10 seconds, unless the molecule itself is considered. This effect has been observed in laminated specimens.

The difficulty of working with alternate currents, if the core be subdivided, in order to investigate the effects observed, using the method in the 'Proceedings of the Royal Society,' vol. 53, p. 352, is the necessity for the very accurate control and measurement of the magnetising force. Small variations of this force would at once mask the effects observed. In the paper just mentioned a considerable difference was observed between cyclic curves obtained with the ballistic galvanometer and by means of alternate currents having frequencies of 72 and 125 per second in the case of a laminated hard steel ring for maximum $B = 16{,}000$. On the other hand, no such difference was observed in the case of a laminated soft iron ring when maximum B was 4000.* It would seem from the experiments in this paper that the amplitude of induction would not be so great for high frequency and small induction density B, and this is of importance in the case of iron cores for transformers. It is worth noting that when working on solid rings with the ballistic galvanometer induced currents may account for apparent magnetic instability.

Mr. H. H. Hodd has helped me in the experimental part of this paper, and I here wish to tender him my thanks.

"On a new Method of Determining the Vapour Pressures of Solutions." By E. B. H. WADE, B.A. Communicated by Professor J. J. THOMSON, F.R.S. Read May 13, 1897.

(Amplified Abstract, received December 22, 1897.)

On a previous occasion† I gave some boiling points of salt solutions under atmospheric pressure. As the dimensions of that abstract made a full account of the experimental method impossible, I have been given this opportunity, by the courtesy of the Council of the Royal Society, of describing the apparatus and procedure by which those results were obtained.

§ 1. *Difficulties to be overcome.*

The exact determination of boiling points of solutions has been attended hitherto with a good deal of difficulty. The boiling point of the pure solvent is first determined. Salt is then added, and the boiling point is redetermined. The experiment consists, in fact, of two parts, and the difficulty lies in making the circumstances in which the first part of the experiment was carried out identical with

* See 'Electrician,' September 9, 1892.

† 'Roy. Soc. Proc.,' vol. 61, pp. 285—287.

those in the second. Examples of such circumstances are, barometric pressure, rate of ebullition, height of flame employed, depth of experimental liquid, and many others, and there is no doubt that the chief reason why the boiling-point method has been so little utilised, is the inability to reproduce these conditions. In particular, if the pressure under which the boiling point is to be measured is much less than 760 mm., the difficulties are so much increased that no one seems even to have attempted to make observations under such conditions.

§ 2. *Principle on which success depends in measuring by the Boiling-Point Method the Vapour Pressure of Salt Solutions.*

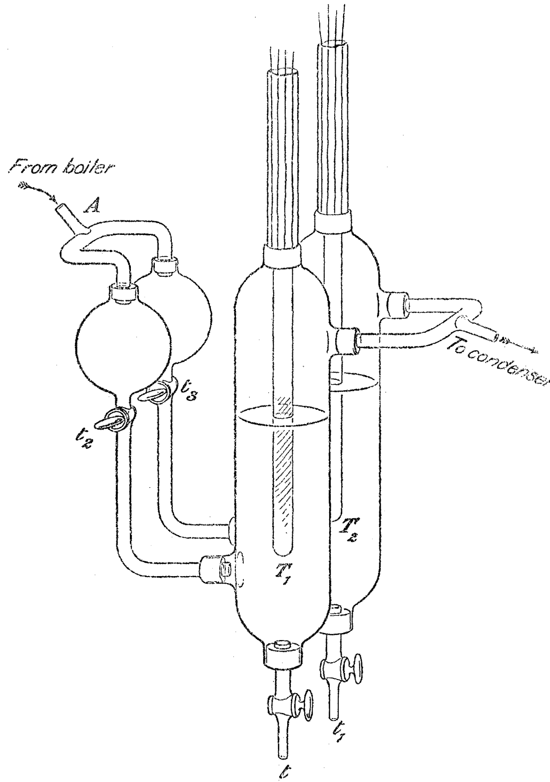
The difficulty in applying and extending the boiling-point method disappears in a great measure if not entirely, if the apparatus is duplicated, *and the difference alone is measured of pure water and solution boiling under similar conditions and under the same pressure, the magnitude of which need not then be known to within a millimetre.*

