THE PERMEABILITY OF AIRSHIP FABRICS.—PART I.

Submitted by the Director of Air Services.


Introductory.—This paper is intended as a brief survey of the airship and balloon fabrics in use at the present time and their behaviour as gas-holding materials.

A short account (Part I.) is given of the types of apparatus for testing the permeability of fabrics by hydrogen so far as these are not known to have been described before, chiefly with a view to giving some idea of the degree of accuracy attainable, and of the variety of methods that can be used.

An account of some experiments made with a view to discovering more about the nature of rubbered fabrics is given in Part II., while a special section (Part III.) is devoted to the leakage of seams.

The experimental work, the results of which are given here, has been carried out by the Staff of the Chemical Laboratory, R.N. Airship Station, Kingsnorth, during the past two years.

Much is due also to the work of the Inspector of Proofing and his Staff at the R.N.A.S. Testing Laboratory, School of Technology, Manchester.

PART I.

A. Different classes of proofing.

1. Rubber.—In the case of non-rigid airships and kite balloons indiarubber is the proofing material par excellence. Rubber maintains this position not so much in virtue of its gas-holding properties, which are poor compared with those of certain other materials, as on account of its other properties, such as its perfect flexibility; its indifference to atmospheric changes; its adhesive properties, whereby several plies of textile material may be stuck together; and, lastly, its comparatively long life, in this climate at least. Rubber proofed fabrics differ according to

(1) the quality of the rubber employed;
(2) the ingredients incorporated with the rubber;
(3) the mechanical treatment the rubber has received in the course of manufacture;
(4) the method of application to the cotton fabric;
(5) its arrangement among the plies of cotton; and
(6) the method of vulcanisation.

It will be seen, therefore, that the number of possible varieties of rubber fabric that may be met with is legion; and it is hardly ever safe to infer from the behaviour of one kind of fabric that of another kind. It is only as the result of tests so numerous that they can be dealt with statistically that any very definite conclusions can be reached about this most erratic material.

Assuming that the methods of manufacture are suitable, fabric having a permeability by hydrogen sufficiently low for use in balloons can be obtained with a layer of rather less than 100 gm./sq. metre weight of rubber between two plies of cotton fabric of suitable weave and texture. A layer as thin as 50 gm./sq. metre results as a rule in a fabric with a very considerable leakage. The application of more than 100 gm./sq. metre, whether to make one thick layer of rubber or several comparatively thin ones, results in little or no decrease in permeability. It is believed that a "facing" of rubber does not have so great gas-holding properties as a layer between two textures of cotton.

The average permeability of rubbered airship fabrics now used is not usually much less than 10 litres per sq. metre per day, but with improved methods of manufacture lower results tend to be obtained. There is considerable evidence that the limiting permeability obtainable with rubber is of the order of 4 lits./sq. metre/24 hrs., and that as manufacturing defects are eliminated, the average permeabilities will tend nearer and nearer to this figure.* This conclusion has been come to as the result of the examination of a large number of tests made by the Inspector of Proofing. If the results for any given specifications and makes be expressed as a "frequency curve," it is found that the curve slopes steeply to zero frequency at a permeability between 3 and 5 litres, and that the position of zero frequency is about the same for varying weights of proofing. Values about 5 litres/sq. metre/24 hrs. are fairly common; results lower than 3 litres are only recorded four times in all out of some 6,000 tests at Manchester and Kingsnorth. The only test-piece that was available for retest undamaged gave a higher result six weeks later.

One very noticeable feature about rubbered fabrics is that the permeability is not constant. The usual course of variation is believed to be a slight increase in permeability shortly after manufacture followed by a slow decrease. This does not invariably occur; thus, sometimes a fabric remains steady for a considerable time, then changes quite suddenly, and one case

*Note.—For comparison, the limiting permeability of goldbeaters' skin is somewhere about 0·01 litres/sq. metre/24 hours.
is on record of a fabric the permeability of which oscillated irregularly between two values. The changes to which these phenomena are due are not, as far as is known, oxidation changes, but are connected rather with the phenomena known to the manufacturers as "after vulcanisation." Oxidation of the rubber, as is well known, results in first of all a decrease in permeability, but finally in a very rapid increase. Another cause of variation in permeability which, fortunately, is very rare in airship fabrics is that connected with "sulphuring up." This process, if it occurs, results in a very large increase in permeability. The process, which is not well understood, appears to consist in sulphur, which is present in a colloidal state, crystallising out, and leaving comparatively large pores in the rubber.

2. Nitrocellulose dope.—Airship envelopes have frequently been painted with dope which leaves a film composed of nitrocellulose and castor oil. This film, which usually contains 2 parts by weight of castor oil to 1 of nitrocellulose, is very tough, elastic and flexible, and, when protected by an outer coating containing aluminium powder, retains its flexibility for a long time. Its properties depend to some extent on the solvents that have been used, but chiefly on the quality of the gun-cotton and the amount of castor oil present. It is liable, to an uncertain extent, to undergo decomposition, as the result of which the cotton fabric in contact with it is injured. It has also other practical disadvantages as an airship proofing.

Normally it is used in conjunction with rubbered fabric as a final outer coating; the weights of dope applied vary considerably, but 100 to 150 gm./sq. metre are commonly used. A film of dope of this range of weights will reduce the permeability of a very leaky fabric to about 5 to 6 litres/sq. metre/24 hours, and that of a fabric already pretty gas-tight to 3 or 2 litres, or even less. This substance does not show the same variability as rubber. Until the dope actually begins to decompose or become brittle, the permeability remains more or less constant.

3. Goldbeaters' skin.—This material, which is used almost exclusively for the gasbags of rigid ships, is an animal membrane obtained from the ceca of cattle. Similar skins can be obtained from other animals and other parts of animals, but this skin, in spite of its small size (about 30 inches by 10 inches), is the most valuable on account of its evenness and thinness. A dry skin weighs about 15 to 30 grammes/sq. metre. Goldbeaters' skins vary very greatly in size: 30 inches by 10 inches is the minimum size that used to be specified for military balloons.

The skins are applied wet, a certain amount of glycerine being added to the water to keep them from drying up. They are either stuck to rubbered fabric with rubber solution (British
practice) or to unproofed cotton fabric with glue (German practice); one or two layers are applied. The surface of the skins is, as a rule, varnished with a linseed oil varnish to protect them from changes of humidity.

