuric fulminate.)

Detonation is practically obtained by the second method.

4. The explosive effect further depends on the degree of confinement (or tamping) to which the explosive is exposed before ignition. Thus gunpowder produces but little useful effect unless strongly confined, but guncotton, dynamite and such like explosives, when detonated, have a very considerable effect without any tamping; their power is, however, increased by confinement.

*For instance, the action of sulphuric acid on a mixture of sugar and chlorate of potash.

This effect of tamping is in reality due to the rate of explosion, for in the case of detonation the transformation into gas is so rapid that the resistance of the air is sufficient tamping. The following extract illustrates this point :

"With nitro-glycerine a volume of gas, nine hundred times that of the liquid used, is set free all but instantaneously. * * * It can readily be seen that the sudden development of this large volume of gas, which becomes at once a part of the atmosphere, would be equivalent to a blow by the atmosphere against the rock* ; or, what would be a more accurate representation of the phenomenon, since the air is the larger mass, and acts as the anvil, a blow by the rock against the air. It may seem very singular that our atmosphere can act as an anvil, against which a rock can be split, and yet it is so, and, if the blow has velocity enough, the atmosphere presents as effective a resistance as would a granite ledge. The following consideration will, I think, convince you that this is the case : I have here a light wooden surface, say, one yard square ; the pressure of the air against the surface is equal, as I just stated, to about nine tons ; but the air presses equally on both sides, and the molecules have such great mobility that, when we move the surface slowly, they readily give way, and we encounter but little resistance. If, however, we push it rapidly forward, the resistance greatly increases, for the air-molecules must have time to change their position, and we encounter them in their passage. If, now, we increase the velocity of the motion to the highest speed ever attained by a locomotive —say, one and one-fifth mile per minute—we should encounter still more particles, and find a resistance which no human muscle could overcome. Increase that velocity ten times, to twelve miles a minute, the velocity of sound, and the air would oppose such a resistance that our wooden board would be shivered into splinters. Multiply again the velocity ten times, and not even a plate of boiler-iron could withstand the resistance. Multiply the velocity once more by ten, and we should reach the velocity of the earth in its orbit, about 1,200 miles a minute, and, to a body moving with this velocity, the comparatively dense air at the surface of the earth would present an almost impenetrable barrier, against which the firmest rocks might be broken to fragments. Indeed, this effect has been several times seen, when meteoric masses, moving with these planetary velocities, penetrate our atmosphere. The explosions which have been witnessed are simply the effect of the concussion against the aeriform anvil at a point where the atmosphere is far less dense than it is here. So, in the case of the nitro-glycerine, the rock strikes the atmosphere with such a velocity that it has the effect of a solid mass, and the rock is shivered by the blow."†

*A cartridge of nitro-glycerine is supposed to have been placed on a rock.
†The New Chemistry, by Josiah P. Cooke, Jr.

DETONATION.

5. The effects produced by an explosive when detonated are so important to the Military Engineer that detonation must be considered a little more in detail.

6. It has already been said that an explosive detonates when the transformation into gas is almost instantaneous. Certain substances in unstable chemical equilibrium are those most readily detonated, and once the equilibrium of any molecule is disturbed, the transformation is transmitted with enormous rapidity throughout the mass. Experiments have been made to ascertain the velocity with which detonation travels, and the following are some of the results: The velocity of detonation of dry guncotton varies from 17,500 to 20,000 feet per second; but the rate of detonation is greater in wet guncotton, thus the guncotton which, when dry, detonated at the rate of 17,500 feet per second, detonated at the rate of 20,000 feet per second when saturated with water. The rate of detonation of dynamite was found to range from 19,500 to 21,600 feet per second, but that of nitro-glycerine is only 5,500 feet per second, which is probably due to the explosive being liquid and *unconfined*.*

As a comparison it may be stated that in a hose filled with gunpowder the explosion travels at the rate of from 10 to 20 feet per second.

7. The sensitiveness of explosives to detonation varies considerably. Some explosives, for instance the terchloride of nitrogen,† are so sensitive as to be, at present, practically useless. Others, such as the mercuric fulminate, although readily detonated by simple percussion or by the application of heat, can be safely used in small quantities. And lastly, guncotton, dynamite, etc., cannot be readily detonated by percussion or heat, but the more sensitive explosives are capable of *inducing* their detonation. Thus, in practice, fulminate of mercury is employed to start the detonation of guncotton and dynamite.

8. "The manner in which a detonation operates in determining the violent explosion of guncotton, nitro-glycerine, etc., has been the subject of careful investigation. It has been demonstrated experimentally that the result cannot be simply ascribed to the direct operation of the heat developed by the chemical changes of the charge of detonating material used as the *exploding* agent.

*These experiments were carried out by Professor Abel by stretching insulated wires across a row of guncotton discs at intervals of six feet. The rupture of these wires, by the detonation, gave spark records on the cylinder of a Noble's chronoscope, from which the velocity was calculated. The experiments with dynamite and nitro-glycerine were made in a similar manner.

†See § 121 Bloxam's Chemistry, 4th Edition.

An experimental comparison of the mechanical force exerted by different explosive compounds, and by the *same* compound exploded in different ways, has shown that the remarkable power possessed by the explosion of small quantities of certain bodies (the mercuric and silver fulminates) to accomplish the detonation of guncotton, while comparatively very large quantities of other highly explosive agents are incapable of producing that result, is generally accounted for satisfactorily by the difference in the amount of force brought to bear suddenly upon some portion of the mass operated upon. Most generally, therefore, the degree of facility with which the detonation of a substance will develop similar change in a neighbouring explosive substance may be regarded as proportionate to the amount of force developed within the shortest period of time by that detonation, the latter being, in fact, analogous in its operation to that of a blow from a hammer, or of the impact of a projectile.

"Several remarkable results of an exceptional character have, however, been observed by the author, which indicate that the development of explosive force, under the circumstances referred to, is not always ascribable to the sudden operation of mechanical force. These were especially observed in the course of a comparison of the conditions essential to the detonation of guncotton and nitro-glycerine by means of particular explosive agents (such as the chloride of nitrogen), as well as in an examination into the effects produced upon each other by the detonation of those two substances, nitro-glycerine being *very* susceptible of explosion by guncotton, while the detonation of the latter can only be accomplished by comparatively large quantities of nitro-glycerine. The explanation offered of these exceptional results is to the effect that the vibrations attendant upon a particular explosion, *if synchronous*, with those which would result from the explosion of a neighbouring substance in a high state of chemical tension, will, by their tendency to develop those vibrations, either determine the explosion of that substance, or, at any rate, greatly aid the disturbing effect of mechanical force suddenly applied; while, in the instance of another explosion, which develops vibratory impulses of different character, the mechanical force applied through its agency has to operate with little or no aid; greater force, or a more powerful detonation, being, therefore, required in the latter instance to accomplish the same result."*

9. The following facts, established by experiment, exemplify the above remarks, and also illustrate some points on the transmission of detonation.†

*The Recent History of Explosive Agents by Prof. Abel, F.R.S., Professional Papers, Royal Engineers, 1874.

†Extracted from "Notes on Gunpowder and Guncotton," by Major Wardell, R.A.

(1.) A fuze containing over 1 oz. *gunpowder*, strongly confined, exploded in contact with compressed guncotton, only inflames it, although the explosion of the fuze is apparently a sharp one.

(2.) Forty-five grains of *mercuric fulminate*, exploded *unconfined on the surface* of compressed guncotton, only inflames or disperses it.

(3.) A fuze containing 9 grains of mercuric fulminate, *strongly confined*, exploded *in contact* with compressed guncotton, *detonates* it with certainty.

(4.) An equal quantity of fulminate, similarly confined, does *not* detonate *uncompressed* guncotton, in which it is embedded, but merely disperses and inflames it.

(5.) One hundred and fifty grains of compressed guncotton detonated in proximity to *dynamite*, detonates the latter.

(6.) Three ounces of dynamite, and much larger quantities, detonated *in contact* with compressed guncotton only disperses it.

(7.) Detonation being established at one extremity of a continuous row of distinct masses of compressed guncotton or dynamite, travels along the whole length thereof...............

(8.) A row of guncotton discs, 30 feet long, 0·5 inch apart, can all be detonated from one end.

(9.) Discs of guncotton, weighing about 8 ounces each, placed six inches apart in the open, are blown away or broken up by the detonation of the central disc.

(10.) A disc of guncotton, 2 ounces in weight, inserted into a wrought iron tube 5 feet long, and detonated, transmits the detonation to a similar disc at the other extremity of the tube.

EXPLOSIVES USUALLY EMPLOYED FOR MILITARY ENGINEERING PURPOSES, AND THEIR APPLICATION.

10. The explosives principally used in the British Service are Gunpowder, Guncotton, and the Mercuric Fulminate. In some foreign countries dynamite is used instead of guncotton, but in France dynamite has lately been replaced by guncotton. Besides these there are numerous explosives in the market, such, for instance, as Nitro-glycerine, Lithofracteur, Dualine, Cotton-powder, Glyoxiline, and Horsley's powder, the effect of the explosion of which is generally similar to that of guncotton, but they do not appear to be as suitable for Military purposes as the Service article.

GUNPOWDER.

11. The class of gunpowder best suited and generally used for Military Engineering purposes is that known as L. G. (large grain). Larger grained powders, such as pebble powder, burn too slowly and are therefore not so suitable.*

Application.

12. Gunpowder should be used whenever a *lifting* effect is required, and is, therefore, employed in the following cases: Land mines, blowing up houses, embankments and cuttings, quarrying and blasting rock (guncotton is generally preferable in this last case.) Gunpowder is also used for submarine mines, demolishing stockades, palisades, gates, etc., when guncotton or dynamite are not available.

GUNCOTTON.

13 The service article is "compressed" guncotton, and is manufactured† in three forms: discs, slabs and granulated. The granulated guncotton is principally used for submarine mines to fill up holes left when packing the charge. The discs and slabs are made in different sizes, the dimensions of the principal of which are given in Table I.

The discs and slabs are provided with holes for the insertion of the shanks of the "detonators,"‡ and these holes are so arranged in the slabs that each slab can, if required, be cut into three or four parts, each part containing a hole.

14. Guncotton can be detonated when wet, but then requires a stronger initial detonation, which is practically effected by means of a small charge of dry guncotton. This dry charge is called a "primer," and should not be less than 2lbs.

Guncotton is principally used in the wet condition for submarine mines. For Land operations the charges are generally small for which reason dry guncotton is more frequently used.

As already mentioned, guncotton produces a powerful effect when detonated unconfined either when wet or dry. It is this property that makes guncotton peculiarly useful to the Military Engineer for *cutting* through iron and wood. Tamping, however, increases the effect by about one-half.

15. For security, the bulk of guncotton is stored in a wet condition; the quantity of water it should contain ought to prevent it burning, and this is found to be about 15 p.c. by weight. Gun-

*For further information see Artillery Course.

†A description of the manufacture of guncotton will be found in § 359 Bloxam's Chemistry, 4th Edition.

‡See §§ 33 and 37.

when thoroughly soaked it is 21.23 pc of water cotton can be kept in this wet condition for indefinite periods of time without injury to the explosive. But since dry guncotton is frequently required there must be some means of drying it, and the following are the authorized instructions on the subject:*

(1.) When time permits, the most simple way of drying guncotton, is by exposing it to the air of a dry room until it ceases to lose weight, or by leaving it in the open air, during dry weather, in situations where it will be exposed to sun or wind. With a dry atmosphere, guncotton may be dried by exposure to open air, even without sun, in about five days.

(2.) When it is desired to dry guncotton quickly, steam heat should be used, and a special apparatus has been constructed, for use in the field and at stations, for carrying out this operation safely and expeditiously.

(3.) This apparatus consists of two principal parts: a boiler and a drying chamber, which, when they are about to be used, are placed at a distance of about 6 feet from each other, and are connected together by means of an indiarubber tube of that length. The boiler is of copper, and is provided with a covering of felt and sheet zinc. It is heated by a central charcoal fire, and is furnished with a glass water gauge, a stop-cock for filling, and a short exit pipe, on to which is slipped the vulcanized indiarubber tube, which connects it with the double-bottomed drying chamber. It is also provided with a short chimney fixed on a hinge, closed at the top with a diaphragm of wire gauze, and fitted with a damper, which is only to be kept a little open while the apparatus is in use. To the stand of the boiler, beneath the fire grating, is attached a tray in which water is to be kept, while the fire is burning. The drying chamber consists of an oblong steam chest, made of stout sheet tin, and fitted with two short pipes at the two ends, one for the entrance of steam through the indiarubber tube, the other for the escape of steam and condensed water. The sides of the steam chest are gradually constricted towards the top, on to which fits a hood of bright sheet tin, with handles, and provided with a short wide conical shaft. A wide tube, having a number of perforations, is fixed along the centre of the top of the steam chest, and forms a channel for distributing, over the different parts of the bottom of the chamber, the cold air which enters this channel by openings through the two ends of the chamber; thus, when the apparatus is working, a constant and rapid current of air enters and is distributed over the entire lower part of the oven, while the hot air, laden with moisture, expelled from the heated guncotton which is placed upon the steam chest, escapes through the shaft of the hood. Grating or

*Extracted from "Instruction in Military Engineering," Vol. I, Part IV.

shelves of coarse copper wire gauze are placed upon the top of the steam chest, on either side of the ventilating channel, and the guncotton to be dried rests upon these; in this way the dry air which enters the chamber is made to circulate on all sides of the discs or slabs of guncotton. The steam chest is enveloped in stout felt and enclosed in a wooden case, which is raised from the ground upon legs. The hood of the chamber is fitted with a protected thermometer, which reaches down to the top of the steam chest, and projects sufficiently outside the hood to be read while in position.

(4.) The mode of using the apparatus in the field would be as follows:—First, fill up the boiler with water, through the stop-cock, until the water rises to the top of the glass gauge. Next, ascertain that the exit pipe is free, and blow through the vulcanized tube to make sure that the steam can pass freely into the hood chamber. Then light a charcoal fire in the boiler, filling the cylindrical fire-place not more than one third with charcoal, and after the steam has been issuing freely from the exit pipe of this drying tray for five minutes note the reading of the thermometer, which should not be allowed at any time to exceed 150° Fahr. Then put the discs or slabs on the steam chest, cover them with the hood, and let them be exposed to heat for a period varying with the size of the disc.

For $1\frac{1}{4}$ inch disc..............................	4	hours.
Other sizes below 3-inch discs	6 to 8	"
3-inch discs and parts of slabs	12	"
Whole slabs (according to thickness)	18 to 24	"

(5.) The water in the boiler must be replenished from time to time, so as to keep it within the glass tube of the gauge. In replenishing the charcoal fire it should not be made up higher than about one-third up the cavity.

(6.) A rough but good indication as to whether the discs or slabs of gun-cotton are dry is afforded by holding a small piece of cold clean plate glass up before the face, and placing against it, for a moment, one of the pieces of guncotton in the warm condition, as taken from the oven. If moisture is still being given off, a film of dew will be at once seen upon the glass, round the surface of the gun-cotton. A piece of plate glass mounted in a frame with handle is supplied for this purpose.

(7.) In drying the *large primers* used for submarine mines, or for any special operations in which the 9-ounce or other large primers are used, it is important to ascertain that *complete* dessiccation of the gun-cotton is effected. For this purpose, after the drying has been continued for nearly the prescribed period, one or two of the discs or slabs are removed from the oven, left exposed to the air for about half an hour (until cold), and then weighed, (the weight being noted upon the gun-cotton with pencil). If the weight is the same after a further exposure of the gun-cotton to the heat for about one hour, allowing it to cool as before, the drying operation is complete.

Application.

16. Guncotton is a suitable explosive to use :

(1.) When a shattering local effect or a blow is required.

(2.) When tamping cannot be resorted to.

The following are the principal instances of its use for Military Engineering purposes:

Submarine mines.

Cutting through iron ; for instance, in the demolition of iron bridges, or in cutting railway rails.

Cutting through wood ; for instance, in cutting down trees, making openings in stockades and palisades, and blowing in gates.

Cutting through masonry and brickwork ; for instance, demolishing houses, making openings in defensible walls, etc.

NITRO-GLYCERINE.

17. Nitro-glycerine is an oily liquid ; its effect when detonated is similar but more powerful than that of guncotton.* Prof. Abel says of this explosive : "The economy in time and labour effected by its use in blasting and tunnelling in hard rock is undoubtedly greater, under favorable circumstances, than with guncotton or any of the most powerful substitutes for guncotton. Moreover, the liquid form, high specific gravity, and insolubility in water of nitro-glycerine, are peculiarly valuable properties under some circumstances ; thus, blasting in wet holes, or actually under water, can be carried on with nitro-glycerine expeditiously and without any special appliances. * * The poisonous nature of nitro-glycerine, which injuriously affects the health of those handling and using it, is one of its defects. It is stated, however, that the human system may become accustomed to its influence. * * The comparatively high temperature at which nitro-glycerine freezes, and the slowness with which it thaws, even at normal atmospheric temperatures, constitutes a source of inconvenience, and, in some respects, of danger. * * It has been established beyond all doubt, that the material is much less susceptible of detonation in the frozen than in the liquid condition ; * * * The accidents which occurred with frozen nitro-glycerine appear

*The method of manufacturing nitro-glycerine will be found at § 412 Bloxam's Chemistry, 4th Edition.

to have arisen from a recklessly rough usage of the material; and, so far as the apparently great safety or inertness of the frozen substance will lead to recklessness, it does constitute a source of danger. The necessity for thawing the nitro-glycerine (and its preparations) for use, unless exploding arrangements of a special character be provided, has also proved to be a source of accident. * * *

"The principal defect of nitro-glycerine, when employed in its pure state as a blasting material, arises, however, from its liquid nature, and its consequent tendency to leak out of receptacles in which it is transported, stored, or used. In blasting operations the nitro-glycerine with which a hole is charged will flow into fissures in the rock, and may thus be conveyed to parts where its existence cannot be suspected, and where it may be afterwards accidentally exploded during the boring of other holes."*

DYNAMITE.

18. Dynamite is a nitro-glycerine preparation formed by the absorption of that liquid by a silicious infusorial earth called "Kieselguhr." By this means several of the defects of nitro-glycerine are removed, and the explosive thus produced is still very powerful. The effect of nitro-glycerine on the human system is not, however, entirely prevented, and there appears to be a chance of the oil exuding which might possibly cause a premature explosion, and there is the same inconvenience and possible danger owing to the high freezing point. Kieselguhr will absorb 3 times its own weight of nitro-glycerine, and this forms the strongest dynamite, called Nobel's No. 1 dynamite. There are several other similar preparations in the market in which the Kieselguhr is replaced by other inert porous solids, or in some cases partially or entirely by porous explosive solids, such, for instance, as: Horsley's blasting powder, consisting of chlorate of potash and nut-gall powder with 20 p.c. of nitro-glycerine; and Dualine, which is Schultze's sawdust powder impregnated with the oil.

Dynamite is made up in small cylindrical parchment cartridges, this form being very suitable for blasting rock.

19. *Treatment of frozen dynamite.*—If dynamite cartridges are frozen and are thereby stuck together, they should on no account be separated. Frozen dynamite can be thawed by placing it either in a warm room or in a vessel surrounded by hot water, but in no other way should heat be applied. The detonation of 2 lbs. of dry guncotton or of 2lbs. of thawed dynamite will induce the detonation of frozen dynamite.

*"The recent history of explosive agents," by Prof. Abel, F.R.S., Professional Papers of the Corps of Royal Engineers, Vol. XXII, 1874.

Application.

20. Dynamite can be used for the same purposes as guncotton.

MERCURIC FULMINATE.

21. This explosive is only used to supply the initial detonation for guncotton or dynamite. It detonates with violence when struck or when heated above 360° F. It is made up for use in small charges of from 5 to 20 grains, mixed with nitrate and chlorate of potash, and placed in fuzes or caps called "detonators."*

COMPARISON OF GUNPOWDER, GUNCOTTON AND DYNAMITE.

22. It is generally said that guncotton is four times stronger than gunpowder weight for weight, but this cannot be taken in an absolute sense, because the effect of guncotton is so totally different to that of gunpowder. A comparison can, however, be made of the *useful* work done when both explosives are tamped. But even in this case the comparison fails when the object is to *move* a large mass of earth, as in land mining.

If neither explosive is confined, the comparison evidently fails entirely.

Guncotton appears to be a little stronger and rather more violent in its action than No. 1 dynamite, as was exemplified by some experiments carried out at Chatham ; a contrary result was, however, obtained from experiments made at Graudenz in 1873.

For some operations dynamite has an advantage over compressed guncotton in that its plastic nature allows of its being gently pressed into inequalities.

*For further information on the qualities and capabilities of explosives see P. 101 et seq. R.E.I. Occasional papers, Vol. IV. P. 887 et seq. Journal R.U.S.I., Vol. XXI. P. 65 et seq. Minutes of Proceedings of the R.A. Institution, Vol. IV.

CHAPTER II.

CONSTRUCTION OF MAGAZINES FOR THE STORAGE OF EXPLOSIVES.

23. It is clearly of the greatest importance that the site and design of the buildings in which explosives are stored, termed magazines, should be such as to reduce to a minimum the risk of an explosion.

24. As regards the *site* the following are the principal points to be considered. To reduce to a minimum the chance of an accidental explosion the magazine should be as isolated as possible, and especially kept at at distance from towns or villages, factories, wooden buildings, etc. In order that an accidental explosion may produce the least possible damage the magazine should also be isolated, especially from important buildings, and a hollow site is an advantage in this respect, but it may interfere with the drainage. Lastly, the site should be chosen with a view to easy communication.

As for the *design* it will depend to a considerable extent on the kind of explosive to be stored. The design of magazines to contain gunpowder and guncotton will now be considered.

GUNPOWDER MAGAZINES.

25. When in bulk, gunpowder is stored in barrels containing 100 lbs. of powder each, or else in metal-lined wooden cases, if the magazine is damp. These barrels are placed on racks made of wood, the object of which is to be able to obtain several tiers of barrels without pressing on those in the lower tiers. A convenient arrangement of the racks is to have them on either side of the magazine, leaving a central passage. There should also be side passages, but if this is not possible a space at least 6 inches wide should be left between the wall and the barrels for ventilation. A small crane is usually provided to shift the barrels; it is placed on an overhead traveller running on the top stringers of the racks.

The walls of the magazine should be of masonry, brickwork or concrete, and the roof a brick arch* of a thickness depending on the weight of earth, etc. carried by the arch; but in no case should it be less than 9 inches (2 rings). To prevent damp, which is the principal difficulty to be contended with, hollow walls should be used, that is, a thin brick wall should be built, leaving a hollow space between it and the main wall; and further, the arch of the roof, if covered with earth or concrete, should have one ring of perforated bricks placed in the centre of the arch ring, and care should be taken that the perforations are through the length of the bricks, and that the bricks are so laid in the work that there will be a *continuous* air space from one end of the arch to the other. A more effective arrangement, however, is to build an inner arch, in continuation of the brick lining of the walls, leaving a hollow space between it and the main arch. The two arches should not be bonded together. The ventilation is another point to be carefully attended to, and for this purpose air-inlets and outlets capable of being opened or shut to any desired extent, must be provided. These inlets and outlets should be closed with wire gauze to prevent the chance of sparks entering the magazine through them. Occasionally windows can be placed in magazines, but this, though convenient, is not necessary; in any case, however, arrangements should be made for lighting without having to bring lights into the body of the magazine. This is generally done by means of "light passages," as shown in Figs. 1 and 2, PL. VII, C.D., Text-book of Fortification.

A shifting room or ante-chamber should be provided at the entrance to the body of the magazine.

For security all the metal fittings in a magazine are made of gun metal. To prevent grit, and also damp, the floors are constructed in the following special manner. Battens are secured to an asphalte floor laid on concrete, and to these, and placed across them, small battens are screwed down at close intervals. The spaces between the battens are filled with cork shavings.

Magazines may either be exposed to Artillery fire or not, in either case the internal arrangements are the same as given above. The exterior will, however be different.

MAGAZINES EXPOSED TO ARTILLERY FIRE.

26. These magazines must have earth or concrete protection thick enough to leave a large margin beyond the penetration of the heaviest ordnance at all likely to fire against the magazine. The best arrangement in this respect is to sink the magazine in the ground, as shown at *e*, Fig. 1, PL. XV. P. F, Text-book of

*In large magazines it will probably be necessary to use two or more arches.

Fortification; but if this cannot be done the walls should be protected by masses of concrete or earth, and the roof covered in the same way; see Figs. 1 and 2, PL. VII, C.D., Text-book of Fortification. In any case the magazine should be hidden from view as much as possible.

MAGAZINES NOT EXPOSED TO ARTILLERY FIRE.

27. If the magazine is not exposed to Artillery fire the dimensions of the walls and roof will be determined by the stability of the structure, and it must be remembered that those walls acting as the abutments to the arch of the roof will require to be thick enough to resist the thrust. Further, to localize, as far as possible, the effect of an accidental explosion in the magazine, the walls should be made thick, so that the force of the explosion may be deflected upwards.

This is the arrangement adopted for large store magazines, and in order to minimize the effect of an accidental explosion it is best, instead of building one large magazine, to build several small magazines to contain from 1,000 to 2,000 barrels each, separating them from each other by earthen or concrete traverses. The roofs of such magazines should offer as much resistance as possible to falling splinters, and for this reason they are made in the form of parabolic arches; these arches should be covered by an ordinary roof to throw off the rain. Fig. * shows a suitable arrangement on plan for a large store magazine and Fig. * gives a section of one of the magazines.

GUNCOTTON MAGAZINES.

28. Guncotton was formerly stored in tanks containing 1 ton each, and in which it could be kept in a wet condition.

Special wooden packing cases containing 50 lbs. (nominally) have now been sealed for use. These boxes are made of deal payed on the inside with marine glue, and to make them airtight the lid is screwed down over a layer of flannel. They are provided with an air-hole in the lid closed by an ordinary screw, and also with a hole for draining off water, placed low down in one of the ends of the box, and fitted with a brass socket and screw plug. The guncotton in these boxes can be re-wetted, when necessary, by attaching a flexible tube by means of a screw-junction to the plug hole, opening the air hole and forcing in water. As soon as the water has risen to the level of the air hole it is let out again, and the holes are closed.

*Drawn by the Cadets.

The boxes are placed in a guncotton store half sunk under ground, and are piled up in two rows, one on each side of the store, leaving a central passage. The length of the magazine should be slightly longer than required by the number of boxes the magazine is designed to contain so as to allow of the boxes being shifted at Inspections. A water tank, with its bottom flush with the roof, should be provided for wetting the guncotton.

Wet guncotton being inflammable, no special precautions are necessary unless the magazine is to be made bomb-proof.

29. Dry guncotton is only kept in small quantities in hermetically sealed tin cylinders, which are placed in cupboards provided for the purpose or in a special magazine.

EXAMPLES.

1. Find the length of racks to contain 500 barrels of powder, the barrels being arranged 6 tiers in height and 2 rows in depth. Calculate also the scantling of the necessary timbers.

2. Find the dimensions of a magazine to contain 1,000 barrels of gunpowder, and find the number of air-inlets required.

3. Find the dimensions of a magazine to contain 5,000 barrels of gunpowder and arrange the racks.

4. A magazine, proof against siege Artillery, is roofed over by a segmental arch of 20 feet span and 6 feet rise. The walls are 6 feet high. Find the thickness of the walls supporting the arch supposing one of them exposed to Artillery fire and the other not.

5. The thickness of covering of the roof of a magazine, exposed to siege Artillery, is limited to 7 feet. Find the proportion of concrete and earth.

6. Find the dimensions of a guncotton magazine to contain 200 boxes.

CHAPTER III.

USE OF EXPLOSIVES.

INTRODUCTORY.

30. When explosives are used for any purpose a certain quantity of the explosive, called the *charge*, the weight of which is determined by calculation or by estimation, has to be placed in a position depending on the object in view. Occasionally, instead of using one large charge, two or more charges are fired simultaneously. The selection and the work to be done in reaching and preparing the receptacle or chamber to contain the charge are questions treated of in other parts of the Course of Military Engineering, so that it will only be necessary here to consider :

1. The preparation of the charge.
2. The preparation of the firing arrangements.

The manner of making up the charge will depend principally on the object for which the explosion is required and on the explosive to be used, but the method in which the charge is to be fired will affect the first steps of the preparation.

The firing of the charge can be effected by heat, by electricity or by percussion. When firing by means of heat a "leader" containing gunpowder is used. These leaders burn either slowly or practically instantaneously; Slow-match and Bickford's fuze belong to the former class; Quick-match, Powder hose, Ord's hose and Bickford's instantaneous fuze to the latter.* When electricity is the means adopted a current of electricity is conducted to the charge by wires; and when by means of percussion a blow has to be given to the charge.

Electricity should, if possible, always be employed when the charge is covered by tamping, when it is required to fire at a given instant of time, or when several charges are to be fired simultaneously; but when not available can, in these cases, be replaced by instantaneous leader. Bickford's fuze is most suitable for a single charge, which can be reached up to the last moment before firing.

*These various leaders are described in §§ 71-75.

The immediate cause of the explosion is the ignition in the body of the charge of a small quantity of explosive, generally either mealed powder or mercuric fulminate, which ignition is produced by either of the three methods mentioned above. This arrangement is called a "fuze."*

FUZES.

31. The fuzes in use are of several different kinds, and their construction depends—

1. On the explosive.
2. On the method of firing.

The fuzes intended for use with *gunpowder* contain mealed powder, but those to fire *guncotton* or *dynamite* contain mercuric fulminate, and are called "detonators."

The actual construction of the fuze depends, however, on the method of firing.

FUZES FOR USE WITH SLOW OR INSTANTANEOUS LEADER.

32. *For gunpowder* no actual fuze is required, as the leader enters into the charge and ignites it.

33. *For guncotton* a detonator is used, consisting of an empty thin brass tube the size of a swan quill, 4 inches long, to which is attached a tapering tin tube 2 inches long, containing about 20 grains of mercuric fulminate. Over the mercuric fulminate a small plug of wood is placed, through which a strand of quick match† is passed to convey the flash from the Bickford's fuze. To use this detonator, Bickford's fuze‡ is pressed into the empty tube, which is then slightly bent to retain the Bickford.

34. *For dynamite*, copper caps, 1 inch long, are used as detonators. They contain about 5 grains of mercuric fulminate, and to use them Bickford's fuze is pressed into the empty part of the tube. It should be noticed that guncotton detonators can be used with dynamite, but that a single dynamite cap is not powerful enough to detonate guncotton.

35. *Makeshift guncotton detonator.*—A makeshift detonator for guncotton can be made by first fastening together 3 or 4§ dynamite caps, side by side‖, with silk or thread, after which they are

*It will be observed that the name Bickford's fuze does not altogether conform to this definition.

†See § 72.

‡See § 71.

§From some experiments carried out at Gibraltar by the author, it was found that 2 dynamite caps seldom failed to detonate guncotton when confined, but always failed to do so when unconfined.

‖It is not safe to press the caps into each other.

secured to a slip of wood with a further frapping. To insure the simultaneous ignition of all the caps a small quantity of mealed powder, done up in tissue paper, should be placed against the mouths of the caps. The end of a piece of Bickford's fuze is then pressed against the mealed powder, taking care that it has been cleanly cut, and is firmly secured to the caps by strapping it to the slip of wood. A wrapping of soft paper is now wound tightly round the caps, and down for about two inches along the Bickford. It is best to use "waterproof" Bickford, for it appears that the flame occasionally issues from the sides of the ordinary kind, and the guncotton will then be ignited before the detonation of the caps takes place, thus causing a failure*; but if waterproof Bickford cannot be obtained a thicker and longer serving of paper will answer the purpose.

ELECTRICAL FUZES.

36. There are many different kinds and patterns of electrical fuzes in the Service, but they all can be divided into two classes, namely—

Low tension or wire fuzes.

High tension or chemical fuzes.

and each class comprises fuzes for gunpowder and for guncotton.

WIRE FUZES.

37. These fuzes depend on the heating of a very thin metallic wire, called the "bridge," by the passage of an electrical current.† This wire, which is generally made of an alloy of iridium and platinum, is embedded in a mixture of guncotton‡ dust and gunpowder, and this, in its turn, fires either a small quantity of F.G. powder or else some mercuric fulminate, according as the fuze is intended for use with gunpowder or with guncotton.