The difference of temperature referred to may very profitably be measured by the platinum resistance method. A decided advantage of methods which obey the principle above stated, lies in the fact that, whereas the differences of vapour pressure, measured at a common temperature, diminish very rapidly as the temperature is lowered, the difference of temperatures, measured under a common pressure, varies much less rapidly. As an example, suppose that a certain solution under a pressure of 760 mm. has a boiling point 0·52° higher than pure water, then under 360 mm. it will be found to have a boiling point 0·45° higher than that of pure water, a diminution of only 14 per cent. The corresponding diminution in the difference of tension would be 53 per cent.

The first apparatus employed by me to take the difference of boiling points of pure and salt water was in form very simple, and constructed from ordinary laboratory apparatus. A description of it is here introduced, mainly because it illustrates the principle of the more complex apparatus shortly to be described.

A current of steam from a boiler divides itself at A, fig. 1, and passes through two precisely similar pieces of apparatus, one containing pure, the other containing salt, water. The contents are agitated by the steam, and so raised to their boiling points, and the difference alone of the temperatures in the liquids was found by the two platinum thermometers T_1 T_2. Without giving details of this measurement it may at once be said that, as soon as it was complete, solution could be drawn off at the tap t_1 and its concentration determined. The remaining taps (t_2, t_3) serve to regulate the flow of steam, and the bulbs to prevent a suck-back. The apparatus worked

FIG. 1.



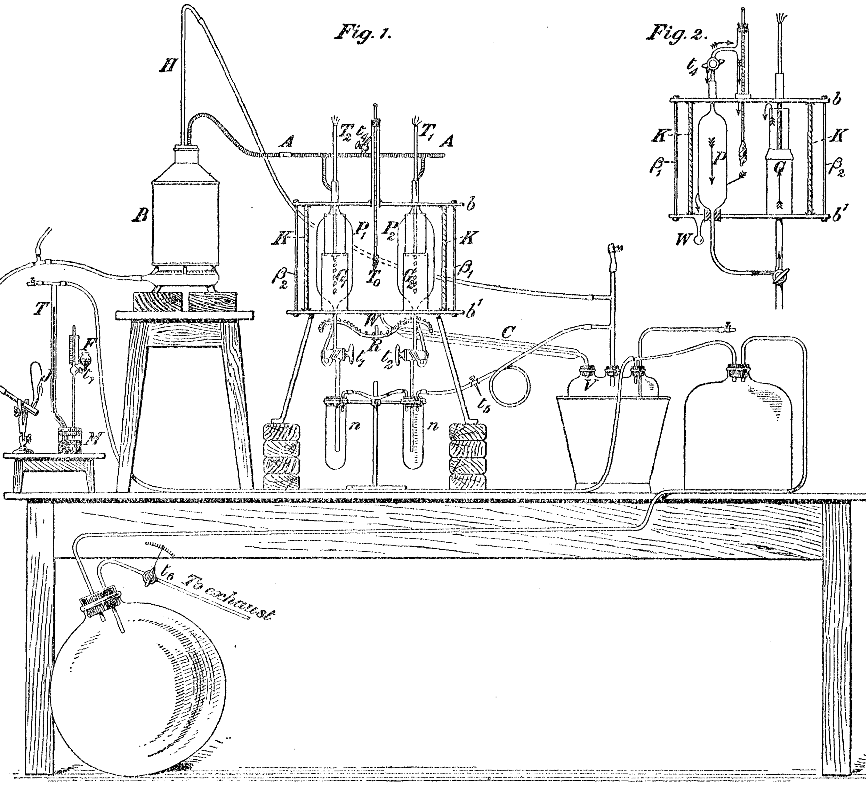
well, but the condensation was so rapid that the contents of the U-tubes accumulating became unmanageable. The difficulty was only partially overcome by jacketing with flannel. The trouble was all the greater, inasmuch as the estimation of temperature by the platinum method requires some little time. The only possible way of obviating this condensation was to employ a steam-jacket, and in order to do so the apparatus was completely reconstructed, so that it assumed the form described in the next section.