The permeability of a skin-lined fabric free from mechanical defects is so small as to be practically unmeasurable. As the skins are very fragile and liable to damage, and are only gas-tight while still soft, this ideal is seldom realised in practice. A good skin-lined fabric should not leak more than 2 or 3 litres/sq. metre/24 hours, and permeabilities well below 1 litre/sq. metre/24 hours are frequently met with.

Experiments have been made with a view to substituting artificial membranes for the expensive and not very plentiful goldbeaters' skins. These have given promising results, but it is too early yet to speak with certainty about them.

4. Of the other materials that can be used for proofing fabric, only linseed oil and gelatine appear to deserve any mention. Very low permeabilities (less than 1 litre) can be obtained by the use of linseed oil; the material has, however, many disadvantages, one of which is that oxidation is always going on as long as the material lasts. Linseed oil is, at the present time, used chiefly as a protective varnish for goldbeaters' skin.

Gelatine is a material that may possibly come into use, as it is about the only substance other than rubber which can be used to stick two plies of cotton together and to make seams. Permeabilities almost as low as those of goldbeaters' skin can be obtained with it. Its chief disadvantages are its hygroscopic nature and its liability to decompose.

B. Permeability of fabrics by gases other than hydrogen.

Very little, unfortunately, is known with regard to the permeability of airship fabrics by any gas but hydrogen.

1. Helium.—The permeability of a rubbered and a skin-lined fabric by helium was examined by Dr. Guy Barr (R. & M. 232, December, 1915). The ratio of hydrogen to helium permeability was found to be about 3 : 2 for the rubbered fabrics and somewhere about 2 : 3 for the skin-lined one.

2. Carbon dioxide.—The permeability of a rubbered doped fabric (D.F. 127) was, according to experiments made at Kingsnorth, about the same for carbon dioxide as for hydrogen, 6 litres/sq. metre/24 hrs. in each case. It is possible that the results are not quite comparable as the CO₂ permeability was found using moist gases and the hydrogen using dry gases.

3. Oxygen and nitrogen.—A matter of great practical importance about which too little information is available is the permeability of fabrics by air. It is seldom that the flying capabilities of an airship are seriously affected by loss of hydrogen,
unless there are large holes present, even when the envelope is very porous according to ordinary standards. On the other hand, the performance of a ship depends on its lift, and its lift depends on the purity of the hydrogen, and this in turn depends on the rate at which air leaks into the envelope. Clearly it is more important to know how quickly an envelope will gain air, which can be removed only by deflation and re-inflation, than how quickly it will lose hydrogen which can easily be replaced.

These remarks do not apply to kite balloons where hydrogen supply itself is a difficulty. With these both hydrogen and air leakage must be as low as possible.

A few rough experiments have been made on this subject. The method employed was to fill a small cylindrical balloon of rubbered fabric with a known volume of hydrogen. The hydrogen pressure inside was kept up by means of a weighted net. Samples of the gas were withdrawn from time to time for analysis, and at the end of the experiment the volume of the residual gas measured.

The balloon used had a capacity of about 200 litres and a surface of nearly 2 sq. metres. The experiments showed that in the five days that each test lasted about 200 litres of hydrogen escaped and 14 litres of "air" entered. The "air" inside the bag was, however, considerably richer in oxygen than that outside. In one experiment; which was considered more reliable than the others, at the end of 129.2 hours 207.7 litres of hydrogen (plus a little carbon monoxide) escaped and 3.72 litres of oxygen and 11.21 litres of nitrogen entered. This result shows that, assuming the gases diffuse proportionally to their partial pressures, but neglecting the change in partial pressures during the course of the experiment, and giving round numbers only, the bag had a permeability of

\[
\begin{align*}
20 \text{ litres hydrogen/sq. metre/24 hours} & \\
1.9 & \text{ oxygen} & \\
1.4 & \text{ nitrogen} & \\
1.5 & \text{ air} & *
\end{align*}
\]

As the hydrogen permeability found was higher than would have been expected from the fabric alone, probably a good deal of the leakage was due to the seams. Leakage through seams is probably the result of the escape of hydrogen through small apertures under its excess hydrostatic pressure. This process might be expected to give a higher value for the ratio of hydrogen to air permeability than the passage of the gases through the rubber fabric. The value obtained in these experiments, roughly 1 : 15, is the same as that mentioned by Dr. Barr (A.C.A. Reports,

* By neglecting the changes in partial pressures during the experiment the values will all appear too low; but they will be roughly in the right proportion to one another.
1912–13, p. 272). The approximate correctness of this ratio has been confirmed in the case of one airship envelope, at least, by examination of gas consumption and purity records.*

With regard to skin-lined fabrics: if, as is believed, the permeability is due to the solubility of the gases in the water contained in the skins, it would be expected that the ratio of hydrogen to air leakage would be the same as the ratio of the solubilities. The relation, if true for a perfect skin, would not necessarily hold for any actual skin-lined fabric or gasbag, the leakage of which is known to be mainly through defective places. The only evidence available on the point is the result of measuring lift and purity of an actual skin-lined gasbag over a period of a fortnight. The results, which are very rough, indicate that the bag lost 113 cu. ft. of hydrogen, while 59 cu. ft. of air entered. The permeability calculated from the area was

\[
3.2 \text{ litres hydrogen/sq. metre}/24 \text{ hours.}
\]

\[
1.7 \text{ ,, air ,, ,,}
\]

These results are of great interest as tending to show that in spite of the much lower permeability to hydrogen, a skin-lined envelope may actually lose purity faster than a rubber-proofed one.

C. Methods of measuring the permeability of fabric by hydrogen.

1. The method by combustion.—The method principally used in this country is that first worked out by Messrs. Rosenhain and Barr at the National Physical Laboratory and described by them in 1910 (A.C.A. Reports, 1909–1910, p. 86). The method is frequently referred to as the N.P.L. method.† The apparatus used in certain laboratories has, however, been considerably modified from that described in their paper.

2. Apparatus used at Kingsnorth.—The modification of this apparatus in use in the Kingsnorth Laboratory is shown diagrammatically in Fig. 1.

A circular test piece 41 cms. in diameter is cut from the fabric to be tested. This is placed between a pair of steel or copper drums shown in Fig. 2. The flanges of the drums are machined flat, and the seal between the fabric and the flange

* Since writing the above, a paper by Caro and Stück has been found in the Deutsche Zeitschrift für Luftschiffart, April, 1911, p. 7. The authors made analyses of the gas in envelopes of, apparently, two-ply rubbered fabric. They found a ratio of 1 : 3.3 for air : hydrogen leakage, and that nitrogen went in faster than oxygen. These results the authors consider to be in accordance with what they naively refer to as the "Diffusiongesetz."