The explosive mixture, in which the platinum wire is embedded, is placed in the hollow of a beech-wood or ebonite cup, and is retained there by a canvas diaphragm. The platinum wire is soldered to two short pieces of fine copper wire, which pass through holes bored for the purpose in the head of the cup, and are connected either to small copper tubes let into the body of the fuze or to short leads of insulated copper wire. To place the fuze in circuit§ the circuit wires are either passed through these copper tubes and secured or else connected to the short leads.‖

*This effect was noticed at the experiments mentioned above.

†See § 819, Ganot's Physics translated by Atkinson, 9th Edition.

‡The guncotton dust makes the fuze more sensitive. Originally, a strand of fleecy guncotton was wrapped around the platinum wire.

§See § 92.

‖The method of making these joints is described in § 102.

To the cup is fastened either a small tube containing F. G. powder, if the fuze is intended for gunpowder, or a shank containing about 20 grains of mercuric fulminate if for use with guncotton.

Makeshift wire fuzes.

38. It may happen that no Service fuzes are available, wire fuzes can then be improvised as follows. It should, however, be remembered that these makeshift fuzes are not so reliable as the Service fuzes, and if great care is not taken in making them a failure will probably occur.

For gunpowder.

39. A piece of *dry* wood is prepared 3″ long and ½″ × ¼″ in section, and the edges are rounded off. Two fine holes are made about ½″ from one end, which will be called the head of the fuze, care being taken that they are at least ⅛″ apart, and through these holes copper wires are pushed in opposite directions and bent down along the piece of wood. These wires should project about ¼″ above the head of the fuze, and are secured by a tight frapping of silk placed between the fine holes and the head of the fuze. The other ends of the copper wires are connected to short leads of insulated wire.¹ The joints should, if possible, be soldered,* and they are then laid on the wood and fastened to it by a frapping of paper, or better still, with indiarubber tape. Great care must be taken that there is no contact between the copper wires or the short leads except where insulated. The ends of the copper wires projecting above the head of the fuze are now bent into as small hooks as possible by means of a pair of pliers and a fine platinum wire, or, if this is not procurable, some wire obtained from lace, is nipped in these hooks and, if possible, soldered. The length of fine wire in circuit should be ¼″. The fuze should now be tested for *resistance* as explained in § 211. The next process is to make a small cup, surrounding the platinum wire, to contain a small charge of mealed powder; this can be done by winding a strip of paper around and beyond the head of the fuze and securing it with sealing wax. After the mealed powder, which should be ground very finely, has been put into the cup and *gently* pressed down a paper wrapping is put on to secure it.

For dynamite.

40. A piece of wood is prepared in the same way as for a gunpowder fuze, but should be cut about 4″ long so as to allow of a "horn" being formed at the head about 1″ long and ″ thick. A shoulder should be made on this horn on which the dynamite cap

*See § 100.

can rest, so as to prevent it from slipping down, which might either sever the wire bridge or make a connection between the two copper wires. The dynamite cap is secured by a silk or thread frapping to the horn. The remainder of the detonator is made like a makeshift gunpowder fuze.

For guncotton.

41. If a Bickford detonator* can be obtained the construction is exactly the same as described for dynamite, the shank of the detonator taking the place of the cap. But if only dynamite caps be available provision should be made for 3 caps.† The piece of wood will therefore have to be cut 4″ long and $\frac{1}{2}'' \times \frac{3}{4}''$ in section. This requires an alteration in the arrangement of the copper wires. They are passed through the $\frac{1}{2}''$ thickness in the *same* direction, and one of them is passed back again through a third hole so that the ends connected to the short leads will be on opposite sides of the piece of wood, and those soldered to the fine wire on the same side of the piece of wood. Otherwise this detonator is made in the same way as the dynamite makeshift detonator.

HIGH TENSION FUZES.

42. The general construction of these fuzes is the same as that of the low tension fuzes. The difference being that the thin iridio-platinum wire is replaced by a sensitive chemical preparation, which is decomposed and ignited by the passage of an electrical current of high potential; hence the name given to this kind of fuze.‡ The fine wires connected to the copper tubes or to the short insulated leads are encased in gutta-percha to insure the spark passing through the composition. It appears that these fuzes deteriorate from age. Their electrical resistance§ is very high, but varies considerably, not only in different fuzes, but in the same fuze, if exposed to climatic influences.

43. The above is the general construction of the Service fuzes, but there are numerous slight modifications according as the fuze is intended for Land, Submarine or Naval service, and also according to the pattern of the fuze. The principal electrical fuzes in the Service are given in Table I. It will be noticed that there is a regular system of distinguishing these fuzes by paint marks.‖

*See § 33.

†See § 35.

‡The word tension is used by some authors in the same sense as potential. Prof. Clerk Maxwell's definition of tension is, however, "the state of strain or pressure exerted upon a dielectric in the neighbourhood of an electrified body." See § 726*a*, Ganot's Physics, translated by Atkinson, 9th Edition.

§See Table I.

‖**For further information on fuzes see p. 26, I.M.E., Part IV.**

COMPARISON OF WIRE AND HIGH TENSION FUZES.

44. As will appear in the sequel the electrical condition of the circuit and of the fuzes can be tested in the Field when wire fuzes are employed, but not when high tension fuzes are used.* This is a distinct advantage of wire fuzes, and further, they are less liable to deterioration. But, on the other hand, less apparatus is required for high tension fuzes, and a greater number of these fuzes can be fired simultaneously.† On the whole it appears, therefore, "that for mines, etc., which are required to be ready for use for an indefinite period of time before firing, the 'low tension' fuzes, on account of the facilities which they afford for testing, are the best; while for immediate operations, such as blasting, hasty demolitions, firing guns at proof, etc., the high tension fuzes are handiest on account of the portability of a frictional machine, or of a magnetic exploder‡; bearing in mind always the increased necessity for high insulation when using these forms of electricity, and the possible deterioration of these fuzes from the influence of climate or time."§

PREPARATION OF CHARGE.

PREPARING FUZES FOR USE.

45. The first step in preparing a charge is to get the fuze ready.

The preparation of fuzes for use with slow or instantaneous leader has already been described at page 18.

In preparing *electrical* fuzes for use it is best to connect them to short lengths (from 6 to 30 feet) of insulated wire in the manner described under the head of "jointing,"‖ and these insulated wires are afterwards connected to the remainder of the circuit wires when the charge has been placed in position. If time is an object, and the fuze can be reached at the last moment before firing, these insulated wires can be dispensed with. Two detonators should, if possible, be used with guncotton, in case one of them were defective, and these detonators should be so connected to the circuit wires that one-half of the current will pass through one detonator and the other half through the second detonator; the manner of doing this is also described under the head of jointing.

*See §§ 117, 118 and 127.

†See §§ 87 and 89.

‡Provided a quantity dynamo, which will fire wire fuzes, is not available.

§Official Treatise on Ammunition, 1878.

‖This applies only to Land operations.

PREPARATION OF PRIMERS.

46. The fuzes, when prepared as described above, are placed, before loading, in a portion of the charge, unless the charge is very small. This portion of the charge may conveniently be called the "primer," and its preparation depends on the nature of the explosive and also on the object of the explosion.

GUNPOWDER.

47. The powder is generally* placed in a bag, and for this purpose leather bags are issued from store, but if these are not procurable a sand-bag can be used; this sand-bag should be tarred if there is any likelihood of damp, and always if the charge is to remain unfired for any length of time.

When the bag is about one-third full, either the end of the leader or the electrical fuzes, with the short lengths of insulated wire attached, are put in with about one foot of slack of leader or wires. The bag is then nearly filled with powder and firmly secured at the mouth with wire or string. Every precaution should be taken to prevent the leader or fuzes being pulled out of the bag, and this can be done by making a knot on the leader or wires.

GUNCOTTON.

48. A small disc or slab of *dry* guncotton is taken, and the shanks of the detonators are gently pressed into the holes provided for the purpose. If the holes are too small they should be enlarged by means of a tool called a "rectifier," or if too large some paper should be wrapped round the shank. A "rectifier" is provided with each box of detonators, and also the following caution:

"Electric detonators must, on no account, be forced into the guncotton primers by screwing or twisting.

"This cylinder of detonators contains a 'Rectifier.'

"Before inserting a detonator into a Primer, force the Rectifier into the hole for the detonator, up to the full extent to which the detonator should enter, and then withdraw it by twisting."

49. A primer to detonate a charge of *wet* guncotton consists of 2lbs. of *dry* guncotton, and a disc or slab prepared as above is placed in the centre of the dry guncotton, the whole being placed in an india-rubber waterproof bag,† the packing being done as described for preparing a gunpowder primer, and using the same precautions. To insure that no moisture finds its way from the wet guncotton into the primer the mouth of the bag must be

*Blasting rock and quarrying are exceptions.

†These india-rubber bags are articles of store.

closed up hermetically as follows: A clip is prepared consisting of two pieces of wood, the mouth of the bag, well smeared with india-rubber solution,* is placed in this clip, and is closed by screwing the two pieces of wood together. Two grooves should be made in the clips for the wires to pass through, so that they may not be crushed and to make a closer joint.

DYNAMITE.

50. To prepare a dynamite cartridge as a primer, it is opened and the head of the cap or detonator is gently pressed into the explosive; to assist the operation it is well to make a small hole with a smooth piece of wood. The cartridge should then be closed and the fuze secured by string or wire.

PREPARATION OF CHARGES FOR VARIOUS PURPOSES.

51. The remainder of the preparation of the charge depends entirely on the object of the explosion. The making up of the charge for the various cases in which explosives are used in Military Engineering Land operations will therefore be considered separately.†

The weight of explosive to be used in each of the following cases can be determined from the data given in Table I.

LAND MINES.

52. Gunpowder is the explosive best suited for land mines, and the charge is placed in a chamber prepared at the end of the gallery in the manner explained in § 473 F.‡ The charge is best made up in bags, and this is also the most convenient arrangement for bringing the powder to the head of the gallery. Tarred sand-bags can be used for this purpose, but india-rubber bags (vulcanized)§ containing each 100lbs. of powder, should be used if the mine is wet. The mouths of these india-rubber bags are closed with clips, as explained for the similar bags used for gun-cotton primers.||

The bags are packed as tightly as possible in the chamber, the priming bag being placed in the centre. If the mine is to be fired by powder hose, the hose is laid in a wooden trough placed for the purpose along the bottom left-hand corner of the gallery.

*Prepared by dissolving india-rubber in naphtha.

†The best method of firing the charge has been given in each case, although that part of the subject has not yet been discussed It is to be understood that the leader or circuit wires are arranged as described under the head of preparation of firing arrangements.

‡It should be remembered that the following only deals with the actual making up and placing of the charge.

§These india-rubber bags are articles of store.

||See § 49.

But if instantaneous hose or electricity is to be employed for firing, the leader or the wires are secured to the upper left-hand corner of the gallery.* They should not extend much beyond the end of the tamping, and with electricity the final connections are made just before firing. The best method of firing land mines is by electricity, more especially so if two or more mines are to be fired simultaneously.

The charge being placed, the next operation is the tamping, which is best done by means of sand-bags about one-half full. The amount of tamping should not be less than 1½ times the L. L. R.† for a two-lined crater, or twice for a three-lined crater.

The quantity of gunpowder to be used in a land mine depends on the depth of the charge below the surface (the L.L.R.), and on the effect to be produced. This question is, however, fully treated of in "Mining."

DEMOLISHING CUTTINGS AND EMBANKMENTS.

53. Here, again, a lifting effect is required, and therefore gunpowder is the most suitable explosive to use. The making up and placing of the charge, and the best methods of firing, are the same as for Land mines.

FOUGASSES.

54. A small chamber is prepared at the bottom of the inverted cone, as shown in Fig. 1 PL. VIII F.F.‡, just large enough to contain a box holding the charge, or, the charge can be made up in sand-bags which are tightly packed into the chamber, the priming bag being placed in the centre. This latter is probably the best method.

A wooden shutter is placed over the charge, the object of which is to equalize the effect on the stones, which are next put in; the [illegible] few layers should be laid by hand, and the remainder should [illegible]t in carefully so as not to injure the leader or the wires.

[illegible]ougasse should be fired either by means of instantaneous leader or by electricity, but the latter method is preferable. The leader or the wires are placed for protection in a groove cut for the purpose, and are secured to the ground just above the fougasse; the final connections (for electricity) are made shortly before the fougasse is to be fired.

*This is the authorized arrangement given in I.M.E. Part IV, but it would appear preferable to bury the instantaneous leader or the wires along the bottom left hand corner of the gallery, the frames being generally removed as the tamping proceeds.

†Line of least resistance.

‡Text-book of Fortification.

RAILWAY RAILS.

55. The object in cutting through a railway rail is to render the line impassable to trains. For this purpose a small charge of guncotton or of dynamite is prepared as a primer and secured to the web of the rail by means of string or wire, and is generally fired by Bickford's fuze.* See Figs. 6 and 7, PL. XLIV, F.F.†

BRIDGES.

56. Iron or wooden bridges can be demolished by cutting through the lower boom‡ of one of the girders by means of guncotton or dynamite.

To effect this with guncotton a primer is placed on one of the lower booms at the centre of the bridge, and on either side in contact are secured slabs or discs of guncotton. In the case of wooden bridges a saving of explosive can be effected by placing the charge in an auger hole. Dynamite is used in the same way. The charge is best fired by means of Bickford's fuze.

COLUMNS OR UPRIGHTS.

57. Columns or uprights of wood or iron can be cut through by placing a "necklace" of guncotton round them. This necklace is most conveniently made of 1 or 2 oz. discs strung together by means of string or wire passed through the detonator holes. One of the discs is prepared as a primer, and the charge is best fired by Bickford's fuze.

A wooden upright can, however, be cut through with a less quantity of explosive if the charge is placed in an auger hole.

Dynamite can be used similarly.

Trees are treated in the same way as wooden uprights.

STOCKADES.

58. The object is to cut a passage through the stockade,§ and this can be best done by means of guncotton. The charge can be easiest made up, and is in a convenient form for carrying, if secured to a thin board equal in length to the width of the passage to be opened, generally from 8 to 10 feet. The discs or slabs of guncotton can be secured to the board by string or wire passed through the detonator holes and through holes in the board. The primer is best prepared with Bickford's fuze fitted with quick match, and should be placed in the centre of the charge. The amount of the charge depends on the strength of the stockade. See Fig. 1, PL. XLIV, F.F.†

*The Bickford's fuze is here, and in the subsequent cases, regarded as the means of exploding the detonator.

†Text-Book of Fortification.

‡Also called "chord."

§See page 54, Guide to the Course of Military Engineering, etc.

If guncotton or some similar explosive is not available, gunpowder can be used, employing a very large charge made up in bags, which are piled against the foot of the stockade. If possible, some earth, placed in sand-bags, should also be brought up in order to confine the charge. See Fig. 2, PL. XLIV, F.F.

PALISADES.

59. The charge is prepared in the same way as for stockades, but a less charge being required, it will be found necessary in this case to cut the slabs of guncotton, supposing these are used.

GATES.

60. Guncotton or dynamite are the most suitable explosives in this case, but if they are not available gunpowder can be used.

If guncotton or dynamite are employed, the charge can be placed in a bag, or better still, secured to a thin board, as in the case of stockades.

If gunpowder is used, the charge must be placed in a bag (or in more than one if a large charge is required) and is either nailed to the gate or placed at its foot.

These charges are best fired by means of Bickford's fuze, fitted with quick match.

WALLS.

61. The object is either to clear away walls, or, to open a passage in a defensible wall.

Guncotton or dynamite should be employed, and when the object is to open a passage the charge must be prepared precisely in the same way as for stockades. But if more time is available a great saving of explosive will be effected by removing a few bricks or stones and placing the charge in the hole thus formed; tamping, even if slight, will increase the effect.

The charge is best fired by means of Bickford's fuze.

BLOWING DOWN HOUSES.

62. Houses can be blown down by placing charges of gunpowder, made up in bags or barrels, in the corners of the building, and confining these charges with earth.

If the house is to be "prepared" for demolition, as in the defence of a village, one charge of gunpowder placed in the centre of the building is generally the best arrangement, unless electricity is available.

The charges can be fired either by instantaneous leader, Bickford's fuze, or electricity. The two last methods are preferable.

Houses can also be demolished by means of guncotton or dynamite used in the same manner as for demolishing walls, and the charges are best placed in succession and then fired by means of Bickford's fuze.

BLASTING ROCK.

63. The object of blasting rock is to shatter the stone as much as possible, the stone not being required for use, guncotton or dynamite are, therefore, the best explosives for the purpose.

When time is an object, a charge of either of these explosives simply placed on the rock will, if large enough, shatter it. The exact form of the charge will depend on the shape of the rock, and advantage should be taken of any hollow as it will tend to confine the charge. The discs of guncotton or the cartridges of dynamite can be tied together with the primer in the centre and fitted to the shape of the rock at the point where the charge is to be placed. Bickford's fuze is the best method of firing.

If there is plenty of time it will be cheaper to bore holes* in the rock and use them as chambers for the explosive. When guncotton or dynamite are employed a slight tamping is all that is necessary, but with gunpowder the tamping must be very firm, in order that the L.L.R. may not be along the bore hole. If the hole be inclined downwards the charge can be poured in, but if only slightly inclined or if horizontal, a scoop, or better still, a cartridge, can be used, which last arangement must always be adopted if the hole be inclined upwards. The fuze should be inserted midway in the charge. The charge having thus been placed, the tamping is proceeded with as follows : Some brick-dust is poured in and gently pressed (so as not to meal the powder), with a *copper* jumping bar. The next layers are rammed tight, about one inch at a time, and it is of advantage to occasionally put in layers of damp sand. Brick-dust is the best material for tamping, but sand or earth may also be used.

Bickford's fuze is the readiest means of firing.

QUARRYING.

64. In this case the object is to remove the stone without injuring it, so that it will be fit for building. Gunpowder is the best explosive for this purpose, and the method of making up the charges is the same as for blasting rock; they are usually exploded with Bickford's fuze.

*For the methods of boring holes see p. 17 I.M.E., Part IV, and p. 2-16, Blasting and Quarrying Stone, by Sir John Burgoyne (Weale's Series).

Gibraltar method.

65. The following method of quarrying is employed at Gibraltar: A bore hole from 16 to 30 feet deep is made in the first instance, and a small "shaking" charge of powder is put in; this charge, when exploded, forms a small chamber at the bottom of the hole. A larger "shaking" charge can now be put in and exploded, thus increasing the chamber and hence the size of the next charge, and so on until the charge is sufficiently large to blow out a large mass of rock. The first charges are only a few ounces in weight, and they then increase to 1, 5, 20, 50, 100, up to 500 or 700 lbs., for the final charge.

STONE PIERS.

66. Small stone piers can be cut through by detonating guncotton or dynamite attached to them, and the best plan is to secure the charge to a board.

Larger piers require a chamber to be formed, and this can be done either by means of explosives used as in blasting rock, or by hand.

When the chamber is prepared it is loaded in a similar way to a land mine.

In this case if there is no difficulty about tamping, gunpowder or guncotton are equally effective; but it should be remembered that guncotton requires a smaller chamber than gunpowder. If there is any difficulty, however, about the tamping, guncotton or dynamite are preferable.

The charge can be fired either by Bickford's fuze or by electricity.

ARCHES.

67. In demolishing arches a chamber has to be prepared in the manner and in the positions given in § 208 F. See also Fig. 4, PL. XLIV, F.F.*

The charge is prepared and fired exactly in the same way as for a land mine.

If an arch has to be hastily demolished a charge of guncotton or dynamite can be placed over, or better still, under the crown of the arch, and can be fired most simply by Bickford's fuze, unless the bridge is to be "prepared" for demolition, when the charge should, if possible, be fired by electricity.

If these explosives are not available, then gunpowder must be used.

HASTY DEMOLITIONS.

68. Hasty demolitions differ from deliberate demolitions in that

*Text-book of Fortification.

very little time is available. Tamping must, therefore, be reduced in quantity, or even omitted altogether, and chambers can rarely be formed. It follows that larger charges are necessary, and that guncotton and dynamite are more suitable than gunpowder. Otherwise there is no difference in the manner of making up the charges.*

PREPARATION OF FIRING ARRANGEMENTS.

69. It has already been pointed out† that the immediate cause of the explosion of the charge is the explosion of the fuze, and it has also been seen that there are three distinct means of doing this, namely:

1. By slow or instantaneous leader.
2. By electricity.
3. By percussion.

Firing by percussion is so rarely used that it will not be considered, but the two first methods will now be inquired into in detail.

PREPARATION OF FIRING ARRANGEMENTS WHEN USING SLOW OR INSTANTANEOUS LEADER.

70. The object of the leader is to enable the person firing the charge to be at a safe distance when the explosion takes place. This can be done by attaching the *fuze* to a short length of slow leader, or to a long length of instantaneous leader, or both kinds of leader may be combined.

Several varieties of slow and instantaneous leader are employed in the Service. The following is a description of the more usual kinds and of the manner of using them.

BICKFORD'S FUZE.

71. Bickford's fuze‡ is made by placing a train of mealed powder between two coatings of jute-thread twisted in opposite directions. A peculiar waterproof composition is then laid on, and the whole is served with layers of tape, gutta-percha, thread, or even of metal, according to the particular use for which the fuze is intended.§

*A description of the demolition of a Fort at Furruckabad, in 1858, by Lieut. Scratchley, R.E., will be found at p. 529, Spon's Dictionary of Engineering. A description of large blasts with gunpowder at Holyhead and at Seaford will be found in the same work at pages 532 and 560. For an account of some blasting operations at Singapore see p. 53, Vol. IV, Occasional papers, R.E.I.

† § 30

‡See footnote, *p. 18.

§A description of the manufacture of Bickford's fuze will be found at p. 1607, Spon's Dictionary of Engineering.

The rate of burning is from 2.4 to 4 feet per minute, and the more the fuze is handled the quicker it burns. If it is required to be able to ignite the fuze at any given instant of time, the exposed end should be prepared by splitting the fuze, inserting a few strands of quick match*, and securing with twine or tape; but the usual way, although the fuze will not ignite so readily, is to cut it diagonally with a sharp knife.

The other end of the fuze is either inserted into gunpowder or into a detonator, as already explained at page 18.

QUICK MATCH.

72. Quick match is made by boiling cotton-wick in a solution of mealed powder and gum.

When unenclosed, quick match burns at the rate of about 0·23 feet per second, but if enclosed in a tube, the heated gases rushing through the tube increase the rate of burning to about 15 to 30 feet per second, and it then forms an instantaneous leader, such as Ord's hose or Bickford's instantaneous fuze.

Quick match, when unenclosed, is used for priming.†

POWDER HOSE.

73. Powder hose consists of a linen casing filled with gunpowder. The case is an article of store, but it can also be made as follows: Strong linen is cut into strips 4 inches wide, the edges are turned over outwards, then the double parts are brought together and "serged" by passing the needle through the four thicknesses of stuff and back again over all. This makes a tube one inch in diameter, which is now filled with fine powder by means of a copper or a paper funnel. Twenty feet is the longest length of hose that can be filled easily at one time, and this filling can be done from the upper window of a house.

Powder hose is used with charges of gunpowder, and then only when the other descriptions of instantaneous leader are not to be had. No preparation is required at the exposed end, and the other end is secured to the charge, as explained in § 47.

This hose is very liable to injury, and must, therefore, if possible, be surrounded by a casing of wood. The angles are the points most liable to injury. The method of placing the hose in a gallery is explained in § 52.

Powder hose burns at the rate of from 10 to 20 feet per second.

ORD'S HOSE.

74. This hose consists of several strands of quick match enclosed in a casing of coarse painted canvas, cemented together

*See § 72.
†See § 71.

with india-rubber solution, and strengthened with two servings of cotton thread. It can be joined to Bickford's fuze with a scarfed joint secured with wrappings of paper or tape.

Ord's hose is used for the same purposes and in the same manner as powder hose, but is much preferable.

It burns at the rate of 15 feet per second; dampness, tight packing, and junctions reduce this rate. Dampness, however, only affects this hose temporarily.

BICKFORD'S INSTANTANEOUS FUZE.

75. This instantaneous leader has been recently introduced, and consists of a strand of quick match covered by several layers of gutta-percha and waterproof tape, and it can be used under water.

It can be joined to itself by baring short lengths of the quick match, twisting these together and wrapping a slip of paper round the joint. If the joint is to be placed under water, or is liable to damp, it should be waterproofed by means of india-rubber tape, in the same way as an electrical joint.* This fuze is generally used with gunpowder, but the quick match, when bared, can be pushed into a guncotton detonator or a dynamite cap. The exposed end of the hose is generally jointed to a short length of Bickford's slow fuze to enable the operator to get away.

Bickford's instantaneous fuze burns at the rate of 30 feet per second.

FIRING THE CHARGE.

76. When a charge is to be fired by slow or instantaneous leader, heat has to be applied to the exposed end of the leader, when prepared as described above. An ordinary match will answer the purpose, but a vesuvian is far preferable. Slow match and port fire can also be used with advantage.

PREPARATION OF FIRING ARRANGEMENTS WHEN USING ELECTRICITY.

77. As already mentioned, the explosion of electrical fuzes is determined by the passage of an electrical current which, according to the nature of the fuze, either melts a fine iridio platinum wire or decomposes a sensitive chemical composition. The following are, therefore, required when firing by electricity:

1. A source of electricity, or firing machine.

2. A means of conducting the electrical current through the fuze, or, technically speaking, the fuze must be placed "in circuit" with the source of electricity.

*See § 100.

SOURCES OF ELECTRICITY.

78. On the nature of the fuze depends the *quality* of the electrical current to be employed. Wire fuzes require the heating effects of electricity, and for this a current of large quantity is necessary,* but the potential need not be high. Tension fuzes† require the chemical effects of electricity, that is, the current must have a high potential*, but its duration need only last long enough to start the decomposition. A high potential is also necessary in this case on account of the high resistance of these fuzes.

SOURCES OF ELECTRICITY WHEN USING WIRE FUZES.

79. Two descriptions of apparatus are used to fire wire fuzes, namely:

1. Battery of Voltaic cells.
2. Magneto electric machines.

Battery of Voltaic cells.

80. Since a powerful current is required, each cell in the battery must have a high electro-motive force and a low internal resistance. Such are Grove's, Bunsen's and Poggendorff's cells.‡

The cells in use in the Service are the "Military Grove" and a special pattern Leclanché.

Military Grove cell.

81. The cells are flat, and the outer cell is made of ebonite. The zinc plates are curved round the porous cell to expose as much surface as possible, and the surface immersed is twice $4'' \times 2\frac{1}{2}''$. The platinum plates are made of sheet platinum, and have $4'' \times 2\frac{1}{2}''$ immersed. Twelve of these cells are placed in a box, and the terminals are connected to two binding screws placed outside the box. The box has a compartment for 12 spare porous cells.

82. "To prepare the battery for use, all metallic contacts should first be brightened with emery paper.

"Sufficient sulphuric acid to charge the battery is then diluted with water in the proportion of 1 acid to 10 water in a wooden or earthenware vessel, the zincs having been first amalgamated.§

*See §§ 819 and 784 Ganot's Physics, 9th Edition.

†High tension fuzes are usually called tension fuzes.

‡For an explanation of the theory of Voltaic cells, reference is made to Book X, chap. 1, Ganot's Physics, 9th Edition.

§See "Sundry Recipes."

"The plates and porous cells are placed in their cells or compartments, and the zinc and platinum plates united by clamps. The outer cells are then filled to within half an inch of the top with dilute sulphuric acid, and afterwards the porous cells with pure nitric acid, and the battery is ready for action.

"An ebonite funnel with a small nozzle is convenient for filling the cells, and should too much liquid be poured into any cell by mistake, the superfluous acid may be withdrawn by a glass pipette"*.

The battery must be taken to pieces immediately after use.

Leclanché cell.

83. The special pattern Leclanché cell used for firing charges is, in principle, of the same construction as the commercial pattern described in § 803 Ganot's Physics. But, to reduce the liquid resistance, the surface of the zinc exposed is much increased, and for portability the outer cell is made of ebonite, and the porous cell is replaced by a felt bag.

"The elements are amalgamated zinc and graphite, and the exciting liquid a saturated solution of sal ammoniac. In order to increase the constancy of the battery the graphite plate is placed in a porons diaphragm of felt, and packed in with binoxide of manganese, and the latter substance being a comparatively bad conductor has mixed with it an equal quantity of graphite; both these substances are tightly packed in lumps about the size of a pea. The head of the graphite is run with lead in order to give a place for the attachment of the binding screw. This lead head and its junction with the graphite are then coated with a mixture of equal parts of china clay, and pitch, to prevent deposition of moisture there.

"If moisture should get to the point of junction, local action would ensue, and in time partially insulate the head from the plate."*

These cells are issued in boxes of 10, ready for use; each cell contains a charge of sal ammoniac, so that to prepare for use it is only necessary to pour in water to within one inch of the top of each cell. The battery will then last for several months, and when it requires renewing all that has to be done is to pour out the liquid from each cell and replace it by a concentrated solution of sal ammoniac.

84. These cells may occasionally require taking to pieces, and they can then be set up again as follows:

"Amalgamate the zinc plate and clean the binding screws.

*Instruction in Military Engineering, Part IV.

"Make up a saturated solution of sal ammoniac in one of the ebonite cells, letting the level of the liquid be $1\frac{1}{2}$ inches from the top. Put in a zinc amalgamated plate, and try if the current from it in conjunction with each graphite in turn will redden the standard wire. A fuze does very well for this.

"Put aside those graphite plates which do not redden.

"Coat the binding screws of the remainder with earth or putty, and submerge the head to a depth of 1 inch below the surface of a molten mixture of equal parts of china clay, and pitch. When this has hardened remove the clay and brighten the screw.

"Put the graphite plate in the felt or other porous cell, and pack it tightly with equal parts of binoxide of manganese and graphite, each in lumps about the size of a pea if possible, but in no case put in fine powder.

"Choke the felt cell at the top, taking care that it does not reach above the bottom of the pitch mixture.

"Dip the head of the ebonite cell to the depth of 1 inch in molten paraffin.

"Put in the zinc plate first and then the graphite, and close the whole of the top with crude black paraffin, leaving one hole through which to pour the liquid and another for the escape of air, these holes being kept open by pieces of quill or glass.

"The lead head should stand at least 1 inch clear above the top of the ebonite cell.

"Pour in the saturated solution of sal ammoniac until it reaches to within 1 inch of the top of the cell."*

85. These Leclanché cells are not as powerful as Grove's cells, as they have a smaller electro-motive force and a larger liquid resistance, consequently a greater number must be used to produce the same effect; but they are far more convenient to use.

Makeshift battery.

86. A makeshift battery, capable of firing wire fuzes, can be made as follows :†

" Cut from sheet copper a number of plates each 6 inches by 8 inches. The exact thickness is immaterial, but No. 22 B.W.G. is very suitable.

" To each copper plate solder a strip of thin copper.

" Cut a number of zinc plates of the same size, and if possible one tenth of an inch thick; if this thickness is not at hand ordinary roofing zinc will answer very well.

*Instruction in Military Engineering, Part IV.

†A representation of this makeshift battery is given in Figs. 1 to 5, Plate XI, Instruction in Military Engineering, Part IV.

"Solder a slip of copper on to the zinc plates of the same dimensions as soldered on to the copper plates. Where the copper slips are soldered to the copper and zinc plates pay over the joint with some hot pitch, extending it for at least half an inch beyond the edges of the soldering. Take a number of slips of coarse blanket or felt, cut 6 inches by 14 inches, damp these slips in water, wring them out, double them, and having put between each zinc and copper plate one of these doubled slips, bind each pair of plates together with spun yarn, taking care that the zinc and copper do not touch each other. Have ready a box made of dry deal three quarters of an inch thick, whose internal dimensions are 15 inches long, 6½ inches wide, and 8 [illegible] inches deep.

"This box is to be divided into 10 cells or compartments by divisions of deal half an inch thick, grooved a quarter of an inch into the sides and bottom.

"The sides and bottom of the box having been put together with joints made good by hot pitch, or what is better by marine glue, the grooves for the division and the whole interior of the box should be payed over with the same substance. The divisions themselves should then be coated over and slid down into their places and fixed there by nails, whilst the pitch or glue is hot. The whole box, and each compartment of it, should be quite watertight.

"Have ready a quantity of dilute sulphuric acid, made by pouring slowly a quart of the acid into eight quarts of water, contained in a wooden bucket or tub.

"Put a pair of plates, tied up as already described, into each cell or compartment; the zincs all facing the same end of the box.