§ 3. *The Apparatus employed.*

The apparatus which is about to be described is that which yielded the experimental numbers.* Although its principle is fully contained in the very simple model of the last section, yet its form is somewhat complicated.

* 'Roy. Soc. Proc.,' vol. 61, pp. 285—287.

(PLATE 1.)



The essential part of the apparatus is as follows: $b\ b'$ (Plate 1, figs. 1, 2) are two horizontal circular plates of tinned brass. K is a vertical glass cylinder which is gripped between them. The two junctions are made fast with india-rubber bands.

Five vertical brass rods (of which two, $\beta_1\ \beta_2$, appear in the figure) hold the plates $b\ b'$ and cylinder K in position. The combination will in future be referred to as the "drum." $G_1\ G_2$ are two cylindrical tubes; the lower part of each is made of tinned brass, the upper of glass. They are destined to hold pure water and solution respectively. Outside and below the drum they terminate in a pair of three-way taps $t_1\ t_2$.

$P_1\ P_2$ are two pipettes, each passing through both lid and base of the drum. Each pipette can be connected to the corresponding G-tube in the manner shown in the plate (fig. 2). The upper extremities of the pipettes are placed in connection by a horizontal tube A.

B is a boiler, and the steam generated in it passes along A,

downwards, through the pipettes, and upwards through the G-tubes. It then spreads into the drum (thus jacketing the G-tubes), and finally passes through the waste W into the condenser C. This circulation is indicated by means of the arrows in the diagram (fig. 2). The condenser leads to a Woulfe's bottle V in which the pressure may be adjusted to any value.

A mercurial thermometer, T_0, passes through the lid b, and its bulb is near the centre of the drum. Its stem is jacketed by a tube, connected through a tap t_4, with the steam supply in A. If this tap is left *wide* open the steam from the generator flows almost entirely through it into the jacket tube and thus into the drum, avoiding the alternative circuit through the G-tubes. By regulating the tap t_4 we can therefore adjust the flow through the G-tubes with considerable nicety.

T_1 T_2 are two platinum thermometers, and by means of them the difference of the temperatures of pure water and solution, boiling under similar conditions, may be ascertained.

If it is desired to add or remove liquid to or from the G-tubes, the three-way taps t_1 t_2 are set so as to connect them with the reservoirs, n n, instead of with the pipettes P. When the operation is being carried on under ordinary pressure, the contents of the G-tubes will descend into the reservoir; on the other hand, by forcing air into the reservoir, any liquid therein will ascend into the G-tube. At reduced pressure the descent takes place as before, and in order to make liquid ascend it is no longer necessary to blow, but merely to open the three-way tap t_5 to the atmosphere. On doing this the reservoir r is placed out of connection with the low pressure in the Woulfe's bottle V, and into connection with the atmospheric pressure, and any liquid in the reservoir at once ascends.

