I. THE MEASUREMENT OF SURFACE TEMPERATURES

WITH SPECIAL REFERENCE TO

SURFACES UNDERGOING EVAPORATION

II. THE CONSTRUCTION & TESTING OF A HYGROSTAT

III. THE RELATION OF INDOOR & OUTDOOR HUMIDITIES

& THE DETERMINATION OF

A CORRELATION FACTOR BETWEEN THEM FOR

CERTAIN PERIODS OF THE YEAR

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II. The Construction and Testing of a Hygrostat.

III. The Relation of Indoor to Outdoor Humidities and the Determination of a Correlation Factor Between them for Certain Periods of the Year.

Thesis submitted for M. Sc. Degree

by

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I. The Measurement of Surface Temperatures with special reference to Surfaces undergoing Evaporation.

Introduction.

The rate of evaporation of water from any colloidal or crystalloidal material, when other factors are the same, is directly proportional to the vapour pressure difference.

This is expressed by formulae of the type:

$$-\frac{dw}{dt} = k\,(p_s - p_a) \text{ ------------------ } (I).$$

Where w is the water content,

p_s = vapour pressure of the evaporating liquid.

p_a = partial vapour pressure of the liquid in the atmosphere,

For the particular case when a substance is dried in an atmosphere of zero humidity the above equation reduces to,

$$-\frac{dw}{dt} = k\,p_s \text{ ------------------- } (2).$$

i.e. evaporation is greatest when ps is greatest or when the surface is hottest.

As a substance dries, its moisture content becomes less and there-fore the vapour pressure decreases. The rate of evaporation depends on the difference between the vapour pressures in the material and in the atmosphere so it is obvious that this rate decreases as the material dries.

B.A. Keen as the result of a study of evaporation of water from soils, obtained an empirical equation expressing the influence of this factor namely,

$$A.\frac{dw}{dt} = 2303 \log_{10} (w+k) - \log_e K \text{ ----------------- } (3)$$

Where A.and K.are constant.

Since the available surface from which evaporation,takes place decreases as the moisture content decreases,this will affect the rate of evaporation.This factor is accounted for,by the following equation:

$$-\frac{dw}{dt} = D \sqrt[3]{(\frac{ws}{100}) + 1} \text{ ---------------------- } (4)$$

Where D is a constant

w = percentage of water by weight.

s = real specific gravity of soil.

Combining these two equations,the rate of evaporation is expressed by,

$$B \frac{dw}{dt} = \sqrt[3]{(\frac{ws}{100} + 1)} \left[2.303 \log 10(w+k) - \log_e k\right] \text{ -------- } (5)$$

This is an example of the way in which evaporation problems have to be solved.Many equations exist,expressing the rate of evaporation under the influence of different factors.All are necessarily empirical to some extent,and the constants involved have to be determined for each different drying substance.

No complete explanation of the factors influencing evaporation is available.One of the most important factors,viz.the effect of the diminshing vapour pressure in the material as its moisture content decreases,can only be completely determined when the relation between vapour pressure and water content is accurately known.

The vapour pressures in successive layers of a drying material depend on the moisture content and on the temperatures involved. These factors are of great importance in industrial drying processes.For example,in the paper industry,where large rolls of wet paper have to be dried out,it is found that when the paper has dried out to a certain extent,the layer from which the great part of the evaporation is taking place is slightly below the surface.The way in which heat is applied to dry the rolls has such an effect on the vapour pressures in the paper that a great deal of expensive investigation has been carried out to determine the most economical methods of using the heat emergy.This way of solving the problems is empirical and very costly but no other way is open until the influence of the various factors influencing the rate of evaporation is accurately known.

During an investigation of these and other hygrometrical problems it became increasingly evident that a complete explanation could not be given until the surface temperatures and temperature gradients near drying surfaces could be determined with precision. This problem presented numerous difficulties and has been made the subject of a detailed subsidiary investigation.

A critical review of Methods of measuring surface temperatures.

The chief difficulty in the solution of this problem is to find a satisfactory method of measuring surface temperatures. So far there has been no available data on the accurate measurement of the surface temperatures of moist porous solids while undergoing evaporation.

There have been developed several methods of measuring the temperatures of metallic surfaces such as boiler tubes, surface walls etc. An examination of these methods and their special difficulties that have to be overcome was essential to enable the writer to select a method to apply to the problem of moist surfaces. It was found that none of these was satisfactory and that a new method had to be devised for use in the case of moist surfaces.

The greatest difficulty to be overcome is the effect of the temperature gradient near the surface.

Fig(I) illustrates the steepness of this temperature gradient near a hot surface.Simple experiments show that the steepest part of the gradient is in the region next to the surface.This region appears to be a gas film adhering to the surface.

Consideration of the different possible ways of measuring the surface temperature shows at once that the ordinary bulb thermometer and resistance thermometer are impracticable.

The bulb of the former when in contact with the surface is actually at a temperature approximating to the average temperature at a distance of a millimeter or so from the surface.Screening the bulb with felt only raises the temperature by a small amount.

The resistance thermometer is constructed for immersion in a region of uniform temperature.It suffers from the same defect as the ordinary thermometer in that it cannot attain the temperature of a surface with which it is brought into contact.

The only practicable method of measuring surface temperatures is the thermoelectric method.This makes use of the fact that if two pieces of the same wire are joined to the ends of a wire of a different metal and the circuit completed,an electromotive force is set up which depends on the temperatures of the two junctions. Acircuit made in this way with precautions against strain and chemical action on the wires can be used for measuring.

temperatures if the temperature of one junction is known.

This is the principle underlying the methods at present in use for measuring surface temperatures.

A resumé of these methods is given together with criticism of their ranges of serviceability.

The Factors influencing surface temperature for metallic surfaces readings are:

(a)Temperature gradient near the surface.

(b)Convection currents.

(c)The nature of the surface as regards
(I)heat conductivity
(2)electrical conductivity

Methods in use.

(I) The exploring couple.
(2) The imbedded couple.
(3) The soldered couple.
(4) The compensated couple.
(5) The severed couple pressed against the surface.
(6) " " " imbedded in the surface.
(7) " " " soldered to the surface.
(8) The electroplated severed couple.

In all the above, one junction is assumed to be at 0°C. With the exception of (4) and (8) they have all been testedby the writer. These methods, with the exception of the exploring junction, are designed for the measurements of the temperatures of metallic surfaces only.

The followingcritical review includes the results of a comparison of the compensated couple with other methods, by Adams and Kean(1), in order to make it as comprehensive as possible.

The Exploring Junction.

The advantage of this method isits mobility. It can be moved from one part to another of a surface at will. Unfortunately however it is not sufficiently accurate.

The reasons for this can be seen at once from fig(2). When the junction is touching a hot surface it actually lies in the region of steep temperature gradient. This film near the surface is much thinner than the junctionhead which consequently does not reach the temperature of the surface. The degree to which this affects the reading depends upon the size of the junction. When the temperature of an enclosure is measured the size of the junction does not affect the reading but for surface temperatures greater care has to be taken to make the junction as small as possible.

A second factor that decreases the value of the temperature recorded is the loss of heat from the junction by conduction along the wires of which the couple is composed. This depends on the heat conductivities of the wires, the areas of cross-section, and the temperature gradients outwards from the surface.

The latter can be decreased somewhat by surrounding the junction with a heat insulating substance, cotton wool or felt, which also reduces loss due to convection currents. Making the junction from as fine wires as possible reduces heat loss by conduction but there is a limit to the fineness of wire used, determined by the amount of strain and rough usage which has to be withstood in practice.

The Imbedded Junction (fig3)

The difficulties due to poor contact in the using of the exploring junction are removed by one of two methods.The first is by imbedding the junction in the surface .A special punch is available for inserting a junction in a hole drilled in a metal surface,The concave tip of the punch forces the metal around the hole tightly against the junction, ensuring its holding firm and maintaining good contact.

The depth to which the junction is inserted is determined by experience.If it is buried too deep then it is not the surface temperature that is being found by it but the temperature within the metal.Conduction of heat along the wires is a factor that holds for the imbedded couple as for the first method,nevertheless it is a more sensitive method than that of the exploring couple.

It was found by experiment that of a number of couples made from the same coils of wire, the loose or exploring couples were less sensitive and showed greater variation in thermoelectric power among themselves than junctions attached to the surface.

The Soldered Junction (fig4)

Attaching a junction to a surface by means of soldering is another way of overcoming the difficulty of poor metallic contact. The amount of solder used must be as small as possible for if a lump of solder projects from the surface its temperature will obviously be slightly below the surface temperature.Careful soldering however prevents this.

The temperature recorded by this method is in general less by a few percent than the imbedded couple reading.In the one case the junction is actually on the surface and in the other within the surface.The effect of the heat conduction along the wires is greater at a point where they meet the surface than at a point slightly below the surface.

The Compensated Couple (fig5)

The above methods,intended to improve metallic contact have the disadvantages of being fixed to one place.Boyer&Buss have designed a thermo-couple that can be moved about over a surface and is compensated for heat losses along the wires. Thermo-couple wires are soldered to a silver disc which is placed against the surface.Heat conduction along the wires is eliminated by heating a similar disc, placed a short distance from the first, to the same temperature as the surface.

This is done by means of a heating coil set behind the outer disc. The temperature of the outer disc is raised until the thermocouples attached to both discs record the same temperature. There is no heat loss along the wires from the surface disc when a uniform temperature exists between the discs, so that the temperature recorded by either thermo-couple equals the surface temperature required.

The size of the compensated couple makes it inapplicable to cases where the surface is moist. The discs were 2½ cms in diameter and the wooden frame in which they were set was 8cms square. It was found that unless the couple was kept moving over a surface ~~heat~~ the screening of the part under it from convection and radiation effects, built up the surface temperature in this region. The method was designed for moving surfaces and has been found very satisfactory for this purpose. Further development of this method in the direction of making the area of the head of the couple smaller would be of use, but the objections on the score of surface screening would still hold for moist surfaces.

The severed thermocouple.

The idea of separating the wires forming a junction and making the surface whose temperature is required, from the connecting link between, is not new, Several experimenters have used this method but without appreciating its full possibilities.

Fig(6) illustrates the simplest case of the severed couple, the pressing of two wires against a surface.

Fig(7) shows them imbedded in the surface and,

Fig.(8) soldered to the surface.

In principle these three methods are the same, though they differ as regards convenience. The imbedded & soldered methods are both capable of great precision. Pressing the wires to the surface does not ensure good enough contact so that readings obtained by this method are unreliable.

The severed couple has the advantages over the soldered couple of:–

(a) Allowing better contact to be made with the surface. Less solder is necessary to attach a single wire to a surface than, is the case for a junction.

(b) Decreasing the heat loss due to conduction along the wires, for more heat is removed from the point of contact of two wires than from the point where a single wire meets the surface.

The possibility of using this method to estimate accurately the heat losses along the wires led to a very detailed study, By the writer of its applications to temperatures of metallic and non-metallic moist surfaces. The theory of methods of Calculating heat losses is given below.

The electroplated thermocouple.

A new method of improving metallic contact with the surface and of reducing heat losses as much as possible was devised by OTHMER and COATS*. The wires forming the thermocouple were wound round the the surface and layers of the same metals as those of which the wires were composed, were electrolytically deposited on the surface. For instance a copper wire was attached to the surface with a film of deposited copper and a nickel wire with nickel.

The results of this method were described as satisfactory. It is in principle the severed couple, contact being made in a different way. It is doubtful whether, in practice, the extra work necessary for application of this method justifies its use.

It will be noticed that the above methods have all been designed with the same object, namly, the elimination of errors due to heat conductionand poor contact. The compensated couple and perhaps the electroplated couple are the only ones that apparently succeed in eliminating heat losses. The size of the former, which produces a screening effect on the surface, makes it of little use when a surface is undergoing evaporation, and the latter method is obviously in-applicable to any but metallic surfaces.

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*"Measurement of Surface Temperatures" D.F. Othmer and H.B. Coats. Journ. Industrial and Eng. Chem. Feb. 1928.

Theory of a Practical Method of Calibration of Errors.

There are two way of approching a problem like that of surface temperatures, where certain errors have to be accounted for. One way is to eliminate the errors, the other is to calibrate them.

All of the methods used so far have been based on the "elimination" principle. Some are successful in this regard, with a special class of surfaces, namely, metallic surfaces under steady conditions.

It was suggested to the writer by Dr A.N. Shaw of McGill University, that the use of the severed Thermocouple on the "calibration" principle, would successfully solve the problem of measuring the temperatures, not only of metallic surfaces but moist porous surfaces as well.

This can be done in the following way:

A soldered couple and a severed couple made of suitable metals A.&B. are soldered to a surface, the temperature of which is to be measured. Figure(9) illustrates this theory.

The amount of heat conducted along a wire is a function of

(a) The area of cross-section.

(b) The conductivity of the wire.

(c) The temperature gradient along the wire.

For simplicity the wires are taken all of the same cross-sectional area. Hence the heat loss by conduction, represented by δ, depends upon (b) and (C)

The amount of heat conducted along A_1 or A_2 is δA.

" " " " " " B_1 or B_2 is δB.

IF the true surface temperature is θ, the temperatures at the points where the wires meet the surface are less than θ by quantities proportional to δA. or δB.

i.e. Temperature at end of A_2 is $\theta - \epsilon A$. where ϵA. represents the temperature change corresponding to a loss of heat of amount ~~of~~ δA.

Similarly the temperature at the end of B_2 is $\theta - \epsilon B$.

Since A_1 and B_1 meet at the same point, its temperature will be $\theta - (\epsilon A + \epsilon B)$

The couples can be calibrated by immersing the surface in an oil bath at known temperatures. If the constant temperature junction of the circuit is kept at $0°$C then:-

Couple $A_1 B_1$ measures Temp. $\theta - (\epsilon a + \epsilon B)$

" A_2 B_2 " " intermediate between

$(\theta - \epsilon A)$ and $(\theta - \epsilon B)$.

depending on the relation of A. and B. to the surface metal in the thermo-electric series.

In very many cases met with in practice the surface metal is copper. If we use as thermo-elements the metals copper and constantan then, assuming B. is copper and A. constantan, couple A. B. measures temp= $\theta - \epsilon A$.

The difference between the temperatures recorded by A_1B_1 & A_2B_2 B . is therefore $\theta-\epsilon A-\theta+(\epsilon A+\epsilon B)=\epsilon B$.

The temperature recorded by the couple A_1A_2 is also ϵB since the temperatures at the ends of the couple are, $\theta-(\epsilon A+\epsilon B)$ and $\theta-\epsilon A$.

In this case A_1 may be joined directly to A_2. through a galvanometer as the surface itself forms the second element of the couple.

ϵB, the temperature change due to conduction along copper is greater than that for constantan owing to the higher conductivity of the copper. The relationship between ϵA, ϵB, and the constants of the respective metals is dealt with under the heading of "Theoretical calculation of errors".

The above method of finding the change of temperature due to conduction was applied by the writer, in a slightly varied form, to the measurement of the surface temperature of liquid in an attempt to correlate ϵA. and ϵB.

A single exploring couple of copper-constantan was used to measure the temperature in four different ways, These are indicated in fig.11. The liquid used was kerosene which was heated by means of a heating coil.

(a) couple in surface with both wires vertical. Temp recorded is $\theta-(\epsilon A+\epsilon B)$

(b) with one wire (copper) immersed, giving temp, $\theta-\epsilon A$ as no heat is conducted along B. in this position.

Similarly temperature recorded by (c) is $\theta - \epsilon B$.

Temperature recorded when couple is at surface with both wires lying also in the surface $= \theta$

The difference between (b)&(d)$=\epsilon A$ &(c)-(a)$=\epsilon B$.

The practical difficulties met with in trying to keep the wires exactly in place caused some variation from the above estimated readings--convection currents in the liquid also had this effect.

