A PHYSICAL METALLURGY LABORATORY MANUAL

by

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METALLURGY

LABORATORY INSTRUCTIONS AND REPORTS

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SECTION I

METALLURGY LABORATORY INSTRUCTIONS

FOREWORD

With the rapidly increasing importance placed by industry upon the development, treatment, examination and testing of metals and their alloys, there follows increasing stress on sound fundamentals in metallurgical laboratory practice as employed by the student majoring in this field.

Following a study of the requirements which must usually be met by the graduate who intends to continue his work in metallurgy, a series of experiments has been carefully planned, performed, and thoroughly studied to determine their value to the student.

This work was done under the direction and direct supervision of Professor H. V. White, Head of the Department of Metallurgical Engineering of Virginia Polytechnic Institute, and with the facilities of the laboratory under his charge.

General instructions in the selected experiments and typical laboratory reports are contained in the pages which follow. Since a large part of the experimental work was done with laboratory equipment developed for these specific experiments, description of apparatus and certain explanations are included in Section II, Experiment Reports.

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THE LABORATORY INSTRUCTION MANUAL

It is the purpose of the instructions contained in the pages following:

1. To outline for the student a series of laboratory experiments illustrating the fundamental theories and facts pertaining to the various courses of study in Physical Metallurgy.

2. To give general and specific instructions in the performance of experiments, care and use of laboratory equipment, study of recorded information, and writing of reports.

An effort is made to guide the student in laboratory work rather than lay out for him "rule-of-thumb" methods of performing a "cut-and-dried" set of standard experiments. It is recognized that, for instructions to be of value, care must be exercised not to destroy initiative or relieve the student of the task of finding and using recorded information. With this in mind, certain highly important data, facts, and features are either omitted or only referred to without elaboration.

The experiments outlined here may be altered or replaced entirely by other experiments with equal or even better results. However, this possibility is limited by the following necessary considerations:

EXPERIMENT NO. 1

THE COOLING CHARACTERISTICS OF A PURE METAL

OBJECT: To plot from experimental data, the cooling curve for pure tin through the liquid solid transformation point, and to study the characteristics of cooling.

APPARATUS: Electric furnace

Ring stand

Ring and crucible holder

Pyrex crucible

400 C. thermometer

Bushing to center thermometer

Pyrex thermometer protecting tube

Stop watch

MATERIALS: 150 grams of pure tin

Wax cover

EXPLANATION OF SET UP: The apparatus was set up as shown in the diagram, page 2. The crucible holder which is of steel lined with asbestos, was supported by the ring stand, and could be raised to allow removal of the furnace.

The pyrex crucible was fitted with a bushing to center the thermometer. A clamp on the thermometer rested on the bushing and prevented the thermometer protecting tube from resting on the bottom of the crucible. The wax cover excluded the air from the molten specimen, thus preventing oxidation.

1. The time allotted to the student for a laboratory period.

2. The number of laboratory periods allotted to the course.

3. The number of students in the laboratory.

4. The cost and availability of materials consumed by the experiment.

5. Available equipment.

GENERAL PROCEDURE

Experiments are assigned by the instructor at the beginning of the laboratory period or, in some cases, far enough in advance of the period to allow the student time to study the instructions and necessary parallel work. Two students constitute a group, and work together, independent of other groups except where otherwise specified.

The student should bear in mind that the written instructions are expected to relieve the instructor of certain time-absorbing details and make him available for explanations, advice and suggestions. Therefore a thorough study of the laboratory procedure should be made before the instructor is called on for assistance.

LABORATORY REPORTS

In most cases, calculations should be made, data and results checked and, as far as possible, errors and troubles cleared up before the student leaves the laboratory. Full advantage should be taken of long waiting periods sometimes necessary between readings, adjustments and manipulations. The laboratory report should be prepared outside and submitted one week after the experiment is performed.

Experiment reports are not examined by mass production methods, therefore no fixed form of presentation is specified. Other than the necessary information for filing, they should contain:

Title, Object, Apparatus and materials used, Explanation of set-up, where necessary, Data and curves, if any, and Discussion or conclusions.

TABLE OF REFERENCES

References are given immediately following the title
of many of the experiments, and in some cases in the body
of the instructions. To save repetition of titles, etc.,
capital letters are used throughout to indicate these
references, and this table is a key to the various publi-
cations referred to.

When a reference is included in the body of a set of
instructions it will be designated - Ref. A, - followed
by the numbers of pages to be consulted.

Key Letter	Title, Author, Etc.
A	National Metals Handbook
B	Principles of Metallographic Laboratory Practice, by Kehl, 1939 - 1st edition.
C	Pyrometry, by Wood and Cork, 1927 - 1st edition.
D	Principles of Metallography, by Williams and Homerberg, 1939 - 4th edition.
E	Engineering Physical Metallurgy, by Heyer, 1939 - 1st edition.
F	Physical Metallurgy, by Woldman 1930 - 1st edition.
G	An Introduction to Physical Metallurgy, by Van Wert, 1936 - 1st edition.
H	Principles of Physical Metallurgy, New Second Edition - Gilbert E. Doan

GENERAL INSTRUCTIONS

There are certain routine methods, procedures and precautions that are common to several or all experiments. Instead of repeating them in the instructions for each experiment, they are listed and only referred to by number.

GENERAL INSTRUCTION NO. 1

Temperature Measurements through the Critical Points for Low Melting Point Pure Metals and Alloys

APPARATUS:

Bunsen burner, ring stand, ring and crucible holder, pyrex crucible, 400°C thermometer, pyrex thermometer protecting tube, thermometer bushing and clamp.

MATERIALS:

Metal specimen, furnished by the instructor or prepared under his direction. Wax cover.

SET UP:

The asbestos lined crucible holder, attached to the ring, is supported by the ring stand in position to be heated by the Bunsen burner in the standard manner.

PROCEDURE AND PRECAUTIONS:

The thermometer is placed in the protecting tube as soon as the specimen is heated to high enough temperature to melt the wax cover. The brass bushing is used to center the thermometer. The clamp is placed to hold the thermometer bulb near the center of the mass of molten metal.

After the temperature run is completed the thermometer should be removed before the wax cover freezes.

GENERAL INSTRUCTIONS NO. 2

Immersion Corrections for Thermometer Readings

Temperature readings taken from a thermometer should be corrected when necessary for partial immersion and constant error and corrected readings recorded on the report data sheet.

Temperature curves which are plotted to show shape only, may be plotted from uncorrected temperature readings. Corrections should be made, however, for all points of specific interest. Thermometer corrections are made for:

(1) Constant error, plus or minus.

(2) Correction for immersion,

$$T_c = (.0001D)T_r$$

Where T_c is the corrected temperature, T_r is the temperature as read.

D is the number of degrees of emergent mercury column in excess of the degrees which would be exposed if the thermometer were immersed according to specifications.

GENERAL INSTRUCTIONS NO. 3

The Preparation of Alloy Specimens

The preparation of alloys of two or more metals sometimes involves necessity for precautions, not easily found in published data. Failure to produce the desired specimen may be due to

(1) Melting the metals in the wrong order.

(2) Lack of proper control of temperature, resulting in rapid oxidation.

(3) Improper fluxing.

(4) Bad technique in pouring.

The student should calculate the weights for the percentages specified for the alloy, weigh out the proper amounts of each metal and set up the apparatus for melting and pouring the specimen. He should then call on the instructor for specific instruction in melting, mixing, fluxing, and pouring. In some cases, where a very small percentage of a metal is required, it is necessary, for accurate results, to make up a "Master Alloy" in quantity enough to prepare all of the specimens. A "Master Alloy" is one considerably richer than desired, from which the alloys are prepared by dilution.

The correct quantity of this alloy is weighed out to give the proper composition for the desired specimen.

GENERAL INSTRUCTION NO. 4

Cutting and Surfacing Specimens Preparatory to Polishing

To get a true picture of the internal structure of
a metal it is often necessary to cut the specimen through
the center and examine the inside surface under the micro-
scope.

If the specimen has been previously heat treated in
such a way that further heat applied will alter the structure
desired, great care is exercised to avoid heating during
cutting and grinding. These operations are carried out at
slow speed and with wheels well flooded with water.

Soft metals applied to grinding wheels and abrasive
discs clog the pores between grains, rendering them in-
effective. For this reason, the hack saw and file are
always used on this type of metal.

REFERENCES

B, Page, 3.

GENERAL INSTRUCTIONS NO. 5

The Brown Potentiometer Pyrometer

FOREWORD:

The Brown Potentiometer is used for accurately measuring temperatures in several of the experiments regularly assigned in the laboratory. Intelligent use of any instrument demands a knowledge of the basic principles upon which the instrument is designed. If the student is unable to reproduce and explain, from memory, the electrical circuit upon which the potentiometer is based, he lacks the fundamentals essential to procedure in pyrometrics. He should therefore review his study in potentiometer circuits and consult one or more of the reference texts in the Metallurgy Library.

The following directions assume the necessary basic knowledge.

REFERENCES:

C, Pg. 66-78

DIRECTIONS:

Mechanical Balance - Before using the potentiometer it is advisable to check the galvanometer for mechanical zero; that is, to see that the galvanometer pointer rests on zero when no current is flowing through it. To accomplish this, the "Bal-Zero" knob is turned to zero. If the

pointer shows deflection from zero, adjustment is made

through the screw head exposed just above the galvanometer

scale.

The instrument seldom requires this adjustment, the

necessity for which is due only to rough handling or acci-

dental heavy shock. If the student has any doubt as to

the necessity for this or any other adjustment, or of his

ability to make the adjustment correctly, he should consult

one of the instructors.

Current Standardization - The current which is to "Buck"

the current from the thermocouples is supplied by a dry cell

within the instrument. This standardization should be

checked before each experiment and when the instrument is

in use for several hours it should be checked not less

frequently than at the end of each hour or service. To

check, the "Bal-Zero" knob is turned to "Bal" position, and

the thermocouple switch to "On" (either low or high range).

If unbalance, indicated by deflection of the galvanometer

from zero, is observed, adjustment is made by turning the

"Rheostat" knob, (clockwise, if the deflection is to the

left, and counterclockwise, if to the right). The "Bal-

Zero" knob is held at "Bal" position until the thermocouple

switch is turned to "Off".

Measuring Temperatures - The instrument is provided

with two scales, low range, from zero to 1000°F, and high

range, from 1000°F to 2000°F. The thermocouple switch is used for selecting the scale necessary for the temperature to be measured.

To make a measurement, the scale is set at a reading estimated to be that of the temperature to be measured, and the thermocouple switch thrown to the proper scale. The reading is then adjusted by turning the main knob until the galvanometer pointer shows zero deflection. The instrument thus indicates the temperature of the hot junction of the Chromel-Alumel couple to which it is connected.

GENERAL INSTRUCTION NO. 6

Electric Heat Treating Furnaces and Controls

REFERENCE:

C - Pg. 193-201.

A number of experiments regularly assigned in the laboratory require heat treating specifications which are not conveniently met by manual control of furnace temperature. For this reason the laboratory is equipped with the Hoskins Electric Muffle furnace and the Hevi Duty Electric multiple unit furnace with Leeds and Northrup Micromax control.

Both furnaces are resistance type, electric with manually adjusted rheostat for control of heating rate. The equipment is so wired that either furnace may be operated at 110 or 220 volts, with or without automatic control by the L & N. Micromax.

The Micromax is a potentiometer pyrometer built on the same principle as the Brown Pyrometer, (See General Instruction No. 5.) However the mechanical construction of the Micromax differs in that the voltage balance across the galvanometer is automatically, rather than manually, controlled. Also, the instrument is designed to hold the furnace at any desired temperature. The knob on the front of the instrument may be turned, moving the lower pointer along the scale to the maximum temperature

desired. When the furnace reaches this temperature a relay switch is automatically actuated, operating the power switch on the furnace, thus holding the temperature within a few degrees of the setting.

Before using this equipment the student should not only review his study of potentiometer circuits, as in the case with the Brown potentiometer pyrometer, but familiarize himself with the switchboard and wiring between the furnace and pyrometer.

Since this apparatus is used for a number of experiments, it is well to have some idea of what to expect as to heating and cooling rates under different voltage and resistance settings. For this reason the student should keep a record in his notes, of voltage applied and approximate rheostat settings, with corresponding heating rates for each run made. These data are found to be helpful in estimating proper settings for subsequent heat treating experiments.

GENERAL INSTRUCTIONS NO. 7

Instructions for Using

the Standard Brinell Hardness Machine

REFERENCES:

A. see index.

B. pages 133 - 140.

A. S. T. M. Standards, latest edition.

These are special instructions applying to the machine
in the laboratory and are not intended as complete working
instructions. The student must consult the references for
the theory of the test and methods for making the test.

Note carefully - A Brinnell test on brittle materials
is dangerous and may result in serious physical harm to
the operator and observers.

A brittle material may not stand the heavy loan con-
centrated on a small area as required in making the test.
If the material is too brittle sudden rupture will take
place with mild explosive violence, throwing small frag-
ments of the test specimen. As the specimen is little
below eye-level there is considerable danger that the
fragments may strike someone in the face.

If there is any doubt about the ability of the specimen
to take the test without breaking, a shield should be

placed around the specimen. The shield should be put in place before the load is applied and kept in place until the load is removed.

ORDER OF STEPS PERFORMED IN MAKING TEST.

1 - The hand wheel on the base of the machine is checked to see that it is turned counterclockwise as far as it will go.

2 - The properly prepared specimen is placed on the anvil of the machine and raised until in solid contact with the ball.

3 - The handwheel is turned clockwise until the dial on the machine indicates the desired load. If any doubt exists, the shield is put in place before the hand-wheel is turned.

4 - The dial is held at the desired load for the proper period of time.

5 - The handwheel is turned counterclockwise as far as it will go, the anvil lowered, and the specimen removed.

6 - The impression is measured with the special microscope and the hardness number either calculated or, if the student is thoroughly familiar with this calculation, recorded from the table of Brinell Hardness Numbers. This table may be found in any handbook, and there is a copy of it

The reading obtained is correct for the load in question and is to be used when making tests.

INSTRUCTIONS FOR USING DEAD WEIGHT BRINELL MACHINES

Under certain conditions the standard Brinell machine cannot be used for hardness determinations. For these cases two small dead weight machines are provided. One of these machines has a weight of 45 Kg; the other 120 Kg. A series of balls of different diameters is provided for each machine.

The student should consult the references for details of load and ball diameter to be used for these special Brinell tests. The latest edition of the Standards of the American Society for Testing Materials gives the details.

To use these machines the properly prepared specimen is placed on the anvil and elevated by means of the small hydraulic jack until the specimen comes in contact with the ball. One full stroke of the pump, made very slowly, will now elevate the weights from their rest and apply the full dead load on the ball resting on the specimen.

After holding for the proper time the specimen is removed, the impression measured, and the number calculated. The table of Brinell Hardness Numbers cannot be used directly because it applies only to standard tests; that is, to either 500 or 3000 Kg loads on a 10 mm. ball.

GENERAL INSTRUCTION NO. 8

Standard Laboratory Equipment and Procedure

No instruction is here given in certain laboratory
technic which has to some extent been standardized. To
aid the student in finding information on such procedure
and equipment, the following references are given:

SAMPLING:

 B, pages 2 and 3.

MOUNTING:

 B, pages 17-21.

 D, page 260.

POLISHING:

 B, pages 7 and 8.

 D, pages 260-269.

ETCHING:

 B, pages 23-29, 104-108. Appendix, pages 291-312.

 D, pages 311-317.

 F, pages 239-238.

MICROSCOPE AND PHOTOMICROGRAPHY:

 B, pages 42-101.

 D, pages 270-296.

 F, pages 3-13.

EXPERIMENT NO. 1

TITLE:

The Cooling Characteristics of a Pure Metal.

OBJECT:

To plot from experimental data the cooling curve for pure tin and study the characteristics of cooling.

REFERENCES:

D, pages 2-4

E, page 11

F, page 26

APPARATUS:

General Instruction No. 1, Stop watch.

MATERIALS:

150 grams of pure tin. (Specimen in crucible furnished by instructor.)

PROCEDURE:

Heat is applied by the burner and the thermometer placed according to instructions.

The burner is shut off when the thermometer shows a

temperature of about 70 °C above the melting point of tin.
When balance is indicated by no further rise in temperature, readings of time and temperature are recorded.
These readings are taken in 30 second intervals from beginning of cooling through a temperature of about 50 °C
below the melting point of pure tin. To prevent undercooling, the liquid should be stirred gently with the
thermometer between each reading.

CALCULATIONS:

General Instruction No. 2.

CURVES:

A curve is plotted between temperature, as ordinate,
and time, as abscissa, to show the characteristics of
cooling.

QUESTIONS:

(1) Why does the cooling curve above the freezing
point not follow a straight line?

(2) What takes place at the temperature indicated
by the first definite break in the curve?

(3) What does the end of the horizontal section of
the curve indicate?

(4) Why does continued loss of heat not lower the
temperature along this line?

EXPERIMENT NO. 2

TITLE:

The Equilibrium Diagram for a Binary Alloy.

OBJECT:

To plot, from experimental data, the equilibrium diagram for the Lead-Tin series and study the characteristics of cooling.

REFERENCES:

A, (see index).

D, pages 17-27.

F, pages 23-26.

APPARATUS:

General Instruction No. 1.

MATERIALS:

150 grams of each of the following specimens:

(1) 90.% Lead, 10.& Tin.

(2) 50.% Lead, 50.% Tin.

(3) 40.% Lead, 60.% Tin.

Each specimen in a pyrex crucible furnished by the instructor.

PROCEDURE:

By the procedure employed in Experiment No. 1, data is recorded and cooling curves plotted for each of the three specimens.

CALCULATIONS:

General Instructions No. 2.

CURVES:

A cooling curve is plotted for each of the three specimens and points on these curves listed in the data with corresponding points for other compositions furnished by the instructor and the Equilibrium Diagram for the lead-tin series plotted.

Tamman's eutectic-freezing-time curve is plotted on the same sheet with the same abscissa and, time of freezing of the eutectic, as ordinate. The intersection of the eutectic and the solid solution lines is indicated by the composition at which the eutectic freezing time becomes zero.

QUESTIONS:

(1) What does the first break in each of the cooling curves except those for pure metal and eutectic indicate?

(2) Why does the horizontal section of the cooling curves for 40.% Pb and 60.% Sn extend over a longer range of time than for any other composition?

(3) Why do the cooling curves for Lead-Tin alloys, richer in lead than 80.5%, and richer in tin than 97.4%, not show the horizontal line, or constant temperature range, found in the curves that fall between these compositions?

EXPERIMENT NO. 3

TITLE:

The Relation between the Physical Properties and the
Internal Structure of Alloys.

OBJECT:

To plot from experimental data the Composition-Hardness
curve for Zinc-Cadmium alloys and study the relation of
physical properties to internal structure.

REFERENCES:

D, pages 47-50.

A, (see index).

APPARATUS:

Electric furnace.

Clay crucible.

Cast iron specimen mold.

Tongs.

Welch triple beam balance.

Brinell hardness testing machine, microscope and chart.

MATERIALS:

Pure zinc and cadmium metal.

Amonium chloride, (Flux).

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PROCEDURE:

General Instruction No. 4.

Six specimens of Zinc-Cadmium alloy are made up and molded, compositions as follows:

Specimen No. 1, --- Pure zinc.

Specimen No. 2, --- 99.% Zn, 1.% Cd.

Specimen No. 3, --- 98.% Zn, 2.% Cd.

Specimen No. 4, --- 97.% Zn, 3.% Cd.

Specimen No. 5, --- 96.% Zn, 4.% Cd.

Specimen No. 6, --- 95.% Zn, 5.% Cd.

Each specimen is removed from the mold as soon as it is solid. After cooling to room temperature the composition is stamped on each casting and two Brinell impressions made in each at 500 Kg. load, with 10 cm. ball, held for 60 seconds. (General Instruction No. 6). Measurements of two approximately perpendicular diameters for each impression, are made with the Brinell microscope, the average of these taken and the corresponding hardness, taken from the Brinell chart, recorded.

CURVES:

A curve is plotted between composition, as abscissa, and Brinell hardness, as ordinate. On the same curve sheet, and with the same abscissa, that part of the equilibrium diagram which covers the same composition is plotted from data found in the A.S.M. Handbook, Reference, A.

QUESTIONS:

(1) Judging by the relation between the hardness curve and the zinc-rich section of the equilibrium diagram for zinc-cadmium alloys, what appears to be the factor limiting the increase in hardness effected by the addition of an alloying metal?

(2) In what way does the trend of the hardness curve indicate that the maximum hardness for a solid solution of Cd in Zn is higher than that for Zn in Cd?

(3) What would likely be the trend for the hardness curve for:

> (a) An alloy of two metals which form the eutectic, but are completely insoluble in each other in the solid state.
>
> (b) An alloy of two metals which show complete miscibility in the solid state.

(4) Answer similar questions concerning the effect of composition on electrical and thermal conductivity, and tensile strength.

EXPERIMENT NO. 4

TITLE:

The Microstructure of Eutectic Alloys.

OBJECT:

To study the microstructure of a series of binary alloys and learn to recognize the mechanical mixture known as eutectic.

REFERENCES:

A. (See index)

D. Chapter II

E. Chapter II

F. Pg. 48-52

APPARATUS:

Welch triple beam balance.

Clay crucible.

Electric or gas furnace.

Cast iron specimen mold.

Tongs.

Tools for cutting metals for specimens.

File.

Polishing wheel.

B. & L. Metallograph, or microscope.

MATERIALS:

Stock metals, furnished by instructor, polishing papers, polishing powder. Etching solution, see Reference, D, Appendix.

PROCEDURE:

Each student is assigned the preparation of a specimen of eutectic alloy, selected by the instructor possibly from the following list:

```
Silver - Copper----------------Specimen, 10 grams.
Bismuth - Cadmium--------------Specimen, 25 grams.
Bismuth - Tin------------------Specimen, 25 grams.
Cadmium - Lead-----------------Specimen, 25 grams.
Cadmium - Tin------------------Specimen, 25 grams.
Cadmium - Zinc-----------------Specimen, 25 grams.
Lead - Antimony----------------Specimen, 50 grams.
Lead - Tin---------------------Specimen, 50 grams.
Tin - Zinc---------------------Specimen, 25 grams.
Copper - Copper oxide----------Specimen, 50 grams.
Copper - Copper phosphide------Specimen, 50 grams.
```

The eutectic composition of the assigned specimen is determined from Reference A, (see index). The specimen is prepared according to General Instructions No. 4. After a study of Reference B, Chapter I through page 17, the specimen is polished and etched under the supervision of the instructor. Each student examines all of the

specimens prepared by the class and includes in his report

drawings which show similarity and essential differences

between various eutectic microstructures.

EXPERIMENT NO. 5

TITLE:

The Macrostructure and Microstructure of "Alpha" Brass.

OBJECT:

To determine the effect of various commercial

mechanical and thermal treatments on the internal structure

of Alpha brass, (70% Cu, 30% Zn). Study is made of the

brass:

(a) As cast.

(b) Cast and annealed.

(c) Cold worked.

(d) Cold worked and annealed.

The observed effects are general for all solid

solutions, and are very important in commercial handling

of many alloys.

REFERENCES:

A, See index.

B, Appendix, Table VI.

E, Pages 107-114.

D, Pages 108-113, Pg. 64, Fig. 59., Pg. 103, Fig. 81.

F, Pages 118-130.

APPARATUS:

     Triple beam balance.

     Cutting tools for metal bar.

     Gas furnace and crucible.

     Cast iron bar mold.

     Handling tools.

     Hammer and anvil.

     Electric heat treating furnace and controls.

     Hack saw, file, polishing plates, and polishing wheel.

     B & L metallograph or microscope.

MATERIALS:

     Stock shot copper, and stick zinc.

     Polishing papers and powder.

     Etching reagents.

PROCEDURE:

     The cast iron mold is measured. The correct weights of copper and zinc, necessary to fill the mold with the desired brass, are calculated. Allowance is made for estimated 5% oxidation of the zinc upon melting.

     The materials are cut and weighed out. Instruction No. 4 is followed for melting and casting the bar.