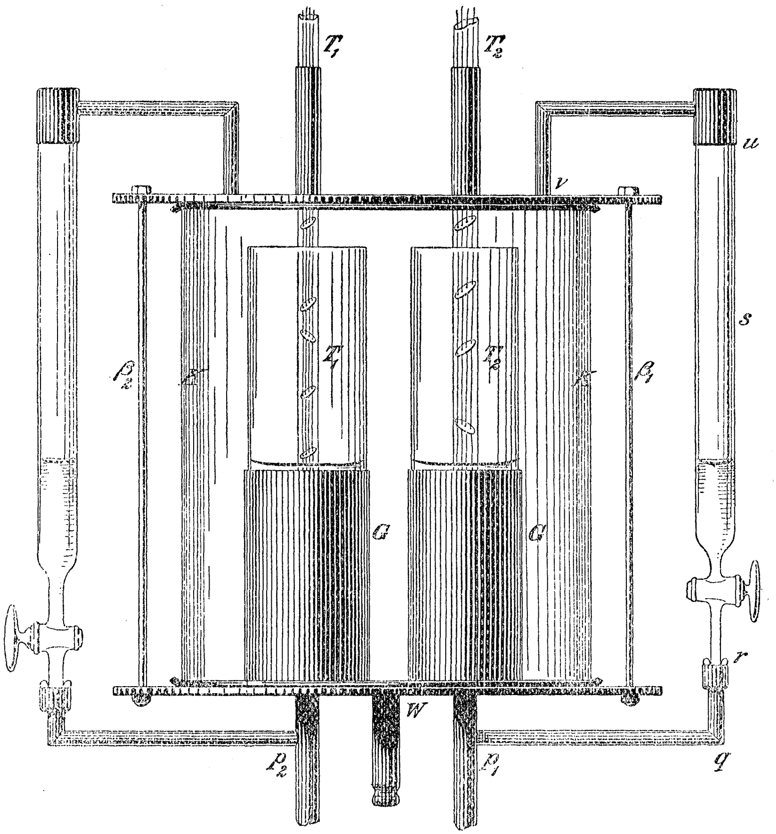
Improvements.—When the apparatus came to be used, some improvements were made as the result of experience. It was found, for instance, that the drum was not able completely to prevent the condensation in the G-tubes, so that the depth of liquid in them tended to increase. As such changes of depth were found to be a source of error, at any rate when they proceeded unequally in the two G-tubes, it was necessary either to equalise or prevent them. Though this could easily be done by running off liquid from time to time through the three-way taps t_1 t_2, such a proceeding was for many reasons very undesirable. Moreover, the attention of the observer was quite sufficiently occupied at the bridge and galvanometer (§ 4).

In one series of experiments, therefore, a very small symmetrically shaped double ring-burner was placed with one half under each G-tube, and condensation was thus exactly balanced. As this burner was not used in the experiments already published (*loc. cit.*) it is

not necessary to consider it further, except to say that the numbers in that series are in good accord with those in a series obtained by the help of the ring-burner.

In the first-named series no attempt was made to prevent the slight condensation. The burners were dispensed with and the equalisation of depths or "levelling" was effected by an automatic device to which special attention must be drawn.

(PLATE 2.)



The two metal tubes by which the steam ascended into the G-tubes were perforated at p_1 p_2 (Plate 2). From each a narrow metal tube was carried horizontally as far as q, when it bends upwards as far as r. At this point it gives place to a burette s. The top of the burette fits into a metal tube at u which bends round, first horizontally then vertically, and finally passes through the lid

of the drum at *v*. If the three-way taps t_1 t_2 (Plate 1, not seen Plate 2) are closed, any liquid in the G-tubes "finds its own level" on the burettes, and then by means of the same three-way taps the level in question may be adjusted to any desired mark on the burette.

If a current of steam from the boiler is now caused to pass through the G-tubes, the liquid is dragged out of the burette into the G-tubes.* The current of steam used in practice was never sufficiently rapid to empty the burettes. Suppose, now, that condensation proceeds more rapidly in one G-tube than in the other. Owing to the increased hydrostatic pressures, the velocity of steam on that side automatically diminishes, and in consequence some liquid slips out of the G-tube and back into the burette, till the former velocity is reproduced. It is not claimed that this device *entirely* equalized the levels of the liquids, but it certainly tended in a very marked way to do so. This is best demonstrated by closing the burette taps. On doing this the readings become unsteady at once.