A further application of this method,not yet tried out,would be to use the two junctionsof a circuit in a combination of the four methods used (e).One junction as in (a) and the other as in (b)when connected through a galvanometer,would give a direct measure of ϵB.and if the junctions were placed close toghther,variation in the surface temperature would affect both equally.

A large number of couples were made and very many readings taken in the above series of experiments-the results of which are given in the data sheets.Before describing the more elaborate experiments to which those already described have led,an account is given of the apparatus used in these investigations and the precautions taken to avoid spurious effects.

Description of Apparatus.

Thermocouples.

As it was intended to apply the results of calibration experiments to the determination of temperatures of moist surfaces, the range of temperatures for which the relationship between ϵA, ϵB, and the true temperature was needed was from 0° to about 200° c.

Copper and constantan were selected as elements for thermocouples for the following reasons:-

The thermo-electric power of a Copper-constantan couple is high (approximately 40 microvolts per degree centigrade). Graph I shows the thermo-electromotive force at different temperatures of the exploring junction for three widely used thermo-couples, viz.

Copper-Constantan(c); Chromel-Alumel(h); Platinum-platinrhodium (p); Graph (2) shows the relation between thermo-electric power $\frac{de}{dt}$ and temperature for these types of couples.

For the range required in this investigation, Copper-constantan is seen to be more sensitive than either of the other combinations.

Further advantages of copper-constantan are:

(a) relatively inexpensive.

(b) easily soldered together or to a copper surface,

(c) the fact that a severed copper constantan-couple soldered to a copper surface is virtually a junction at the point of contact of the constantan wire.

(d) The thermo e,m.f. for the range 0° to IOO°c, within which data was most required, is very nearly linear as seen in Graph (3). This means that interpolation in cases when it is not convenient to have the constant temperature junction at 0°c is made easier.

Methods of measurement.

There are two methods of measuring temperatures with a thermocouple. In each, one junction has to be at a constant temperature, preferably 0°C.

The E.M.F. may be measured directly with a millivoltmeter. This method is used in engineering practice but for the purposes of laboratory research it is not sufficiently accurate. The other way of measuring E.M.F. is by means of a potentiometer. This is a null method and far more sensitive than the former.

The potentiometer method is shown in diagram(I) An E.M.F. of amount greater than the thermo-electric E.M.F. is maintained across the potentiometer wire. Its value is kept constant by continual calibration against a standard cell. The thermo-electric circuit is completed through a galvanometer and a sliding contact on the potentiometer wire.

Thus-if a balance point is obtained at a distance of $\frac{I}{n}$th the length of the wire from the end to which the thermo-circuit is connected, the thermo e.m.f. = $\frac{I}{n}$ of the known emf across the wire.

Constant Temperature Junction.

This is best done by inmersing the junction in a mixture of ice and water contained in a thermos flask.To prevent strain or chemical action on the junction,it was placed in a narrow glass tube containing oil and the tube sealed.This was then immersed in the 0°c.mixture.

The potentiometer used was a Kohlrausch Slide wire potentiometer fitted with extension coils,manufactured by the Leeds-Northrup Company.It consists of ten turns of wire wound in grooves on a marble drum,the sliding contact inside an ebonite case.A scale is marked round the movable case and the reading taken through a glass window on which the number of turns is stated.

The scale,one revolution of which represents onetenth of the length of the slide wire,is divided into 100 parts,each of which is subdivided into two.As the length of one of these divisions ($\frac{1}{200}$ of a single revolution) is about .3 cms,the eye can estimate to $\frac{1}{5}$th of this smallest division i.e. the instrument can be read accurately to $\frac{1}{5}$ of the $\frac{1}{200}$ th part of a turn or $\frac{1}{1000}$ of a turn. As there are ten turns,reading can be obtained to $\frac{1}{10,000}$ th part of the length of the wire.

The Galvanometer used was a D'Arsonval moving coil galvanometer of about 60 ohms resistance.

The Source of E.M.F. necessary to balance the thermo-electromotive force was a storage cell of about I.3 volts.

This was calibrated by means of a standard cell of E.M.F. I.0I83 volts at I7 C.

The storage cell circuit included a resistance box and a rheostat.

The standard cell was connected to the terminals of the resistance box through a galvanometer and a tapping key.

The E.M.F. across the potentiometer wire can be kept constant by occasionally pressing down the tapping key in the standard cell circuit and changing the resistance of the rheostat until there was no deflection in galvanometer (G_1). R is constant and by the above means the potential difference across R is maintained at a voltage $\simeq$ E.M.F. of standard cell.

There is therefore, no need to know the exact value of the rheostat resistance (r)

The results of experiments on calibration of the apparatus are given below.

Results of Calibration Experiments.

Resistance of slide-wire potentiometer =28.I33 ohms.

Accuracy with which position of sliding contact could be read - $\frac{I}{I0,000}$ of whole wire.

i.e. resistance could be read to $\frac{28.I33}{I0,000}$ = .00283 ohms.

Resistance of galvanometer = 62 ohms.

Sensitivity of galvanometer.

Galvanometer in circuit with rheostat, standard cell and tapping key.

Voltage of cell = I.0I8 volts.

Resistance glvo.= 62 ohms.

Rheostat reading	Galvo. deflection
I.I x 10^6 ohms	I3. 8 cms
I.0 x 10^6 ohms	I4. 8 cms

Hence I cm deflection = I.0I8 x 62 $\left(\frac{I}{I{\cdot}0 \times 10^6} - \frac{I}{I.I \times 10^6}\right)$ volts

" " " $= 5.65 \times 10^{-6}$ volts

" (millimeter on galvanometer scale- 0.56 micro volts

Sources of Error in measurement of Thermo- E.M.F.

Before actual e.m.f. measurements are taken, both junctions of a couple are brought to the same temperature by immersion in the ice and water mixture. The potentiometer wire is left in the thermo-electric circuit but no e.m.f is applied.

As seen in diagram (2), the potentiometer wire in this particular circuit is just a variable resistance. There should be no galvanometer deflection with this arrangements. In a thermo-electic circuit however, every junction of one wire with another, as at the galvanometer or potentiometer terminals is a thermo-couple. If the temperatures of all junctions are the same no effects arise, but heating of one or more junctions relatively to the others causes e.m.f.s, in the circuit. In general, junctions at terminal points are of copper or brass and the thermo-electric power of a copper-copper or copper brass junction is small compared with that of a copper-constantan couple.

But these spurious effects are of the order of magnitude of the "ϵ" quantities, which it desired to measure.

For this reason great care has had to be taken to eliminate these spurious effects. The trouble is, that after testing the circuit before taking a temperature reading, the touching of a junction, or a draught created by an open window in the vicinity of the apparatus, introduces a spurious e.m.f. which is often large enough to invalidate the results of the particular experiment.

Frequent testing of the circuit for spurious effects is therefore necessary.

It was discovered that the sliding contact on the potentiometer introduced a slight heating effect.

Referring to the second diagram it can be seen that if a spurious e.m.f. of amount e, exists in the circuit, the galvanometer deflection will correspond to a current=

$$= \frac{e}{\text{Resistance of circuit.}}$$

The resistance of the circuit includes the galvanometer resistance and the resistance of part of the sliding contact. External e.m.f.s. are not included.

Since the resistances of the galvanometer and potentiometer were in the ratio of about two to one, changing the position of the sliding contact automatically altered the galvanometer deflections. It was found that if galvanometer readings were taken immediately after moving the sliding contact, they were considerably greater than would be expected by calculation from the known change in resistance that had taken place. The more rapidly the contact was moved the greater was the deflection, up to a certain limit. Also the deflection was in the same direction when the contact was moved in the opposite direction. This source of error, then was due to the heating up of the join between the spring contact and the wire.

The time taken for the galvanometer deflection to regain its normal value was found to be about one and a half minutes. To correct for this source of error, a short period should elapse between adjustment of the contact and reading the galvanometer.

Testing of various types of couples.

Several specimens of each type of couple described in this paper, were made, and readings of the surface temperature of a copper vessel containing water at 100°C were recorded.

Compared with exploring couple readings; the severed couple gave readings 10% to 15% higher; and the soldered couple [both wires together] recorded temperatures from 5 to 10% higher.

It was also found that severed couples showed much less, variation, one from another, than did ordinary exploring couples.

The experiments on a heated copper vessel were useful for comparison of different types of couples, in that they could be carried out quickly, and allowed of a large number of tests of new couples to be made. They were not sufficiently accurate however, for determinations of the heat losses along the wires.

Application to moist porous surfaces.

The differences between such a surface and a metallic surface are

(a) much lower heat conductivity.

(b) " " electical " .

(c) effect on surface temperature, of heat energy changes in the process of evaporation.

The objections to the use of the various types of thermo-couples for measuring the temperatures of metallic surfaces have still greater force when moist surfaces are considered. The heat conducted along the wire from a point on the surface is to some extent replaced by heat conducted from the surrounding portion of a metallic surface. Due to the lower heat conductivity of a non metallic surface, the resulting loss of heat will be relatively greater.

A compensated couple is of no use in this instance because it shields the surface from evaporation.

Consideration of the possible means of solving the problem leaves no doubt that a form of the severed couple is the most hopeful of success.

Diagram (3) shows how this could be dome. Constantan and copper wires soldered to a copper gauze, the latter embedded in the surface have the advantages of:-

(a) providing a constantan-copper junction at the point where the constantan wire meets the surface. (b) The gauze having much greater conductivity than the material it is imbedded in, would raise the temperature of the Con.-copper junction nearer to the true surface temperature.

A simpler procedure is to follow the method described for calibrating the heat losses from thermo-couple wires in the surface of a liquid.

Temperature gradients in the wet material could be found by using a series of thermo-couples as in diagram(4)

Relative sensitivities of different severed couples.

The results of the experiments on the brass bar, with its ends at $0^\circ + 100^\circ$C were inconclusive as regards values of $\epsilon_A + \epsilon_B$. This was due to the extreme difficulty of keeping temperature conditions, absolutely constant.

They showed however that for a severed copper-constantan couple soldered to brass, that the constantan junction determined the sensitivity of the couple. Different constantan junctions differed with respect to each other by about 1% in sensivity but the sensitivities of the junctions formed by a single constantan wire with several copper wires were the same.

To test this more accurately, the bar, with two constantan and two copper wires soldered to it, was immersed in a tank of ice and water at 0° C. Each couple was in turn connected up with a constantan-copper junction, kept in a thermo-flask containing hot water. The water cooled gradually. It was desired to find how the readings of the different couples varied as the temperature of the junction common to each of the combinations, was altered.

Diagram (3) illustrates this.

In order to compare couple A_1B_1 with A_2B_2. for instance, since the two readings cannot be taken simultaneously, it was necessary to take readings with an ordinary couple "S" in circuit with the cooling junction, before and after each severed couple reading. The times at which the readings were taken were noted. Actually each scale reading given on the data sheet is an average of six consecutive readings.

The time ,recorded is a mean between the times at which the Ist and 6th readings were taken in each case.

The potentiometer scale readings for each of the couples were ~~re~~ plotted against the times at which the readings were taken.

A curve drawn through all the point for the "S" couple represents the way in which the temperature of the cooling junction changes.

The points on the graph for the different severed couple readings are near this comparison curve.Points below the comparison curve indicate that those particular couples were less sensitive than the "S" couple, and points above represent more sensitive couples.Graphs(4)&(5) show the relative sensitivities of the different couples.They indicate clearly that the constantan-brass junction in a severed couple of "constantan-brass-copper" determines the sensitivity of the couple.

This holds also in the case of couples soldered to a copper surface.

The assumption that the temperature recorded by a copper-constantan severed couple soldered to a copper surface,is very nearly equal to the temperature at the junction of the constantan wire with the surface,is therefore justified.

In conclusion the writer acknowledges the advice and assistance throughout the work of -

Dr. A. Norman Shaw, D. Sc., F.R.S.,

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and various other texts on temperature measurement.

Moisture Problems.

(I)" Some factorsaffecting the evaporation of water fromSoil.
E.A. Fisher.
I Journal Agric.Science Vol ~~I~~XIII part II.Apr.I923.

(2)" II " " " Vol XVII part III.July.I927.

(3)" Discontinuities in the drying process. E.A.Fisher
Proc.Roy.Soc. A. Vol.I05.I924

(4)" Imbibitional soil moisture.Journ.Agric.Sci.Vol XIV part II
Apr.I924

(5)" Drying of woollen & worsted fabrics.E.A.Fisher G.Barker.
Journ.text.Inst.Vol.XVIII I927

(6)" Some fundamental factors in the drying of paper products
W.K.Lewis,W.H.Adams,F.W.Adams. Pub.Mass.Inst.Tech.NoI84 May I927

SENSITIVITIES of SEVERED COUPLES.

FIRST SERIES of READINGS. Circuit Constants: R = 5000 ohms
E = 1·018 volts

Couple.	Average Scale Read	Average Time	Relative Time
S	5·5993 turns.	4. 31½ p.m.	0 mins.
A_1B_1	5·5360	4.36½	5
S	5·4928	4.40½	9
A_1B_2	5·4412	4.44¾	13¼
S	5·4025	4.48¼	16¾
A_2B_2	5·4003	4.52½	21
S	5·2883	4.58½	27
A_2B_1	5·2337	5.07¼	35¾
S	5·1535	5.10¾	39¼

SECOND SERIES.

Circuit constants same.

Couple	Av. Scale Read.	Av. Time	Relative Time
S	4·8980 turns	5. 11¼ p.m.	0 mins.
A_1B_1	4·8683	5.14½	3¼
S	4·8438	5.17¼	6
A_1B_2	4·7652	5·26	14¾
S	4·7425	5.29¼	18
A_2B_2	4·7623	5.32¼	21
S	4·6960	5.35	23¾
A_2B_1	4·7167	5.37¾	26½
S	4·6510	5.40½	29¼

Fig. 1.

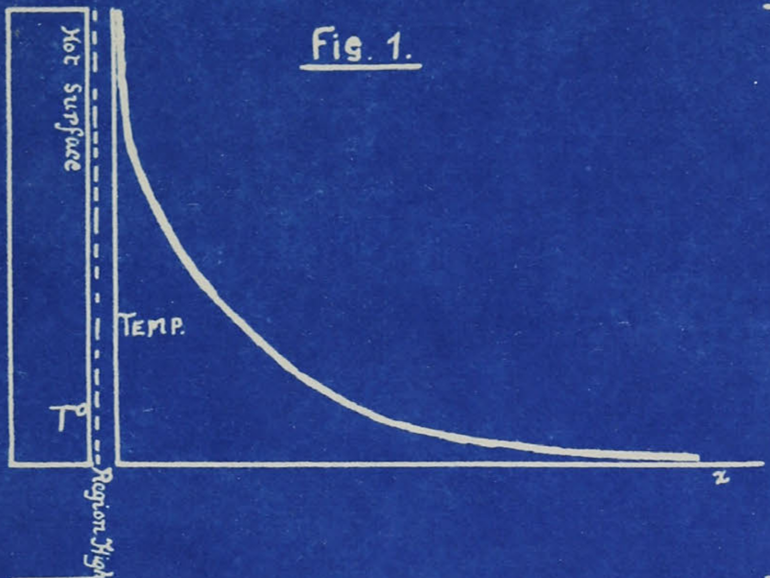


Diagram of Simple circuit.