     Four pieces are cut from the bar and treated as specified in the table on the following page. Each piece is then polished, etched and examined under the microscope.

TREATMENT OF SPECIMENS

Cold Working: Upsetting with hammer or press for about

20% reduction in length.

Annealing: Heating to 750°F, holding for 20 minutes,

cooling in air. Fast cooling, as in

water, would not change the structure but

would cause internal stresses.

Specimen	Length	Treatment
(a)	3/8"	None (as cast).
(b)	3/4"	Annealed, sawed in half for examination of center.
(c)	1"	Cold worked and annealed. Sawed for examination in center.
(d)	1-1/4"	Cold worked, annealed and cold worked; sawed for examination of center.

The electric heat treating furnace with automatic control is used for annealing. The work should be arranged so that all specimens be placed in the furnace for annealing on the same heat run.

The general discussion in the laboratory report should point out and explain the differences noted among the four specimens. Appearance of each may be shown by a freehand sketch.

EXPERIMENT NO. 6

TITLE:

The effect of Cold Working of Metal.

OBJECT:

To determine the hardness effect due to the cold
working of alpha brass.

REFERENCES:

D, pages 53-73.

G, pages 205-211.

F, pages 118-130.

APPARATUS:

Hydraulic press or hammer and anvil.

Micrometer.

Hack saw and file.

Brinell hardness testing machine.

MATERIALS:

Bar of alpha brass as cast, 1/2" square, (Experiment
No. 5).

PROCEDURE:

Six one inch specimens of alpha brass are cut from

the half inch square cast bar, annealed and treated as follows:

Specimen No. 1, cut 1/2", left as cast.

Specimen No. 2, cut 1", cold worked 10%.

Specimen No. 3, cut 1", cold worked 20%.

Specimen No. 4, cut 1", cold worked 35%.

Specimen No. 5, cut 1", cold worked 50%.

Specimen No. 6, cut 1", cold worked 65%.

The specimens are filed flat and a Brinell hardness impression made in each end.

CURVES:

A curve is plotted between percent cold reduction, as abscissa, and Brinell hardness as ordinate.

The specimens are marked for identification and kept for use in Experiment No. 8.

EXPERIMENT NO. 7

TITLE:

The Effect of Annealing Temperature on Grain Size.

OBJECT:

To study the effect on the internal structure of alpha brass, due to annealing after cold work, and to determine the effect of the recrystalizing temperature on grain size.

REFERENCES:

D, pages 78-81.

F, pages 118-130.

APPARATUS:

Press or hammer and anvil.

Electric heat treating furnace and controls.

Hack saw and file.

Polishing and etching equipment.

Microscope.

MATERIALS:

Six one inch specimens of half inch square cast alpha brass.

Polishing and etching materials. D. Appendix, Pg. 323.

PROCEDURE:

The six specimens are cut from the brass bar and upset about 30%. All specimens are placed in the heat treating furnace and the controls set for a slow heating rate. One is removed and cooled in air as the furnace reaches each of the following temperatures: 650°F, 850°F, 1000°F, 1100°F, 1200°F, and 1300°F.

The specimens are marked for identification, cut, filed, polished, etched, and examined under the microscope.

The size of the grain in each specimen is noted and a discussion of effect of the annealing temperature included in the experiment report.

EXPERIMENT NO. 8

TITLE:

The Effect of Cold Work on Grain Size Following
Annealing.

OBJECT:

To study the internal structure of alpha brass after
cold working and annealing and to determine the effect of
the degree of cold work on the grain size.

REFERENCES:

D, pages 76 - 81.

F, " 118 - 130.

APPARATUS:

Electric heat treating furnace and controls.

Polishing equipment.

Microscope.

MATERIALS:

The six specimens tested in Experiment No. 6.

PROCEDURE:

The six specimens are annealed at 800°F for 20 minutes.
They are then cut, filed, polished, etched and examined
under the microscope. The size of the grain in each speci-
men is noted and a discussion of the effect of cold work
included in the experiment report.

EXPERIMENT NO. 9

TITLE:

The Heating and Cooling Characteristics of Carbon Steel Through the Gamma$\rightleftharpoons$Alpha Transformation Points.

OBJECT:

To plot the "Time-Temperature" curve for carbon steel, to determine the critical points, and to study the characteristics of heating and cooling through the Gamma$\rightleftharpoons$Alpha transformation.

REFERENCES:

A, See Index, (Critical points).

E, Pages 161-163.

APPARATUS:

Electric furnace, (Small vertical tube resistance).

Thermo-Electric pyrometer with chromel-alumel thermocouple and calibrated leads.

Manual control rheostat for furnace power line.

Stop watch.

MATERIALS:

Specimen of carbon steel drilled to receive thermocouple.

EXPERIMENT NO. 10

TITLE:

The Dilation Effect of Allotropic Changes in Steel.

OBJECT:

To study the volume effect of the allotropic changes
in steel, brought about by changes in temperature.

REFERENCES:

B, pages 282-288.

APPARATUS:

Electric vertical tube furnace.

Brown potentiometer pyrometer.

Thermocouple, (Cr.-Al.) and leads.

Fused silica tubes.

Dial indicator, (Ames).

MATERIALS:

Round bar "Armco Iron", Dia. 10 mm., length, 203 mm.,
or bar of steel of same dimensions.

NOTES ON APPARATUS:

The vertical tube furnace is constructed according to
U. S. Bureau of Standards specifications. Since the fused

silica tubes are very expensive and fragile, a minimum
of handling is necessary. Therefore the student is
assigned the complete apparatus, previously set up.

The Brown potentiometer is discussed under General
Instruction No. 5.

PROCEDURE:

The apparatus is accompanied by blue print showing
the construction of the furnace and location of the
specimen and indicator. A study is made of the set up
and check made to see that the thermocouple is placed
properly and connected to the pyrometer to read the
temperature of the specimen.

In order to facilitate calculations from recorded
data, the face of the dial indicator is turned so that
the pointer indicates a positive reading before heating
is begun.

The power is turned on the furnace and the tempera-
ture watched until about 1200°F is reached. Simultaneous
readings of temperature and elongation, as indicated by
the dial, are recorded. These readings are taken at 20°F
intervals until elongation begins to decelerate. From
this point readings are taken as rapidly as possible until
shrinkage is complete and normal expansion is resumed,
after which they are taken as in the first part of the run.

The power is shut off and, as the temperature falls,
readings are taken as before, the rapid readings being

taken during expansion at about constant temperature.

From the recorded data, a heating and cooling curve is plotted between elongation and temperature.

QUESTIONS:

What takes place within the metal, causing sudden contraction, on heating, and expansion, on cooling?

Calculate the theoretical change in volume and compare it with that found by experiment. Why does the actual change differ from the theoretical?

What is the critical point shown by the curves, and why do not the heating and cooling curves coincide?

EXPERIMENT NO. 11

TITLE:

The Malleableizing of White Cast Iron.

OBJECT:

To study the methods and effect of malleableizing white cast iron.

REFERENCES:

F, pg. 77.

G, pg. 149-151.

H, pg. 355-358.

APPARATUS:

Electric heat treating furnace and controls.

Standard Brinell machine with microscope and chart.

Abrasive disc cut off machine and bench grinder.

Polishing plate and disc polishing machine.

Metallographic microscope.

MATERIALS:

Twelve specimens of centrifugally cast high silicon white cast iron.

Abrasive polishing papers, grains, 2 through 3/0.

Titanium dioxide and water.

600 grain alundum powder

1½% Nital etching solution.

PROCEDURE:

The specimens are broken from a scrap of centrifugally cast white iron pipe. All except specimen No. 1 are placed in the furnace, the power turned on, and the control set for a maximum temperature of 1700°F.

A section of number 1 is cut, polished, etched and examined under the microscope. Findings are recorded.

Specimen No. 2 is removed from the furnace as soon as the set temperature is reached. The others, in order, are removed at intervals of one hour. Each specimen is tested for hardness (General Instruction No. 6) as it is removed from the furnace and cooled in air. As soon as it is found that hardness does not decrease by longer soaking at 1700°F. the furnace control is set to 1300°F.

One specimen is removed when the temperature reaches 1300°F. and the remaining, at one hour intervals, except the last, which is left to cool in the furnace.

All specimens are tested for hardness, and the following polished and examined under the microscope:

No. 1,

The first that shows no change in hardness at 1700°F.

That which is soaked one hour at 1300°F.

CURVES:

The Brinell hardness curve and the temperature curve

are plotted on the same sheet with time as abscissa.

QUESTIONS:

What is the factor limiting reduction in hardness at 1700°F.?

What takes place when the temperature is dropped to 1300 F., allowing further precipitation of carbon?

What advantage does this method have over that of carrying out the complete treatment at 1300°F.?

EXPERIMENT NO. 12

TITLE:

The Microstructure of the Unstable Equilibrium Phases of Hypereutectoid Carbon Steels.

OBJECT:

To study the microstructure of martensite, secondary troostite, secondary sorbite, and spheroidized cementite.

REFERENCES:

A, See index.

D, pages 154-157.

E, pages 202-218.

F, pages 86-89.

G, pages 176, 259-263.

H, pages 226-228.

APPARATUS:

Electric heat treating furnace with automatic control.

Abrasive disc cut off machine and bench grinder.

Surface polishing plate and disc polishing machine.

Metallographic microscope.

MATERIALS:

Specimen of 1.2% carbon steel, $\frac{1}{2}$" square X 6".

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Abrasive polishing papers, No. 1 through 3/0.

600 grain alundum powder.

1½% Nital etching solution.

10% salt quenching bath.

PROCEDURE:

A 6 inch specimen is cut from a ½ inch square stock bar of 1.2% carbon steel as rolled. This specimen is placed in the furnace and the temperature brought up to 1700°F., held for 15 minutes, and quenched in 10% brine solution. A sample specimen, No. 1, is cut, (See General Instruction No. 7.) from this bar, polished, etched, and examined under the microscope.

The remainder of the original bar is cut in three parts, specimens 2, 3, and 4. Each is marked by grinding notches in the end.

The furnace control is set to 300°F. When cooling has reached this point the three specimens are placed in the furnace.

Specimen No. 2 is soaked at this temperature for 30 minutes and cooled in air. The temperature is raised to 500°F. and No. 3 soaked for 30 minutes, and No. 4 for the same time at 650°F.

A sample is cut from each specimen, polished, etched and examined.

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The remainder of No. 4 is replaced in the furnace as
No. 5, held at 650°F for 4.5 hours and allowed to cool
in the furnace. This is also prepared and examined under
the microscope. Each of the five specimens is given the
file test for hardness.

A general discussion of the change in structure and
hardness of thus hardened and drawn carbon steel is in-
corporated in the laboratory report.

EXPERIMENT NO. 13

TITLE:

The Formation of Primary Troostite in Martensite.

OBJECT:

To study the unstable equilibrium phase, "primary troostite."

REFERENCES:

A, See index.

B, Page 177.

D, Page 144 and 150.

E, Page 214.

F, Pages 90-92.

G, Page 176.

APPARATUS:

Equipment used in Experiment No. 12.

Permanent magnet.

MATERIALS:

Sample of .85% carbon steel.

Materials used in Experiment No. 12.

PROCEDURE:

The sample of eutection carbon steel is placed in the

furnace and the temperature brought up to 1700°F and held for about 15 minutes. The specimen is then removed from the furnace and tested at short intervals with the horse-shoe magnet. When it shows first signs of magnetization it is quenched in 10% brine solution. A sample is cut from the specimen, polished and etched as explained in Experiment No. 12 and examined under the microscope.

QUESTIONS:

During what period of the above procedure is troostite formed?

Why is steel of eutectoid composition selected for the study of the formation of primary troostite?

What is the principal difference between "Primary" and "Temper" troostite?

EXPERIMENT NO. 14

TITLE:

The Microstructure of Pearlite and Primary Sorbite.

OBJECT:

To study the formation and fundamental differences between pearlite and primary sorbite.

REFERENCES:

A, see Index.

D, pages 130, 144, 154.

E, page 214.

F, page 90-91.

APPARATUS:

Equipment used in Experiment No. 12.

MATERIALS:

Polishing and etching materials used in Experiment No. 12.

Two samples of .50% carbon steel from bar stock as rolled.

PROCEDURE:

Both specimens of .50% carbon steel are placed in the

furnace, heated to 1700°F, and soaked at this temperature for about 15 minutes. Specimen No. 1 is removed and cooled in air and No. 2 cooled in the furnace. Both are cut, polished, etched and examined under the microscope.

QUESTIONS:

What is the difference in appearance of the dark areas noted in the two specimens? Why is this difference shown?

Calculate the theoretical percentage of light and dark areas and explain why specimen No. 2 more nearly approaches the theoretical than does No. 1.

EXPERIMENT NO. 15

TITLE:

The Widmanstatten Structure of Carbon Steel.

OBJECT:

To study the Widmanstatten lines formed in low carbon steel by air blast cooling from well above the critical temperature.

REFERENCES:

A, see Index.

E, page 406.

G, pages 141-147.

H, pages 170-187.

APPARATUS:

Equipment used in Experiment No. 12.

High pressure air jet.

MATERIALS:

Two specimens of .26% carbon steel cut from bar stock as rolled.

PROCEDURE:

The two specimens are heated together in the furnace

to 2000°F. and soaked for about 15 minutes at this tem-
perature. No. 1 is removed and cooled by air blast to
well below red heat. No. 2 is left to cool in the furnace.
A sample is cut from each specimen, polished, etched, and
examined under the microscope.

A discussion of the appearance of the Widmanstatten
structure and the theory which explains its formation is
included in the laboratory report.

QUESTIONS:

Explain the occurrence of the Widmanstatten lines
at predominantly 60 or 90 degrees to each other.

What is the relation between this structure and that
of martensite?

EXPERIMENT NO. 16

TITLE:

The Effect of Cooling Rate on Hardness of Carbon Steels.

OBJECT:

To study the hardness effect of different cooling rates on carbon steels of various carbon content.

REFERENCES:

A, See Index.

B, Page 138.

D, Pages 143-145.

E, Pages 251-256.

G, Pages 257-261.

APPARATUS:

Electric heat treating furnace with automatic control.

Abrasive disc cut off machine and bench grinder.

Standard Brinell hardness testing machine with microscope and chart. (General Instruction No. 6)

Steel marking dies.

MATERIALS:

Three $\frac{1}{2}$" X 2" specimens of each of the steels listed in the table below (next page), cut from stock bar

as rolled.

SPECIMEN:	C%	Mn%	P%	S%	Si%
A,	.26	.52	.029	.040	.16
B,	.85	.72	.038	.035	.21
C,	.15	.77	.013	.136	.06
D,	.50	.90	.013	.038	.27
E,	1.03	.48	.039	.036	.22
H,	"Armco" ingot iron, Approx. 0% carbon.				

10% brine quenching solution.

Quenching oil.

Soft iron wire.

PROCEDURE:

The specimens are stamped for identification and wired together in three batches. Each batch contains one each of the specimens listed above. The wiring is done in such a way that the specimens are separated for even quenching on all surfaces.

The three batches are placed in the furnace, heated to 1700°F., soaked at this temperature for about 15 minutes, removed and cooled as follows:

No. 1, cooled in air.

No. 2, quenched in oil.

No. 3, quenched in brine solution.

One surface of each specimen is ground to remove scale, (See General Instruction No. 7) and to prepare surface for Brinell impression.

Each specimen is given the standard Brinell test for hardness. Two impressions are made in each with 10 cm. ball and 3000 Kg. load, and the average taken as the correct reading.

CURVES:

Two sets of curves are required to show the effect of both composition and cooling rate on hardness.

The hardness effect of composition for each cooling rate is shown on one curve sheet and the effect of cooling rate for each composition on the other. (Reference A, see Quenching media, cooling rate.)

A general discussion of the effect of cooling rate on the hardness of carbon steels is included in the laboratory report:

QUESTIONS:

What effect does composition appear to have on the change in hardness due to change in cooling rate?

Possibly at what composition, indicated by the slope of these curves, would the hardness be in nearly direct proportion to cooling rate?

EXPERIMENT NO. 17

TITLE:

The Hardening and Tempering of Eutectoid Carbon Steels.

OBJECT:

To study the hardness effect of temperature and time in the tempering or drawing of eutectoid carbon steel from the martensitic state.

REFERENCES:

A, See Index

E, Pages 211-215.

F, pages 86,87.

G, Pages 262-263.

H, Page 316.

APPARATUS:

Equipment used in Experiment No. 16.

MATERIALS:

Thirteen specimens of .85% carbon steel cut to 2" length from 1/2" square stock bar as rolled.

Iron wire.

Ten per cent brine solution.

PROCEDURE:

The thirteen specimens are wired together with proper
spacing for even quenching, and placed in the furnace.
The temperature is brought up to 1700°F. and held for
about 15 minutes, after which the furnace is shut off and
the specimens removed and quenched in 10% brine solution.

Specimen No. 1 is tested for hardness. The other
twelve are grouped in three batches of four specimens each.
When the furnace temperature has dropped to about 550°F.
the three batches are placed in the furnace and the tempera-
ture brought up to and held at 572°F. The four specimens
in batch No. 1 are tempered at this temperature and removed
from the furnace as follows:

No. 1 after 30 minutes.

No. 2 after one hour.

No. 3 after two hours.

No. 4 after three hours.

All are cooled in air.

Batch No. 2 is tempered in the same manner at 932°F.

Batch No. 3 is tempered at 1292°F., the last specimen
being left to cool in the furnace.

Each piece is prepared and tested for hardness by the
same procedure employed in Experiment No. 16.

CURVES:

The curve included in the experiment report should

show the effect of time at each drawing temperature on
hardness of tempered martensite. Projected low points on
these curves are used to plot the Hardness-temperature
curve.

QUESTIONS:

Of the two factors, time and temperature, which is the
more important in the tempering of martensite? How is
this shown by the hardness curves?

In what temperature range does difference in temperature
have the greatest effect on reduction in hardness?

What appears to be the upper limit of tempering
temperature?

EXPERIMENT NO. 18

TITLE:

The Softening Effect of Temperature in Tempering of Martensite.

OBJECT:

To study the effect of temperature on hardness in the tempering of martensite formed in eutectoid carbon steel.

REFERENCES:

See Experiment No. 17.

APPARATUS:

Equipment used in Experiment No. 16.

MATERIALS:

Eight samples of eutectoid carbon steel, (Steel B, Ex-periment No. 16) cut to 2" length from 1/2" square stock bar as rolled.

Iron wire.

Ten per cent brine solution.

PROCEDURE:

The eight specimens are marked for identification,

wired together with proper spacing for even quenching, and placed in the furnace. The temperature is brought up to 1500°F. and held for about 15 minutes. The furnace current is then cut off and the specimens removed and quenched in brine.

One piece is tested and the Brinell hardness recorded. The furnace is allowed to cool to about 250°F. All specimens are replaced in the furnace, the rheostat set for slow heating, and the power turned on.

As the temperature rises, one piece is removed at each of the following temperatures, degrees F.: 300, 500, 700, 900, 1100, 1200, 1300, 1320, 1340, 1350, 1360. The first few pieces removed are quickly tested for hardness and replaced in the furnace for treatment as specimens drawn at higher temperatures. All are cooled in air and tested for hardness.

CURVES:

From the recorded data a curve is plotted to show the effect of drawing temperature on hardness.

QUESTIONS:

In what temperature range does change in temperature appear to have the greatest effect on change in hardness?

What is the upper limit of drawing temperature and how is it shown by the curve?

Explain what takes place within the metal at this temperature limit.

EXPERIMENT NO. 19

TITLE:

The Austempering of Carbon Steel

OBJECT:

To study the method of austempering, and the difference in properties between austempered steel and tempered or drawn martensite.

REFERENCES:

D, Page 149.

E, Pages 221, 222, Table XXIX.

APPARATUS:

Electric heat treating furnace and controls used in Experiment No. 12.

Gas or electric crucible furnace, and cast iron crucible.

Thermo-Electric pyrometer with chromel-alumel thermocouple and calibrated leads.

Abrasive disc cut off machine.

Rockwell hardness testing machine.

Vise, hack saw, hammer and file.

MATERIALS:

Two specimens of 1/4" diameter drill rod, .75% carbon steel, about three inches long.

Lead for quenching and drawing bath.

Ten per cent brine solution.

PROCEDURE:

The two specimens of steel are placed in the heat treat-furnace, heated to 1500°F. and soaked at this temperature for about 15 minutes.

During this procedure the cast iron crucible is placed in the crucible furnace and the lead melted. The thermocouple is connected to the pyrometer and inserted in the molten lead. The temperature of the lead bath is brought up to, and manually held at, 650°F.

After the two specimens are heated as explained above, No. 1 is removed from the furnace, quenched in brine, and immersed in the lead bath. No. 2 is removed from the furnace and quickly immersed in the lead bath. Both pieces are held submerged in the lead at 650°F. for thirty minutes, removed and cooled in air. As steel will float in lead, it is necessary to take preliminary measures to weight the samples down.

Each of the pieces is placed in the vise and struck with a hammer until rupture occurs. The difference in toughness and elasticity is noted. Each is given the file and Rockwell hardness tests and the difference noted.

A general discussion of the physical properties effected by austempering is included in the laboratory report.

EXPERIMENTS NO. 20

TITLE:

Case Carburizing of Low Carbon Steel.

OBJECT:

To study the method of case carburizing and the results obtained on low carbon steel.

REFERENCES:

A, See Index.

E, Pages 316, 327-329, 334-339.

F, Pages 106,111.

APPARATUS:

Electric furnace. (Vertical tube resistance type)

Potentiometer pyrometer with automatic control.

(See General Instruction No. 3)

Iron pack hardening box and cover.

Abrasive disc cut off wheel and bench grinder.

Steel marking dies.

Surface polishing plate and disc polishing machine.

Bakelite specimen mounting press.

Metallographic microscope.

MATERIALS:

Following specimens cut from 1/2" round stock bar
as rolled: 1- No. j, S.A.E. 1020, .20 % C. Cold rolled.

1- No. K, S.A.E. 1112, .12 % C. Bessemer Screw

E. F. Houghton's "Pearlite" pack hardening compound.

Special laboratory granulated pack hardening compound.

Ten per cent brine solution.

Polishing papers and 600 grain alundum powder.

$1\frac{1}{2}$% Nital etching solution.

Bakelite, (Granulated, raw), Brass identification
washers.

PROCEDURE:

The specimens are cut from bar stock, stamped for
identification, and packed with the mixture of the two
carburizing compounds in the iron pack hardening box.
Care is taken that the pieces are well surrounded by the
compound and do not come in contact with each other or
the sides of the box. The box is completely filled with
the compound and the lid sealed on with fire clay.

The box is placed in the furnace and the temperature
brought up to 1700°F. where it is held for eight hours.
The specimens are then quenched from this temperature
in brine solution.

A section is cut from near the middle of each bar,
mounted in bakelite, polished, etched and examined under

the microscope. The field is examined from the extreme outer surface to the center of the specimen.

A discussion of the findings and the explanation of the change in appearance from the outer circumference to the center of the specimen is included in the laboratory report.

QUESTIONS:

In what way do the two specimens differ in appearance?

Give the reason for this difference.

Under what type of industrial requirements would steel thus treated be preferable to hardened high carbon steel?

EXPERIMENT NO. 21

TITLE:

The McQuid-Ehn Test for Grain Size in Steel

OBJECT:

To determine the grain size in steels by the McQuaid
Ehn test.

REFERENCES:

A, See Index.

D, Pages 160-168.

E, Pages 230-241.

H, Pages 344-349.

APPARATUS:

Equipment for heat treatment and preparation of
specimens used in Experiment No. 20.

Bausch and Lomb Routine Metallograph with ground
glass screen.

A. S. M. Grain size chart.

MATERIALS:

Following 2" specimens cut from 1/2" round stock
bar as rolled. 1- No. J. S.A.E. 1020, .20 % C. Cold rolled.

1- No. K. S.A.E. 1112, .12 % C. Bessemer Screw.

1- No. L. S.A.E. 1095, .95 % C. Hot rolled.

Other materials used in Experiment No. 20.

