

THE DESIGN OF A GUARDED
RING HOT PLATE FOR TESTING
THE THERMAL CONDUCTIVITY
OF HOMOGENEOUS MATERIALS

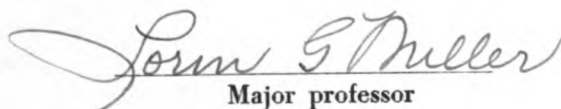
Thesis for the Degree of M. S.
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James Treat Anderson
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This is to certify that the
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**The Design of a Guarded Ring Hot Plate for
Testing Thermal Conductivity of Homogeneous Materials.**
presented by

James T. Anderson

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M.S. degree in M.E.


Major professor

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THE DESIGN OF A GUARDED RING HOT PLATE FOR TESTING THE
THERMAL CONDUCTIVITY OF HOMOGENEOUS MATERIALS

By
JAMES TREAT ANDERSON

A THESIS

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THESIS

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INTRODUCTION

Until the year 1945 all testing work on the thermal conductivity of insulating materials was done in a somewhat haphazard manner, with each investigator deciding for himself what the test conditions should be, and as a result the information available in tabular form necessarily had to be accompanied by explanatory notes as to the conditions. In addition, it was left up to each investigator to set for himself his own limits of accuracy. All in all, this practice led to widely varying data for materials seemingly the same.

However, in 1945, the American Society for Testing Materials, in conjunction with the American Society of Heating and Ventilating Engineers and the American Society of Refrigeration Engineers, developed and published a standard method of testing, which should eliminate the aforementioned difficulties. In addition, these organizations instituted a testing program for the purpose of revising all available data. To insure uniform and acceptable testing methods and equipment in the cooperating laboratories, a standard sample of corkboard was sent to each laboratory to be tested under the new method. The results from this test along with the corkboard sample were sent to the United States Bureau of Standards for retesting and checking. Any laboratory whose test results

checked within three per cent of the Bureau of Standards is to be accredited, and will proceed with testing for data revision.

This standard method of test merely set up conditions and limits for testing and did not specify in any way how these conditions and limits were to be accomplished. In this writing, it is hoped that a satisfactory method for accomplishing the prescribed test is presented in such a way that anyone wishing to set up similar equipment will be able to do so without having to have a specialized background in this type of work. As will be seen though, a step by step rigid development is not used, but discussion is employed, and latitude of method is left up to the individual.

HISTORICAL BACKGROUND

Ever since Bernoulli¹ conceived the molecular motion theorem of heat in 1738, men have tried in various ways to evaluate the amount of heat transmitted under given conditions, by conduction. Among the first of these experimenters was Count Rumford,² who, in 1804, set up an iron rod with copper cups soldered to the ends of it. In the rod, at equal intervals, he drilled small holes for the placing of thermometers, and in the copper cups he put crushed ice and boiling water, respectively. He was trying to prove that conduction obeyed the same law as radiation, and succeeded in merely finding that temperature distribution in a uniform, homogeneous bar was essentially uniform.

The next experimenter of note was Tyndall³ who set up a relatively complicated apparatus for measuring relative conductivities. Roughly this consisted of an electrically heated, mercury filled pad butting up against one side of a small cubical sample, with another mercury filled pad butting up against the opposite side. The receiving pad had a thermocouple built in, connected to a galvanometer. In operation the heating pad was turned on

1. Tyndall, John, Heat As A Mode of Motion, D. Appleton & Co., 1890, p 119.

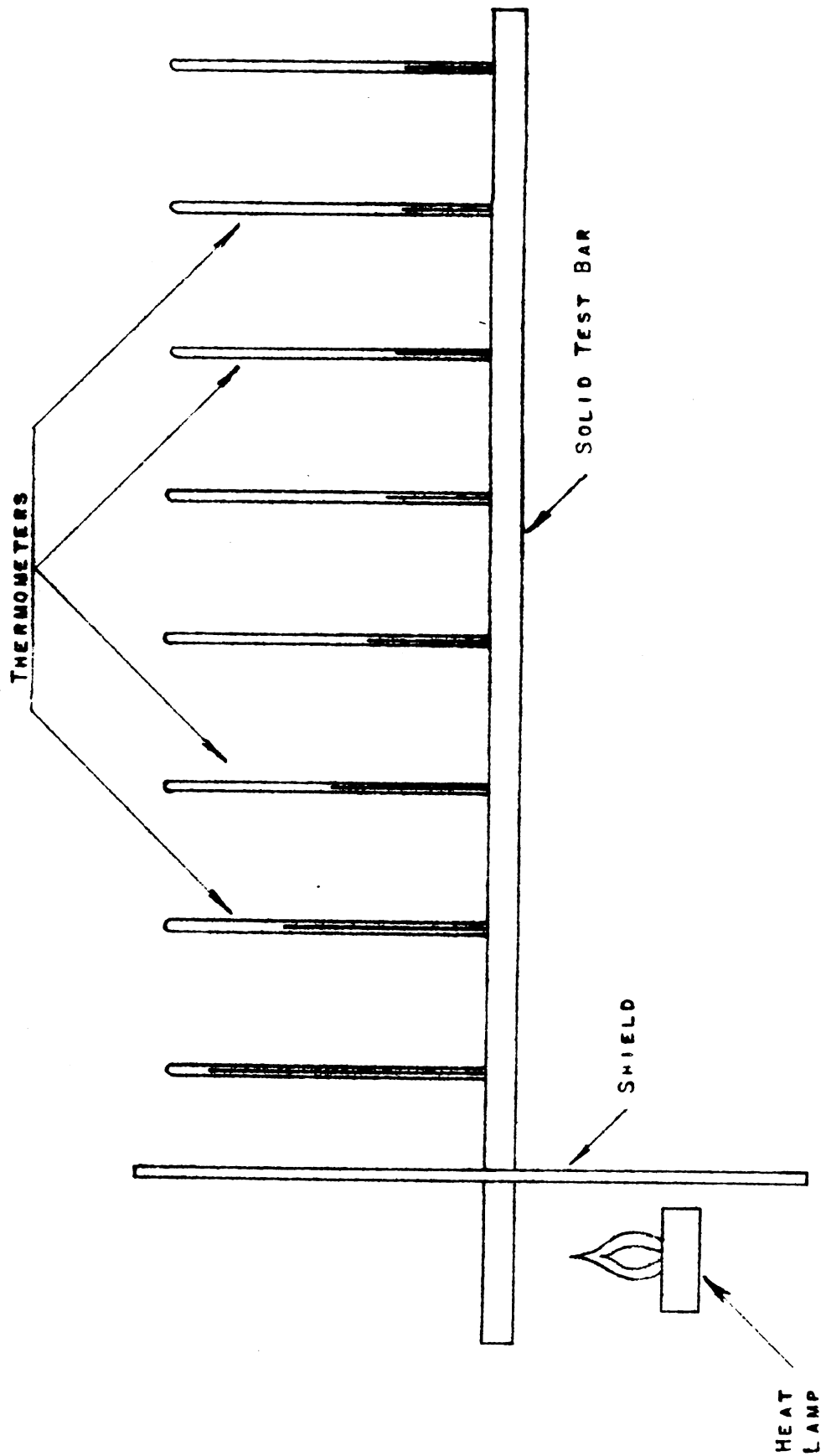
2. Thompson, Benjamin (Count Rumford), The Works of Rumford, American Academy of Arts & Sciences, Vol. II, p 144.

3. Tyndall, op. cit., p 245.

for exactly sixty seconds; then the galvanometer switch on the thermocouple was closed and maximum deflection noted. Of course, as Tyndall mentioned, this method did not take into account the specific heat of the sample, but it did have some value in determining relative conductivities of wood across grain and with the grain.

The first really quantitative experimentation was accomplished by Principal Forbes⁴ in 1850. Forbes set up a long, homogeneous bar, exposed to the atmosphere with thermometer wells drilled at regular intervals. (See Illustration Page 5.) One end of the bar was heated to a constant temperature and steady state conditions maintained while temperature readings were taken. The same bar was then heated its entire length to the initial temperature, and time-temperature readings for the cooling period, taken under the same atmospheric conditions as the initial test, were made. Now with a knowledge of the specific heat of the bar at all these temperatures, Forbes computed the heat loss per unit length of the bar for any temperature per unit length of the bar for any temperature per unit of time. By taking any given cross section and making a summation of the heat losses from the bar beyond the cross section, he could say this summation must be the heat flow through the cross section and establish the thermal conductivity of the bar.

