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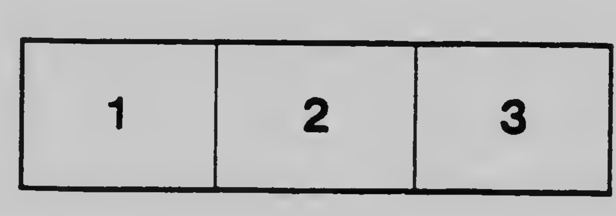
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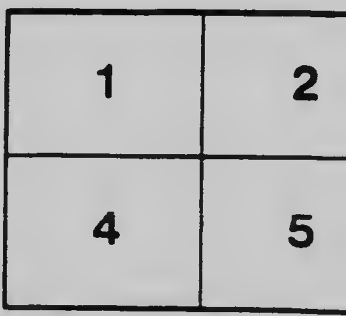
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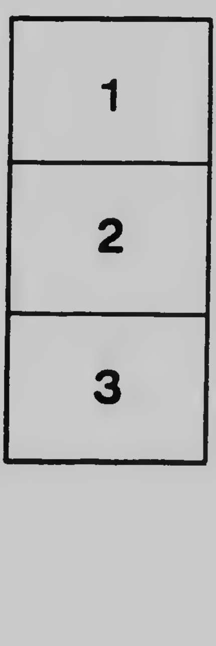
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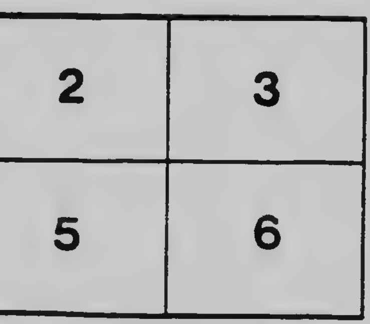
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UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES

No. 75: ON THE PERMEABILITY OF THIN FABRICS AND FILMS TO HYDROGEN AND HELIUM, BY J. C. McLENNAN AND W. W. SHAVER

(Reprinted from the Philosophical Magazine, Vol. XL)

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From the PHILOSOPHICAL MAGAZINE, *vol.* xl. *September* 1920.

On the Permeability of Thin Fabrics and Films to Hydrogen and Helium. By Prof. J. C. McLENNAN, *F.R.S., and* W. W. SHAVER, *B.A., University of Toronto.*

1. *Introduction.*

IN a recent paper by R. T. Elworthy* and V. F. Murray the diffusion of hydrogen and helium through thin rubber fabrics was discussed, and the results of measurements made by them on several samples of balloon fabrics were given. In these experiments the amount of gas diffusing through the fabrics was measured by a Shakespear Katharometer and by a Jamin Interferometer. As the method was one capable of wide application it was decided to use it in determining the permeability of liquid films to various gases, and the following paper describes some experiments made upon the passage of hydrogen and helium through soap films. The study of gas transfusion through membranous tissues is an important physiological problem, and it was thought on this account that it would be useful and might prove interesting to measure the rate of gas diffusion through films of various materials, with a view to formulating a more exact theory of the process of gas transfusion than exists at present.

* Proc. Roy. Soc. Can., May 1919.

II. *Preliminary Experiments.*

In order to test the apparatus and to acquire a working familiarity with the instruments, a preliminary study of the diffusion of hydrogen through the fabrics used by Elworthy and Murray was made. The apparatus used and the method of assembling it was the same as described in their paper. The fabrics used by them were inserted as a separating diaphragm in an air-tight drum-like vessel. Two gases were brought into this drum, one on either side of the fabric, and their transfusion was determined by tests on the gases by means of the instruments mentioned above. For a full description of the Shakespear apparatus the reader is referred to the paper by Elworthy and Murray. It will suffice here to say that this apparatus was made by the Cambridge Scientific Instrument Co., and that its principle is based on the variation in resistance of a heated platinum coil, constituting one branch of a Wheatstone Bridge circuit, when the gas mixture surrounding the cell has its thermal conductivity varied by changes in its component parts. The two methods adopted were (1) to pass a continuous stream of pure air and one of pure hydrogen on opposite sides of the fabric as a dividing diaphragm, and (2) to enclose a known quantity of pure air on one side and to pass a continuous stream of pure hydrogen past the other side of the fabric.

In the present experiments both methods were followed, but gas tests were made with the katharometer only. It was found that 20° C. was a more suitable temperature for working at than 15°·5 C. as previously used by Elworthy and Murray. The measurements obtained were made by keeping the permeameter and connexions in a thermostat at 20°·0 C., the variation in temperature being not more than 0°·2 C.