PROCEDURE:

The specimens are carburized by the method employed in
Experiment No. 20, but left in the packhardening box to
cool in the furnace. A sample of each specimen is cut,
ground, mounted, polished, etched, and placed on the stage
of the metallograph. The image of the hypereutectoid
field is projected on the ground glass screen at 100X.
Comparison of grain size is made with the A. S. M. chart.

QUESTIONS:

Why should the carburizing temperature not be carried
above 1700°F.?

Why is the grain size not revealed in steels below
hypereutectoid composition?

What is the difference between a fine grain steel
and a coarse grain steel with fine grain?

Why is the size of the grain in steel considered of
such great commercial importance?

EXPERIMENT NO. 22

TITLE:

The Simple Time-Temperature Curve for Eutectoid Carbon
Steel

OBJECT:

To plot from experimental data the simple "Time-
Temperature" curve for eutectoid carbon steel and study
the characteristics of cooling through the gamma — alpha
transformation point.

REFERENCES:

A, See Index, (Critical points)

D, Pages 258-259

E, Pages 162-165

F, Pages 57

APPARATUS:

Electric furnace (Small vertical tube resistance).

Brown potentiometer pyrometer.

Chromel-alumel thermocouple and leads.

Two 22.5 ohm adjustible rheostats.

Stop watch.

MATERIALS:

Four specimens of steel, (Sample B, .85 % C., .72 % Mn.)

1/2" square X 1-1/2" cut from stock bar as rolled.

PROCEDURE:

One corner of each of the four specimens is ground to leave a small hole in the center of the batch for receiving the thermocouple. The pieces are bound together with wire, the thermocouple inserted and connected to the pyrometer, and the batch placed in the furnace for heating. The two rheostats are connected in series in the furnace power line. With the line resistance out, the temperature of the furnace is brought up to about 1500°F. (See General Instruction No. 5.)

The rheostats are adjusted for about 35 ohms which gives a fairly reasonable cooling rate. Readings are taken of time, at half minute intervals, and corresponding temperature, from 1400°F. to 1200°F.

CURVES:

From the recorded data the simple time-temperature curve is plotted.

QUESTIONS:

What is the point indicated by the break in the curve?

What is the allotropic change which takes place in the steel at this point?

Is the heat involved exothermic or endothermic?

What difference would be noted in this point on the curve had the steel been of hypoeutectoid composition?

EXPERIMENT NO. 23

TITLE:

The Inverse Rate Curve for Carbon Steel

OBJECT:

To plot, from experimental data, the "Inverse Rate" curve for .26 % carbon steel and locate the critical points.

REFERENCES:

B, Page 278.

D, Pages 258-260.

F, Page 57.

APPARATUS:

Equipment used in Experiment No. 22.

Two stop watches.

MATERIALS:

Four pieces of steel, .26 % C., .52 % Mn., .16 % Si., 1/2" square X 1-1/2", prepared as in Experiment No. 22.

PROCEDURE:

The apparatus is set up as in Experiment No. 22 and the specimens heated to about 1600°F. with full power on the furnace. The rheostats are adjusted for about 35 ohms

in the power circuit. As cooling begins, readings are taken of temperature and corresponding time for each ten degree drop in temperature from 1600°F. to about 1200°F. Since the cooling rate at high temperature is rapid, a little practice in taking and recording readings may be necessary. At the beginning of the run the observer sets the instrument dial to selected temperature for start. When the galvanometer pointer reaches zero he starts the first watch, and immediately sets the dial to the next temperature, ten degrees lower. When the galvanometer pointer reaches zero he simultaneously stops the first watch and starts the second, reads the first watch, punches it back to zero, and sets the instrument dial for the next ten degree drop.

The recorder records the temperature and the corresponding time for drop of ten degrees to that temperature.

CURVES:

From the recorded data, the "Inverse Rate" curve is plotted.

QUESTIONS:

What advantage does this method of determining critical points in steel have over the simple time-temperature method?

What transformation points are noted on the curve?

Which is the most pronounced and why?

EXPERIMENT NO. 24

TITLE:

The Effect of Temperature on Grain Size in Carbon Steels.

OBJECT:

To show that the simple horse-shoe magnet may be used to detect the upper limit of the critical range in steels containing more than 0.45% carbon.

To show that heating a steel to far above the A_{c3} will result in the formation of a coarse grain.

To show that heating a coarse grain steel to just above the A_{c3} will result in the formation of a fine grain; i.e., will refine the grain.

APPARATUS:

Small gas fired furnace.

Abrasive disc cut off wheel.

Horse-shoe magnet, tongs, vise and hammer.

MATERIALS:

Bar of steel D, $\frac{1}{2}$" square, (.50% C, .90% Mn.)

Pyrofax gas and compressed air.

PROCEDURE:

One piece of steel about 2 inches long is cut from

the stock bar. A second piece, about the same length, is obtained by nicking the bar about half way through and breaking with a hammer to reveal the fracture.

Each of the two specimens is nicked half way through to be broken later into two one inch pieces.

Both specimens are placed in the furnace and heated to a white heat, about 2200°F., soaked for a few minutes, removed from the furnace and cooled in air.

One of the specimens is placed back in the furnace and, during slow heating, removed at short intervals, tested with the horse-shoe magnet, and quickly replaced in the furnace. When the steel is found to be nonmagnetic it is removed and cooled in air.

Each specimen is then held in a vise and broken with a hammer to reveal the fracture.

Resistance to fracture and appearance of the grain in each specimen is noted.

QUESTIONS:

Which of the two specimens appeared to have the greater strength and why?

Why can not this method be used to determine the A_{c3} points in steels of less than .45% carbon?

To what extent can the method be applied to steels of more than .83% carbon?

EXPERIMENT NO. 25

TITLE:

The Temperature-Difference and Derived Differential Cooling Curves.

OBJECT:

To plot, from experimental data, the temperature difference and derived differential cooling curves for carbon steel and locate the critical points.

REFERENCES:

B, Pages 278-280.

D, Pages 258-260.

F, Pages 58.

APPARATUS:

Electric furnace, (Vertical tube resistance).

Brown potentiometer pyrometer.

Rubicon galvanometer and 50 ohm shunt.

Two adjustible rheostats for furnace power circuit, total 45 ohms.

Chromel-Alumel straight and difference thermocouples and leads.

Nickel bar, 1/2" square X 3/4" drilled for thermocouple.

MATERIALS:

Carbon steel specimen, 1/2" square X 3/4" drilled for thermocouple.

PROCEDURE:

The specimen, neutral body and thermocouples are assembled, (Reference B, Figure 148) and placed in the furnace. The thermocouple leads are connected in such a way that the pyrometer indicates the temperature of the specimen and the deflection of the galvanometer is proportional to the difference in temperature between the specimen and the neutral body.

With all resistance out of the power circuit the temperature is brought up to about 1500°F. The rheostats are then adjusted for full resistance of 45 ohms and cooling begins.

When the temperature difference appears to become constant, the galvanometer is set to read 10 mm. deflection.

Readings are taken of temperature of the specimen in 5°F. increments and corresponding galvanometer deflection. Reading is also taken at maximum deflection of the galvanometer. The range of cooling is taken from about 1400°F. through 1100°F.

CURVES:

From the recorded data, the "Temperature-Difference" and "Derived Differential" cooling curves are plotted.

QUESTIONS:

Explain the constant temperature difference between the specimen and the neutral body.

Discuss the difference between the two curves.

EXPERIMENT NO. 1

THE COOLING CHARACTERISTICS OF A PURE METAL

OBJECT: To plot from experimental data, the cooling curve for pure tin through the liquid solid transformation point, and to study the characteristics of cooling.

APPARATUS: Electric furnace

  Ring stand

  Ring and crucible holder

  Pyrex crucible

  400 C. thermometer

  Bushing to center thermometer

  Pyrex thermometer protecting tube

  Stop watch

MATERIALS: 150 grams of pure tin

  Wax cover

EXPLANATION OF SET UP: The apparatus was set up as shown in the diagram, page 2. The crucible holder which is of steel lined with asbestos, was supported by the ring stand, and could be raised to allow removal of the furnace.

The pyrex crucible was fitted with a bushing to center the thermometer. A clamp on the thermometer rested on the bushing and prevented the thermometer protecting tube from resting on the bottom of the crucible. The wax cover excluded the air from the molten specimen, thus preventing oxidation.

Clamp

Thermometer

Bushing

Pyrex crucible

Crucible holder

Ring

INSULATION

Refractory
cylinder

Wax cover

Heating element

Thermometer
protecting
tube

Sample of
metal

FURNACE

REFRACTORY FURNACE SUPPORT
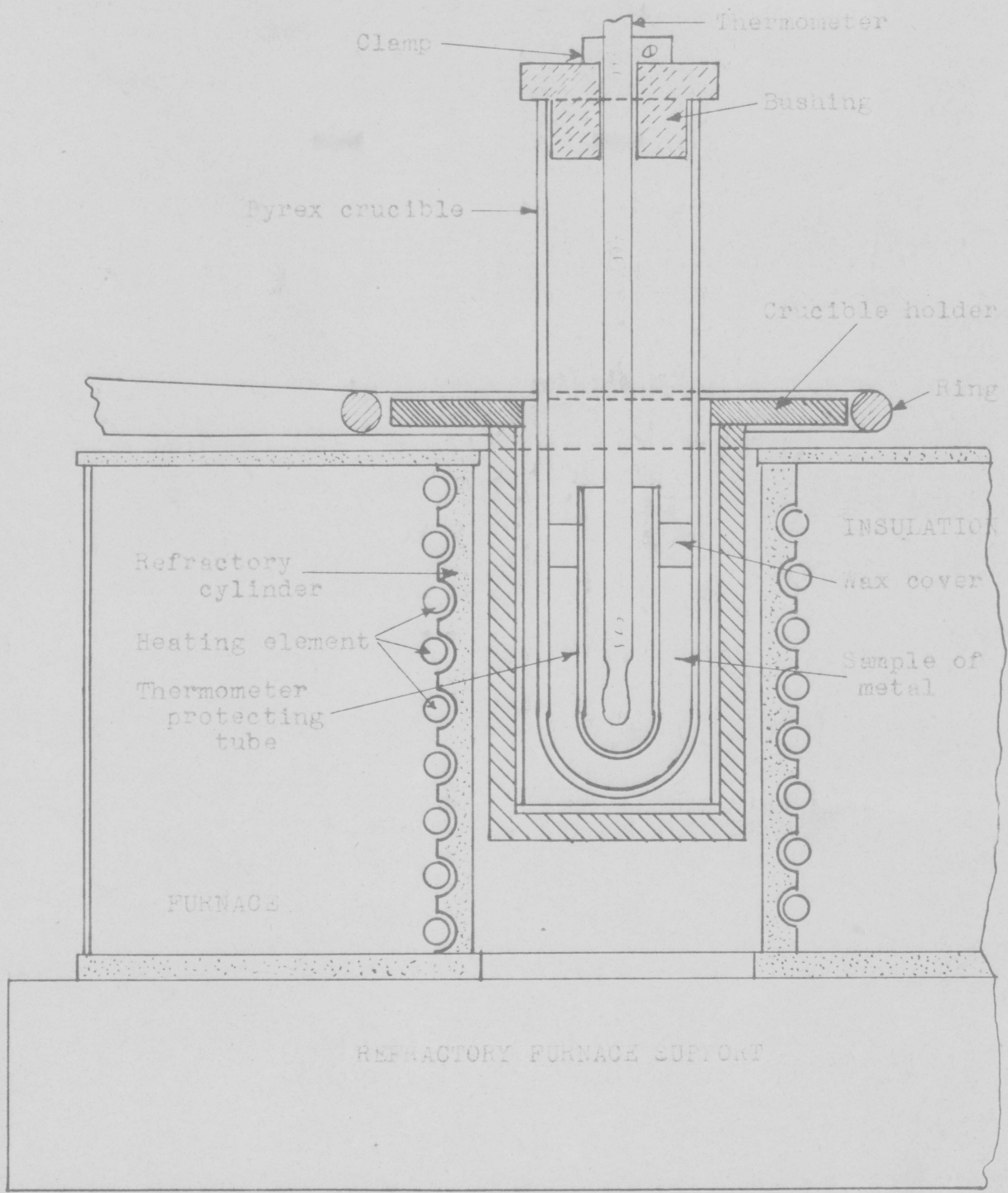
DIAGRAM OF APPARATUS, EXPERIMENT NO. 6.

PROCEDURE: The apparatus was set up as shown in the diagram. The furnace circuit was closed and the metal heated to a point well above the melting point of pure tin, (232°C). This point was taken arbitrarily at 300°C. When this temperature was reached the heating unit was removed and the temperature continued to rise until a heat balance was reached between the metal and the crucible holder. Cooling then began and the temperature readings were taken from 300°C. in half minute intervals through a point well below the freezing point of tin, (232°C). This point was taken at about 150°C. From these readings a curve was plotted between time, as abscissa, and temperature, as ordinate.

CONCLUSIONS: From the curve, page 6, it is noted that the metal cooled at almost constant rate to about 232°C. This rate of cooling was not exactly constant, due to the change in heat gradient between the crucible and the atmosphere.

At 232°C. the temperature ceased to fall, as shown by the horizontal section of the curve. At this temperature solidification or freezing began and continued through a period of about 11 minutes. The curve then assumed the direction of almost constant temperature drop showing that solidification was complete.

The period of constant temperature was due to the dispensation of the heat of fusion of the metal which continued until all of the metal was solid.

4

PRECAUTIONS AND SOURCES OF ERROR:

The thermometer used in this experiment had a constant error of about −1.4°C. The correction for partial immersion was 6 C. The total correction was .6-(-1.4), or 2°C.

Since the shape of the curve is the important item to be studied, the curve was plotted from readings. Points in the curve are 2°C below corrected readings.

Care was taken to stir the liquid between each reading to prevent under cooling.

It is noted that the horizontal line showing temperature of freezing was plotted through temperature at beginning of freezing. This is actual temperature, though some of the points toward the end of freezing drop below this line. The theory is, that the heat conducted through the thermometer causes crystalization around the bulb, thus insulating it to a small degree. The readings were therefore lower than the actual temperature of the freezing metal.

DATA

COOLING CURVE FOR PURE TIN.

THERMOMETER CORRECTION, (2 °C)

READING NO.	TIME MIN.	OBSERVED TEMP. °C.	READING NO.	TIME MIN.	OBSERVED TEMP. °C.
1	0.0	300	23	11.5	229
2	0.5	293	24	12.0	229
3	1.0	287	25	12.5	229
4	1.5	280	26	13.0	229
5	2.0	274	27	13.5	229
6	2.5	267	28	14.0	229
7	3.0	261	29	14.5	229
8	3.5	255	30	15.0	228
9	4.0	249	31	15.5	228
10	4.5	243	32	16.0	227
11	5.0	237	33	16.5	226
12	5.5	231	34	17.0	224
13	6.0	230	35	17.5	218
14	6.5	230	36	18.0	212
15	7.0	230	37	18.5	207
16	7.5	230	38	19.0	201
17	8.0	230	39	19.5	196
18	8.5	230	40	20.0	191
19	9.0	230	41	20.5	186
20	9.5	230	42	21.0	182
21	10.0	230	43	21.5	177
22	10.5	230	44	22.0	173

COOLING CURVE
for
PURE TIN

Thermometer Correction, (+2°C)

230°C

Temperature °C

Time in minutes

6
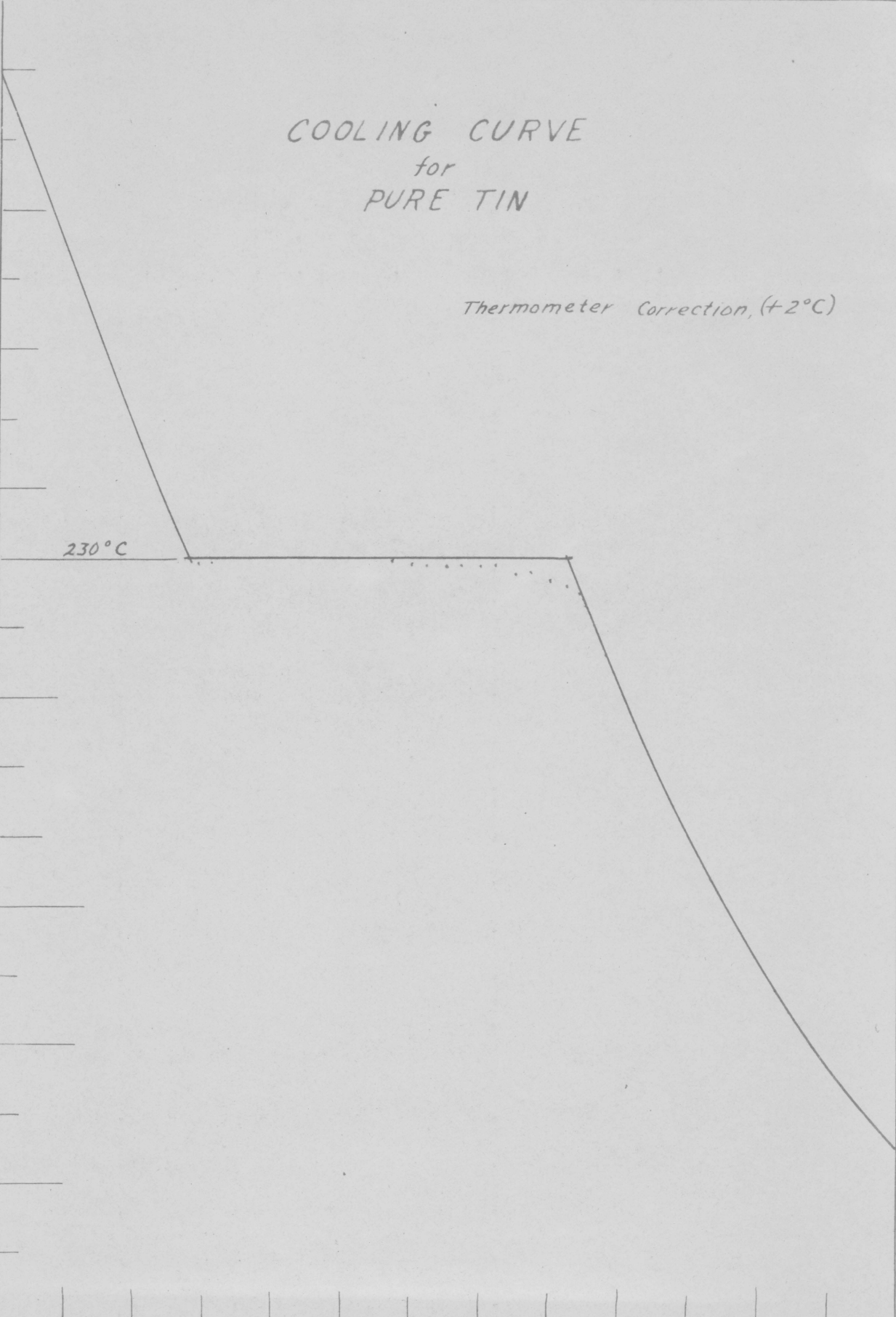
EXPERIMENT NO. 2

THE EQUILIBRIUM DIAGRAM FOR A BINARY ALLOY

OBJECT: To plot from experimental data the Equilibrium Diagram for alloys of lead and tin.

APPARATUS: Equipment used in Experiment No. 1.

MATERIALS: 150 gram samples of alloys of lead and tin from 100% Pb, in increments of 10%, through 0% Pb. (Total, 11 samples). Wax cover.

EXPLANATION OF SET UP: The apparatus was set up as shown in Experiment No. 1.

PROCEDURE: Temperature and time readings were taken and a cooling curve plotted for each of the samples by the same procedure employed with the pure metal in Experiment No. 1. From these curves, the Equilibrium Diagram, page 12, was plotted in the following manner;

With composition, (0% to 100% Pb.) as abscissa, and temperature as ordinate, the liquidus curve was plotted through the points indicating the beginning of freezing in each of the cooling curves. These points were shown by a sudden decrease in the rate of cooling as explained in Experiment No. 1. (See points "A" on cooling curves.)

Two curves were formed intersecting at the point, B.

This is the Eutectic point showing the temperature of freezing of the saturated solution of each of the metals in the other.

The time of freezing at the eutectic temperature was recorded from each of the cooling curves and the "Tammans' time curve" was plotted on the same sheet with the equilibrium curve with the same abscissa, but with time as ordinate. From the points at which times became zero, verticals were dropped to intersect the eutectic temperature horizontal through B. These points are C and D. CE and DF were drawn dotted, indicating that points were not located on these lines.

CONCLUSIONS: From a study of the equilibrium diagram, page 12, it is seen that;

Either of the pure metals, lead or tin, has its freezing temperature lowered by addition of the other. This is shown by the liquidus lines, EB and BF.

The eutectic freezing temperature for lead and tin is about 183°C. This is also shown in each of the cooling curves.

The eutectic composition of lead and tin is approximately 61.5% Sn., and 38.5% Pb.

No eutectic is formed in compositions richer in lead than 86.5% nor in tin than 97.5%. These compositions form solid solutions when freezing. Any composition indicated

by a point to the left of C, when cooled, will start freez-
ing at the liquidus line EB, the lead dissolving the tin.
When the temperature reaches the solidus line EC, freezing
will be complete and all of the metal will be in solid
solution.

The same takes place in a composition between C and B
with the exception that more tin is present than will be
taken into solid solution by the lead. Consequently, as
the temperature falls below the liquidus line the liquid
becomes richer in tin until a saturated solution is reached
at the eutectic temperature. At this point the eutectic
alloy freezes. Any composition at the temperature indicated
by a point above the liquidus should be liquid throughout.
Any below the solidus ECBDF should be solid throughout.
Any point falling between these lines would indicate crystals
of solid solution and liquid of composition nearer the
eutectic than shown by the point. As example, point "a"
would indicate a composition of 75% Pb and 25% Sn. At the
temperature indicated there should exist crystals of solid
solution, Pb 88% and Sn 12%. Naturally the liquid would be
richer in tin than the original composition. As the temper-
ature falls the liquid becomes richer in tin until the eutec-
tic temperature is reached. There freezing of the eutectic
takes place. At the temperature indicated by a, there
should exist crystals of solid solution (Pb 88%, Sn 12%)
as shown by the poing, b. In equilibrium with these crys-
tals there should exist a liquid of composition shown by

C, (Pb 52.5%, Sn 47.5%). Letting the vector, bc, represent the 150 gram sample, ab/bc equals the proportion of liquid present and is 36.8%. The amount of solid would be 63.2%.

SOURCES OF ERROR: The same sources of error that were encountered in Experiment No. 1 were prevalent here. Beside these there was one other to be considered. Theoretically, point c should show a composition of which there is no eutectic. The experiment would have shown this had enough time been allowed in cooling for the solid solution crystals to become uniform in composition and a saturated solution. This was impossible, since that time would approach infinity. Therefore C shows a composition richer in lead than the theoretical would show.

DATA

THE EQUILIBRIUM DIAGRAM FOR THE LEAD-TIN SERIES

COMPOSITION PER CENT		BEGINNING OF FREEZING OF SOLID SOLU-TION. (Corrected reading) °C.	EUTECTIC FREEZING TIME, MINUTES
Pb.	Sn.		
100	0	327	0
90	10	302	0
80	20	276	1.7
70	30	255	4.2
60	40	236	6.2
50	50	214	8.2
40	60	185	11.2
30	70	193	8.7
20	80	204	5.8
10	90	215	2.9
0	100	232	0.