4. Forbes, Principal, Transactions of the Royal Society of Edinburg, 1861-1862.



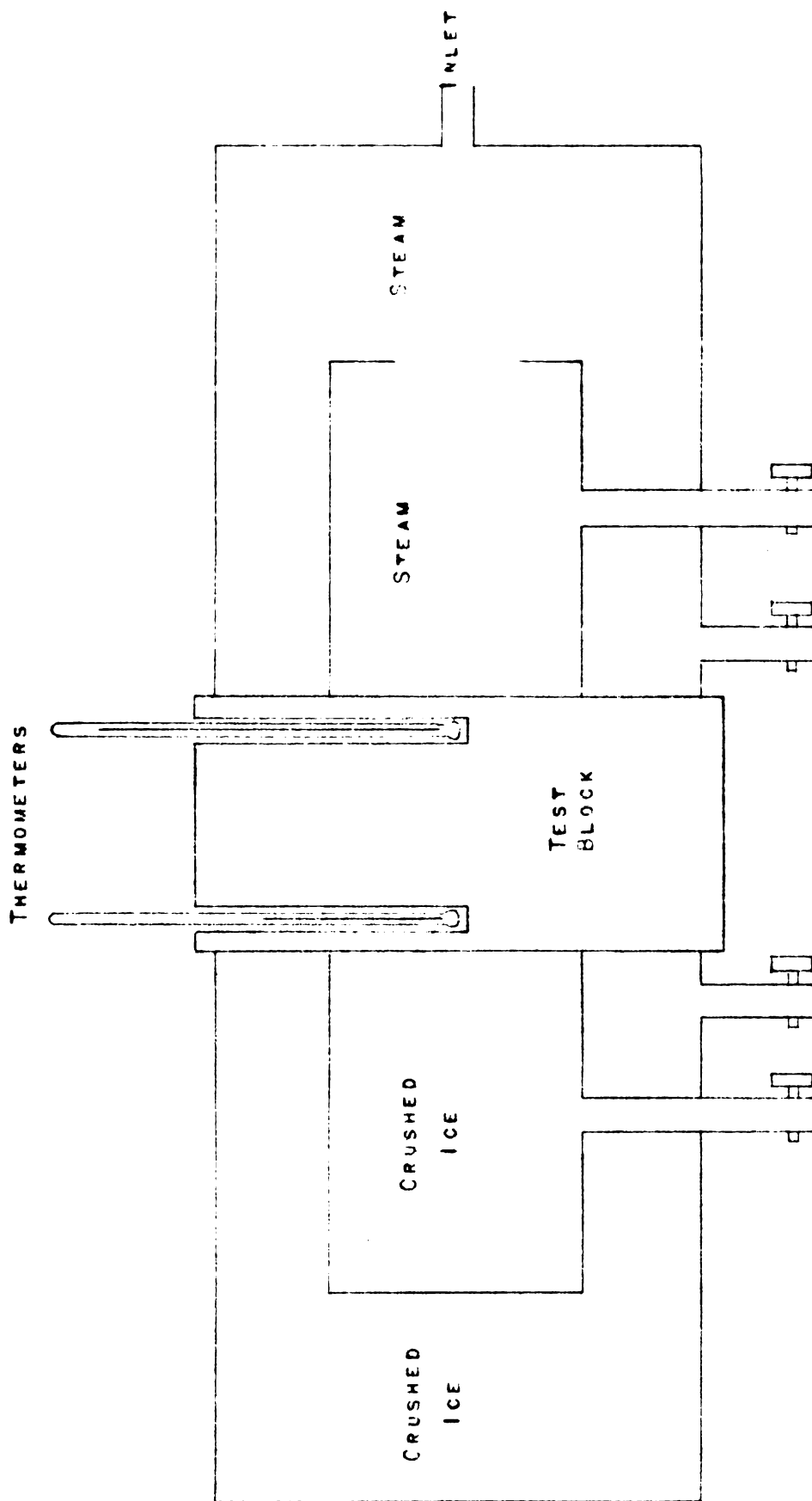
PRINCIPAL FORBES BAR TEST

In 1888, J. C. Maxwell⁵ claimed the obvious way to measure thermal conductivity would be to form a test specimen into a uniformly thick plate, and bring one of its surfaces to a known low temperature and the other surface to a known high temperature and determine the quantity of heat passing through in unit time. However, Maxwell then gave this method up because of the seeming impossibility of measuring the surface temperatures accurately.

Six years later, 1894, Thomas Preston⁶ described a very crude forerunner of the present guarded hot plate, seemingly based upon Maxwell's theorizing, and doing away with the surface temperature difficulty. Preston started with a large block sample enclosed on two opposite sides by containers filled with crushed ice and steam. (See Illustration Page 7.) These containers had smaller containers within them, also facing upon the sample and also filled with crushed ice in one and steam in the other. A short distance in from these faces, two holes were drilled for thermometers and the distance between the thermometers was considered the thickness of the sample for computation purposes. The cross sectional area of the inner containers was the area for computation and the heat supplied was measured either by weighing the melted ice water, or condensed steam per unit time.

5. Maxwell, J. C., Theory of Heat, Longmans, Green & Co., 1888, p 268.

6. Preston, Thomas, Theory of Heat, MacMillan & Co., 1894, p 527.



PRESTON'S GUARD RING

A more sensitive apparatus was devised by Lees⁷ in 1898. It had a series of three copper plates with an electrical heating coil sandwiched between plates one and two, and the sample between plates two and three. (See Illustration Page 9.) By measuring the power input to the coil and being careful about the air movement about the pile, it was possible to calculate the surface coefficient "h." Then by equating heat into the sample to heat out of the sample, thermal conductivity was calculated.

The first experimental equipment built along the lines of present day equipment was described by Poensgen⁸ in 1912. It had a central heating plate, with guard ring, flanked by cold plates supplied with cold water. The whole was buried in a box of sawdust, and temperature readings were taken by thermocouples.

In 1920, according to Robert Lander,⁹ professor at the University of Minnesota, the generally accepted guarded hot plate design was evolved and constructed. This hot plate has proven successful and is the instrument used in determining the thermal conductivities for insulation given in references available at this date.

7. Poynting, J. H. and Thompson, J. J., Heat, A Textbook of Physics, Charles Griffin & Co., 1904, p 102.

8. Saha, M. N. and Srivastava, B. N., A Textbook of Heat, Indian Press Ltd., 1931, p 316.

9. Lander, Robert, Factors Affecting Thermal Conductivity, University of Minnesota Technical Paper No. 49, 1944.

CONSTANT TEMPERATURE AIR

COPPER DISC
ELECTRICAL HEATING COIL
COPPER DISC
TEST SAMPLE
COPPER DISC

CONSTANT TEMPERATURE AIR

LEES DISC APPARATUS

THERMAL CONDUCTIVITY

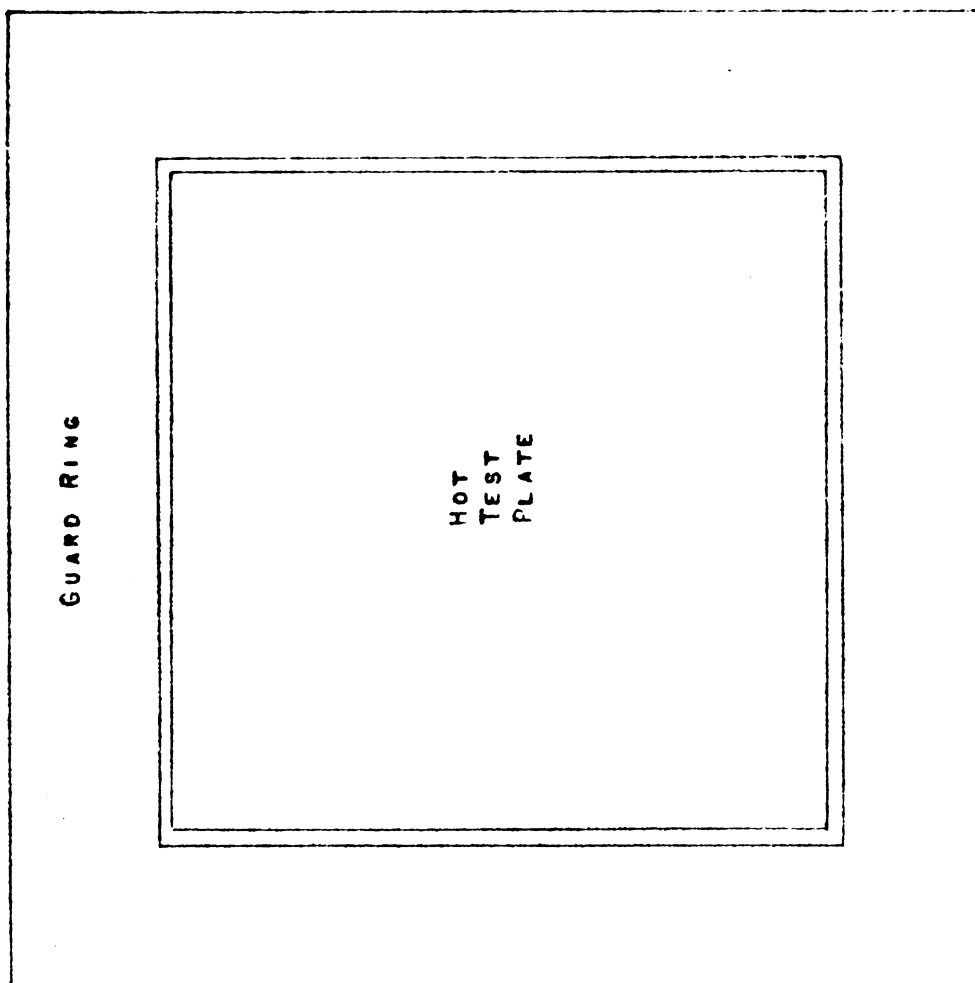
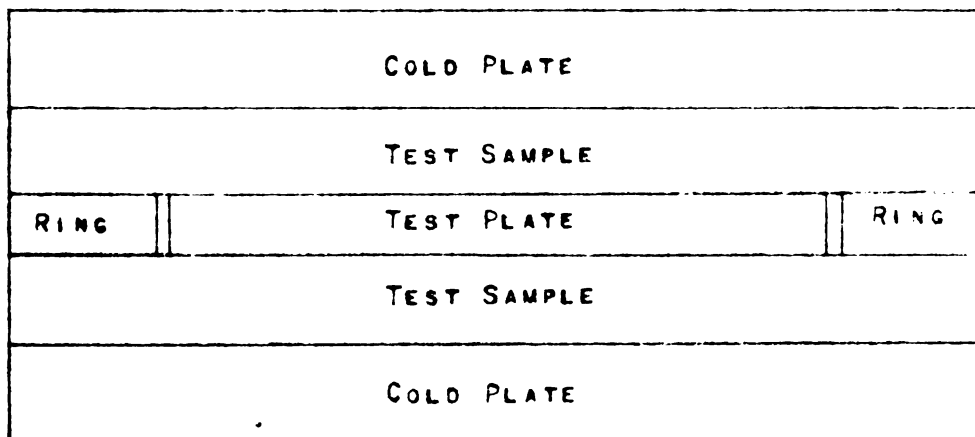
Thermal conduction is defined as the transfer of heat energy, in which the molecules of higher kinetic energy transmit part of their energy to adjacent molecules of lower kinetic energy by direct molecular action.¹⁰ Because the kinetic energy of the molecule is directly proportional to its temperature the heat transferred will occur in the direction of decreasing temperature. In the case of pure conduction, the amount of heat transferred is affected in linear proportion to the mean temperature of the material in question. In other words a plot of thermal conductivity versus mean temperatures would be linear. Present day accepted methods of insulating is to trap small air spaces in highly thermal resistant material, giving a cellular or granular insulation, which does not conform to pure conduction transmission, but rather combines conduction with radiation across the minute air spaces. Radiant energy transmission is proportional to the fourth power of the absolute temperature and therefore, when combined with the linear characteristics of conduction, will give a non linear variation with changes in mean temperature. Again referring to thermal conductivity versus mean temperature it will be seen that now with increasing values of mean temperature, thermal conductivity will increase at