† This method, however, is designated the "Combustion Method" in this paper to avoid confusion between the principle introduced by Rosenhain and Barr, and the actual apparatus used at the National Physical Laboratory.
is made with sugar syrup.* The method of making the seal and inserting the fabric is as follows. The face of the flange of one drum is smeared over carefully and evenly with the sugar, and the fabric is laid on top. The other drum, similarly sugared, is placed above, and the two clamped together with six screw clamps. The test piece is of smaller diameter than the external diameter of the drum, so that the cut edge of the fabric will be surrounded with sugar syrup. The internal diameter of the drum, which forms the edge to which the sugar extends, is taken as the diameter of the test piece (= \(0.0989\) sq. metre area). On this account care must be taken that no sugar spreads beyond the edge of the flange and over the fabric.

Each drum is provided with three tubes, two for inlet and outlet of air or hydrogen, and one for connection to a manometer.

Hydrogen from a bottle† is passed through the bottom drum. The hydrogen is passed through quickly at first to sweep out air, but subsequently quite slowly. It escapes through a water seal the height of which is adjusted so that the hydrogen is at a pressure of 3 cm. of water above the pressure in the upper drum, as indicated by the manometer.

Air is passed through the upper drum at a rate of 15 litres per hour. The air stream is maintained by a simple type of water pump (shown diagrammatically in Fig. 4)‡ operated by a constant head of water, and is drawn from out of doors to avoid the possibility of contamination with hydrogen. Before entering the drum the air is given a preliminary drying over calcium chloride and sulphuric acid. On leaving the drum the air is passed through a long tube packed with calcium chloride in the first half and a mixture of 3 parts \(P_2O_5\) and 2 parts of fine (but not powdered) pumice in the last. It then passes through a silica tube containing a helical wound platinum wire, which is kept at brightly glowing temperature by an electric current of 2 to 2½ amps.§ (Fig. 3.) The water obtained by combustion of the hydrogen in the air stream is collected in a weighed U tube filled with \(P_2O_5\) and pumice.

Before making a test, the top half of the drum, drying tube, and furnace are tested for leaks by passing a stream of air in the usual way, and plugging up the end of the furnace. If there

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* This syrup can be made up as follows:—

Two parts of cane sugar are dissolved in 1 part of water by heat, a few drops of dilute hydrochloric acid are added. The solution is boiled in vacuo for several hours until the consistency is judged to be suitable.

The syrup should be such that it flows with extreme slowness at ordinary temperatures. It is now bought from a sugar-boiling firm, and is very concentrated "corn syrup."

† The purity of this hydrogen is usually over 99 per cent.; the impurities are CO and nitrogen.

‡ This pump was devised by Air Mechanic R. G. Walton.

§ This type of furnace is due to Mr. B. D. Porritt, the North British Rubber Company's chemist. He prefers hard glass to silica, but silica has always been found satisfactory and has the advantage that moisture deposits from leaky fabrics do not matter.
is no leak at the pressure at which tests are made, the air stream will stop. This is shown by a sulphuric acid bubbler in the air supply. No test is carried out until the apparatus has passed this test satisfactorily. Leaks in the lower half of the drum seldom occur, and, as they are usually too small to be of any importance, this half of the drum is not tested.

In making a test the air and hydrogen streams are allowed to run for two hours before attaching the collecting tube. This preliminary "equilibrium period" is required to sweep out the apparatus and dry the fabric.

The collecting tube is usually attached for 1½ to 2½ hours, by which time a reasonable amount has been collected.

From the area of the test-piece, the weight of water collected and the time of test, the permeability is calculated in terms of litres of hydrogen per sq. metre per 24 hours, the hydrogen being supposed to be at 15°.5 C. and 760 mm. pressure.

The temperature of the test piece and its drum is maintained constant by placing the drum in a biological incubator maintained at 15°.5 C. The variations in temperature are usually within ±½° C. The apparatus is arranged so that six tests can be done simultaneously by one operator.

3. Tests of reliability of apparatus. Method of sealing.—Owing to the troublesome and messy character of the sugar seal, it was sought to dispense with it and use rubber washers in special drums between which the fabric could be tightly clamped. Though no leaks could be detected in the ordinary way, it was found that irregular results were obtained, however carefully the experiments were carried out. The irregularity may have been due, among other things, to (a) leakage through the cut end of the fabric; (b) leakage round the washers; (c) uncertainty in the delimitation of the area under test. The use of sugar solution eliminates such defects largely, if not entirely. The incompleteness of the sealing with rubber washers was shown by surrounding the drum with an atmosphere of hydrogen in place of air. Under these conditions a large leakage of hydrogen into the drums was found. The leakage found when a sugar seal was used was extremely small and not sufficient to affect the result appreciably.

Sugar is preferred to vaseline or other sealing materials, because it is easily washed off and leaves the fabric, after it has been dried again, practically unchanged.

Vaseline, on the other hand, although more convenient in some ways than sugar, does not leave the rubber unchanged for long and cannot be satisfactorily removed. Where a fabric only has to be tested once, vaseline is probably the best sealing material; but where repeated tests are required, sugar or a similar solution must be used. For certain skin-lined fabrics however, sugar is not well suited.
4. Equilibrium period.—It is obviously necessary to ensure that, prior to the commencement of the test period proper, the apparatus from the upper face of the fabric to the end of the combustion furnace is filled with a uniform mixture of hydrogen and air. Mixture of this same composition passes through the furnace during the test period, while the hydrogen is burnt, and remains filling the apparatus at the close of the test. The composition of this mixture clearly depends on the permeability of the fabric, and on the rate of air current. The main purpose of the so-called equilibrium period is to fill the apparatus uniformly with this mixture. The space to be swept out is, in the Kingsnorth apparatus, approximately 2.75 litres, and most of this is in the upper half of the test drum. Tests were made to see what time was required to replace the air in the apparatus completely by hydrogen and to replace hydrogen completely by air. For this purpose a disc of thin sheet copper was put across the drum in place of the usual fabric. Hydrogen was passed into the top half of the drum (where the air is ordinarily passed in during a test) whence it passed through the drying tubes and furnace at 16 litres/hour. After about 20 minutes a sample of the issuing gas was collected in a tube initially full of pure hydrogen. About 10 mins. were occupied in collecting the sample, which was found to contain 2 per cent. of air. After 40 mins. from the start another such tube was put in and left for 10 mins. The sample now collected contained no air, and therefore the whole of the apparatus had now been swept out and filled with hydrogen. The hydrogen supply was now cut off and air was passed in at 15 litres per hour. A sample of the issuing gas was collected after 30 mins. and contained about 15 per cent. of hydrogen. A sample collected after 50 mins. was pure air and contained no hydrogen. These results together prove that this apparatus can in 40 to 50 mins. be completely swept out and filled uniformly with a gas entering at about 15 to 16 litres per hour. In confirmation of this the following experiment was done. A 2 per cent. (approx.) mixture of hydrogen and air was passed into the apparatus, filled with air and having the copper disc across the drum, at the rate of about 15 lits./hour. After 15 mins. from the start the furnace was heated, a weighed absorption tube was attached and left on for 15 mins. and so on, the weights of water collected during successive 15-minute periods being determined. The results are given in the following table:

<table>
<thead>
<tr>
<th>Period in mins. from start</th>
<th>Gms. water collected</th>
<th>Rate in lits./hr. at which mixture was passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 to 30</td>
<td>0.0610</td>
<td>14.5</td>
</tr>
<tr>
<td>31 to 46</td>
<td>0.0718</td>
<td>14.8</td>
</tr>
<tr>
<td>47 to 62</td>
<td>0.0740</td>
<td>15.0</td>
</tr>
<tr>
<td>73 to 78</td>
<td>0.0700</td>
<td>14.4</td>
</tr>
<tr>
<td>79 to 94</td>
<td>0.0704</td>
<td>14.0</td>
</tr>
</tbody>
</table>
The amounts collected in successive periods after the first are roughly constant. The irregularity is probably partly accounted for by variations in the rate of flow.

A further experiment on duration of equilibrium period more nearly reproduced the conditions of actual test. A diffusion screen was made and placed across the drum as the fabric would be in a test.

The diffusion screen consisted of a disc of thin sheet copper in which seven holes, well distributed, were bored. The holes in the metal were about 2 mm. diameter, and were covered with pieces of uralite cemented on with Chatterton's compound, and so covered up with the compound that only about 1 sq. mm. of the uralite was left exposed at each hole, a few trials having shown that this area of exposed uralite was suitable. Hydrogen was then passed through the lower half of the drum and air through the top at 15 litres per hour, as in an ordinary test. The assumption underlying this experiment is that diffusion through the porous uralite begins and attains its maximum and steady rate immediately the lower drum is filled with hydrogen. Thus there is steady diffusion of hydrogen from below into the steady air current passing through the upper half of the drum, and all the conditions of actual testing are reproduced except that no rubbered fabric is present. After 30 mins. from the start, the furnace was heated and a weighed absorption tube was attached for 15 mins. and then replaced by another and so on until six successive tests of 15 mins. each had been made. The results are given below:

<table>
<thead>
<tr>
<th>Period of test in mins. from start</th>
<th>Gms. of water collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>30–45</td>
<td>0.0188</td>
</tr>
<tr>
<td>46–61</td>
<td>0.0208</td>
</tr>
<tr>
<td>62–77</td>
<td>0.0214</td>
</tr>
<tr>
<td>78–83</td>
<td>0.0210</td>
</tr>
<tr>
<td>94–109</td>
<td>0.0214</td>
</tr>
<tr>
<td>110–125</td>
<td>0.0220</td>
</tr>
</tbody>
</table>

It is clear that at some time between 45 and 60 mins. from the start the apparatus has become uniformly filled with a mixture of hydrogen and air.

The results of the experiments just described all agree in fixing about 45 to 50 mins. as the time necessary, under the conditions given, for sweeping out the apparatus and uniformly filling it with a gas or mixture of gases entering it. This may be called the equilibrium period of the apparatus.

There remains the question whether any further period is required when a fabric is in place. The following test was done on a well-dried fabric. The air and hydrogen currents were set
going, and after 50 mins. a weighed absorption tube was attached and furnace heated. The tube was left on for an hour, and then at once replaced by another. This was repeated until four successive one-hour tests had been made.

<table>
<thead>
<tr>
<th>Duration of test in mins. from start of equilibrium period</th>
<th>Gms. of water collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>50–110</td>
<td>0.0381</td>
</tr>
<tr>
<td>110–170</td>
<td>0.0381</td>
</tr>
<tr>
<td>170–230</td>
<td>0.0389</td>
</tr>
<tr>
<td>230–290</td>
<td>0.0384</td>
</tr>
</tbody>
</table>

It is clear that in this case there is no appreciable change after the first hour, the variations being rather smaller than those already observed in repeated tests on the same fabric after a prolonged equilibrium period. The length of equilibrium period necessary has also to be considered in connection with temperature control and with the drying of the fabric. These points are referred to in some detail in later paragraphs.

At Kingsnorth an equilibrium period of two hours is normally given, and many double and treble tests on the same fabric have shown this to be sufficient.

5. Efficiency of drying and absorption tubes.—Special tests have proved that the drying tubes do their work satisfactorily. No appreciable increase of weight is observed when a weighed absorption tube is attached to the apparatus and a stream of air passed through for an hour or two at 15 to 20 lits./hour. The test on the absorption tubes was to place three weighed tubes in series during an actual permeability test. When the first tube was of the pattern ordinarily used in this work (i.e., a U tube with limbs about 4 inches by 1/4 inch and well charged with P₂O₅ and pumice), no change in weight was observed in either of the others. Even with a smaller tube not so freshly charged the water passing in to the second tube was never more than one or two milligrammes.

6. Blank tests with a hot furnace.—If a current of air only is passed through the train of apparatus, the furnace heated, and a weighed absorption tube attached for an hour or so, no change in weight is observed provided the furnace has been kept hot with the air current passing through for a short time (say, 15 mins.) before the weighed tube is attached. This procedure is always followed in actual testing and is particularly necessary with a newly-made furnace or after the apparatus has been out of use for a time.

7. Efficiency of furnaces.—This was tested by passing a known volume of hydrogen, diluted considerably in a stream of air, through the drying tube and heated furnace and collecting and weighing the water formed.
The hydrogen was contained in a water-jacketed tube of known volume connected below to a water levelling vessel and fitted at the top with a two-way tap. One way of the tap led out to air, and the other to a length of very fine bore capillary tube which at a welded joint met a wider glass tube. This was in its turn connected at one end to the train of drying tube and furnace and at the other end to an air supply. By suitably adjusting the levelling vessel from time to time it was possible to keep a slow stream of hydrogen passing through the capillary into the air current, and by adjusting the latter it was possible to pass into the furnace a known volume of hydrogen mixed with air at an approximately known concentration. Two sets of experiments were made at different concentrations of hydrogen roughly corresponding to permeabilities of 12 and 60 litres/sq. metre/day respectively.