EQUILIBRIUM DIAGRAM
for
LEAD-TIN SYSTEM
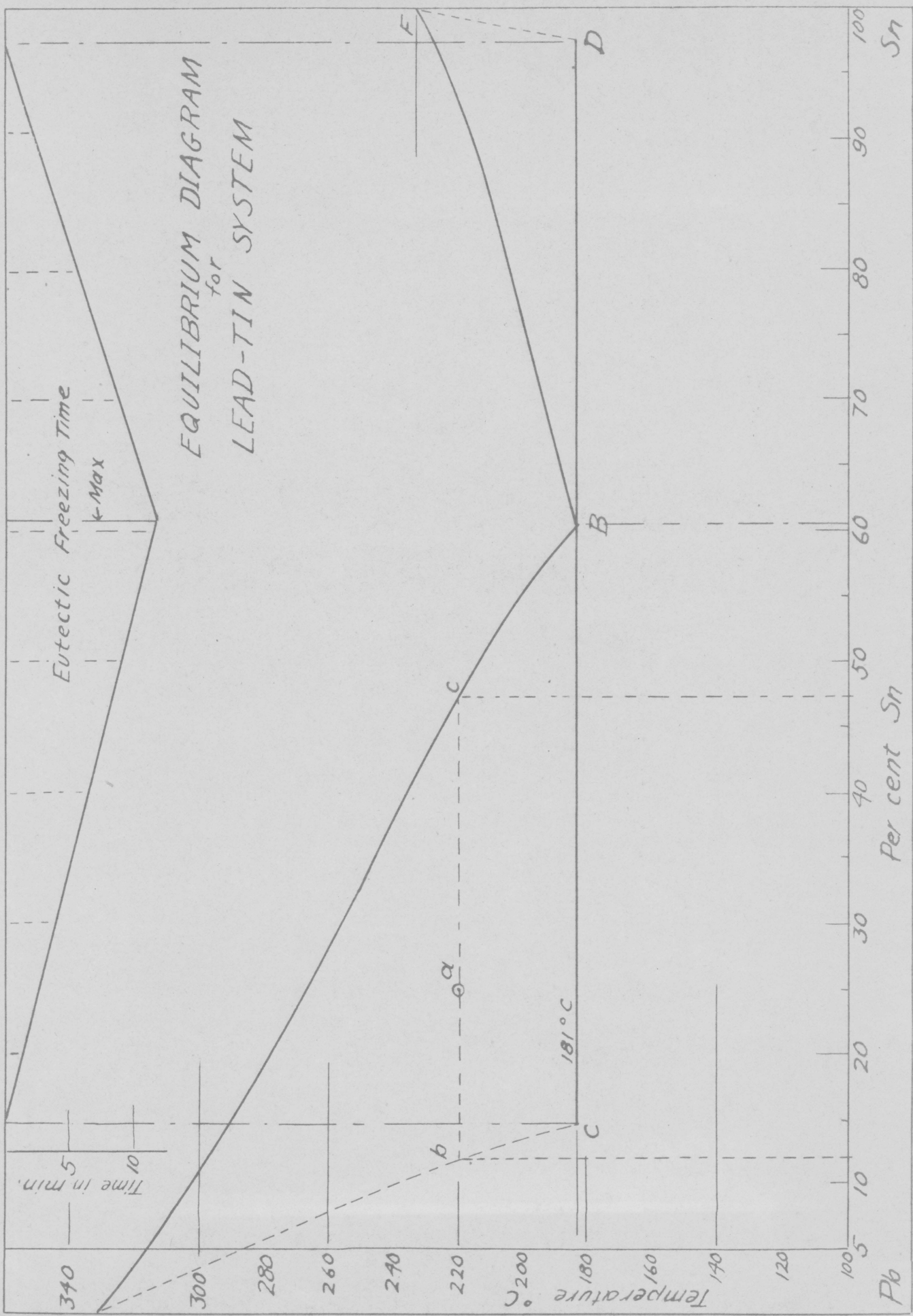
$Pb = 90\%$
$Sn = 10\%$

Pb = 80%
Sn = 20%

A → 273°C

250

Temperature °C

200

181°C

T

150

2 4 6 8 10 12 14 16 18 20 22 24

Time in minutes.

17

Pb = 30%
Sn = 70%

Pb = 20%
Sn = 80%

300

250

202 °C   A

200

181 °C

T

150

Temperature °C

2   4   6   8   10   12   14   16   18   20   22   24

Time in minutes

$Pb = 10\%$
$Sn = 90\%$

330

300

250

Temperature °C

200

T

150

2   4   6   8   10   12   14   16   18   20   22   24

Time   in minutes
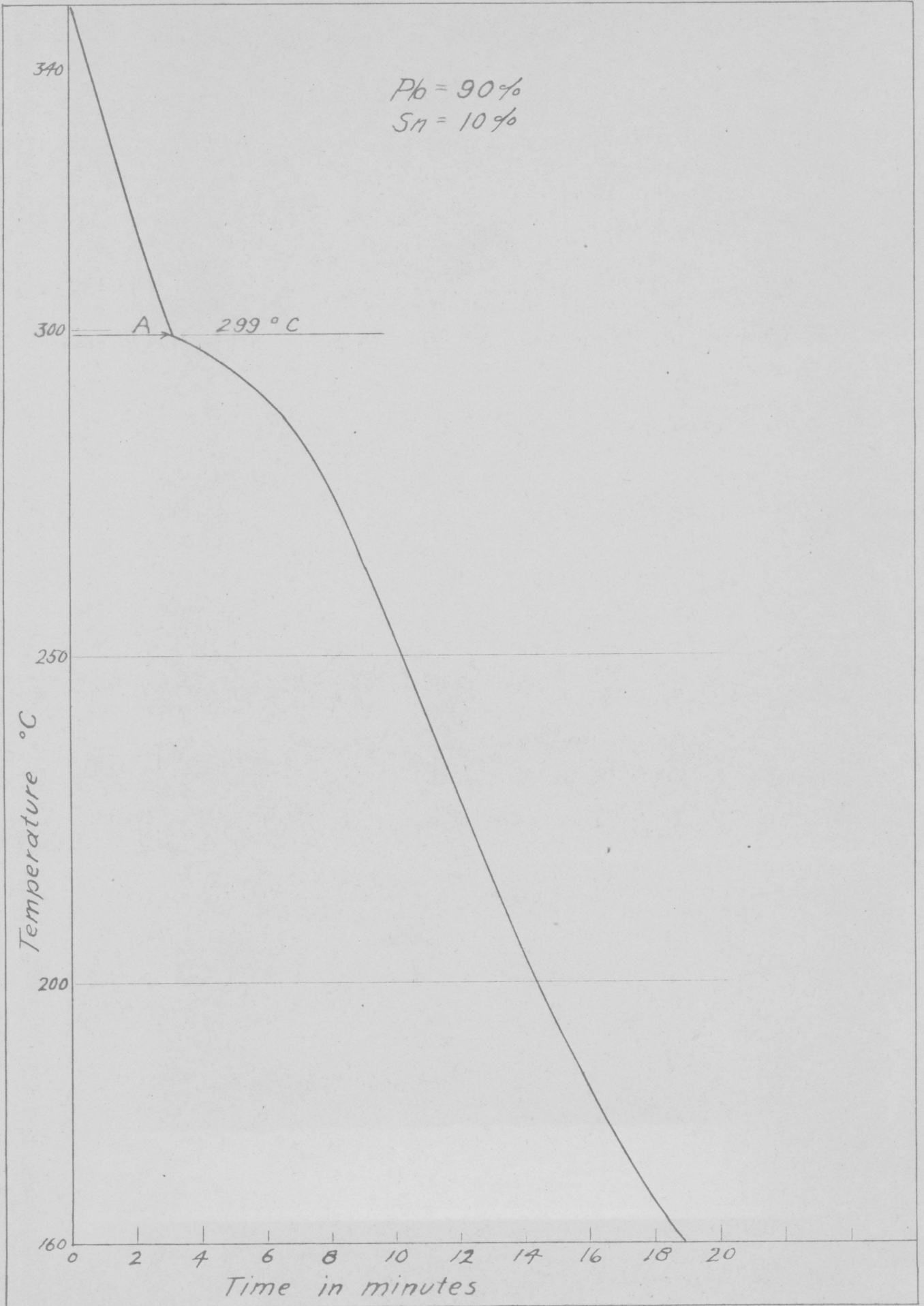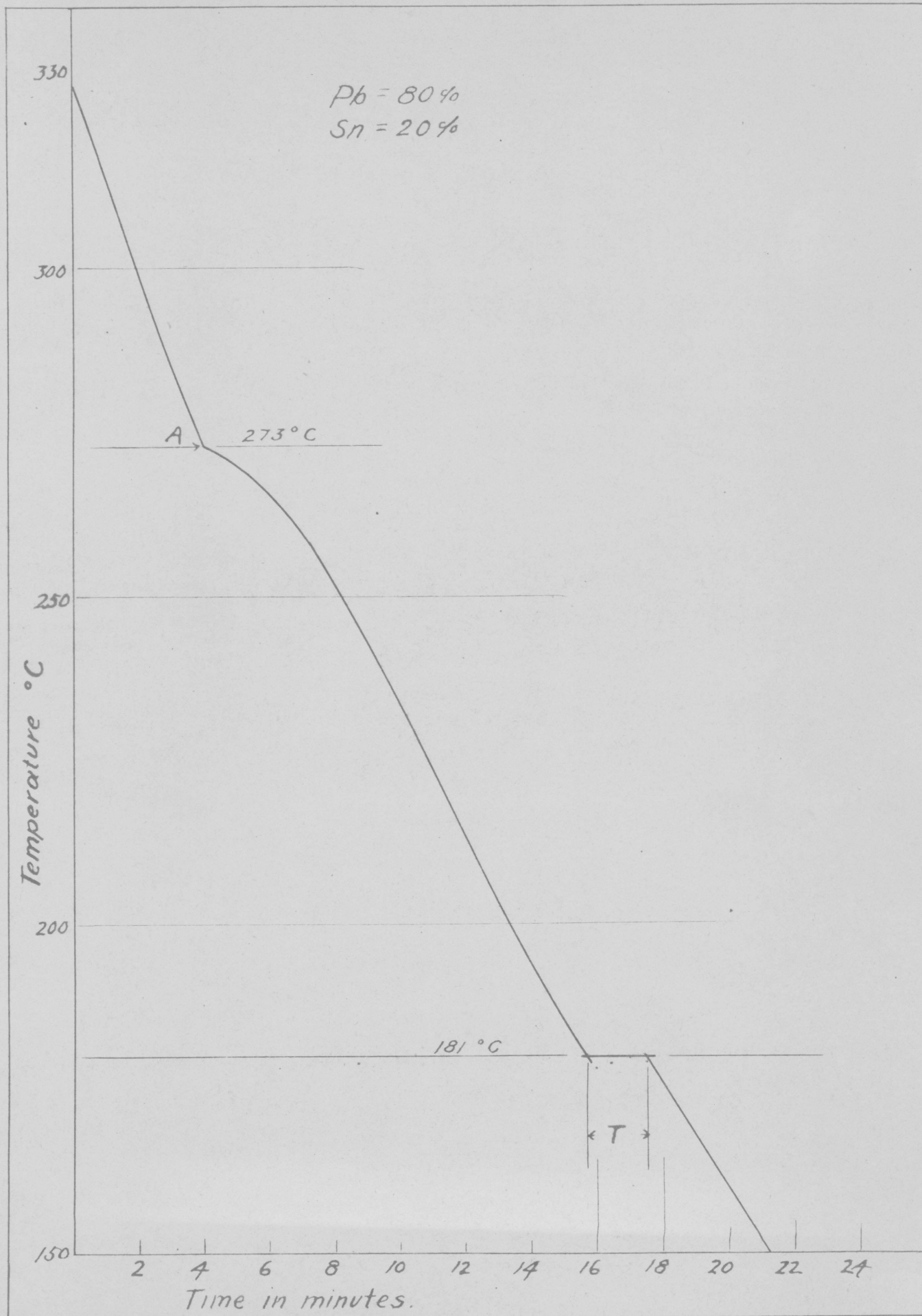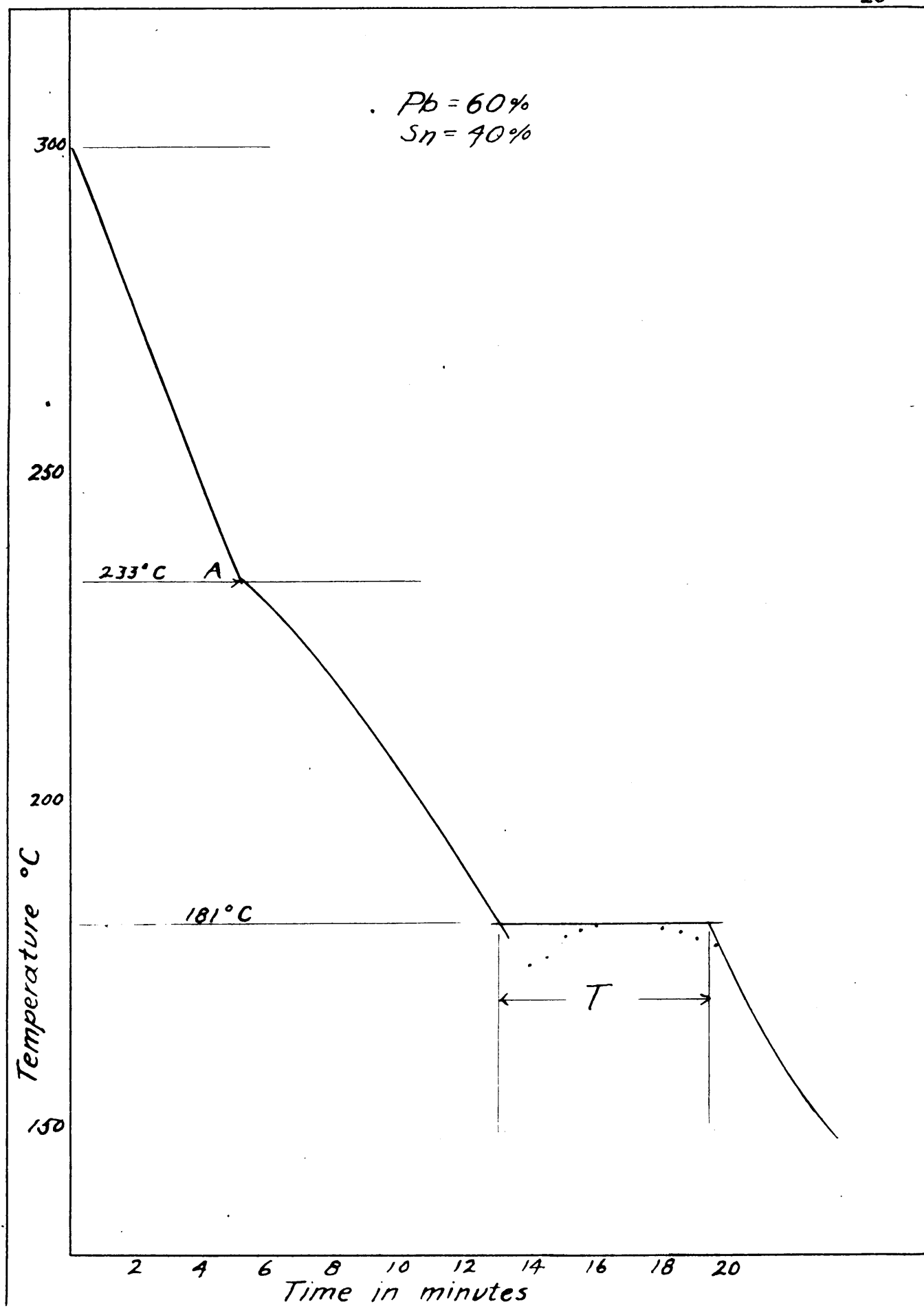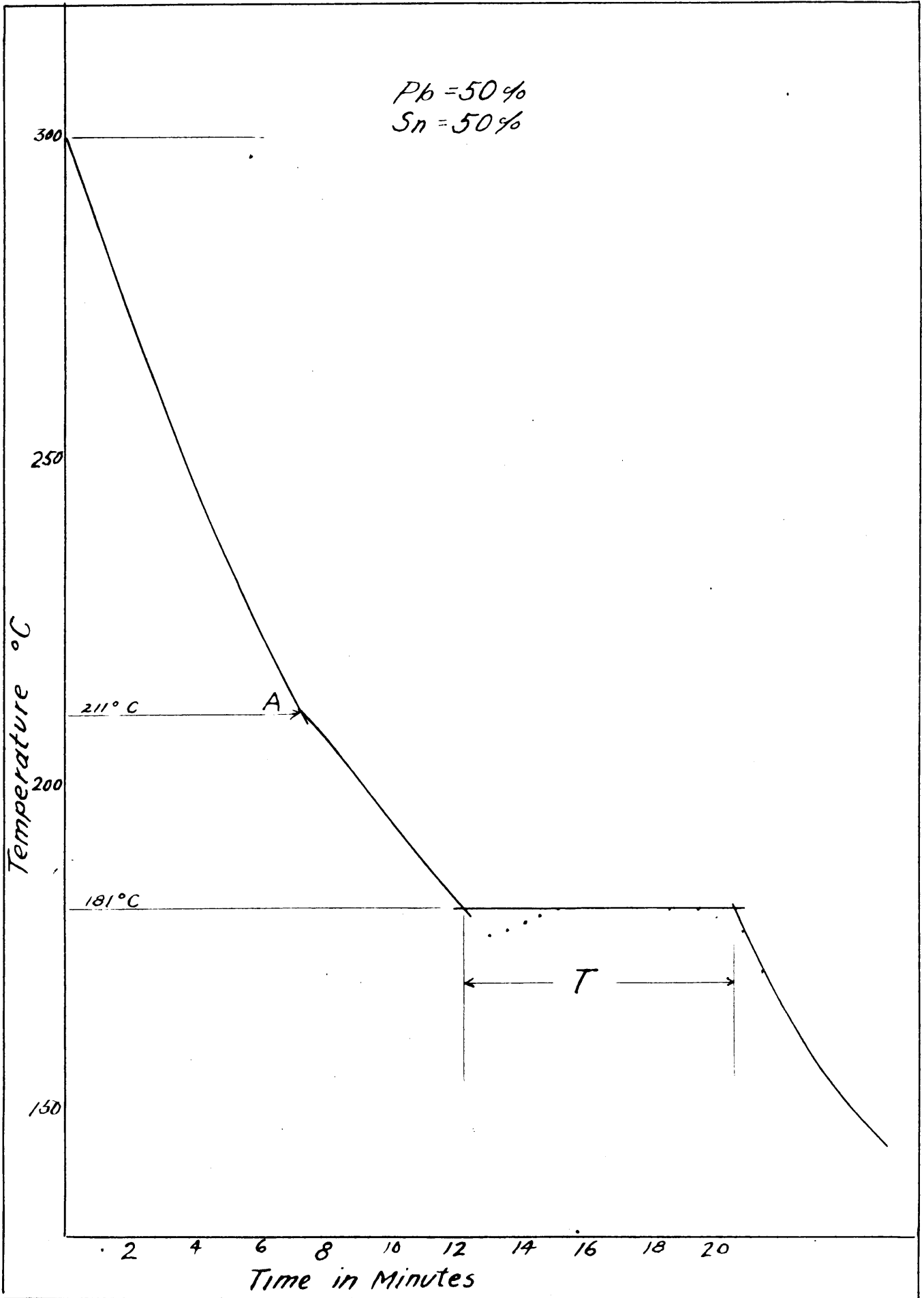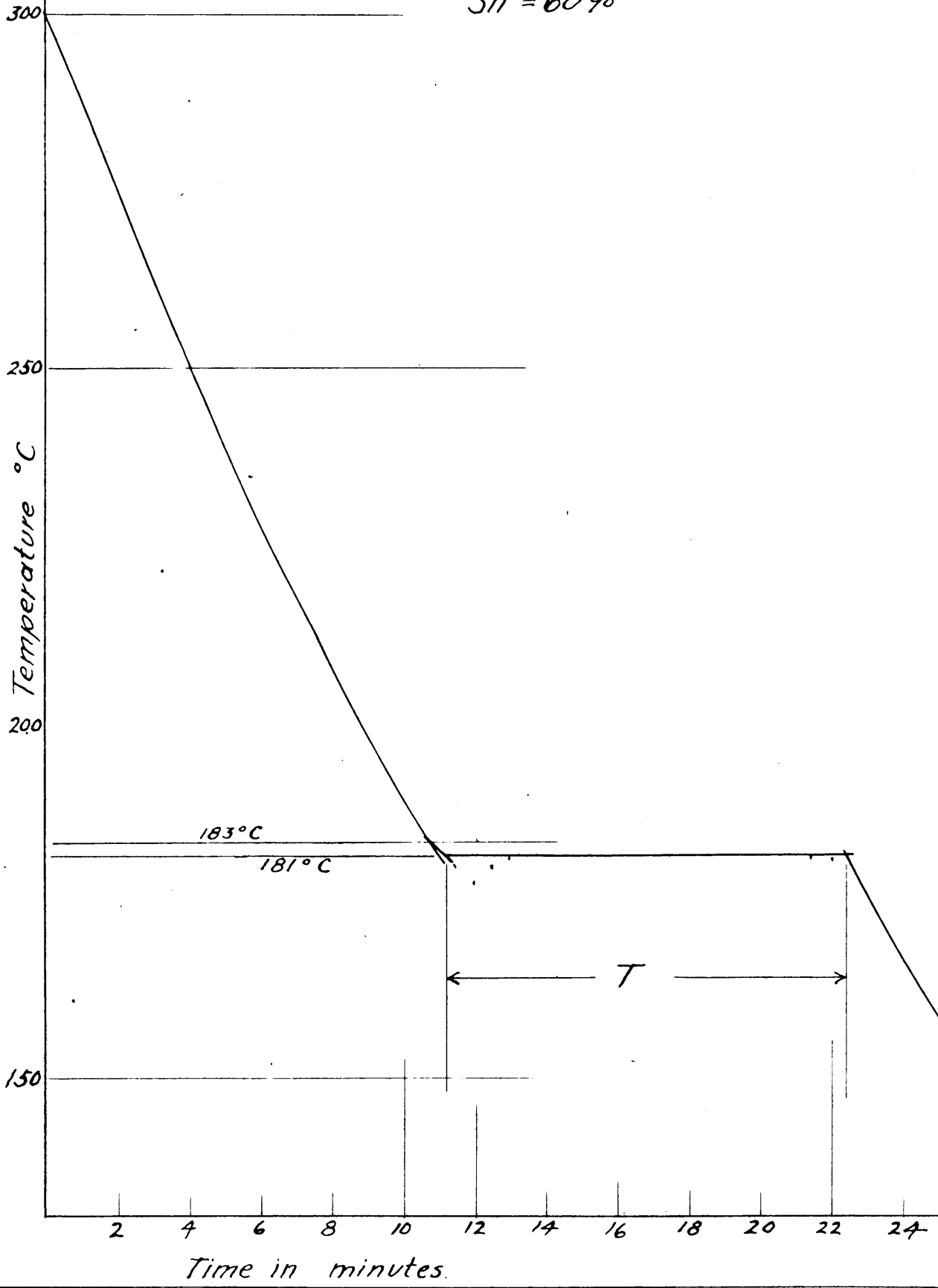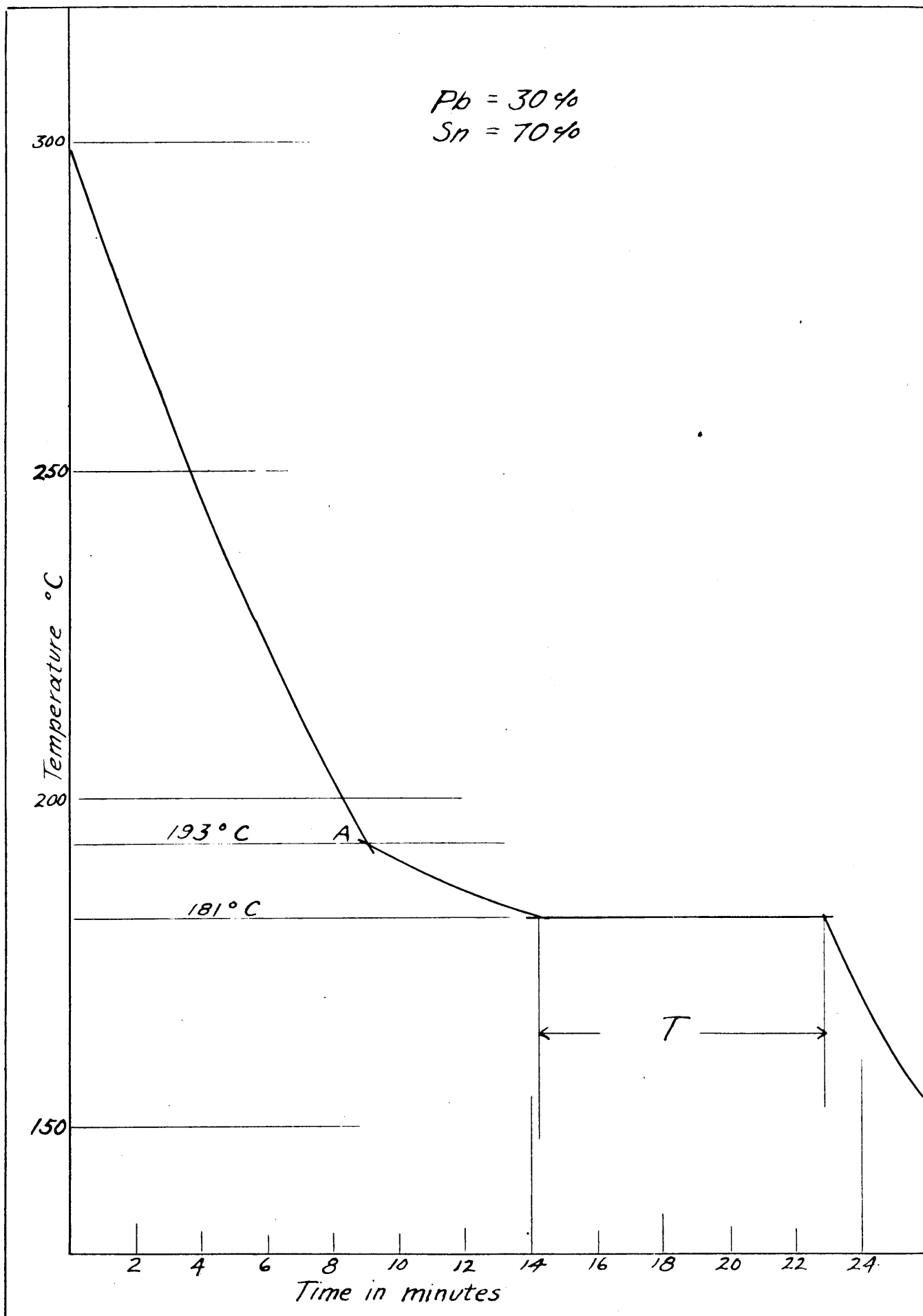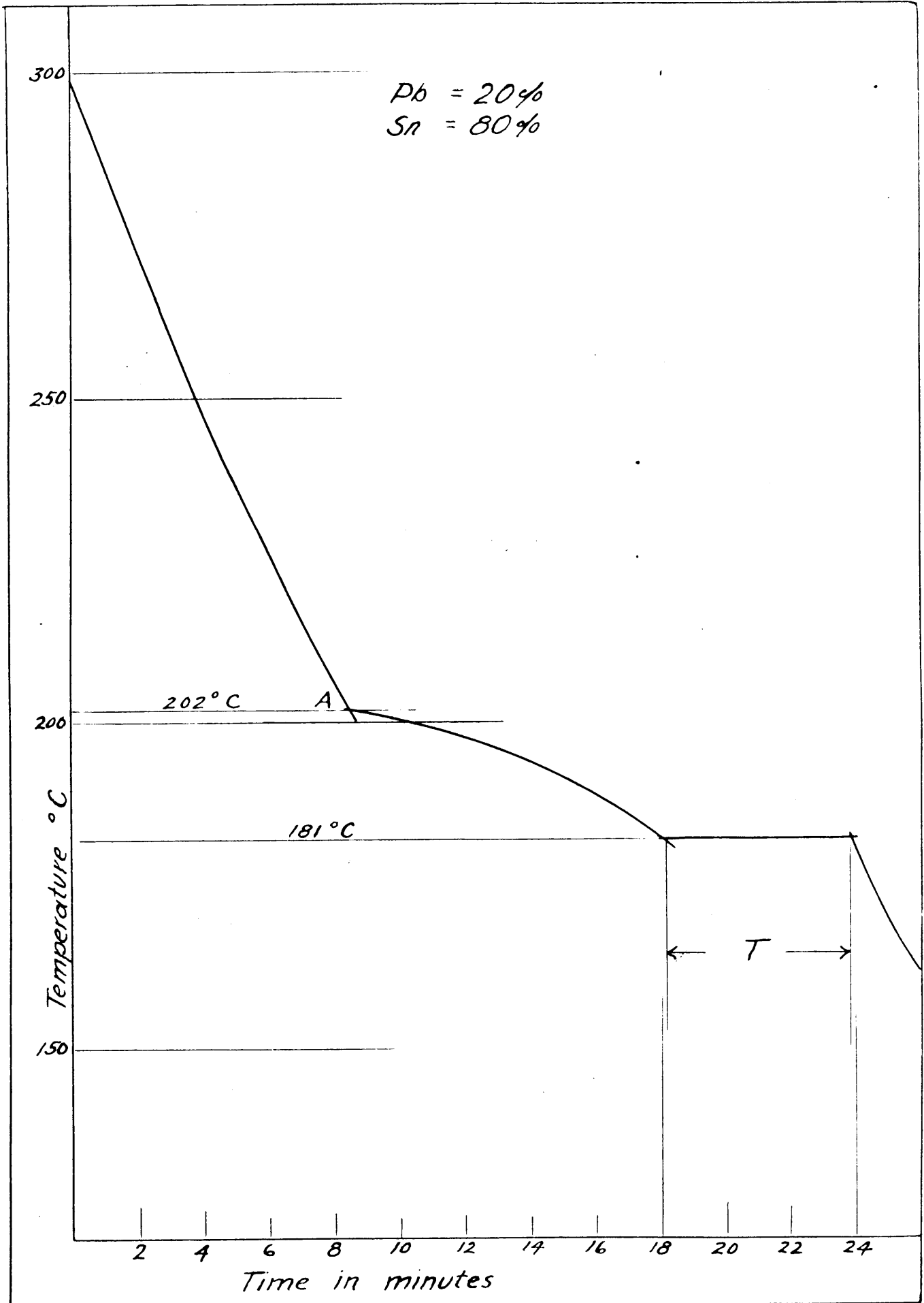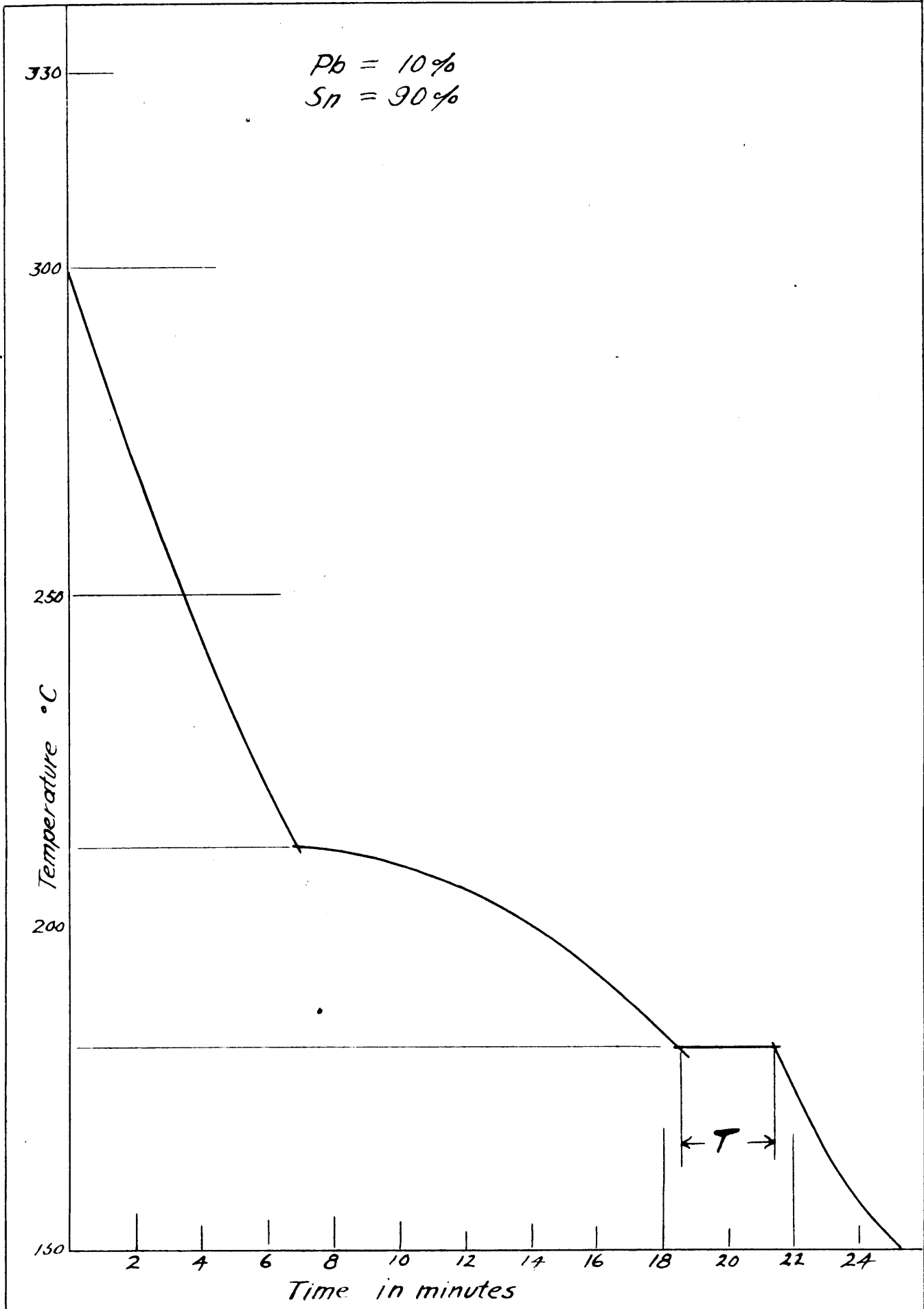
EXPERIMENT NO. 3