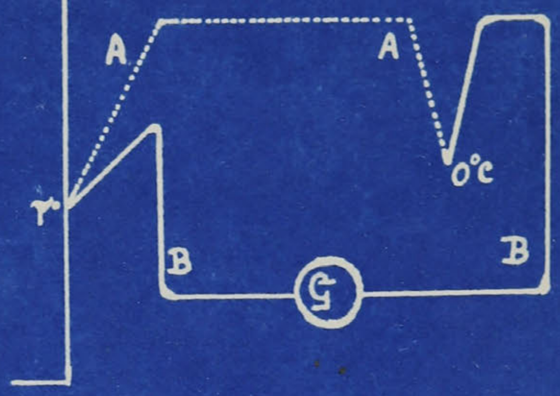


Fig. 2

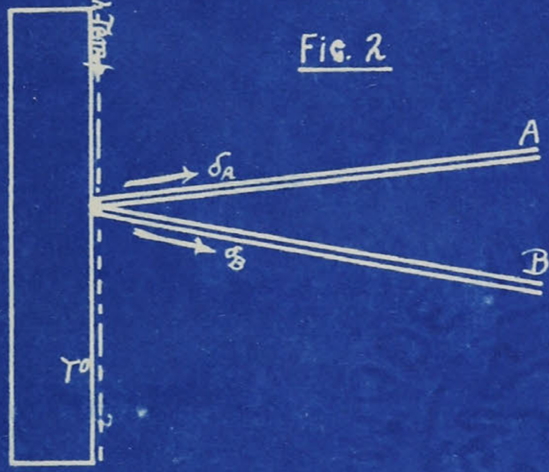


Fig. 3.

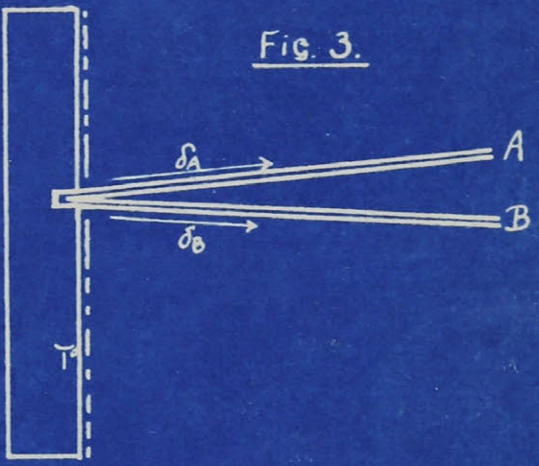


Fig. 4

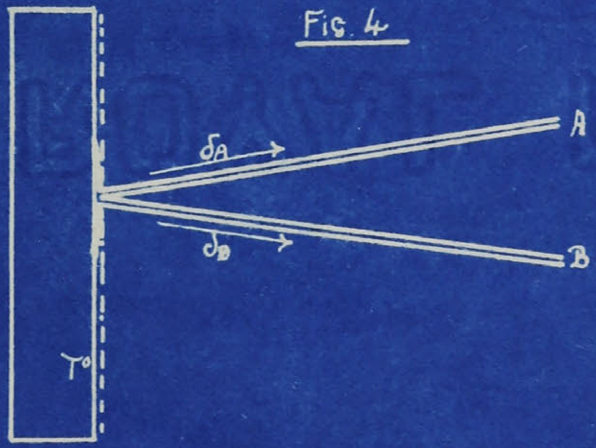


Fig. 5.

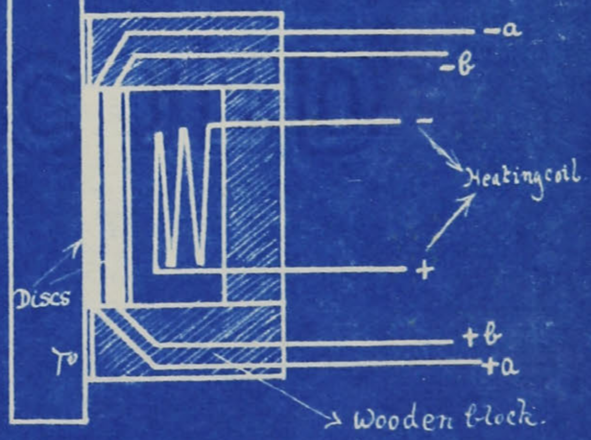


Fig. 6

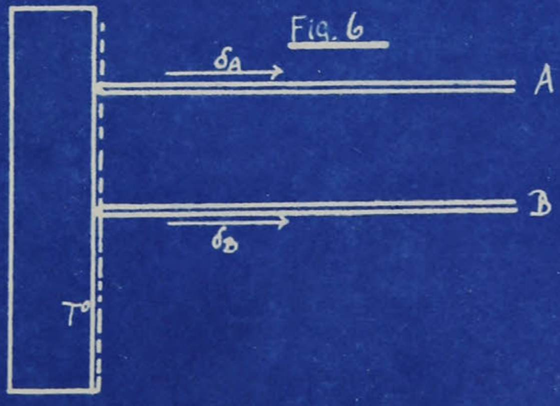


Fig. 7.

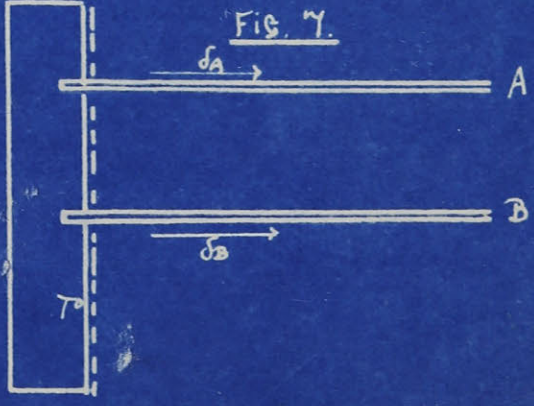


Fig. 8.

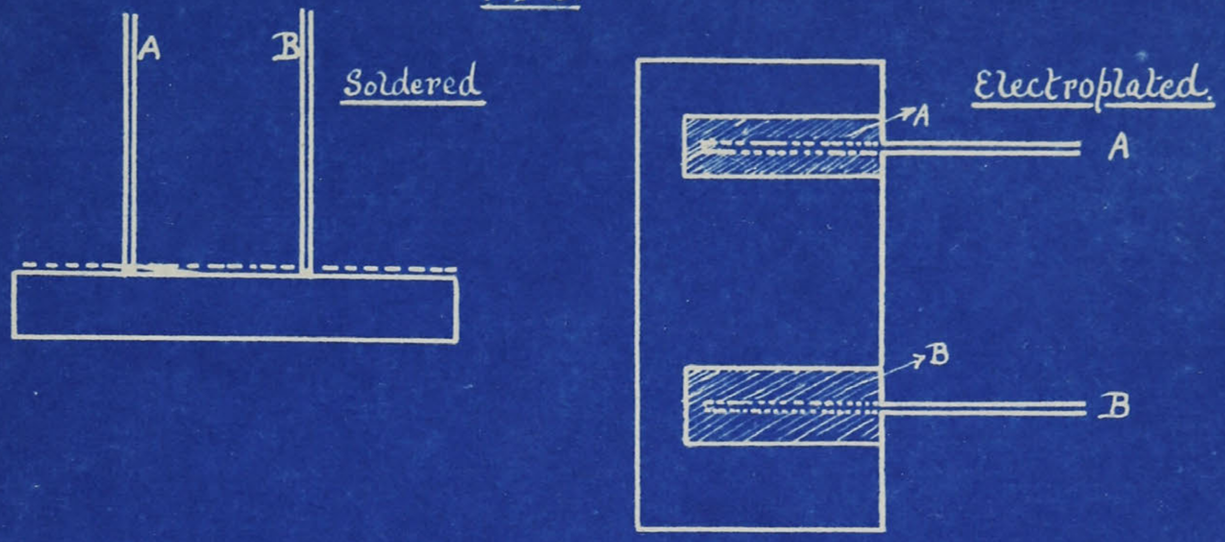


Fig. 9.

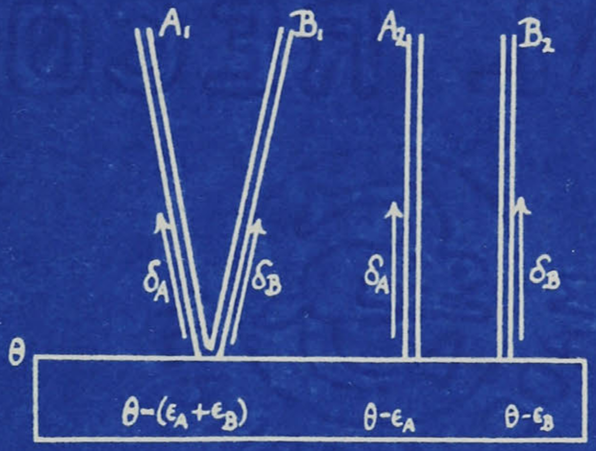


Fig. 10.

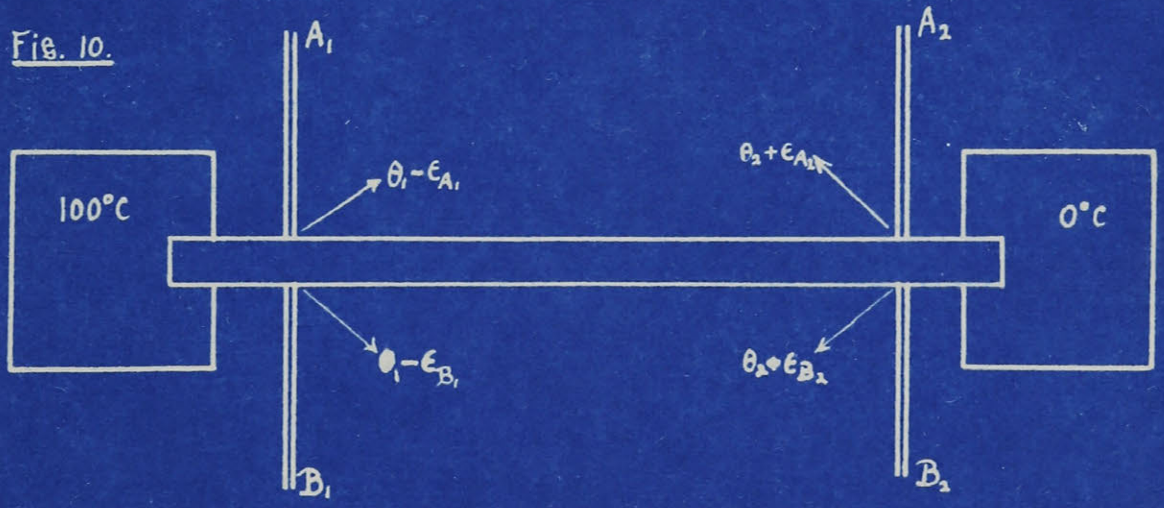
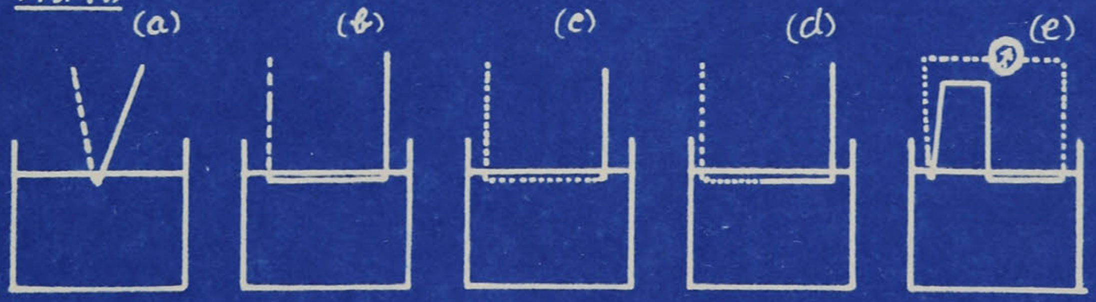


Fig. 11.



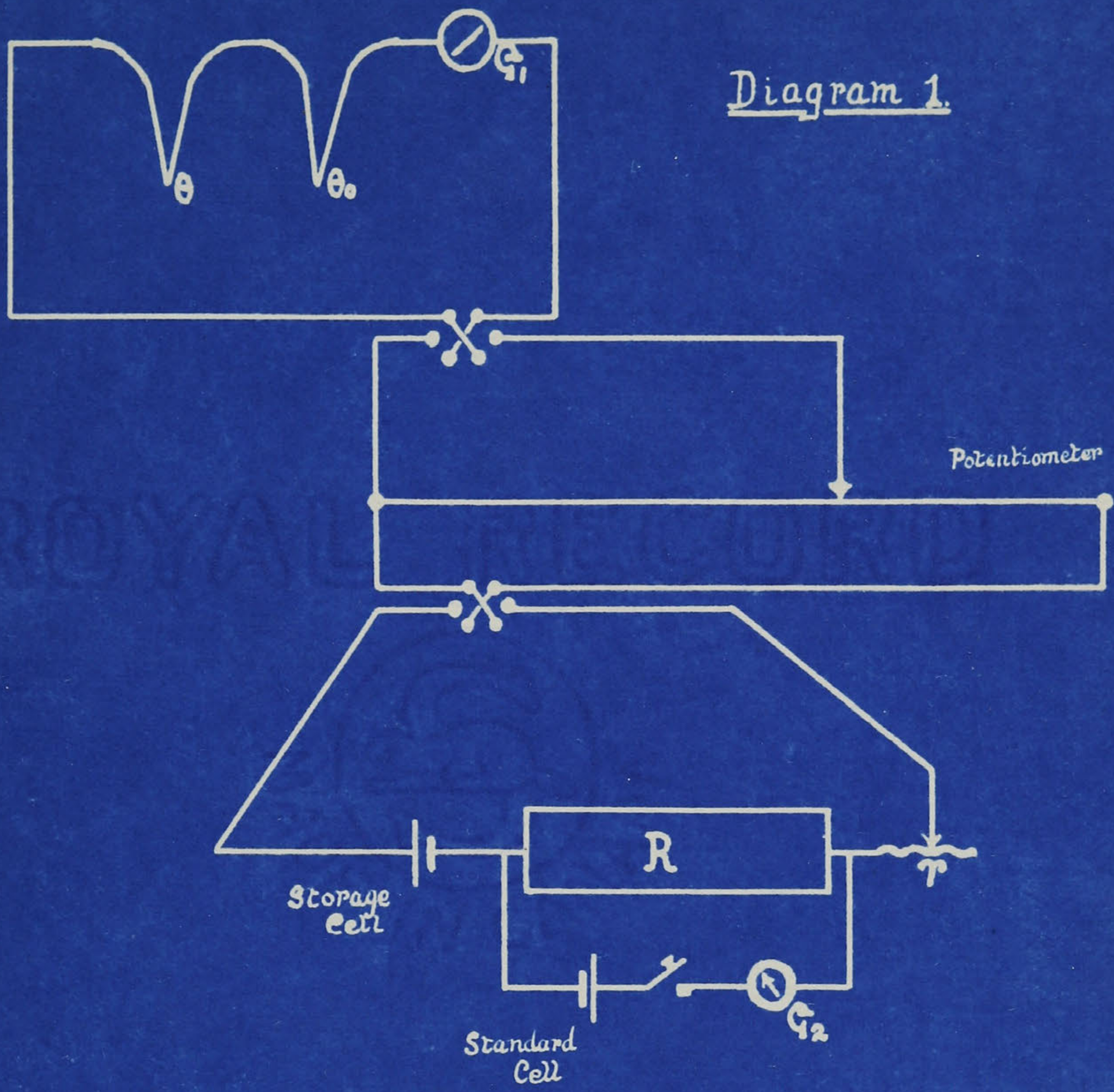


Diagram 1.

