THERMAL CONDUCTIVITY

BY

W. E. BAUER

ARMOUR INSTITUTE OF TECHNOLOGY

1917

Thermal Conductivity

A THESIS

PRESENTED BY

W. Ernst Bauer, Jr.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 31, 1917

APPROVED:

Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

ACKNOWLEDGEMENT.

The author herewith expresses his indebtedness to Prof. James Clinton Peebles of the Mechanical Department, whose co-operation and indefatigable interest has made it possible to present this thesis.

INTRODUCTION.

The object of this thesis has been to design and construct an apparatus for measuring the thermal conductivity of various engineering materials,being a continuation of the work begun last year by Mr.Bradley Sayre Carr. Certain improvements and additions have been made in the apparatus as designed by Mr.Carr,which,it is hoped,will produce a more satisfactory instrument.

The fundamental principles underlying Mr.Carr's design seemed correct and therefore were adopted as a basis for the construction of this apparatus. The accuracy of the results obtained from any conductivity test,depends upon the maintenance of constant conditions and upon the accurate measurement of heat;and since this may be done by electrical means better than by any other,this method has been employed.

Criticism of Former Design.

Experience in the use of the apparatus designed by Bradley Sayre Carr developed the fact that the instrument was faulty, and subject to improvements in the following particulars:

1. In the construction of the main coil.
2. In the design and construction of the auxiliary coil.
3. In the limitation regarding the thickness of the test specimen.
4. In various other mechanical features.

First. In the design of the main heating coil.

The conductivity of a material tested in this apparatus, may be calculated by substituting the current supplied I, and the temperature difference t, in the equation.

$K = 22.25 \frac{I^2}{t}$ (See Carr's thesis pp 49-50)

In calculating the constant 22.25, the resistance of the heating coil, which was made of "Nichrome," was taken as o.192 ohms per foot. "Nichrome" has a temperature coefficient of 0.00024 per degree Fahr. (see Driver-Harris catalogue) which means that as the temperature increases its resistance also increases. Thus the constant 22.25 is really not a constant at all, but a variable, the value of which is affected by the temperature of the heater. When accuracy is required, the resistance of the coil under test condition must be determined and a new constant calculated. This involves time and labor, and is a serious hindrance to efficient work with the instrument.

Second. In the design of the auxiliary coil.

The auxiliary coil in this apparatus consists of three turns of #26,B.&.S.gauge, advance wire,wound in a grooves cut in the edges of the copper plates. Inasmuch as the copper-plates in themselves are but 1/8" wide. These narrow grooves made it necessary to use a small diameter wire,and also made it exceedingly difficult to insulate the coil from the copper plates.
At first,asbestos insulation was used. This was found to be unsatisfactory. Then silk insulation was used which also proved to be unsatisfactory. Thus this groove does not provide for a sufficiently large sized wire and for its proper insulation.

Third. In the limitation regarding the thickness of the test specimen.

The method of holding the three plates

together made it necessary to mount each plate in a wooden frame. The design of the various plates determines the width of such frames. The frames around the cold plates must be at least 1 1/8"thick, and the frame around the hot plate at least 1 1/16". The thickness of the hot plate,and that of the cold plates,which come into contact with the test specimen, are 11/16" and 5/8" respectively. If the frames are brought in contact with each other,a space of 7/8"remains between the test portions of the plates, and therefore specimens of less than 7/16" thickness cannot be tested in this apparatus.

Fourth. In various other mechanical features. The one mechanical features which has caused more trouble and more

loss of time than any other, was the use of four copper clips to hold the hot plate together. These made it necessary to trim the corners of each specimen, so that it would clear the clips.

The method of holding the three plates together proved very unsatisfactory. After a year's use, the frames have been pulled out of shape by the spacer rods.

Another bad feature of this apparatus is that it practically requires two men to set it up. The weight and the lack of compactness make it very hard to handle the instrument.

The wiring in this apparatus is very complicated. All the leads from the heating coils and thermo-couples are brought out and connected to binding posts on the frame of the plate. These binding posts are connected by loose wires either

to a switching device,entirely separate from the apparatus,or each other. It must also be noticed that for certain circuits a certain kind of wire must be used. Thus,for every test,the entire circuit must be traced out,requiring a great deal of patience and time. Since these wires are all exposed,any little jar may disconnect them,and if this is not immediately attended to,the whole test may be spoiled.

Design of Apparatus.

The design of this apparatus is based upon the fact that,if the temperature diference existing between two opposite faces of a rectangular parallelepiped is known,and the amount of heat flowing through it,its thermal conductivety may be determined.

The materisl is placed between,and actually brought in contact with,two surfaces of the apparatus. One sufface is at a higher temperature than the other; the

higher temperature than the other; the former is part of the "Hot-plate,"and the latter is part of the "Cold-plate."