Some tests were also made with a furnace glowing only very feebly, and some with a furnace having a platinum spiral somewhat pressed up against the wall of the silica tube. Mean results of several tests of each kind are given below.

<table>
<thead>
<tr>
<th>Approx. comp. of mixture in % H₂</th>
<th>Arrangement of furnace</th>
<th>Current in furnace</th>
<th>Wt. water obtainable from H₂ used</th>
<th>Wt. water actually collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>Usual – –</td>
<td>1.8 amps.</td>
<td>0.174 gm.</td>
<td>0.175 gm.</td>
</tr>
<tr>
<td>0.3</td>
<td>Pt. spiral pressed against silica tube.</td>
<td>1.8 , ,</td>
<td>0.172 ,,</td>
<td>0.172 ,,</td>
</tr>
<tr>
<td>0.3</td>
<td>Silica furnace tube stained with deposited pt. and carbon.</td>
<td>1.8 ,,</td>
<td>0.171 ,,</td>
<td>0.172 ,,</td>
</tr>
<tr>
<td>0.3</td>
<td>Spiral glowing only feebly.</td>
<td>1.5 ,,</td>
<td>0.169 ,,</td>
<td>0.168 ,,</td>
</tr>
<tr>
<td>1.5</td>
<td>Usual – –</td>
<td>1.8 ,,</td>
<td>0.171 ,,</td>
<td>0.169 ,,</td>
</tr>
</tbody>
</table>

It will be seen that, except in the last case, the weight of water collected is correct to within about ¼ per cent., an accuracy more than sufficient for the purposes of routine testing and, indeed, considerably greater than the accuracy with which results can be reproduced in repeated tests on the same piece of fabric. If in the last case the water collected in a guard absorption tube in series with the main tube had been included, the figures for water obtainable and actually collected would have been 0.171 and 0.170 respectively, bringing this result into line with the others as regards agreement between the figures.

It may be added that these experiments on furnace efficiency form a very comprehensive test of the reliability of the whole apparatus, beyond the test drum, and include a test of the gastightness of the connections when the apparatus is used in the ordinary way, i.e., with little or no excess of pressure inside over that of the atmosphere.
8. Accuracy of temperature control.—Such results as are available show that the variation of permeability with temperature is considerable, amounting to about 5 per cent. per 1°C. in the neighbourhood of 15°C. It is therefore necessary to make all tests at as nearly constant a standard temperature as possible. The constant temperature chamber of the Kingsnorth apparatus is a biological incubator adjusted to maintain a temperature of 15.5°C. With ordinary care the temperature variations during tests do not exceed 0.5°C. above or below the standard even when the room temperature differs from that of the incubator by as much as 10°C. In hot summer weather it is, of course, necessary to see that a good stream of ice water is kept flowing through the cooling jacket of the cupboard. The space inside accommodates six test drums placed one above another on horizontal shelves. The height of the cupboard inside is about 45 inches.

The temperature variation throughout the cupboard does not amount to more than about 0.2°C. or 0.3°C. Tests have been made to discover whether the temperature inside a test drum is the same as that of the chamber when a rapid current of air is being passed from a hot room through the upper half of the drum. The results are given below:

<table>
<thead>
<tr>
<th>Room</th>
<th>In cupboard</th>
<th>Inside drum</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.5</td>
<td>16.3</td>
<td>16.3</td>
</tr>
<tr>
<td>21.0</td>
<td>16.3</td>
<td>16.3</td>
</tr>
<tr>
<td>19.8</td>
<td>16.3</td>
<td>16.5</td>
</tr>
<tr>
<td>21.0</td>
<td>16.4</td>
<td>16.5</td>
</tr>
<tr>
<td>25.0</td>
<td>16.8</td>
<td>16.8</td>
</tr>
</tbody>
</table>

At the time of test the supply of ice water was insufficient to keep the apparatus to the standard temperature, but it is clear that the temperature taken in the cupboard is a fair record of the temperature inside the drums.

Three temperatures are recorded during a test, viz., at the start of the equilibrium period, when the absorption tubes are put on, and when they are taken off. In hot weather the first temperature may be considerably above 15.5°C., for the incubator has to be open some time while the test drums are being put in and connected up, and, moreover, the drums themselves form a very considerable mass of warm metal which has to be cooled down in the incubator. For this reason the equilibrium period may, under such conditions, have to be prolonged till the temperature of the incubator falls.

9. Variations in hydrogen pressure.—In all ordinary tests the hydrogen pressure is kept at 3 cms. of water higher than that on the air side. It is found that with fabrics of the
usual order of permeability this excess pressure can be varied between 1 cm. and 6 cms. without seriously affecting the result obtained. As the pressure can easily be kept constant to within \( \pm 5 \text{ mm.} \), no error on this score is to be apprehended.

The following results show what the effect is:

<table>
<thead>
<tr>
<th>( H_2 ) pressure</th>
<th>Test piece.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1 cm. - -</td>
<td>12-0, 12-0 10-5, 10-7 14-0, 14-0 11-8, 10-1</td>
</tr>
<tr>
<td>12-1</td>
<td>10-8</td>
</tr>
<tr>
<td>Mean</td>
<td>12-0</td>
</tr>
<tr>
<td>3 cm. - -</td>
<td>14-2, 13-7 10-9, 9-9 15-4, 13-9 11-1</td>
</tr>
<tr>
<td>12-9</td>
<td>10-0</td>
</tr>
<tr>
<td>Mean</td>
<td>13-6</td>
</tr>
<tr>
<td>6 cm. - -</td>
<td>13-0, 11-9 10-6, 11-0 15-1, 15-2 12-3, 12-4</td>
</tr>
<tr>
<td>12-6, 12-2</td>
<td>10-6, 10-5 15-1, 14-6 12-0, 11-5</td>
</tr>
<tr>
<td>12-7</td>
<td>10-7</td>
</tr>
<tr>
<td>Mean</td>
<td>12-5</td>
</tr>
</tbody>
</table>

If the mean for all four fabrics be taken, the following is obtained:

11-9 lits./m\(^2\)/24 hours at 1 cm. pressure.