"Fold together, with two folds, the copper slips which have been fixed to the copper plate of one cell and the zinc plate of the cell next to it.

"Fill each cell by means of a jug with the dilute acid up to rather less than an inch of the top of the cell.

"The battery is then ready for use.

"The acid should not be poured into the cells until the moment before the battery is wanted for use, and the plates should be disconnected and thoroughly washed directly the charge has been fired."*

Magneto-Electric Machines.

87. A special pattern magneto-electric machine is in use in the Service, and is known as a *Quantity Dynamo*.†

*Instruction in Military Engineering, Part IV.

†A representation of this quantity dynamo is given in Fig. 2, Pl. IX, Instruction in Military Engineering, Part IV.

This machine consists of a Siemens' armature*, which is made to revolve between the poles of a horse-shoe magnet by means of cog wheels. The residual magnetism in this electro-magnet induces a current of electricity in the wires of the Siemens' armature directly it commences to revolve, and this current is led, by means of a commutator†, through the coils of the electro-magnet, thus increasing the intensity of magnetism in the magnet. This increases the current in the Siemens' armature, which further strengthens the magnetism, and so on until the full capacity of the machine is reached, which is effected with two or three turns of the handle. It has been found necessary to introduce a resistance of about 42.8 ohms‡ into the circuit to reduce the current, for the intensity of magnetism produced, in the present pattern of machine, is so great that one man could not otherwise work it.

The machine is provided with a key so arranged that, when depressed, the resistance of 42.8 ohms is "cut out" of circuit, and the current has then, not only to pass through the coils of the electro-magnet, but also through the line wires which are attached to binding screws provided for the purpose, thus firing the fuzes.

"This dynamo may be relied on to fire 30 iridio-platinum wire detonators (No. 13) through a resistance equal to that of 500 yards of No. 16 B.W.G.§ copper wire."‖

For protection the machine is placed in a box, and can be worked without taking it out. This box is painted white, and has the word "Quantity" painted on it.

88. To use the instrument the line wires are connected to the binding screws, the handle is turned round sharply two or three times, and the key is then firmly depressed, continuing to turn the handle.

SOURCES OF ELECTRICITY WHEN USING HIGH TENSION FUZES.

89. Since these fuzes require a current of high potential a battery of Voltaic cells is practically unsuitable because of the number of cells that would be required. The Service apparatus for firing these fuzes is called a *Tension Dynamo*,¶ and is of similar construction to the quantity dynamo, the points of difference being that the electro-magnet is wound with a much greater length of finer wire (it is this which gives a high potential to the current produced by the machine), and, instead of a firing key, a self-acting

*See § 901, Ganot's Physics, 9th Edition.

†See § 899, Ganot's Physics, 9th Edition.

‡See § 142.

§Birmingham wire gauge.

‖Instruction in Military Engineering, Part IV.

¶A representation of this tension dynamo is given in Fig. 2, Pl. IX, Instruction in Military Engineering, Part IV.

catch is provided, which sends the current through the fuzes at the end of the second full turn of the handle. A micrometer spark measurer is also attached, the use of which is explained in §

This machine "will fire as many as 80 fuzes at once in continuous circuit,* and 60 fuzes in groups of two in divided circuit."* The machine is placed in the same kind of box as the quantity dynamo, but can be distinguished from the latter by the absence of a key, by the box being painted black, and by the word "Tension" painted on it.

90. "The mode of using this dynamo is as follows: Turn the handle slowly, with right-handed rotation, until the sharp click of the automatic firing catch is heard, then put on the line and return wires and turn the handle sharply three times, this fires the fuze or fuzes."†

91. Other apparatus can be used to fire tension fuzes, such, for instance, as Ruhmcorff's coil‡ and Von Ebner's frictional machine‡.

MEANS OF CONDUCTING THE ELECTRICAL CURRENT THROUGH THE FUZES.

92. The electrical current is conducted through the fuzes by wires, which, must be insulated, to prevent loss by leakage. One wire, called the "line wire," leads from the positive pole of the firing apparatus to the fuzes, and another, called the "return wire," from the fuzes back to the negative pole. This arrangement is known as the "circuit." These insulated wires are generally called the "cable."

For low tension fuzes it is very essential that the wires have a low resistance, but for high tension fuzes good insulation is the most important requisite.

93. The Service cable for land operations consists of seven No. 20 B.W.G. twisted strands of tinned copper wire, insulated with Hooper's indiarubber and served first, with a layer of felt and then with platted string.

94. If the Service cable is not available or cannot be had in sufficient quantity, the part of the circuit above ground can be formed of bare copper or iron wires, insulated on poles in a similar way to telegraph wires. If telegraph insulators cannot be obtained the neck of a bottle or a piece of india-rubber fastened round the wire will answer the purpose. The parts of the circuit under

*See § 97.

†Instruction in Military Engineering, Part IV.

‡See §§ 784 and 905, Ganot's Physics, 9th Edition.

ground must be made of insulated wire, and if not obtainable ready made, some bare wire can be insulated in the following manner: Thin strips of linen or cloth well saturated with tar are wrapped spirally round the wire to be insulated, and then payed over with a coat of pitch and tar mixed, put on hot. Marine glue if obtainable is a better material than tar or pitch.

95. When using tension fuzes the return wire may be dispensed with, using "earths" instead, that is the return wire from the fuze, which in this case may be bare, is attached to a metal plate placed in the earth, and the negative pole of the firing apparatus is connected in the same way to another earth plate. The Earth then becomes as it were the return wire. Earth plates should have an area of about 30 square inches, and if the ground is not damp it should be made so. These earth-plates increase the resistance of the circuit, and should therefore on no account be introduced into a circuit connected to wire fuzes.*

96. Short lengths of wire are frequently required in making up the circuit. For this purpose, either portions of Service cable or insulated copper wire not less than No. 16 B.W.G. can be used.

ARRANGEMENT OF THE CIRCUIT.

97. When only one fuze has to be fired the circuit is called a simple circuit; the arrangement is represented in Fig. 1.

When several fuzes have to be fired *simultaneously* the circuit may be arranged so that the current flows through all the fuzes in succession without being divided; the fuzes are then said to be connected in "continuous circuit," as shown in Fig. 2. Or the current can be divided, before passing through the fuzes, into as many branches as there are fuzes; this arrangement is called

*This applies to Land operations only.

connecting in "divided circuit," and is shown in Fig. 3. Or lastly, a combination of both arrangements may be adopted when the fuzes are said to be connected in "combined divided and continuous circuit," and some of these arrangements are shown in Figs. 4 and 5.

Selection of the arrangement of the circuit.

98. When a combined divided and continuous circuit is employed the part of the current flowing through each branch must be of sufficient strength to ignite the fuzes in that branch; in one respect, therefore, a division of the circuit tends to increase the battery power required. But, on the other hand, the division of the circuit diminishes the electrical resistance which increases the current.* It appears, therefore, to be a matter for calculation to ascertain the most economical arrangement of the circuit as regards battery power.

A disconnection in a continuous circuit would entail the failure of all the fuzes, but with a divided, or with a combined divided and continuous circuit, a disconnection, if in one of the branches, will only cause the failure of the fuze or fuzes in that branch.

Again, if wire fuzes are placed in continuous circuit and they happen to be unequally sensitive, the most sensitive fuze or fuzes will ignite first, thus causing a disconnection, and the failure of the remaining fuzes.

On the whole it appears, therefore, that one should :

(a.) "When using tension fuzes, always use the continuous circuit, and by preference the continuous circuit with divided fuzes.

(b.) "With wire fuzes use the continuous circuit if there are a sufficient number of cells in the battery to fire the requisite number of fuzes.

*See § 145.

(c.) "If the wire fuzes have been tested (resistance measured) and can be relied on, it is better and simpler to use a single fuze in each charge, otherwise they should be in pairs divided."

JOINTING.

99. Electrical joints have to be made when the circuit wires are too short, when using divided circuits, and, as already seen, when preparing electrical fuzes for use.

The joints are the weak points of a circuit; they must therefore be very carefully made. When firing with wire fuzes it is essential that a perfect metallic contact be obtained, for otherwise the resistance in the circuit will be increased, and possibly to such an extent as to cause a failure. It is most important therefore that the ends of the wires to be connected should be perfectly bright and clean, and, since the metal soon begins to oxidise, which increases the resistance, the joint must be soldered, unless the charge is to be fired shortly after making the joint. Further, to prevent leakage, the joint should be insulated more or less effectively according to the liability to leakage.

When firing with high tension fuzes the same precautions should be taken, but in this case the insulation of the joint is the most important point to attend to.

The method of making electrical joints in circuit wires is as follows:

Two-way joints.

100. *Jointing the wires together.*—"For jointing insulated wires, strip the insulating material for two inches from the ends of the wires, avoiding using a knife when pliers are at hand, but in any case taking particular care not to nick the wire itself when cutting the insulating covering; next clean the bared wires until they are quite bright, then cross the wires, as shown in Fig. 6, and

Fig. 6. *Fig. 7.*

Fig. 8. *Fig. 9.*

bend them round each other as shown in Fig. 7, then with each end take two full turns, Fig. 8, and bend the projecting ends so that they overlap the insulated part of the wires; this is done in order that the overlapping ends may strengthen the joint at the point A, that being the part at which the joint usually gives way. See Fig. 9.

Fig. 10.

Fig. 11.

Fig. 13.

Fig. 12.

"*Soldering the joint.*—The joint should now be soldered;* this is best done by moistening the wires with a solution of chloride of zinc, commonly called by workmen "spirits of salt killed with zinc." A soldering bolt, having on it a drop of molten solder, is then pressed against the under side of the joint. If the wires have been properly cleaned and the bolt is sufficiently hot, the molten solder will rise or "sweat" up between the wires of the joint, forming a perfect metallic union.

"If the bolt has been overheated the solder will not cling, or as it is called take to it; when this is the case, file the end of the bolt, whilst hot, until it is quite bright, touch it with some chloride of zinc, and rub it on the solder until the molten metal clings to it.

"The soldering should be done as quickly as possible, to avoid injuring the insulation of the wire by the heat of the bolt.

"*Insulating the joint.*—As soon as soldered the joint should be insulated by wrapping india-rubber tape round it, stretching the tape whilst wrapping it, and making each turn overlap the preceding one by one half its breadth (Fig. 10.)

"The wrapping is finished off with a single hitch. Failing rubber tape, common tape dipped in tar may be used.

"Joints for circuits in which tension fuzes are used need not be soldered, but should be insulated. In very dry soil, and where the joint can be inspected up to the last moment before firing, it is not necessary to insulate with rubber tape; in this case it will suffice to frap them round with some loose rope yarns.

*It is desirable to solder joints when wire or low tension fuzes are used, but it is not absolutely necessary to do so, provided that the wire is well cleaned and good contact insured.

"In very wet soil or in water, india-rubber solution should be used with the india-rubber tape, smeared over the successive layers of tape as wound round."*†

If the joint is *not* soldered, no india-rubber solution should be placed on the wires, for it might get between the wires, which would increase the resistance in the circuit. In this case, therefore, a layer of india-rubber tape should be put on before applying any of the solution.

"*Jointing iron wires.*—Joints in iron wires are made as above described, but sal ammoniac is the best flux for soldering. If the wire be galvanized it will be necessary to file or scrape off the coating of oxide of zinc."*

If iron wires are too stiff to bend, it is best to make a "Brittannia" joint. This joint is made by slightly bending the ends of the wires to be connected, placing them side by side, with an overlap of about one inch, and then frapping them together with fine iron or copper wire. See Fig. 11.

Three-way joints.

101. Three-way joints are used for connecting up divided circuits. Two of the wires are twisted together as for a two-way joint, and then the end of the third wire is slipped between them and twisted round. (Fig. 12.) The remainder of the joint is made in a similar manner to a two-way joint.

Connecting electrical fuzes to the circuit wires.

102. The joints connecting the fuzes to the short‡ lengths of insulated wire must be made with all the precautions mentioned above. If the fuze is provided with short leads§ the connections are made by a simple two-way joint, or by a three-way joint if two fuzes in divided circuit are to be placed in each charge. But if the fuze has eyelet holes the short lengths of insulated wire are connected direct to the fuze, and in doing this great care must be taken to prevent the possibility of the current passing between the wires instead of through the fuze. The manner of making the joint in this case is as follows:

*Instruction in Military Engineering, Part IV.

†When the joint is to be placed under water it can be further insulated and strengthened by slipping over it, after the tape has been laid on, a short length 3" of india-rubber tubing, the ends of which are then firmly secured with twine. The india-rubber tubing should, of course, be slipped on to one of the wires before commencing the joint. This india-rubber tubing is an article of store for Submarine mining.

‡See § 45.

§See § 37.

"The eyelet holes or tubes should first be carefully rimed out with a small nail or bradawl so as to make sure of a good metallic contact. The wires should then be bared to a length of about 1¾ inches and inserted through the tubes, (one through each tube) in opposite directions, the ends projecting about three-quarters of an inch. These ends should then be bent round their own standing part just below the insulation; the line wires should then be brought together, and the head of the fuze together with the line wires should be frapped round rather tightly with india-rubber tape, commencing from the lowest part of the fuze head and extending to at least an inch above the insulated part of the wires.* If the india-rubber tape is not at hand common tape dipped in tar will answer. See Fig. 13.

"It is not necessary to insulate the head of the fuze in this way in hasty demolitions where the priming disc is not actually inserted into the charge, and is not liable to be wetted."†

LAYING THE CIRCUIT WIRES.

103. Those parts of the circuit wires which are to be in the open are laid along the ground if the wire is insulated, the wires being placed about a yard apart; but if the wires are bare they are attached to poles, as mentioned in § 94.

To lay out the cable it will be found convenient to have it rolled on a drum fitted to a wheelbarrow or truck.

In galleries the wires should be looped to a light line to prevent any strain coming on them, and they are then fastened to the top of the gallery frames to prevent injury from trucks, etc.

The line wires should not be left connected to a roll of insulated wire, for atmospheric disturbances might cause an induced current‡ capable of firing the fuzes.

FIRING THE CHARGE.

Firing Keys.

104. It has already been mentioned that the Quantity Dynamo is provided with a firing key, and that the Tension Dynamo has an automatic firing arrangement.

105. A firing key is used in connection with Voltaic batteries, which admits of the charge being exploded at any given instant and allows of a firm contact being obtained. This firing key consists of a brass spring, to which is soldered a platinum point, and which is connected to a binding screw. The base of the instru-

*Great care should be taken to prevent the line wires touching, except where insulated.

†Instruction in Military Engineering, Part IV.

‡See § 886 Ganot's Physics, 9th Edition.

ment is made of ebonite, and a second platinum point is attached to this base and is connected to a second binding screw. When these platinum points come into contact the two binding screws are *electrically* connected, and to prevent this occurring prematurely an ebonite catch is provided which, when in position, prevents the brass spring being depressed.*

FIRING.

106. If the charge is to be exploded by means of a *Voltaic battery*, the return wire is connected to the negative pole of the battery *on the order to prepare to fire*. The line wire is then connected to one binding screw of the key, the safety catch being in position, after which the other binding screw is connected by a short lead to the positive pole of the battery.

On the word "*Fire*" being given, the safety catch is released and the key sharply and firmly depressed.

107. When the charge is to be fired by a *dynamo* the circuit wires are connected to the binding screws, *on the order to prepare to fire*, and the handle is placed in position.

On the word "*Fire*" the machine is worked as explained in § 88 or § 90.

EXAMPLES.

1. A makeshift wire fuze has an iridio-platinum wire bridge .00144″ diameter, and .3″ long. Calculate the resistance of the bridge at the fusing point.

2. The L.L.R. of a common mine is 18 feet. Calculate the charge. Within what radius from the charge would a gallery belonging to the enemy be destroyed, supposing it to be on the same level as the charge?

3. The L.L.R. of a mine is 15 feet. It is required to produce a radius of rupture of 50 feet. Find the necessary charge.

4. Find the dimensions of the chamber for a common mine to contain 500 lbs. of powder. The ground sill of the gallery, at the point where the charge is placed, is 17 feet below the surface. Find the position of the chamber relatively to the gallery.

5. It is wished to form a lodgment 50 yards long and about 10 yards wide. The gallery, in which the mines are to be placed, is 15 feet under ground. Ascertain the number of charges required and calculate their weight.

*A representation of this Firing Key is given in Figs. 3 and 4, Pl. IX, Instruction in Military Engineering, Part IV.

6. It is decided to fire a charge of 3,000 lbs. of gunpowder to destroy a counter-mine estimated to be 20 feet below the surface. At what distance from the counter-mine should the charge be lodged, so as just to destroy the counter-mine, the attack gallery being 16 feet below the surface?

7. A charge is placed at a point 16 feet below the surface, which is estimated to be on the same level and 60 feet from a defence gallery. Calculate the charge so that the defence gallery may just be ruptured. What charge would be required if the defence gallery were 24 feet below the surface?

8. It is wished to demolish 20 yards of a Pasley's counter-sloping escarp revetment, without counter-forts, 25 feet high, by means of gunpowder. Arrange the charges and calculate their weight. Supposing that the mines are to be fired by electricity, show how to arrange the circuit wires.

9. A charge of 8 ozs. of guncotton will cut through an iron rail weighing 60 lbs. to the yard. Find the charge for a 40 lbs. rail.

10. A rolled beam 12″ deep, and having flanges 6″ wide and .9″ mean thickness, is to be cut through with guncotton. Calculate the amount of the charge required to cut through the lower flange.

11. A plate girder has a lower boom composed, at the centre, of two rivetted wrought iron plates 8″ wide and each $\frac{1}{2}$″ thick. The boom is connected to the web by angle irons $3\frac{3}{4}'' \times 3\frac{3}{4}'' \times \frac{1}{2}''$. Calculate the charge required to cut through the boom.

12. The lower chord of an iron bridge, 210 feet span, is formed of linked plates, the top chord consists of a cast-iron tube.* Select the best place for a guncotton charge and calculate the amount necessary.

13. The lower chord of a Howe truss consists of a beam of fir 12″×8″. Calculate the charge of dynamite required to demolish the truss, *(a)*, when placed in an auger hole, *(b)*, when placed as a necklace.

14. It is intended to cut through a log of timber, 14″×12″ in section, by means of dynamite placed in an auger hole. Find the necessary charge.

15. A fir tree is 1′6″ in diameter. Find the quantity of guncotton required to cut down the tree when placed as a necklace. Compare the expense of this arrangement with that of placing the charge in an auger hole.

*The dimensions, etc., of such a bridge will be found in the Phœnixville Album Plates, 4 and 5.

16. A fir tree is 3 feet in diameter, and is to be cut down by means of guncotton placed in auger holes. Arrange the charge and calculate its amount.

17. A stockade constructed of timbers 12″ square is to be breached by means of guncotton. The breach is to be 8 feet wide. Calculate the charge required, and show how to arrange it with the Land Service sizes of guncotton.

18. Find the charge of guncotton required to breach an iron rail stockade made of rails 65 lbs. to the yard. The breach to be 6 feet wide. Arrange the charge, using the Land Service sizes of guncotton.

19. A palisade is made of cedar posts 6″ diameter, placed 4″ apart in the clear. Estimate the charge of guncotton to make a breach 10 feet wide, and arrange it, using the Land Service sizes of guncotton.

20. It is decided to demolish a stone wall 2 feet thick and 50 yards long by means of a series of guncotton charges each weighing 2 lbs. Find the distance apart of the charges, and the total weight of explosives required.

21. It is required to make a breach 8 feet wide in a brick wall 1′ 6″ thick, and 8 feet high, by means of a charge of dynamite placed against the foot of the wall. Find the weight of explosive required.

22. The plan of a house is a rectangle. The house has 27 feet frontage, and is 32 feet deep. In front there are two windows and a hall door, and at the back three windows. The walls are of brick, 1′6″ thick. Find the number and weights of the charges of gunpowder required to demolish the house.

23. A bore hole $1\frac{1}{2}''$ diameter is jumped in limestone so as to give an L.L.R. of 3 feet. How many inches of gunpowder should be put in to blast the rock? What would be the guncotton charge?

24. The piers of a bridge are built of granite ashlar, and the dimensions on plan are 20′0″ × 10′0″. Find the charge of gunpowder required to demolish each pier. The chamber and the gallery leading to it are to be formed by blasting with guncotton. Estimate the weight of guncotton required for this purpose.

25. A brick arch 3 feet thick carries a road 20 feet wide, and is to be demolished hastily by means of a guncotton charge placed under the crown of the arch. Show how the charge should be arranged, and calculate its amount.

26. A segmental brick arch 24 feet span carries a road 30 feet wide. The angle of the segment is 120°, and the thickness of the arch ring is 2′6″. Charges of gunpowder are to be placed behind one of the haunches in order to demolish the arch. Arrange these charges and calculate their weight.

27. A common mine whose L. L. R. is 16 feet is to be fired by Bickford's instantaneous fuze, to which is connected a short length of Bickford's fuze. The length of the gallery from the bottom of the shaft to the charge is 80 feet, and the height of the shaft 12 feet. Find the length required of both kinds of fuze.

28. Three wire fuzes are to be fired simultaneously, Would it be a good arrangement to connect two of the fuzes in divided circuit, and the other in continuous circuit with them ?

CHAPTER IV.

TESTING.

108. In order to guard as far as possible against failure, the whole of the stores and apparatus employed when using explosives should be examined and tested as carefully as time and circumstances will permit. This can only be carried out to a very limited extent when the charge is fired by means of slow or instantaneous leader; but when firing by electricity, and using wire fuzes, the condition of the circuit can be ascertained at any time up to the moment of firing.

109. The various electrical tests required for Land operations can be performed with the apparatus contained in the "Field Service Jointing and Testing box," namely:

1 Box of resistance coils with thermo-galvanometer attached. § 167.

1 Three-coil galvanometer. § 170.

1 Test cell. § 163.

1 Reel of iridio-platinum wire .0014″ diam.

A description of these instruments will be found in the § stated against them.

The examination and testing required under various circumstances will now be considered.

EXPLOSIVES.

GUNPOWDER.

110. There does not appear to be any ready method of determining the strength of gunpowder, unless provided with the proper apparatus, such as used at Waltham Abbey,* but the following tests can be applied in the Field to ascertain—

(1) "*If the powder have a proper colour, a proper amount of glaze, a sufficiently hard and crisp texture,* and if it be *free from dust.*—These points can be judged by the hand and eye alone; and re-

*These methods of testing gunpowder are considered in the Artillery course.

quire a certain amount of experience in the examiner. The cleanness of the powder can be easily tested, by pouring a quantity from a bowl, held two or three feet above the barrel, in a good light. If there be any loose dust, it will be readily detected.

(2) " *If it be properly incorporated.*—This is tested by "flashing;" that is, burning a small quantity on a glass, porcelain, or copper plate. The powder is put in a small copper cylinder, like a large thimble, which is then inverted on the flashing plate. This provides for the particles of powder being arranged in pretty nearly the same way each time, which is very important. If the powder has been thoroughly incorporated, it will "flash," or puff off when touched with a hot iron, with but few "lights" or sparks, and leaving only some smoke marks on the plate. A badly incorporated powder will give rise to a quantity of sparks, and also leave specks of un-decomposed saltpetre and sulphur forming a dirty residue. Although a very badly worked powder could be at once detected, yet, as a *comparative* test, "flashing" needs an experienced eye to form an accurate judgment. Powder once injured by damp will flash very badly, no matter how carefully it may have been incorporated. This arises from a partial solution of the saltpetre.

(3) " *Size, shape, and proportion of the grains.*—Shape can be judged by the eye alone, and the *size* of grain, in large *uniform* powders "*cut*" by machinery, is usually tested in the same way, or by actual measurement ; but a *granulated* powder can usually be readily sifted on the two sieves which define its highest and lowest limit of size ; it must all pass the one and be retained on the other."*

GUNCOTTON.

111. Guncotton is tested at Waltham Abbey for free acid and soluble guncotton, but the operations are of too delicate a nature to be performed in the Field. The test for dryness has already been described.†

The strength of the Service guncotton can be relied on.

DYNAMITE.

112. The strength of dynamite can be roughly ascertained by detonating a known weight of it against wood or preferably iron, and comparing the effect with the effect good dynamite is known to produce.‡

*Notes on gunpowder and guncotton by Major Wardell, R.A.

†See § 15.

‡See Table I.

TESTING WHEN FIRING BY MEANS OF SLOW OR INSTANTANEOUS LEADER.

113. The condition of guncotton detonators for use with Bickford's fuze, and of dynamite caps, can only be ascertained by firing one or two of them.

114. The quality of Bickford's fuze, Ord's hose and Bickford's instantaneous fuze can be ascertained by inspection, and the rate of burning by cutting off a certain length and finding the time it takes to burn, by measurement in the case of slow leader, and by estimation in the case of instantaneous leader.

TESTING WHEN FIRING BY MEANS OF ELECTRICITY.

115. One of the advantages of firing charges by means of electricity is the possibility of ascertaining the electrical condition of the apparatus, etc., employed, because the chances of failure are greatly reduced thereby, although, as already remarked, the necessary testing can only be done imperfectly in the Field. This testing is carried out as follows:

TESTING ELECTRICAL FUZES.

116. These fuzes admit of testing, as regards some of their electrical qualities, without firing, but their other capabilities can only be ascertained by firing.

Wire fuzes.

117. Wire fuzes may fail owing to any of the following defects:

1. Bad connection of the permanent leads, or of the copper tubes, to the fine copper wires.

2. Metallic contact in the fuze.

3. Employment of too fine or too coarse iridio-platinum wire in the manufacture.

4. A disconnection.

The first two defects can be ascertained by a test for resistance.* The first defect increases and the second decreases the resistance. An accurate test for this resistance can be made as explained in § 197, and any fuze whose resistance differs in excess or defect more than 10 p.c. from the normal resistance should be rejected (see Table I). But the apparatus available in the Field does not allow of a sufficiently accurate measure of the resistance being made, and all that can be done is a rough test made as explained in § 211, which only *indicates* the first defect, but cannot detect the second.

*See § 128.

The third defect can only be detected by measuring the current required to fire the fuze (see § 243), and for important work it is advisable to try a few fuzes from every box for "firing current."

The fourth defect can be found without difficulty, for no current can pass through the fuze, and this can be ascertained by means of a galvanometer. See § 247.

In selecting fuzes, which are to be exploded simultaneously, they should, if possible, be taken from the same cylinder, as being more likely to be uniform.

High Tension fuzes.

118. These fuzes are liable to the following defects:

1. Bad connection of the permanent leads, or of the copper tubes, to the fine copper wires.

2. Metallic contact in the fuze.

3. Chemical composition deteriorated.

4. A disconnection.

The first, second and fourth defects can be detected in the same way as the corresponding defects of wire fuzes, but not with any great certainty, because the electrical resistance of the composition is high and is liable to vary. The second defect would be indicated by a low resistance, but a high resistance might be due either to the first or third defect. It should be observed that the first defect is not of the same importance in these fuzes as in wire fuzes, owing to the high potential of the current. A high resistance generally indicates a deterioration of the fuze composition, but certainty in this respect can only be arrived at by firing.

In the Field it is only possible to obtain a rough approximation to the resistance of these fuzes (see § 210), and to determine it accurately recourse must be had to the method explained in §§ 197, 198, and 204.

A resistance of from 1,500 to 2,000 ohms* may be considered satisfactory.

Fuzes of recent manufacture should be chosen, if a large number are to be fired simultaneously, and those whose resistance is very high should be rejected.

TESTING FIRING APPARATUS.

BATTERIES.

119. The methods of testing a battery of voltaic cells to ascertain

*See Table I.

if it is powerful enough to do the work that may be required of it, are explained in §§ 244, 245, and 246.

Calculation of Battery power.

120. The number of cells required to fire a given number of fuzes can be found by calculation by means of Ohm's law.* This law asserts that—

$$C=\frac{nP}{r+n\rho}$$

where C is current, P the electro-motive force, r the external resistance in the circuit, ρ the liquid resistance in *each* cell, and n the number of cells, so that if C, P, r and ρ are known, n can be found.

If there is only one fuze in circuit, C is taken as the current required to *fire* the fuze. But if two or more fuzes are in circuit, the current must be sufficiently powerful to *fuse* the iridio-platinum wire of each fuze,† and the value to be taken for C, in each case, will depend on the fuzes employed and on the arrangement of the circuit. Thus if the fuzes are in continuous circuit, C will be the current required to fuse one platinum wire, but if the arrangement is "continuous circuit with divided fuzes" the current must be capable of fusing two platinum wires, and so on. The current required by the Service fuzes has been found by experiment, and is given in Table I, but when using unknown or makeshift fuzes, the strength of the fusing current must be determined as explained in § § 242 and 243.

The electro-motive force P, of the Service cells, is given in Table I, but when working with unknown cells it can be found as explained in §§ 234 and 235.

The liquid resistance of the cells in use in the Service is also given in Table I, but if not known it can be found as explained in § 221.

r can be estimated as follows: First, supposing the fuzes to be in continuous circuit, then the resistance will be made up of the resistance of the fuzes (at the point of fusion) together with that of the line wire, of the connections between the fuzes and of the return wire. Thus, if f is the number of fuzes, r_1 the resistance of each fuze (at the point of fusion), l the total length of line wire, connections, and return wire (say in yards,) and r_2 the resistance of this wire per yard, then

$$r=fr_1+lr_2$$

But if the arrangement is "continuous circuit with divided fuzes,"

*See § 145.

†This has been ascertained by experiment.

the resistance of the fuzes will be halved, but that of the circuit remains the same. Hence, in this case

$$r=\frac{fr_1}{2}+lr_2$$

The resistance in other and more complicated cases can be found similarly, and a general formula could be established to meet all cases, but it would not be of much practical use.

In all cases, directly the circuit is connected up, the resistance can be measured as explained in § 199.

The values of C, P, r and ρ having thus been determined, the number of cells can be calculated, and it is usual to add 50 p.c. to make up for defective joints, leaks, etc.

Examples.

121. 1st Example.—Two gunpowder mines with single fuzes are placed in continuous circuit. Find the battery power required under the following conditions:

Circuit wires of Service cable.
Line wire, length, 200 yards.
Connections, " 40 "
Return wire, " 180 "
Fuzes: No. 14 Low tension Land Service.
Cells: Leclanché.

It will be found on reference to Table I that:

$C=0.8$ weber, $P=1.45$ volt, $\rho=0.15$ ohm, $r_1=2.6$ ohms, $r_2=0.006$ ohm per yard.

Hence—

$$r=2\times 2.6+(200+40+180)\ 0.006=7.72 \text{ ohms.}$$

And by Ohm's Law—

$$0.8=\frac{1.45\,n}{7.72+0.15n}$$

Or

$$n=4.7.$$

The number of cells used would therefore be 7.

2nd Example. The same two mines but arranged in divided circuit. Length of wire from battery to point where current divides, 160 yards; and the same distance from the point where current re-unites back to the battery. Length of each lead in divided part of circuit, 40 yards. Cells and fuzes as before. Find the battery power required.

The resistance from the point of division to the point of re-uniting of circuit through one of the mines is $40\times 0.006+2.6=2.84$ ohms. And the resistance in both circuits between the same points is clearly:

$$\frac{2.84}{2}=1.42 \text{ ohms.}$$

Hence $r=1.42+2\times 160\times 0.006=3.34$ ohms.
Thus

$$2\times 0.8=\frac{1.45n}{3.34+0.15n}$$

Or $n=4.4$.
And 7 cells would be used.

3rd Example. Same arrangement as in the second example, but using Military Grove cells instead of Leclanché cells.

The resistance of the circuit wires will not be altered, but different values must be given to P and to ρ, namely:

$$P=1.956 \text{ volts}, \ \rho=0.08 \text{ ohm.}$$

Therefore,

$$2\times 0.08=\frac{1.956\ n}{3.34+0.8\ n}$$

And $n=2.9$.
4 cells would therefore be used.

QUANTITY DYNAMO.

122. This machine is tested by fusion of wire in the same way as a battery.

TENSION DYNAMO.

123. This instrument is tested by measuring the length of the spark it produces, and, as already mentioned, it is provided with a spark measurer. The test is carried out as follows:

The micrometer screw is set to zero, and the two platinum points are then made to touch by screwing up the lower adjustment screw. The two points should only just touch, and this can be ascertained by passing a current from a test cell through the measurer, with a galvanometer in circuit, the needle will be deflected the instant the points touch. The micrometer head is then unscrewed to $\frac{50}{5000}''$ and the spark is passed by working the machine,* the interval between the points is then gradually increased until the spark only just passes. If the instrument is in good order a spark $\frac{200}{5000}''$ long should be obtained.