10. American Society of Heating and Ventilating Engineers, Guide, 1948, p 97.

a rate greater than linear. This effect becomes more pronounced with the increased amount of entrapped air space and the higher mean temperatures, and consequently greater portion of radiant transfer. Due to this phenomena it is not possible to simply determine two values of thermal conductivity and extrapolate for desired values beyond the temperature range covered by the two tests. It is necessary to conduct a number of tests to definitely establish the variance of conductivity with mean temperature over any given range of desired mean temperatures.

DESCRIPTION OF APPARATUS

The guarded ring hot plate consists of a central electrically heated square flat plate with two heavy copper facings. This central plate has an electrically heated guard ring plate, in the same plane, surrounding it, and separated by a small air gap from it. (See Illustration Page 12.) On the two faces, uniformly thick slabs of homogeneous test material are placed, completely covering both central plate and guard ring. Now, two so called cold plates are placed on the outside surfaces of the test slabs; the whole is clamped together forming a large sandwich. These cold plates are liquid cooled copper plates capable of conducting the heat away from the sample as fast as it is supplied by the hot plate. This entire assembly is surrounded by adequate insulation to keep heat transfer not normal to the sample to a minimum.



SCHEMATIC CROSS SECTION OF GUARDED HOT PLATE

The electrical circuits of the central plate and guard ring are completely separate, the central plate circuit being metered, and the guard ring being unmetered. The object of the guard ring being to keep the heat flow from the central plate perpendicular to the test slabs, all that is necessary is that it be at the same temperature as the central plate. Electrical input to the plate and ring is controlled by coarse and fine rheostats.

Temperature readings are all made by thermocouples conveniently joined to a selector switch. Temperatures recorded are; side of test samples facing central plate, side of samples facing cold plates, and differential temperature between central plate and guard ring.

It can be seen from this description that all the elements of the thermal conductivity equation are directly measurable quantities:

$$k = \frac{QL}{A(t_1 - t_2)r}$$

Where: k = thermal conductivity in b.t.u. inch per sq. ft. deg. F. hr.

Q = b.t.u. input to central plate

L = thickness of test sample

A = total area of both faces of central plate

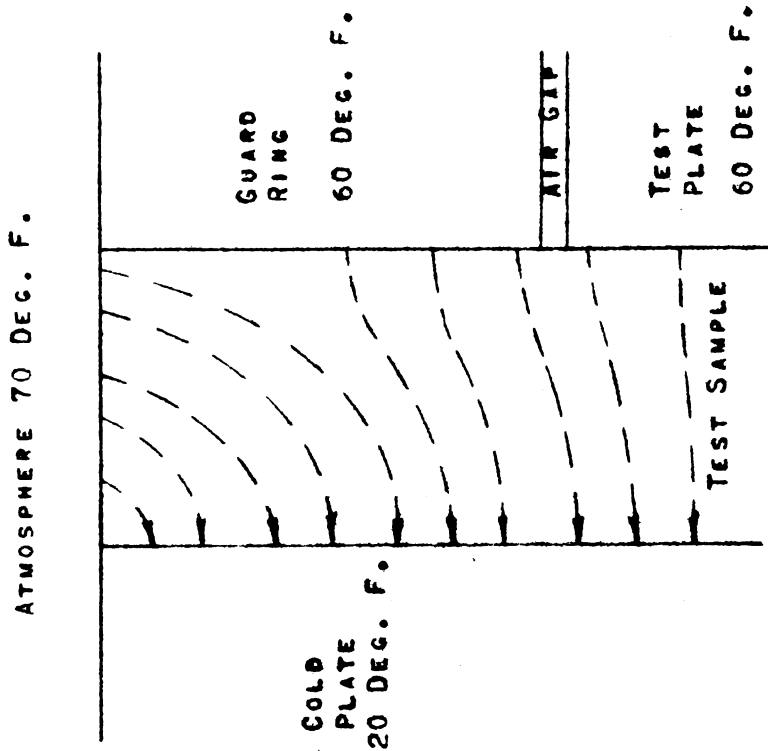
t_1 = average temperature of hot side of test sample

t_2 = average temperature of cold side of test sample

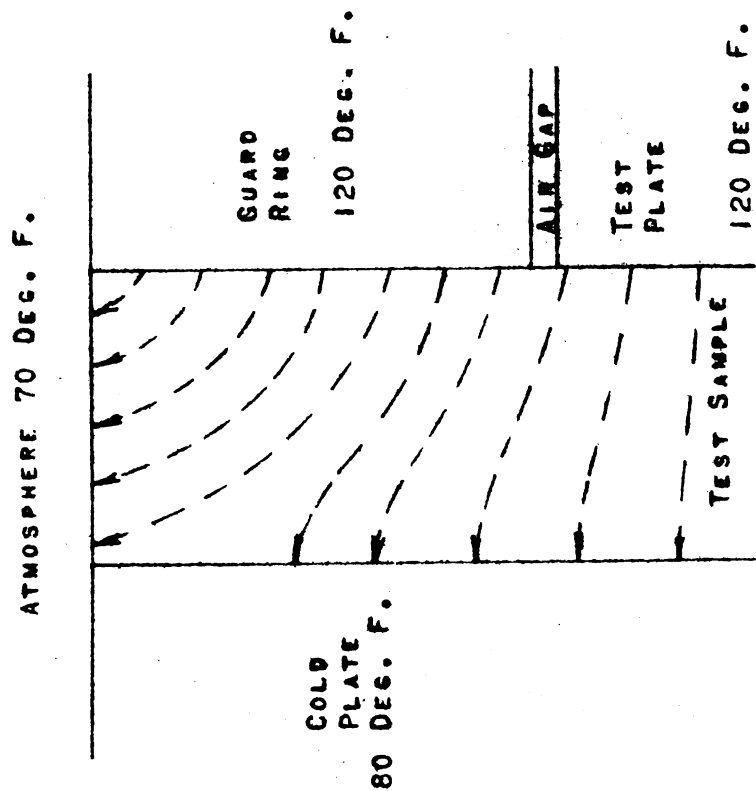
r = time of test in hours

GUARD RING PRINCIPLE

Keeping in mind the principle that heat flow is completely dependent upon temperature difference, the reason for keeping the guard ring at exactly the same temperature as the test plate is readily apparent. All heat transfer from the edge of the hot plate assembly is thus supplied by the guard ring. However, the path of the heat flow through the test specimen is dependent upon three temperatures, that of the test plate and guard ring, of the cold plate, and of the atmosphere surrounding the entire apparatus. The relatively large temperature differential between the hot plate and cold plate will have the effect of causing heat to follow a straight line between the plates, while the surrounding temperature will have the effect of diverting the heat flow lines either toward or away from the edge depending upon the relative temperatures involved. (See Illustration Page 15.) This latter effect, of course, is minimized by the insulation surrounding all edges of the equipment, but must still be accounted for. Remembering that for accurate results in testing for thermal conductivity by this method, the heat flow must be as nearly perpendicular to the plates as is practical, the ratio of width of guard ring to thickness of test sample must be considered. This ratio is set at one and one-half by the standard test. A ratio of greater than one and one-half means that a sample thinner than necessary is used and



LOW TEMPERATURE TEST



HIGH TEMPERATURE TEST

ENLARGED CROSS SECTIONAL VIEWS OF HEAT FLOW LINES IN EDGE OF TEST SECTION OF GUARDED HOT PLATE
EDGE INSULATION REMOVED

consequently a greater percentage of error in measuring the thickness of the sample is introduced. A ratio less than one and one-half will not provide a wide enough thermal protection border around the test section and thus the temperature of the hot plate will be affected, putting the test results in error.