12-4 " " 3 "

12-6 " " 6 "

Thus for a \( \frac{1}{2} \) per cent. increase in total hydrogen pressure (5 cm. in 1,000 cm. water pressure) there is a 6 per cent. increase in permeability.

10. *Purity of hydrogen.*—By using hydrogen diluted with air it has been found that the permeability is approximately proportional to amount of hydrogen present, as was found previously by Barr and Thomas (A.C.A. Reports, 1912–13, p. 272) using a volume method.

As the hydrogen used is never below 99 per cent. pure, no correction is needed on this account.

11. *Atmospheric pressure variations.*—Experience shows that within the limits of accuracy of the method the normal variation in atmospheric pressure is without influence on the results. This is what would be expected.
The following results on one fabric exemplify this.

<table>
<thead>
<tr>
<th>Barometric press. Cms. Hg.</th>
<th>Permeability. Lits./m²/day.</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.0</td>
<td>11.2</td>
</tr>
<tr>
<td>74.5</td>
<td>11.3</td>
</tr>
<tr>
<td>74.9</td>
<td>11.3</td>
</tr>
<tr>
<td>75.1</td>
<td>11.7</td>
</tr>
<tr>
<td>75.9</td>
<td>11.7</td>
</tr>
<tr>
<td>76.4</td>
<td>11.2</td>
</tr>
<tr>
<td>76.6</td>
<td>11.7</td>
</tr>
<tr>
<td>76.7</td>
<td>11.3</td>
</tr>
<tr>
<td>76.9</td>
<td>11.4</td>
</tr>
</tbody>
</table>

12. *Presence of volatile combustible matter containing hydrogen.*—It has sometimes been found that the second of two successive tests on a piece of fabric has given an appreciably lower result than the first. This has often been observed with some types of skin-lined fabrics and with fabrics containing a newly-made seam, and it has been traced to the presence of small amounts of “naphtha” or other hydrocarbon solvent left in the fabric. That this may be a source of serious and insidious error will be seen when it is realised that 0.01 gm. of “naphtha”* carried along in the air current and burnt in the course of 2 hours would correspond, in the weight of resultant water, to a permeability of 1.4 lits./sq. metre/24 hours. On a skin-lined fabric this would, of course, be a particularly serious error. There is no practicable way of removing these vapours from the gas current in the course of routine testing, and reliance has to be placed on thorough airing of the fabrics and on getting concordance in successive tests. Although ordinary rubber proofed fabrics are, from their mode of manufacture, not likely to contain any residual hydrocarbon solvent, yet it is conceivable that traces might remain thoroughly absorbed in the vulcanised rubber. Obviously such traces, if they exist, are held very tenaciously, and it is just possible that their absence is not proved by getting a null result in doing a blank test in which air only is run through the apparatus. It may be that the more drastic “airing” due to the passage of hydrogen through the fabric is required to dislodge them. In this case, of course, they would escape detection in the blank test and yet give an erroneously high result.

13. *Hygroscopic state of fabric.*—Ordinarily, fabrics are placed in the test drums in the air-dry condition, and no attempt is made to bring them to a standard state of dryness other than they attain during the equilibrium period; but, since nearly dry gases are passed through, probably the fabrics are nearly completely dried.

*It is assumed that this is xylene.*
The hygrometric state of a fabric undoubtedly affects its permeability, as the following figures show. The fabrics were proofed on one face, and plain cotton on the other. They were first carefully dried in a desiccator and tested with dry gases in dried drums. The hydrogen and air were then passed in through water, and the permeabilities of the fabrics taken again from time to time as they got damp and until a fairly steady value was reached.

**Permeabilities in Lits./sq. m./day.**

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Dry Fabric</th>
<th>After passage of moist gas</th>
<th>Decrease % of dry value after</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12 hrs.</td>
<td>50 hrs.</td>
</tr>
<tr>
<td>A</td>
<td>10.9</td>
<td>10.8</td>
<td>9.3</td>
</tr>
<tr>
<td>C</td>
<td>11.4</td>
<td>10.7</td>
<td>8.8</td>
</tr>
<tr>
<td>E</td>
<td>47.2</td>
<td>30.5</td>
<td>22.8</td>
</tr>
<tr>
<td>G</td>
<td>26.4</td>
<td>15.8</td>
<td>15.6</td>
</tr>
<tr>
<td>I</td>
<td>10.3</td>
<td>9.6</td>
<td>8.1</td>
</tr>
<tr>
<td>K</td>
<td>9.9</td>
<td>7.7</td>
<td>7.6</td>
</tr>
</tbody>
</table>

It will be seen that the effect of moisture is greatest on fabrics of high permeability, and that on fabrics of moderate permeability the effect of considerable moisture, short of full saturation, is slight. (See decrease in permeability after 12 hours’ exposure to moist gas for test pieces A, C, and I.) From this it is fairly certain that small differences in hygrometric condition near to complete dryness, such as would obtain in ordinary routine testing of fabrics, are without appreciable influence on the permeability. This conclusion is borne out by the fact that in successive tests on the same piece of fabric there is no general increase in permeability as the fabric is brought from air dry to the perfectly dry condition.

Dr. Shakespear (R. & M. 317, February, 1917) has suggested that it would be preferable to test fabrics not dry, but at constant humidity, say, 60 per cent. saturation, to represent service conditions. It is not considered, on the whole, that this procedure would be an improvement, as it would complicate the apparatus considerably, would make no appreciable difference in the case of good fabrics, and would tend, if anything, to mask the difference between the good and the bad. For the purpose of testing fabrics delivered direct from the manufacturers and cut from the middle of the piece, as is done at Manchester, testing at 60 per cent. humidity might lengthen rather than shorten the equilibrium period. Such fabrics are probably nearer dryness than 60 per cent. humidity.
14. Order of accuracy of results obtained.—It is necessary to notice how far the efficiency of the apparatus and the relative absence of obvious sources of serious error are reflected in the general accuracy of the results obtained. As to this a statement can be made, but it is not possible to present here the full data for forming an opinion, such data consisting, of course, of the very many results obtained where the same piece of fabric has been repeatedly tested.

It may be stated, then, that an agreement to within 5 per cent. is observed in a majority of cases and to within 10 per cent. in a large majority, where ordinary rubber-proofed or doped fabrics are being tested.* With good skin-lined fabrics having low permeabilities of the order of 1 or 2 litres/sq. metre/day the agreement is not quite so good. The order of accuracy given above is, of course, quite good enough for the routine testing of airship fabrics.