III. *Calibration.*

The katharometer used to detect small percentages of hydrogen or of helium in air had already been calibrated for both gases; but this calibration was checked by noting the galvanometer deflexions for a given sample of gas, deducing the percentage of helium or hydrogen present from the calibration curve and then checking the result by actually weighing a known volume of the sample studied. It was found that the values obtained by the latter method fitted in very closely with the calibration curve of Elworthy and Murray. It may be stated here that in their work it had been well established that the curve obtained by plotting galvanometer deflexions against percentages of hydrogen or helium present in air was a straight line through the origin. The calibration showed that (1) 259 mm. deflexion on the scale 1 metre from the galvanometer represented 1 per cent. hydrogen in air, and (2) 163 mm. deflexion on the scale 1 metre from the galvanometer represented 1 per cent. of helium in air.

The following table gives a comparison of the results obtained in the present experiments with those obtained by Elworthy and Murray when using the same fabrics. In each case the permeability is given as being the number of litres of gas permeating 1 square metre of a fabric in 24 hours:—

TABLE I.

	Results obtained in this investigation. Temp. 20° C.		Results obtained by Elworthy and Murray. Temp. 15°·5 C.	
Fabric No.	Method I. Using Katharometer.	Method II. Using Katharometer.	Method I. Using Interferometer.	Method II. Using Katharometer.
*II. B......	9·6	9·8	8·4	9·7
III. A ...	8·4	8·0	0	8·6
IV.	5·0	...	5·5	4·7
V. B	6·3	...	6·7	6·4
VI. A ...	8·0	...	...	8·1
VI. C......	7·8	7·5	...	8·1
XII.	5·4	...	...	...

IV. *Permeability of Films.*

After the preliminary experiments had been made, an attempt was made to employ the same method in making a determination of the transfusion of hydrogen and of helium through a soap film. Sir James Dewar † in a paper presented at a meeting of the Royal Institution of Great Britain in Jan. 1917, described many interesting experiments with long-lived soap bubbles and films, among them being a determination of what he calls "gas transference" through

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* The fabric numbers refer to samples of balloon fabrics described in the papers by Elworthy and Murray.

† Dewar, Paper, "Soap Bubbles of Long Duration," presented at weekly meeting of the Royal Institution of Great Britain, Jan. 19, 1917.

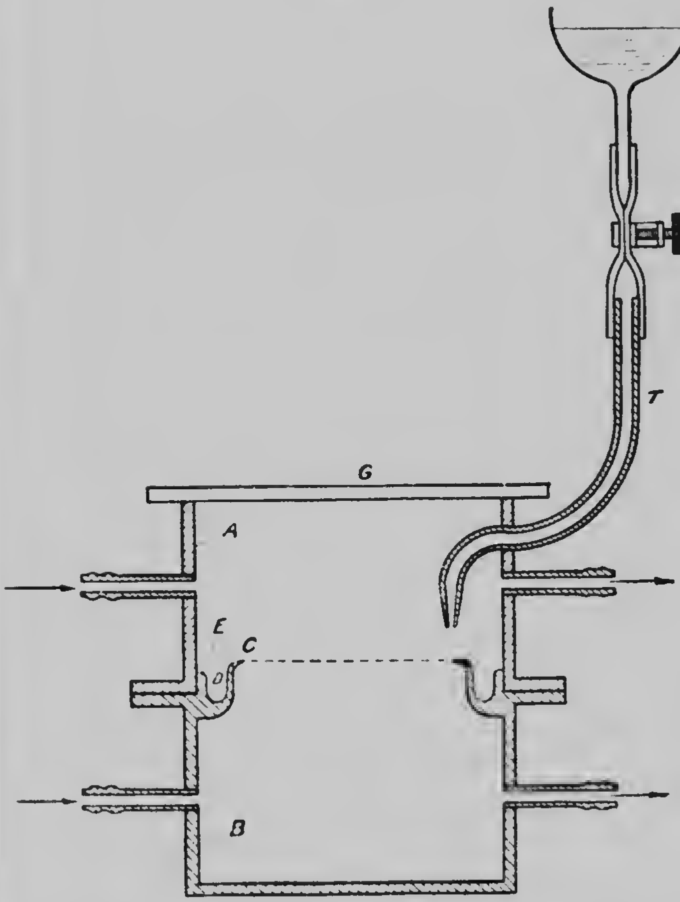
a soap bubble, by blowing a hydrogen bubble in hydrogen and noting the decrease in diameter as time went on, due to the slight excess pressure inside the bubble. What he measured was the excess of the rate of gas diffusion outward over the rate inward through the film, and he found that as the soap bubble became thinner the gas transference became greater. In the present experiment the endeavour was to determine the actual rate of gas flow per square centimetre through the film, keeping the film as nearly constant in composition and thickness as possible.