One more appliance has to be described affecting the adjustment of the pressure in the drum. It was necessary that any fluctuations in pressure (not necessarily the result of leaks) should at once be detected and smoothed down. Neither mercurial thermometers nor manometers are sufficiently rapid in their indications for this purpose, and manometers consisting entirely of light liquids are very cumbrous. The following combination proved to be what was wanted (Plate 1). The bottle M is more than half full of mercury, the remainder being occupied by water coloured red by fuchsin. A rubber cork, having two holes, fills the mouth of the bottle, leaving no air-space between itself and the surface of the red water. The tall tube T passes through one hole of the cork and below the level of the mercury. T is connected by a rubber tube to the Woulfe's bottle V, so that when the latter is exhausted the mercury rises in T.

Through the other hole in the cork passes a capillary tube whose lower end terminates in the coloured liquid without reaching down so far as the surface of the mercury. The upper end of this capillary tube is open to the air. About midway up it communicates through a side tube with the funnel F, which is also open to the air. The coloured liquid in the bottle M extends up the capillary tube and half way up F. The usefulness of the apparatus turns on the fact that if t_7 is open any fall in pressure in the Woulfe's bottle will show itself mainly by a small rise of the mercury surface in T, but if t_7 is closed, by a fall, about tenfold greater, of the light liquid in the capillary. This is due to the fact that the cross-section of T is great compared to that of the capillary. The apparatus can therefore be

* Compare the action of Giffard's injector. It should be added that, when in use, the whole system, *p*, *q*, *r*, *s*, was packed with canvas, except near the meniscus in *s*.

made of low sensitiveness till the pressure is within a little of what is desired, and then by closing the tap t_7 its sensitiveness can be increased tenfold. Thus the observer, with his eye on the scale of the capillary and hand on the tap t_6, can make a momentary connection either with the exhaust pump or the external air, and so regulate the pressure with great precision.

§ 4. *The Electrical Instruments.*

So much for the mechanical portion of the apparatus: it remains to describe the electrical part.

The outfit consists of two Callendar-Griffiths platinum thermometers, a battery acting through a resistance of 50 ohms, a pair of "equal arm" coils, a galvanometer, and a bridge whose 80 cm. of wire balance the difference of resistance of the two thermometers, thus indicating the difference of their temperatures.

The method of compensating and connecting these thermometers is fully described by Griffiths;* the bridge, however, will require a little comment. The wire was ordered to be 0·5 ohm to the metre, to which value it approached very nearly. It was furnished with the same platinum-silver wire as the standard instruments recently supplied to Kew Observatory. The scale unit was approximately 2 cm. The bridge itself was furnished with Professor Callendar's device for obviating the greater part of the thermo-electric effects by connecting the galvanometer to a wire running parallel to the bridge wire, and in all respects similar to it. These effects are further removed by a Griffiths's thermo-electric key.

All contacts were so designed as to fall within a very narrow compass, where they can if necessary be enclosed in a box to prevent injury. The equal arm coil was made of two pieces of wire having (when wound) precisely the same resistance and temperature coefficient. They are intertwined in a core of paraffin so as to be at equal temperatures. The actual temperature is then a matter of indifference.

The battery employed was a single dry cell. The galvanometer, after repeated attempts, was made very sensitive. The manner of reading its deflection differed somewhat from the ordinary one. The method is similar to that of Poggendorff, except that the scale is in the eye-piece of the telescope, which is focussed (by reflection from the galvanometer mirror) on a signal. Instead, therefore, of observing the movements of a scale relative to a fixed line in the focal plane of the telescope, one observes the movements of a line relative to a fixed scale in the focus of the telescope. In this there is nothing new. But no one, so far as can be ascertained, has

* 'Phil. Mag.,' January, 1895.

inquired what is the best relation of the distances between the observer and galvanometer on the one hand, and the signal and galvanometer on the other. Usually they are made equal, but a simple calculation shows that for a given angular displacement of the mirror the reading may be increased by bringing the observer near to the galvanometer and removing the signal to as great a distance as possible. Using this disposition of the galvanometer, very minute deflections of the mirror were plainly visible.