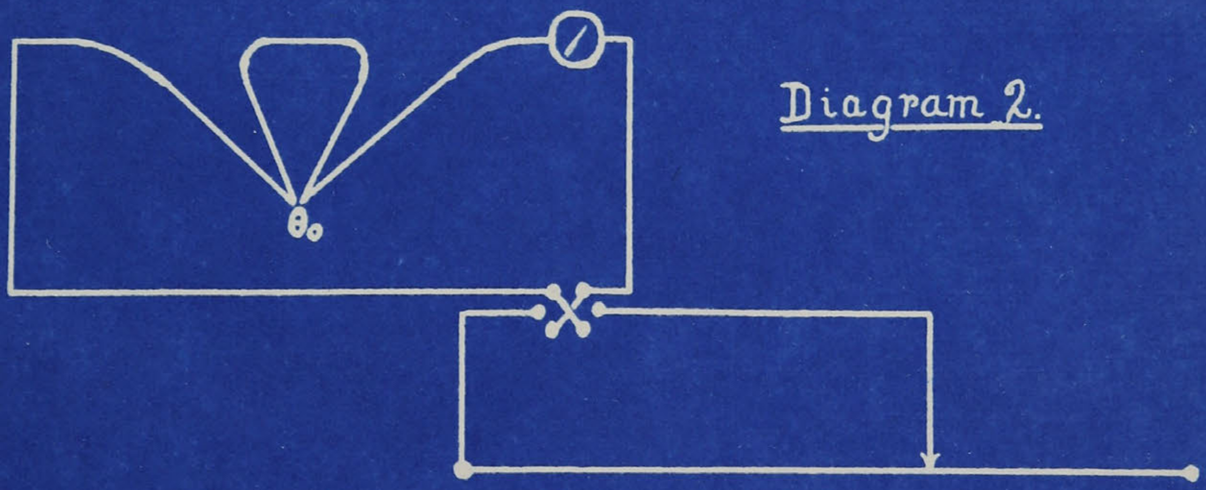


Diagram 2.

Diagram 3.

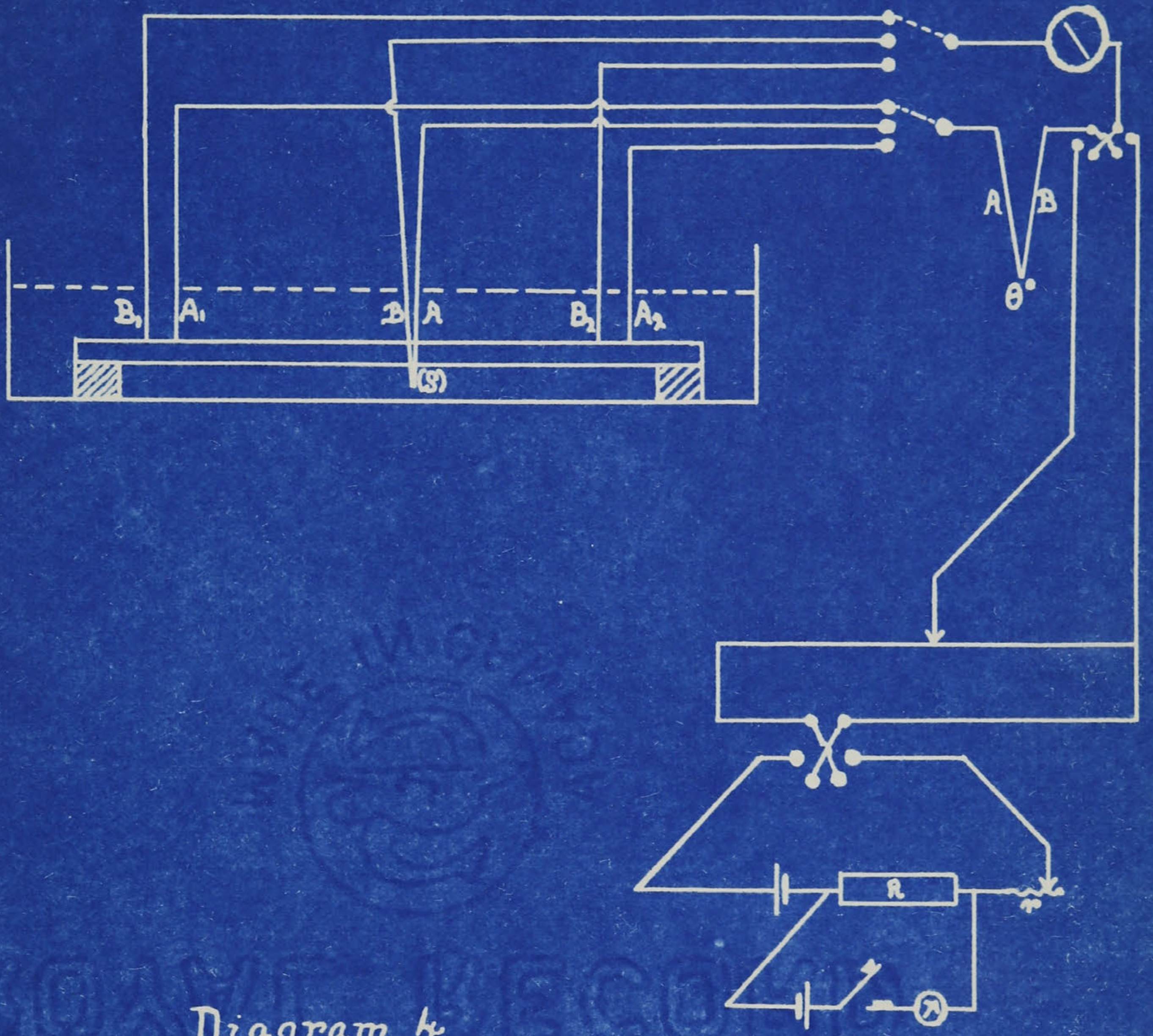
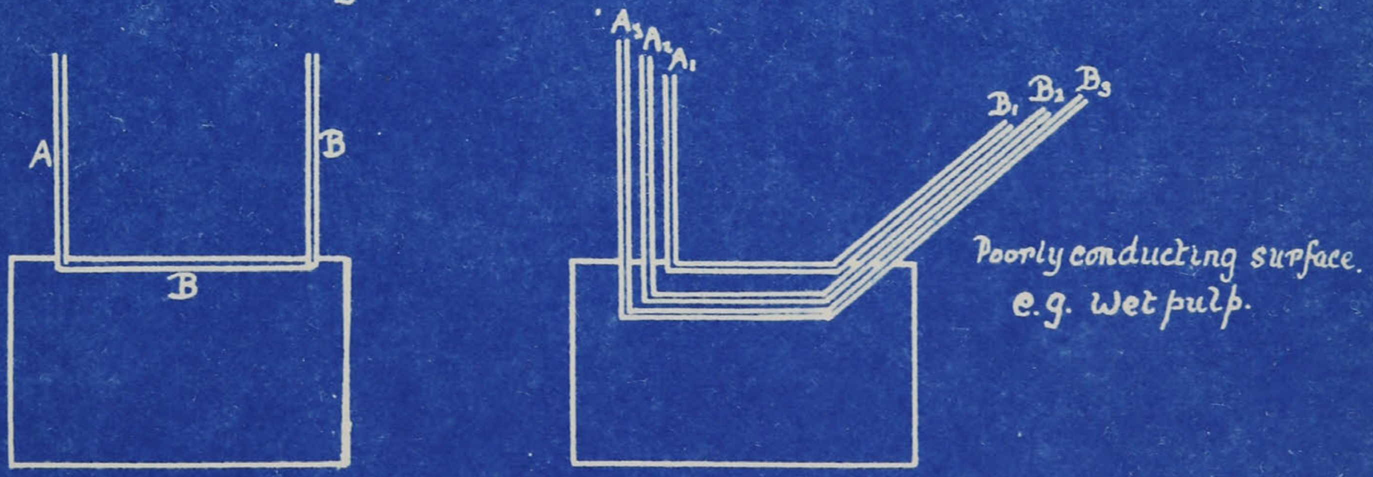
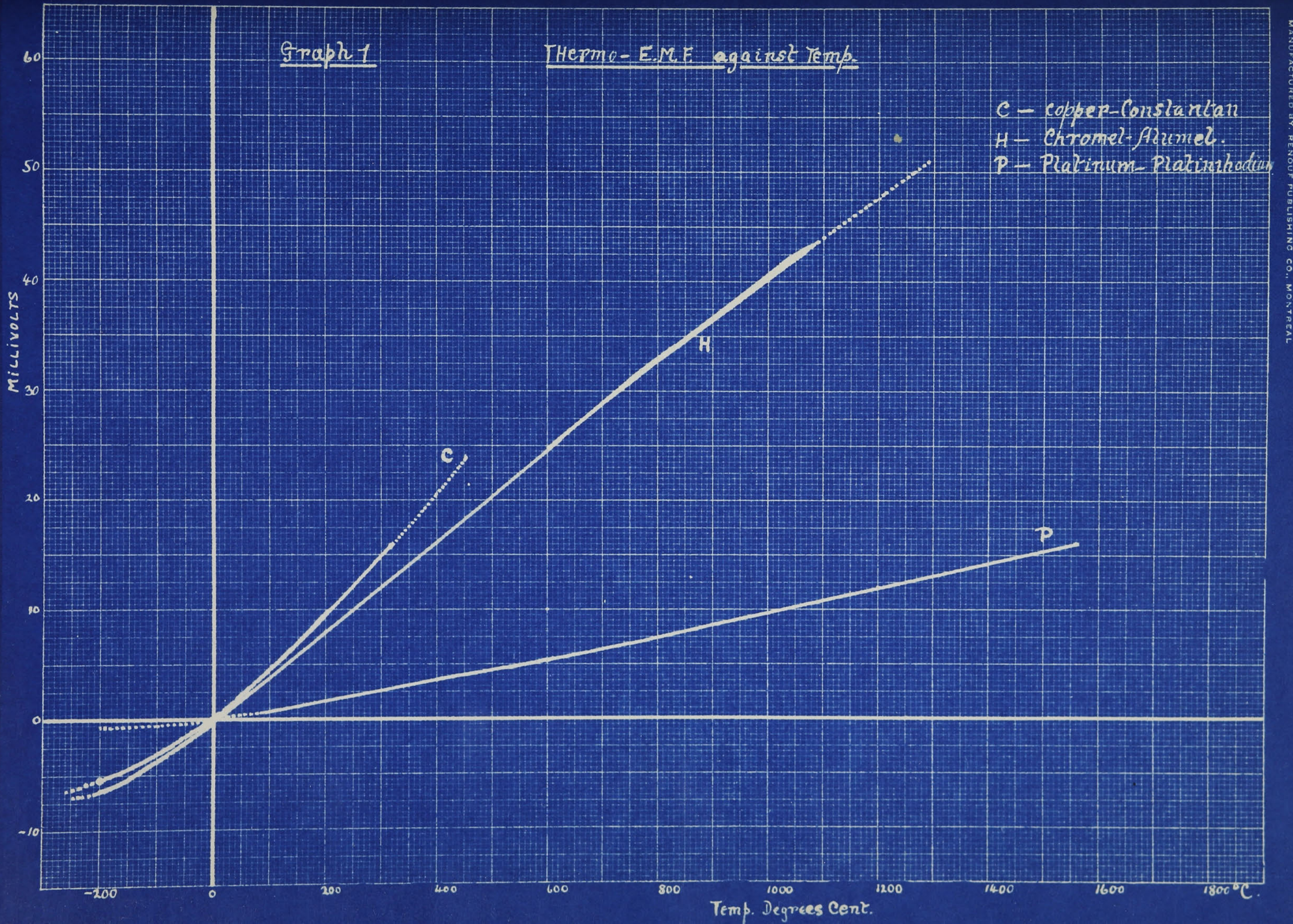


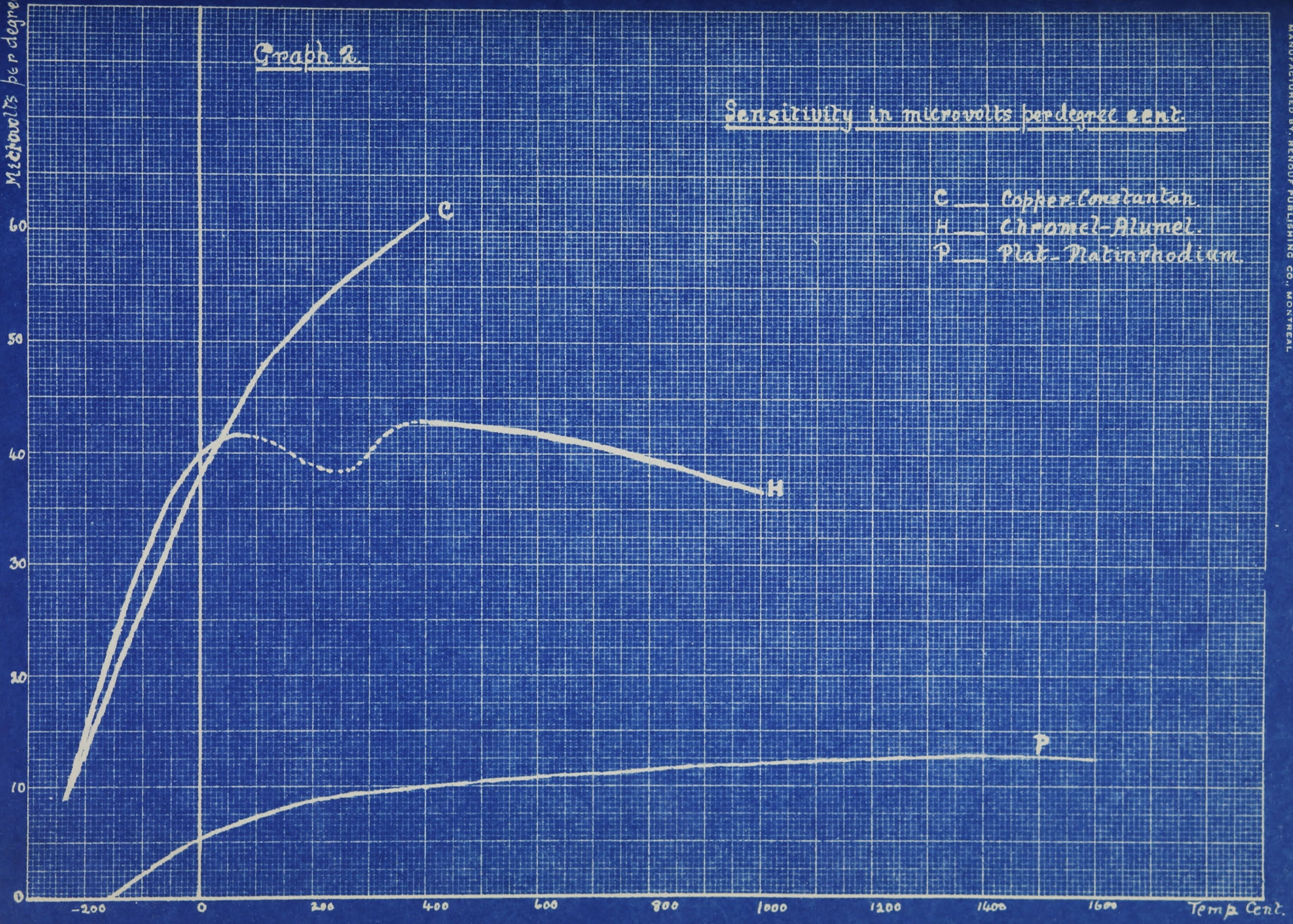
Diagram 4.