There are cases where the discrepancy between the results of successive tests is much greater than 10 per cent., and is not traceable to any obvious error in technique. This has been observed by thoroughly experienced and careful workers fully alive to the necessity for attention to the minutiae of technique. It is difficult to resist the conclusion that such discrepancies are the result of changes in the fabric and what might be called spontaneous changes not to be referred to any change of condition, such as temperature or moisture content. The following is an extreme example of this kind of change. Three adjacent strips the full width of a fabric were cut at Manchester, and the two outer ones tested there whole. The middle one was sent to Kingsnorth, and from it two test circles were cut. The Manchester results for double tests on the two pieces were in the usual units

\[
\begin{align*}
3.6 & \quad \text{and} \quad 3.3 \\
3.8 & \quad \text{and} \quad 3.0
\end{align*}
\]

The Kingsnorth experiments were begun about a week later, and the first double tests on the two circles gave

\[
\begin{align*}
5.8 & \quad \text{and} \quad 7.6 \\
5.2 & \quad \text{and} \quad 7.3
\end{align*}
\]

This difference between the Manchester and Kingsnorth figures might prove nothing except the superficial variation in the cloth. Further tests pointed, however, to a slow change in permeability of the same piece of cloth. The two circles were taken out of the test drums, washed, dried, and re-tested after the

* Out of 146 results of double or treble tests taken without selection from the laboratory records over a certain period 56 per cent. agreed to within 5 per cent., 84 per cent. to within 10 per cent., 93 per cent. to within 15 per cent.
lapse of four days from the first test. The results were now

\[
\begin{align*}
9.3 & \quad 9.4 \\
10.5 & \quad 10.9
\end{align*}
\]

The pieces were once more washed, dried and tested after an interval of a week. The results were now

\[
\begin{align*}
9.9 & \quad 9.7 \\
9.7 & \quad 9.2
\end{align*}
\]

It will be seen that the fabric suffered a rapid change at first, and after about a fortnight settled down to a more or less steady value very far removed from the original one.

It is known that in rubber-proofed fabrics the process of vulcanisation goes on slowly after the cloth is finished, and it may be that this process is accompanied by changes in the permeability that do not necessarily tend continuously in one direction. The bearing of this where the reproducibility of results is made the criterion of their accuracy is obvious. There are few cases of large discrepancies in carefully-conducted experiments where double or triple tests on a fabric have been done as a continuous operation. They have almost always occurred where a fabric has been re-tested after an interval, having, of course, been washed and dried between the two tests.

There is another possible explanation of the discrepancies in such cases. It may happen that a large portion of the permeability of a given piece is narrowly localised in one small bad area. If this happens to be close to the sealing margin of a test piece, it may possibly be sugar sealed in one test and not in another. This could hardly occur where a double test was done as a continuous operation. It is doubtful how far the "spontaneous" change of the fabric can be held accountable for the small discrepancies of the order of 5 per cent. that are frequently observed in continuous double tests. Those who most fully realise the necessity for scrupulous care in all the details are unwilling to ascribe the whole of this discrepancy to controllable conditions.

It may be emphasised again that, bearing in mind the possibilities of inconsistency in fabrics, a 5 per cent. degree of accuracy suffices for all routine testing. At the same time there are problems in connection with permeability that are by no means merely of academic interest, for the solution of which a higher order of accuracy than 5 per cent. is desirable.

15. Permeability apparatus at Manchester.—This apparatus was designed with a view to testing the maximum possible quantity of fabric with as little expenditure of time and labour as possible.

The test pieces are rectangular about \(\frac{1}{2}\) sq. metre in area, and comprise the full width of the fabric, exclusive of the selvedges. Vaseline is used for sealing, with a mercury seal in addition, and the fabric is cut smaller than the outside of the flange.
of the drum to seal the edge of the fabric. The drums are of iron with accurately machined faces in contact with the fabric. Wire netting is arranged to keep the fabric from sagging. Drums are arranged so that test pieces can be changed with minimum amount of labour and handling. They are water jacketed, and the temperature control is obtained with sufficient exactness for routine tests by passing the water from the town mains through them.

The hydrogen obtained from bottles is passed through soda lime, calcium chloride, sulphuric acid, and escapes after passing the drum through a water seal. The air, obtained from a large air reservoir, is passed through sulphuric acid, soda lime, calcium chloride, and a small sulphuric acid bubbler before entering the drum. The combustion furnaces are designed so that adjustments are easily made and the collecting tubes easily and rapidly attached and removed. Fig. 5 shows the arrangements of the furnace and $P_2O_5$ collecting tube.

A two-hour equilibrium period is given, and half an hour suffices for the test.

Control experiments with this apparatus showed

(1) Not more than 2 per cent. of hydrogen escapes combustion.

(2) Absorption by the $P_2O_5$ tubes is complete.

(3) No absorption takes place in the $P_2O_5$ tubes when the furnaces are cold.

(4) No vapours are given off by the vaseline which might affect the results.*

16. Comparison of Kingsnorth and Manchester apparatus.—It is seen that there is no essential difference between the Kingsnorth and Manchester methods, except the difference in size of the test pieces and the different methods used for sealing.

Comparative tests were rendered difficult because it was impossible owing to the shapes and sizes of the test pieces to test the same piece of fabric in both instruments. The first tests were made on pieces of new fabric. This was first tested at Manchester, and then adjacent samples tested at Kingsnorth. These experiments served only to show that the permeability of the fabrics was gradually increasing. Old fabrics which were believed to be in a steady state were therefore selected.

The results with one fabric X.M. 4045 were:

Means of two groups of three adjacent test pieces tested at Kingsnorth:

23.2 and 15.5 litres/sq. metre/24 hours at 15° C.

* This is not intended to be a complete description of the apparatus, but to indicate its main features. A diagram (Fig. 5) of the furnace is, however, inserted, as its design is considered to be of general interest.
Means of tests on two pieces at Manchester cut between the groups of Kingsnorth test pieces:

23.2 and 16.3 litres/sq. metre/24 hours at 15°-5 C.

These results are not very conclusive because of the extreme variability of the fabric from place to place. Thus the six individual Kingsnorth test pieces leaked 10.9, 11.4, 47.2, 26.4, 10.3, and 9.9 litres/sq. metre/24 hours. These figures are all the means of 5 closely agreeing results.