CIRCUIT.

124. The circuit wires should be tested both before and after connecting up, in the following manner:

TESTING CIRCUIT WIRES.

125. The circuit wires should always be tested for *continuity* and sometimes also for *insulation*. These tests are performed as explained in §§ 247, 210 and 212.

If it is found that there is a disconnection in the wire, the next operation is to localize the fault, and this can be done as explained in § 248.

*See § 90.

If the insulation is defective the place or places where the leak occurs must be found. Frequently this can be done by simple inspection, but otherwise a test should be made as explained in § 213.

With wire fuzes the continuity test is the most important, because the insulation resistance can be neglected if it is not less than 1000 ohms, as will be seen by the following example: Let the resistance of a circuit be 10 ohms, and the insulation resistance 1000 ohms, and, for simplicity, suppose that there is only one leak; then if C is the total current, the part flowing along the conductor beyond the leak will be*

$$\frac{1000}{1000+10}C = .99\,C$$

so that the loss can be neglected.

But when high tension fuzes are used the insulation test is the most important, because, in the first place, the spark will jump across the interval (if not too great) between the two ends of the wire where there is a disconnection. Secondly, on account of the high resistance of the circuit, the loss by leakage would be considerable, if the insulation were at all defective, as will appear by the following example: Let the resistance of the circuit be 20,000 ohms (about 10 tension fuzes), and suppose the insulation resistance to be 40,000 ohms; then the portion of the current passing through the fuzes is

$$\frac{40,000}{40,000+20,000}C = \tfrac{2}{3}C$$

where C is the total current, so that one-third of the current is lost.

TESTING COMPLETE CIRCUIT.

126. The complete circuit can only be tested in the Field when wire fuzes are used, because the means available are not sufficient to measure the high resistance in circuit when high tension fuzes are employed. The method of testing the complete circuit is explained in § 199.

The measurement of the resistance of the circuit should be made as soon as the circuit is completed, and in those cases where galleries have to be tamped the test should be made at intervals whilst the tamping is going on, so as to at once detect any injury to the circuit wires.

If there is no apparatus at hand for *measuring* the resistance of the circuit, a test for "continuity" should, if possible, be made. (See § 247.)

*See "theory of divided circuits," § 147.

EXAMPLES.

1. Find the number of Leclanché cells required to fire one No. 14 fuze, the length of Service cable in circuit being 500 yards.

2. Find the number of Leclanché cells required to fire two No. 14 fuzes, arranged in divided circuit, through 500 yards of Service cable.

3. Find the number of Leclanché cells required to fire two No. 12 detonators, arranged in continuous circuit, through 500 yards of Service cable.

4. Find the number of Grove cells required to fire two No. 12 detonators, arranged in continuous circuit, through 500 yards of Service cable.

5. How many cells, whose electro-motive force is 1 volt, and whose liquid resistance is 1 ohm, would be required to fire one No. 14 fuze through 500 yards of Service cable? If the liquid resistance were increased to 3.1 ohms, how many cells would be necessary?

6. Show that 36 commercial pattern* Leclanché cells can be so arranged as to fire two No. 13 detonators, connected in divided circuit, through 200 yards of Service cable. (Electro-motive force 1.45 volt, liquid resistance 2 ohms.)

7. Three gunpowder mines are to be fired simultaneously. The primers are prepared with divided fuzes, and the length of circuit wires is as follows:

Line wire 200 yards; from No. 1 mine to No. 2 mine 30 yards; from No. 2 mine to No. 3 mine 40 yards; return wire 190 yards. The line wire consists of Service cable, the connections between the mines of No. 16, B.W.G. insulated copper wire, and the return wire of No. 13, B.W.G. bare iron wire. Find the battery power required, using Leclanché firing cells.

8. Ten guncotton charges are to be fired, simultaneously. Each charge contains two No. 13 detonators, connected in divided circuit, and the charges themselves are arranged in two sets of five each, each set being connected in continuous circuit. The line and return wire are together equal to 300 yards, and each branch is 10 yards long; the former consists of Service cable and the latter of No. 16, B.W.G. insulated copper wire. Find the battery power required, using Grove cells.

9. The fusing current of some makeshift wire fuzes was found by experiment to be 4.5 webers and their resistance, at the point of fusion, to be 0.17 ohm. Two gunpowder mines are to be fired by means of these fuzes; each mine contains two fuzes in divided

*See § 803, Ganot's Physics, 9th Edition.

circuit, and the mines themselves are arranged in continuous circuit. The line and return wires each consist of 20 yards of No. 18, B.W.G. copper wire, insulated with tarred tape, to which is connected 180 yards of No. 9, B.W.G. bare iron wire. The connection between the mines is 35 yards long, and is made with No. 18, B.W.G. copper wire, insulated with tarred tape. Find the battery power required, using Leclanché firing cells.

10. Show the effect of connecting a Leclanché test cell to a firing battery of 10 Leclanché cells.

11. Six mines are connected in combined continuous and divided circuit, three mines being placed in each continuous circuit. The resistance of the circuit is measured, and is found to be 4 ohms.* It is also found that 10 of the firing cells will just fuze the standard .0014″ iridio-platinum wire through 14 ohms (*not* including the resistance of the wire itself.) Calculate the number of cells required to fire the mines, supposing the liquid resistance of each cell to be .15 ohm.

12. Two guncotton charges are to be fired by electricity; they are connected in continuous circuit with divided fuzes. The *measured* resistance is found to be 3 ohms. How many Grove cells would be required to fire the charges.*

13. A defective Service cable is laid in position, and it is then found that the insulation resistance is only 100 ohms. A bare return wire of No. 14, B.W.G. iron wire laid on the ground, has to be used. Find the battery required, using Leclanché firing cells, to fire one No. 13 detonator, the length of line wire and of return wire being each 200 yards. Find also the battery power required to fire 6 No. 13 detonators in continuous circuit, neglecting the connections between the detonators. How many cells would be required in both the above cases if the return wire were insulated?

14. Given that a certain quantity dynamo can fuze the standard .0014″ iridio-platinum wire through 54 ohms, and that the internal resistance of the machine is 13.4 ohms, find the number of No. 12 detonators, and also of No. 14 fuzes, the machine could be relied on to fire through 300 yards of Service cable.

15. With the same data as in example 14, find the number of No. 12 detonators and No. 14 fuzes, arranged in pairs divided, that could be fired by the machine through 300 yards of Service cable.

16. A tension dynamo is tested, and it is found that the spark is only $\frac{150}{5000}$″ long. How many No. 5 detonators, connected in continuous circuit, would this machine probably fire?

*In this case, provided the cells are perfect, it is not necessary to add 50 p.c. to the calculated number of cells since the *actual* resistance in circuit is known. The resistance thus measured includes that of the fuzes when cold, and this resistance is increased at the point of fusion.

PRECAUTIONS.

TO BE TAKEN WHEN USING EXPLOSIVES.*

EXPLOSIVES.

GUNPOWDER.

1. Examine the gunpowder, and if its quality and strength is unknown, test it as far as time and means will admit. § 110.

2. Powder barrels are to be opened with a mallet and a copper drift, or else a wooden drift, but never with a hammer or an iron drift.

3. Only one barrel is to be open at the same time.

4. All tools (scoops, scales, etc.,) should be made of copper.

5. The charges should be made up outside the magazine, and if possible on a skin or mat.

6. The men working should take off their boots.

7. No *naked* lights to be allowed near the powder.

8. Care should be taken not to spill any powder.

9. Sentries to be posted to prevent any one approaching with a naked light or smoking.

GUNCOTTON.

1. Dry guncotton should be stored in a spark-proof air-tight box labelled "dry." § 29.

2. Wet guncotton should be inspected periodically to see that it contains the proper percentage of water. § 15.

3. Ascertain that the guncotton used for *primers* is perfectly dry. § 15, (6.)

4. When carrying guncotton made up in charges, it should be protected with a spark-proof covering.

*These precautions are principally abstracted from the preceding part of the book. Reference has been made to the corresponding paragraphs.

DYNAMITE.

1. If dynamite is frozen the cartridges must not be separated until thawed. § 19.

2. The thawing of frozen dynamite must be done with great care. § 19.

3. When using dynamite in cold weather place it in a receptacle surrounded by hot water.

4. Dynamite must be handled with the same care as dry guncotton or gunpowder.

5. If the quality of the dynamite is unknown, test it, if possible. § 112.

PREPARATION OF FUZES.

General.

1. See that the proper fuzes are selected.

For gunpowder the fuze contains mealed powder. § 31.

For guncotton, detonators must be used; they have a shank painted red containing mercuric fulminate. § 31, Table I.

The bodies of wire fuzes are painted white; those of tension fuzes black, Table I.

Wire fuzes should be taken from a box whose markings show that the wire of the fuzes is the same as that on which the calculations were based. § 120.

2. Examine the fuzes and test them, if possible. §§ 117 and 118.

When testing electrical fuzes use a test cell whose liquid resistance is *not less than* 12 *ohms*. § 163.

Electrical detonators must be placed in a strong box, whilst being tested, in case of accidental explosion.

3. Secure the fuze to the leader, or to the circuit wires, in such a manner as to prevent any chance of separation.

The thin brass tube of the Bickford detonators for guncotton is slightly bent, and the mouth of dynamite caps is gently pinched with a pair of pliers, after the leader has been introduced. Great care must be taken not to disturb in any way the mercuric fulminate.

ELECTRICAL FUZES.

1. See that the joints between the fuze and the circuit wires are good (i.e., wires and eyelets scraped and brightened, a firm contact obtained and the insulation good.) When using wire fuzes look especially to the contact; when using high tension fuzes to the insulation. § 102.

2. See that the fuzes are perfectly dry outside.

3. If the fuze has eyelets, wrap the head with india-rubber tape to more effectually insulate the leading wires from each other. This must always be done when working in water—in damp soil, and when the charge is likely to remain any length of time unfired—otherwise it is not necessary, but it is better to do so if time permits. § 102.

4. It is better to place two fuzes, connected in divided circuit, in each charge. This should always be done, if possible, when using guncotton. § 45.

PREPARATION OF CHARGES.

General.

1. The charge should not be made up sooner than necessary.

2. Take great care that there is no chance of the fuze or fuzes being withdrawn.

3. Never apply solder to any wires near the charge, unless the charge is well covered with some fire proof substance.

GUNPOWDER CHARGES.

Primer.

1. Use a tarred sand-bag if the ground is damp, or an india-rubber bag, hermetically closed, if the ground is wet. § 47.

2. Place the fuze or fuzes at about the centre of the primer.

3. Secure the leader, or the circuit wires, in such a manner as to prevent them from being withdrawn from the primer. § 47.

Charge.

4. Place the charge in tarred sand-bags, if the ground is damp, or, if the charge is to remain unfired any length of time; but, if the ground is wet, use india-rubber bags or other water-proof receptacle.* §§ 52—68.

GUNCOTTON CHARGES.

Primer.

1. To prepare the primer, insert the "rectifier" into the detonator holes to its full extent, and then withdraw it by twisting. § 48.

2. Insert the shank of the detonator without twisting or other "force," and see that it fits tightly into the guncotton. § 48.

3. Detonators should be secured to the primer by means of string or wire.

*Blasting rock is an exception.

Primer for wet guncotton.

4. Not less than two lbs. of *perfectly* dry guncotton should be used as a primer for wet guncotton. §§ 14 and 49.

5. Having inserted the detonators, seal the primer up in a water-proof bag, the mouth of which is closed hermetically by means of a clip and india-rubber solution. § 49.

Charge.

6. Insure as close a contact as possible between the primer and the charge; absolute contact is imperative when wet guncotton is employed.

7. See that the continuity is good.

8. If the charge is to be placed under water use a water-proof bag.

DYNAMITE CHARGES.

Primer.

1. Insert the detonator, (the leader or circuit wires being attached) into a hole made in the explosive by means of a smooth piece of wood. § 50.

2. Close the cartridge and frap with wire or string to prevent the detonator being withdrawn.

Charge.

3. Take the same precautions as for guncotton charges.

PREPARATION OF FIRING ARRANGEMENTS.

FIRING BY MEANS OF LEADERS.

1. Examine the leader and ascertain its rate of burning. § 114.

2. When using slow leader use a sufficient length to enable the operator to get to a place of safety.

3. Instantaneous leader should generally be fitted with a short length of slow leader.

4. When the leader is to be ignited, without fail, at any given instant, it should be fitted with quick match. § 71.

5. Carefully secure the leader to the primer to prevent any possibility of separation.

6. Great care must be taken not to injure the leader during the process of loading or tamping. § 52.

FIRING.

1. Use a vesuvian or a port-fire. § 76.

FIRING BY MEANS OF ELECTRICITY.

SOURCES OF ELECTRICITY.

General.

1. See that the connections are bright and clean.

2. Test the firing-apparatus (battery or dynamo) shortly before firing. §§ 119, 122, 123, 244, 245 and 246.

Batteries.

3. Calculate the number of cells required. § 120.

4. Make up the battery with amalgamated zincs. § 82.

5. When using Grove cells do not pour the acids into the cells sooner than necessary. § 82.

7. See that the cells are kept as dry as possible, rejecting leaky ones.

CIRCUIT.

1. Examine and test the cable. §§ 125, 210, 212 and 247.

2. See that all the joints are good. §§ 99—101.

Solder the joints, if the charge is not to be fired for some time.

Insulate any joint that will be placed under ground, using india rubber solution if there is any wet or damp. If the joint is not soldered do not place any india-rubber solution on the wires.

3. Serve exposed portions of the *dielectric* with spun yarn.

4. See that no stress can come on the cable during the process of laying, and also afterwards, and that it is not injured during the process of loading or tamping. § 103.

5. When using wire fuzes test the complete circuit for resistance. §§ 126 and 199.

6. Test for resistance, or continuity, at intervals during the process of tamping. §§ 199 and 247.

In both the above tests a test cell whose liquid resistance is *not less than* 12 *ohms* must be used. § 163.

7. When a number of charges are to be fired in succession by means of the same cable, the cable should be tested for continuity after each discharge. § 247.

8. To be safe from the effects of atmospheric induction, a roll of insulated wire should *not* be connected to a charge except just before firing. § 103.

CAUTION.—The man who attaches wires to a charge is responsible for his own safety. He must see both ends of the wires he connects.

FIRING.

1. The firing apparatus is not to be brought up sooner than necessary.

2. With voltaic batteries—Use a firing key, and see that the safety catch is in place. § 105.

3. With dynamos—Remove the handle. The person in charge of the operations must keep the handle in his own possession.

4. No connections at the firing point are to be made until the order to "Prepare to fire" is given. This order must only be given after all is reported clear. §§ 106, 107.

TABLE I.

EXPLOSIVES.

GUNPOWDER.

Size of grain of various gunpowders—

R.F.G². will pass through a mesh 12 to the inch, but not through a mesh 20 to the inch.
R.L.G· " " 4 " " " 8 "
R.L.G². " " 3 " " " 6 "
P ; cubes ⅝" side.
P₂. ; cubes 1½" side.

Volume—1 lb. of gunpowder occupies about 30 cubic inches. Price per lb., (average) 6 pence not including carriage.

GUNCOTTON.

Dimensions and weights of the principal forms of compressed guncotton in the British Service.

NATURE.	DIMENSIONS IN INCHES.		WEIGHT WHEN DRY.	NO. OF Perforations.	PURPOSE.
	DIAMETER.	LENGTH.			
Discs.	$3\frac{1}{10}$	2	9 ozs.	2*	Submarine mining.
	$1\frac{1}{4}$	2	1 "	1	Blasting.
	$1\frac{1}{4}$	1	1 "	1	
	$1\frac{3}{4}$	1	2 "	1	
Slabs.	$6\frac{1}{8} \times 6\frac{1}{8} \times 1\frac{3}{4}$		$2\frac{1}{2}$ lbs.	4*	Torpedo and Submarine mining,
	$6\frac{1}{8} \times 6\frac{1}{8} \times 1\frac{3}{8}$		2 "	3†	Demolition of stockades, walls, &c
	$6\frac{1}{8} \times 6\frac{1}{8} \times 1$		$1\frac{1}{2}$ "	4†	

In store, guncotton should contain 20 p.c. of water; 15 p.c. will prevent it from burning.

Time required to dry various discs and slabs:—

$1\frac{1}{4}$ inch discs	4 hours.
Other sizes below 3-inch discs...........	6 to 8 "
3-inch discs and parts of slabs...........	12 "
Whole slabs (according to thickness)...	18 to 24 "

*Only a certain number of these discs or slabs are perforated (25 discs per ton), and these are intended for primers.

†A proportion of 2lbs. slabs cut in three and of 1½lb. slabs cut in two are supplied with the R.E. Field company equipment.

Price per lb. (average) 2s., not including transport.

DYNAMITE.

Dimensions and weights of various cartridges :—

Length, 6¼ inches.

Diameter, 1 to 1½ inches.

Weight, 3 to 5 ozs.

CONSTRUCTION OF MAGAZINES.

GUNPOWDER MAGAZINES.

Gunpowder in bulk is stored in barrels or metal-lined cases.

Metal-lined wood cases for ammunition.

——		*Weight.* lbs.	ozs.	*External Dimensions over Case.* in.	*Remarks.*
Whole common	Empty ..	45	0		
	Filled ..	varies.		16·75 ×	With filled cannon cartridges.
	" ..	129	0	16·75 ×	With 330 fuzes, mortar large.
	" ..	133	0	20·62	With 1,000 fuzes, mortar, small
	" ..	70	0		With 26lbs. of quick match.
Half common	Empty ..	27	0	13·44 ×	With filled cannon cartridges.
	Filled ..	varies.		13·44 ×	With 1,200 fuzes, hand grenade.
	" ..	57	8	16·75	
Quarter common	Empty ..	16	8	10·25 ×	With filled cannon cartridges.
	Filled ..	varies.		10·25 ×	With 125 fuzes, time, Armstrong.
	" ..	79	0	13·88	

Barrels used for ammunition.

——		*Weight.* lbs.	ozs.	*Dimensions.* *Diameter.* *End.* in.	*Middle.* in.	*Height* in.	*Remarks.*
Ammunition, Gun.	Whole..	31	0	15·3	17·3	21·	For filled cannon cartridges *in dry magazines* or for occasional transport.
	Half....	19	0	11·9	13·4	16·9	Do., seldom used.
Budge, Mark I.........		10	0	10·2	11·6	14·2	For loose powder for mortars.
Cartridge, small-arm.	Half....	12	0	11·9	13·4	16·9	To contain respectively 2,240 and 1,300 cartridges, blank, Boxer, for Snider rifles, ·577″ bore, Mark II.
	Quarter	7	12	10·2	11·6	14·2	
Powder	Whole..	30	0	15·	17·	21·	To contain respectively 100 50, and 25 lbs. of loose powder, R.L.G. or L.G.
	Half....	18	0	11·9	13·4	16·9	
	Quarter	11	8	10·2	11·6	14·2	
	Eighth	5	10½	7·1	8·5	11·5	For conveyance of small quantities of loose powder.

Racks.—The dimensions of the timbers used in the racks depend on the arrangement of the barrels, and are to be obtained by calculation. Barrels should not be piled in more than 5 tiers without support, and can be stacked to within 2 feet of the roof.

Passages.—Longitudinal passages 4 feet wide; side passages 2 feet wide; in any case 6″ must be left between wall and ends of barrels. In large magazines transverse passages, about 4 feet wide, are useful.

WALLS.

Height—From 6 to 10 feet.

Thickness—Walls acting as abutments to the arch of the roof must be designed to resist the thrust. Minimum thickness 2 feet.

Walls exposed to Artillery fire; thickness of protection (earth, concrete or masonry alone or combined) 1½ times the depth* to which the heaviest shell the wall is likely to be exposed to will take effect, when fired with delayed action percussion fuzes.

Walls of store magazines, 5 feet thick, to minimize the effect of an accidental explosion.

Brick lining.—4½″ thick when attached to outer wall, 9″ when detached.

Damp-proof course of asphalte on floor level, ½″ thick.

ROOFS.

Magazines exposed to Artillery fire.

Thickness of arch ring when carrying earth and concrete covering:

Span, in feet		10	12	14	16	18	20	22	24
Thickness for block-stone arches	Segmental 120°.	1 2 ″	1′4″	1′5″	1′6″	1′7½″	1′9″	1′10½″	2′0″
	semi-circular	1 1½	1 3	1 4	1 5	1 6	1 7	1 8	1 9

Brick arches are made as nearly as possible of the same thickness as the above. Rubble stone arches should be made about one-fourth thicker.†

Protection against damp.—If an inner arch is built there should be a clear space of 3″ between the two arches, and they should not be bonded together. The inner arch should be capable of standing unloaded.

Roofcovering.—Concrete over arch, 1 foot thick, nearly filling the spandrils, and forming a valley for drainage. Asphalte over concrete ¾″ thick. Earth covering, 1½ times the depth* to which the heaviest shell to which the roof is likely to be exposed will take

*See Table A, Guide to the Course of Military Engineering.

†Extracted from a table given in "Instruction in Construction," by Col. Wray, R. E.

effect when fired with delayed action percussion fuzes. If this thickness cannot be obtained, then for every foot of earth in defect add 3″ to the concrete over arch or to the arch ring itself. The concrete is supposed to be made with Portland cement; 1 cement to 7 shingle and sand.

Magazines not exposed to Artillery fire.

The arch must be designed to support the following loads: (1) weight of arch itself, distributed, (2) weight of ordinary roof over arch, of snow lying on this roof, and the wind pressure, concentrated at the points of contact.

Roof covering.—Slates, tiles, or metal.

FLOORS.

Thickness of concrete 9″ to 1′ 0″.

Thickness of asphalte $\frac{3}{4}$″. (Joined to the damp-proof course in the walls so as to form a continuous damp-proof surface.)

Oak plates 4″ × 1″. Battens 3″ × 1$\frac{7}{8}$″, $\frac{3}{8}$″ apart, and secured to the oak plates with brass screws.

VENTILATION.

Outlet shafts.—The total effective area should allow 1 sq. inch to 100 cubic feet of interior space, if the magazine is above ground; and 1 sq. inch to 60 cubic feet, if the magazine is under ground. In large magazines the air can be taken at two or three points, and then led to one up-take shaft.

Inlets, about 9″ × 3″ in section, should be placed about 10 feet apart, and their total effective area should be at least equal to that of the outlets. In magazines above ground the inlets establish communication with the outside air, and in underground magazines with a passage surrounding the magazine.

Inlets and outlets should be provided with shutters or louvres, so as to allow of their being entirely closed or opened to any desired extent in any weather.

The air-space in hollow walls should also be ventilated.

LIGHTNING CONDUCTORS.*

Lightning conductors should be placed on the highest part of the building, and 50 feet apart, so that no portion of the building is more than 25 feet from a conductor.

Height of rod above the magazine, about 5 feet.

*The following data have been taken from a paper by Captain Bucknill, R.E., Vol. XXV, R.U.S.I.

The rod is best made of iron (galvanized) weighing 6 lbs. per yard, and it is advisable to terminate it with several points.

The *conductor* attached to the rod is best made of galvanized iron wire rope, round or flat, weighing 8lbs. per yard if one conductor is connected to each rod, and 4lbs. per yard if two are used.

Earths.—A conductor should always be led both to a shallow and to a deep earth, the former to provide for wet weather and the latter for dry weather.

Shallow earths are best formed by laying the conductor in a shallow trench, 1 foot deep for clay, and 2 feet deep for sand, gravel or shingle; 25 feet long in ordinary soil, and 50 feet long in very porous soils. This trench is filled with coke and ashes.

Deep earth connections can be made by sinking a well about 3 feet in diameter to a depth of 10 feet below the subsoil water level in the driest season. No mortar or cement to be used for the lining of the bottom 10 feet of the well. The "earth" itself consists of a galvanized cast-iron pipe offering 24 sq. feet of outside surface, and it should be surrounded with lumps of coke.

All *joints* should have an area 6 times the area of the conductors they connect, and should be run in with molten zinc or lead.

All metal surfaces, except those entirely within the magazine, should be connected to the lightning conductors. This can be done by means of a horizontal band.

EARTHEN TRAVERSES BETWEEN STORE MAGAZINES.

Crest, 5 feet above top of roofs.

Thickness at top, about 20 feet.

Top slopes, $\frac{1}{6}$.

Side slopes, $\frac{1}{1}$.

Distance of foot of slope from wall of magazine, about 20 feet.

GUNCOTTON MAGAZINES.

Dimensions of guncotton 50 lbs. boxes: Length, 2′ 4″; height, 1′ 1″; width, 1′ 9″.

Internal dimensions of magazine.

Width, 10 feet; length, depends on the number of boxes to be stored. These boxes can be piled in 5 tiers and in two rows, one on either side of the central passage; 6 feet in excess should be allowed for shifting the boxes at inspections. Height, 7 feet.

Floor; made of concrete, 12″ thick, sloped to the centre of the passage to a drain covered over with perforated tiles, or with an iron grating.

Walls; the building is half-sunk, and earthen traverses, about 3 feet high, are placed against the walls; the walls must be thick enough to resist this earth-thrust.

Roof; ordinary.

A *tank*, holding 10 gallons per ton of guncotton, should be provided, and it should be fitted with a pipe to which a flexible hose can be attached; the bottom of the tank to be flush with the roof.

A small shifting-room should be provided.

FUZES.

*Fuzes for use with slow or instantaneous leader.**

Guncotton detonator.—Empty brass tube 6″ long, diameter, .25″; tapering tin tube 2″ long, smallest diameter .17″. Charge, 20 grains of mercuric fulminate. Painted red all over.

Official name—Detonator No. 8, for Bickford's fuze, Mark II.

Guncotton detonator for instantaneous fuze.—Similar to detonator No. 8, but empty tube shorter and coned; closed with a wooden stopper covered with paper until required for use. Intended principally for Naval Service. Painted red all over.

Official name—Detonator No. 15, for instantaneous fuze, Mark I.

Dynamite cap.—Made of copper, length 1″, diameter ⅛″. Charge about 5 grains of mercuric fulminate.

*Bickford's fuze is included under the head of preparation of firing arrangements.

SERVICE ELECTRICAL FUZES.*

Explosive for which intended.	*Number and pattern.*	*Service.*	*Colour.*	*Whether provided with eyelets or short leads.*	*High or low tension.*	*Wire bridge.*	*Electrical resistance, in ohms.*	*Current to fire or to fuse wire bridge, in webers.*
GUNPOWDER.	No. 1, Mark III	Land ..	Black	Eyelets ...	High ..	—	1,500 to 2,000	—
	No. 14, Mark I	Land ..	White	Short leads	Low ..	Iridio-Platinum .. Diam. 0.0014″ .... Length 0.25″	At 60°F. 1.05 .... At fusing point 2.6 ..	To fire 0.32. To fuse 0.8.
GUNCOTTON.	No. 5, Mark II	Land .	Head—black .. Tube—red	Eyelets	High ..	—	1,500 to 2,000	—
	No. 9, Mark II	Naval ..	Head—yellow. Shoulder—yellow Tube—red	Short leads	Low ..	Silver-platinum .. Diam. 0.0014″ .... Length 0.25″	At 60°F. 1.65 .... At fusing point †	To fire † To fuse †
	No. 12, Mark II	Sub-marine	Head—white .. Shoulder—blue Tube—red	Short leads	Low ..	Iridio-platinum .. Diam. 0.003″ .... Length 0.25″	At 60°F. 0.32.... ... At fusing point 0.74 ..	To fire 0.85 to 0.9 To fuse 1.65
	No. 13, Mark I	Land ..	Head—white .. Shoulder—white Tube—red	Short leads	Low ..	Iridio-platinum .. Diam. 0.0014″ .. Length 0.25″	At 60°F. 1.05 .... At fusing point 2.6....	To fire 0.32 To fuse 0.8

Dimensions { Gunpowder fuzes—Length 1.25″, diam. .7″.
Guncotton detonators—Length over all, about 2.5″, diameter of head, .6″ to .7″.

*This table does not include all the electrical fuzes in the Service.

† This data could not be obtained.

PREPARATION OF CHARGES.

PRIMERS.

Bags.

India-rubber bags for gunpowder primers containing 100lbs. of powder. Body; length 12", width 15" (when empty). Neck; length $5\frac{1}{2}$", width 9".

Leather bags for gunpowder contain 90, 50 or 28 lbs. of powder.

India-rubber bags for dry guncotton primers (for use with wet guncotton); length 14", width $5\frac{1}{4}$" (when empty.)

FORMULÆ AND DATA

For calculating the weight of the charge required for various purposes, arranged in alphabetical order.

ARCHES.

In the following C is the charge in lbs., L the line of least resistance, T the thickness of arch-ring and B its breadth, in feet.

Gunpowder.

Charges placed behind the haunch of the arch at two-lined intervals—

For moderate demolition

$$C=\tfrac{6}{5}L^3.$$

For violent demolition

$$C=\tfrac{8}{5}L^3.$$

These charges to be placed at a distance of $2L$ from side walls and not less than $3L$ from top of road. L should not be less than $1\frac{1}{2}$ feet and not greater than 5 feet. Tamping at least $3L$.

Single charge, or a line of charges, placed in a trench cut over crown of arch to the keystones and covered with the excavated rubbish—

$$C=\tfrac{3}{2}T^2B$$

Guncotton or dynamite.

Charge placed on crown of arch, uncovered—

$$C=\tfrac{3}{4}T^2B$$

placed in a trench and covered—

$$C=\tfrac{3}{8}T^2B$$

BLASTING ROCK.

Gunpowder.

$$c=aL^3$$

where c is the charge in ozs., and a is a constant, depending on the nature of the rock. For rock of ordinary tenacity $a=\frac{1}{2}$. Experiments should be made to determine the value of a if the blasting operations are to be of any extent. L is the line of least resistance in feet.

Tamping, not less than $1\frac{1}{2}L$.

Guncotton or dynamite.

Charge placed in a bore hole and the hole filled with sand or powdered brick.

$$c=bL^3.$$

For soft slaty rock $b=\frac{1}{5}$; for hard granite $b=\frac{1}{8}$.

A 9-oz. disc of dry guncotton, placed on a hard boulder 3 feet in diameter, will generally shiver it.

BLOWING DOWN HOUSES.

Gunpowder.

Charges placed in angles of building, or against walls at two-lined intervals, and tamped.

$$C=\frac{4}{10}T^3$$

where C is charge in ℔s. and T thickness in feet.

See also demolition of walls below.

BRIDGES AND COLUMNS OF WOOD OR IRON.

The charges of guncotton required for the demolition of iron and wooden bridges and columns can be found from the formulæ given under the head of cutting through iron and wood.

CUTTING THROUGH IRON PLATES AND THROUGH WOOD.

The charge of guncotton or dynamite required can be calculated from the following equations, in which

c=charge in ozs.
t=thickness in inches.
b=breadth in inches.

Wrought iron—Charge placed in contact with the iron.

For solid plates

$$c=2.1t^2b.$$

For laminated plates (rivetted), each lamina $\frac{1}{2}''$ thick. (Not applicable if $t<1''$)

$$c=1.7t^2b.$$

Wood—Squared logs of fir.

Charge placed in contact, across the whole width of the log.

$$c=0.023t^2b.$$

Charge placed in auger holes

$$c=0.08tb.$$

FOUGASSES.

The usual charges are 80, 50 and 25 lbs. of gunpowder.

A fougasse fired at Chatham in 1867 threw about 5 tons of stones over a surface 160 yards long by 60 yards on either side of the axis, the centre of which was about 170 yards from the fougasse. The charge was 80 lbs. of gunpowder.

GATES.

Gunpowder.

Barrier gates : one charge of 40 to 100lbs., according to strength of gate.

Town gates : one charge of 200lbs.

Guncotton or dynamite.

One charge of 50lbs. is sufficient to blow in any gate.

LAND MINES.

Let

L=line of least resistance in feet (L.L.R.)

D=diameter of crater in feet.

R_h=horizontal radius of rupture in feet.

R_v=vertical radius of rupture in feet.

C=weight of charge in lbs.

then* for *ordinary soil,*

$$C=0.0008\ (L+2D)^3.$$

$$R_h=0.35\ (L+2D)=\tfrac{7}{4}\sqrt[3]{10C}$$

$$R_v=\tfrac{1}{6}\ (7L+D)\dagger$$

If $D<2L$ the mine is said to be *undercharged.*

If $D=2L$ the mine is called a *common mine*, and in this case the formulæ become—

$$C=\tfrac{1}{10}L^3$$

$$R_h=\tfrac{7}{4}L$$

$$R_v=\tfrac{7}{5}L$$

If $D>2L$ the mine is said to be *overcharged.*

*These are empirical formulæ, and do not appear to be very reliable for overcharged mines. Formula *(a)* gives possibly the most accurate weight for the charge.