The temperature difference between these two plates,is measured by the deflection of a milli-volt meter. This deflection is caused by the e.m.f. of the copper constanton thermo-couple placed in the hot plate and the cold plate,respectively. The e.m.f.thermo-couple is a function of the temperature difference existing between the two junctions,and hence the e.m.f. produced is a measure of the temperature difference between the two plates.

The amount of heat passing through the material is calculated from the electrical energy supplied to the hot plate,and since all the losses are accounted for,this energy must pass through the material into the cold plate where it is absorbed by the circulating water.

This apparatus is divided into:

a) a hot plate,

b)two cold plates,

c)a base

d)electrical circuits,switching devices,etc.

Description of the hot plate.

The hot plate consists of a mam heater and an auxiliary heater. The mam heater is made by winding #32,B.&.S. gauge,$\frac{1}{4}$"wide, Advance ribbon around a slate core 11"square and $\frac{1}{2}$"thick so that the turns are equally spaced about 5/16"from each other. Around the edges of the slate core are wound three turns of #30 B. &.S. gauge $\frac{1}{4}$"wide,"Nichrome" ribbon,insulated from each other by mica board. On either side of this slate core, a copper plate,insulated from the heating coils by mica board,is placed,and rigidly

held in position by flat headed brass screws,which are fastened to narrow strips of bronze 0.57 inches wide and 3/8inch thick running along the edges of the slate core.

To account for the heat lost through the edges of the hot plate,each copper cover plateis divided so as to confine the test area to an inner portion 6 inches square, and an outer guard ring. A 1/8" air space left between the two parts,the latter being joined at the four courners by thermal-couples of "Advance"wire. By observing the deflection a galvanometer,connected in series with the two portions of the hot plate ,the temperature difference may be determined. If there is no deflection, both portions are at the same temperature. Any temperature difference caused by the lateral escape of heat may be compensated for by the auxiliary coil. By maintaining the test square area and that of the guard ring at the same temperature,a sufficiently

large area of the test specimen is heated to uniform temperature.

The difficulty in the design of the main heating coil,as previously described, is overcome by the use of "Advance"ribbon, which has no temperature coefficient,in place of "Nichrome".

Instead of winding the auxiliary heater in a narrow slot cut in the edges of the copper plates,and using a small diameter wire,this coil was wound around the edges of the slate core,so that it could be easily insulated,and a much larger cross-section of material could be used.

The other objection regarding the four clips holding the hot plate together, was met by making the copper plates a little larger than the slate core,so that narrow strips of metal could be placed

along the edges of the slate core and between the copper plates to which they could be rigidly fastened.

For the various dimensions and details of the hot plate,refer to drawing number 2 in the back cover pocket of this book.

Description of Cold Plates.

On each side of the hot-plate,a cold plate is placed,so that two speci- men of the same material may be tested at once. These plates are similar in a all respects,except that one is the right- hand and the other the left-hand plate. They consist of copper plates 12"square and 1/8"thick,securely fastened by flat headed brass screws to aluminum castings, as shown in drawing #1. Through these slates cold tap water is circulated, flowing ing in at the bottom and out at the top.

These plates were so designed that, their entire cooling surface may be brought into contact with the heating surface of the hot plate. This was accomplished by changing the position of the manifolds on the extreme upper and lower ends they were placed on the back about $\frac{3}{4}$" from the upper and lower ends,-thus meeting the objection in regard to thelimitation of the thickness of the test specimen.

Description of the Base.

The base merely consists of a slate plate,mounted on a wooden frame, with the special switching device and terminals permanently attached to it, as shown in drawing number3.

The use of this base made it possible to conceil all the wiring except the leads to the cold plates.

Another decided advantage obtained by using a base is that it makes the whole apparatus self-contained and easily handled.

Description of Wiring.

A dragramatic outline of the wiring is given in blue-prints form,from which the various circuits may be traced. The electrical energy supplied to the main heating coil,is measured by an connected in series with the main heating coil ammeter. In order to measure the current passing through this coil,the switch of the auxiliary coil must be open because if both switches are closed,the ammeter records the current through the auxiliary coil,the switch of the main coil,must be open. The eternal resistance is regulated until the heat generated in the auxiliary coil gives the same temperature for the test square and the

guard ring areas of the copper cover plates of the hot plate.

Number 1,2,3,and 4 on the wiring diagram are "Advance"wires soldered to the center of the respective plates as shown. Number 5,6,7,8,9,and 10 are copper wire soldered to the various plates as indicated.

With the special switching device, all the wireing is concealed and permanently connected. By turning the nob of this device,the various circuits may be connected to the galvanometer.

Circuit 9-5 runs from the center of the hot plate to the center of the left-hand cold plate.

Circuit 10-8 runs from the center of the hot plate to the center of the right-hand cold plate.

Circuit 9-6 is between the guard ring and square test area of the left-

hand cover plate of the hot plate.

Circuit 10-7 is between the guard ring and the square test area of the right-hand cover plate of the hot plate.

All the electrical circuits are exactly similar to those in the other apparatus for the same general principles have been followed.