THE RELATION BETWEEN THE PHYSICAL PROPERTIES

AND THE INTERNAL STRUCTURE OF ALLOYS

OBJECT: To study the relation between composition and hardness of alloys of zinc and cadmium.

APPARATUS: Electric furnace.

Clay crucible and specimen mold.

Balances.

Brinell hardness testing machine with microscope and chart.

MATERIALS: Pure zinc and cadmium metal.

Ammonium chloride.

EXPLANATION OF SET UP: The electric furnace was the same used in Experiments 1 and 2.

The cast iron mold is shown in Fig. 1, page 25. It consists of a base and two sides, designed to mold a specimen of approximate dimensions, ($\frac{1}{2}$" X 1" X $1\frac{1}{4}$").

The Brinell testing machine is of standard make. The pressure is applied hydraulically. The standard 10 mm. ball was used. The microscope for measuring the diameter of impression is graduated in .05 mm.

PROCEDURE: Six 100 gram samples of zinc and cadmium were weighed out as follows;

100 gm. Zn & 0 gm. Cd.   Pure Zn.

99 gm. Zn & 1 gm. Cd.   1% Cd.

98 gm. Zn & 2 gm. Cd.   2% Cd.

97 gm. Zn & 3 gm. Cd.   3% Cd.

96 gm. Zn & 4 gm. Cd.   4% Cd.

95 gm. Zn & 5 gm. Cd.   5% Cd.

Each of these six samples was, in turn, melted in the crucible, stirred with a pine stick, fluxed with ammonium chloride, poured into cast iron mold, and removed as soon as solid. The composition was stamped on each specimen. After cooling reached room temperature two Brinell impressions were made in each at 500 Kg. with 10 cm. ball, held for 60 seconds. Measurements were taken with the graduated microscope, of two perpendicular diameters of each impression, and recorded on the data sheet, page 24. The average of these diameters was computed and the corresponding hardness recorded.

A curve was plotted between composition, as abscissa, and hardness, as ordinate. On the same sheet, that part of the equilibrium diagram which covers the same range of composition was plotted. Data for this curve was taken from the A. S. M. Handbook.

CONCLUSIONS: It is noted, from the curves, page 26, that, as the percentage of cadmium is increased from zero, the hardness of the alloy increases at a remarkable rate up to maximum at the composition equal to the limit of solid solubility of cadmium in zinc, about 1.8% Cd. At this point the curve shows a uniform decrease in hardness as the percentage of cadmium is increased into the eutectic range.

This indicates that the hardness of a saturated solid solution of cadmium in zinc is greater than that of zinc in cadmium, and that any intermediate composition shows an average hardness between the two solid solution saturation points. It is found that other physical properties of alloys are affected in the same manner by varying composition.

SOURCES OF ERROR: The principal sources of error lay in the difficulty in reading the diameter of the impressions made by the ball of the Brinell machine. The crystaline structure of the alloy tends to cause breaks in the circumference of the impressions.

DATA

READ-ING	COMPOSITION, % Zn.	COMPOSITION, % Cd.	DIAMETER OF IMPRESSIONS RIGHT 1	DIAMETER OF IMPRESSIONS RIGHT 2	DIAMETER OF IMPRESSIONS LEFT 1	DIAMETER OF IMPRESSIONS LEFT 2	MM. AV.	BRINELL HARDNESS
1	100	0	4.72	4.42	4.53	4.35	4.43	31.
2	99	1	3.28	3.24	3.27	3.26	3.26	59.
3	98	2	3.12	3.14	3.10	3.17	3.13	64.
4.	97	3	3.11	3.16	3.25	3.26	3.20	61.
5	96	4	3.19	3.18	3.02	3.14		
6	95	5	3.24	3.27	3.27	3.30	3.27	58.

Check reading for No. 5

5	96	4			3.20	3.24	3.22	60.

Base

Removable side

Removable side

Base

Base

Specimen Mold

Pressure gage

Ram

Steel ball

Specimen

Anvil

Screw height adjustment

BRINELL HARDNESS TESTING MACHINE

Crucible
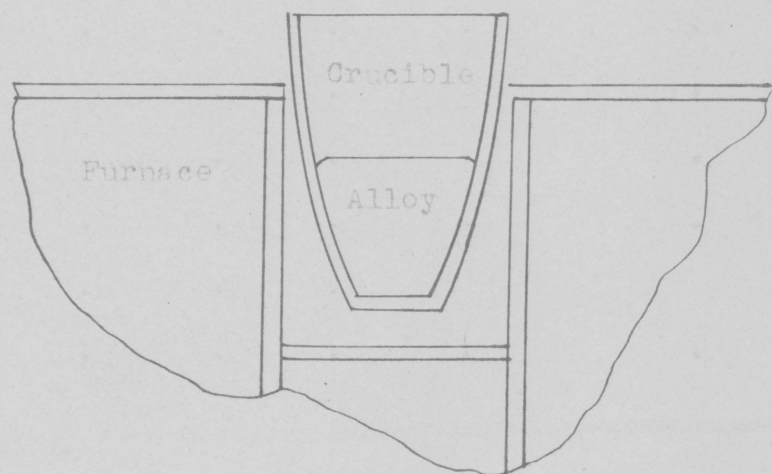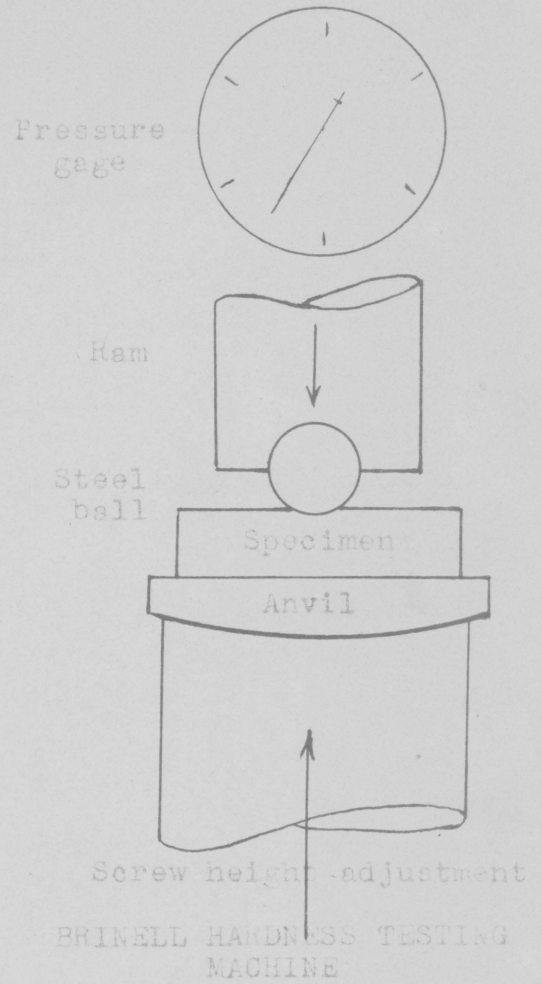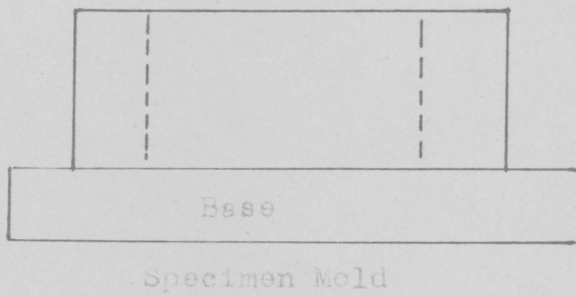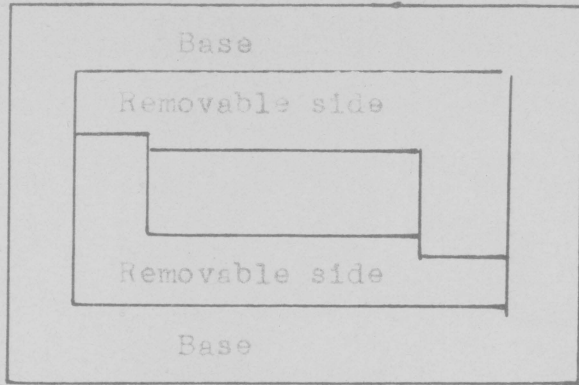
Furnace

Alloy

FURNACE SET UP FOR MELTING ALLOY

Hardness Characteristic Curve.
for
Zinc - Cadmium

Equilibrium Diagram.

27
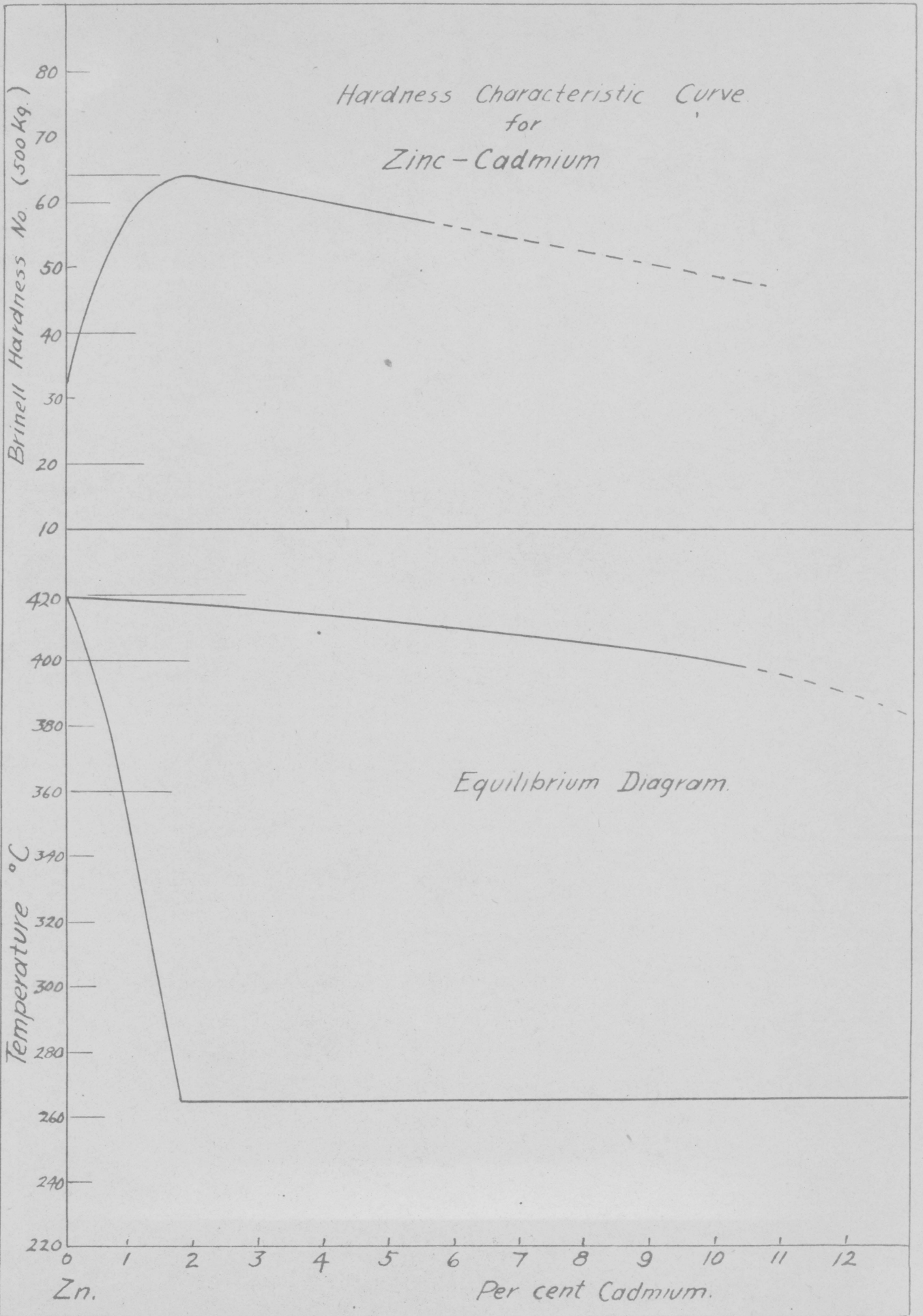
EXPERIMENT NO. 9

THE HEATING AND COOLING CHARACTERISTICS OF CARBON STEEL
THROUGH THE GAMMA $\rightleftharpoons$ ALPHA TRANSFORMATION POINT

OBJECT: To study the heating and cooling characteristics
of carbon steel through the gamma $\rightleftharpoons$ alpha transformation
point and to determine the critical points.

APPARATUS: Electric furnace.

Thermo-Electric Pyrometer, (Hoskins Type H A

No. 0, Serial No. 17060 for Chromel-Alumel

thermo-couple.)

Chromel-Alumel thermo-couple and leads.

Potentiometer, (L.& N. Type K, No. 245837)

Resistance wire No. 30, 5.96 ohms per foot

Power control rheostat, (Ware and Leonard)

Stop Watch.

MATERIALS: Specimen of carbon steel.

EXPLANATION OF SET UP: The apparatus was set up as shown
in the diagram, page 29. The electric furnace is the same
used in Experiments 1, 2, and 3.

The control rheostat, R_1, is adjustible for control of
the heating rate of the furnace.

The specimen, S, is a bar of carbon steel of approx-
imately eutectoid composition, (.83% C.) $1\frac{1}{2}''$ diameter and
$2''$ long. The hole, H, was drilled to receive the thermo-
couple.

The Hoskins Thermo-Electric Pyrometer is a milli-volt meter, graduated for chromel-alumel thermo-couple in degrees F.

The resistance, R_2, is resistance wire No. 30, 5.96 ohms per foot. It is placed in the thermo-couple circuit to correct for error in the length of the leads. The amount of this resistance was determined by trial and error comparison with the Leeds and Northrup Potentiometer.