†This formula was obtained from some experiments made at Chatham, and mentioned at p. 121, Text-book of Fortification and Military Engineering, R.M.A., Woolwich.

The weight of the charge can also be obtained from the following formula :

$$C=\tfrac{1}{10}L^3\left\{\frac{\left(\frac{D}{2L}\right)^2+1}{2}\right\}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (a)$$

Camouflets.—The maximum charge for a camouflet can be obtained from formula *(a)* by putting $D=0$, hence

$$C=\tfrac{1}{40}L^3$$

Increase in charge to allow for deficient tamping.

Diminution in tamping.	Increase in charge.
$\frac{1}{3}$	$\frac{1}{4}$
$\frac{2}{3}$	$\frac{1}{2}$
No tamping.	2

Charges for clay and rock—

For clay, 1.55 C.

For rock or masonry, 2.25C.

C being the corresponding charge for ordinary soil, as given above.

Tamping.—Length of gallery to be tamped—

For common mines, $1\frac{1}{2}L$.

For an overcharged mine giving a 3-lined crater, $2L$.

PALISADES.

A palisade of triangular timbers, 8″ × 8″ × 10″ in section, with 4″ in the clear between the timbers, can be cut through by a charge of guncotton $1\frac{1}{3}$ lbs. per foot run.

PIERS OF STONE OR BRICK.

In the following, C is the charge in lbs., L the line of least resistance, B the breadth, and T the thickness of the pier, in feet.

Gunpowder.

Compact solid mass of masonry or brickwork, with circular, polygonal, or square base. Charge placed in centre of mass.

For moderate demolition

$$C=\tfrac{1}{10}L^3.$$

For violent demolition

$$C=\tfrac{3}{20}L^3.$$

High bridge pier, 20 or more feet high. Charges placed at two-lined intervals, in the centre of the masonry.

For moderate demolition

$$C=\frac{1}{3}L^3.$$

For violent demolition

$$C=\frac{1}{2}L^3.$$

High bridge pier founded on earth, with an equal pressure of earth on both sides. Charges placed under the centre of the foundations at two-lined intervals.

For moderate demolition

$$C=\frac{4}{10}L^3.$$

For violent demolition

$$C=\frac{6}{10}L^3.$$

Short thick bridge pier. Charges placed in the centre of the masonry at two-lined intervals.

For moderate demolition

$$C=\frac{1}{3}L^3$$

For violent demolition

$$C=\frac{2}{3}L^3$$

Short thick bridge pier founded on earth, with an equal pressure of earth on both sides. Charges placed under the centre of the foundations at two-lined intervals.

For moderate demolition

$$C=\frac{4}{10}L^3.$$

For violent demolition

$$C=\frac{8}{10}L^3.$$

Tamping.—Not less than $1\frac{1}{2}L$ for moderate demolitions, and $2L$ for violent demolitions.

Guncotton or dynamite.

Small piers.

Charge placed in contact, untamped.

$$C=\frac{2}{3}T^2B.$$

Charge placed in a groove $\frac{1}{6}T$ deep and tamped.

$$C=\frac{1}{3}T^2B.$$

Large piers.

$\frac{2}{5}$ths of the corresponding gunpowder charge.

Tamping $=L$.

RAILWAY RAILS.

8 ozs. of guncotton will blow away 1 foot of a rail weighing 70 lbs. to the yard. One-third of a 2 lb. slab ($10\frac{2}{3}$ ozs.) will cut through the heaviest rail.

REVETMENTS.

In the following, C is the charge in lbs., and L the line of least resistance in feet.

Gunpowder.

Revetment without counterforts.

Charges placed at the back of the revetment at two-lined intervals.

For moderate demolition

$$C=\tfrac{3}{20}L^3.$$

For violent demolition

$$C=\tfrac{4}{20}L^3.$$

If the charges are not placed at two-lined intervals they should be altered in the proportion $\frac{\text{actual interval}}{2L}$. The interval should not exceed $4L$.

Revetment with counterforts.

Charges placed in the centre of each counterfort, at two-lined intervals.

For moderate demolition

$$C=\tfrac{1}{5}L^3.$$

For violent demolition

$$C=\tfrac{1}{4}L^3.$$

Charges of $\frac{3}{20}L^3$, at two-lined intervals, demolish the intermediate parts, and shatter the counter-forts without bringing them down.

Charges of $\frac{1}{5}L^3$ at $1\frac{1}{4}$-lined intervals produce violent demolition.

If the distance between the counterforts be unusually great, in proportion to the thickness of the revetment, one or two mines should be placed between the counterforts at the back of the wall. The L.L.R. should be about equal to the thickness of the wall at the base.

Counter-arched revetments.

Charges placed in the centre of each vaulted chamber.

$$C=\tfrac{1}{3}L^3.$$

L is measured from centre of chamber to face of revetment.

STOCKADES.

Gunpowder.

Single stockade of 10″ timbers: One charge of 40 lbs. if covered with sandbags, or one charge of 60 lbs. if uncovered.

Single stockade of 14″ timbers: One charge of 100 lbs. uncovered.

Double stockade of 14″ timbers, with an interval not exceeding 3′ 6″ between the rows: One charge of 200 lbs. uncovered. If the interval between the rows exceeds 3′ 6″, two distinct explosions must be made.

TABLE I.

Guncotton or dynamite.

$$C = 0.023t^2$$

where C is the charge in lbs. per foot run, and t the thickness of the stockade in inches.

Double stockade of 14″ timbers, with an interval not exceeding 3′ 6″ between the rows: 25 lbs. per foot run, or one charge of 80 lbs.

Iron rail stockade, rails about 70 lbs. per yard, placed touching each other: 7 lbs. per foot run.

TREES.

Charge of guncotton or dynamite placed as a necklace.

$$c = 5G^2.$$

Charge of guncotton or dynamite placed in auger holes.

$$c = 0.08G^2$$

where G is the girth of the tree in feet and c is the charge in ozs.

WALLS.

Gunpowder.

By blasting.—The following table* gives the charges placed at two-lined intervals in various holes required for *complete but moderate* demolitions. The L. L. R. is measured in feet, and is equal to half the thickness of the wall. The charges should be fired simultaneously.

Description of hole.	*Diameter of hole in inches.*	*Depth to which each hole is to be bored in feet.*	*Charge in lbs.*	*Remarks.*
Single	$2L$	$1.5L$	$0.33L^3$..	This is the best size of hole.
Single	$1.33L$ ..	$1.75L$	$0.4L^3$	Single holes should be bored alternately from opposite sides of the wall.
Single	L	$2.2L$	$0.5L^3$	
V........	L	$1.4L$	$0.33L^3$	Half the charge, or $0.17L^3$, to be in each hole forming the V; the holes should overlap slightly.
X	$0.67L$ ..	$2L$	$0.33L^3$	Half the charge, or $0.17L^3$, to be in each of the two holes forming the X.

"A 14″ wall, however well built, can be breached by charges of 60 lbs. of powder, weighted with sand-bags, the charges being not more than 5 to 6 feet apart."†

* Abstracted from Instruction in Military Engineering, Part IV.

†Aide-memoire to the Military Sciences.

Guncotton.

Charges placed uncovered in contact with the wall, and when breach $>2t$.

$$C=0.0035t^2$$

where C is the charge in lbs. per foot run and t is the thickness of the wall in inches.

Charges placed in holes about $\frac{1}{2}t$ deep, $3t$ apart, and covered with sand or earth.

$$c=0.03t^2$$

where c is the charge in each hole in ozs. and t the thickness of the wall in inches.*

FIRING ARRANGEMENTS.

SLOW AND INSTANTANEOUS LEADERS.

Rate of burning,—

Bickford's fuze	2.4 to 4 feet per minute.
Powder hose	10 to 20 feet per second.
Ord's hose	15 " "
Bickford's instantaneous fuze...	30 " "

ELECTRICAL CIRCUIT WIRES.

Resistance of various Service Cables.

	Resistance per yard in ohms, at 60° Fahr.
No. 16 B.W.G., insulated with gutta-percha, to 8 B.W.G....	0.008
No. 22 B.W.G., 7-strand, insulated with Hooper's india-rubber to 0.23 inch, and served with hemp braiding. External diameter 0.32 inch. (C Troop cable)	0.006
No. 20 B.W.G., 4-strand, insulated with Hooper's india-rubber to 0.24 inch, and covered with two servings of tarred hemp. External diameter 0.44 inch..............	0.007

There are numerous other cables in the Service, but they are intended solely for Submarine mining, or for the electric light.

Resistance of copper and iron wire.

If, for any wire,

r_2 = resistance per yard in ohms at 60°F.

d = diameter in thousandths of an inch.

N = number of yards per lb.

* This formula has been deduced from experiments made by the author at Gibraltar.

then,—

For copper wire whose conductivity is 88.6 p.c. that of pure copper wire—

$$r_2 = \frac{34}{d^2}$$

$$r_2 = 0.00031\,N.$$

For iron wire—

$$r_2 = \frac{210}{d^2}$$

$r_2 = 0.00166\,N$; telegraph wire.

$r_2 = 0.0019\,N$; ordinary wire.

B. W. G.*	Diameter in thousandths of an inch.	Copper.			Iron.	
		No. of yards per lb.	Resistance at 60° F. Conductivity 88.6 p.c. of pure copper.	Resistance at 60° F. Conductivity 72.2 p.c. of pure copper.	No. of yards per lb.	Resistance at 60° F. (Telegraph wire.)
8	165	4	0.0012	0.0015	5	0.0077
9	148	5	0.0015	0.0019	6	0.0096
10	134	6	0.0019	0.0023	7	0.0117
11	120	8	0.0024	0.0028	9	0.0146
12	109	9	0.0029	0.0034	11	0.0177
13	95	12	0.0038	0.0045	14	0.0233
14	83	16	0.0049	0.0059	18	0.0305
15	72	21	0.0066	0.0079	24	0.0405
16	65	26	0.0080	0.0096	30	0.0497
17	58	33	0.0101	0.0121	37	0.0624
18	49	46	0.0142	0.0170	52	0.0875
19	42	62	0.0193	0.0231	71	0.1190
20	35	89	0.0277	0.0333	103	0.1714
21	32	107	0.0332	0.0398	123	0.2051
22	28	140	0.0434	0.0520	161	0.2678
23	25	175	0.0544	0.0653	202	0.3360
24	22	226	0.0702	0.0843	260	0.4339

Correction for temperature.—The resistance of copper increases 0.21 p.c. for a rise of one degree Fahrenheit and that of iron about the same.

The electrical conductivity of copper is much affected by impurities as will be seen by the following table:†

*Authorities differ as regards the diameter of several Nos. of B. W. G. ; the above are from careful measurements of Mr. Holtzapffel.

†Extracted from a paper by Capt. Bucknill, R.E., in Vol. XXV., Journal R.U.S.I.

Pure copper	100.
Lake Superior	98.8
Commercial	92.6
Burra Burra (Australian)	88.7
Best selected	81.3
Bright wire	72.2
Tough	71.0
Demidoff	59.3
Rio Tinto	14.2

Temperature about 60° Fahr.

The resistance of wrought iron is more constant than that of copper.

SOURCES OF ELECTRICITY.

Grove's cell.

E. M. F., 1.956 volt.

Liquid resistance: 0.08 ohm.

Dimensions of Military pattern cell: outer cell (ebonite), $3'' \times 2'' \times 4\frac{3}{4}''$ deep; inner porous cell, $2\frac{3}{4}'' \times \frac{1}{2}'' \times 4''$ deep.

Dimensions of box containing 10 cells with 12 spare porous cells: $22\frac{1}{4}'' \times 4\frac{1}{2}'' \times 8\frac{1}{2}''$ deep.

Charge for one cell: sulphuric acid, dilute (1 acid to 10 water), 11 oz. fluid; nitric acid, strong $1\frac{3}{4}$ oz. fluid.

Zinc plates: purest rolled zinc, No. 10, B. W. G., U shaped, with twice $4'' \times 2\frac{1}{2}''$ immersed.

Platinum plates: sheet platinum, $4'' \times 2\frac{1}{4}''$ immersed.

Mean distance between zinc and platinum plates, $\frac{1}{2}''$.

Leclanché firing cell.

E. M. F., 1.45 Volt.

Liquid resistance: 0.15 ohm.

Dimensions of Military pattern cell: height, $14\frac{1}{2}''$; diameter, $4\frac{1}{8}''$.

Dimensions of box containing 10 cells: $1'\ 11'' \times 9'' \times 10\frac{1}{2}''$ depth (inside).

Charge for one cell: sal ammoniac, 3 oz., dissolved in $\frac{3}{8}$ pint of water; weight of binoxide of manganese and graphite mixture, $2\frac{1}{2}$ lbs.

Quantity dynamo.

The data in connection with the quantity dynamo at the R. M. College of Canada are as follows:

E. M. F., 50 volts, (approx).

Internal resistance, 13.33 ohms.

Resistance of revolving coil (Siemens' armature), 8.03 ohms.

Resistance of electro magnet coils, (both together) 5.3 ohms.

Extra resistance cut out on depressing firing key, 24.64 ohms.

The machine will fuse the 0.003″ standard iridio-platinum wire through 15 ohms., and the 0.0014″ wire through 54 ohms.

Tension dynamo.

This dynamo will fire 80 fuzes in simple circuit, and 60 when connected as divided fuzes.

The machine should be able to produce a spark $\frac{200''}{5000}$ long.

SUNDRY RECIPES.

Amalgamating zinc plates.

1st Method. First dip the plate into dilute sulphuric acid (one acid to 10 water) until a strong action commences; then pour a little mercury on each side of the plate and spread by means of cotton waste attached to a stick. If the plate is greasy, first wash it well with a strong solution of carbonate of soda.

2nd Method. First clean the plate by means of dilute sulphuric acid as in the first method; then place for one minute in a bath composed of one part by weight of $Hg\ NO_3$ (proto-nitrate of mercury) and 20 parts of water. The plate must afterwards be well washed in water.

Cleaning copper plates.

If the plate be very dirty, place it in dilute sulphuric acid, and then rub with sand and water. Should this fail, heat the plate red-hot before applying the acid.

Moderately dirty plates can be cleaned with sand and water alone.

Cement for Leclanché firing cell.

48 parts by weight of French resin, 48 of bitumen, 3 of oil of naphtha, and one of india-rubber.

Crude black paraffin may be used as a substitute for the above, and for repairs.

Solder for jointing circuit wires.

1 Tin and 1 Lead, fusing point 320° Fahr.

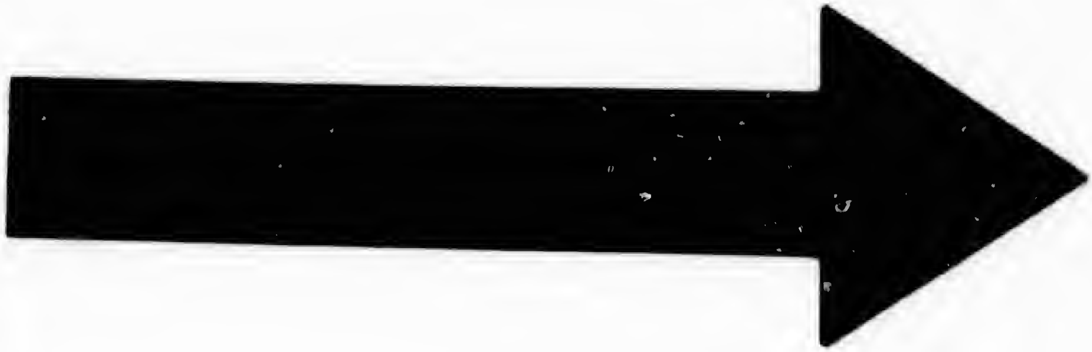
Fluxes for soldering.

Metal to be united.	*Fluxes.*
Copper.	Sal ammoniac, Chloride of zinc, or rosin.
Iron.	Borax, or Sal ammoniac.
Zinc.	Chloride of zinc.

Soldering fluid is a concentrated solution of chloride of zinc.

Marine Glue.

"One part of indiarubber is dissolved under gentle heat in 12 parts of mineral naphtha or coal tar. When melted, 20 parts of powdered shellac are added, and the mixture is poured out on metal plates to cool. It is applied by a brush in a melted state, and is specially suitable for all work exposed to wet or moisture."



PART II.

ELECTRICAL MEASUREMENTS.

List of symbols used.

R: resistance, total in a circuit.
r, r_b, etc. " of wires, unplugged in a box of coils, etc.
ρ: " liquid of a cell.
g: " of a galvanometer.
s: " of a shunt.
g_s: " of a shunted galvanometer.

P: highest potential in a circuit; also electro-motive force.
p_a: potential at the point A in a circuit.

C: current, total in a circuit.
c, c_1, etc., currents in the various branches of a divided circuit.

K: capacity.

Q: quantity of electricity.

δ: deflection of a galvanometer, in degrees.

d: deflection of a reflecting galvanometer, in divisions of scale.
D: " " " " " " due to an instantaneous current, and corrected for resistance of suspensions and air.

r_x, c_x, etc.: unknown resistance, unknown current, etc.

PART II.

ELECTRICAL MEASUREMENTS.

CHAPTER I.

INTRODUCTORY.

127. The purposes for which current electricity is used by the Military Engineer are very numerous, and, in most cases, various measurements, more or less accurate, have to be made. The following pages contain the more usual methods of making these measurements.

Certain electrical terms and laws are of frequent occurrence, definitions of the former, and a statement of the latter, are therefore appended.*

DEFINITIONS.

128. *Resistance.* —Electrical resistance is the opposition a body offers to the passage of electricity through it, and it is found by experiment to depend: On the nature, on the length, on the cross-section and on the temperature of the body. It is the inverse of conductivity.

Liquid resistance.—The resistance offered by a voltaic cell to the passage of electricity is called the liquid resistance of the cell.

129. *Conductors* and *Non-conductors.*—Substances which offer a small resistance are called conductors: those which offer a practically infinite resistance are called non-conductors. So far, no absolute conductor or non-conductor has been found, and the transition from one class to the other is gradual.

130. *Insulator.*—This is another name for a non-conductor.

*For detailed information on these points, reference is made to the Course of Electricity.

131. *Dielectric.*—A dielectric is an insulator separating two conductors and through which electrical action may take place.

132. *Potential.*—The charge of electricity at any point on a body is capable of doing a certain amount of work, or, has a certain potential energy. This potential energy, divided by the quantity of electricity at the point, is the potential at that point. The electrical potential at any point of a given distribution of electricity may also be defined as: The amount of work required to be done on a unit quantity of electricity in moving it from infinity to the point, against the repulsion (algebraically considered) of the given distribution of electricity, supposing the distribution not to be disturbed by the movement.

133. *Difference of Potential.*—The excess, or defect, of electrical potential at one point above that at another is called the difference of potential between the two points. Difference of potential bears the same relation to electrical attraction that difference of level bears to gravity, and that difference of temperature bears to heat. The difference of potential, between any two points, may also be defined as "numerically equal to the amount of work required to force a unit of electricity from the one point to the other, in the direction opposed to that in which it tends to move."*

134. *Electro-motive force.*—This term is used to express the power of a source of electricity, and is equal to the difference of potential which can be maintained by the source.† For instance the E. M. F. of a voltaic cell is the difference of potential between its two electrodes.

135. *Current.*—If by any means a difference of potential be established between the two extremities of a conductor, for instance, by means of a voltaic cell or of a magneto-electric machine, there will be a constant flow of electricity along the conductor so long as the difference of potential is maintained. This flow is called an electrical current, and its strength is measured by the number of units of quantity of electricity which flow past any cross-section of the conductor in unit of time.‡ The direction of flow is considered to be from the higher to the lower potential.

*A Physical Treatise on electricity and magnetism by J. E. H. Gordon, B.A., Cambridge.

†It will be observed that this is not a strictly correct term, for it is a question of work and not of force which is at issue.

‡The comparison of this phenomenon to the flow of a fluid is convenient; the probability is, however, that a transfer of vibrations takes place.

136. *Capacity.*—The capacity of an insulated conductor is the quantity of electricity required to raise, by one unit, the potential of the conductor. Hence if K is the capacity, P the potential, and Q the quantity contained by the conductor :

$$Q=KP$$

137. *Polarization.*—This is the name given to the deposition of hydrogen, on the negative plate of a voltaic cell, which occurs when the cell is placed in circuit, and which causes a reduction in the E. M. F. of the cell.* The amount of this polarization depends in the first place on the nature of the cell; those cells which polarize rapidly are called inconstant, and those which polarize slowly are called constant. Daniell's and Grove's cells are amongst the most constant. The amount of polarization also depends on the resistance in circuit, and the higher the resistance the less the polarization.

As will be seen in the sequel polarization renders inaccurate several of the methods of measurement.

UNITS.

138. The measurement of all physical quantities can be made to depend on the fundamental units of space, mass, and time,† and the units of measurement thus derived are called *absolute* units in contra-distinction to *arbitrary* units.

For scientific purposes the centimetre, the gramme and the second have been chosen as the fundamental units, and the units derived from them are said to belong to the C. G. S. system.

The various measurements made in connection with current electricity are expressed in terms of units based on the magnetic properties of an electrical current,‡ and are called electro-magnetic units; the absolute electrical units, thus obtained, belonging to the C. G. S. system, are, however, of inconvenient magnitudes, and they are therefore multiplied or divided by some power of 10.

The following are the principal units required.

139. *Current.*—It is found by experiment that the attraction exerted by a current on a magnetic pole is $\frac{mlC}{a^2}$ where m is the intensity of the magnetism of the pole, l the length of the current acting on the pole, C the strength of the current, and a the distance of the pole from the current. The absolute unit of current on the C. G. S. system is clearly therefore: The current each centimetre of which attracts a unit magnetic pole, placed at a distance of one centimetre from it, with a force of one dyne.

*See § 796, Ganot's Physics, 9th Edition.

†See § 932, Ganot's Physics, 9th Edition.

‡See § 810, Ganot's Physics, 9th Edition.

(The *dyne* is the unit of force of the C. G. S. system, and is the force which can, in one second, increase the velocity of one gramme by a velocity of one centimetre per second.)

The practical unit is called a Weber and is=C. G. S. unit $\times 10^{-1}$.

140. *Quantity.*—The absolute unit of quantity is the quantity of electricity flowing, in one second, past any cross-section of a conductor carrying a unit current.

The practical unit is called a Weber*, and is=C.G.S.unit $\times 10^{-1}$.

141. *Difference of Potential or Electro-motive force.*—The absolute unit of difference of Potential is the difference of potential between two points, when one erg of work would have to be done to move a unit quantity of electricity, against electrical repulsion, from one of the points to the other.

(The *erg* is the unit of work of the C. G. S. system, and is the amount of work done by one dyne working through one centimetre.)

The practical unit is called the Volt, and is=C. G. S. unit $\times 10^{8}$.

142. *Resistance.*—The absolute unit of resistance is the resistance through which one absolute unit of difference of potential can cause one absolute unit of current to flow.

The practical unit is called the Ohm, and is=C. G. S. unit $\times 10^{9}$.

Occasionally very high resistances have to be expressed and for this purpose the megohm=1,000,000 ohms, is used.

The ohm is sometimes called the B. A. unit (British Association).†

143. *Capacity.*—The absolute unit of capacity is the capacity of a condenser which can hold one unit of quantity of electricity at unit potential.

The practical unit is the Microfarad, and is=C.G.S. unit $\times 10^{-15}$. The Farad is 1,000,000 microfarads.

144. Some idea of the magnitude of these units will be obtained from the following:

The electro-motive force of a Daniell's cell is about 1.12 volt.

The resistance of a pure copper wire, 48.5 metres long, one millimetre in diameter, at 0° Centigrade, is one ohm.

The current produced by one Daniell's cell in a circuit, whose resistance is one ohm,‡ is approximately one Weber.

*Called "Farad" by some authorities.

†The value of the ohm was determined by a Committee of the British Association after a lengthy and laborious series of experiments, and standard resistances of one ohm are issued by the Association.

‡Including the liquid resistances of the cell.

"The capacity of most submarine cables is about one-third of a microfarad per knot."*

144 A. The following are the decisions of the Electrical Congress, held in Paris in the autumn of 1881, on the subject of the Nomenclature of Electrical Units :

1.—On adoptera pour les mesures électriques les unités fondamentales : centimètre, gramme-masse, seconde (C.G.S.)

2.—Les unités pratiques, l'Ohm et le Volt, conserveront leurs définitions actuelles.

3.—L'unité de résistance (Ohm) sera représentée par une colonne de mercure d'un millimètre carré de section, à la température de zéro degré centigrade :

4.—Une commission internationale sera chargée de déterminer, par de nouvelles expériences, pour la pratique, la longueur de la colonne de mercure d'un millimètre carré de section, à la température de zéro degré centigrade, qui représentera la valeur de l'Ohm.

A ces quatre premières résolutions ont été ajoutées les trois propositions suivantes :

5.—Qu'on appelle Ampère le courant produit par un Volt dans un Ohm.

6.—Qu'on appelle Coulomb la quantité d'électricité définie par la condition qu'un Ampère donne un Coulomb par seconde ;

7.—Qu'on appelle Farad la capacité définie par la condition qu'un Coulomb dans un Farad donne un Volt.

*Rough Notes of Lectures on Electricity, S. M. E., Chatham.

CHAPTER II.

ELECTRICAL LAWS ON WHICH MEASUREMENTS ARE BASED.

OHM'S LAW.

145. This law asserts that

$$C \propto \frac{p-p_1}{r}$$

where C is the current, $p-p_1$ the difference of potential between two points in a circuit, and r the resistance between the same two points; and by properly choosing the units this law can be written.

$$C=\frac{p-p_1}{r}$$

Such units are the absolute units on the C. G. S. system, and likewise the practical units derived from them; so that a difference of potential of one volt will produce a current of one weber in a circuit whose resistance is one ohm.*

This law is of the greatest importance for electrical measurements.

Graphic representation of Ohm's Law.

146. Ohm's law can be represented graphically as follows:

Let r be the resistance between two points, A and B, in a circuit carrying a current C, and let p_a, p_b be the potentials at A and B respectively. Measure $ab=r$, to some convenient scale, along an initial straight line representing zero potential, then a will represent the point A and b the point B. At a and b raise perpendiculars aa' and bb' to the initial line, equal to p_a and p_b, to the

*From Ohm's Law:

$$(\text{absolute C.G.S. unit of current})\,10^{-1}=\frac{(\text{absolute C.G.S. unit of difference of potential})\,10}{(\text{absolute C.G.S. unit of resistance})\,10^{9}}$$

That is,

$$1\ \text{Weber}=\frac{1\ \text{Volt.}}{1\ \text{Ohm.}}$$

same scale on which ab was measured; then if θ is the angle of inclination of $a'b'$ to the initial line.

$$\tan\theta = \frac{aa' - bb'}{ab} = \frac{p_a - p_b}{r} = C$$

The straight line $a'b'$ represents, therefore, the current flowing in the conductor, that is its strength is measured by the tangent of the angle of inclination of this straight line to the initial line.

Further, if the resistance between, say, A and any third point X on the conductor is known, the potential at X can be found graphically by measuring ax in the proper direction along the initial line and raising a perpendicular xx' to meet $a'b'$. The intercept xx' measures the potential at X.

THEORY OF DIVIDED CIRCUITS.

147. Suppose that a circuit, carrying a current C, divides into two branches at the point A and re-unites again at the point B. Let the resistance in the two branches be r_1, and r_2, and let c_1, c_2 be the currents in the same branches respectively. Let p_a be the potential at A and p_b that at B, and r the total resistance in circuit between the points A and B. Then by Ohm's law:

$$C = \frac{p_a - p_b}{r}, \quad c_1 = \frac{p_a - p_b}{r_1}, \quad c_2 = \frac{p_a - p_b}{r_2}$$

And clearly

$$C = c_1 + c_2.$$

Hence it will be found that:

$$\frac{c_1}{c_2} = \frac{r_2}{r_1}$$

$$c_1 = \frac{r_2}{r_1 + r_2}.C$$

$$c_2 = \frac{r_1}{r_1 + r_2}.C$$

$$r = \frac{rr_1}{r_1 + r_2}$$

A similar method of investigation can be followed in the case of a current dividing into three or more branches.

EFFECT OF AN ELECTRICAL CURRENT ON A MAGNETIC NEEDLE.

148. If a wire, carrying a current of electricity, be placed in the neighbourhood of a magnetic needle, and not at right angles to it, the needle will be deflected in a direction depending on the direction of the current, and on the position of the wire according as it is above or below the needle.* Ampère has given the

*See § 810, Ganot's Physics, 9th Edition.

following *memoria technica* from which the direction of deflection can in all cases be obtained. "Imagine an observer placed in the wire facing the needle in such a manner that the positive current enters at his feet and issues at his head, then in all cases the north-pointing pole will be deflected towards the left of the observer."

When a horizontal magnetic needle is deflected by an electrical current it is under the action of two couples, namely, the couple produced by the current and the couple due to the magnetic attraction of the Earth. As the needle deflects, the values of the moments of these two couples vary: that due to the current diminishing, and that due to the Earth increasing, until the position of equilibrium is attained, when both must have the same value.

If the needle is swung on a horizontal axis and is counter-weighted, the counter-weight will produce a couple, whose action corresponds to that due to the Earth's attraction in the previous case.

The moment of the couple produced by the electrical current is found by experiment to vary, amongst other things, directly as the strength of the current.

149. An *Astatic system* is a combination of two horizontal needles having the same magnetic intensity, rigidly connected to the same vertical axis and placed parallel to each other, with the S. pole of one needle facing the N. pole of the other. The Earth has, therefore, no directing effect on an astatic system; but it can be shown that the deflecting couple produced by a current is increased. In the astatic systems in practical use, however, one needle is slightly stronger than the other, so that there is a small directive couple. For both reasons, therefore, an astatic system is much more sensitive to an electrical current than a single needle.

150. The construction of galvanometers depends on the above properties of magnetic needles.

CONDENSATION OF ELECTRICITY.

151. If an insulated conductor, in connection with a source of electricity, be separated from another conductor by a dielectric (air, glass, gutta-percha), electricity will be *condensed* on the conductors, and the amount of condensation will depend on the dielectric and on the proximity of the conductors.* The potential on the condenser connected with the source will clearly be the same as that of the source, so that condensation of electricity

See § 755, Ganot's Physics, 9th Edition.

means: increase of electrical density without increase of potential. An instrument capable of accumulating electricity in this manner is called a "condenser."

RELATION BETWEEN CURRENT AND WORK.

152. To show that the work done is proportional to the square of the current flowing through a conductor.

Let C be the current flowing through a conductor. Select two points, A and B, on this conductor, and let r be the resistance, and $p_a - p_b$ the difference of potential between them. Then the potential energy transformed in time t is

$$(p_a - p_b)\, Ct,$$

But

$$C = \frac{p_a - p_b}{r}$$

Hence

$$C^2 rt = \text{work}.$$

And since r and t are constants,

$$C^2 \propto \text{work}.$$

CHAPTER III.

INSTRUMENTS AND APPLIANCES USED IN MAKING ELECTRICAL MEASUREMENTS.

CIRCUIT WIRES.

153. Circuit wires, or leads, generally consist of copper wire about 0.05″ diam., insulated by means of gutta-percha or silk, preferably the former.

154. *Binding screws.*—Each terminal of an electrical measuring apparatus is provided with a brass screw and nut, in order that the end of the connecting wire may be firmly secured. Separate double-binding screws are used to make temporary joints in wires.

155. *Making connections.*—The ends of the conducting wires should be bared and brightened with a piece of emery cloth, or with the back of a knife, so as to remove all the oxide, and thus obtain a good metallic contact. When this is done the ends are bent, with a right-handed hook, round the binding screws, which are then firmly screwed down.

CONTACT KEYS.

156. A contact key is an instrument by means of which a circuit can be closed or broken at pleasure, and it is especially useful when currents of very short duration are required. There are several different patterns of these instruments, but generally speaking the construction is as follows :

The base of the instrument is made of ebonite, or hard wood. A small brass stud, to which a platinum point is soldered, is secured to the base and connected by a wire to a binding screw. A brass lever is also attached to the base, and connected to a second binding screw ; this lever carries a second platinum point, placed immediately over the first one, but kept separated from it by means of a spring acting on the lever.