At this point a knowledge of the contents of the Standard Test Method adopted in 1945, applying to the guarded hot plate, would be helpful in understanding the discussion that will follow. It is herewith reproduced in its essentials.

**"STANDARD METHOD OF TEST FOR
THERMAL CONDUCTIVITY OF MATERIALS BY MEANS
OF THE GUARDED HOT PLATE¹**

A.S.T.M. Designation: C 177 - 45

Adopted, 1945²
* * *

"INTRODUCTION

1. (a) This method describes procedures to be used in determination, by means of the guarded hot plate, of the thermal conductivity of insulating, building, and other materials, whose conductivities do not exceed the maximum value for which these procedures are applicable as specified in Section 2.

(b) Because of the requirements prescribed in this method as to conditions under which conductivity tests shall be made, it should be recognized that the conductivity coefficients obtained will not necessarily be the values pertaining under all service conditions. As an example, the method provides that the conductivity coefficients shall be obtained by test on dry specimens, while

1. Under the standardization procedure of the Society, this method is under the jurisdiction of the A.S.T.M. Committee C-16 on Thermal Insulating Materials.

2. Prior to adoption as standard, this method was published as tentative from 1942 to 1945, being revised in 1945.

in service such a condition will seldom be realized.

(c) The guarded hot plate is generally used for determining the thermal conductivity of homogeneous materials in the form of flat slabs, and this method covers the procedure for such tests. It is recognized, however, that it is frequently desirable to determine the conductivity of certain materials used as pipe coverings, etc., and also materials constituting a wall construction or a part thereof. For such purposes the guarded-end or calibrated-end pipe methods of test and the guarded hot box method are recommended.

(d) For satisfactory results, the principles governing the size, construction, and use of apparatus for the test described in this method should be followed. If the results are to be reported as having been obtained by this method, then all of the requirements prescribed in this method shall be met.

(e) It should be recognized that it is impossible in a method of this type to establish details of construction and procedure covering all contingencies so that it can be followed by a nontechnical person; and that, on this account, technical knowledge on the part of those using this method concerning the theory of heat flow, temperature measurement, and general testing practices cannot be dispensed with as a result of the standardization of the method. It is further recognized that it would be unwise, because of the standardization of this method, to restrict in any way the activities of research workers in the further development of new and improved methods.

"SCOPE

2. (a) For practical purposes, this method of test is limited to the determination of the thermal conductivity of materials having conductivities not in excess of 5.0 Btu. in. per sq. ft. per hr. per deg. Fahr.

(b) The method is further limited in its application to thermal conductivity tests between the extreme temperatures of -50 F. and 1400 F., or between mean temperatures of approximately 0 F. and 1200 F.

"SYMBOLS AND DEFINITIONS * * *

"APPARATUS

4. (a) It is not intended in this method to include detailed requirements for the construction or operation of any particular guarded hot plate for determining conductivity values. * * * Any plate conforming to the

limitations prescribed in Paragraphs (b) to (j) will be satisfactory. * * *

Note 2. -- The surfaces of the heater plates and cooling plates should be finished to as nearly a true plane as possible and should be checked periodically. Variations over 90 per cent of the surface should be nil with maximum variations on any portion of the surface not exceeding 0.003 to 0.005 in.

(c) In the design of the guarded hot plate for testing materials for use in any particular temperature or conductivity range, due consideration shall be given to the materials used in the construction of the hot plate with respect to their performance at the temperature to which the plate will be subjected. Consideration shall also be given to the rate at which heat must be supplied and absorbed by the heater and the coolers in designing the electrical resistance and current-carrying capacity of the heating element. Otherwise, no particular variations need be made in the design of hot plates for use in determining the conductivity of materials at the widely different mean temperatures mentioned in Section 2 (b).

(d) Heating units having metallic surfaces shall have a definite separation or air gap not greater than 1/8 in. between the measuring area of the central surface plate and the guard surface plates. These plates shall have highly emissive surfaces. The separation between the main central section and the guard section of the heating units shall not exceed 3/4 in., and this separation is allowable only if the spacing bars on either side of the plate separation are of heavy copper in order to distribute the heat on the surface plates. In all other cases the separation shall not exceed 1/8 in. The test area shall be calculated from the center of one separation to the center of the other separation across the central surface of the plate.⁴

(e) The heater of the guarded hot plate shall be provided with at least two thermocouples on each face of the central surface plate, and at least two thermocouples on each face of the guard surface plate, located at opposite edges. These thermocouples may be read either individually to indicate any temperature difference that may exist between the central and guard surface plates or

4. In putting a new heating unit into operation for the first time, care should be taken to insure that the two faces of the heating unit maintain essentially equal temperature throughout the temperature range of the apparatus.

they may be connected differentially, and thus indicate such temperature difference directly. The differential method of connecting the center-to-guard thermocouples is the more sensitive, and is to be preferred. When the thermocouples are to be read individually, they may be peened, welded, or soldered to the surface plates. When they are to be connected differentially, it is essential that they be electrically insulated from each other. This may be accomplished by installing the thermocouples in shallow grooves in the surface plates with an electrically insulating cement, in such a manner that the bead of each thermocouple is in the plane of the surface of the plate.

(f) The cooling units shall have the same surface dimensions as the heating unit. They may consist of metallic plates cooled by a fluid, electrically heated plates maintained at temperatures below that of the heating unit, or thermal insulation applied to the cool surface of the test specimen, depending on the mean temperature desired.

(g) The edge insulation may be of any convenient loose-fill or blanket-type insulating material to reduce edge losses from the heater plate, test specimens, and cooling plates. It shall be of such thickness that the resistance to edge losses shall be at least twice and preferably three or more times the thermal resistance of the specimen in the direction of normal heat flow.

(h) The surface temperatures of the test specimen may be determined either by means of thermocouples mounted in the hot and cold plates or by thermocouples located in the surface of the specimen, depending on the nature of the material to be tested. For nonrigid materials that have a unit conductance of less than 1.0 Btu. per sq. ft. per hr. per deg. Fahr. and that conform to the surfaces of the plates, the surface temperatures of the specimens shall be taken as those indicated by the thermocouples attached to the hot and cold surface plates. For this purpose both the hot and cold plates shall each be supplied with at least two thermocouples mounted in the surfaces of the plates as described in Paragraph (e). Preferably, the thermocouples should be insulated from the plates and read differentially between the hot and cold plates, the surface temperatures of the specimen being taken as those of the plate surfaces in contact with it. For rigid materials that fail to conform to the surfaces of the plate, and for all materials having a unit conductance higher than 1.0 Btu. per sq. ft. per hr. per deg. Fahr., separate surface thermocouples shall be used. These thermocouples shall be mounted on the surface of the specimen in any convenient manner suitable for the purpose, such that

the thermocouple junction is flush with the surface of the specimen. When thermocouples are used in the surface of the specimen, there shall be placed between the surfaces of the specimen and the hot and cold plates a piece of blotting paper or asbestos paper, depending on the temperatures encountered. For nonrigid materials of low conductivity, the use of thermocouples in the plates is preferred; while for rigid materials and those of high conductivity, the use of surface thermocouples is preferred. In the intermediate range the choice of method is left to the judgment of the operator.

(i) The thermocouples mounted in the surfaces of the plates shall be made of wire not larger than No. 23 A.w.g., while those used as surface thermocouples shall be made of wire not larger than No. 29 A.w.g.

(j) A potentiometer having a sensitivity of 5 microvolts or less shall be used for all measurements of electromotive force.