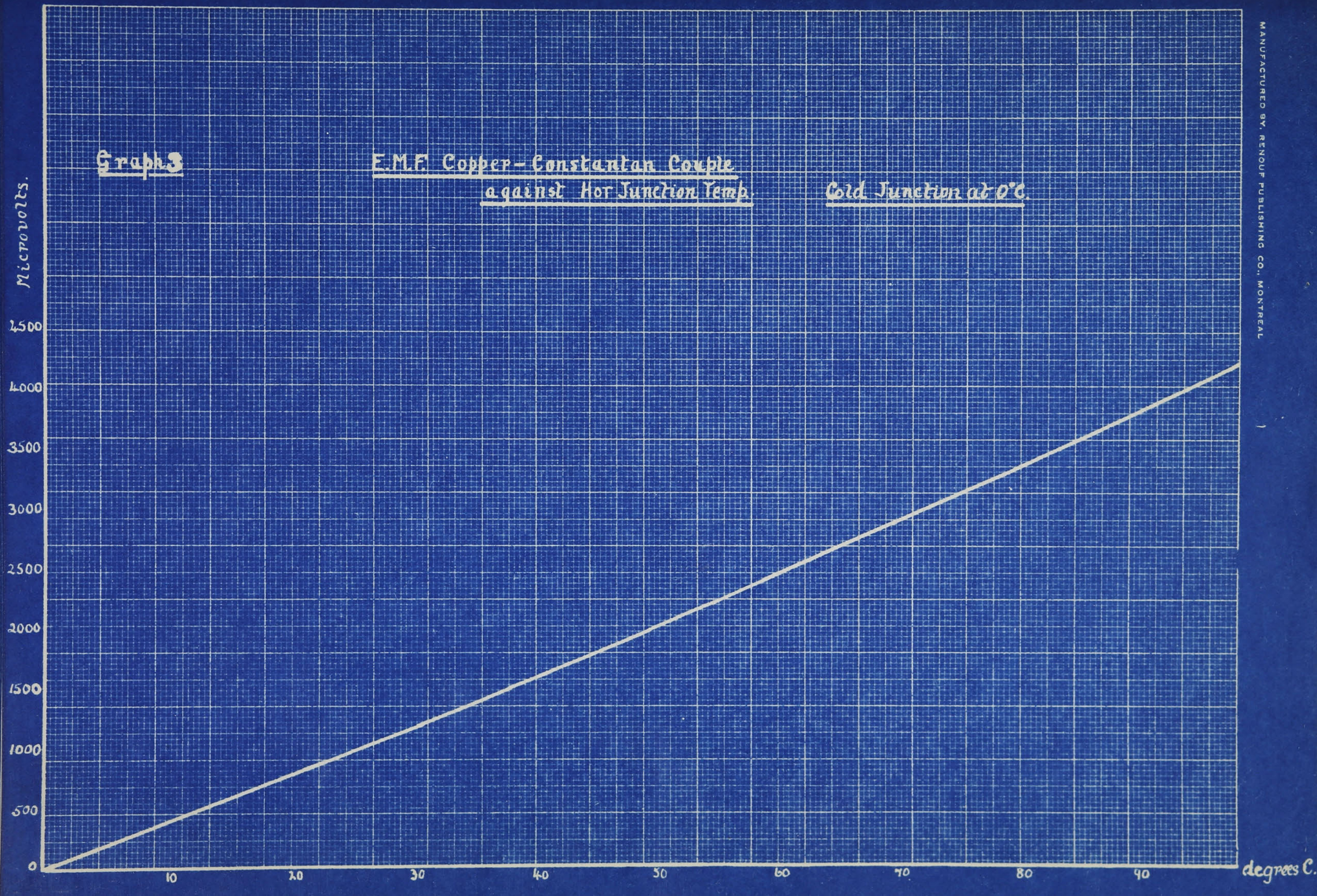




Graph 1

Thermo- E.M.F against Temp.

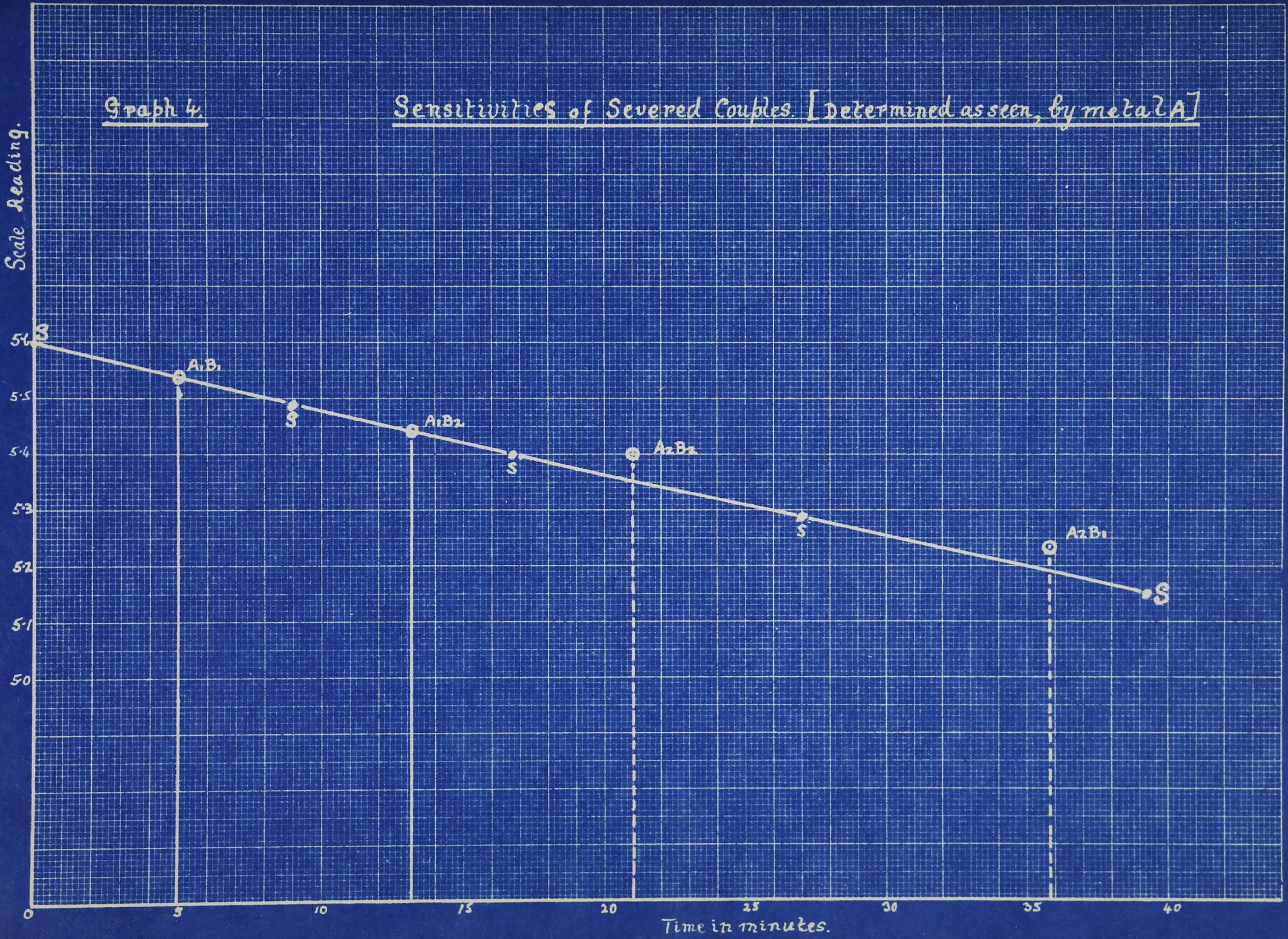

Graph 2.
Sensitivity in microvolts per degree cent.
C — Copper-Constantan.
H — Chromel-Alumel.
P — Plat.-Platinrhodium.
Microvolts per degree.
60
50
40
30
20
10
0
-200
0
200
400
600
800
1000
1200
1400
1600
Temp Cent.
C
H
P



Graph 3

E.M.F. Copper-Constantan Couple against Hot Junction Temp.

Cold Junction at 0°C.

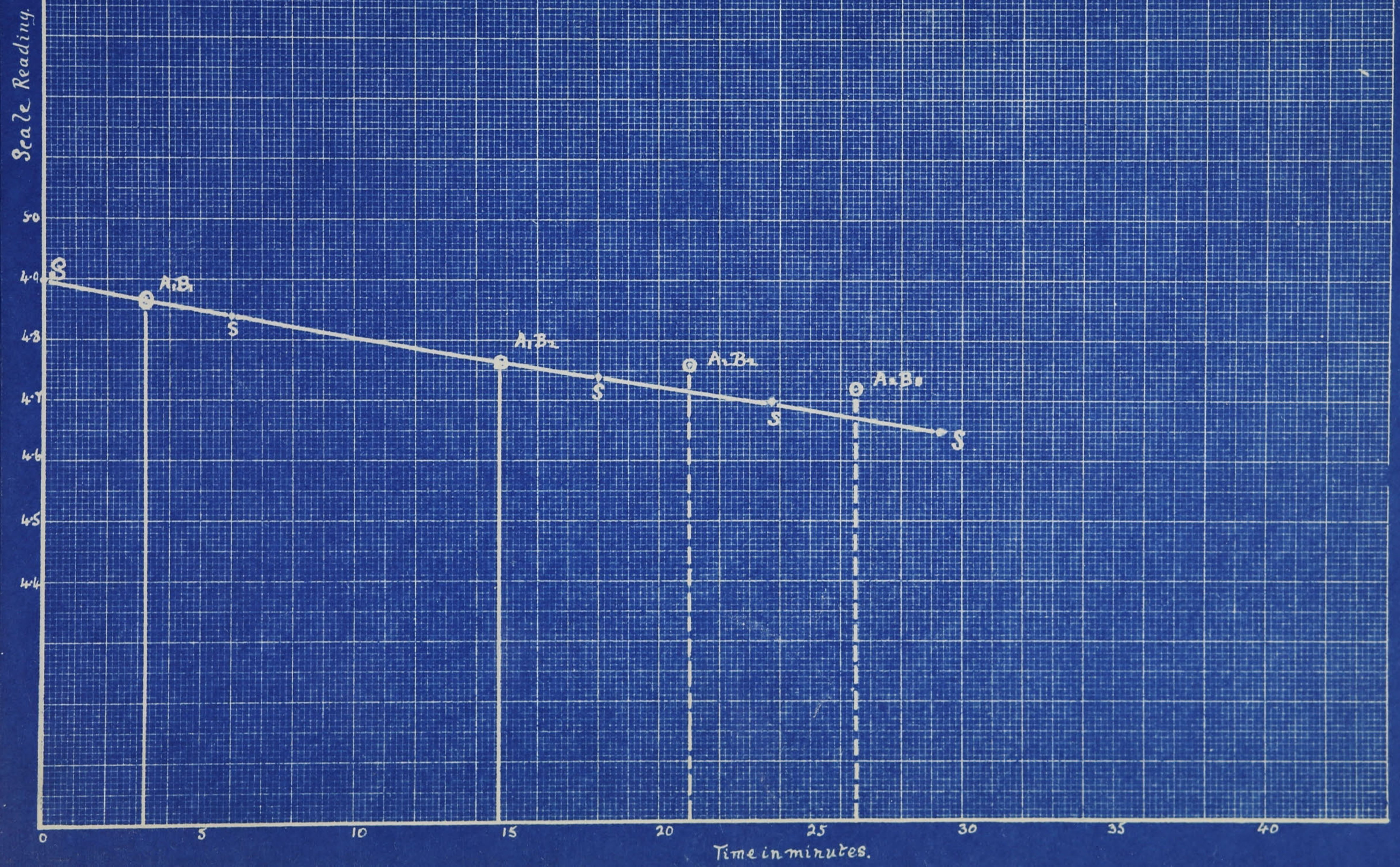


Graph 4.

Sensitivities of Severed Couples [Determined as seen, by metal A]

Graph 5

Sensitivities of Severed Couples



II The Construction and Testing of a Hygrostat.

One of the tasks undertaken in furtherance of an investigation of hygroscopic problems was the construction of a hygrostat.

In order to obtain moisture equilibrium curves for various substances, it is necessary to have some means of keeping them at a constant relative humidity for a considerable length of time. If small amounts of material have to be dealt with, dessicators containing solutions of Sulphuric acid of different strengths may be used for this purpose.

Solutions of certain salts have the same property of maintaining, in an enclosure at a certain temperature, a constant relative humidity, the value of which depends on the strength of the solution. Calcium Chloride solutions are very suitable for such purposes as the range of humidities it is possible to obtain with varying concentrations, is very large.

For this reason and also for the purpose of investigating the influence of air currents on the rate of drying of samples, the hygrostat set up at this laboratory was constructed on a fairly large scale.

The Department of Mines, Ottawa, was kind enough to give us the main structure of a hygrostat which had been used for coal humidifying tests, and a similar method of humidity control to that used at Ottawa with some modifications, was constructed and installed here.

Specifications of the Apparatus.

The diagram shows the apparatus as finally constructed,drawn to a scale of one to ten.

It consists of a chamber into which trays holding material for tests are fitted;a metal flue through which air currents of different velocities can be passed,and a fan to create the draught, the fan being driven by a motor from outside the circulation system.

The relative humidity within the hygrostat is determined by the strength of a solutions of Calcium Chloride.This is fed to a container inside the flue and from thence down a number of pieces of lamp wick.The air inside the hygrostat circulates continually through the strips of wetted wicks and thus is humidified to the degree desired.

The drying chamber has a volume of between four or five cubic feet,the metal flue is about eight inches in diameter,and the height of the hygrostat,exclusive of the Calcium Chloride reservoir is sixty-three inches.

The working of the apparatus depends on two features,viz "The air circulation,"and "the method of humidity control".

The air circulation.

This part of the system was completely redesigned and a more powerful motor installed.

The motor is a direct current WingScruplex of one eighth h.p. VoltsII5;Amps.I4;Revs. I750;obtained from the Wing manufacturing Co.of New York.

At Ottawa a motor had been installed inside the apparatus in the section which is now used as an auxiliary drying chamber (marked (d)in the diagram).Due to the unavoidable splashings of Calcium chloride solution drying out on the motor it was rendered useless in a comparatively short time.To avoid this trouble the new motor was set up outside the hygrostat and the fan (c)was driven by means of a driving rod,passing through the wall of the apparatus.

The bearingsin which the rod was held were oiled through a tube which also passed through the casing.

The motor was driven from the lighting circuit (IIOvolls) and its speed controlled by a rheostat,attached to the supports of the apparatus.

Humidity Control.

A large Winchester bottle placed above the drying chamber,served as a reservoir of Calcium Chloride solution.This flowed through a system designed to prevent flooding to a beaker inside the vertical section of the flue.The system devised for preventing flooding is illustrated in the right hand side of the diagram .

It is entirely new and can easily be adapted to control the flow of solution to another wick system in the hygrostat if such is constructed.

A secondary reservoir in the shape of a long glass cylinder(A) is fed from the main reservoir,the flow being controlled by a clip over a rubber junction.A tube passing from(A)to a collecting jar prevents the level of liqiid in(A)from rising above the level of the of the end of the tube,which is adjustable.The solution is siphoned from(A)into the beaker(B)where it cannot rise above the level in(A).Nine strips of wick(C)held in the beaker by a lead sinker to which they are attached,pass over corks on the rim of the beaker. These take up solution by capillary attraction and thus bring it into contact with the ascending stream of air.

The liquid is recovered by means of the tray (D) and vessel (E).

Commercial Calcium Chloride may be used for making up solutions provided it is partly freed from impurities. This can be done by allowing the solution to stand long enough for scum to rise to the surface and heavy material to settle to the bottom .

The resulting solution, siphoned from a point at half the depth is very satisfactory. This is important because if dirt is allowed to settle in the wicks, the power of sucking up solution is gradually lessened and renewal of the wicks becomes necessary.

Testing of the Hygrostat.

A hygro-thermograph was used to test the hygrostat. The records were complete in twenty four hours. This instrument was calibrated before hand and the graph drawn illustrates the degree with which it agreed with readings taken by a thermometer and Assman Psychrometer. The temperature curves follows the true temperature fairly evenly but the relative humidity record varies slightly.

A solution of Calcium Chloride of Specific Gravity I.3 was made up corresponding to an equilibrium relative humidity of 60%.

With this solution and slightly stronger ones giving a lower value for the relative humidity, satisfactory tests were obtained.