§ 5. *The employment of the Apparatus to measure the difference of the Boiling Points of Pure Water and Solution.*

The mode of employing the apparatus varies somewhat, according as it is required to work with weak or strong solutions, and at high or low pressures. The procedure with the weak solutions at 760 mm.* is as follows:—Steam from the generator is caused to circulate through the empty G-tubes and drum, and a position is found on the bridge, such that on making contact the galvanometer is undeflected. A reading of the bridge scale is taken and entered as "hypsometer null point." Water is now added to each G-tube, and caused to boil by the passage of steam. A similar null point is found and entered as "water null point." If the burettes (Plate 2) are properly adjusted the two null points are identical. In order now to measure the change in the boiling point due to the presence of a small quantity of salt, some water is removed from one G-tube, and replaced by a few c.c. of stock salt solution. The bridge is again balanced. It was found desirable that this balance should be obtained at the fifteenth minute of ebullition, and therefore at this moment the bridge must be correctly set, the levels duly adjusted, and the galvanometer observed to be undeflected. This is a work of considerable difficulty, but it may be accurately performed if all one's movements are regulated by the indications of a clock, so that each takes place at its appointed time. The observer ascertains, for instance, in a number of preliminary experiments, what gain takes place in the reading of the burettes during fifteen minutes, and in an actual experiment the levels are previously so adjusted that they shall be as nearly as possible correct at the end of such a period. The fifteen minutes may now be allotted to observations at the bridge and galvanometer, and then one may be sure of a close balance at the last minute. The levels of the burettes are finally recorded, and a sample of solution is withdrawn from the G-tubes for analysis. As a result of the precautions described, the burette reading was almost invariably found to be within $1\frac{1}{2}$ mm. of the desired height. In any case a correction (L) can always be made at the rate of $0{\cdot}001^\circ$ per $1\frac{1}{2}$ mm. inequality

* 'Roy. Soc. Proc.,' vol. 61, pp. 285—287.

in level. Another (G) is made, proportional to the swing of the galvanometer, if the observer has failed to procure an exact balance at the fifteenth minute.

§ 6. *Conclusion.*

This paper professes to be no more than a description of the method employed in obtaining the results.* I must therefore postpone till a later occasion all discussion of the precautions employed and of the accuracy obtainable. In conclusion, I wish to acknowledge my indebtedness to Mr. Griffiths for much invaluable assistance, and to Professor Thomson for permission to work in the Cavendish Laboratory.

February 17, 1898.

SIR JOHN EVANS, K.C.B., D.C.L., Treasurer and Vice-President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On the Connection between the Electrical Properties and the Chemical Composition of different kinds of Glass." By Professor ANDREW GRAY, LL.D., F.R.S., and Professor J. J. DOBBIE, M.A., D.Sc.