"SAMPLING AND PREPARATION OF SPECIMENS

5. (a) When this method is used as a guide in determining the thermal conductivity of special samples for control of manufacturing processes, for determining compliance with purchase specifications, and for other similar purposes, the selection and preparation of samples must obviously be left to the discretion of the person desiring the information. When, however, standard tests are to be made for the purpose of reporting thermal conductivity of a given material for consumer use, or for any other purpose where a definite statement of the history and condition of the sample is not available, and in all cases where the test is reported as having been performed in accordance with this method, the material shall be sampled and the specimens shall be prepared in accordance with Paragraphs (b) to (h).

(b) The sample shall be selected so as to provide two specimens as nearly identical as possible and of such size as to completely cover the heating unit. The specimens shall be of sufficient thickness to give a true average representation of the insulating material to be tested. Since excessive thickness of the specimens and consequent excessive dimensions of the area of the guarded hot plate unnecessarily complicate the manipulation of the test procedure, the specimens shall not be too thick. The thickness of the specimen shall be great enough to allow a sufficiently accurate measurement of this dimension for calculating the thermal conductivity. The relationship between the maximum thickness of the test specimen used and the minimum dimensions of the guarded hot plate shall be as follows:

Minimum Linear Surface Dimensions of
Guarded Hot Plate (Square or Round), in.

Maximum Thickness of Test Specimen, in.	Central Section or Test Area of Heating Unit	Guard Section or Guard Area of Heating Unit
1.....	4	1½
1½.....	8	2¼
2.....	12	3
4.....	12	6

(c) The sample shall be chosen as a fair representative of the material of the particular type on the market, or that to be used by the consumer. It should, therefore, preferably be purchased on the open market by an unbiased person. Three separate samples, not expected to have originated from the same day's output at the manufacturing plant, nor from a single shipment therefrom, shall be thus obtained from three different sources. The three or four tests prescribed in Section 6 (a) shall be made on each of these three samples in determining the conductivity of the given material.

(d) In testing all forms of homogeneous materials, the surfaces of the test specimens shall be made as plane as possible, by sandpapering or otherwise, in order that intimate contact between the specimens and the plates or the paper may be effected.

(e) The sample from which the test specimens are to be taken shall be weighed in the as-received conditions and then dried at 215 F. until excess moisture is driven off as indicated by a constant-weight determination. (If the material is one that may be chemically affected by heating to 215 F., the sample shall be dried in a desiccator at from 120 to 140 F.) The as-received weight, the dry weight, and the necessary physical dimensions of the sample for calculation of the density of the material as tested shall be recorded. (For solid and blanket-type materials the physical dimensions shall be determined separately before and after drying. The density of loose-fill materials shall be based on the volume occupied in the guarded hot plate and the weight after drying.)

(f) Samples of homogeneous solid materials to be used for test shall be dried in accordance with Paragraph (e), and the specimens cut to size, or molded or pressed into the proper size and shape, with due consideration to the treatment of the material in question, weighed,

and placed in the guarded hot plate for measurement of thickness, prior to testing, in accordance with Section 6 (c).

(g) Samples of blanket-type materials to be used for test shall, after being dried in accordance with Paragraph (e), be measured for thickness in accordance with the Standard Methods of Test for Thickness and Density of Blanket Type Thermal Insulating Materials (A.S.T.M. Designation: C 167) of the American Society for Testing Materials.⁵ Two representative specimens of the material cut to proper size shall be weighed, then placed in the guarded hot plate and compressed to the specified thickness, and the thickness measured in accordance with Section 6 (c).

(h) Samples of loose-fill materials to be tested at any prescribed density shall, after drying in accordance with Paragraph (e), be confined in the shape of a square or circular slab of dimensions suitable for the particular hot plate to be used and of a thickness not less than five times the size of any particle composing the test specimen, provided that in no case shall the thickness be less than 1 in. Two representative portions of the sample, of such weight (determined to an accuracy of plus or minus 0.5 per cent) as will give the prescribed density when packed into spaces of the required dimensions, shall be weighed out and fluffed up. The test specimens shall then be prepared in accordance with either method 1 or 2, as follows:

Method 1. -- The guarded hot plate shall be set up with the required distances between the heating unit and the cold plates. Each portion of the sample shall be divided into four equal parts. One part shall be placed in one side of the apparatus and vibrated or tamped until it occupies just one-quarter of the volume of that side. The remaining parts shall be introduced in the same way, one at a time, packing the material down by vibrating or tamping until it occupies its appropriate volume. The other sample shall then be placed in the other side of the apparatus in exactly the same manner.

Method 2. -- Two shallow square or circular boxes having outside flat dimensions the same as those of the guarded hot plate shall be used. The edges shall be made of wood strips $\frac{1}{4}$ in. in thickness and of such width as to make the depth of the box equal to the thickness of the specimen to be tested. The two square or circular faces shall be made by gluing blotting paper or asbestos paper to the edges of the strips. With one face in place and the boxes lying horizontally, one portion of the

5. 1944 Book of A.S.T.M. Standards, Part II.

sample shall be placed in each box, the material pressed down, and the other paper face glued in place. These two boxes containing the test specimens shall then be placed in the guarded hot plate. For materials the densities of which cannot be altered at will, the container shall be placed in a horizontal position with one side open, an excess of the dried sample weighed and poured in, the container shaken, and the excess material leveled before the upper paper face is glued in place. The weight of the material used shall be obtained by weighing the excess and subtracting it from the weight of the original material.

"PROCEDURE

6. (a) At least three and preferably four determinations shall be made on each specimen at mean temperatures which will cover the range of temperatures over which the material is to be used. For any test, the temperature difference across the specimen shall be not less than 40 F. The above mean temperatures of the specimen shall differ from each other by at least 30 F.

(b) The atmosphere surrounding the test equipment shall have a dew-point temperature not higher than the coolest part of any surface or material in, or forming a part of, the test apparatus.

(c) If the thermocouples mounted in the surfaces of the plates are used to determine surface temperatures (Section 4 (h)) the thickness of the test specimen shall be taken as the distance between the surfaces of the hot and cold plates when the specimen is in place in the apparatus. If separate surface thermocouples are used, the thickness of the test specimen shall be taken as the distance between the surfaces of the hot and cold plates when the specimen is in place in the apparatus, minus the thickness of the two layers of blotting or asbestos paper used.

(d) The heating element of the central heater shall be supplied with electrical energy regulated to give the desired temperature gradient through the test specimen and held constant within plus or minus 1 per cent, means being provided to measure this energy. Automatic regulation is recommended. Where automatic regulation is not available, the energy input shall be regulated by means of manual adjustment. The rate of electrical energy input to the guard ring shall then be adjusted so that the maximum temperature difference (Paragraph (e) between the center and guard surface plates during the 5-hr. test observation period shall be not greater than 0.75 per cent of the average temperature drop through the two halves of

the specimen, as determined by the differential thermocouples or the surface thermocouples. The average temperature difference between these surface plates during the test period shall be not greater than 0.2 per cent of the temperature drop through the specimen.

(e) The cooling units shall be so adjusted that the temperature drops through the two test specimens shall not differ by more than 1 per cent.

(f) After steady state has been reached, the test shall be continued with the necessary observations being made to determine temperature difference, center-to-guard thermal balance, and heat input until successive observations made at intervals of not greater than 1 hr., over a period of 5 hr., give thermal conductivity values that are constant to within 1 per cent.

(g) Upon completion of the test, the specimen shall be reweighed and the weight recorded.

"CALCULATIONS

7. (a) The density of the sample after drying, the moisture in the sample as received, and the moisture regain during test shall be calculated as follows:

$$D = \frac{A}{B}$$

$$M = \frac{C - A}{B}$$

$$R = (G - F) \times \frac{A}{F} \times \frac{1}{B}$$

where:

D = density of the sample after drying (pounds per cubic inch or grams per cubic centimeter),

M = moisture in the sample as received (pounds per cubic inch or grams per cubic centimeter),

R = moisture regain during test (pounds per cubic inch or grams per cubic centimeter),

A = weight of sample after drying prior to test (pounds or grams),

B = volume of sample after drying (cubic inches or cubic centimeters),

C = weight of sample as received (pounds or grams),
F = weight of specimen prior to test (pounds or grams),
and
G = weight of specimen after test (pounds or grams).

(b) Thermal conductivity shall be calculated by means of Eq. 1 (Section 3 (b)).

"REPORT

8. (a) The report of the results of each test shall include the following:

- (1) Name and any other identification of the material,
- (2) Thickness of specimen tested.
- (3) Dry weight of sample before test,
- (4) Density of dried sample (before test),
- (5) Moisture in sample "as received,"
- (6) Moisture regain during test,
- (7) Temperature range of test,
- (8) Hot-surface temperature,
- (9) Cold-surface temperature,
- (10) Mean temperature of test,
- (11) Heat input in Btu. per sq. ft. per hr., and
- (12) Thermal conductivity

(b) The conductivity-mean temperature relationship for any material tested shall be obtained from a curve resulting from plotting the thermal conductivity versus mean temperature, and representing the average of the tests on the three samples tested. The maximum deviation obtained from this average curve, and the mean temperature at which this maximum occurs shall be reported."