V. *Description of Apparatus.*

A small cylindrical brass chamber (see fig. 1) was made for the film in two sections with a ground brass joint, which, when covered with soft wax and pressed together, made the vessel air-tight. Each section was 6·1 cm. in diameter and 7·0 cm. in height, having inlet and outlet tubes as shown in the diagram. The top section A, fig. 1, was closed by a window of plate glass, G, put on with hard wax, so that when a source of light was held directly over the chamber, its image in the film could be distinctly seen and in this way the character of the surface of the film—whether concave, convex, or plane—was known at once by the character of the image produced. Knowing the curvature of the film one could adjust the pressures of hydrogen and air on either side very accurately and so as to keep the film plane and therefore eliminate the diffusion due to excess pressure on either side. The brass ring C, fig. 1, supporting the film was 4·95 cm. in diameter, and ground down to a sharp edge. An annular channel, D, was made in the outer part of the supporting ring, and the whole soldered in the lower section of the film chamber, leaving about 0·5 cm. of the brass ring projecting above the wax surface. In this way the soft wax used in making the joint air-tight was prevented from contaminating the film and destroying its surface tension.

To overcome the difficulty of evaporation and drainage from the film, that is to keep its composition and thickness constant, the air and hydrogen used were both saturated with water vapour before entering the chamber, and, in addition, a means of adding solution to the film was provided in the following way. A bent tube, T, was inserted in the upper chamber as indicated in the diagram, having a thistle tube connected to the outer end by rubber tubing. A small amount of the same soap solution used in making the film was poured into the thistle tube and a drop of this was allowed to fall on the film at short intervals (say, every two or three minutes), the flow being regulated by a clamp on the rubber tubing. The excess solution drained off the edges of the film into the lower section of the chamber. In this way the film was kept at a practically constant maximum thickness and the variations in diffusion due to changes in the film were eliminated as far as possible.

Fig. 1.



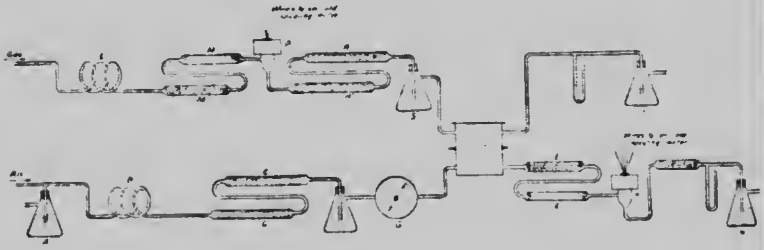
VI. *Air Circuit.*

The air was let in through a T-tube A (see fig. 2), which permitted the rate of flow to be varied by raising or lowering the water level. With any given level the pressure was adjusted so that the air always gently bubbled through the base of the T-tube. In its course through the system the air passed through a copper warming coil B and two tubes filled with cotton wool moistened with glycerine so as to eliminate all dust particles, as it was found that the introduction of dust particles soon caused the soap films to rupture. It was then bubbled through water and led through a gas-meter which measured the rate of flow. From the gas-meter the air, saturated with water vapour, was led through the lower section of the film chamber, D, sweeping out with it the hydrogen gas which diffused through the film. From there the air was dried in the phosphorus pentoxide tubes E and E′, and tested by the katharometer K, finally bubbling out through the water in H at a pressure of about 1 cm. of water.

VII. *Gas Circuit.*

The gas circuit shown in fig. 2 was somewhat similar, except that the gas was tested before entering the film chamber by a purity meter P. of the katharometer type, and then passed through the cotton wool tubes R and R′, bubbled through water in the bottle S, and thence to the film chamber, and, finally, bubbled out through water in U, at a pressure of about 1 cm. of water. The pressure of the gas in the circuit was altered very slightly by adjusting the tube U, so that the film surface remained plane. The rate of flow used was about 2 litres per hour.

Fig. 2.



VIII. *General Procedure.*

When readings were taken the air and the gas under test were allowed to flow past the film until the katharometer reading giving the percentage of gas in the air was steady. This required one half hour, and then readings were taken at two minute intervals for forty minutes, and note was taken of the rate of flow of air by means of the gas meter. This ranged from 2 to 10 litres per hour. After one set of readings was taken, if the film still remained intact, the rate of air flow was changed, and after conditions became steady again another set of results was obtained. In this way as many as four sets of readings were taken without renewing the film.