Assembly of Apparatus.

Drawing #4 is an isometric view of the assembled apparatus. The two cold plates are held in position by four adjustable screw-clamps,one in each corner. This method avoids the use of the four spacer rods,together with the various wooden frames.

The test samples are inserted between the hot and cold plate. A uniform pressure on the sample,and perfect aligment may be easily obtained by the proper manipulation

of the screw-clamps.

The cooling water used is lead by suitable piping from the city main. The piping is so arranged that the flow of water through the cold plates can be separately regulated; and by means of a master control valve, the entire supply may be adjusted. The supply pipe is connected to the inlet nipples of the cold plates by rubber tubing. The same arrangement is used to discharge the water to waste.

Calibration of Apparatus.

The calibration of this instrument is very important, for upon it the accuracy of the results depend. A test thermal-couple was made of approximately the same length of wires as in the apparatus, and connected to a galvanometer. The cold junction placed in a beaker containing

ice and water, while the hot junction was placed successively in boiling benzole, water and toluol, and the galvanometer deflections in each case. The cold junctions was nest taken from the cold bath and allowed to come up to room temperature. The hot junction, however, was again successively placed in the various liquids and readings taken as before. The cold junction was now immersed in the boiling benzole and the hot junction was placed successively in boiling toluol and boiling water. Finally the cold junction was placed in boiling water, while the hot junction was in boiling toluol.

The temperature of the junctions were measured by thermometers, the bulbs of which were securely fastened to the junctions of the thermo-couple. A reading of the galvanometer was taken for each one of these combinations. These results were plotted on cross section paper,

the deflection of the galvanometer being used as abscissae and the corresponding temperature as ordinance.

This method of calibration was employed because the temperature of these various substances could easily be maintained constant, insuring accurate results.

To ascertain whether this curve is a calibration of the thermo-couple in the instrument, the cold plates were alternately immersed in a bath of water and melting ice. The hot bath was allowed to stand long enough in the room, so these thermal couples were connected to the galvanometer and the deflection recorded.

Another set of observation were made similar to the preceding ones, except that tap water was used for the cold bath.

Both these points fell on the original curve, which justifies the use of this curve as a calibration of the thermal couples in the instrument.

The data as observed is recorded on the following page.