II. "On the Magnetic Deformation of Nickel." By E. TAYLOR JONES, D.Sc. Communicated by Professor ANDREW GRAY, F.R.S.

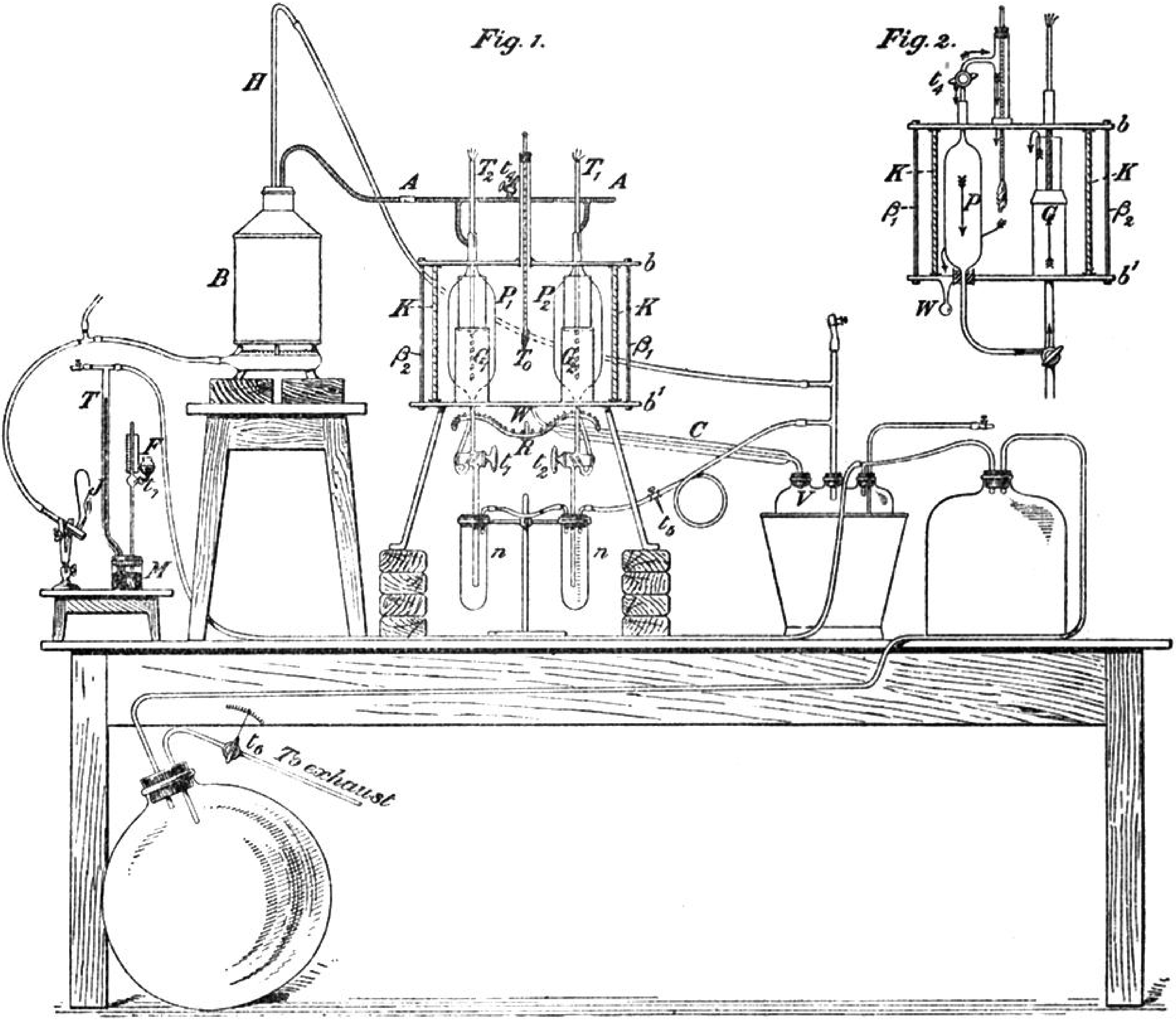
III. "Upon the Structure and Development of the Enamel of Elasmobranch Fishes." By CHARLES S. TOMES, M.A., F.R.S.

IV. "On artificial temporary Colour-blindness, with an Examination of the Colour Sensations of 109 Persons." By GEORGE J. BURCH, M.A. Communicated by Professor GOTCH, F.R.S.

V. "Contributions to the Mathematical Theory of Evolution. On the Inheritance of the Cephalic Index." By CICELY FAWCETT and KARL PEARSON, F.R.S.

* 'Roy. Soc. Proc.,' vol. 61, pp. 285—287.

(PLATE 1.)



(PLATE 2.)