DIAGRAM OF APPARATUS FOR RUNNING HEATING AND COOLING
CURVE FOR CARBON STEEL
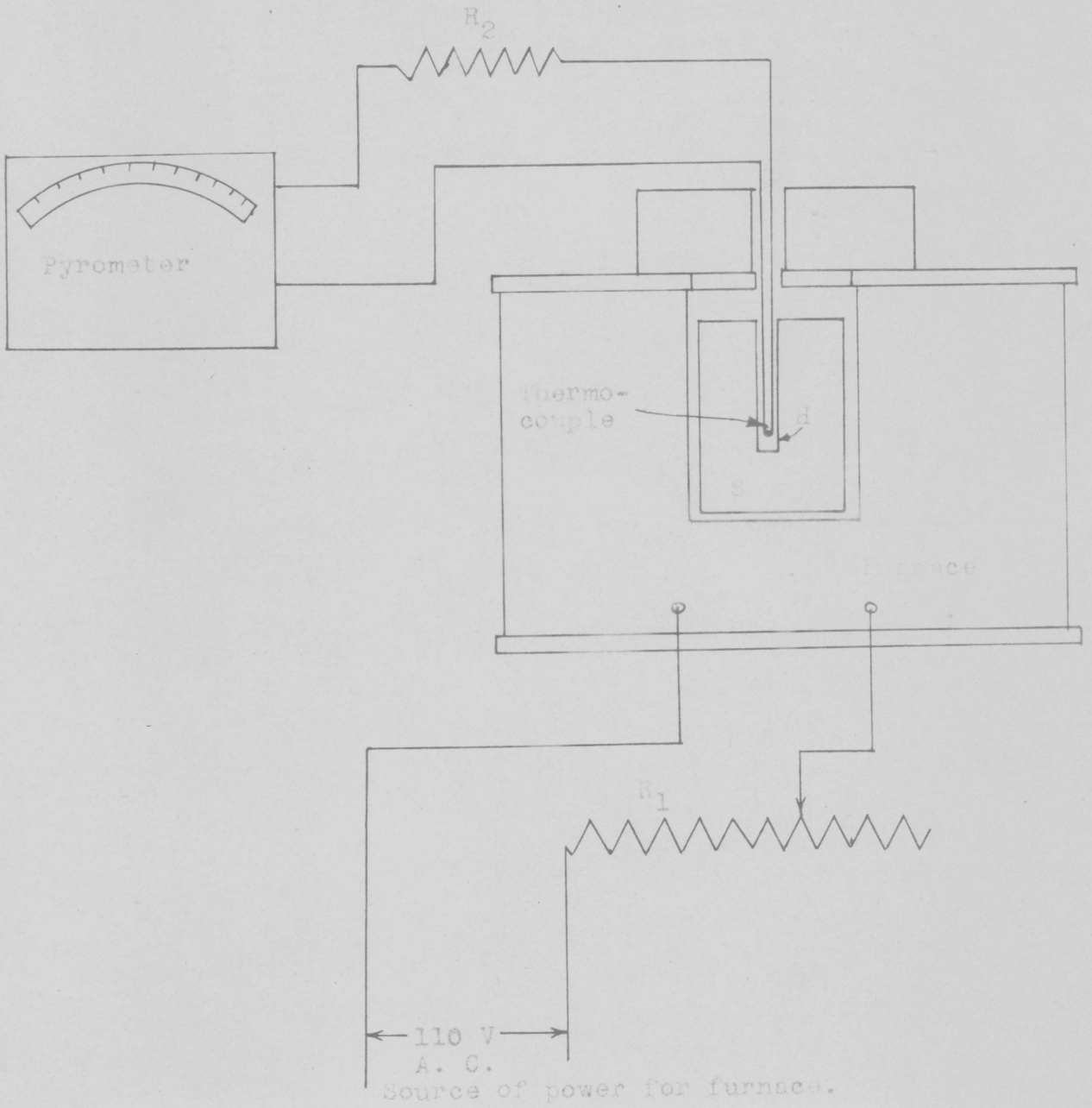
PROCEDURE: The apparatus was set up as shown in the diagram, page 29. The temperature was brought up to about 700 °F and the thermo-couple leads connected to the pyrometer and then to the potentiometer. Readings were taken in both cases, comparison made and resistance adjusted to calibrate the pyrometer.

The control rheostat was adjusted for a heating rate of about 30°F per minute.

When 1000°F was reached temperature readings were taken each half minute and recorded as shown in the data, page 32. When the temperature reached 1600°F the furnace was shut off and readings continued through cooling to about 1200°F.

From these data the curve, page 33, was plotted between time, as abscissa, and temperature, as ordinate.

CONCLUSIONS: A study of the curve, page 33, reveals the fact that the temperature of the steel rose at about constant rate to approximately 1400°F. At this point the temperature remained practically constant for about four minutes. This shows that a transformation was taking place in the steel, absorbing heat and thus holding the temperature constant, even though heat was being supplied.

When this transformation was complete the temperature began to rise at approximately the same rate as before the transformation. After the current to the furnace was shut

off, cooling began and continued at almost constant rate until a temperature of 1370°F. was reached. At this point the curve becomes again horizontal, showing a transformation in which heat was being given off by the steel. When the transformation was complete the cooling continued at uniform rate.

At the first transformation, noted above and shown in the curve as Ac_1, pearlite, the eutectoid of alpha ferrite and cementite, changed to austentite, a solid solution of carbon or iron carbide in gamma iron.

Upon cooling, the temperature, Ar_1, indicates the reverse change.

It is noted that these two temperatures were not the same. Ac_1 was raised and Ar_1 lowered from the theoretical due to the rapid rate of heating and cooling respectively. The eutectoid temperature lies between these points and is approached by each as the rate of heating and cooling is retarded.

"Over heating" at Ac_1, and under cooling at Ar_1 are indicated by the curve. These show a lag in the transformation which was due also to the rate of heating and cooling.

DATA

TIME MIN.	TEMP. °F.	TIME MIN.	TEMP. °F.	TIME MIN.	TEMP. °F.	TIME MIN.	TEMP. °F.
0.	1000	12.5	1400	24.5	1605	37.0	1358
0.5	1020	13.0	1408	25.0	1615	37.5	1360
1.0	1040	13.5	1415	25.5	1610	38.0	1365
1.5	1060	14.0	1410	26.0	1605	38.5	1370
2.0	1070	14.5	1410	26.5	1590	39.0	1370
2.5	1096	15.0	1410	27.0	1580	39.5	1370
3.0	1115	15.5	1410	27.5	1572	40.0	1370
3.5	1135	16.0	1410	28.0	1560	40.5	1370
4.0	1150	16.5	1412	28.5	1546	41.0	1370
4.5	1170	17.0	1415	29.0	1532	41.5	1370
5.0	1185	17.5	1420	29.5	1522	42.0	1370
5.5	1200	18.0	1428	30.0	1508	42.5	1365
6.0	1219	18.5	1435	30.5	1492	43.0	1362
6.5	1235	19.0	1450	31.0	1480	43.5	1358
7.0	1252	19.5	1470	31.5	1468	44.0	1355
7.5	1265	20.0	1483	32.0	1455	44.5	1345
8.0	1280	20.5	1500	32.5	1445	45.0	1335
8.5	1295	21.0	1512	33.0	1435	45.5	1325
9.0	1308	21.5	1527	33.5	1425	46.0	1318
9.5	1322	22.0	1540	34.0	1415	46.5	1305
10.0	1335	22.5	1555	34.5	1400	47.0	1284
10.5	1350	23.0	1565	35.0	1392	47.5	1285
11.0	1363	23.5	1580	35.5	1380	48.0	1275
11.5	1375	24.0	1595	36.0	1370	48.5	1268
12.0	1385	Furnace cut.		36.5	1365	49.0	1258

Heating and Cooling Curve
for
Eutectoid Carbon Steel
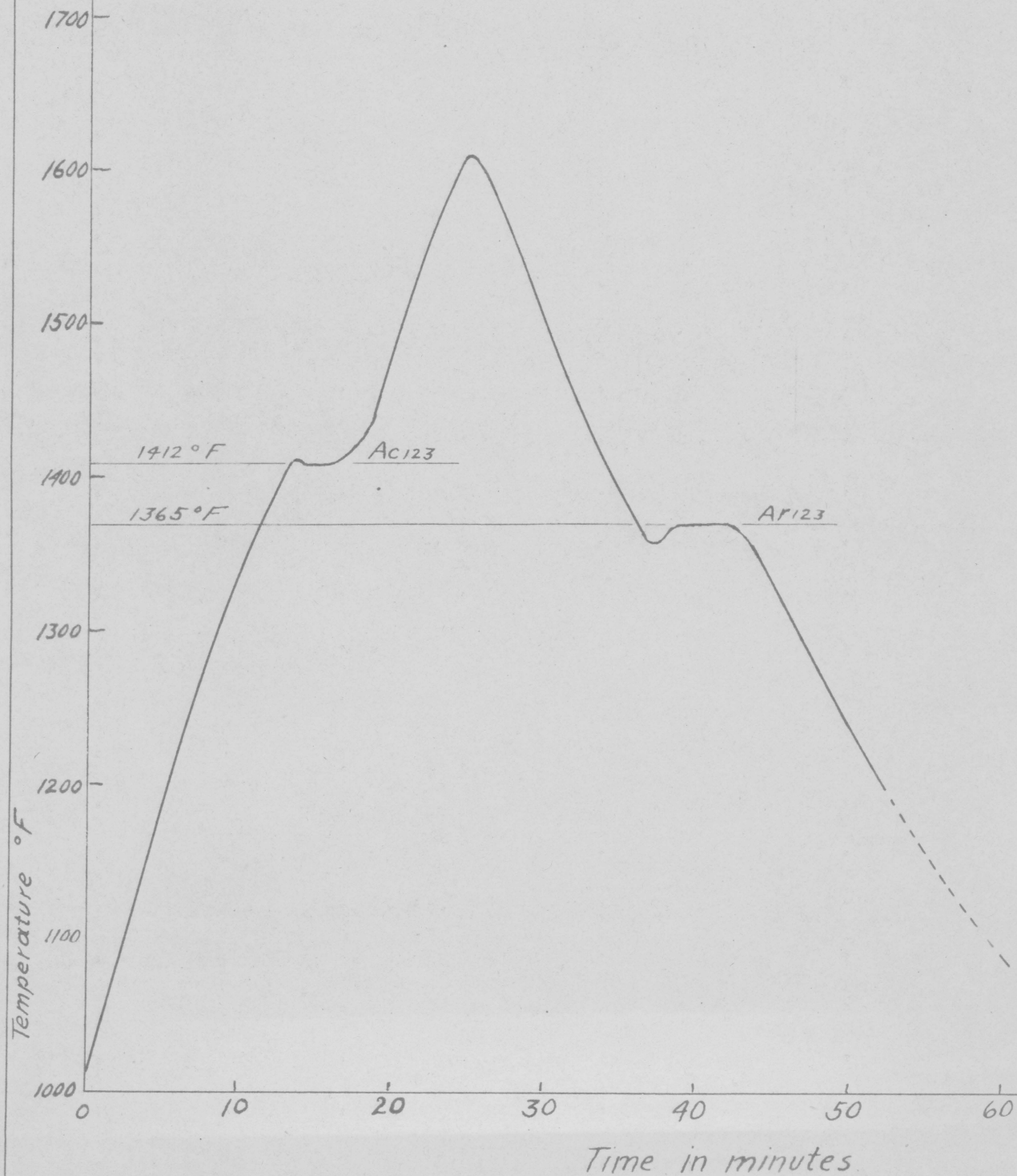
EXPERIMENT NO. 10

THE DILATION EFFECT OF ALLOTROPIC CHANGES IN STEEL

OBJECT: To study the volume effect of the allotropic changes in iron and steel brought about by changes in temperature.

APPARATUS: Electric vertical tube furnace.

Pyrometer, (Hoskins Type HA, No. 0, Serial 19799)

Thermo-couple, (Chromel-Alumel)

Fused silica tubes

Dial indicator, (Ames)

Steel scale, (mm.)

Surface plate and blocks.

MATERIALS: Round bar of "Armco" iron, (10 mm. dia. X 203 mm.)

EXPLANATION OF SET UP: The set up is shown in the diagram, page 36. The furnace is of the resistance type with vertical tube heating chamber. It was constructed in the Virginia Polytechnic Institute shops according to U. S. Bureau of Standards specifications.

The large fused silica tube is closed at the bottom and supported by the clamp at the top which also supports the dial indicator so that the relative position of the tube and indicator is fixed. The specimen of iron rests on the bottom of the large tube and connection with the indicator plunger, P, is made by the closed silica tube. Any movement of the top of the specimen, due to expansion or con-

traction, is thereby transmitted and shown on the dial indicator.

The dial indicator is designed to magnify motion or change of position. When the plunger, P, is moved in or out the motion is transmitted by gear and pinion to the axis of the pointer. The pointer indicates on the dial which is graduated for .01 mm. motion of the plunger.

The pyrometer is similar to the one used in Experiment No. 9.

Dial indicator

Thermo-couple leads

Clamp

Closed silica tube

Furnace

Resistance for calibrating pyrometer

Pyrometer

Open end silica tube

Heating element

Specimen

Thermo-couple

Source of furnace power, 110 V. A.C.
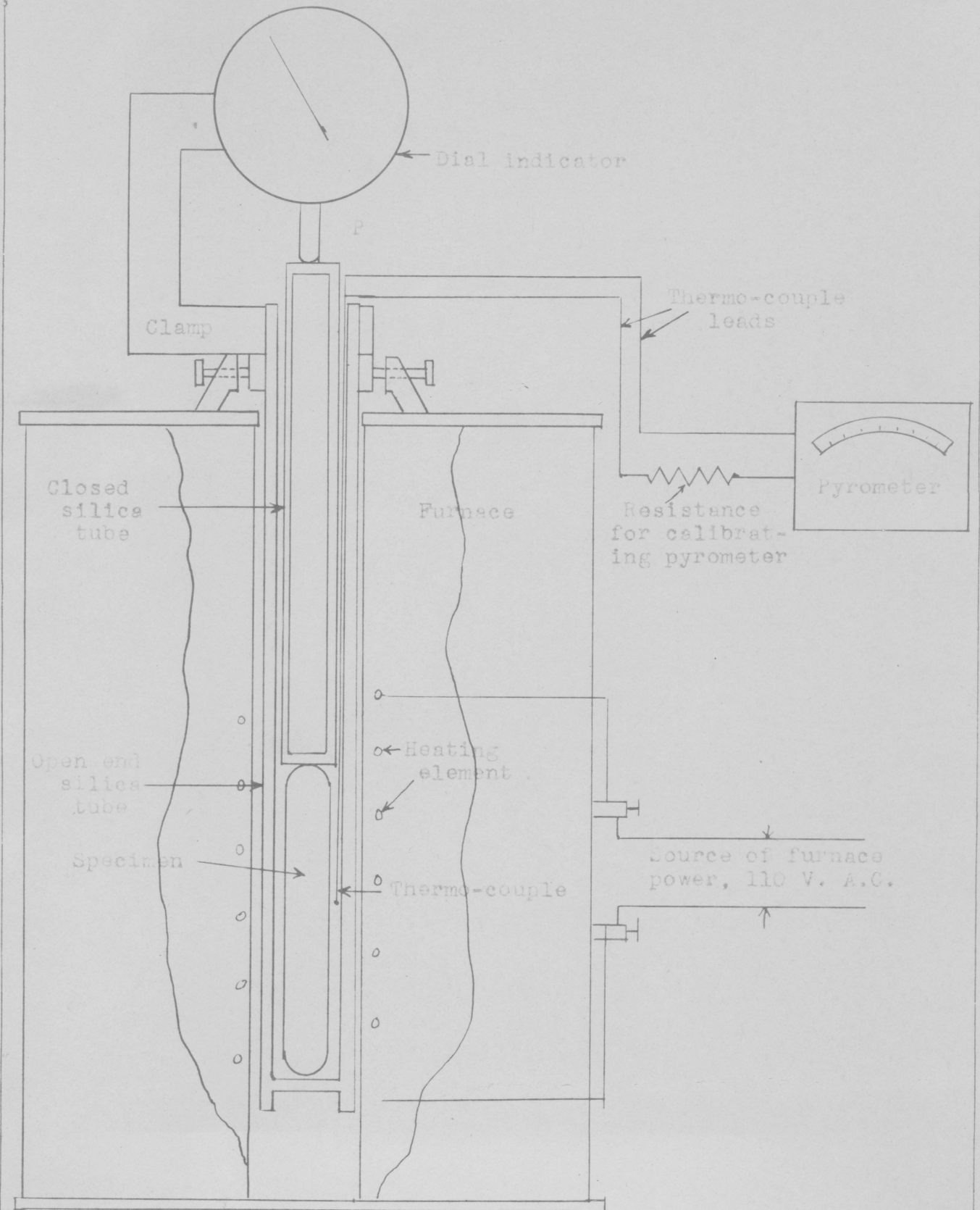
FURNACE AND DILATOMETER

PROCEDURE: The specimen was measured accurately by use of the surface plates, blocks and scale. It was then placed in the large silica tube and the closed end tube placed to rest on the specimen. As the tubes are very fragile and costly, great care was exercised in handling them.

The apparatus was set up as shown in the diagram. The dial readings on the pyrometer watched. When about 1200°F. was reached, readings were taken simultaneously of temperature and elongation, as shown on the dial indicator. These readings were taken at 20°F. increments until elongation began to decelerate. From this point readings were taken as rapidly as possible until shrinkage was complete and normal expansion renewed. Readings were taken then as in the beginning of the run.

The power was shut off of the furnace at about 1780°F. and as the temperature fell, readings were taken as before. The rapid readings were taken on cooling during the period at which the indicator showed expansion.

All readings were recorded on the data sheet, page 41, and a curve plotted between temperature, as abscissa, and elongation, as ordinate, page 42.

CONCLUSIONS: A study of the curve and calculations brings out the fact that, as iron is heated, unfiorm expansion takes place to about 1620°F. This is the Ac_3 point at which alpha iron changes to gamma iron. Shrinkage in **volume** starts here and is accounted for by the following theory;

Alpha iron which exists below this temperature is "Body Centered Cubic", BCC., with a lattice parameter of 2.906 Angstrom units, Å. Gamma iron which exists above this temperature is "Face Centered Cubic", FCC., with a lattice parameter of 3.6 Å. The BCC unit cell contains two atoms and the FCC four. If the volume of the FCC were twice that of the BCC there would be, of course, no change in the total volume of the metal at the transformation point, due to the fact that it requires the atoms of two BCC cells to make one FCC. The difference is shown in the calculations, page 40. It shows a theoretical volume shrinkage of 4.83%, or a linear shrinkage of 1.6%.

For the same reason, upon cooling, a theoretical linear expansion of 1.7% is shown.

The actual experiment showed a linear contraction of .149% on heating and a linear expansion of .166% on cooling.

The great difference between the theoretical and the experimental figures is due to the bulk of the metal and the rapid rate of heating and cooling. The heat gradient between the outer surface and the center of the bar caused expansion and contraction in the center to lag, thus holding back the change which would normally take place in the outer surface.

The temperature difference between the Ac_3 and Ar_3, the heating and cooling transformation points respectively, was due also to the rapid rate of heating and cooling. This difference is shown by the curve.

SOURCES OF ERROR: The divisions on the scale of the pyrometer are in 20 degrees. This made it difficult to read within close limits.

The expansion and contraction of the fused silica tubes were not taken into account. The coefficient of expansion of silica is, however, very low and the temperature range during the transformation of iron is small. This would tend to make the error almost negligible.

CALCULATIONS

Theoretical linear change.

Per cent elongation during allotropic change from α to γ.

Alpha iron is BCC, two atoms per unit cell, Lat. Par. 2.905 $\overset{o}{A}$.

$\dfrac{(2.905)^3}{2} = 12.2576$ cu. $\overset{o}{A}$., volume allowed to each atom.

Gamma iron is FCC, 4 atoms per unit cell, Lat. Par. 3.6 $\overset{o}{A}$.

$\dfrac{(3.6)^3}{4} = 11.664$ cu. $\overset{o}{A}$., volume allowed to each atom.

$12.2576 - 11.664 = .5936$ cu. $\overset{o}{A}$., difference between volume

per atom in alpha and gamma iron.

$\dfrac{.5936}{12.2576}$ X 100. $= 4.86\%$ decrease in volume per cell and is

equal to per cent decrease in total volume of specimen,

since the number of atoms do not change.

$\sqrt[3]{1.0486} - 1. = .016$, or 1.6% decrease in length on heating.

Change from gamma to alpha iron would be,

$\dfrac{.5936}{11.664}$ X 100. $= 5.08\%$. $\sqrt[3]{1.0508} - 1. = .017, = 1.7\%$ increase

on cooling.

- -

Linear change by experiment. From α to γ iron on heating.

Contraction, .92 mm. $-$ .615 mm. $= .205$ mm. from curve.

Length at beginning of change from alpha to gamma. Original

plus expansion from 65 to 1620 degrees F. .0018(1620-65)

$= 2.8$. Original length plus expansion, 203. 2.8 205.8 mm.

$\dfrac{.305}{205.8}$ X 100. $= .149\%$ linear contraction on heating.

$\dfrac{.85 \quad .51}{204.89}$ X 100. $= .166\%$ linear expansion on cooling.

DATA

SPECIMEN, H, ARMCO IRON, LENGTH, 203 MM., DIA., 10. MM.

HEATING				COOLING			
TEMP. °F	DIAL mm	TEMP. °F	DIAL mm	TEMP. °F	DIAL mm	TEMP. °F	DIAL mm
1200	.12	1620	.92	1778	.76	1570	.66
1220	.165	1630	.915	1775	.77	1565	.7
1240	.205	1640	.9	1770	.775	1560	.76
1260	.25	1645	.86	1760	.77	1560	.78
1280	.295	1655	.84	1740	.725	1556	.8
1300	.335	1660	.82	1720	.675	1550	.82
1320	.375	1665	.8	1700	.625	1545	.83
1340	.452	1675	.76	1680	.575	1540	.84
1360	.47	1680	.72	1660	.54	1535	.85
1380	.51	1690	.7	1620	.51	1530	.85
1400	.545	1695	.65	1600	.51	1520	.845
1420	.585	1700	.62	1592	.515	1500	.825
1440	.63	1710	.615	1585	.525	1480	.8
1460	.66	1720	.62	1580	.535	1460	.77
1480	.705	1730	.63	1580	.55	1440	.74
1500	.745	1740	.65	1580	.56	1420	.71
1520	.785	1750	.67	1580	.57	1400	.675
1540	.825	1760	.69	1580	.58	1380	.645
1560	.86	1770	.71	1580	.59	1360	.61
1580	.895	1775	.74	1575	.6	1340	.58
1600	.91	1778	.76	1570	.61	1320	.54
				1570	.62	1300	.51
				1570	.64	1280	.475

Dilatation Curve
for
"Armco" Iron
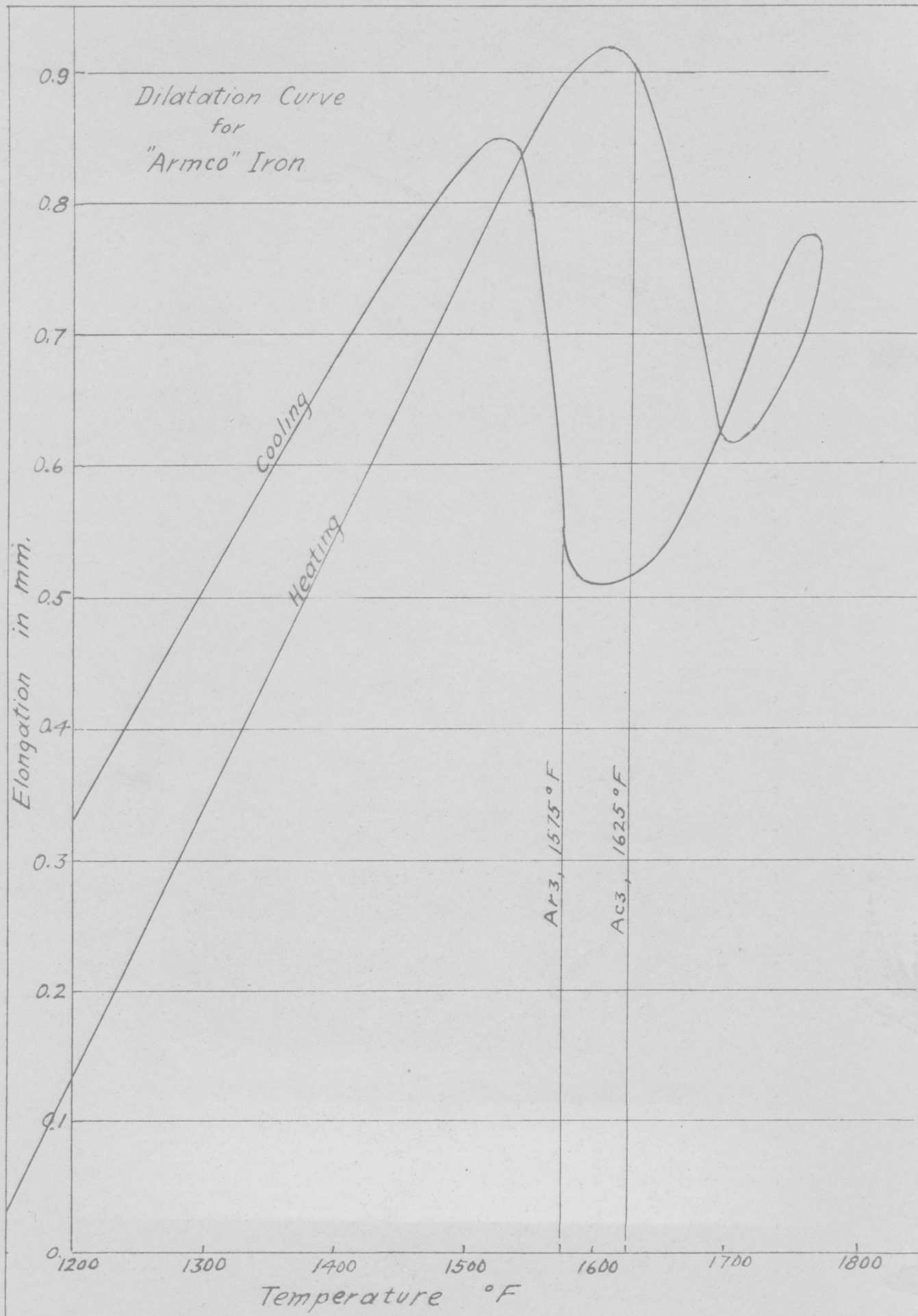
EXPERIMENT NO. 11

THE MALLEABLEIZING OF WHITE CAST IRON

OBJECT: To study the methods and effect of malleableizing white cast iron.