DISCUSSION

Basically the design of the National Research Council on Heat Transmission, 1932, twelve inch Hot Plate, will do as a starting point for the new design to conform to the new specifications. (See blueprints in back cover pocket.) Recommended changes, additions, or improvements to this design are as follows:

HEATING ELEMENT

The existing heating element of nichrome wire in conjunction with heavy copper face plates is satisfactory enough for equi-temperature distribution on the surface, however, the possibility of substituting sheet rubber heating elements, (trade name Uskon,) should not be overlooked. These elements would automatically take care of temperature distribution to the extent that metal foil faces might be used in place of the heavy copper plates. Flexible faces such as these would prove to be worth while in the testing of materials which have irregular surfaces, by better contact. At this date though, according to the U. S. Rubber Co., manufacturers of Uskon, the gap necessary, between the central plate and guard ring, to install conductors is greater than the one-eighth inch allowable.

POWER MEASURING METERS

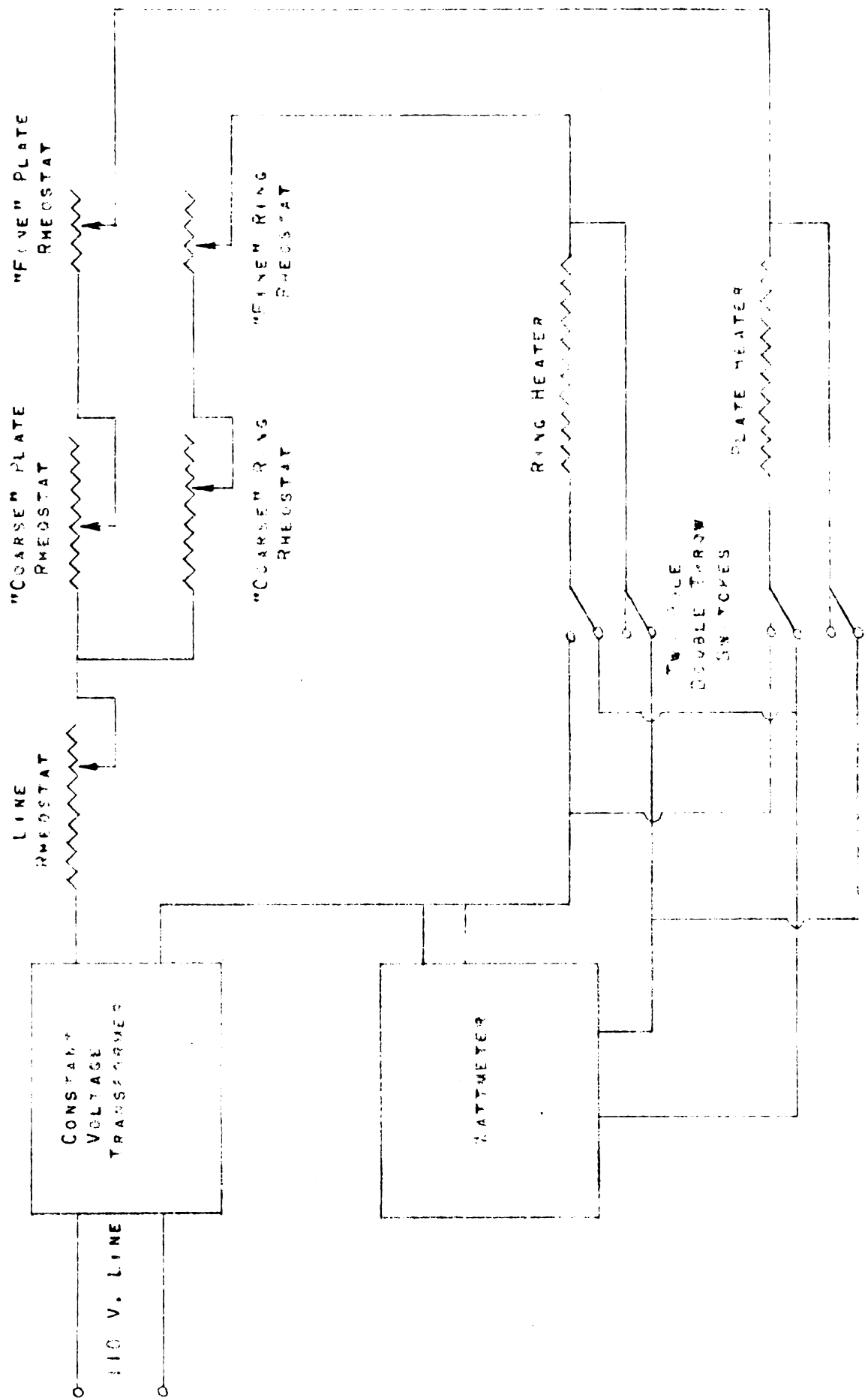
In place of separate voltmeter and ammeter, a watt-meter may be used, thus cutting down on reading time.

POWER SUPPLY

Specifications demand that the power input to the hot plate shall not vary more than plus or minus one per cent for the duration of the test. This may be accomplished by using an electronic voltage regulator with a direct current power supply. However, this is rather burdensome, and an extremely easy solution to this problem can be found in using a constant voltage transformer of the Solar Type. This transformer will regulate an input from 95 to 125 volts, to 115 volts plus or minus one-half per cent.

GUARD RING POWER SUPPLY

Adjusting the rheostats controlling power to the guard ring can be accomplished by successive adjustment followed by a waiting period to note changes on the differential thermocouples between the central plate and guard ring. This is a time consuming procedure and the chance of over-correcting or under-correcting is high. By arranging the guard ring power circuit so it may be routed through the wattmeter by pushbutton will offer the opportunity of taking data on the guard ring power consumption when properly balanced. (See Illustration Page 28.) This data may be used, on subsequent testing of similar material, to initially set the rheostats to a close approximation of the correct value, thus saving considerable time.



COARSE PLATE FLUORESCENT POWER CIRCUIT

VAPOR PROOF HOOD

To conform to the dew point specifications an adequately vapor proofed hood must be supplied. For convenience this hood should be large enough to allow all connections, tubing, and wiring to be put through a stationary back section. The front, top, and sides could be made with a ceiling pulley and counterweighted. Construction would be two thicknesses of three ply plywood with metal foil between them, the whole unit covered with aluminum paint inside and out.

DEHUMIDIFICATION APPARATUS

To accomplish the lowering of the dew point of the air surrounding the test equipment below the lowest temperature in the equipment either mechanical or chemical dehydration may be used. In case extremely low mean temperatures¹¹ are to be used in testing the mechanical refrigeration method has the advantage of lowering heat input to the backsides of the cold plates from the atmosphere. Under ordinary specified test conditions, (i.e., 40 Deg. - 70 Deg. - 100 Deg. F. mean temperatures) this effect is not so important, and the advantages of chemical dehydration such as economy, ease of installation, and convenience may be considered.

11. Rowley, F. B., Jordan, R. C., and Lander, R. M., Low Temperature Thermal Conductivity Studies, University of Minnesota Technical Paper No. 59, 1947.

The equipment may consist of a centrifugal forge blower, a stack suitable for inserting chemicals, and the necessary fittings. (See Illustration Page 31.) The object is to "blow out" the hood surrounding the hot plate with relatively dry air, then seal the hood and utilize concentrated sulphuric acid to complete the drying process. The preliminary air was pre-dried by forcing it over open pans of calcium chloride and through a ten inch deep bed of the same material. It was found that starting with air containing 95 grains of moisture per pound of dry air, this method would take out 60 grains per pound. The concentrated sulphuric acid was found capable of keeping the dew point low enough to employ 20 degree F. coolant in the cold plates.

ANGLE IRON CLAMP BRACKET

The solid angle iron bracket that holds the clamping screws quite often is a hindrance when charging or working on the apparatus. Therefore, an improvement would be to replace the fixed cross bar across the top of the hot plate with a removable bar, which would need only hooks at the ends to hold it in place similar to a fixed C clamp.