IX. *Purity of Gases.*

The purity of the gases under test was in both cases comparatively high. The hydrogen was obtained from a commercial supply which was guaranteed to be of 99 per cent. purity. The helium used was first purified by passing it through a set of four charcoal tubes at the temperature of liquid air. Its purity was tested by means of a quartz density balance, and found to be 99·2 per cent.

X. *Soap Solution.*

The soap solution used was one made up according to Boys' formula, and contained 2 per cent. sodium oleate, 24 per cent. glycerine, and 74 per cent. water, with a few drops of strong ammonia.

XI. *Results.*

The following are the results obtained. The last column gives the number of cubic centimetres of gas transfusing through one square centimetre of film per hour.

The readings were taken at room temperature which varied slightly as shown in the table. However, taking the average values obtained for the two gases, we find the ratio of the transfusion of helium to that of hydrogen to be 0·70. In the case of balloon fabrics, Elworthy and Murray found this ratio to be 0·67. Expressing the average results for hydrogen and helium in the case of a soap film in the same terms as the permeability of balloon fabrics, we find the permeability of films to these gases given by Elworthy and Murray for

TABLE II.

(a) *Hydrogen.*

Duration of film.		Temp.	Transfusion of gas in c.c. per sq. cm. of film per hour.
H.	min.	°C.	
1	52	18·6	4·8
1	35	20·0	5·2
0	59	20·1	4·2
1	45	19·6	4·3
1	20	20·8	3·5
1	10	19·7	4·1
1	07	19·1	3·8
4	40	19·2	3·1
		19·1	3·1
		19·7	3·8
		19·1	3·6
		Average	4·0

(b) *Helium.*

Duration of film.		Temp.	Transfusion of gas in c.c. per sq. cm. of film per hour.
3	41	18·4	3·0
		18·3	2·4
		18·0	3·1
5	15	19·5	2·2
		19·3	2·8
		18·7	2·8
		18·7	3·4
		Average	2·8

hydrogen to be 960 and for helium 670 litres per square metre per day. For the most highly porous balloon fabrics tested by Elworthy and Murray the transfusion of hydrogen was only about 10·0 litres per square metre per day, and of helium 7·1 litres per square metre per day. It is interesting to note that while soap films were very much more permeable to hydrogen and helium than were the balloon fabrics tested, the ratios of the permeabilities of both fabrics and films to the two gases were practically the same. This is the more interesting when it is considered that while in the case of the films the membrane was of the continuous type, in the case of the fabric there was a possibility of the diaphragm being discontinuous. It may be, however, that on account of the fabrics being "doped" the discontinuity referred to was negligible. In this case the process of transfusion of the gases through the substance of the fabric would probably be of the same nature as that of transfusion through the films.

XII. *Diffusion of Hydrogen through Wet and Dry Cotton Fabrics.*

Some experiments were made on the transfusion of hydrogen through a closely woven cotton fabric when wet and also when dry. When this fabric was dry the gas diffused through it so rapidly that it was impossible to obtain a measure of the rate of transfusion with the katharometer. On the other hand, when the fabric was thoroughly wetted with distilled water it was found that the transfusion of hydrogen through it was so slow that it could not be detected with the katharometer, even when the rate of flow of the air past the fabric was reduced to as low a value as 2·4 litres per hour.

It was noted in the experiments on the transfusion of hydrogen through soap films that as soon as the film became thinner than the red-green stage the rate of diffusion rapidly increased. It is evident, therefore, that the rate of diffusion depends very largely on the thickness of the films used. In the case of the wet cotton fabrics the thickness of the water films filling up the interstices was very much greater than that of the soap films investigated.

XIII. *Summary of Results.*

1. The rate of diffusion of hydrogen through a series of balloon fabrics has been determined.

2. The permeability of soap films whose thickness corresponds to the red-green stage has been found for helium to be 670 litres per square metre per day and for hydrogen 960 litres per square metre per day at 20° C.

3. The rate of transfusion of helium through soap films has been shown to be 0·70 of that of hydrogen through similar films.

4. The diffusion of hydrogen through water films filling the interstices of a wet cotton fabric has been shown to be very low; with soap films showing interference colours the rate of diffusion of both hydrogen and helium was found to be considerable.

The Physical Laboratory,
University of Toronto.
May 15th, 1920.

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