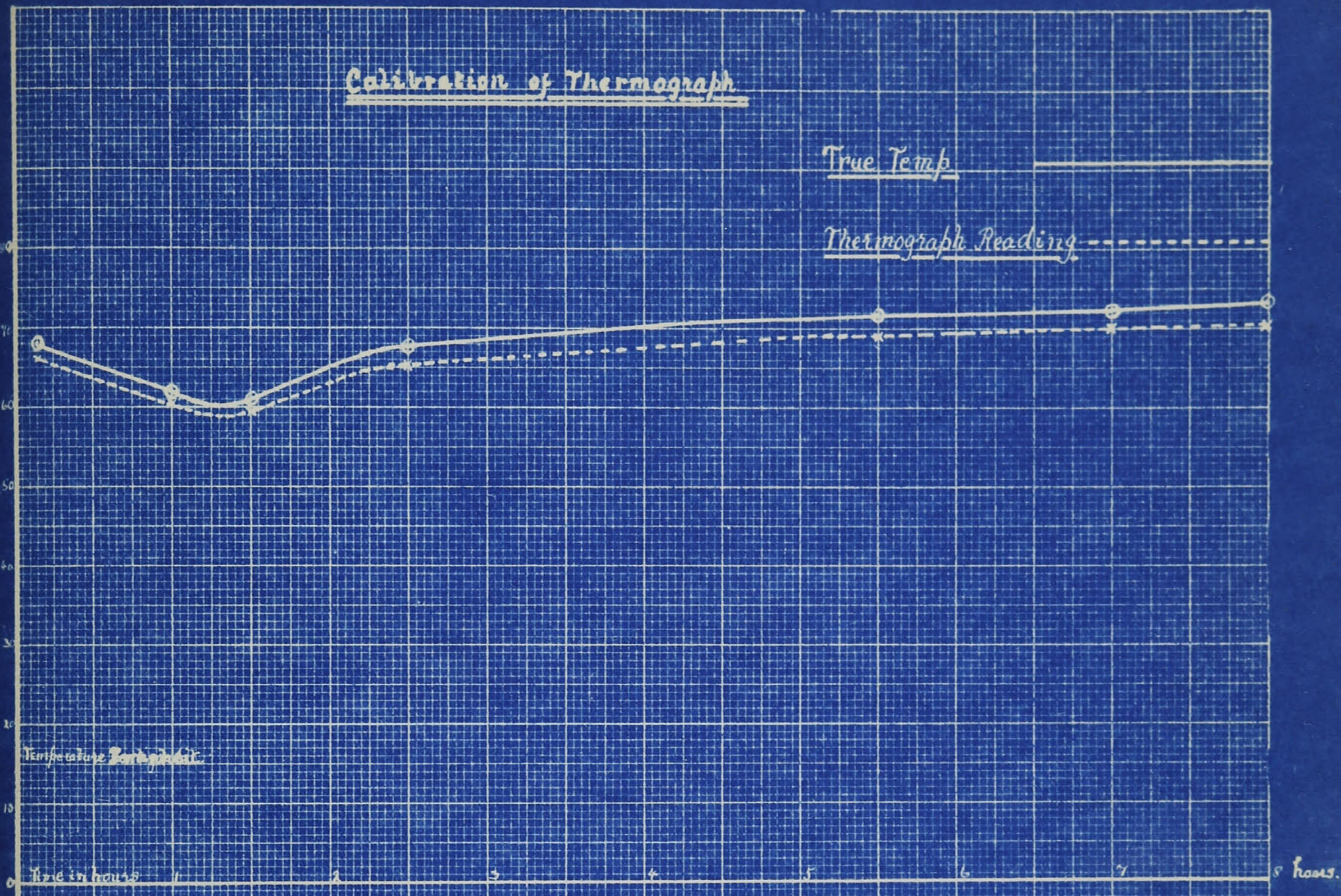
This was during the early fall. Later on under winter conditions the relative humidity recorded in the hygrostat fell short of the estimated value by a considerable amount.

Increasing the rate of flow of solution corrected this defect to some extent but examination showed that it was due to two causes.

One was the effect of small leaks in the apparatus which remained undetected when the room humidities had been not very different from the humidity in the hygrostat. In midwinter the room humidity averaged 15% so that when humidities of 60% or more were attempted in the apparatus, exchange of air between hygrostat and room made a greater difference.

The other cause of lower readings was the greater rate of absorption of moisture by the wood of which the drying chamber was made. The interior was thoroughly wetted as a test and ahumidity recordtaken immediately afterward showed how rapidly the wood absorbed the moisture. This passed through the walls under the influence of a humidity gradient of 60% to 15% and evaporated into the room.

Although careful sealing of joins in the structure with wax and paint have eliminated the former source of error, it is felt that entire reconstruction of the drying chamber with metal interior is necessary. This will be done at the earliest opportunity.


Calibration of Thermograph

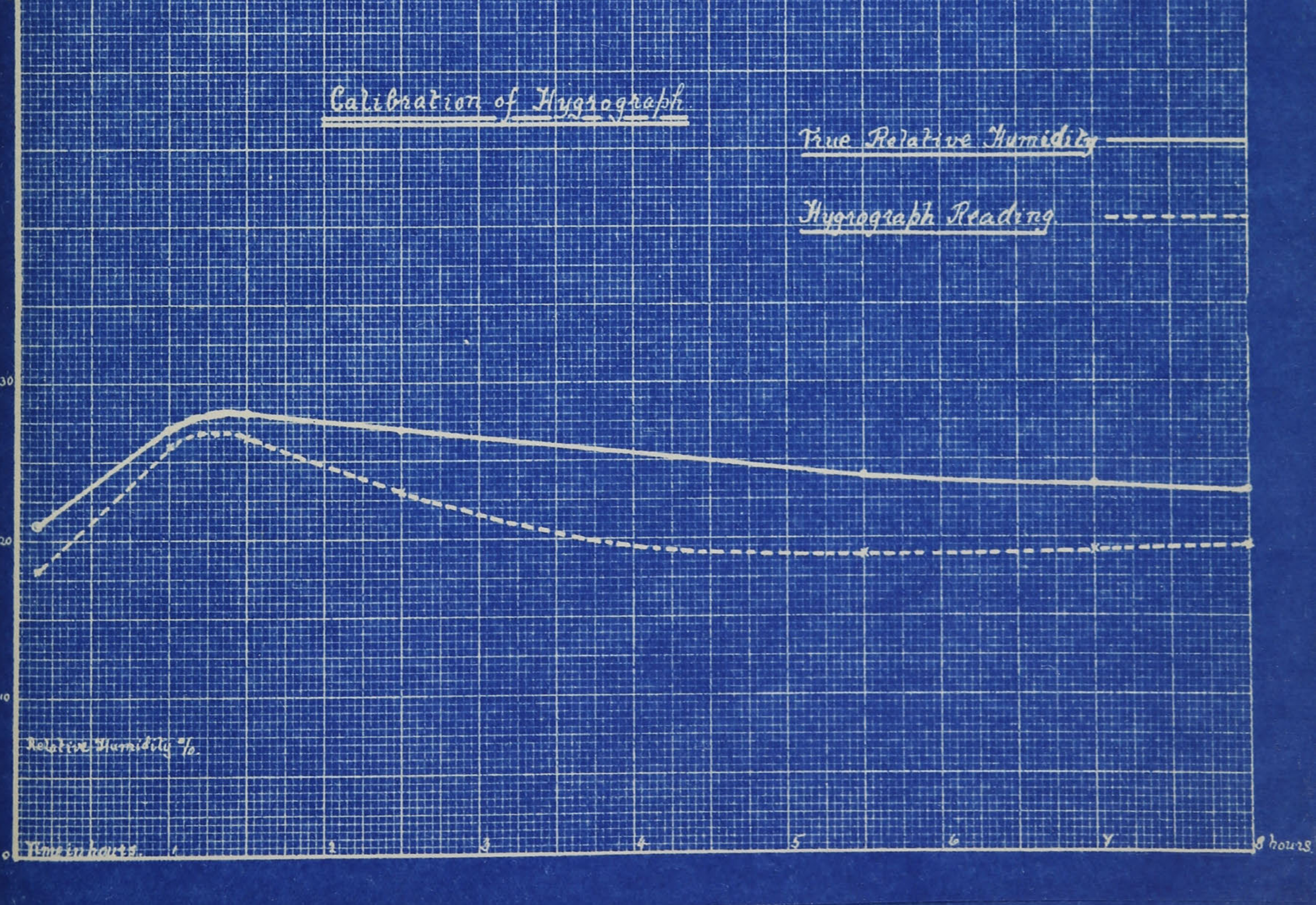
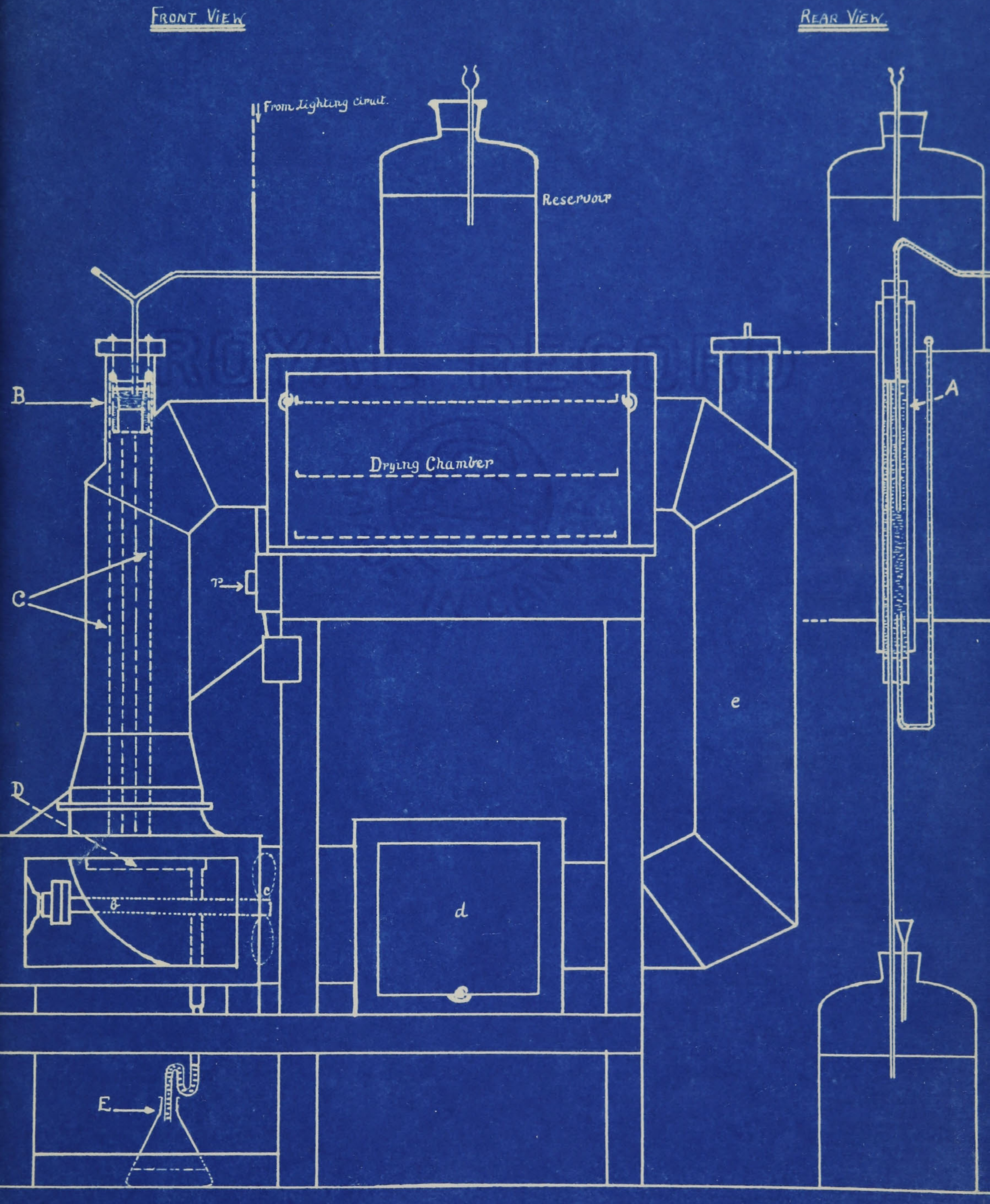

Calibration of Hygrograph

Diagram of Hygrostat.



III The Relation of Indoor to Outdoor Relative Humidities and the determination of a Correlation Factor between them for certain periods of the year.

The more recent papers appearing in textile journals have stressed the important influence of humidity conditions in the making of different fabrics and on the fading of coloured materials.

Fading, whidh at one time was attributed solely to the effect of exposure to light, is now known to be very largely dependent on humidity conditions as well as light exposure. The papers on this subject published in the Reports of the British Research Association for the Wollen and Worsted Industries in September I927, prove conclusively that fading of fabrics increases as the relative humidity increases.

An example of fading of the same material under different relative humidities. taken from the above mentioned report is shown in Graph I.

Experiments were carried out in England and in India to obtain the data required and practically all conditions of Relative Humidity, temperature, and light exposure occuring in populous centres, obtained at one or other of the testing stations.

From such data manufacturers can submit samples of goods intended for a certain climate to tests at a laboratory, where the humidity and light exposures of the particular climate can be reproduced.

For this purpose tables of average monthly relative humidities and temperatures for places distributed allover the globe have been compiled. A point that struck the writer concerning the utility of such tables for fading test purposes was that the humidity values given for certain places were considerably different from the average humidities to which fabrics would be exposed in practice.

For example, the figures given for Montreal were:-

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rel. Humidity.	83	82	78	69	65	70	72	73	76	76	8I	84
Temperature F.	I3	I5	25	40	55	65	69	67	59	45	32	I8

These values are for out door conditions.

Now as far as clothing, furnishing fabrics etc, are concerned, the indoor conditions of humidity and temperature are the more important. The average person, especially between November and April, spends a very large proportion of his time indoors, and clothes not actually being worn are of course exposed to indoor conditions the whole time. In Montreal during the winter, most people spend at least three quarters of their time under indoor conditions.

In a more even climate like that of England, the difference between indoor and outdoor humidity conditions is not great, but in Canada, during the winter, there is a very great difference, even when some attempt is made at artificial humidification.

With the idea of finding a correlation factor between indoor and outdoor relative humidities, indoor temperatures and relative humidities were recorded each day for a period of a month in midwinter and also for a month in the spring.

One of the research laboratories of the MacDonald Physics Building was used for this purpose. Two people used the room regularly and as the door was nearly always open, the conditions approximated to an average interiors without artificial humidification. The corresponding outdoor temperatures and humidities were obtained from the University Meteorological Observatory close at hand.

Graphs II and III show the variation of both indoor and outdoor relative humidities for the months of January and April.

Since the relative humidity depends on both the absolute humidity and the temperature, the **above** curves are really functions of two variables.

These variables have not the same values indoors as outdoors so in order to compare humidities in the two cases the temperature variable must be eliminated by reducing outside conditions to the indoor temperatures holding at the same time. This method was adopted because the inside temperatures were far more constant than those outside.

This was done by calculating the outdoor absolute humidity from the outside values for temperature and relative humidity. From this absolute humidity the equivalent relative humidity at the indoor temperature was found. This may be called the equivalent indoor humidity.

For example the readings for January 20th were:-

P.T.O.

	Temperature.	Relative Humidity.
Outdoor	22oF	79 %
Indoor	69oF	I9 %

From psychrometric tables we have:-

Saturation vapour pressure at 22°F=0.II3cms.

Saturation vapour pressure at 69°F=0.707cms.

These correspond to I00% Relative Humidity at the above temps.

Therefore the actual vapour pressure at 22°Fand79% R.H.

$$=\frac{0.II3\times 79}{I00}=0.089\text{cms}$$

A vapour ressure of 0.089 cms at 69°F is equivalent to a relative humidity of $\frac{0.089}{0.707}$ of saturation or I2.6%

Graphs IV and VI show the variation of the indoor relative humidity and the equivalent indoor relative humidity as defined above, for January and April respectively.

Graphs V and VII show the indoor and outdoor temperature variation for the same periods.

The ratio of the indoor relative humidity to the equivalent indoor relative humidity at any time may be called the correlation factor between them.

GraphsVIII shows how this factor varies with repect to the equivalent indoor relative humidity. Values of this factor obtained in January are marked as dots and values for April as crosses.