A more even fabric, M. 12, was taken, therefore, and the test pieces were all cut from the middle; the Manchester pieces being cut longitudinally instead of transversely. The reason for this is that a fabric usually differs more from side to side than along its length.

The results were:

Kingsnorth test pieces at temp. 15° C. gave 6.4, 6.2, 6.5, 7.2, 8.0, 6.8, mean 6.8 litres.

Manchester test pieces, temp. 15°-5 C, 5.6 and 6.5, mean 6.1 litres.

Lastly a doped fabric, D.F. 138, was tested,

Kingsnorth test pieces at 15°-5 C. 4.2, 4.5, 4.3, 3.8, mean 4.2.

Manchester test piece at 15°-5 C. 5 litres.

It is clear that while these tests show roughly that the two instruments are in agreement, they show very well the variable nature of the material dealt with.

It may be mentioned that the carrying out of all these tests was superintended by one observer.

16. Other methods of testing permeability by hydrogen. Volume methods.—The older volume methods of measuring permeability are fully described by Austerweil (Die angewandte Chemie in der Luftfahrt). The only one that is deserving of further mention is the Renard Surcouf balance, because this has been much used. The disadvantages of this instrument are discussed by Dr. Guy Barr (Rubber Industry, 1914, p. 265). Not only is it inaccurate, as he points out, but it is also very slow in use. Each test takes about 24 hours.

17. Mr. Short’s method.—A very ingenious method has been suggested by Mr. H. W. Short, working on the same principle as his “leak detector.” That is to say, the rate at which hydrogen leaks through a fabric into an air chamber is measured by the deflections of a leak detector in communication with it. An apparatus working on this principle has been used to some extent, and appears to be fairly satisfactory. No high degree of accuracy is to be expected by this method, and the calibration of such an instrument is not a simple matter. For simplicity and cheapness of construction, however, such an instrument would be difficult to beat, and the method holds out possibilities of an
instrument which will do what the ordinary leak detector does, but will give quantitative readings and have a greater sensitivity.

18. Dr. Shakespear's method.—Dr. Shakespear's method has already been described in A.C.A. Reports for this year by himself, and by Dr. Barr, so that no further description is necessary. (See R. & M. 504.)

Experience with this instrument at Kingsnorth indicates that the instrument is to be relied on under the conditions of calibration and within the limits of accuracy of the calibration.

Nothing is known, however, as to the principle on which the "katharometer" works beyond that it is supposed to be a thermal conductivity effect. It is not clear how far the readings of the instrument are likely to vary with varying conditions or with lapse of time.

The great merit of the instrument appears to be that it is very nearly "foolproof," and that whereas the working of the combustion method is quite a difficult matter and needs considerable experience, Dr. Shakespear's instrument can be used by a comparatively unskilled person.

The small size of the test pieces, 0.009 sq. metre, compared with 0.1 sq. metre with N.P.L. and Kingsnorth apparatus and 0.33 sq. metre at Manchester, renders it of very little use for routine testing purposes when it is desired to have a fair average of the fabric examined.

As the variability of the fabric is much greater in every case than the error of the apparatus, it is the total area tested that is the best measure of the reliability of the result. To test 90 sq. metres of fabric per week, as is done at Manchester, would be almost an impossibility on Dr. Shakespear's apparatus. Probably the instrument could be modified to take large test pieces, but it might lose in accuracy thereby.

This small size of test piece is, however, an advantage for certain purposes where it is desired to "explore" a fabric to find out what the variations actually are.

It is considered that the proper functions of the combustion method and Dr. Shakespear's method are complementary, i.e., that each instrument has its own proper sphere of usefulness. Other methods that have been suggested from time to time need only be mentioned briefly.

19. Various methods.—Frenzel (Uber die Gasdurchlässigkeit der Gummierten Ballonstoffe 1914 (!)) describes a method depending on the estimation of small quantities of hydrogen in air with an interferometer. He used a stream of air, as in the combustion method, but measured the speed of the air stream and found the concentration of H\textsubscript{2} from time to time. This method suffers from the fact that to obtain satisfactory sweeping out of the
PERMEABILITY APPARATUS AT KINGSNORTH LABORATORY.

GENERAL ARRANGEMENT OF APPARATUS (Diagrammatic)

FIG. 1

Air
Phosphorus Pentoxide

Calcium Chloride

Glass Wool

Furnace

Pressure Tubing Connection

Phosphorus Pentoxide Absorption Tube

3 cm.

Water Seal

Drum containing Fabric
Screw Clamps holding the Halves together not shown.

Sulphuric Acid Dryer

Hydrogen

Water Gauge
DETAILS OF PERMEABILITY APPARATUS AT KINGSNORTH LABORATORY.

PERMEABILITY DRUM (TURNED OUT OF SOLID STEEL AND TINNED).
(BOTH HALVES ARE IDENTICAL).

FIG. 2

SECTION

FIG. 3

SECTION OF FURNACE.
FIG. 4.

Air drawn from outside is sucked in here

Water flows in here from a head of 8°

This tube about 3/8 bore

Air

Six inch Water Seal

AIR BLOWER.
SUPPLYING AIR TO APPARATUS IN KINGSNORTH LABORATORY.

FIG. 5.

Phosphorus Pentoxide Absorption Tube.

Steel Pin

Cork

Mercury Seal

Plug

Platinum Helix

Mercury Seal

Plug

Steel Pin

FURNACE AS USED AT R.N.A.S. LABORATORY MANCHESTER.
WHOLE FURNACE OF FUSED SILICA.
DIAGRAMMATIC NOT TO SCALE.
apparatus a very rapid air current must be used, so that the actual concentration of hydrogen is very small. Moreover, it is necessary to keep the air stream constant over considerable periods, and to measure the volume of air pretty accurately.

The interferometer is not considered to be a particularly suitable instrument for this class of work. Dr. Shakespear’s "katharometer," for instance, would probably be better, as it can be made much more sensitive than an interferometer.

Other methods suggested from time to time involve the use of a delicate gas balance, the measurement by a thermocouple of the heating of platinum-black by absorption of hydrogen, and other ingenious devices for detecting and measuring small concentrations of hydrogen.

20. On the whole, experience goes to show that for general purposes the combustion method is the one that is most to be relied on. Of the alternative methods, which all depend on the measurement of some change in the physical properties of air due to the presence of small quantities of hydrogen, the method described by Dr. Shakespear appears to be the most suitable on account of the high sensitiveness of the instrument and the ease of its manipulation.