APPARATUS: Electric Muffle Furnace, (Hoskins, Type FD 204,
     No. 5459, with control board and rheostat.)
     Wheelco Capacitrol, (Model 600, No. 6C-0036,
     0 to 2500 degrees F.), Thermo-couple, C-A.
     Standard Brinell machine, microscope and chart.
     Alundum disc cut off machine.
     Bench grinder.
     Surface polishing plate.
     Cincinnati Horizontal Disc Polishing Machine.
     Bausch & Lomb Routine Metallograph, No. 215.

MATERIALS: Twelve specimens of centrifugally cast high
     silicon white cast iron.
     Norton abrasive polishing papers, 2 through 3/0.
     Titanium dioxide and water, polishing compound.
     600 grain alundum powder.
     $1\frac{1}{2}\%$ Nital etching solution.

PROCEDURE: The specimens used in this experiment were broken from a short section of six inch centrifugally cast high silicon white iron pipe.

All except specimen No. 1 were placed in the electric furnace and the power turned on with the control set for a maximum temperature of 1700°F.

A section of No. 1 was cut, polished, etched, (Procedure given on Page 45), and examined under the microscope. Findings were recorded.

The other specimens remained in the furnace, and were removed as shown on the data sheet, page 46. Each specimen was tested for hardness as it was removed from the furnace and cooled.

When it was found that hardness did not change by longer soaking at 1700°F., the control was set for 1300°F, and the other specimens removed as shown on the data sheet.

When soaking at 1300°F. failed to change the hardness the furnace was shut off and the last specimen allowed to cool in the furnace.

Specimens No. 1, 5, and 8 were examined under the microscope and the findings recorded.

TESTING OF SPECIMENS

BRINELL HARDNESS: The specimen was ground on the bench grinder for surface clear of scale. Hardness test was made by the same procedure employed in Experiment No. 3 except that a 3000 Kg. load was used instead of the 500 Kg.

MICROSCOPIC EXAMINATION:

Specimen No. 1.; A small section was cut off with the alundum disc cut off machine. One cross section face was ground on the side of the bench grinder wheel, polished by hand on No. 2, 1, $\frac{1}{2}$, 0, 2/0, and 3/0 emery polishing paper and finally on the disc polishing wheel with 600 grain alundum powder. It was etched with $1\frac{1}{2}\%$ Nital etching solution and examined under the microscope at 100 and 400 magnification.

Specimens No. 5 and 8.; These were treated in the same way as No. 1, except that graphite was applied to the polishing papers No. 0, 2/0, and 3/0 and titanium dioxide was used for final polishing, due to precipitated carbon in the specimens.

DATA

SPECIMENS FROM CENTRIFUGALLY CAST WHITE IRON PIPE

Spec. No.	Temp. °F	TIME IN HOURS & MINUTES				Brinell Read	Hard. No.
		Clock	Furnace	At 1700	At 1300		
1	Room	2:30	0.	0.	0.	2.5	578
2	1700	3:45	1:15	0.	0.	2.7	514
3	1700	4:45	2:15	1:	0.	3.8	255
4	1700	5:45	3:15	2:	0.	3.95	235
5	1700	6:45	4:15	3:	0.	3.95	235
6	1700	7:15	4:45	3:30	0.	3.95	235
7	1300	8:15	5:45	3:30	0.	4.65	167
8	1300	9:15	6:45	3:30	1.	4.65	167
9	1300	10:15	7:45	3:30	2.	4.65	167
10	Cooled in furnace					4.65	167

REMOVAL FROM FURNACE

1, White iron as cast in chill mold.   Polished.

2, Heated to 1700°F. in 1 Hr. 15 min.

3, As No. 2, and held at 1700°F. for 1 hour.

4, As No. 2, and held at 1700°F. for 2 hours.

5, As No. 2, and held at 1700°F. for 3 hours.   Polished.

6, As No. 2, and held at 1700°F. for 3.5 hours.

7, As No. 6, and cooled to 1300°F. in 1 hour.

8, As No. 7, and held at 1300°F. for 1 hour.   Polished.

9, As No. 7, and held at 1300°F. for 2 hours.

10, As No. 9, and cooled in furnace.

CONCLUSIONS: From a study of the curve, page 48, and the microscopic examination of the specimens, it appears that the following takes place during the malleableizing cycle;

White cast iron, specimen No. 1, consisting of pearlite and cementite, showed a Brinell hardness of 578. Microscopic examination showed crystals of pearlite with interstitial cementite, Fig. 1, page 102. When this is heated pearlite changes to austenite at 1333°F. Change in composition is shown in the diagram, page 49. At this temperature a slow reaction takes place. Cementite breaks down forming carbon and, in addition, gamma ferrite which dissolves cementite, forming pro-eutectic austenite. The rate of this change reaches maximum at 1700°F. Time permits the change to continue until equilibrium is established. Here the hardness was found to be Brinell No. 235. Microscopic examination showed pearlite, a small amount of alpha ferrite and nodular carbon, Fig. 2, page 102.

Since primary austenite is a solid solution and will not precipitate carbon at this temperature, the temperature was lowered to 1300°F. or just below the eutectoid point. At 1333°F., all of the austenite changes to pearlite. Held at 1300°F. for a period of time, pearlite precipitates carbon, forming alpha ferrite and carbon. The hardness test showed Brinell No. 167. The specimen was soft and fairly malleable. Microscopic examination showed large crystals of alpha ferrite and nodular carbon, Fig. 3, page 102.

Hardness Curve (Malleableizing Cycle)
for
High Si. White Cast Iron Pipe.

Temperature-Time Curve

Temperature - Time Curve
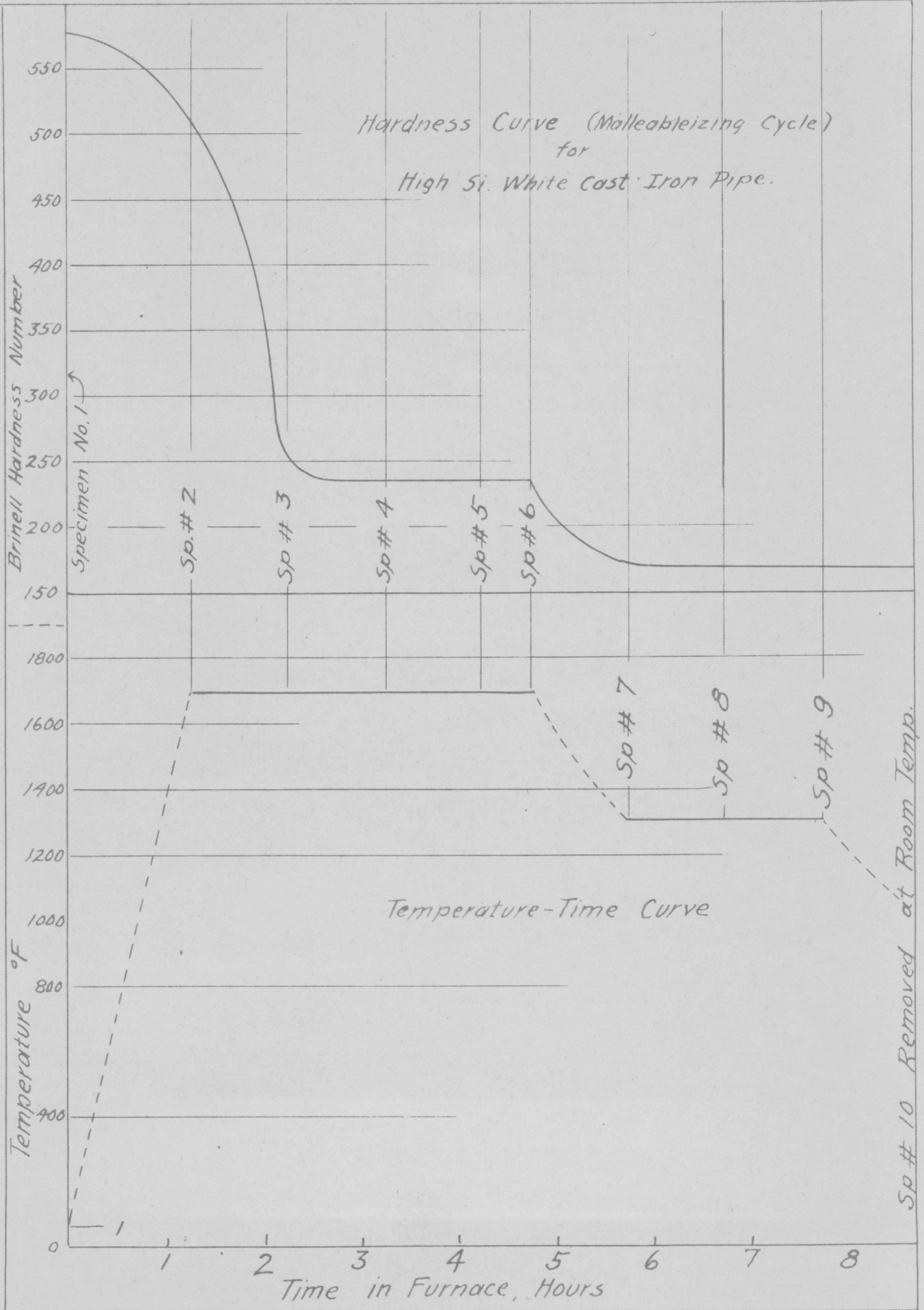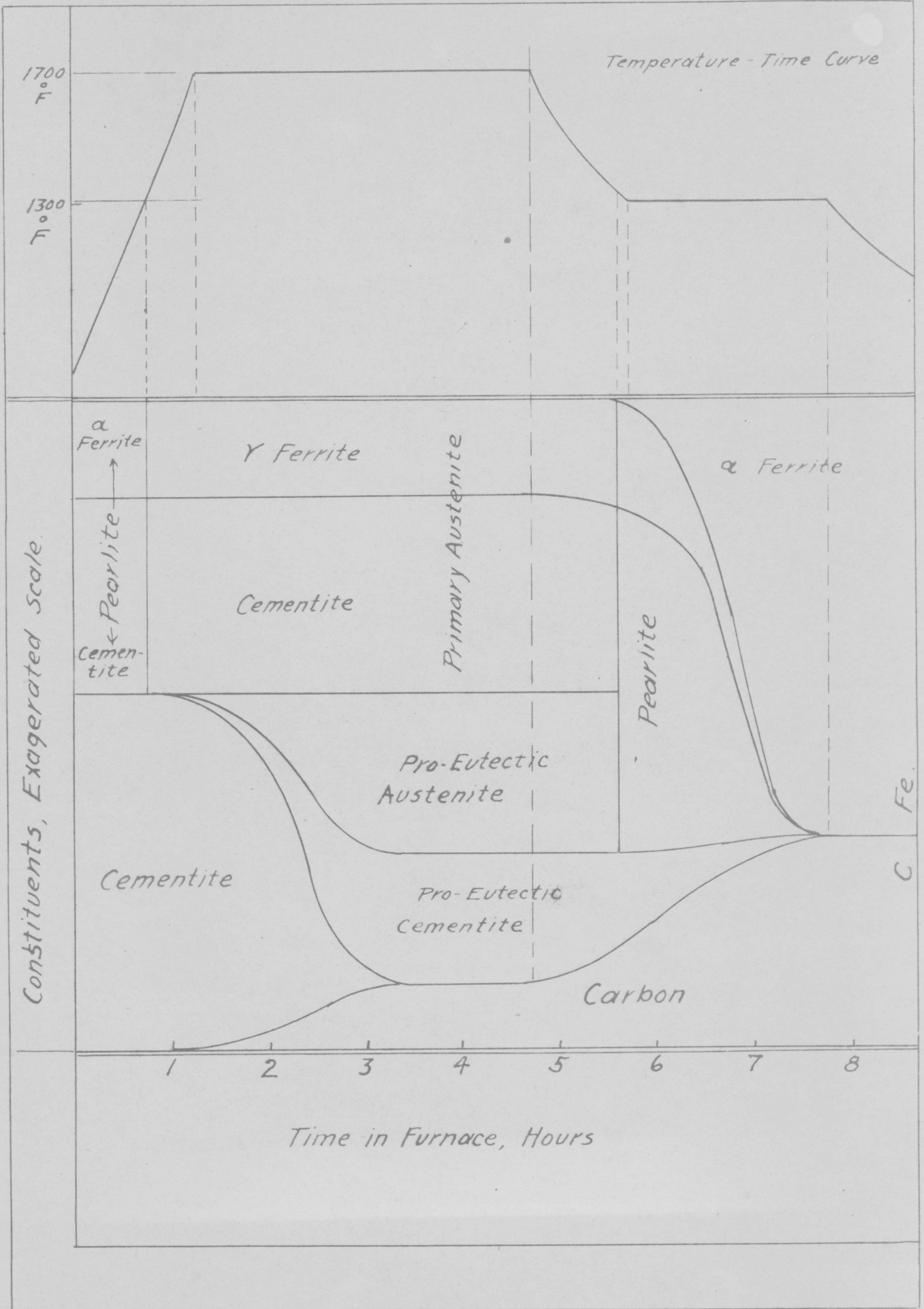
SECTION II

METALLURGY LABORATORY REPORTS

VIRGINIA POLYTECHNIC INSTITUTE

EXPERIMENTS PERFORMED UNDER THE DIRECTION OF

Professor H. V. White

REPORTS SUBMITTED BY

E. J. Freeman

EXPERIMENT NO. 12

THE MICROSTRUCTURE OF THE UNSTABLE EQUILIBRIUM PHASES

OF HYPEREUTECTOID CARBON STEELS

OBJECT: To study the microstructure of martensite, second-
ary troostite, secondary sorbite, and spheroidized cementite.

APPARATUS: Electric Multiple Unit Furnace, (Hevi-Duty

Electric Co. No. 43502).

Wheelco Capacitrol, (Model 600, No. 6C-0036,

0 to 2500°F.), Thermo-couple, C-A.

Alundum disc cut off machine.

Bench Grinder.

Surface polishing plate.

Cincinnati Horizontal Disc polishing machine.

Bausch and Lomb Routine Metallograph, No. 215.

MATERIALS: Specimen of 1.2% carbon steel $\frac{1}{2}$" square by 6".

Norton abrasive polishing papers, 1 through 3/0.

600 grain alundum powder.

$1\frac{1}{2}$% Nital etching solution.

10% Brine solution.

PROCEDURE: A six inch specimen was cut from a $\frac{1}{2}$ inch stock
bar of 1.2% carbon steel as rolled. This specimen was placed
in the furnace and the temperature brought up to 1700 de-
grees F., held for 15 minutes, and quenched in 10% brine so-
lution. A sample specimen, No. 1, was cut from this bar,
polished, etched and examined.

The remainder of the original specimen was cut in three parts, specimens No. 2, 3, and 4. All were placed in the furnace, heated, and cooled as shown on the data sheet, page 52. A sample was cut from each, polished, etched and examined under the microscope. The remainder of specimen No. 4 was replaced in the furnace and treated as shown in the data as specimen No. 5. A sample was cut from this specimen, polished, etched, and examined under the microscope. Each specimen was tested for hardness by filing.

CONCLUSIONS: The microscopic examination and file test showed the following:

No. 1, Formation of martensite which is a solid solution of cementite in alpha ferrite. Due to quick cooling this is an unstable phase. The file test showed extreme hardness.

No. 2, A needle like structure of slightly tempered martensite. A negligible amount of cementite precipitated. The file test showed very little change in hardness.

No. 3, More highly tempered martensite, with slight softening.

No. 4, Secondary troostite, much softer than No. 3.

No. 5, Secondary sorbite. Cementite precipitated and spheroidized to a small extent. File test showed great reduction in hardness.

DATA

Specimen: 1.2% carbon steel as rolled.

HEAT TREATMENT   RESULT

    HARDENED   TEMPERED

No.	Temp. °F	Held Hrs.	Cooled	Temp. °F	Held Hrs.	Cooled	
1.	1700	.25	Quench- ed in	Not tempered			Martensite
2.	1700	.25	10% Brine	300	.5	Air	Tempered martensite
3.	1700	.25	"	500	.5	Air	"
4.	1700	.25	"	650	.5	Air	2nd troostite
5.	1700	.25	"	650	4.5	Furnace	2nd sorbite

Polishing with Norton abrasive polishing papers
No. 2, 1, ½, 0, 2/0, 3/0.

Finish with polishing disc and 600 grain alundum powder.

Etching with 1½% Nital.

EXPERIMENT NO. 13

THE FORMATION OF PRIMARY TROOSTITE IN MARTENSITE

OBJECT: To study the primary unstable phase, "Troostite."

APPARATUS: Equipment used in Experiment No. 12.

Permanent magnet.

MATERIALS: Sample of .85% carbon steel.

Other materials used in Experiment No. 12.

PROCEDURE: The sample specimen of eutectoid composition carbon steel, was placed in the furnace. The temperature was brought up to 1700 degrees F. and held for about 15 minutes. The specimen was then removed from the furnace and tested at short intervals with the permanent magnet. When it showed first signs of magnetization it was quenched in 10% brine solution.

A sample was cut from the specimen, polished and etched as explained in Experiment No. 12 and examined under the microscope.

CONCLUSIONS: Microscopic examination showed, at about
650X magnification, small nodules of primary troostite in
a field of martensite. The nodules consisted of extremely
fine pearlite which began to form from austenite at the
Ar_1 point, which, in eutectoid steel, coincides with the
Ar_2 and Ar_3 points. At this point, Ar_1, where non-magnetic
gamma iron changes to magnetic alpha iron, slow cooling
would tend to form pearlite. However, the instant that
this point was reached, as shown by the magnet test, the
specimen was quenched. This rapid cooling caused the little
pearlite which had time to form, to be extremely fine grain-
ed and nodular, and is called troostite, Fig. 4, page 102.
That which did not have time to form troostite remained in
the unstable solid solution state, or martensite.

The nodular primary troostite appears as dark areas,
almost circular, with only faintly visible radial lines of
extremely fine pearlite.

EXPERIMENT NO. 14

THE MICROSTRUCTURE OF PEARLITE AND PRIMARY SORBITE

OBJECT: To study the fundamental differences between pearl-
ite and primary sorbite.

APPARATUS: Equipment used in Experiment No. 12 and 13.

MATERIALS: Two samples of .50% carbon steel cut from
            stock bar $\frac{1}{2}$" square as rolled.
        Other materials used in Experiments No. 12 and 13.

PROCEDURE: The two specimens of .50% carbon steel were
placed in the furnace, heated to 1700°F. and held at
that temperature for 15 minutes. The power was shut off
and specimen No. 1 removed from the furnace and cooled in air.
Specimen No. 2 was left to cool in the furnace.

     One short piece was cut from each of the original
specimens, polished, etched and examined under the micro-
scope by the same procedure employed in Experiment No. 13.

CONCLUSIONS: Specimen No. 2, which was cooled in the fur-
nace is here considered first.

     The slow cooling allowed time for the precipitation of
ferrite and the consequent change in austenite to eutectoid
composition. The austenite, by slow cooling through the

Ar_1 point, changed to pearlite of eutectoid or .83% carbon in composition and was 50/83, or about 60.5% of the total metal. The pearlite is identified by the lammelar structure as shown in the dark areas, Fig. 6, page 102. The light area is ferrite, about 39.5% of the steel.

Specimen No. 1 was cooled in air. This more rapid cooling did not allow equilibrium to become established between the austenite and the precipitated ferrite. There fore when the Ar_1 point was reached, less than the normal amount of ferrite had been precipitated and the austenite did not reach eutectoid composition. Thus the composition of the pearlite formed was less than .83% carbon and the amount greater than 60.5% of the total. The pearlite formed was extremely fine grained due to the rapid cooling through the Ar_1 point. This fine pearlite is called sorbite, and differs from normal pearlite in that the structure does not appear lammelar. Figure 5, page 102 shows dark areas, sorbite, and light areas, ferrite.

EXPERIMENT NO. 15

THE WIDMANSTATTEN STRUCTURE OF CARBON STEEL

OBJECT: To study the Widmanstatten lines formed in low carbon steel by air blast cooling from well above the critical temperature.

APPARATUS: Equipment used in Experiment No. 12.

High pressure air jet.

MATERIALS: Two specimens of .26% carbon steel cut from

half inch square stock bar as rolled.

Materials used in Experiment No. 12.

PROCEDURE: The steel specimens, No. 1 and 2, were placed in the furnace and the temperature brought to 2000°F. and held for 15 minutes. Specimen No. 1 remained and was cooled in the furnace. Specimen No. 2 was removed and cooled by air blast to well below red heat.

A small specimen was cut from each of the larger samples, polished, etched, and examined under the microscope. The findings were recorded as shown under "Conclusions."

CONCLUSIONS: Specimen No. 1, cooled in the furnace, showed large crystals of pearlite in a field of ferrite, Fig. 7, page 102. The pearlite is identified by the lammelar structure. The composition was eutectoid, and the amount about 26/83, or 31.3% of the total metal.

Specimen No. 2, which was cooled by air blast through the Ar_1 point, showed areas of sorbite cut by traces of ferrite planes, Fig. 8, page 102. The theory substantiated by this, the Widmanstatten structure, is that rapid cooling does not allow time for the precipitated ferrite to reach the grain boundries of the austenite. This ferrite therefore forms, within the austenite crystal, planes parallel to the planes of greatest atomic population. These are octahedral planes cut through the cubic cells, and are predominantly "110" and "100" planes in the BCC and FCC cubic lattices respectively. Martensite is thought to be the Widmanstatten of extremely fine pattern, accounting for the needle like appearance.

The light lines seen under the microscope were traces of the planes. The rapid cooling did not permit equilibrium to be established between the ferrite and the austenite. Thus the sorbite formed from austenite was of less than eutectoid composition and the amount greater than the normal 31.3% which would occur in pearlite from a .26% carbon steel.

EXPERIMENT NO. 16

THE EFFECT OF COOLING RATE ON HARDNESS OF CARBON STEELS

OBJECT: To study the hardness effect of different cooling
rates on carbon steels of varying carbon content.

APPARATUS: Furnace and controls used in Experiment No. 12.