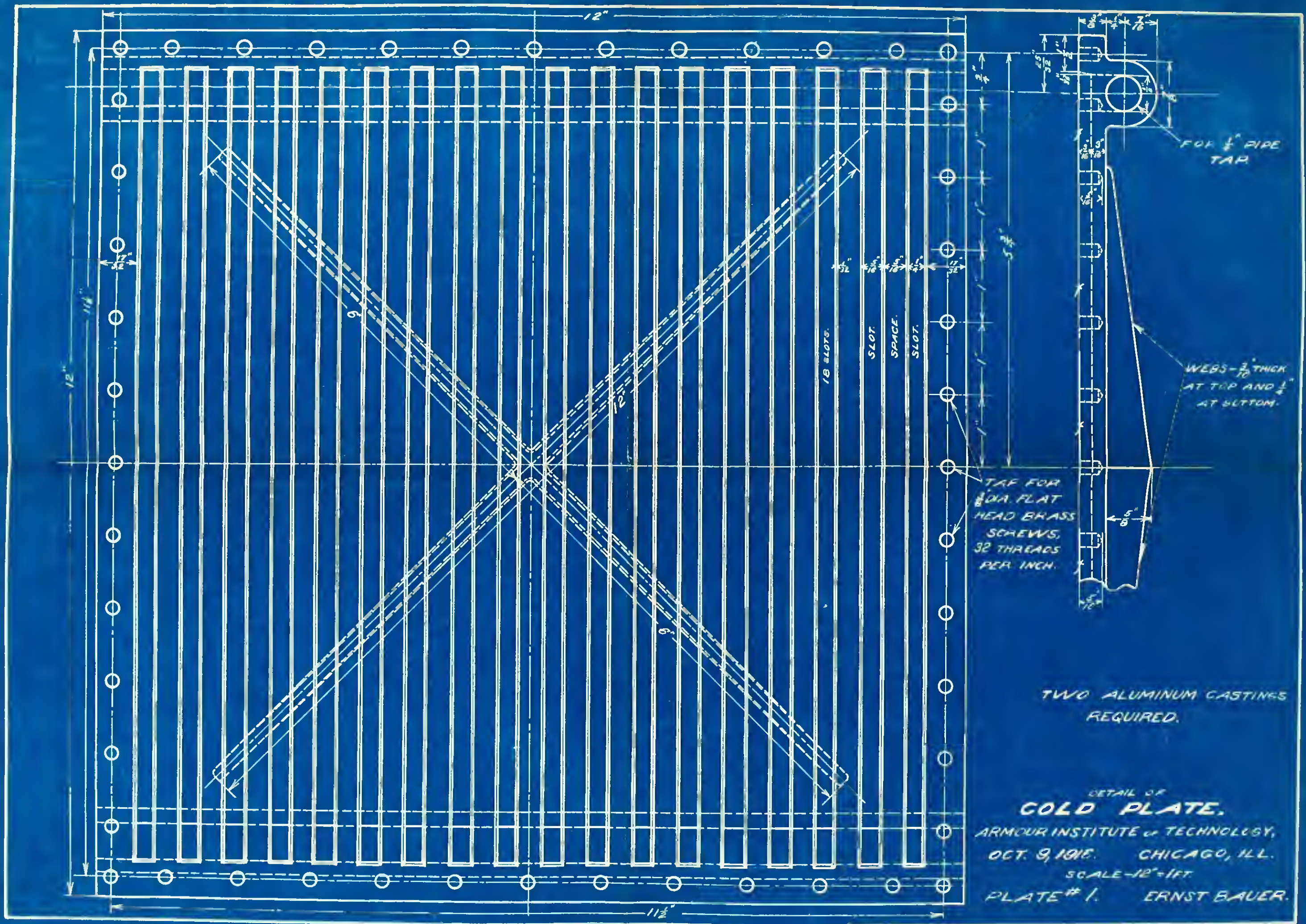
Cold junction Thermometer B.S.#4585

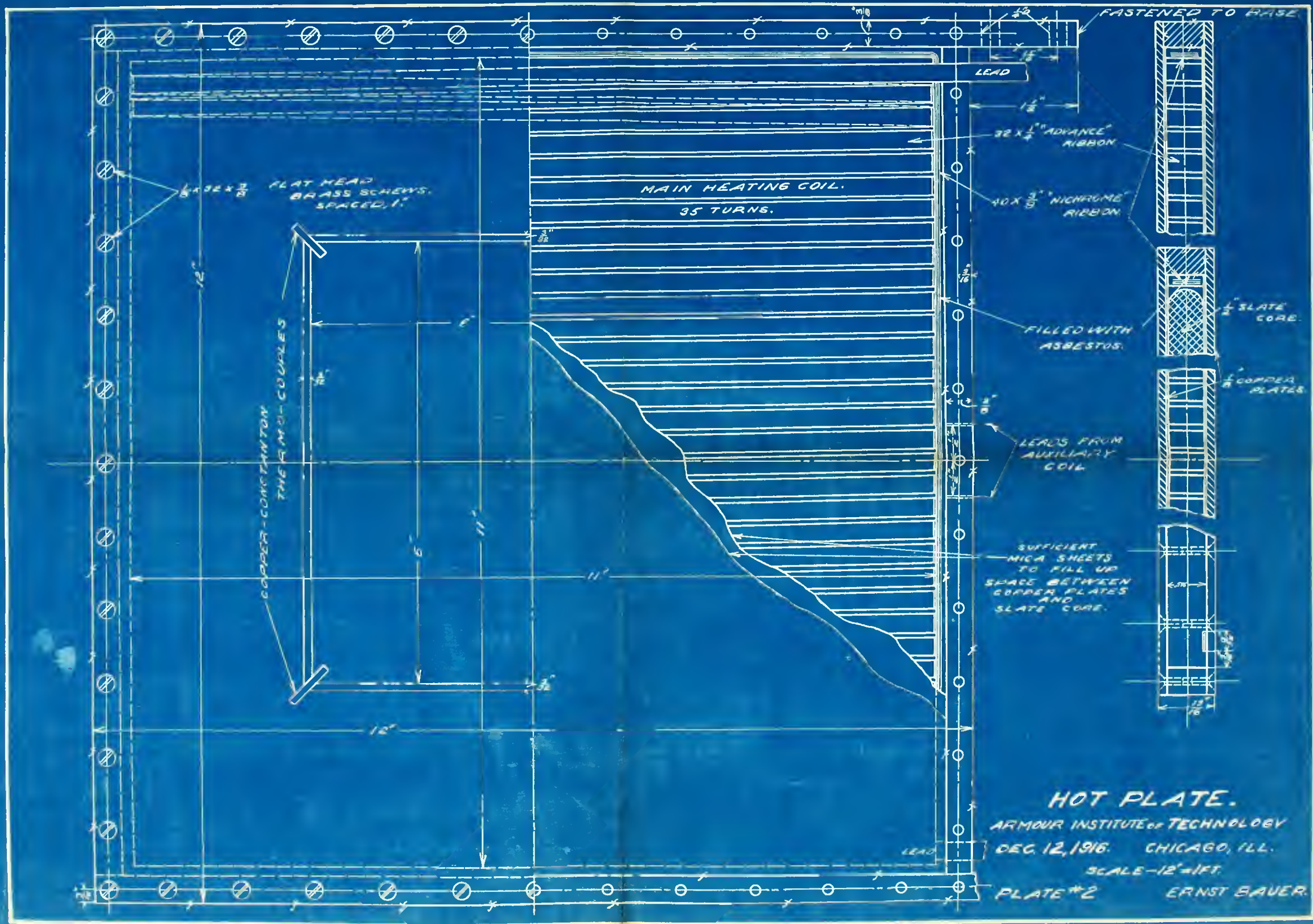
Hot " " "Tykos" #24231

Room temperature " B.S.#1962

Temperature of Cold End.	Temperature of Hot junction.	Temperature Difference.	Galvanometer Diflection.
32.0	175.5	143.5	259.0
32.0	211.5	179.5	315.0
174.5	242	67.5	131.0
174.0	211.5	37.5	70.0
210.5	243.0	32.5	64.0
82.0	250.0	168.0	305.0
80.0	212.0	132.0	232.0
80.0	175.5	95.0	166.0

Temperature of Cold Plate.	Temperature of Hot Plate.	Temperature Difference	Galvanpmeter Deflection.
L.H. 32	71.0	39.0	65.5
R.H. 32	71.5	39.5	66.0
L.H. 32	70.8	36.8	64.5
R.H. 32	69.5	37.5	62.8
L.H. 53.5	64.2	10.7	17.5
R.H. 52	64	12.0	19.5


12"
11½"
12"
9"
12"
9"
18 SLOTS.
SLOT.
SPACE.
SLOT.
FOR ⅛" PIPE TAP
WEBS – 3/16" THICK AT TOP AND ¼" AT BOTTOM.
TAP FOR ⅛" DIA. FLAT HEAD BRASS SCREWS, 32 THREADS PER INCH.
TWO ALUMINUM CASTINGS REQUIRED.
DETAIL OF
COLD PLATE.
ARMOUR INSTITUTE OF TECHNOLOGY,
OCT. 9, 1915. CHICAGO, ILL.
SCALE – 12" = 1 FT.
PLATE # 1. ERNST BAUER.



HOT PLATE.