SELECTOR SWITCH

An improvement upon the thermocouple selector switch can be made by using a silver contact, commercial, multiple contact switch. The silver contacts will do away with



SCHEMATIC DIAGRAM OF CHEMICAL DEHYDRATION SYSTEM

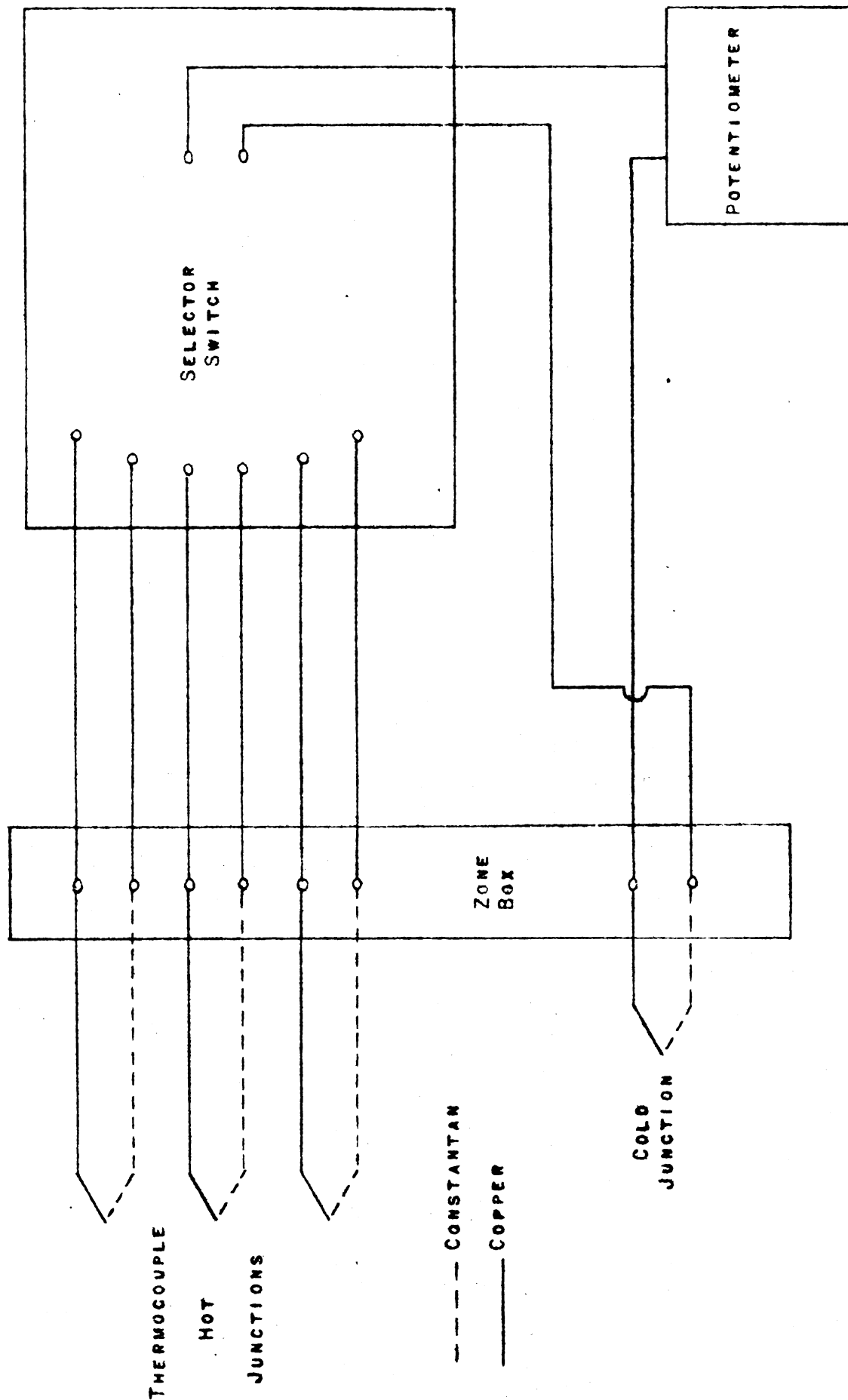
any oxidation that commonly affects the copper contact switch. This type of switch is also compact, does away with possibilities of shorts, and uses soldered connections. All in all, it makes a more permanent, foolproof setup. Switches of this type may be obtained from the Shallcross Manufacturing Company, Collingsdale, Pennsylvania.

CONNECTION BOARD

Installation of a connection board or terminal board on the back of the fixed side of the hot plate would facilitate the replacement and orderly arrangement of thermocouple leads coming from the hot plate. Use of soldered connections is recommended for trouble-free operation. This terminal board would make the replacing of a defective or broken thermocouple lead very easy. One word of caution, make sure this board is at equi-temperature from one end to the other. From the board to the selector switch ordinary copper leads may be used. (See Illustration Page 33.)

MULTIPLE CONTACT CONNECTORS

For ease of operation, removing the galvanometer, potentiometer, and consequently the data station, a short distance away from the hot plate is advisable. To keep from a tangle of extension leads a multiple conductor cable with suitable connectors may be used.



CIRCUIT DIAGRAM FOR COMMON COLD JUNCTION

THERMOCOUPLE COLD JUNCTION

An improvement may be made on the existing thermocouple cold junction by replacing the cold junctions with one cold junction.¹² By proper switching (See Illustration Page 33) the cumbersome large cold junction now may be compact and trouble free.

CONSTANT TEMPERATURE COOLANT SUPPLY

Up to the time of the 1945 standard test specifications the mean temperature of test was allowed to fall where it might, the cold plates being held at whatever temperature the cold water supply was at. The new test specifications call for three mean temperatures, namely, 40 deg., 70 deg., and 100 deg. F., with a temperature differential of at least 40 degrees F. across the sample. This requirement forces the cold plates to be lower than 20 deg., 50 deg., 80 deg. F., respectively, for the three means. The 80 deg. F. temperature is rather easily acquired by allowing a large reservoir of water to come to room temperature. It will stay at this temperature, because the small amount of heat being supplied from the hot plate will be easily dissipated. To obtain a constant temperature below 50 deg. F. a commercial soft drink cooling tank with a quarter horse power compressor, may be used. Fill the cooler body with plain water and set for 28 or

12. American Institute of Physics, Temperature, Its Measurement and Control in Science and Industry, Reinhold Publishing Corp., 1941, p 201.

30 deg. F. This will cause a ring of ice to form on the coils and remain there throughout the test, keeping the temperature well below the 50 deg. F. To obtain a constant temperature below 20 deg. F. adjust the compressor expansion valve so that the pressure on the low side is low enough to insure below 20 deg. F. operation, and allow the compressor to run continuously with an alcohol solution for coolant. A steady state condition will finally result which will be constant enough for testing.

COOLANT PUMP

A laboratory centrifugal pump will prove most satisfactory for circulating the coolant through the cold plates. To insure the best conditions possible, arrange a baffle in the coolant supply to make the distance traveled by the coolant from pump outlet to pump inlet as long as possible.

GALVANOMETER SHORTING SWITCH

A rather useful item in taking the numerous readings required, by potentiometer and galvanometer, is a push button type switch located near the potentiometer and connected directly across the galvanometer. This saves considerable time by cutting out the swinging periods.

COLD PLATE CONSTRUCTION

Formerly the cold plates were made with a double shell to provide an insulating air space to cut down an excessive condensation on the back sides. With a controlled atmosphere this is no longer necessary.

SAMPLE DATA

MATERIAL TESTED: Standard Corkboard From A.S.H.V.E.

DATE: July 28, 1947

<u>Time in Hours</u>	<u>Volts</u>	<u>Amperes</u>	<u>Differential Thermocouples Average</u>
0	24.0	.149	.000
1	24.0	.149	.000
2	24.0	.150	-.002
3	24.0	.149	.000
4	24.0	.149	.000
<u>5</u>	<u>24.0</u>	<u>.149</u>	<u>.000</u>
5 Hour Average	24.0	.1492	-.0004

THERMOCOUPLE NUMBER

(Readings in Millivolts)

<u>Time in Hours</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>
0	1.080	1.073	2.078	2.075	2.075	2.074	1.069	1.069
1	1.076	1.070	2.076	2.074	2.074	2.070	1.072	1.072
2	1.076	1.073	2.081	2.078	2.078	2.077	1.077	1.077
3	1.089	1.082	2.081	2.079	2.079	2.079	1.079	1.079
4	1.089	1.084	2.083	2.076	2.079	2.079	1.082	1.082
<u>5</u>	<u>1.090</u>	<u>1.090</u>	<u>2.083</u>	<u>2.072</u>	<u>2.079</u>	<u>2.070</u>	<u>1.087</u>	<u>1.087</u>
5 Hour Average	1.085	1.080	2.081	2.076	2.078	2.075	1.079	1.079

SAMPLE COMPUTATIONS

Average Cold Plate Temperature = 1.0807 M.V. = 81.0375° F.

Average Hot Plate Temperature = 2.0775 M.V. = 123.90° F.

Average Temperature Difference = 42.8625° F.

Mean Temperature = 102.47° F.

Power Input = 24.0 (.1492) (3.413) = 12.2212 Btu per Hour.

Total Area of Effective Test Area = .889 Sq. Ft.