It was found that for low relative humidities, the correlation factor is large. The reason is that at low humidities, the effect of the moisture evaporating from people or from hygroscopic materials present, is in proportion greater. As the relative humidity increases, this factor gradually approches unity and in warm weather, when indoor temperatures are sometimes less than outdoors, it becomes less than one.

To find the degree to which the presence of people influenced the indoor humidity, a test was made in a large laboratory when about ninety students were present. The windows were open and there was free circulation of air as in the smaller laboratory, while the temperature was about the same. The relative humidity increased by about 8%. Conditions in lecture rooms where the students are more numerous in comparison with available air space, are more extreme, but for rooms where a few people congregate and the air circulation is moderate, the correlation curves found are probably typical.

Comparison of average humidities for the winter months, taken from the meteorological tables for Montreal, with actual indoor humidities gives,

Average Temp. Nov-March inclusive = 20°F.

Average Rel. Humidities " " = 81%

Therefore average Absolute Humidity $= \frac{81}{100} \times 1026$ (Sat. Pressure 20°F = .1026.

Average indoor temperature = 68°F.

Average Equivalent indoor humidity $= \frac{81 \times .1026}{0.684} = 12\%$ (Sat. press. 68°F = 0.684

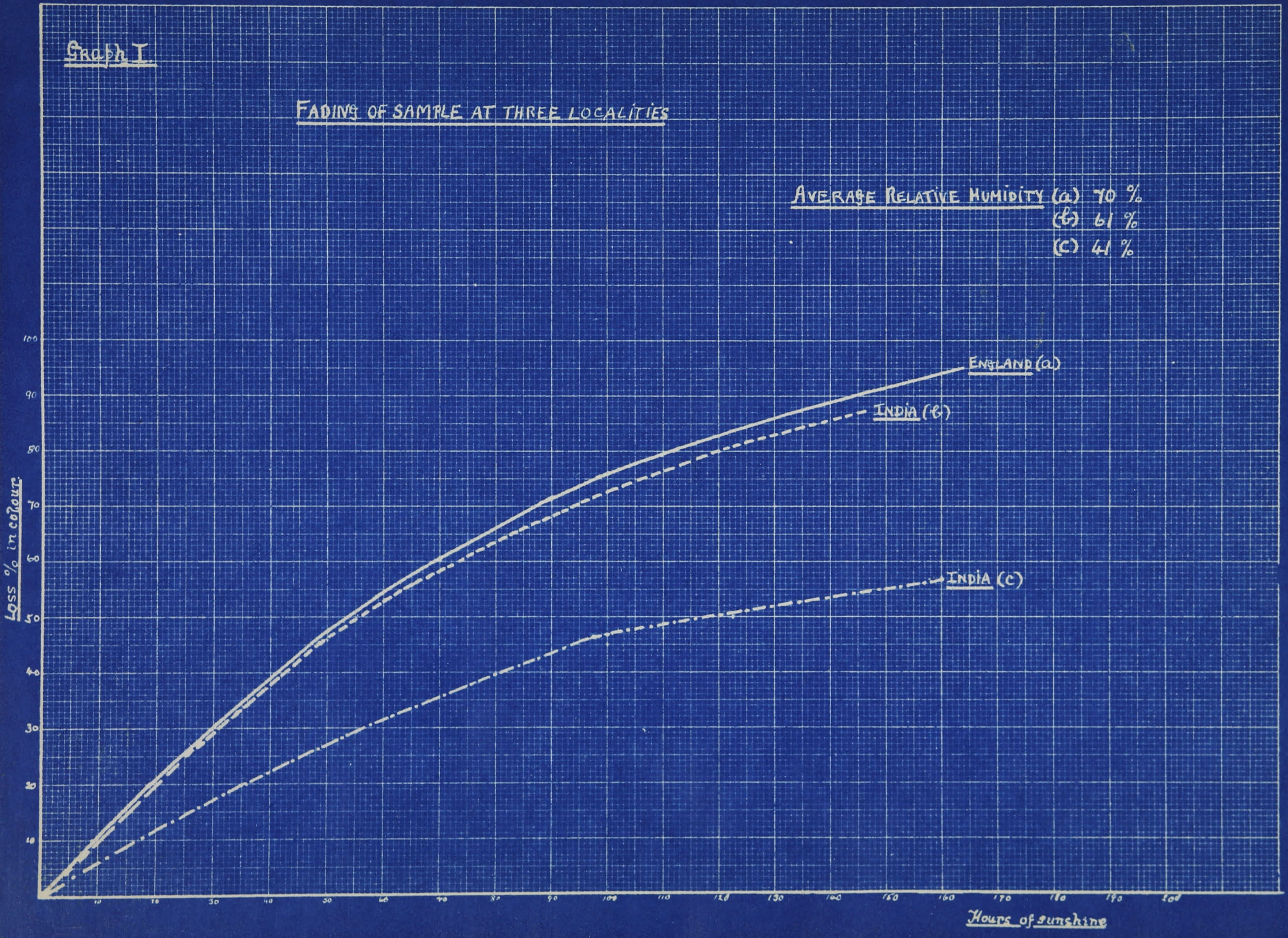
On reference to curves for the correlation factor it can be seen that only on the coldest days does this factor reach the value two. On the average its value for Nov.-March will be less than two so that the actual indoor humidity worked out on this basis wil not be greater than,

12% x 2 = 24%

It is not too much to say that indoor humidities for the five months mentioned are not often above 30%, and that the average is probably nearer 20% for buildings without humidifying devices. As a surprisingly large proportion of private residences as well as large buildings come under this category, the drawing of attention to this point will prove of use.

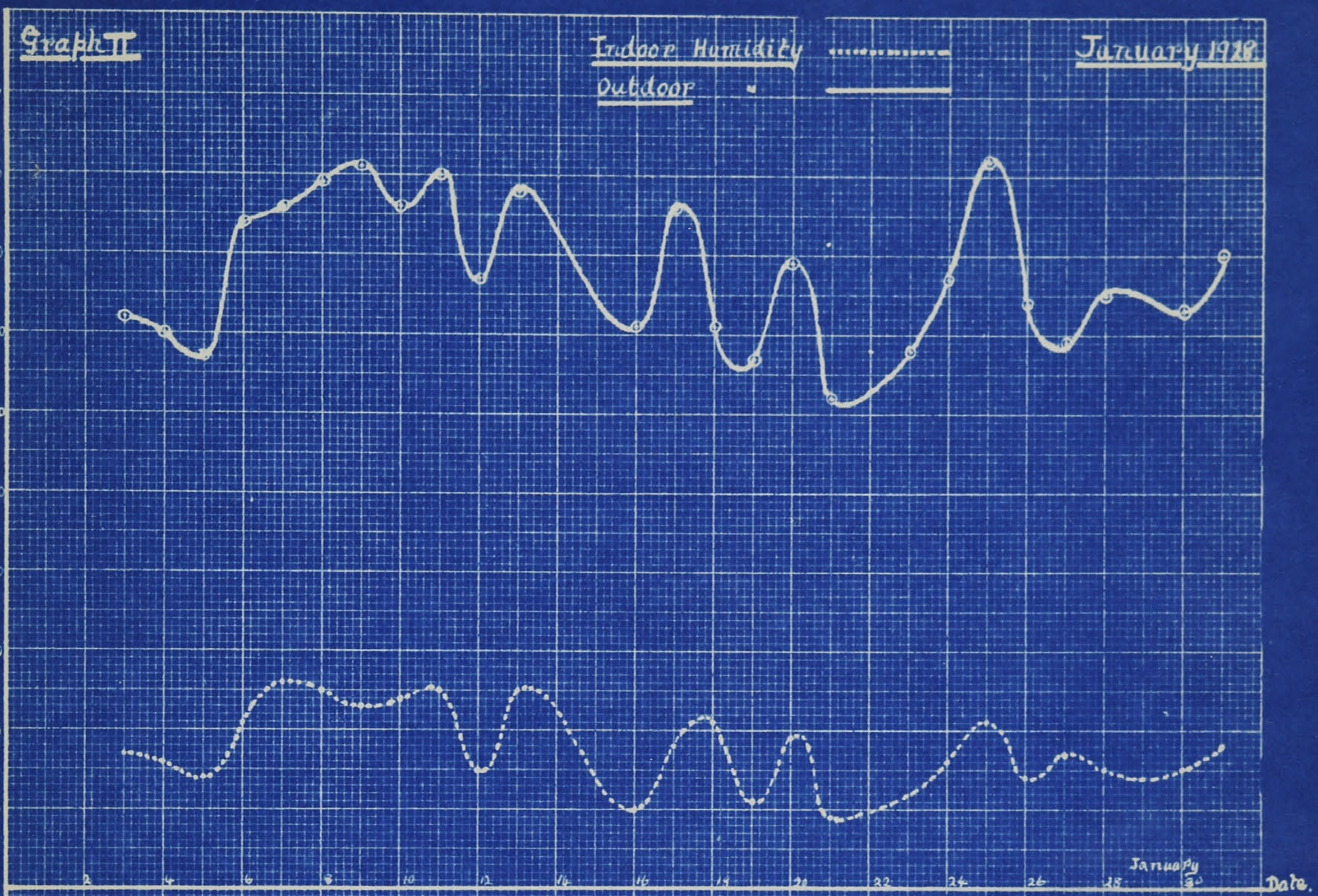
Date	Outdoor Temp	Outdoor R.H.	Absolute Hum.	Indoor Temp.	Indoor R.H.	Equiv. In. R.H.	Correlation Factor.
Jan. 3rd	14·1° F.	72 %	·056 cms.Hg	66 ° F.	17 %	8·8 %	1·93
4	17·4	70	·064	64·5	16	10·6	1·51
5	13·2	67	·050	62·5	14	8·8	1·59
6	31·3	84	·147	68·5	21	21·2	0·99
7	36·9	86	·189	72	26	24·1	1·08
8	33·0	89	·166	72	25	21·2	1·18
9	30·9	91	·155	71	23	20·5	1·12
10	34·3	86	·170	75	24	19·6	1·23
11	29·8	90	·146	73·3	25	17·8	1·40
12	17·1	77	·069	71·5	15	9·0	1·67
13	34·7	88	·177	71·8	25	22·8	1·10
16	0·1	71	·027	64·5	10	4·5	2·22
17	16·1	86	·073	69	18	10·3	1·74
18	29·1	71	·112	69·2	21	15·7	1·34
19	12·5	67	·048	65	11	7·8	1·41
20	22·0	79	·089	69	19	12·6	1·51
21	- 5·8	62	·017	66	9	4·2	2·15
24	15·1	77	·062	66	16	9·7	1·65
25	20·2	92	·095	69	21	13·4	1·56
26	1·3	74	·030	68	14	4·4	3·18
27	0·5	69	·027	71	17	3·6	4·72
28	- 0·6	75	·028	65	15	4·5	3·34
30	5·3	73	·036	68	15	5·3	2·84
31	9·4	80	·049	69	18	6·9	2·61

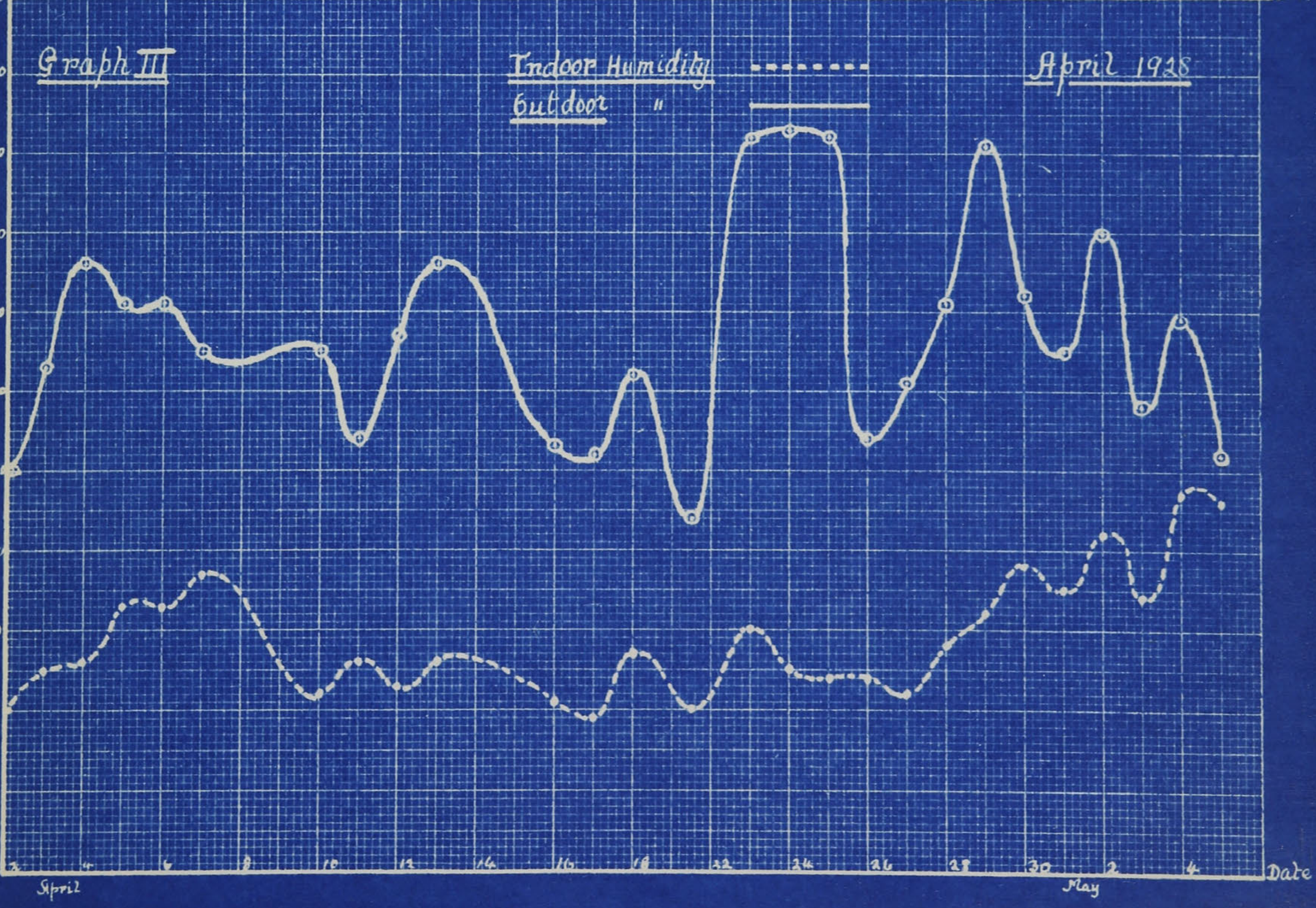
Date	Outdoor Temp.	Outdoor R.H.	Abs. Humid.	Indoor Temp.	Indoor R.H.	Equiv. In. R.H.	Correlation Factor
April 2nd	38 °F.	50 %	·114	71 °F	20 %	15 %	1·33
3	42	63	·168	76	25	19	1·32
4	39	76	·180	76	26	20	1·30
5	55	71	·314	73	33	39	0·85
6	53	71	·286	74	33	34	0·97
7	62	65	·360	74	37	43	0·86
10	35	65	·132	70	22	18	1·22
11	43	54	·149	67	26	23	1·13
12	37	67	·146	75	23	17	1·36
13	40	76	·188	77	26	20	1·30
16	25	53	·069	75	21	8	2·62
17	30	52	·085	65	19	14	1·36
18	42	62	·165	72	27	21	1·29
21	39	44	·104	71	20	14	1·43
23	40	92	·227	75	30	26	1·15
24	33	93	·174	77	25	19	1·32
25	37	92	·202	77	24	22	1·09
26	41	54	·138	75	24	16	1·50
27	41	61	·156	70	22	21	1·05
28	42	71	·189	68	28	28	1·00
29	43	91	·252	73	32	31	1·03
30	44	72	·207	71	38	27	1·41
May 1st	57	65	·302	76	35	34	1·03
2	55	80	·346	70	42	47	0·89
3	59	58	·290	68	34	42	0·81
4	64	69	·410	69	47	58	0·81
5	74	52	·435	69	46	62	0·74