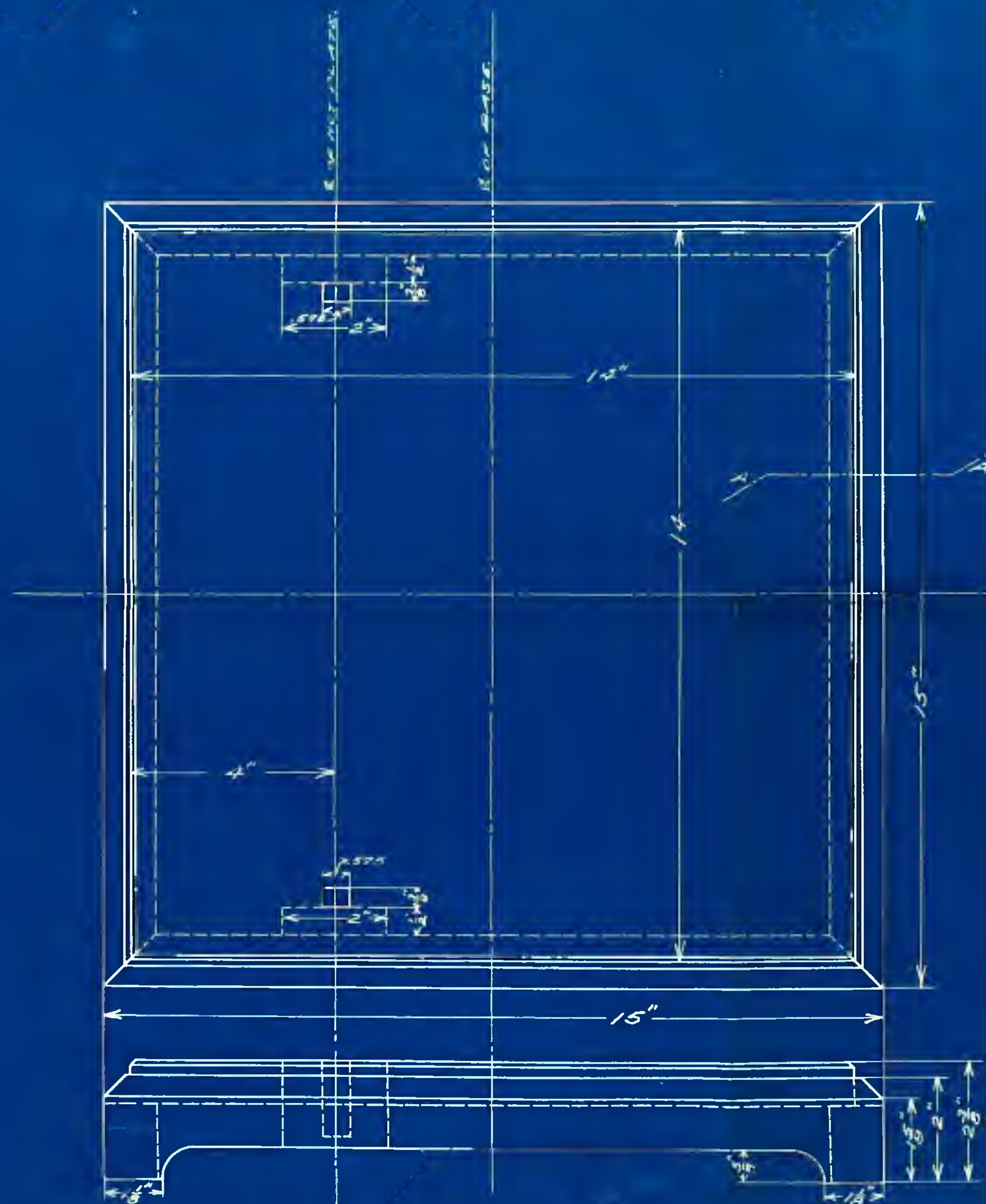
ARMOUR INSTITUTE OF TECHNOLOGY

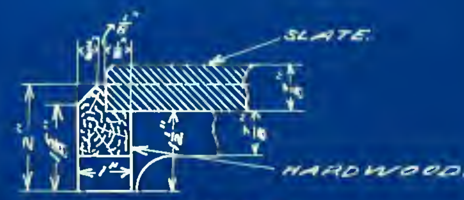
DEC. 12, 1916. CHICAGO, ILL.

SCALE—12"=1FT.

PLATE #2

ERNST BAUER.





SECTION THRU. A.A.

BASE.

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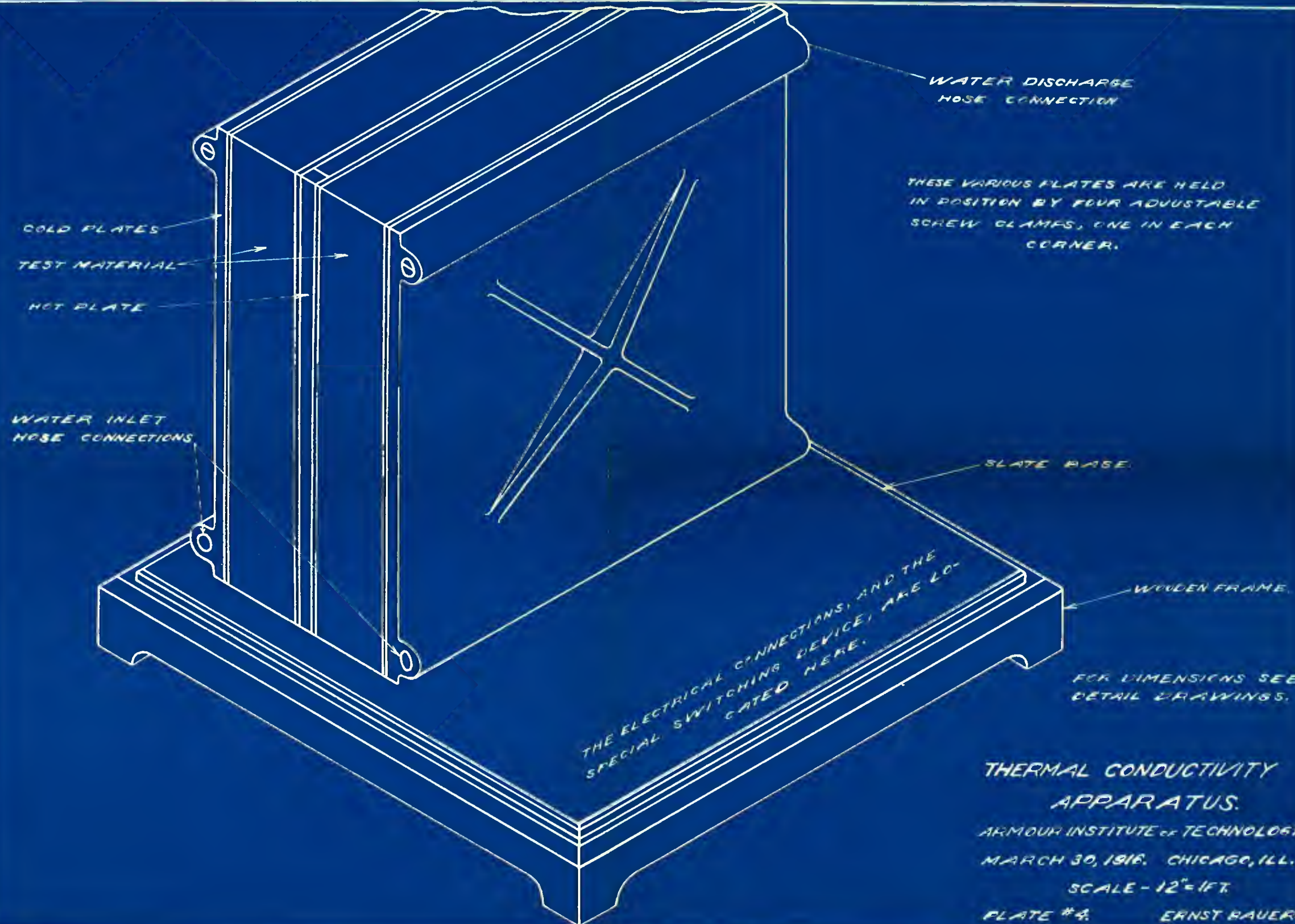
FEB. 26, 1917. CHICAGO, ILL.