To use the instrument the circuit wires are connected to the binding screws, and when it is desired to close the circuit the lever is depressed until the platinum points touch; the circuit is broken the instant the lever is released. Currents of very short duration can therefore be obtained by making rapid contacts, an operation which requires some little practice.

REVERSING KEYS.

157. A reversing key consists of two keys similar to the above, each having a double set of points so arranged, that, on depressing one key continuously a current may be sent in one direction, but directly the first key is released and the second depressed the current will be reversed in direction.

TEST CELLS.

158. It is a matter of considerable importance to select suitable cells for generating the currents required for testing; and, when making *comparative* measurements, "standard" cells should be employed.

159. The standard cells for use when the method of testing requires a *current* of electricity, even if it be only of short duration, should have the following qualities:

1. If made up with pure materials and with the same strength of solutions, they should give the same result.

2. They should polarize very slowly, that is, they should be what are called "constant cells."*

Grove† cells and Daniell† cells are those which, at present, best fulfil these conditions, but they are "two fluid" cells, and the electro-motive force is diminished by the gradual mixing of the fluids. This will generally be the case with two fluid cells, so that a single fluid standard cell is a desideratum.

MODIFIED DANIELL'S STANDARD CELL.

160. The following is a description of a standard cell of almost unlimited endurance, proposed by Major Armstrong, R.E. It is a modification of the Daniell's cell:

"In two porcelain or earthenware chambers, separated from each other by a *non*-porous partition, are placed the zinc and copper elements respectively. A semi-saturated solution of sulphate of zinc is poured into the compartment containing the zinc element, and a saturated solution of sulphate of copper is poured into the other.

*See § 797, Ganot's Physics, 9th Edition.

†See § 799 and § 798, Ganot's Physics, 9th Edition.

"The cell may remain in this condition apparently for years without undergoing any change: it is merely necessary to add distilled water to the solutions from time to time, as their level falls through evaporation, and to prevent the sulphate of copper from creeping up the sides of the cell.

"When it is desired to use the cell as a standard, a string of cotton or twine is dipped in water and used to connect the liquids, which are thus connected electrically, but do not mix for hours. At the conclusion of the experiment, the string is removed and thrown away and a fresh one used next day.

"After employing some of these cells for a couple of years no trace of copper could be detected in the zinc cell.

"The electromotive force varies under conditions, which I have not determined, from 1.083 to 1.065 ohms; that is only 0.83 per cent. from the mean value of 1.074. It is unaffected by raising the temperature to boiling point; and I have not observed that action of light produces any alteration.

"A number of these cells, when first made up, were within an extreme range of 1.069 to 1.077 ohms.

"It is probably desirable to employ commercially pure metals and salts, although I have not found that cells prepared with the above precautions differ in any way from those made up with ordinary commercial materials.

"As I have already stated, this is not, in its present condition, an accurate standard, but it is a very convenient one for work not requiring greater accuracy than can be obtained by its means, especially if it can be checked at starting by some recognized standard. * * * The results obtained with a condenser are not very accurate, as even the current required to fill a capacity of about ⅓ microfarad appears to lower the E. M. F. of the cell at the moment about 2 p.c., * * * but when used with an electrometer gives results within one per cent. of the truth. * * * From experiments made during the past two months I think that the value of 1.07 volts will not differ more than 0.5 p.c. from the correct value. The previous experiments were made with a zinc wire soldered to the zinc element and a copper wire to the copper element, and the variations may have been caused to some extent by damp at the junction of the copper lead with the permanent zinc wire; at any rate, since a copper wire was *soldered* to the zinc element the E. M. F. has only varied from 1.065 to 1.075 volts. The mean value of which is 1.07 volts, which should be taken as the actual value."*

*"A permanent standard cell," by Major Armstrong, R.E., R.E.I., Occasional papers, Vol. IV.

LATIMER CLERK STANDARD CELL.

161. When measuring the E. M. F. of a cell or battery, and the method employed requires only an instantaneous current, it is not important that the cell should polarize slowly, but on the other hand, it is of great advantage (1) if the E. M. F. of the test cell remains constant when set up (but not at work); (2) if the cell does not emit acid vapours, so as not to injure delicate instruments, and (3) if it requires little looking after. Mr. Latimer Clerk's standard cell fulfills these conditions. The following is a description of it.

"At the bottom of a small glass cell is placed some pure mercury, which is then heated to expel moisture. On the surface of the mercury is poured a paste made of: zinc sulphate, dissolved in boiling distilled water to such a point that on cooling a considerable quantity of crystals of the salt are deposited, and a perfectly saturated solution obtained; this solution is mixed with protosulphate of mercury so as to form a thick paste, which is then boiled to drive off air, and is poured hot on the surface of the mercury. A piece of pure zinc is then supported in the paste by means of a cork; the whole is sealed up with paraffine wax. Contact with the mercury is made by means of a platinum wire dipping below its surface in a little glass tube, or neck *reaching* up from the bottom of the cell on the outside. All materials should be pure.* The E. M. F. of these cells is the same within $\frac{1}{10}$th per cent., and they do not vary beyond those limits in the comparison of cells set up for 20 hours with those a year old, provided the temperature does not vary. The E. M. F. is 1.457 volts at $15^{\circ}.5C$, and falls about 0.06 per cent. for a rise in temperature of $1^{\circ}C$." This cell polarizes rapidly when in action. It is therefore not suitable for procuring a current.

LECLANCHE CELL.

162. The Leclanché cell,† although it polarizes‡ rapidly, is suitable for measuring resistance, either when the method employed allows of a momentary current being used, or when it is independent of the E. M. F. of the test-cell.

LECLANCHE TEST-CELL FOR LAND SERVICE.

163. A special pattern of Leclanché cell is used in the Service to carry out the testing in connection with the employment of electricity for firing explosives; it is arranged for portability, and has a high liquid resistance.§

*"The careful washing of the protosulphate of mercury is a matter of essential importance, as the presence of any free acid, or of persulphate, produces a considerable change in the electro-motive force of the cell." A Physical Treatise on Electricity and Magnetism by T. E. H. Gordon, B.A., Camb.

†See § 803, Ganot's Physics, 9th Edition.

‡See § 137.

§See § 128.

The portability is insured by making the cell small, and of vulcanite instead of glass. Only a small hole is provided for pouring in the sal-ammoniac, and this hole should be closed with a cork.

The high liquid resistance is necessary to prevent the possibility of the fuze or charge being fired whilst testing. This liquid resistance should be at least 12 ohms,* and it is obtained by dividing the cell into two parts, connected only by a small hole.

The dimensions of these cells are: $2\frac{3}{4}'' \times 1\frac{3}{4}'' \times 3\frac{3}{4}''$, and they are also supplied in boxes of 6 for use with high tension fuzes.

RESISTANCE COILS.

164. A resistance coil is a coil of wire of a known resistance; it is made of insulated wire wound double around a bobbin, so that there are, as it were, two equal currents flowing in opposite directions, thus neutralizing each other's effect† on a neighbouring galvanometer. The wire is very fine, and is usually made of German silver, or of silver alloyed with 33.4 per cent. of platinum, as it has been found that the resistance of these two alloys is not much affected by temperature,‡ and they also have a high specific resistance.§

BOX OF RESISTANCE COILS.

165. These instruments consist of a number of resistance coils, arranged in a box in such a manner as to allow of any required resistance (within limits) being readily introduced into a circuit. Their construction is as follows: The box has an ebonite top, and on this top is fixed a discontinuous bar of brass, the solutions of continuity occur about every inch and they can be bridged by means of brass pegs. When all the pegs are in position this brass bar has practically no electrical resistance, owing to its large section. But, if a peg be removed, the current can no longer pass along the bar at that point, and must follow another route provided for it through a coil placed in the box, the resistance of which is marked on the ebonite, opposite the peg. Hence, when the peg in question is removed, a resistance, equal to that marked against it, has been introduced into the circuit. In replacing pegs they should be firmly pressed in, and twisted, so as to obtain a good contact. The heads of the pegs are made of ebonite.

*Every cell should have "Resistance not less than 12 ohms" painted on it and signed by the examining officer, as with a less liquid resistance a premature explosion might occur.

†See § 148.

‡See Table II.

§See § 936, Ganot's Physics, 9th Edition.

POST OFFICE PATTERN BOX OF COILS.

166. In the Post Office pattern* the following *separate* resistances are provided :

1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1,000, 2,000, 3,000, 4,000, and Infinity. Total of finite resistances, 11,110 ohms.

So that, as will be seen by trial, any resistance expressed by a whole number, from 1 to 11,110 ohms, can be introduced into a circuit by taking out one or more pegs. This pattern is further provided with other resistances to form a Wheatstone's bridge, and also with two contact keys, the use of which will be explained in the sequel.

FIRING RESISTANCE COILS.

167. A special pattern box of resistance coils, called "Firing resistance coils," has been introduced into the Service for the testing required in connection with the use of electricity for firing explosives. In this box the following separate resistances are provided :

20 resistances of $\frac{1}{20}$th ohm each, marked $\frac{1}{20}$, $\frac{2}{20}$............$\frac{20}{20}$
And 1, 2, 2, 4, 10, 20, 20, 40. Total 100 ohms.

The coils in these boxes are specially made with thick wire, so that the powerful currents required for fusing platinum wire can be passed through them with safety.

The fractional resistances are not provided with separate pegs, but a "wandering" peg is used with them ; it has a binding screw, instead of the usual ebonite head, and is one of the terminals of the box. The fractional resistance in circuit is reckoned in $\frac{1}{20}$ths of an ohm, and is equal to the number of unplugged holes *behind* the wandering peg.

These boxes are also provided with a Wheatstone's bridge arrangement, with one contact key, and with a thermo-galvanometer.†

To obtain accurate measurements it is of the utmost importance that the pegs and holes should be perfectly bright ; they can be best cleaned by means of plate powder and chamois leather.

GALVANOMETERS.

168. It was seen‡ that the moment of the deflecting couple, produced by an electrical current acting on a magnetic needle,

*The box of coils at the R. M. C. is of this pattern, and was made by Messrs. Elliott, London. The same firm make several other patterns, for instance, one of the same total resistance as the Post Office pattern, but of larger dimensions; also a box having a total resistance of 10010 ohms, called the "Dial Pattern."

†See § 189.

‡See § 148.

varies *directly* with the strength of that current. This property is made use of in Galvanometers, which are instruments used, either to measure electrical currents, or only to indicate their presence.

If the same instrument be used to measure various currents the deflecting force produced at each pole of the needle can be shown to vary as $\frac{C}{\Sigma a^2}$, where C is the current, and Σa^2 the sum of the squares of the distances of each element of the current from the pole. Evidently the value of Σa^2 depends on the position of the needle, relatively to the current. There are two classes of galvanometers, however, namely, the sine and tangent galvanometers, in which Σa^2 has a constant value for all positions of the needle.

DETECTORS.

169. In a detector galvanometer Σa^2 is *not* constant, so that the deflection of the needle (measured in degrees) is not proportional to the current. These instruments can therefore only be used for very rough measurements of currents, but they are more specially useful to *indicate* a current.

In the less sensitive class of detectors the needle is swung vertically by means of a counterweight, others, more sensitive, have horizontal needles. Generally there are two bobbins on which the insulated wire is coiled, and the magnetic needle is swung between them. The needle showing the deflections on the dial is not generally magnetic, but is merely an index. The more sensitive vertical detectors ought to be turned at right angles to the magnetic meridian, to neutralize the effect of the dip.

Three-coil galvanometer.

170. This is a vertical detector, having 3 separate coils, whose resistances are 2, 10 and 1000 ohms, respectively. By means of a peg the current may be made to pass at will through any one of the coils.

The dial plate of the instrument is divided into degrees so that the deflections can be measured. As mentioned above, this deflection is not proportional to the current. Data, however, will be found in Table II, by means of which the ratio between the currents flowing through the galvanometer can roughly be determined, the 1000 ohm coil being in circuit.

The 3-coil galvanometers used in the Submarine-mining Service are *calibrated*, that is, a paper dial is attached and is graduated, by trial, so that the deflections may be proportional to the current. In this case the divisions on the arc diminish as the deflection increases.

Astatic galvanometer.

171. This instrument, supplied for Submarine-mining Service, is a horizontal detector, and it has two magnetic needles forming an astatic system. The upper needle acts as an indicator and moves on a dial plate divided into degrees. This galvanometer is sensitive, and has a resistance of 1000 ohms.

SINE GALVANOMETER.

172. In the sine galvanometer the coils are made moveable about a vertical axis, and can thus follow the needle, which is horizontal, as it deflects, Σa^2 is therefore constant and, it can be easily shown that*

$$C=\mu \sin \delta$$

where δ° is the angle of deflection, and μ is a constant.

This class of galvanometer is not much used for measurements.†

TANGENT GALVANOMETER.

173. In the tangent galvanometer the length of the needle is small in comparison to the diameter of the coils, so that Σa^2 is practically constant. It can be shown in this case that*

$$C=\mu \tan \delta \quad \text{nearly.}$$

This is the best class of galvanometer for purposes of measurement.†

THOMSON'S REFLECTING GALVANOMETER.

174. This instrument is constructed as a tangent galvanometer, and, to increase its sensitiveness, an astatic system is frequently employed.

If the galvanometer is not astatic, one coil is used which is placed vertically, and the magnets,‡ cemented to the back of a small mirror, are suspended by two silk threads§ in the centre of the coil. The coil is enclosed in a brass cylinder, one end of which is closed by a plate of glass, and the other by a brass plate containing a small glass disc, through which the magnets can be seen. The instrument is mounted on a brass tripod stand provided with levelling screws.

If the galvanometer is astatic, each system of magnets is surrounded by its own coil. The two coils are placed one over the other and secured to brass pillars, mounted on an ebonite base,

*See Appendix.

†For further information see § 813 and 814, Ganot's Physics, 9th Edition.

‡Several very small magnets, about $\frac{1}{8}$" long, are used so as to obtain as intense a magnetization with as little weight as possible, as then the magnets to return rapidly to rest.

§The resistance to torsion is less with two than with one thread.

which stands on four mill headed screws for the purpose of levelling. The ends of the wires in the coils are connected to four brass binding screws, and to place the instrument in circuit the two centre binding screws are connected together, and the circuit wires are attached to the two outer binding screws, so that the current goes first through one coil and then through the other. The instrument is covered with either a square or a cylindrical glass case.*

The small mirror reflects a beam of light on to a minutely graduated scale, the light proceeding from a lamp placed behind the scale. The beam of light is defined by a narrow slit or by a small telescope with cross hairs; and, by this artifice, the smallest motion can be measured. It will be observed that the angle described by the reflected beam of light is *double* the angle of deflection, δ, of the magnets, and, further, the scale being placed at right angles to the normal position of the beam of light, the number of divisions d described when a current passes, is proportional to the tangent of the angle described by the reflected beam of light. Hence

$$d \propto \tan 2\,\delta$$

but δ° is a small angle, (maximum 5°) so that

$$d \propto 2 \tan \delta$$

or, since the instrument is a tangent galvanometer,

$$d \propto C$$

It is not always convenient to place these instruments so that the magnets will lie in the magnetic meridian; a magnet is therefore attached to the instrument so as to form an artificial magnetic meridian in any required direction. This magnet slides up and down a brass rod fixed to the top of the instrument, and it can be turned round by hand; a slow motion screw is also provided.

To check the vibrations, an aluminium pallet is sometimes connected to the magnets, and in some cases this pallet is placed in water.†

These galvanometers have very high resistances,‡ and are extremely sensitive; they should invariably be used for accurate measurements, but they require great care in working.

Setting up the instrument.

175. The following instructions should be followed in setting up a reflecting galvanometer:

*The reflecting galvanometer at the R. M. College of Canada, is of this description.

†For instance, in the pattern of reflecting galvanometer used for Submarine mining.

‡The resistance of the reflecting galvanometer at the R. M. C. is 7216 ohms at the temperature of 18° *C.*

1. The support should be rigid and not connected with the floor of the room.*

2. The instrument should be levelled, the magnets being approximately in the magnetic meridian.

3. The scale is placed parallel to the magnets, and at the focal distance† of the mirror from the instrument.

4. The lamp being placed behind the scale, the spot of light is brought approximately to zero, by raising or lowering the scale, and, by means of the directing magnet.

5. The spot of light is brought accurately to zero by the slow motion screw. This operation is only necessary when it is required to *measure* the deflection of the galvanometer. When making comparative measurements and the spot of light moves away from the zero, it should be brought back by sliding the scale, which is arranged for the purpose, and not by means of the directing magnet.‡

GALVANOMETER SHUNTS.

176. It frequently happens that the current flowing in a circuit is, either too powerful to pass through a given galvanometer, or else the reading it gives is too large. In such cases what is called a "shunt," is attached to the galvanometer that is, the current is divided just before entering the galvanometer, and is reunited just after issuing from it. The strength of the current flowing through the galvanometer will evidently depend on the relative resistances of the two parts of the divided circuit, and can therefore be regulated at pleasure.

The problem is:

To find the resistance of a shunt such that only $\frac{1}{n}$th of the current will flow through the galvanometer.

Let g and s be the resistances of the galvanometer and of the shunt respectively; then, according to § 147,

Current flowing through the galvanometer

$$=\frac{C}{n}=\frac{s}{g+s}.C$$

or

$$s=\frac{g}{n-1}$$

*A stone pillar brought up, if possible, from the rock forms a good support.

†This distance is supplied by the instrument maker.

‡These instructions are applicable to the instrument at the R. M. C., but will answer, with modifications, for other reflecting galvanometers.

It will be observed that the introduction of a shunt *reduces* the resistance in the circuit. The simplest plan is, to regard the galvanometer and shunt together as a single resistance $=\frac{gs}{g+s}$, and the symbol g_s will be used to express this resistance.

Further if c_g is the current flowing through the galvanometer.

$$c_g=\frac{s}{g+s}.C=\frac{g_s}{g}.C$$

177. Reflecting galvanometers are generally provided with a set of shunts allowing of $\frac{1}{10}$th, $\frac{1}{100}$th, or $\frac{1}{1000}$th of the current flowing through the galvanometer.

These shunts are constructed like resistance coils (§ 164).

Each galvanometer must evidently have its own set of shunts, and their resistances will be $\frac{g}{9}, \frac{g}{99}, \frac{g}{999}$ respectively. Anyone of these shunts can be put in circuit by means of a peg, and there are further arrangements to allow of either none or the whole of the current being sent through the galvanometer; that is, the resistance of the shunt can be made zero or infinite.

Compensating resistance.

178. It was seen that that the resistance of a galvanometer may be regarded as reduced to $\frac{gs}{g+s}$, when a shunt s is applied. This decrease in the resistance will increase the total current, and, in some cases, the part of the current passing through the galvanometer would not be diminished by the application of the shunt. When this occurs a compensating resistance must be introduced into circuit, and, as it is desirable to have the resistance in circuit before and after the introduction of the shunt the same, so that the total current in both cases may be equal,

$$\text{Compensating resistance} = g-\frac{gs}{g+s}$$

EFFECT OF AN INSTANTANEOUS CURRENT ON A GALVANOMETER.

179. When an instantaneous current is passed through a galvanometer, the magnet is acted upon by an impulsive force, or, in other words, it receives a blow; and it can be shown, that the work done on the magnet by the instantaneous current, varies as the square of the quantity of electricity that passes.*

The initial velocity caused by the instantaneous current is gradually checked by the action of three forces, namely, the mag-

*See Appendix.

netic attraction of the Earth, the resistance of the suspensions and, the resistance of the air; and the magnet is finally brought to rest by them. If the resistance of the suspensions and that of the air be neglected it can be shown* that $\sin^2\frac{\delta}{2}$ is a measure of the work done on the needle by the instantaneous current, provided the current has completely passed before the magnet commences to move. Hence clearly

$$Q^2 \propto \sin^2\frac{\delta}{2}$$

or

$$\frac{Q}{Q'} = \frac{\sin\frac{\delta}{2}}{\sin\frac{\delta'}{2}}$$

Now in a reflecting galvanometer

$$\frac{d}{d'} = \frac{\tan 2\delta}{\tan 2\delta'}$$

And since δ and δ' are small angles,

$$\frac{\sin\frac{\delta}{2}}{\sin\frac{\delta'}{2}} = \frac{\tan 2\delta}{\tan 2\delta'} \quad \text{nearly.}$$

Therefore, when using a reflecting galvanometer,

$$\frac{Q}{Q'} = \frac{d}{d'} \quad \text{nearly.}$$

The nearer d and d' are to each other, the more accurate will be the result; by applying a shunt, the larger of the two deflections can be reduced to any desired extent. Thus if the galvanometer be shunted whilst the quantity Q' is passing,

$$\frac{Q}{Q'} = \frac{g}{g+s} \cdot \frac{d}{d'}$$

180. In the above, however, the resistances of the air and that of the suspensions were neglected. It is therefore necessary to apply a correction to allow for these resistances, which cause the amplitude of the oscillations to rapidly decrease. Suppose that the spot of light describes d divisions of the scale in the first oscillation, and d_1 divisions in the succeeding oscillation to the same side, then $d-d_1$ evidently represents the loss in 4 half oscillations, and, assuming that the loss is approximately the same in each half oscillation, the correction to be applied is $\frac{1}{4}(d-d_1)$ or

$$D = d + \tfrac{1}{4}(d-d_1)$$

*See Appendix.

D is called the "corrected" swing, and is approximately the deflection that would obtain if there were no resistance of the air or of the suspensions.

The formulæ for practical use with a reflecting galvanometer are therefore

$$\frac{Q}{Q'} = \frac{D}{D'}$$

$$\text{and } \frac{Q}{Q'} = \frac{g}{g+s} \cdot \frac{D}{D'}$$

if the galvanometer is shunted whilst Q' is passing.

Balistic galvanometer.

181. Professors Ayrton and Perry have contrived an arrangement by means of which the resistance of the air is reduced to a minimum, of which the following is a description :

"One of Elliott's high-resistance reflecting galvanometers was used, but the needles were removed and replaced by the following arrangement :

"Forty small magnets of varying lengths were prepared, and, having been magnetized to saturation, were built up into two little spheres, in each of which all the magnets pointed in the same direction. The spheres were completed by segments cut from a hollow leaden ball. The two spheres were rigidly connected so as to form an astatic combination, which was suspended in the ordinary manner.

"With this arrangement great sensibility was obtained, and the air offered very little resistance to the motion of the needles. It was found that the ratio of the first swing to the second was only 1.1695, a number which is sufficiently near to unity to allow a simple correction to be applied for the damping effect of the air."*

DIFFERENTIAL GALVANOMETER.

182. A differential galvanometer has two distinct coils, and a current of electricity can be divided, on entering the instrument, into two parts, one part going through one of the coils, and the other through the second coil, in such a manner as to produce reverse effects on the magnet; therefore it is, the difference in the strength of the two parts of the current that is observed. If the current be divided into two equal parts, and the coils have been adjusted so as to produce exactly reverse effects, the needle will clearly not move.

*A Physical Treatise on Electricity and Magnetism by J. E. H. Gordon, B.A., Camb.

183. Latimer Clark's differential galvanometer is constructed on the above principle. The instrument is provided with binding screws, by means of which a resistance, known or unknown, can be introduced into either of the divided circuits, and the instrument is so adjusted that, when the resistances thus introduced are equal, the current is equally divided, and further, the effects of each half of the current on the needle are equal and opposite. The instrument is further provided with two shunts of $\frac{1}{100}$th, one in each of the divided circuits, so that, if required, only $\frac{1}{100}$th of either or both of the divided currents need be sent through the corresponding coils. These shunts are introduced into the circuit by inserting a peg, and cut out by removing the same. If only one of the shunts be put into circuit, the part of the current passing through that circuit will be 100 times larger than the other part when the effects produced on the needle are equal and opposite, or in other words, when the needle does not move; an arrangement, which is very useful for various measurements as will be seen in the sequel. A contact key is also attached to the instrument. In this pattern of differential galvanometer, provision is further made, by means of pegs, to enable the whole current to be passed through one coil, or through both coils, in the same direction. When used in this manner it is, however, no longer a *differential* galvanometer.

PRECAUTIONS TO BE TAKEN TO PREVENT INJURY TO DELICATE GALVANOMETERS.

184. A galvanometer can be damaged, more or less seriously, by passing too strong a current through it. Generally speaking, the more sensitive the galvanometer, the weaker the current that can safely be passed through it. The following are the injuries that may be caused, according to the strength of the current:

1. Injury to the needle suspensions.
2. Demagnetization of the needle.
3. Heating of the wire in the coils, causing destruction of the insulation, and even, if the current be strong enough, melting of the wire.

To avoid these injuries the following precautions should be taken:

(1.) The measurements should be taken by a rapid process (short contacts with a key).

(2.) The galvanometer should be "shunted," so that only a part of the current will pass through the instrument.

HINTS TO OBTAIN GOOD GALVANOMETER READINGS.

185. To obtain accurate and reliable measurements with a galvanometer requires considerable practice. Attention to the following points will assist in taking these measurements.

Comparative galvanometer measurements are vitiated :

(1.) By the polarization of the cell or cells supplying the current, which will effect the E. M. F. differently and to an unknown extent in the separate readings.

(2.) By the heat generated by the current, which alters the resistance of the circuit, also to an unknown extent.

Therefore, methods of measurements requiring a current of electricity to be passed for any length of time through a galvanometer are generally unreliable, and the most accurate methods are those in which the readings are taken by means of short contacts.

186. When the cells in use, or to be tested, are very inconstant, and the galvanometer suspensions are not very delicate, a good method of taking readings is as follows: Hold the needle over by a small piece of brass or wood in such a position (found by successive trials) that it will *just* move on making contact. This will be the reading required.

187. The deflection of a horizontal galvanometer should lie between 20° and 50°, and the best is about 35°. The reason is, that below 20° the friction of the pivot has a proportionately large effect, and beyond 50° a large increase in the current is required to make a perceptible alteration in the deflection. The deflection can be kept within the above limits in two ways :

(1.) By using a directing magnet.

This magnet alters the directive couple, and consequently the amount of deflection.

(2.) By shunting the galvanometer.

FIGURE OF MERIT OF A GALVANOMETER.

188. The "figure of merit" of a galvanometer is the resistance through which one volt will give one degree or division of deflection, and is more particularly applicable to reflecting galvanometers. It is determined by noting the deflection due to a known difference of potential, when the resistance in circuit is known and the galvanometer is shunted to a known extent.

In practice the difference of potential of one cell (generally a Daniell) is substituted for a volt.

Thus, if R_F is the figure of merit

$$\mu \times 1 = \frac{1}{R_F}$$

But

$$\mu d=\frac{g_s}{g}\cdot\frac{P}{R}.$$

Hence

$$R_F=\frac{gRd}{g_sP}$$

Example.—Let the directing magnet be so arranged that one volt gives a deflection of 100 divisions through a resistance of 1000 ohms, a shunt of $\frac{1}{999}g$ being employed, then

$$R_F=1000\times 1000\times 100=100 \text{ megohms.}$$

This number is also called the "constant" of the galvanometer, but, as it depends on the position of the directing magnet, the term is misleading.

THERMO-GALVANOMETER.

189. When a current passes through a wire the temperature of the wire is raised, and, if it is fine enough and the current powerful enough, the temperature will be raised sufficiently to cause fusion of the wire. Further, there is a definite strength of current, which will just fuse each kind and size of wire. This evidently gives a means of measuring currents.

190. The box of Firing resistance coils is provided with a couple of clips, between which a very fine wire,* 0.25″ long, can be secured, and these clips are so arranged that a current can be passed through the wire and through the box of coils. By altering the resistance in circuit, by means of the box, the current can be regulated, by trial, so as to just fuse the wire, and, as mentioned above, this current must have some definite value depending on the diameter and substance of the wire. As will be seen, in the sequel, certain comparative measurements can be made by this arrangement, which is called a Thermo-galvanometer.*

CONDENSER.

191. This instrument is the application of the law of condensation stated in § 151, and consists of a large number of leaves of tin-foil, placed like the leaves of a book, but separated from each other by thin sheets of indiarubber. Alternate leaves of tin-foil are connected together so as to form two distinct systems separated by the dielectric (sheets of india-rubber). Each system is connected to a binding screw, and the condenser can be discharged by means of a peg inserted into a brass bar carrying the binding screws. These instruments are made of various

*The wire usually employed in the Service is made of the alloy iridio-platinum, and is either 0.003″ or 0.0014″ in diameter.

capacities, an average size being $\frac{1}{2}$ microfarad. About 300 sheets of tin-foil are required for a condenser whose capacity is 1 microfarad.

When using the instrument, one binding screw should be connected to the source of electricity, and the other binding screw to Earth. One plate will therefore be at zero potential, and the other at the potential of the circuit at the point of connection. The peg should be removed when taking a measurement, and then replaced to discharge the instrument. The peg should always be in position when the instrument is not in use.

192. If a galvanometer (reflecting) be introduced between a condenser and a point in a circuit, the galvanometer will be deflected, at the instant of making contact, by the momentary current due to the filling up of the condenser to the potential at the point in the circuit. Unless the source of electricity is feeble, or the resistance to be overcome very high, the force deflecting the galvanometer is impulsive, and the result of § 180 can therefore be applied.

Now from § 136

$$Q=Kp_a,$$

Hence

$$\frac{Kp_a}{K'p'_a}=\frac{D}{D'}$$

Or

$$\frac{Kp_a}{K'p'_a}=\frac{g}{g+s}\cdot\frac{D}{D'}$$

if the galvanometer be shunted whilst the condenser, whose capacity is K', is connected.

EXAMPLES.

1. What is the E. M. F. of a Latimer Clark's standard cell at 80° Fahr?

2. What length of German silver wire 0.01″ diam. is required for a resistance coil of 1500 ohms? What length of silver wire of the same diameter would be necessary at 0°C and 15°C?

3. In how many different ways can 1500 ohms be introduced into a circuit by means of a Post Office pattern box of resistance coils?

4. Two tangent galvanometers are precisely similar. Compare the deflections when connected in continuous circuit with the deflections when connected in divided circuit.

5. A tangent galvanometer is shunted, the resistance of the shunt being 10 ohms, and it is found that the deflection given by

one cell whose liquid resistance is 0.1 ohm is 50°. The resistance of the shunt is then altered to 50 ohms, and 100 ohms resistance is introduced into the circuit; the deflection is now 21°. Find the resistance of the galvanometer.

6. A tangent galvanometer, whose resistance is 20 ohms, is placed on short circuit with a cell whose E. M. F. is 1.8 volt, and whose liquid resistance is 0.5 ohm. The deflection is 38°. What current is flowing through this galvanometer when the deflection is 46°?

7. A tangent galvanometer and a sine galvanometer are successively placed on short circuit with a cell whose E. M. F. is 1.1 volt, and whose liquid resistance is 1 ohm, and the deflections are found to be 18° and 30° respectively. The resistance of the tangent galvanometer is 2 ohms, and that of the sine galvanometer 30 ohms. What deflection on the sine galvanometer would be given by a current which gives 25° on the tangent galvanometer?

8. A shunt of 11 ohms is connected to a galvanometer whose resistance is 232 ohms. What portion of the current will flow through the galvanometer?

9. A shunt of 12 ohms is applied to a galvanometer whose resistance is 5081 ohms, the total resistance in circuit is then 100 ohms. The shunt is now removed and 100 ohms resistance added to the circuit. Compare the currents flowing through the galvanometer in the two cases.

10. A galvanometer has a resistance of 1050 ohms. It is required to apply a shunt such that $\frac{1}{500}$th of the current will flow through the galvanometer. What should the resistance of the shunt be?

11. Two Daniell's cells give 209 divisions deflection on a shunted reflecting galvanometer. The resistance in the circuit, exterior to the galvanometer, is 3050 ohms, the resistance of the galvanometer itself is 7080 ohms, and that of shunt 7 ohms. What is the figure of merit of this galvanometer in megohms, (1) in terms of one volt, (2) in terms of one Daniell's cell?

12. A certain instantaneous current was found to give 232 divisions of deflection for the first swing, and 200 for the second. Another instantaneous current gave 198 and 170, Compare the quantities of electricity that passed.

CHAPTER IV.

ELECTRICAL MEASUREMENTS.

193. The usual electrical measurements that may be required for Military Engineering purposes can be tabulated as follows:

1. Measurement of Resistance.

a. Resistance, of a conductor, of a galvanometer, of "earths," etc.

b. Liquid resistance of a cell.