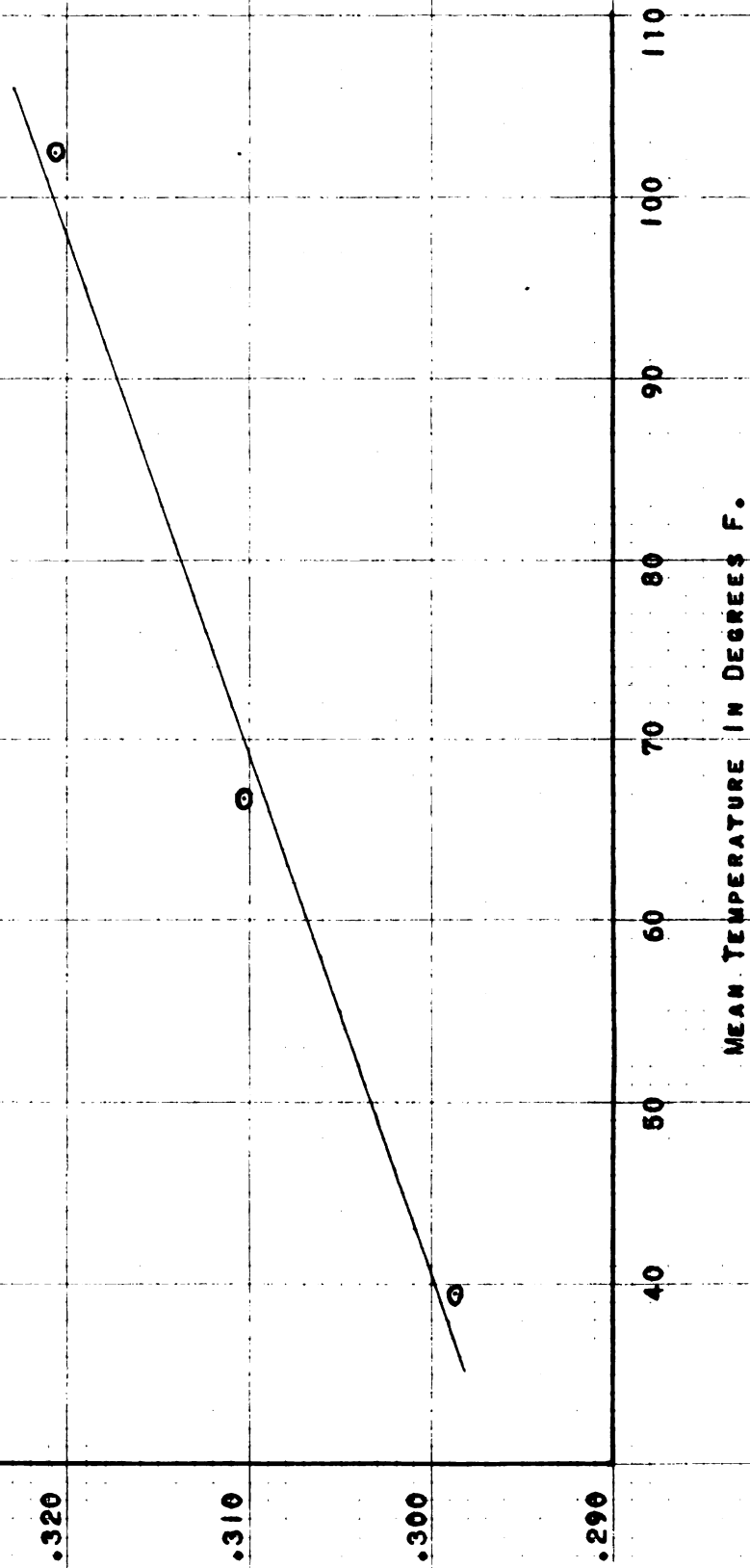
Thickness of Test Samples = 1 inch.

$$\text{Thermal Conductivity} = K = \frac{Q \cdot L}{A (T_1 - T_2)r}$$

$$K = \frac{12.2212 (1)}{.889 (42.86) (1)} = .320781$$

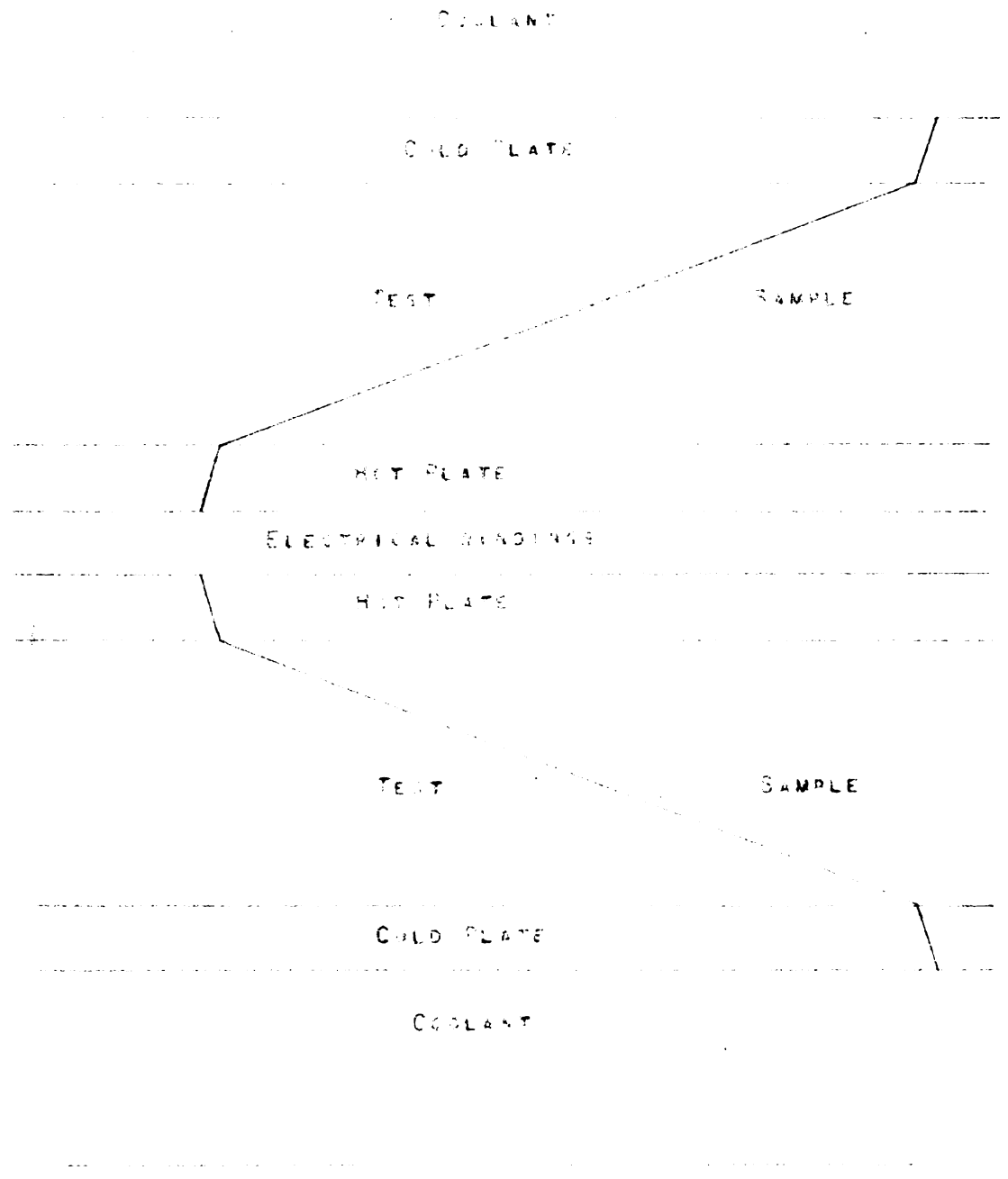
THERMAL CONDUCTIVITY IN (B.T.U. IN.)
(SQ. FT. DEG. F. HR.)

THERMAL CONDUCTIVITY VS. MEAN TEMPERATURE
FOR TEST CORKBOARD



TEMPERATURE
SCALE
DEGREES F.

125 —
120 —
115 —
110 —
105 —
100 —
95 —
90 —
85 —
80 —
75 —



TEMPERATURE PROFILE THROUGH ENLARGED CROSS SECTION OF GUARDED HOT PLATE

BIBLIOGRAPHY & REFERENCES

- American Institute of Physics, Temperature, Its Measurement and Control in Science and Industry, Reinhold Publishing Corp., 1941, p 201.
- American Society of Heating and Ventilating Engineers, Guide, 1948, p 97.
- Brown and Marco, Introduction to Heat Transfer, Chapter 2, McGraw Hill.
- Forbes, Principal, Transactions of The Royal Society of Edinburg, 1861-1862.
- Lander, Robert M., Factors Affecting Thermal Conductivity, University of Minnesota Technical Paper No. 49, 1944.
- Maxwell, J. Clerk, Theory of Heat, Longmans, Green & Co., 1888, p 268.
- Poynting, J. H., and Thomson, J. J., Heat - A Textbook of Physics, Charles Griffin & Co., 1904, p 102.
- Preston, Thomas, Theory of Heat, MacMillan & Co., 1894, p 527.
- Rowley, R. B., and Algren, A. B., Heat Transmission Through Building Materials, University of Minnesota Bulletin No. 8, 1932.
- Rowley, R. B., Jordan, R. C., and Lander, R. M., Low Temperature Thermal Conductivity Studies, University of Minnesota Technical Paper No. 59, 1947.
- Saha, M. N. and Srivastava, B. N., A Textbook of Heat, Indian Press Ltd., 1931, p 316.
- Thompson, Benjamin (Count Rumford), The Works of Rumford, American Academy of Arts & Sciences, Vol. II, p 144.
- Tyndall, John, Heat As a Mode of Motion, D. Appleton & Co., 1890, pp 119-245.

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