SCALE — 6" = 1 FT.

PLATE #3. ERNST BAUER.



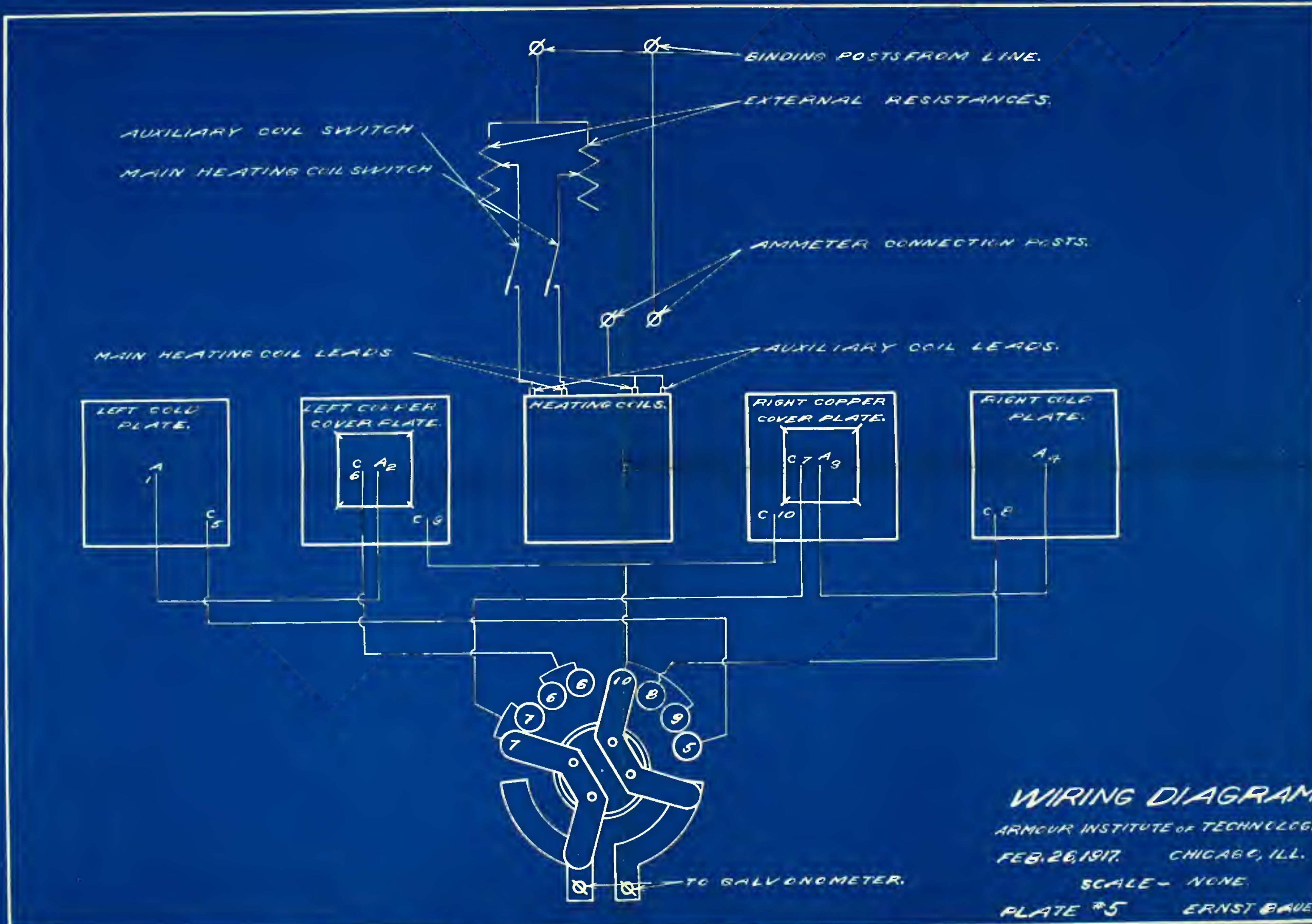
THERMAL CONDUCTIVITY
APPARATUS.