2. Measurement of difference of Potential.

The measurement of the electro-motive force of a source of electricity is a special case.

3. Measurement of the strength of a current of electricity.

4. Measurement of capacity.

MEASUREMENT OF RESISTANCE.

194. The resistance to be measured may be that:

1. Of a conductor, generally a wire.

2. Of a galvanometer, *i.e.* the resistance of the wire composing its coils.

3. Of an electro-magnet.

4. Of the insulation of a circuit.

The general methods of measuring these various resistances are the same, but in some cases, induced* and secondary* currents are generated by the process of measuring, and precautions must be taken to prevent these currents from falsifying the results.

5. Of the liquid in a cell.

The measurement of the liquid resistance of a cell requires special methods, some of which are described in §§ 216–223.

*See §§ 893 and 796, Ganot's Physics, 9th Edition.

195. The resistance of a conductor increases with the temperature, and the effect of an electrical current is to raise the temperature of the conductor through which it is flowing. The test-current employed should therefore not be strong enough to perceptibly raise the temperature of the unknown resistance. When the resistance is required very accurately, the following correction should be made :

The markings, on the box of coils, with which the measurement was made, are only true at a certain temperature, given on the box. If the temperature, at which the measurement was taken, is lower, a deduction must be made from the measured resistance, but if the temperature be higher the correction is to be added. The amount of the correction depends (1) on the difference between the temperature given on the box and that of the experiment, and (2) on the nature of the wire in the coils. The resistance is thus obtained at the temperature of the experiment, but a further correction must be made, if the resistance at the standard temperature of 60° Fahr. is required.*

196. *Connecting unknown resistance to measuring apparatus.*—The unknown resistance should be connected to the measuring apparatus by means of short thick leads, and if the resistance to be measured is small, and accuracy is required, a correction should be made by deducting the resistance of these connections from the measured resistance. When the resistance to be measured is that of very fine wire it is often important to be able to ascertain the exact length of the wire in circuit, in such a case the point of connection must be very clearly defined. This can be done by means of the clips of the thermo-galvanometer, or again by the following arrangement : One end of a short piece of thick copper wire is flattened, and to it one extremity of the fine wire is soldered. The other end of the thick wire is bent into a hook, to make connection with the binding screw of the measuring apparatus. A similar piece of copper wire is soldered to the other end of the fine wire.

BY WHEATSTONE'S BRIDGE.

197. The typical form of Wheatstone's bridge can be represented by a quadrilateral *A B C D* (Fig. 14), the sides and

Fig. 14.

*For data see Table II.

diagonals of which are formed of conductors. Known resistances r_1 and r_2 are placed in the sides AB and AD, a known resistance r_b that can be varied at pleasure (box of resistance coils), in the side BC, and the unknown resistance r_x in the side DC. A test cell and a key are placed in the diagonal AC, and a galvanometer in the diagonal BD. Now, if A is at a higher potential than C, due to the cell placed in AC, there will be a fall of potential along ABC and along ADC; and the rate of fall will depend on the resistances. Evidently, by giving a suitable value to the resistance r_b in BC, the potential at B can be made equal to that at D. When this is the case, no current will pass along the diagonal BD, and this state of things can be ascertained by means of the galvanometer which will then give no deflection.

Now if p_a is the potential at A, p_b that at B or D, and p_c that at C, when the *balance* has been effected, it will appear from Fig. 15 which represents the fall of potential graphically (See § 146) that

$$\frac{p_a-p_c}{p_b-p_c}=\frac{r_1+r_b}{r_b}=\frac{r_2+r_x}{r_x}$$

or

$$r_x=\frac{r_2}{r_1}.r_b \qquad \text{I.}$$

and thus r_x is known in terms of r_1 r_2 and r_b.

Fig. 15.

198. As already mentioned a Wheatstone's bridge arrangement provided in the Post Office box of resistance coils, and in the Firing resistance coils. In the former two sets of resistances of 10, 100 and 1000 ohms are provided; they form the resistances r_1 and r_2, and the binding screws are so arranged, as to enable the connections described above, to be made.

It will be seen that the following convenient values of the ratio $\frac{r_2}{r_1}$ can be obtained by means of the resistances provided:

$$\tfrac{100}{1},\ \tfrac{10}{1},\ 1,\ \tfrac{1}{10},\ \tfrac{1}{100}.$$

Which of these ratios to use clearly depends on the value of r_x, as will be illustrated by the two following examples:

1. r_x large; using ratio $\frac{100}{1}$, r_b is found to be 3010 ohms, hence $r_x=3010\times 100=301{,}000$ ohms.

2. r_x very small; using ratio $\frac{1}{100}$, r_b is found to be 1.2 ohm, hence $r_x = 1.2 \times \frac{1}{100} = 0.012$ ohm.

The Post Office coils have a range of 1 to 11,110 ohms, hence by their means resistances varying from 0.01 to 1,111,000 ohms can be directly measured.

When r_x is quite unknown the ratio of $\frac{1}{1}$ should, in the first instance, be used, until the resistance has been approximately obtained. In such a case also, the galvanometer should be shunted until the balance is nearly reached.

The following arrangement of resistances r_1 and r_2 will be found to give good results:

Unknown resistance between:			make	r_1	r_2.
1,000,000	and	100,000	ohms	10	1000
100,000	"	10,000	"	100	1000
10,000	"	1,000	"	1000	1000
1,000	"	100	"	1000	100
100	"	0	"	1000	10

199. The firing resistance coils are provided with two resistances of 10 ohms each, and these form the branches AB and AD of the Wheatstone's bridge; the remainder of the resistances in the box form the branch BC. The binding screws are arranged so as to allow of the required connections being made, and, in such a manner as to bring the key on the box into the diagonal AC. Since r_1 and r_2 are equal it is clear that when the potential at B is equal to that at D,

$$r_x = r_b, \qquad \text{II.}$$

so that the unknown resistance is equal to the resistance unplugged in the box of coils when the balance has been arrived at. With this Wheatstone's bridge, therefore, resistances varying from 0.05 to 100 ohms, can be measured directly to within 0.05 ohm, if the galvanometer used be sensitive; but in the Field, the 3-coil galvanometer (with the 10-ohm coil in circuit) is the Service instrument. It will be found in this case, that two resistances can be unplugged, one of which makes the galvanometer *just* move to the right, and the other to the left; the mean of these two resistances is within about 1 p.c. of the true value, when using *one* Service test cell.

200. The balance is obtained practically as follows: At first no pegs are removed from the box, a deflection will then be obtained, unless the unknown resistance r_x is zero. The direction of this deflection should be noted thus: "Left (or right) too little." Trial resistances are then unplugged in the box, until finally that resistance has been introduced for which the galvanometer does not deflect. This will be the value of r_b to insert in eqs. I. or II.

201. When working with a very sensitive galvanometer, it will probably happen that the exact resistance ,with which there is no deflection, cannot be unplugged. In this case, when great accuracy is required, the nearest resistances in excess, and in defect, should be introduced, and the deflection of the galvanometer noted in each case. Let d and d_1 be the deflections and r_b the nearest resistance in *defect*, then

$$r_x = \frac{r_2}{r_1}\left\{r_b + \frac{d}{d+d_1}\right\}$$

Measuring the resistance of a coiled wire.

202. If the wire, of which the resistance is to be obtained, be coiled, a momentary induced current will be produced on making and breaking the circuit.* This effect will occur, for instance, when measuring the resistance of a galvanometer, or of the wire of an electro-magnet.

This induced current has its origin in the branch *DC* of the Wheatstone's bridge, (see Fig. 14) and it will cause a difference of potential between the points *B* and *D*, so that there will be a deflection on the galvanometer, even when the resistance which gives the balance is unplugged. But the induced current is only momentary, and disappears directly the test current has been established. Hence, a key should be placed in the diagonal *BD*, by means of which the galvanometer can be kept out of circuit until the induced current has disappeared, when the balance can be obtained. The method of working is to first depress the "battery key," and immediately after the "galvanometer key." The Post Office pattern box of resistance coils is provided with two keys,† and the binding screws on the instrument are so arranged that these keys may be used for the above purpose.

BY LATIMER CLARK'S DIFFERENTIAL GALVANOMETER.

203. It was seen, when describing this instrument, that binding screws are provided to allow of resistances being introduced into each of the divided circuits, and, that there will be no deflection when the currents flowing in each branch, *through the galvanometer*, are equal and opposite. It was also seen that when both shunt pegs are in, or when both are out, these currents will be equal if the resistances introduced are equal ; but that when one shunt peg is left in and the other taken out, the resistance corresponding to the peg that has been left in will be 100 times *smaller* than the other resistance.

Hence, if the unknown resistance be placed in one branch, and a box of resistance coils in the other, a resistance can be unplug-

*See § 893, Ganot's Physics, 9th Edition.

†See § 166.

ged in the box which will either be equal to, or 100 times larger or smaller, than the unknown resistance, according to the arrangement of the shunt pegs, and, when this resistance is unplugged, there will be no deflection on the galvanometer.

The practical working is as follows:

The connections are made as shown in Fig. 16. The shunt

Fig. 16.

pegs being in place, infinity is unplugged in the box of coils,* and a short contact is made with the key attached to the instrument; the direction of deflection of the needle is noted thus, "Left (or right) too much." Trial resistances are then unplugged in the box of coils, until an approximate balance is obtained. The shunt pegs are then adjusted, according to the magnitude thus found for the unknown resistance, and the correct balance obtained. If the resistance be of medium magnitude both shunt pegs should be removed, so as to make the instrument more sensitive. A convenient rule to remember, when the shunt pegs are used for multiplying or dividing, is "Remove the shunt peg on the side of the highest resistance." If the box of coils has a range of 1 to 11,110 ohms, resistances varying from 0.01 to 1,111,000 ohms can be measured by the above method.

MEASURING THE RESISTANCE OF A GALVANOMETER.

204. The resistance of a galvanometer can be found, like that any other unknown resistance, by the methods explained in § 197, etc. But a galvanometer may be used to measure its own resistance by the following method, due to Sir William Thomson.

The ordinary Wheatstone's bridge connections are formed,† with this difference, that a contact key replaces the galvanometer in the diagonal BD, and the galvanometer, whose resistance is to be measured, is put in the side DC as the unknown resistance. Fig.

*If the box of coils does not contain an infinity peg, the same result can be obtained by disconnecting the box. Or, no resistance is unplugged in the first instance, in which case the note should be "Left (or right) too little."

†See § 197.

17.* Now if the resistance r_b be so adjusted that the potential at B is equal to the potential at D, namely if the relation

$$gx = \frac{r_2}{r_1} r_b$$

holds, it is clear that no change will be produced in the strength

Fig. 17.

of the current flowing through the galvanometer when the key is depressed; but this current will either be decreased or increased if these potentials are unequal, and this will be indicated by an alteration in the deflection of the galvanometer on depressing the key.

The practical working is precisely the same as that employed in the ordinary Wheatstone's bridge method,† and need not therefore be further described.

If the current flowing through the galvanometer gives too large a deflection, a shunt of known resistance can be applied, in which case the resistance measured is $\frac{gx s}{gx+s}$ from which gx can be found, since s, the resistance of the shunt, is known.

MEASUREMENT OF VERY HIGH RESISTANCES.

205. If the unknown resistance be greater than can be measured by the previous methods recourse must be had to the following:

The unknown resistance is placed in circuit with a reflecting galvanometer and a test-battery, and the deflection is noted. The unknown resistance is then replaced by a known resistance and the deflection is again noted, one cell only of the test-battery being in circuit, and the galvanometer being shunted.

Let d be the deflection on the reflecting galvanometer, when the unknown resistance r_x is in circuit, given by a test-battery composed of n cells, the E. M. F. of each cell of which is P. Further let d' be the deflection on the shunted galvanometer,

*Compare with Fig. 14.

†See § 200.

when the known resistance r' is in circuit, given by *one* cell whose E. M. F. is P. Then

$$\mu d=\frac{nP}{r_x+g+n\rho}$$

and (§ 176.)

$$\mu d'=\frac{g_s}{g}\cdot\frac{P}{r'+g_s+\rho}$$

Hence

$$r_x=\frac{gd'n(r'+g_s+\rho)}{g_s d}-(g+n\rho)$$

But $(g+n\rho)$ can be neglected, therefore

$$r_x=\frac{gd'n(r'+g_s+\rho)}{g_s d}$$

This method is employed to find the insulation resistance of electrical cables.

Example.—Let $n=20$, $\rho=1$ ohm, $g=7000$ ohms, $s=7$ ohms, $r'=4000$ ohms, $d=100$, and $d'=50$; then

$$r_x=\frac{7000\times 50\times 20(4000+7+1)}{7\times 100}=40{,}080{,}000 \text{ ohms}-$$

206. It will be observed* that the expression $\frac{gd'(r'+g_s+\rho)}{g_s}$ is the figure of merit, in terms of the test cells in use, of the galvanometer.† Thus, if many measurements of high resistances have to be made, and the galvanometer is not altered in any way, the unknown resistance can be found more simply from the formula

$$r_x=\frac{nR_F}{d}$$

Example.—The figure of merit of a galvanometer is 100,000,000 ohms. The number of cells in the test-battery is 15, and they give a deflection of 10 divisions through the unknown resistance. Here

$$r_x=\frac{15\times 100{,}000{,}000}{10}=150 \text{ megohms.}$$

BY TANGENT GALVANOMETER.

207. If δ be the deflection given by a cell, whose E. M. F. is P, when the unknown resistance is in circuit, and δ' the deflection due to the same cell, when a known resistance r' is in circuit, then $\tan\delta$ and $\tan\delta'$ are measures of the two currents.‡

*See § 188.

†That is substituting the E. M. F. of one test-cell for one volt.

‡See § 173.

Now, as explained in § 187, δ and δ' should lie between 20° and 50°; r' can be so chosen as to make δ' any convenient value, and when the unknown resistance is in circuit, the galvanometer can be shunted so as to obtain a good reading, in which case, $\frac{g}{g_s}$ tan δ measures the whole current.*

Therefore

$$\mu \tan \delta = \frac{g_s}{g} \cdot \frac{P}{r_x + g_s + \rho}$$

and

$$\mu \tan \delta' = \frac{P}{r' + g + \rho}$$

whence r^x can be found.

Readings within the above limits, can also be obtained by using a directing magnet, but great care should be taken not to alter the position of this magnet when the known resistance is placed in circuit.

Here

$$\mu \tan \delta = \frac{P}{r_x + g + \rho}$$

and

$$\mu \tan \delta' = \frac{P}{r' + g + \rho}$$

The above method is not accurate, because the test cell polarizes, and P has not therefore the same value throughout, which, of course, is essential to the accuracy of the method.

A reflecting galvanometer can be used for the above measurements, in which case tan δ and tan δ' must be replaced by d and d'.

MEASUREMENT OF RESISTANCE WITH THE THREE-COIL GALVANOMETER.

208. Rough measurements of resistance can be made with a 3-coil galvanometer in the following manner:

209. The deflection, δ, given by one cell (a Leclanché cell for instance), is found when the 1000-ohm coil is in circuit. The unknown resistance is then introduced, and the deflection δ' obtained.

Now

$$C = \frac{P}{1000 + \rho}$$

*See § 176.

And

$$C' = \frac{P}{r_x + 1000 + \rho}$$

But the ratio

$$\frac{C}{C'} = a$$

can be found from Table II, since the deflections δ and δ' are known, hence

$$r_x = (1000 + \rho)\ (a - 1)$$

The value of ρ must be estimated. This method will give results within about 15 p.c. of the truth, when the resistance does not exceed 900 ohms, and is not less than 100 ohms.

210. If the resistance exceed 900 ohms, the second reading should be taken with more than one cell in circuit. For instance, if the resistance does not exceed 10,000 ohms, and is not less than 6,000 ohms, 6 cells should be used.

In this case

$$C = \frac{P}{1000 + \rho}$$

$$C' = \frac{6P}{r_x + 1000 + 6\rho}$$

whence, as in the previous case (§ 209), and neglecting 5ρ.

$$r_x = (1000 + \rho)\ (6a - 1)$$

The general equation is

$$r_x = (1000 + \rho)\ (n\,a - 1)$$

where n is the number of cells with which the second reading δ' is taken.

The following table gives the number of cells to use according to the magnitude of the resistance.

r_x between	100	and	900	ohms,	$n = 1$.
" "	900	"	3,000	"	$n = 2$.
" "	3,000	"	6,000	"	$n = 4$.
" "	6,000	"	10,000	"	$n = 6$.

The resistance of high tension fuzes, and the insulation resistance of the cables used to fire these fuzes, can be found in this way.

The galvanometer should be placed at right angles to the magnetic meridian, so that the index may point accurately to zero. The galvanometer should be gently tapped whilst taking a reading, as the needle is liable to stick.

Example.—Let $\delta = 59°$, and $\delta' = 52°$ taken with 2 cells in circuit; then if $\rho = 18$ ohms,

$$r_x = (1000 + 18)\ (2 \times 1.3 - 1) = 1630 \text{ ohms.}$$

ROUGH TEST OF VERY LOW RESISTANCES.

211. The 2-ohm coil of a 3-coil galvanometer is placed on short circuit with a test-cell and the deflection is noted. The unknown resistance is then introduced into the circuit, and, if it does not exceed about 0.5 ohm, the deflection will be the same as when the test-cell was on short circuit. The 2-ohmcoil is chosen, because its resistance being low, a small alteration in the resistance of the circuit, will cause a change in the current sufficiently great to be detected by the galvanometer.

The above is used for testing the continuity of circuit wires, and for testing wire fuzes, when the apparatus for making an accurate measurement is not available.

ROUGH TEST OF THE INSULATION RESISTANCE OF A CABLE.

212. The following applies only to the Land Service cables used for firing wire fuzes,* and, the object being to ascertain the condition of the cable, rather than its insulation resistance when laid out, the cable is put into water, so as to obtain connection with possible leaks. Care should be taken that both ends of the cable are out of the water and are kept quite dry. The connections are: one end of the cable to the 1,000 ohm coil of a 3-coil galvanometer; the galvanometer, through a key, to one pole of a test cell; and the other pole of the cell to a short insulated lead, of which the last three inches are bared and the metal brightened. This short lead is placed in the water. Now, if there be no deflection on the galvanometer, on depressing the key, the insulation is *practically* perfect. But, if there be any deflection, the insulation is defective, and the more defective it is, the larger the deflection. The free end of the cable is now connected to the short lead; the deflection in this case should not be *less* than twice the former one. The necessary connections are shown in Fig. 18.

Fig. 18.

If the second reading be twice the first reading the insulation resistance is rather more than 1,000 ohms, for the current in the first case is rather less than $\frac{1}{2}$ of the current in the second case,† and hence

*Finding the resistance of leaks on a submarine cable requires a different method.

†See § 170 and Table II.

$$\frac{P}{r_x + 1{,}000 + r + \rho} < \frac{1}{2}\left\{\frac{P}{1{,}000 + r + \rho}\right\}$$

or

$$r_x > 1{,}000 \text{ ohms.}$$

TO DETECT THE POSITION OF AN INSULATION FAULT IN AN ELECTRICAL CABLE.

213. If the above test shows that the insulation resistance is very small, the main fault will probably occur at one or two places. The position of these faults can be found by retaining the connections already made for the insulation test; experimenting with the dry cable at first, and then gradually drawing it through the water. A sudden deflection of the galvanometer clearly indicates a fault.

If the cable be in position, other methods must be employed.

BY FUSION OF FINE WIRE.

214. The thermo-galvanometer attached to the Firing resistance coils can be used, occasionally, for measuring low resistances, when a powerful current is available, and its passage will not injure the wire etc., to which the resistance to be measured is due.

One pole of a battery, capable of fusing fine wire, is connected to the thermo-galvanometer, and the other to the wandering peg; and the resistance through which the battery will *just* fuse a standard wire,* is determined. This measurement must be made by a series of trials, and for the first trial little or no resistance is introduced into circuit. The resistance is then gradually increased, and by 1-20th ohm as the sought resistance is approached; the length of wire deflagrated is a guide to the amount by which to increase the resistance for the next trial. Let r_b be the resistance unplugged in the box of coils when the wire is just fused.

Should too high a resistance be unplugged, a fresh start must be made, for the battery polarizes if the wire be not at once fused. To further insure accuracy, the contacts should be of equal lengths, of about $\frac{1}{2}$ second duration.

The unknown resistance, having now been introduced into the circuit, the resistance through which the same wire can be fused is found; let r'_b be the resistance introduced by the box of coils in this case; then

$$r_x = r_b - r'_b$$

This method is used for measuring the resistances of "earths" in a circuit of submarine mines.

*The best wire to be used is the standard 0.0014″ iridio-platinum wire.

DETERMINATION OF THE RESISTANCE OF FINE WIRE AT THE POINT OF FUSION.

215. The resistance of fine wire at the point of fusion is required, when calculating the battery power necessary to fire electrical wire fuzes. This resistance can be determined in the following manner, by means of a box of Firing resistance coils and a battery capable of fusing the wire.*

The experimental wire is placed in the clips of the thermo-galvanometer, and the connections are so arranged, that the current will pass through the wire and the box of coils. The resistance that can be unplugged, so that the wire is just fused, is then found, taking the precautions, mentioned in § 214, to prevent polarization. Let this resistance be r_b, and let r_x be the resistance of the wire at the point of fusion. *Double* the length of wire is then placed in the clips, and the resistance found through which this length of wire is just fused. Let r_b' be this resistance and it is clear that in this case the resistance of the wire is $2\,r_x$.

Now the currents in both cases are evidently equal, and, since the same battery was employed, it follows that the resistance in circuit must also have been equal; hence

$$r_b + r_x + \rho = r_b' + 2\,r_x + \rho$$

or

$$r_x = r_b - r_b'$$

If l, expressed in inches, be the length of the wire in the first case (*i. e.* the distance apart of the clips†) $\frac{r_x}{l}$ is the resistance of the wire, per inch, at the temperature of fusion.

MEASUREMENT OF THE LIQUID RESISTANCE OF A CELL.

216. The liquid resistance of a cell cannot be found by any of the methods just described, because the current produced by the cell under examination interferes with the measurements. Other methods must therefore be adopted, and in all of them the cell supplies the current used to effect the measurement. Generally speaking, it is more difficult to overcome the effects of polarization when measuring liquid than when measuring ordinary resistances, and it is therefore more difficult to obtain accurate results.

*Grove's cells will give the best results.

†See § 190.

BY MANCE'S WHEATSTONE'S BRIDGE METHOD.

217. The arrangement is very similar to the ordinary Wheatstone's bridge for measuring resistances, and its typical form as follows:

In a quadrilateral *A B C D*, (Fig. 19) formed of conductors,

Fig 19.

the sides *AB* and *AD* contain known resistances r_1 and r_2, the side *BC* a resistance r_b that can be varied at pleasure, and the side *DC* the cell or battery under examination. A galvanometer is placed in the diagonal *AC*, and a key in the diagonal *BD*. It will be noticed, on comparing with the ordinary Wheatstone's bridge (Fig. 14), that the cell takes the place of the unknown resistance, the galvanometer the place of the cell, and the key that of the galvanometer. A second key is placed in *DC*, so that the circuit may be made, or broken at pleasure. On depressing this key the current divides at *C*, re-uniting again at *A*, and the part of the current flowing through the galvanometer is, from § 147.

$$c = \frac{r_1 + r_b}{r_b + r_1 + g} \cdot \frac{P}{\dfrac{(r_b + r_1)\,g}{r_b + r_1 + g} + r_2 + \rho x}$$

When the key in the diagonal *BD* is depressed, the points *B* and *D* become electrically the same, and the part of the current flowing through the galvanometer divides again at *A*, flowing along *AD* and *ABD*. In this case the current flowing through the galvanometer is

$$c' = \frac{r_b}{r_b + g + \dfrac{r_1\ r_2}{r_1 + r_2}} \cdot \frac{P}{\dfrac{r_b\left(g + \dfrac{r_1\ r_2}{r_1 + r_2}\right)}{r_b + g + \dfrac{r_1\ r_2}{r_1 + r_2}} + \rho x}$$

Now the balance is obtained when, on depressing the key in the diagonal *BD*, there is *no change* in the deflection of the galvanometer. This requires that the currents flowing through the galvanometer in both cases shall be equal. That is

$$c=c'$$

The above expressions must therefore be equated, and it will be found on simplification that

$$\rho_x=\frac{r_2}{r_1}.r_b$$

The binding screws provided on the Post Office pattern box of resistance coils allow of the necessary connections being made for Mance's method, and, as the practical working is almost precisely similar to that of the ordinary Wheatstone's bridge method, it is unnecessary to describe it.

BY THE DEFLECTION OF A GALVANOMETER.

218. *Using a tangent galvanometer.*—The cell, or battery, of which the liquid resistance is to be found, is placed in simple circuit with a tangent galvanometer and a box of resistance coils, as shown in Fig. 20. Resistances r^b and r'_b are unplugged, and the corresponding angles of deflection, δ and δ', are observed. Now*

$$\mu \tan \delta=\frac{P}{\rho_x+r_b+g+r}$$

$$\mu \tan \delta'=\frac{P}{\rho_x+r_b'+g+r_c}$$

Whence

$$\rho_x=\frac{(r'_b+g+r_c)\tan \delta'-(r_b+g+r_c)\tan \delta}{\tan \delta-\tan \delta'}$$

The resistance of the galvanometer must therefore be known, or else found.

Fig. 20.

This method, similarly to the last, is unsuitable for inconstant batteries.

If a *reflecting galvanometer* be used, tan δ and tan δ' are replaced by d and d'.

*See § 173.

219. *Using a sine galvanometer.*—A similar method is applicable with a sine galvanometer,* and the resistance can then be found from the formula

$$\rho_x=\frac{(r'_b+g+r_c)\sin\delta'-(r_b+g+r_c)\sin\delta}{\sin\delta-\sin\delta'}$$

220. With either galvanometer a shunt may have to be used, to keep the deflections within proper limits. In this case g must be replaced, in the above equations, by g_s.†

To reduce the effect of polarization r_b and r_b' should be large, and the difference of value between them not too great.

BY THE FUSION OF FINE WIRE.

221. This method is applicable when the battery, of which the liquid resistance is required, is powerful enough to fuse fine wire.

This method can therefore only be used when the liquid resistance is very small, and the E. M. F. is large; as is the case in the voltaic batteries, used for firing electrical fuzes. The standard 0.003″ and 0.0014″ iridio-platinum wires are very suitable.

The thermo-galvanometer, attached to the Firing coils, can be used for the purpose. One pole of the cell, or battery, is connected to the thermo-galvanometer, and the other to the wandering peg, so that the circuit is completed on depressing the key. It is first found what resistance r_b can be unplugged, so that *one* wire will just be fused, and secondly the corresponding resistance r'_b when *two* wires are just fused. In the second case the two wires form a divided circuit, each branch of which has the same resistance, so that the current is equally divided between the two wires; from which it follows that the current necessary to fuse two wires is double the current required to fuse one wire. Now the current in the first case is

$$C=\frac{P}{\rho_x+r_b+r_p+r_c}$$

and therefore in the second case

$$2C=\frac{P}{\rho_x+r'_b+\frac{1}{2}r_p+r_c}$$

where ρ_x is the liquid resistance required, r_p is the resistance of *one* iridio-platinum wire *at the point of fusion*,‡ and r_c is the resistance of the connections.§ Hence

$$\rho_x=r_b-2r'_b-r_c$$

*See § 172.
†See § 176.
‡See § 215, and Table II.
§See § 196.

In finding the resistances r_b and r'_b, the precautions, mentioned in § 214, must be taken.

It will be observed, that the accuracy of this method depends on the diameter of the wire being constant.

BY LATIMER CLARK'S DIFFERENTIAL GALVANOMETER.

222. In this method the connections and pegs are, in the first instance, so arranged that the current flows through only *one* coil, and then they are altered to enable the current to flow through *both* coils, in the *same* direction.* The cell is connected to one side of the instrument, and a box of resistance coils to the other. Let r_b be the resistance unplugged in the box of coils in the first instance, then, for the second reading, a resistance r'_b must be found, such that the deflection of the needle will be the same as before.

Clearly the current in the first instance is double the current in the second instance, that is

$$C=2C'$$

and

$$C=\frac{P}{\rho_x+r_b+g+r_c}$$

$$C'=\frac{P}{\rho_x+r'_b+2g+r_c}$$

where g is the resistance of *one* coil of the differential galvanometer,† and r_c is the resistance of the connections.‡ Hence

$$\rho_x=r'_b-2r_b-r_c$$

The necessary connections are shown in Fig. 21. A suitable

Fig. 21.

deflection§ can be obtained by adjusting r_b, and by arranging the

*See § 183.

†If the galvanometer be shunted, g must be replaced by g_s.

‡See § 196.

§See § 187.

shunt pegs, which must either be both in, or both out; but a directing magnet is more convenient, and its use generally enables r_b to be made zero, when

$$\rho_x = r'_b - r_e$$

Accurate results cannot be expected by this method, if the cell be inconstant, for the method is based on the assumption that P has the same value for both readings.

BY KEMPE'S METHOD.

223. In Kempe's method, the negative pole of the cell or battery, of which the liquid resistance is required, is connected to a reflecting galvanometer. The galvanometer is connected to one plate of a condenser, the other plate is connected, through a key, to the positive pole of the battery, and also to "earth." A box of resistance coils is placed between the negative pole and the key. The arrangement is shown in Fig. 22.

Fig. 22.

The first reading is taken when the resistance in the box of coils is infinite, and the *corrected** deflection D measures the potential P, at the positive pole of the cell. For the second reading, a resistance r_b is unplugged in the box of resistance coils; the corrected deflection D' will in the case measure the potential p at the negative pole of the cell or battery, which is less than P by the fall of potential due to the liquid resistance. From Fig. 23, which exhibits graphically† the fall of potential

Fig. 23.

*See § 180.
†See § 146.

in the circuit through the box of coils, when the resistance r_b is unplugged, it appears that

$$\frac{P}{p}=\frac{r_b+\rho_x}{r_b}$$

But, according to § 192, and since the same condenser is used for both readings (*i.e.*, $K=K'$)

$$\frac{P}{p}=\frac{D}{D'}$$

Hence

$$\rho_x=\left\{\frac{D}{D'}-1\right\}r_b$$

whence ρ_x can be found. In practice r_b can generally be so adjusted as to make

$$D=2D'$$

In this case, therefore

$$\rho_x=r_b$$

This method will give good results, and is applicable to inconstant batteries; but it requires careful manipulation. Great care should be taken to prevent the leads connected to the box of coils from influencing the galvanometer.

MEASUREMENT OF DIFFERENCE OF POTENTIAL.

224. The general problem is to measure the difference of potential between any two points in a circuit. Let these two points be denoted by A and B; let p_a be the potential at A, and p_b that at B, then p_a-p_b is the difference of potential between A and B.

These measurements are made by comparing p_a-p_b with some known difference of potential, such as that furnished by a standard cell.

225. The cells to be used, to obtain the known difference of potential, are either Latimer Clark's standard, Grove's, Bunsen's, or Daniell's.*

BY LAW'S CONDENSER METHOD.

226. One plate of the condenser is connected to the point B,† and the other through a key to the point A; a reflecting galvanometer is introduced between A and the condenser, as shown in

*See §§ 158 161.

†See § 224.

Fig. 24. When the key is depressed, the condenser is charged with a difference of potential, equal to $p_a - p_b$, and the corrected*

Fig. 24.

deflection on the galvanometer measures this difference of potential.

The difference of potential $p_a - p_b$ is next replaced by a standard cell, whose E. M. F. is P', as shown in Fig. 25, and the deflection of the galvanometer is measured.

Fig. 25.

For accuracy, however, both deflections should be nearly the same; the galvanometer should therefore be shunted, as shown in the figure. Then, if D and D' are the corrected* deflections obtained with $p_a - p_b$ and the standard cell respectively, it appears from § 192, since $K = K'$, that

$$p_a - p_b = \frac{g}{g+s} \cdot \frac{D}{D'} \cdot P'$$

If no shunt be necessary, the formula is reduced to

$$p_a - p_b = \frac{D}{D'} \cdot P'$$

This method will, with care, give good results.

BY THE DEFLECTION OF A GALVANOMETER.

227. In this method the measuring apparatus consists of a galvanometer and a box of resistance coils, connected together in simple circuit, and attached to the points A and B,† as shown in Fig. 26.

*See § 180.

†See § 224.