Graph I

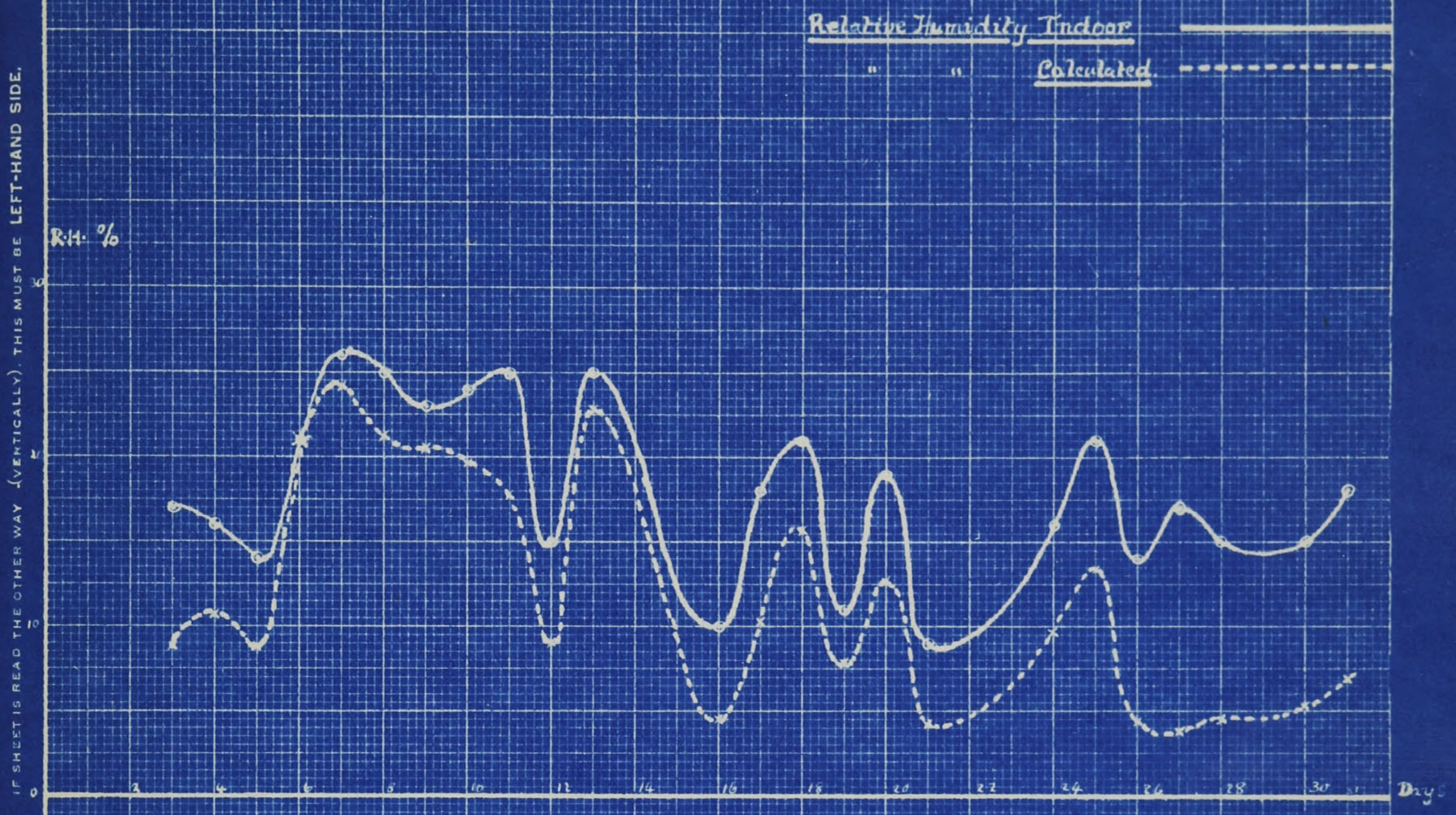
FADING OF SAMPLE AT THREE LOCALITIES


Graph II
Indoor Humidity
Outdoor "
January 1928
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
January
Date.


Graph III
Indoor Humidity
Outdoor "
April 1928
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
22
24
26
28
30
2
4
April
May
Date

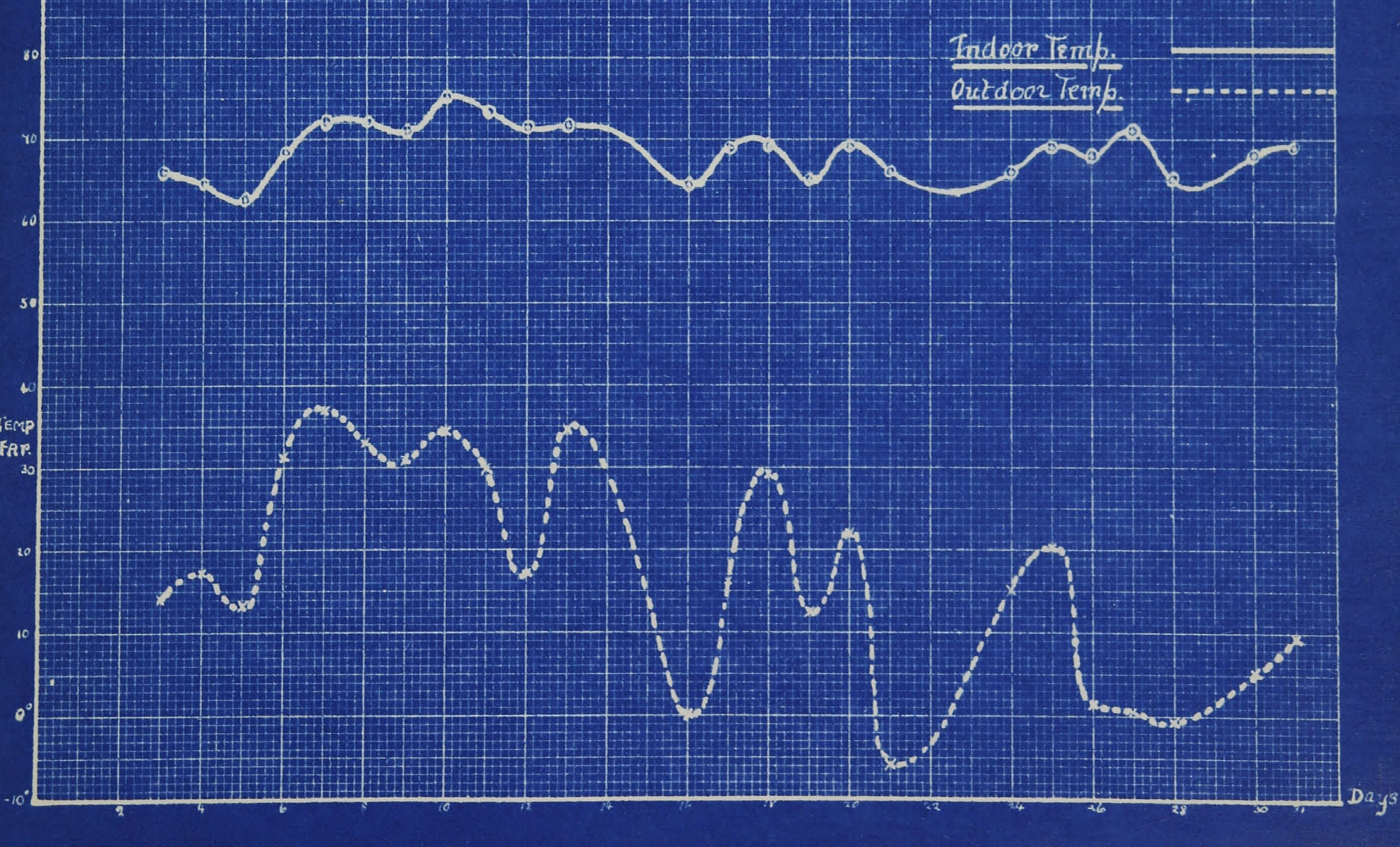
January 1928.

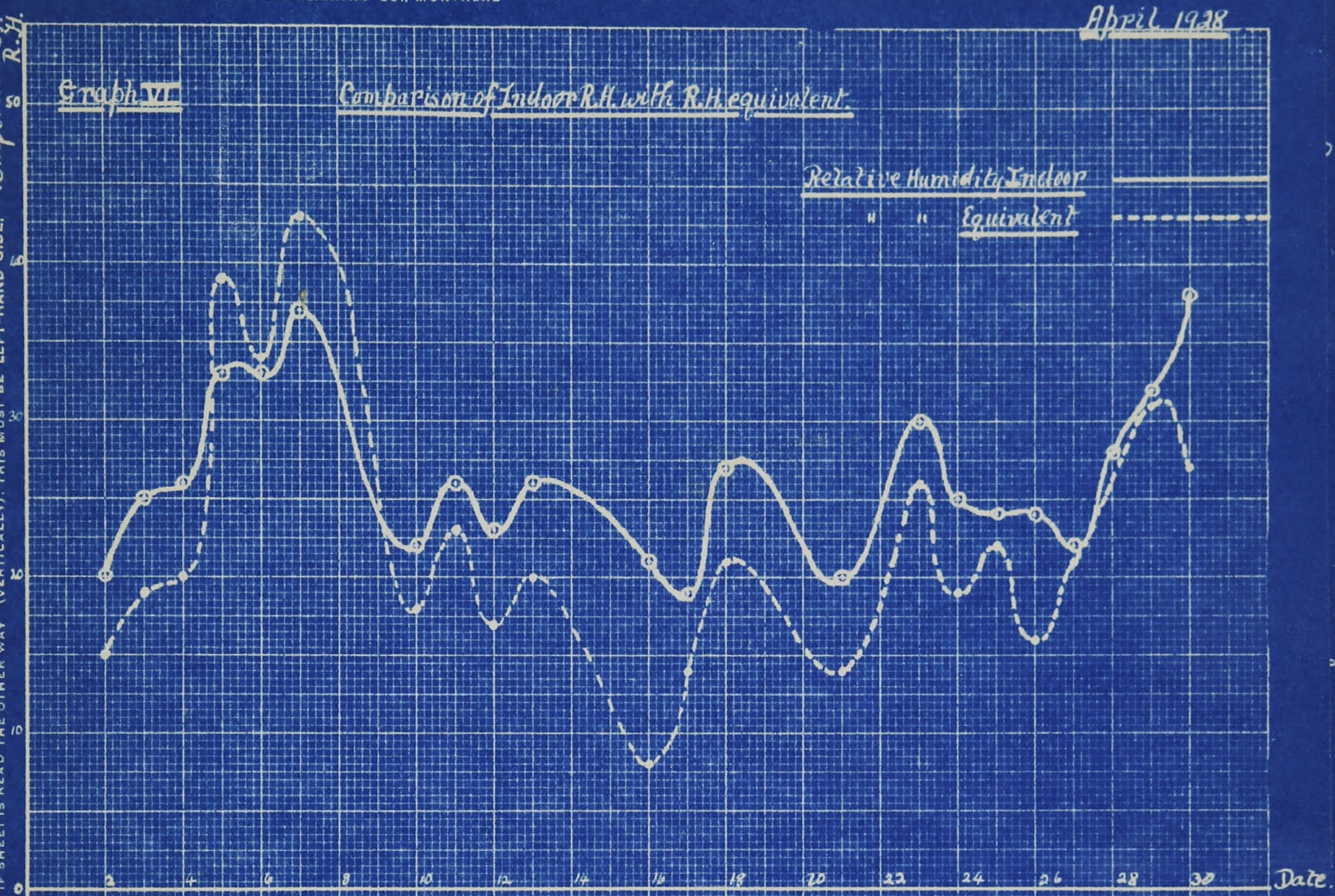
Graph IV Comparison of Indoor Relative Humidity with the R. H. equivalent to open air.



Graph V Comparison of Indoor and Outdoor Temperature

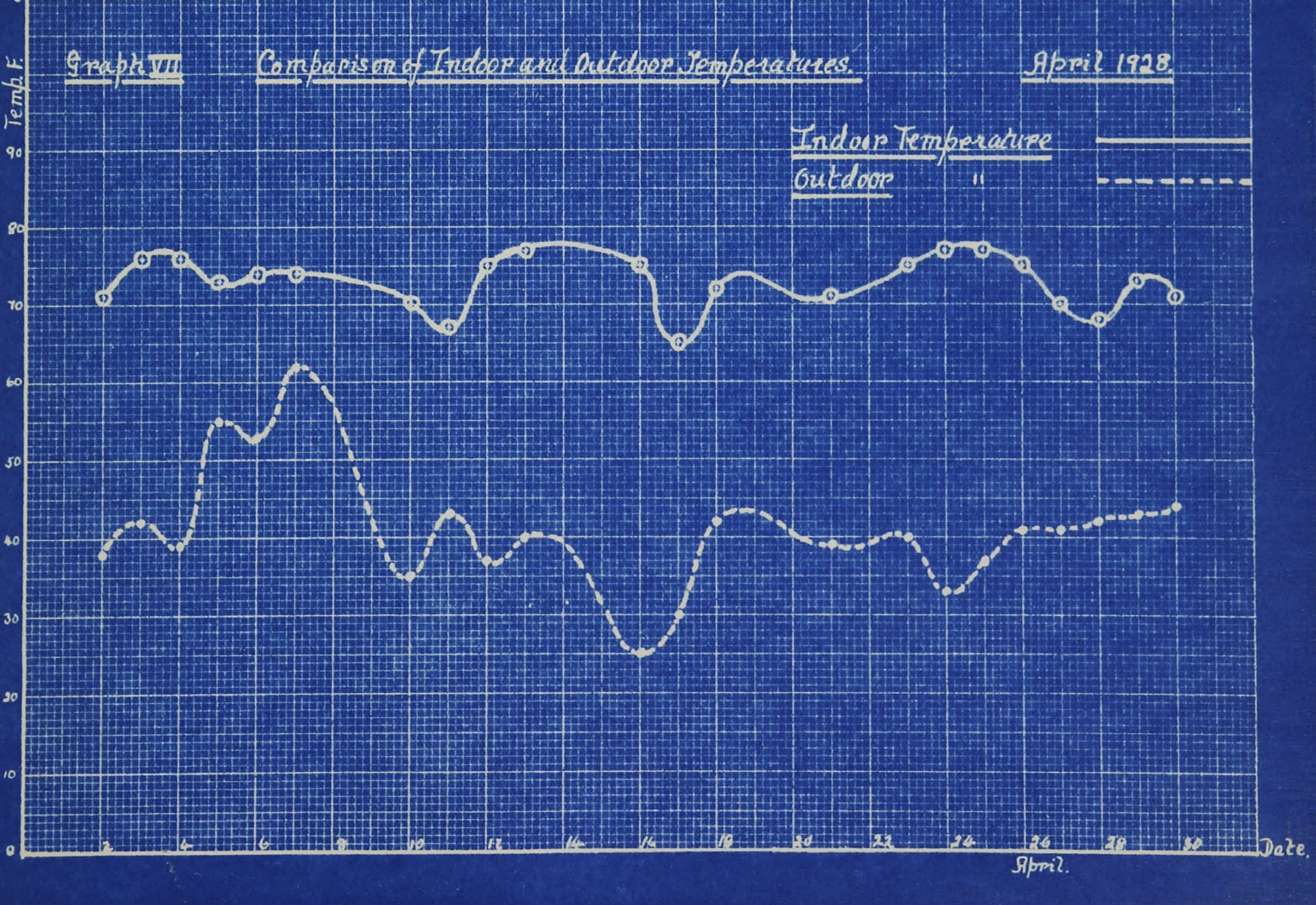
January 1928.





April 1928

Graph VI Comparison of Indoor R.H. with R.H. equivalent.



Graph VII Comparison of Indoor and Outdoor Temperatures. April 1928.

Graph VIII

Correlation Factor