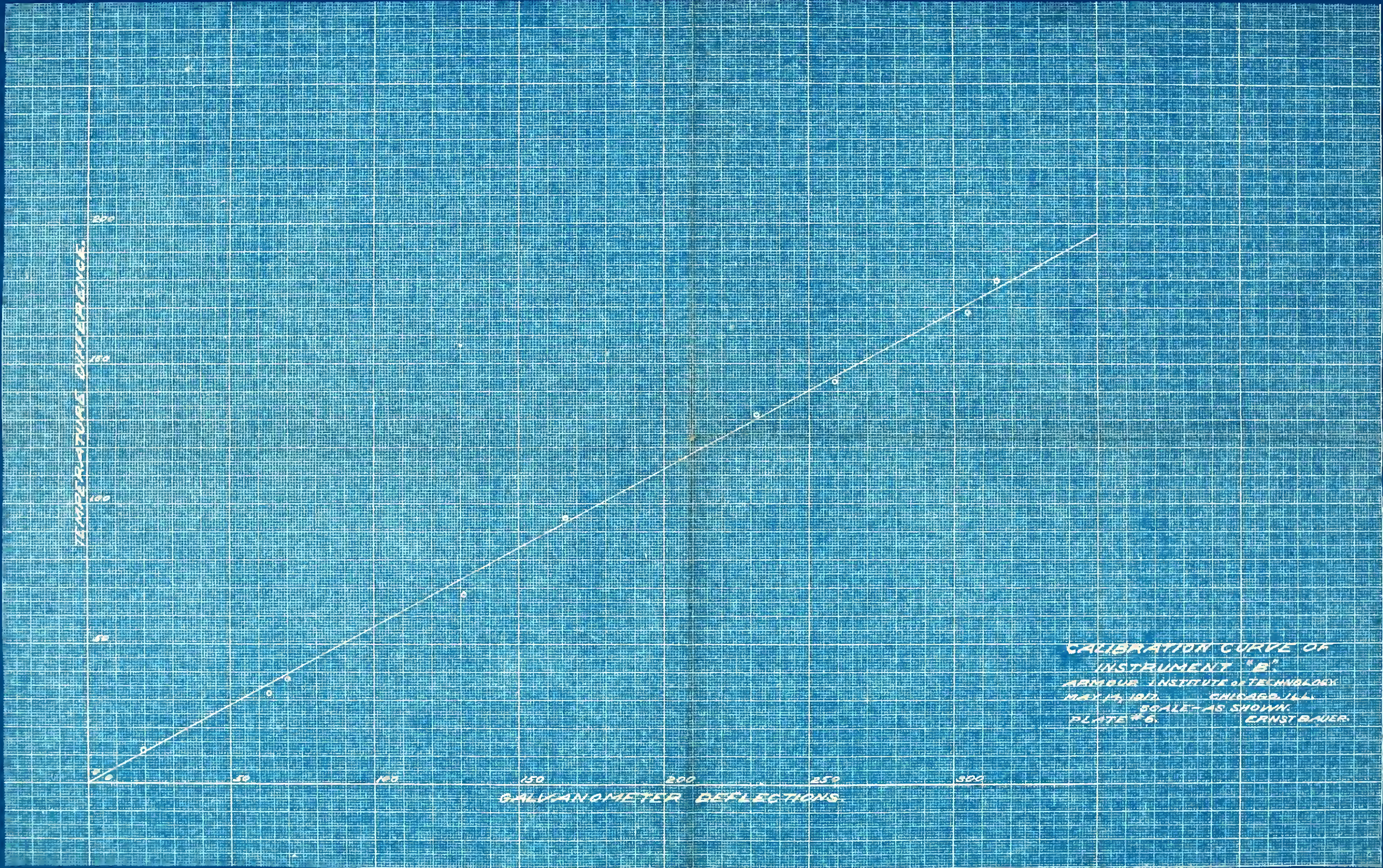
ARMOUR INSTITUTE OF TECHNOLOGY.

MARCH 30, 1916. CHICAGO, ILL.

SCALE - 12" = 1 FT.

PLATE #4. ERNST BAUER.


BINDING POSTS FROM LINE.
EXTERNAL RESISTANCES.
AUXILIARY COIL SWITCH
MAIN HEATING COIL SWITCH
AMMETER CONNECTION POSTS.
MAIN HEATING COIL LEADS
AUXILIARY COIL LEADS.
LEFT COLD PLATE.
A 1
C 5
LEFT COPPER COVER PLATE.
C 6
A2
C 9
HEATING COILS.
RIGHT COPPER COVER PLATE.
C 7
A3
C 10
RIGHT COLD PLATE.
A4
C 8
6
6
7
7
10
8
9
5
TO GALVONOMETER.
WIRING DIAGRAM.
ARMOUR INSTITUTE of TECHNOLOGY,
FEB. 26, 1917.
CHICAGO, ILL.
SCALE - NONE.
PLATE #5
ERNST BAUER


TEMPERATURE DIFFERENCE.
200
150
100
50
50
100
150
200
250
300
GALVANOMETER DEFLECTIONS.
CALIBRATION CURVE OF
INSTRUMENT "B".
ARMOUR INSTITUTE OF TECHNOLOGY
MAY 14, 1917. CHICAGO, ILL.
SCALE—AS SHOWN.
PLATE #6. ERNST BAUER.