A resistance r_b is then unplugged, so as to give a suitable deflection, after which the measuring apparatus is disconnected and

Fig. 26.

attached to a standard cell, when a resistance r_b' is found, by trial, such that the deflection is the same as before. Evidently the current, which flowed through the galvanometer in the first case, is equal to the current flowing in the second case; hence, if $p_a'-p_b'$ be the difference of potential between the points A and B, whilst the measuring apparatus is connected, and P' the E. M. F. of the standard cell.

$$\frac{r}{r+r_b+g}\cdot\frac{p_a-p_b}{\dfrac{r(r_b+g)}{r+r_b+g}}=\frac{P'}{r'_b+g+\rho'}$$

or

$$p'_a-p'_b=\frac{r_b+g}{r'_b+g+\rho}.P' \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(a)$$

228. It will be observed that the introduction of the measuring apparatus alters the resistance of the circuit, and this will affect the difference of potential between A and B. A correction must therefore be applied, as follows: Let R be the total resistance in the circuit, and r the resistance between A and B, before the introduction of the measuring apparatus, then

$$p_a-p_b=rC=\frac{r}{R}.P\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(b)$$

Now, when the measuring apparatus is connected, as a loop, to to the points A and B, the resistance between these points will no longer be r, but becomes $\dfrac{r(r_b+g)}{r+r_b+g}$, and the current is altered to

$$C'=\frac{P}{R+\left\{\dfrac{r(r_b+g)}{r+r_b+g}-r\right\}}$$

and hence

$$p_a'-p_b'=\frac{r(r_b+g)}{r+r_b+g}.C'$$

$$=\frac{r(r_b+g)}{r+r_b+g}.\frac{P}{R+\left\{\dfrac{r(r_b+g)}{r+r_b+g}-r\right\}}\ldots\ldots\ldots\ldots\ldots(c)$$

Eliminating P between the equations (b) and (c), and combining with equation (a), it will be found that

$$p_a - p_b = \frac{R(r_b+g)+(R-r)r}{(r_b'+g+\rho)R}.P'$$

If, however, r_b+g is large in comparison to r, the resistance between the points A and B will not sensibly be altered by the application of the measuring apparatus; in such a case it is therefore unnecessary to make the above correction.

This method has, therefore, the disadvantages of requiring lengthy calculations, and the determination of several resistances. It is further subject to the effects of polarization.

A very delicate galvanometer should be employed, even if fairly accurate measurements are required.

229. The best method of measuring difference of potential is by means of Thomson's electrometer; Latimer Clark's Potentiometer also gives good results. These methods will not, however, be described, as the apparatus for the purpose is not generally available.

MEASUREMENT OF THE ELECTROMOTIVE FORCE OF A CELL OR BATTERY.

230. The measurement of the electromotive force of a cell, or battery, is the measurement of the difference of potential between the poles of the cell, or battery; that is, the poles are the points A and B, mentioned in § 224.

But a simplification can be introduced in the practical working, because the galvanometer and the box of coils can be placed directly in the circuit, and not on a loop.

The arrangements will then be as follows.

BY LAW'S CONDENSER METHOD.

231. The connections given in § 224 will be slightly altered, as shown in Fig. 27, there will, however, be no difference in the calculations.

Fig. 27.

BY THE DEFLECTION OF A GALVANOMETER.

232. The cell, or battery, under examination, a box of resistance coils, and a galvanometer are connected together in simple circuit, as shown in Fig. 28. A resistance r_b is unplugged in the

Fig. 28.

box of coils, and is selected so that a suitable deflection is obtained on the galvanometer. The cell, or battery, is then replaced by a standard cell, and a resistance r_b' is found, with which the deflection is the same as before. Then, since the currents which flow through the galvanometer in both cases are equal,

$$\frac{P_x}{r_b+g+\rho}=\frac{P'}{r_b'+g+\rho'}$$

or

$$P_x=\frac{r_b+g+\rho}{r_b'+g+\rho'}.P'$$

SIR CHARLES WHEATSTONE'S METHOD.

233. In this method the experimental cell, or battery, is placed in simple circuit with a galvanometer and a box of resistance coils. Resistances r_b and r_b' are unplugged, so as to give suitable deflections, δ and δ', on the galvanometer. The experimental cell, or battery, is now replaced by a standard cell, and a resistance r_b'' is found by trial, so that the deflection on the galvanometer will be δ; the resistance r_b''', giving the deflection δ', is then obtained in the same way. The following equations are therefore established:

$$\frac{P_x}{r_b+g+\rho}=\frac{P'}{r_b''+g+\rho'}$$

$$\frac{P_x}{r_b'+g+\rho}=\frac{P'}{r_b'''+g+\rho'}$$

Whence

$$P_x=\frac{r_b-r'_b}{r_b''-r_b'''}.P'$$

This method is evidently largely affected by polarization, and is therefore not suitable for inconstant cells.

USING THE THREE-COIL GALVANOMETER.

234. The E. M. F. of a cell can be approximately measured by means of the 3-coil galvanometer. For this purpose the cell, whose E. M. F. is required, and the cell whose E. M. F. is known, are successively connected in simple circuit with the 1000-coil of the galvanometer, and the deflections noted. Let P_x and P' be the unknown and known E. M. Fs., ρ and ρ' the corresponding liquid resistances.

Then

$$C=\frac{P_x}{\rho+1000},\quad C'=\frac{P'}{\rho'+1000}$$

But the ratio $\frac{C'}{C}=a$ can be found from the measured deflections δ and δ', by means of the data given in Table II. Hence

$$P_x=\frac{\rho+1000}{\rho'+1000}.aP'$$

Generally, ρ and ρ' can be neglected, so that

$$P_x=aP'$$

This last equation is applicable when the E. M. F. of "firing" cells is required, if the instruments for the more accurate methods be not available.

The galvanometer should be placed at right angles to the magnetic meridian, so that the index may point accurately to zero. The galvanometer should be gently tapped whilst taking a reading, as the needle is liable to stick.

Example.—Let $P'=1.96$ volt., $\delta=57°$, and $\delta'=66°$; then, from Table II, $a=0.71$, hence

$$P_x=0.71\times1.96$$
$$=1.39 \text{ volt.}$$

BY THE FUSION OF FINE WIRE.

235. If a cell, or battery, be capable of fusing fine fire, an approximation to its E. M. F. can be found when the current required to just fuse the wire, is known.

For this purpose the cell, or battery, is connected in simple circuit, with the Firing resistance coils and the thermo-galvanometer. The resistance through which the cell, or battery, can just fuse the fine wire, placed in the clips of the thermo-galvanometer, is then found by trial, as explained in § 214. Then

$$P_x=(r_b+\rho)C$$

where r_b is the resistance unplugged in the box of coils, and ρ is the liquid resistance of the cell, or battery, which, if not known, can be found by the method described in § 221. The value of C depends on the nature and on the diameter of the fine wire employed ; its value for the Service standard iridio-platinum wires is given in Table II.

MEASUREMENT OF AN ELECTRICAL CURRENT.

236. The object in view when making measurements of current is to find the strength of the current (in webers) flowing in some given circuit. If the electromotive force in that circuit be known, and also the total resistance in circuit, the current can be easily found from the equation

$$C_x=\frac{P}{R}$$

If P and R are not known they can be measured. This constitutes one of the methods of measuring currents of electricity.

237. Since the strength of the current flowing in a circuit depends on the resistance in that circuit, if the introduction of the measuring apparatus alters this resistance, the current *measured* will not be the current actually sought, and a correction must therefore be applied. This correction can be made as follows :

Let R be the total resistance in circuit before the measuring apparatus is introduced, then

$$C_x=\frac{P}{R}$$

and C_x is the current to be measured.

Now let r be the additional resistance due to the measuring apparatus, and C'_x the current actually measured, then

$$C'_x=\frac{P}{R+r}$$

and hence

$$C_x=\frac{R+r}{R}C'_x$$

BY THE DEFLECTION OF A GALVANOMETER.

238. In this method the unknown current is compared with a known current, such as that produced by a standard cell in a circuit of known resistance.

A galvanometer, shunted if necessary, is first introduced into the circuit under examination, and the deflection noted. The galvanometer, with the same shunt as before, together with a box of resistance coils, is now connected to a standard cell capable of supplying a current,* and the resistance is so arranged, by means of the box of coils, as to obtain the same deflection as before.

Then, clearly,

$$C'_x = \frac{P}{r_b + g_s + \rho}$$

where P is the E. M. F. of the standard cell, and ρ its liquid resistance.

It will be noticed that the liquid resistance of the cell must be known. As it is difficult to measure this resistance accurately, it follows that this method is subject to the effects of polarization, and to the inaccuracy of the measurement of the liquid resistance, which latter inaccuracy is also due to polarization.

MEASUREMENT OF POWERFUL CURRENTS.

239. The following method of measuring powerful currents has been used by Major Armstrong, R.E.:

Two points, between which there is a small resistance r, are selected in the circuit carrying the current to be measured. The measuring apparatus, consisting of a box of coils and a shunted reflecting galvanometer, is connected to these two points, and a high resistance r_b is unplugged in the box of coils. A divided circuit is thus formed, as shown in Fig. 29, and clearly a very

Fig. 29.

small portion only of the main current will flow through the galvanometer, and this portion, c, can be measured as explained in § 238. It will be observed that the introduction of the measuring apparatus does not practically alter the strength of the main current, and hence,†

$$C_x = \frac{r_b + g_s + r}{r} \cdot \frac{g}{g_s} \cdot c$$

Example.—Let $r_b = 10{,}000$ ohms, $g_s = 7$ ohms, $g = 7{,}000$ ohms, and $r = 0.2$ ohm. It is found that $c = \frac{1}{500{,}000}$ weber.

*See § 159.
†See § 147.

Hence

$$C_x = \frac{10{,}000+7+0.2}{0.2} \cdot \frac{7000}{7} \cdot \frac{1}{500{,}000}$$
$$= 100 \text{ webers.}$$

METHOD OF VIBRATIONS.

240. If a magnetic needle be set vibrating, it will oscillate about its position of equilibrium, and would continue to do so were it not for the resistance of the air and the friction of the pivot. The case is strictly analogous to that of a simple pendulum, and hence it can be proved* that, when the amplitude of the oscillations is small, the time of an oscillation is independent of the amplitude. In fact

$$t^2 = \frac{\chi}{F}$$

where F is the force producing the oscillation, applied at each pole of the needle, and χ is a constant depending on the mass and on the shape of the needle.†

Now an alteration in the strength of the magnetic field‡ will alter the value of F, and hence that of t; so that t^2 becomes a measure of the strength of the magnetic field.

If the coils of a *tangent* galvanometer be placed east and west, so that the needle is at *right angles to the coils*, the force due to a current passing through the coils will be in the direction of the magnetic attraction of the Earth, and further, will be constant.

When no current is passing

$$F = MH$$

where H is the horizontal component of the Earth's magnetism and M is the magnetic intensity of each pole of the needle.

Therefore when a current C is passing

$$F = MH + bCM$$

where b is a constant depending on the galvanometer.

Hence if t be the time of an oscillation when under the influence of the Earth's magnetism alone, t' when the magnetic effect of the current, C'_x is added, and t'' when the current C'' is added, then

$$t^2 = \frac{\chi}{MH}, \quad t'^2 = \frac{\chi}{MH + bC'_xM}, \quad t'' = \frac{\chi}{MH + bC''M}$$

or

$$C'_x = \frac{t'^2 - t^2}{t''^2 - t^2} . C''$$

*See § 55, Ganot's Physics, 9th Edition.

†See Appendix.

‡See § 698, Ganot's Physics, 9th Edition.

If therefore C'' be a known current, an unknown current C'_x can be found.

The practical method of working is as follows: The galvanometer is placed with its coils east and west, so that the needle is at right angles to the coils. The needle is then set vibrating, under the influence of the Earth's magnetism alone, and the number of vibrations in a given time are counted, from which t can be deduced. The currents C'_x and C'' are then successively passed through the galvanometer, and the times t' and t'' are found as above.

Accurate results cannot be expected by this method, owing to the effects of polarization.

MEASUREMENT OF THE FUSING CURRENT OF A FINE WIRE.

241. The strength of the current necessary to fuse a given fine wire is required when calculating the battery power necessary to fire wire fuzes, and can be found as follows:

Some of the wire is placed in the clips of a thermo-galvanometer, and a battery,* capable of fusing the wire, is connected so that the current can pass through the Firing resistance coils, and through the wire. Let r_b be the resistance unplugged when the wire is just fused, and r_p the resistance of the wire *at the point of fusion*, then

$$C_x = \frac{P}{r_b + r_p + \rho + r_c}$$

If r_p, ρ and P are not known, they can be found as explained in §§ 215, 221 and 231 or 233.

MEASUREMENT OF THE FIRING CURRENT OF A WIRE FUZE.

242. The *firing current* of a fuze can be found in the same way as the fusing current of a fine wire, and the same formula is applicable. Not to waste fuzes, a high resistance can be unplugged in the first instance, after which the resistance in circuit can gradually be reduced until the fuze is fired; but in this case it is necessary to use Grove's cells, or some other constant element, to avoid the effects of polarization. The resistance r_p of the wire-bridge† can be estimated from its resistance when cold by allowing for the increase of temperature. The temperature at which the fuze is fired can be taken at about 600° Fahr.

MEASUREMENT OF CAPACITY.

243. The capacity of a conductor can be measured by comparison with the capacity of a known condenser.

*Or the time required for, say 10 vibrations, can be observed.

†Of Grove cells, if possible.

As already explained, if a reflecting galvanometer be placed between a cell and a condenser, an instantaneous current will be obtained on depressing the key, and the deflection was shown in § 192 to be proportional to the capacity. Hence if K_x and K' are the capacities of the unknown and known condensers, and D, D' the corresponding *corrected* swings,

$$K_x = \frac{D}{D'} . K'$$

If there be a large difference between the numerical values of D and D', a shunt should be applied to the galvanometer, in which case evidently

$$K_x = \frac{g}{g+s} . \frac{D}{D'} . K'$$

The connections are precisely the same as those given in § 231.

MISCELLANEOUS TESTS.

TESTING THE POWER OF A FIRING BATTERY OR OF A QUANTITY DYNAMO.

244. The most direct way of ascertaining whether a firing battery is powerful enough for the purpose required, is to find the resistance through which it can just fuze one or more fine iridio-platinum wires placed side by side. The number of the wires should be equal to the number of divided circuits to be employed, the diameter of the wire the same as that of the fuzes and the length of each wire the same as that of the bridge of the fuzes.*

The necessary number of wires are placed in the clips of the thermo-galvanometer attached to the Firing coils, and the battery under examination is connected so that the current can pass through the box of coils, and through the wires, on depressing the key. Successive trials are then made, gradually increasing the resistance in circuit, until that resistance is unplugged, through which the wires are *just* fused. This operation must be carried out with all the precautions mentioned in § 214. The resistance thus found should be less than the resistance in the circuit connecting the charges.

When testing a quantity dynamo, very short contacts must be made (about $\frac{1}{2}$ second), because the current increases if the wire be not fused immediately, and it is only the strength of the current on first making contact that can be relied on when firing charges.

*Namely 0.25" for the Service fuzes.

245. When no Firing resistance coils are available, a rough measurement of the power of the battery can be obtained by finding the *length* of standard iridio-platinum wire, which it can just fuse. The resistance through which the wire is fused, or in other words the resistance through which the battery is capable of firing the fuzes can then be found from the following equations :-

$$R_x = \rho + 2.96\, l; \text{ for the } 0.003'' \text{ wire,}$$

and

$$R_x = \rho + 10.4\, l; \text{ for the } 0.0014'' \text{ wire}$$

where l is the length of wire fused, in inches.

246. A fair idea of the condition of each cell of a firing battery can be obtained, by connecting a wire to one pole and then applying it to the other pole of each cell in succession, commencing with the cell to which the wire is attached. The spark should gradually increase in brightness, and any sudden diminution in passing from one cell to the next indicates that the last cell touched is defective.

CONTINUITY TEST FOR AN INSULATED ELECTRICAL CABLE.

247. An electrical conductor can have no solution of continuity, if a current can be passed through it. A test for continuity is, therefore, to connect in simple circuit the cable, a test cell, and a galvanometer. If no deflection be obtained there must be at least one solution of continuity.

PRICKER TEST TO LOCATE A SOLUTION OF CONTINUITY.

248. If the above test indicates a solution of continuity, the fault, or faults, can be located in the following manner:

One pole of a test-cell is connected to one end of the cable, and the other pole is connected to "earth." The cable is then punctured at intervals with a strong needle attached to an earth-plate, the needle touching each time the core of the cable. So long as there is no fault in the cable between the needle and the test-cell, the galvanometer will be deflected, but it will cease to deflect directly the fault is passed. The punctured places should be repaired with indiarubber tape and solution.

EXAMPLES.

1. The resistance of an electrical cable, having a copper core, is 2.56 ohms at 60° Fahr. What will be its resistance at 0° Fahr?

2. The resistance of an iron wire at 5° *C* is found to be 2.654 ohms. The resistance coils, with which the measurement was taken, are made of German silver, and are true at 15.2° *C*. Find the resistance of the wire at 100° *C*.

3. An iron wire, of which the resistance is to be measured, is stretched in a room whose temperature is 40° Fahr. The wire is connected to the measuring apparatus, which is in another room whose temperature is 50° Fahr, through 500 yards of insulated copper cable exposed to a temperature of −10° Fahr. The measured resistance of the cable and wire together is 35.27 ohms, and that of the cable is 2.72 ohms, at 60° Fahr. Find the resistance of the iron wire at 60° Fahr.

4. A resistance has to be accurately measured by means of Wheatstone's bridge. The ratio $\frac{100}{1000}$ is employed, and it is found that, when 319 ohms are unplugged in the box, the galvanometer deflects 21 divisions to the right, and that when 320 ohms are unplugged, the deflection is 5 divisions to the left. What is the true resistance?

5. The resistances r_1 and r_2 of a defective Wheatstone's bridge are marked 10 and 100, but in reality they are 9.8 and 100.5 ohms. A resistance is measured, and it is found to be 106 ohms. What error, in ohms, is caused by the inaccuracy in the bridge?

6. Investigate the effect on the measurement of resistance by Wheatstone's bridge, when the unknown resistance contains a feeble source of E. M. F.

7. Show that no definite result can be obtained with Wheatstone's bridge method if r_1 and r_2 are both zero.

8. Show that with Wheatstone's bridge, more accurate results can be expected when r_1 and r_2 are each 1000 ohms than when they are each 10 ohms, if r_x lies between 1,000 and 10,000 ohms.

9. Can the liquid resistance of a cell be found, by measuring the deflection given by one cell through a known resistance, and the deflection given by two similar cells through another known resistance?

10. A cell, a box of resistance coils and a galvanometer are connected in simple circuit. A second circuit is also connected to the cell, and the resistance in this circuit is made equal to that of the galvanometer and that unplugged in the box of coils, together. The deflection of the galvanometer is noted. The second circuit is then removed, and the resistance in the box of coils is altered until the same deflection is obtained. Show that the resistance added is equal to the liquid resistance of the cell.

11. The difference of potential between two points in a circuit is measured as explained in § 227, and it is found that r_b=100 ohms, r'_b=1,100 ohms, r=100 ohms, R=940 ohms; also g=1000 ohms, ρ=10 ohms, V'=1.07 volt. What error, in volts, is caused by not making the correction given in § 228?

12. The E. M. F. of a cell is to be measured by Law's condenser method. A Grove's cell is used as a standard, and the corrected deflection is 190 divisions. The corrected deflection with the experimental cell is 100 divisions. What shunt should be applied to the galvanometer, whose resistance is 7,100 ohms, in order that the deflections may be more nearly equal?

13. It is found by trial that a certain battery can just fuze 3.8 inches of the standard 0.0014″ iridio-platinum wire. What is the E.M.F. of the battery, given that its liquid resistance is 0.8 ohm. Through what length of Service cable (7-strand) could the battery *fire* one No. 14 fuse?

14. What diminution, in webers, does the introduction of a No. 14 fuze cause in the current flowing through the 2-ohm coil of a 3-coil galvanometer, produced by a Leclanché test-cell whose liquid resistance is 15 ohms?

15. The resistance between two points in a circuit, through which a powerful current is flowing is 0.5 ohm. A box of coils and a reflecting galvanometer, whose resistance is 5,000 ohms, are connected in simple circuit to these points. The galvanometer has a shunt of $\frac{1}{999}g$ ohms applied, and a resistance of 8,000 ohms is unplugged in the box of coils. The deflection of the galvanometer is then 100 divisions. Find the strength of the current, given that the deflection of the galvanometer, caused by a standard cell whose E.M.F. is 1.07 volt, is 200 divisions, when a shunt of $\frac{1}{99}g$ is applied, and the resistance in circuit is 4280 ohms.

16. A circuit is formed of No. 20 B.W.G. copper wire whose conductivity is 88.6 p.c. that of pure copper wire. The difference of potential between two points, 50 yards apart, is found to be 2.83 volts. Find the strength of the current.

17. A fine platinum wire whose resistance is 2 ohms at 5° *C* is placed in a glass vessel containing 100 *c.c.* of distilled water. A thermometer is introduced and a certain current is passed through the wire for 5 minutes and it is found that the temperature of the water is raised from 12° to 18° *C*. Find the strength of the current.

APPENDIX.

Sine and Tangent Galvanometers.

As was stated in § 148, when an electrical current passes through a galvanometer the needle is acted upon by two couples, one caused by the electrical current, the other due to the magnetic attraction of the Earth, and of any magnet sufficiently near to have a sensible influence on the needle. These two attractions together produce the magnetic field* in which the needle is lying, before the current passes, and the lines of force in this magnetic field are parallel to the initial position of the needle, if the directing magnet be not too close. Hence, if M be the intensity of magnetism of each pole of the needle, H the strength of the field, l the length of the needle, and δ the angle of deflection, $HMl \sin \delta$ is the moment of the couple due to the magnetic field.

Each force of the couple produced by the current is bCM, where b is a constant depending on the construction of the galvanometer, and its direction is perpendicular to the coils. Therefore, in a sine galvanometer, the moment of the couple due to the current will clearly be $bCM.l$, and in a tangent galvanometer, $bCM.\ l \cos \delta$.

Hence in a sine galvanometer

$$HMl \sin \delta = bCMl$$

or

$$C = \mu \sin \delta$$

And in a tangent galvanometer

$$HM\ l \sin \delta = bCMl \cos \delta$$

or

$$C = \mu \tan \delta$$

To show that the work done by an instantaneous current on the needle of a galvanometer varies as Q^2.

The current is nearly instantaneous, it will therefore have entirely ceased before the needle commences to move sensibly. Hence the deflecting couple may be taken as acting impulsively, and at right angles to the needle. Now the strength of the current

*See § 689, Ganot's Physics, 9th Edition.

will not generally be constant, for instance, the instantaneous current due to the filling up of a condenser diminishes in strength as the potential of the condenser increases. Let, therefore, C be the current at any time t, then the moment of the deflecting couple is $bCMl$, where b is a constant depending on the galvanometer, M the magnetic intensity of each pole of the needle and l the distance between the poles. Hence the equation of motion is

$$mk^2.d\omega=bCMl.\ dt$$

But C can be considered constant for the short interval of time dt, so that $C.dt$ is the quantity of electricity, dQ, transmitted during the interval dt. Hence

$$mk^2.\ d\omega=bMl.\ dQ$$

Integrating and remembering that $Q=o$ when $\omega=o$, and writting Ω for ω

$$mk^2\Omega=bMlQ$$

But the work done on the needle is $\frac{mk^2\Omega^2}{2}$, hence

$$Q^2\propto \text{ work done on needle.}$$

To show that $\sin^2\frac{\delta}{2}$ *is a measure of the work done by an instantaneous current on the needle of a galvanometer.*

The effect of an instantaneous current is, as seen above, to impress an initial angular velocity on the needle. During the motion, the forces acting on the needle are: the magnetic attraction of the Earth, (forming a couple,) the resistance of the air and the friction of the pivot. The last two forces will, however, be neglected and their effect allowed for by a subsequent correction.*

Let ω be the angular velocity at any time t, and θ the angle described from the position of equilibrium; the remaining letters having the same signification as in the previous paragraph. Then the equation of motion, obtained by taking moments about the pivot, is

$$mk^2\frac{d^2\theta}{dt^2}=-HMl\sin\theta$$

Multiplying both sides of this equation by $2\frac{d\theta}{dt}$, and integrating

$$mk^2\left\{\frac{d\theta}{dt}\right\}^2=2HMl\cos\theta+\text{constant.}$$

But, $\frac{d\theta}{dt}=o$, when $\theta=\delta$, the angle of deflection. Hence

$$mk^2\left\{\frac{d\theta}{dt}\right\}^2=2HMl(\cos\theta-\cos\delta)$$

*See § 180.

Now $\frac{d\theta}{dt}=\Omega$, when $\theta=o$, so that

$$\frac{mk^2\Omega^2}{2}=HMl(1-\cos\delta)$$

$$=2HMl\sin^2\frac{\delta}{2}$$

But HMl is a constant so long as the same galvanometer is used, and no alteration is made in its position, or otherwise. Therefore, $\sin^2\frac{\delta}{2}$ is a measure of the work done on the needle by the instantaneous current.

To find the time of oscillation of a magnetic needle placed under the influence of a uniform magnetic field.

The effect of the magnetic field on the needle, is to apply a force to each pole, parallel to the position of equilibrium. These two forces form a couple, and if θ be the angle of deflection of the needle at any time t, measured from the position of equilibrium, and l the distance between the poles, $Fl\sin\theta$, or $Fl\,\theta$, since θ is a small angle, is the moment of this couple. Hence the equation of motion is

$$mk^2\frac{d^2\theta}{dt^2}=-Fl\,\theta$$

Integrating and remembering that $\frac{d\theta}{dt}=o$, when $\theta=\delta$.

$$mk^2\left\{\frac{d\theta}{dt}\right\}^2=Fl(\delta^2-\theta^2)$$

Whence it will be found that the time of an oscillation is

$$2t=\pi\left\{\frac{mk^2}{Fl}\right\}^{\frac{1}{2}}$$

or, writing t for the time of an oscillation,

$$t^2=\frac{\chi}{F}$$

where χ is a constant.

TABLE II.

THREE-COIL GALVANOMETER.

Table giving the ratio of the currents producing the deflections δ and δ', the 1000-ohm coil being in circuit.

$\delta - \delta'$	Value of a†		$\delta - \delta'$	Value of a†	
	when $\delta > \delta'$	when $\delta < \delta'$		when $\delta > \delta'$	when $\delta < \delta'$
1	1.04	0.96	11	1.49	0.67
2	1.08	0.92	12	1.54	0.64
3	1.12	0.89	13	1.61	0.62
4	1.16	0.86	14	1.67	0.60
5	1.20	0.83	15	1.74	0.57
6	1.25	0.80	16	1.82	0.55
7	1.30	0.77	17	1.90	0.53
8	1.35	0.74	18	1.96	0.51
9	1.40	0.71	19	2.04	0.49
10	1.45	0.69	20	2.13	0.47

Examples.—Let $\delta=61°$. $\delta'=49°$; then $a=1.54$.
Let $\delta=49°$, $\delta'=61°$; then $a=0.64$.

RESISTANCE.

Variation in resistance due to alteration in temperature.

The following formula is given by Dr. Mathiessen, in which r_t is the resistance of the metal, or alloy, at the temperature $t°$ *C* and r^o its resistance at 0°*C*.

$$r_t = r_0 (1 + a\,t \pm b\,t^2)$$

The following are the values of a and b:

	a	b
Most pure metals	0.003824	+0.00000126
Mercury	0.0007485	−0.000000398
German silver	0.0004433	+0.000000152
Platinum silver	0.00031	— —
Gold-silver	0.0006999	−0.000000062

*This Table gives the mean of a series of experiments, made by the author.

†$a = \frac{C}{C'}$, and δ is the deflection due to the current C.

*Table of Resistance of Metals and Alloys at 60° Centigrade, from Dr. Mathiessen's experiments.**

Names of Metals.	Resistance of a wire one metre long and one millimetre in diameter. Ohms.	Resistance of a wire one metre long, weighing one gramme Ohms.	Resistance of a wire 1 foot long, 1-1000th of an inch in diameter. Ohms.	Resistance of a wire one foot long, weighing one grain. Ohms.	Approximate percentage of variation in resistance for 1°C of temp. at 20°C.
Silver annealed......	0.01937	0.1544	9.151	0.2214	0.377
" hard drawn	0.02103	0.1680	9.936	0.2415	
Copper annealed ...	0.02057	0.1440	9.718	0.2064	0.388
" hard drawn	0.02104	0.1469	9.940	0.2106	
Gold annealed	0.02650	0.4080	12.52	0.5849	0.365
" hard drawn...	0.02697	0.4150	12.74	0.5950	
Zinc pressed	0.07244	0.4067	34.22	0.5831	0.365
Platinum annealed	0.1166	1.96	55.09	2.810	
Iron annealed	0.1251	0.7654	59.10	1.097	
Tin pressed	0.1701	0.9738	80.36	1.396	0.365
Lead pressed.........	0.2526	2.257	119.39	3.236	0.387
Mercury liquid	1.2247	13.06	578.6	18.72	0.072
Platinum silver ... alloy, hard or annealed, 2 parts silver, 1 platinum	0.3140	2.959	148.35	4.243	0.031
German silver hard or annealed	0.2695	1.85	127.32	2.652	0.044
Gold-silver alloy hard or annealed, 2 parts gold, 1 silver	1.1399	1.668	66.10	2.391	0.065

*This table gives the resistances of *chemically* pure metals; the resistances of commercial metals are always higher. It has been extracted from a table in "Electricity and Magnetism," by Prof. Fleeming Jenkin, F.R.S.S., etc. The variation in resistance due to temperature are from "Rough Notes of a Course of Lectures on apparatus used in Military Telegraphy and Firing Mines." S.M.E., Chatham.

ELECTRO-MOTIVE FORCE OF VARIOUS CELLS.

					Volts.
Daniell	Zinc*amalg	Sulphuric acid, 7½ to 1	Saturated solution of copper sulphate	Copper	1·079
"	"	22 to 1	"	"	0·978
"	"	"	Nitrate of copper saturated	"	1·000
"	"	"	Sulphate of copper	"	0·909
"	"	Sulphate of zinc	"	"	0·955
"	"	1 part common salt, 4 parts water	"	"	1·060
Grove	"	Sulphuric acid, 7½ to 1	Nitric acid (fuming)	Platinum	1·956
"	"	Salt water	Nitric acid, sp. gr. 1·33	"	1·904
"	"	Sulphuric acid, 22 to 1	"	"	1.810
"	"	Sulphate of zinc	"	"	1·672
Bunsen	"	Dilute sulphuric acid	Nitric acid	Carbon	1·734
Callan	"	"	"	Cast iron	1·700
Poggendorf	"	"	Chrome mixture	Carbon	{ 1·796 { 2.028
Marie Davy	"	Sulphuric acid, 22 to 1	Paste of sulphate of mercury	"	1·524
"	"	Dilute sulphuric acid	"	"	1·33
Leclanche	"	Solution of sal ammoniac	Binoxide of manganese	"	1·481
De la Rue	Zinc	Chloride of silver		Silver	1·059
Becquerel	Zinc amalg	Sulphate of zinc	Sulphate of lead	Lead	0·55
Niaudet	"	Common Salt	Chloride of lime	Carbon	1·65
Duchesnin	"	"	Perchloride of iron	Lead	1·541
"	Platinum	Dilute sulphuric acid	Dilute sulphuric acid	Platinum	1·79
Plante	Lead	"	"	Lead	2·5
Latimer Clark, Standard cell	Zinc amalg	Sulphate of zinc	Paste of sulphate of mercury	Mercury	1·457

Porous Cell.

*This table is due to M. Niaudet, and is given in "A Physical Treatise on Electricity and Magnetism," by J. E. H. Gordon, B.A., Camb.

CURRENT.

The current necessary to *fuse* the standard iridio-platinum wires is—

For the 0.003″ wire...............1.65 weber.
" " 0.0014″ wire ....0.8 "

Heat produced by a current.

Number of units of heat* produced by a current C in time t, in the portion of the circuit whose resistance is r. $= 0.2405\ C^2rt$.

*This unit of heat belongs to the C. G. S. system, and is the quantity of heat required to raise the temperature of one gramme of distilled water, at its maximum density, by 1° Cent. The time is expressed in seconds, the current in webers, and the resistance in ohms.

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