Alundum disc cut off machine.

Bench grinder.

Brinell hardness machine, microscope and chart.

Steel marking dies.

MATERIALS: Three $\frac{1}{2}$ X 2" specimens of each of the steels
listed in the table below, from stock bar as
rolled.

SPECIMEN	C%	Mn%	P%	S%	Si%
A	.26	.52	.029	.040	.16
B	.85	.72	.038	.035	.21
C	.15	.77	.013	.136	.06
D	.50	.90	.013	.038	.27
E	1.03	.48	.039	.036	.22
H	"Armco" ingot iron, Approx. 0% carbon.				

Ten per cent brine solution

Quenching oil

Iron wire

PROCEDURE: The specimens were stamped for identification, wired together in three batches, NO. 1, 2 and 3. Each batch contained one each of the specimens listed under "Materials," page 59. Total was 6 specimens per batch. The wiring was done in such a way that the specimens were separated for even quenching on all surfaces.

The three batches were placed in the furnace and the temperature brought to 1700°F. This temperature was held for 15 minutes, and the furnace shut off.

Batch No. 1 was removed and cooled in air. No. 2 was quenched in oil and No. 3 in brine solution.

One surface of each specimen was ground to remove scale and prepare surface for Brinell impression.

Two Brinell impressions were made with 10 cm. ball and 3000 Kg. load on each and the hardness recorded as shown on the data sheet, page 63.

From this data the hardness curves were plotted as shown on the curve sheets, pages 64 and 65.

CONCLUSIONS: The curves, page 64, plotted between carbon content, as abscissa, and Brinell hardness, as ordinate, show the following:

(1) That the greatest variation in hardness due to carbon content was effected by the most rapid cooling rate, brine quenching, and the smallest by the slowest cooling rate, air cooling.

(2) That, with brine quenching, the hardness increased with increasing carbon content to a maximum hardness at about .70% carbon and rapidly decreased with higher carbon content.

(3) That, with air cooling, maximum hardness was reached at about .90% carbon, near the eutectoid, and that with an intermediate cooling rate, oil quenching, the maximum hardness was not reached in the series of specimens used. The curve indicates that maximum hardness would fall very near the maximum content of carbon steels, 1.7% carbon.

(4) That the hardness effect on pure iron due to heat treatment was negligible.

The curves, page 65, were plotted from points on the composition-hardness curves with cooling time as abscissa and hardness as ordinate, for five steels of different carbon content.

The units of cooling time were calculated from data furnished by the A. S. M. Handbook on quenching media.

The cooling rate for a 4 mm. ball is given as follows; Quenched in water, 3260 °F. per second, from 1328 °F. to 1022 °F. which is through the critical range.

With this taken as unity, other critical rates are given as follows:

10% Brine,   time 1/1.96 or   .51

Oil,   time 1/0.2   or   5.0

Air,   time 1/.028 or 35.0

These figures are taken as relative regardless of the bulk of the specimen cooled.

The curves show:

(1) That in low carbon steels, the decrease in hardness with increase in cooling time is very great in the rapid cooling range.

(2) That as the carbon content is increased, this change becomes more gradual and approaches a straight line possibly near the limit of carbon steels or 1.7% carbon.
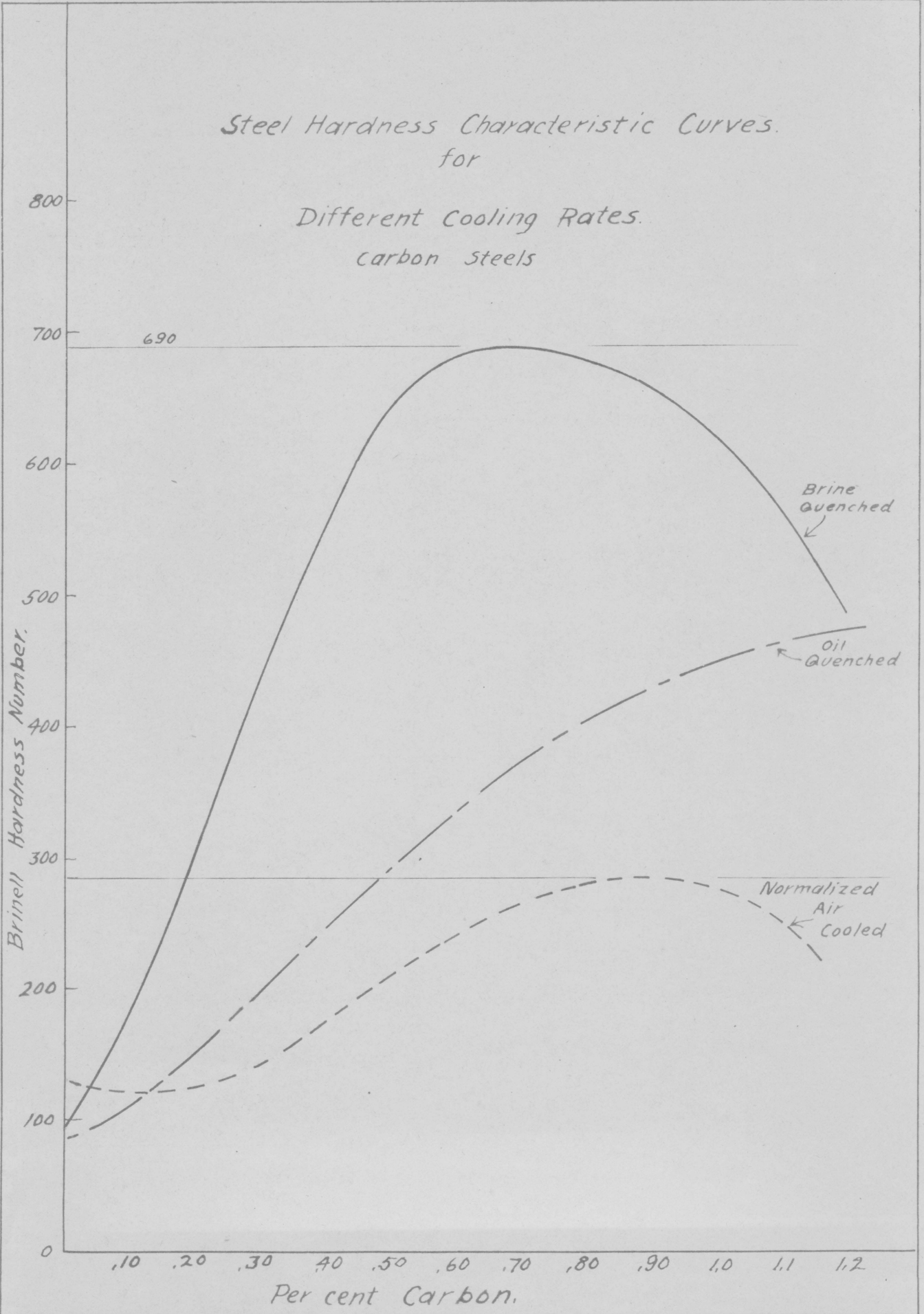
DATA

BATCH	SPECI-MEN	C%	TREAT-MENT	BRIN. IMPRESS. 1	IMPRESS. 2	DIA. MM. Av.	BRIN. HARD
1	H	0.0	1700°F	5.15	5.5	5.32	125
1	C	.15	cooled	5.20	5.80	5.50	116
1	A	.26	in	5.20	5.20	5.20	131
1	D	.50	air	4.10	4.20	4.15	212
1	B	.85	"	3.60	3.60	3.60	285
1	E	1.03	"	3.70	3.70	3.70	269
2	H	0.0	1700°F	6.30	6.35	6.40	86
2	C	.15	Quench-	5.15	5.25	5.20	131
2	A	.26	ed in	4.40	4.45	4.43	185
2	D	.50	oil	3.50	3.55	3.53	269
2	B	.85	"	3.00	3.00	3.00	415
2	E	1.03	"	2.90	2.85	2.88	454
3	H	0.0	1700°F	6.00	6.10	6.05	94
3	C	.15	Quench-	4.10	3.65	3.88	244
3	A	.26	ed in	*	*	*	*
3	D	.50	brine	2.40	2.40	2.40	653
3	B	.85	"	2.40	2.35	2.37	668
3	E	1.03	"	2.50	2.50	2.50	601

* No. 3-A. showed very uneven hardness. Several tests were made
on each surface.
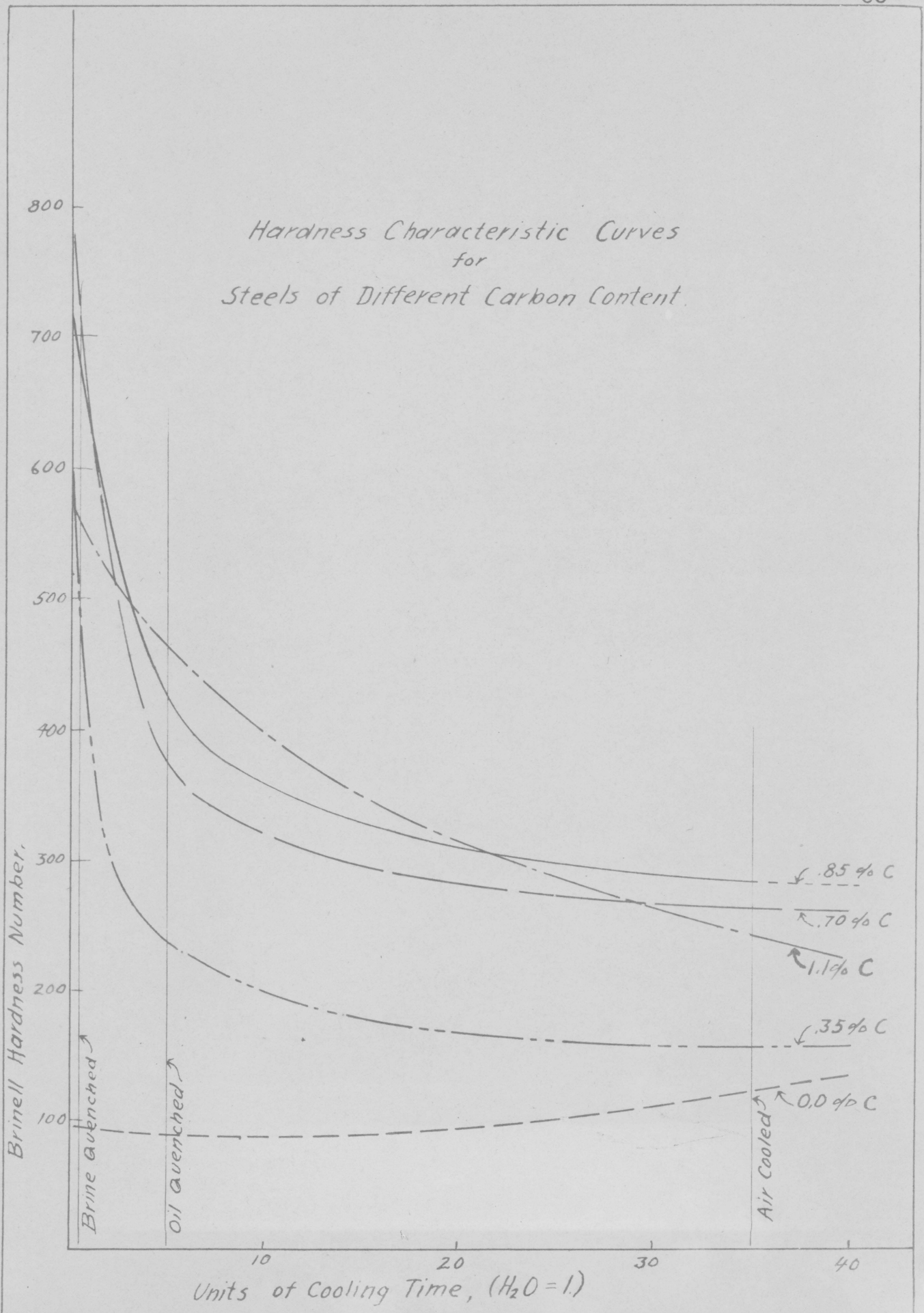
Hardness ranged from 195 to 415.

Steel Hardness Characteristic Curves.

for

Different Cooling Rates.

Carbon Steels

690

Brine
Quenched

Oil
Quenched

Normalized
Air
Cooled

Brinell Hardness Number.

800

700

600

500

400

300

200

100

0

.10 .20 .30 .40 .50 .60 .70 .80 .90 1.0 1.1 1.2

Per cent Carbon.

Hardness Characteristic Curves
for
Steels of Different Carbon Content.

EXPERIMENT NO. 17

THE HARDENING AND TEMPERING OF EUTECTOID CARBON STEEL

OBJECT: To study the hardness effect of temperature and time in the tempering or drawing of eutectoid carbon steel from the martensitic state.

APPARATUS: Furnace and controls used in Experiment No. 12. Brinell hardness machine, microscope and chart. Bench grinder. Alundum disc cut off machine. Steel numbering dies.

MATERIALS: Thirteen specimens of .85% carbon steel cut to 2" length from $\frac{1}{2}$" sq. stock bar as rolled. Iron wire. Ten per cent brine solution.

PROCEDURE: The thirteen specimens of eutectoid carbon steel were wired together, spaced for even quenching, and placed in the furnace. Temperature was brought up to about $1700°F$. and held for 15 minutes to insure thorough soaking. The furnace was then shut off and the specimens removed and quenched in 10% brine solution.

Specimen No. 1 was tested for hardness. The other 12 specimens were grouped in three batches of four specimens each. Each batch was, in turn, placed in the furnace and tempered as shown in the data, page 69.

Each specimen was tested for hardness and the results recorded, page 69.

One curve was plotted between time held in the furnace at constant temperature, as abscissa, and Brinell hardness, as ordinate, for each tempering temperature.

On the same curve sheet the temperature-hardness curve was plotted as follows:

With temperature as abscissa and hardness as ordinate, the curve was plotted through the low-hardness points taken from the time-temperature curves. These points are those which show no appreciable decrease in hardness due to time. They were all taken at about two hours.

CONCLUSIONS: From a study of the curves, page 70, it is seen that in tempering martensite the important factor is temperature rather than time. The "Hardness-time" curves show that the hardness rapidly decreases at a given temperature to a point below which time does not appreciably reduce it.

The "Hardness-temperature" curve, which was plotted through the projected low points on the "Hardness-time" curves, indicates that the greatest effect on hardness in tempering martensite falls in the range of temperature between 300°F. and 1000°F.

Very little change takes place below 300°F. The curve reaches maximum slope at about 700°F. and continues to show softening of the steel through the limit of tempera-

ture to which the experiment was carried, about 1292 °F.
This is just below the eutectoid temperature which is the
limit of tempering.

This highest temperature is above the practical draw-
ing point and is used to make steel more machinable by
spheroidizing the cementite.

SOURCES OF ERROR: The specimens of steel used in this
experiment were not pure carbon steels, but contained small
amounts of Mn., P., S., and Si. The curves, therefore, do
not coincide exactly with those for pure carbon steel.

The "Hardness-time" curves are incomplete due to the
fact that there was some time effect on tempering while the
furnace was being brought up to temperature. However,
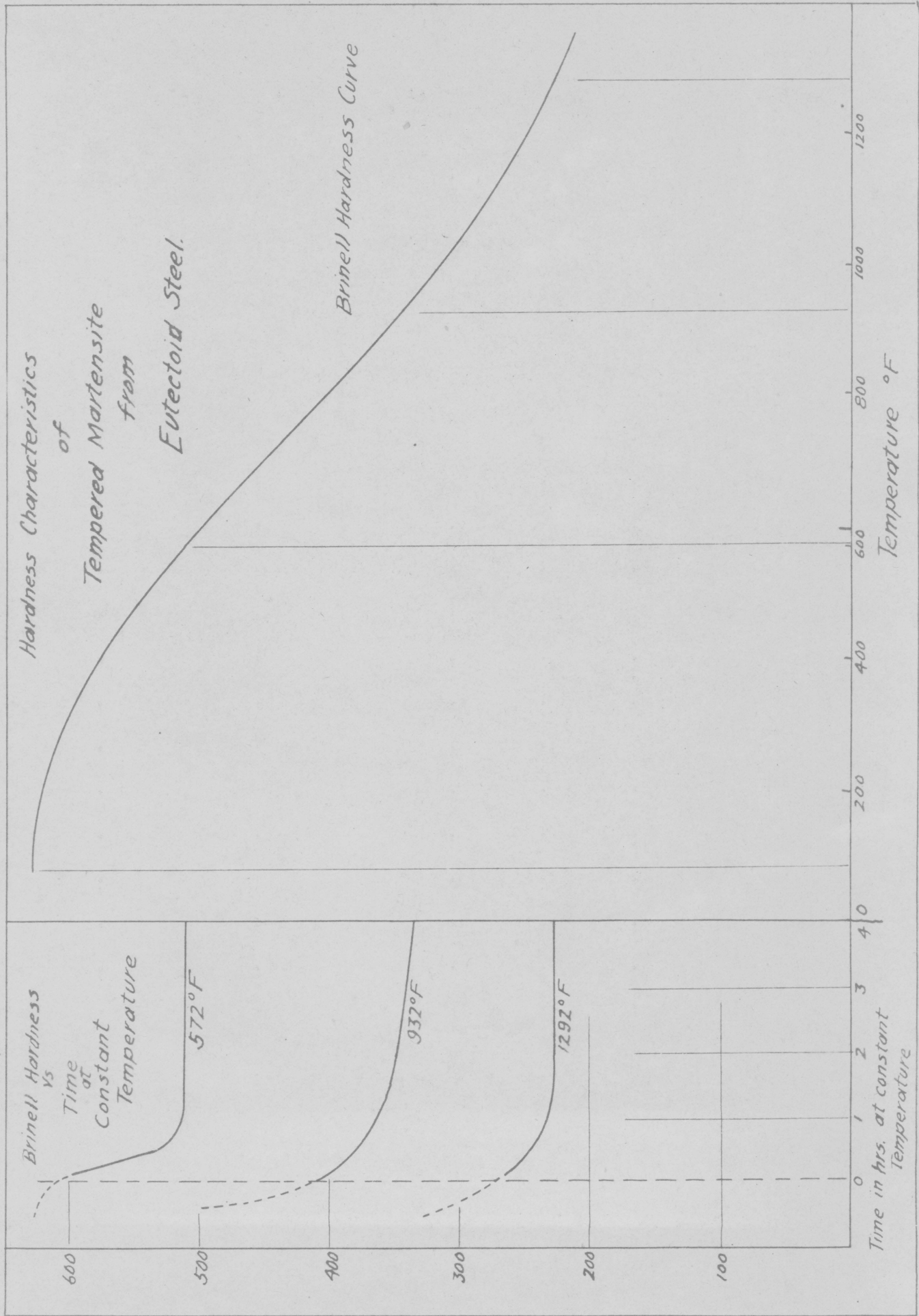this did not affect the low hardness point on the curves.

DATA

Specimen, .85% carbon steel.

All pieces heated to 1700 °F., held 15 minutes

and quenched in 10% brine solution.

SPECI- MEN NO.	TEMPERING °F TIME HRS.		COOL- ED	---BRINELL HARDNESS--- IMPRESSION DIAMETER			HARD NO.
				1	2	Av.	
1.		.		2.45	2.45	2.45	627
2.	572	.5	Air	2.65	2.65	2.65	534
3.	572	1.0	"	2.70	2.70	2.70	514
4.	572	2.0	"	2.70	2.70	2.70	514
5.	572	3.0	"	2.70	2.70	2.70	514
6.	932	.25	"	3.10	3.10	3.10	388
7.	932	.5	"	3.15	3.15	3.15	375
8.	932	1.0	"	3.2	3.2	3.2	363
9.	932	2.0	"	3.3	3.3	3.3	341
10.	1292	.25	"	3.8	3.8	3.8	255
11.	1292	.5	"	3.9	3.9	3.9	241
12.	1292	1.0	"	4.0	4.0	4.0	229
13.	1292	1.0	*	4.0	4.0	4.0	229

* Cooled in furnace.

Hardness Characteristics
of
Tempered Martensite
from
Eutectoid Steel.

Brinell Hardness Curve

Temperature °F

Brinell Hardness
vs
Time
at
Constant
Temperature

572°F

932°F

1292°F

Time in hrs. at constant
Temperature

EXPERIMENT NO. 18

THE SOFTENING EFFECT OF TEMPERATURE IN TEMPERING OF

MARTENSITE

OBJECT: To study the effect of temperature on hardness,

in the tempering or drawing of martensite formed in eutec-

toid carbon steel.

APPARATUS: Equipment used in Experiment No. 17.

MATERIALS: Eight samples of eutectoid carbon steel cut to

2" length from $\frac{1}{2}$" square stock bar as rolled.

Iron wire.

Ten per cent brine solution.

PROCEDURE: The specimens were stamped for identification,

wired together spaced for even quenching, and placed in the

furnace. The temperature was brought up to 1500 °F. and

held for 15 minutes. The furnace current was then shut off

and the specimens quenched in 10% brine solution.

One piece was tested and Brinell hardness recorded as

shown on the data sheet, page 74. The furnace was allowed

to cool to about 250 °F. All specimens were placed in the

furnace and the rheostat control set for slow heating, as

shown by the heating curve, page 75.

The furnace power was turned on and the specimens

removed and cooled in air as shown in the data, page 74.

The first five specimens removed were quickly tested for

hardness and replaced in the furnace for treatment as specimens drawn at higher temperatures.

Curves were plotted as follows:

One was plotted between temperature, as abscissa, and time, as ordinate, to show the heating rate of the furnace.

The "Temperature-hardness" curve was plotted between drawing temperature, as abscissa, and Brinell hardness, as ordinate.

CONCLUSIONS: The "temperature-time" curve, JK, page 75, shows that the heating rate was high at the beginning of the run, and decreased, becoming about constant at 750 °F. and remained so through the complete run.

The "Temperature-hardness" curve, GIA, shows decrease in hardness with increase in temperature. This decrease was slow through 450 °F. and showed most rapid change at about 700 °F. The rate of softening decreased until about 1320 °F. was reached. This is very close to the eutectoid temperature. Here the hardness decreased almost suddenly to A, and then rose rapidly. The theory is, that as the temperature crosses the eutectoid, austenite is formed, from which, on cooling in air, sorbite is formed. The hardness was increased to CD which was taken from a previous experiment on the same steel. The dotted line through B shows the theoretical turn of the curve. This would have been reached if time had been given for complete change to

austenite. The point, A, would thus have been shifted to B or the eutectoid point.

The dotted curve, EIF, is a section of the curve taken from Experiment No. 17, and was placed on this curve sheet to show the effect of time in tempering. Through the practical tempering range, 450 °F. to 770 °F., the time and temperature hardness curve (dotted), falls below the curve, GA. Below 425 °F., it lies above, indicating that even at constant rising temperature the time element played an important part in tempering at low temperatures. No attempt is here made to explain the sudden drop in hardness shown by the line, EG.

SOURCES OF ERROR: The same sources of error encountered in Experiment No. 17 were prevalent here.

DATA

TEMPERING OF MARTENSITE

Eutectoid carbon steel, heated to 1500 °F. and quenched in 10% brine solution.

All specimens cooled in air after tempering.

| SPECIMEN NO. | DRAW TEMP. °F. | TIME IN FURN. MIN. | ------BRINELL HARDNESS------ | | | HARD NO. |
| | | | IMPRESSION DIAMETER | | Av. | |
			1	2		
1	Room	0.	2.4	2.4	2.4	635
2	300	2.	2.5	2.5	2.5	601
3	500	9.	2.55	2.55	2.55	578
4	700	22.	2.6	2.65	2.63	545
5	900	45.	2.9	2.9	2.9	444
6	1100	69.	3.3	3.3	3.3	341
7	1200	79.	3.4	3.5	3.45	311
8	1300	90.	3.6	3.6	3.6	285
9	1320	93.	3.8	3.8	3.8	255
10	1330	94.5	3.8	3.8	3.8	255
11	1340	96.	4.0	4.0	4.0	229
12	1350	97.5	3.9	3.9	3.9	241
13	1360	99.5	3.8	3.8	3.8	255

Tempering Characteristic Curves
for
Eutectoid Carbon Steel
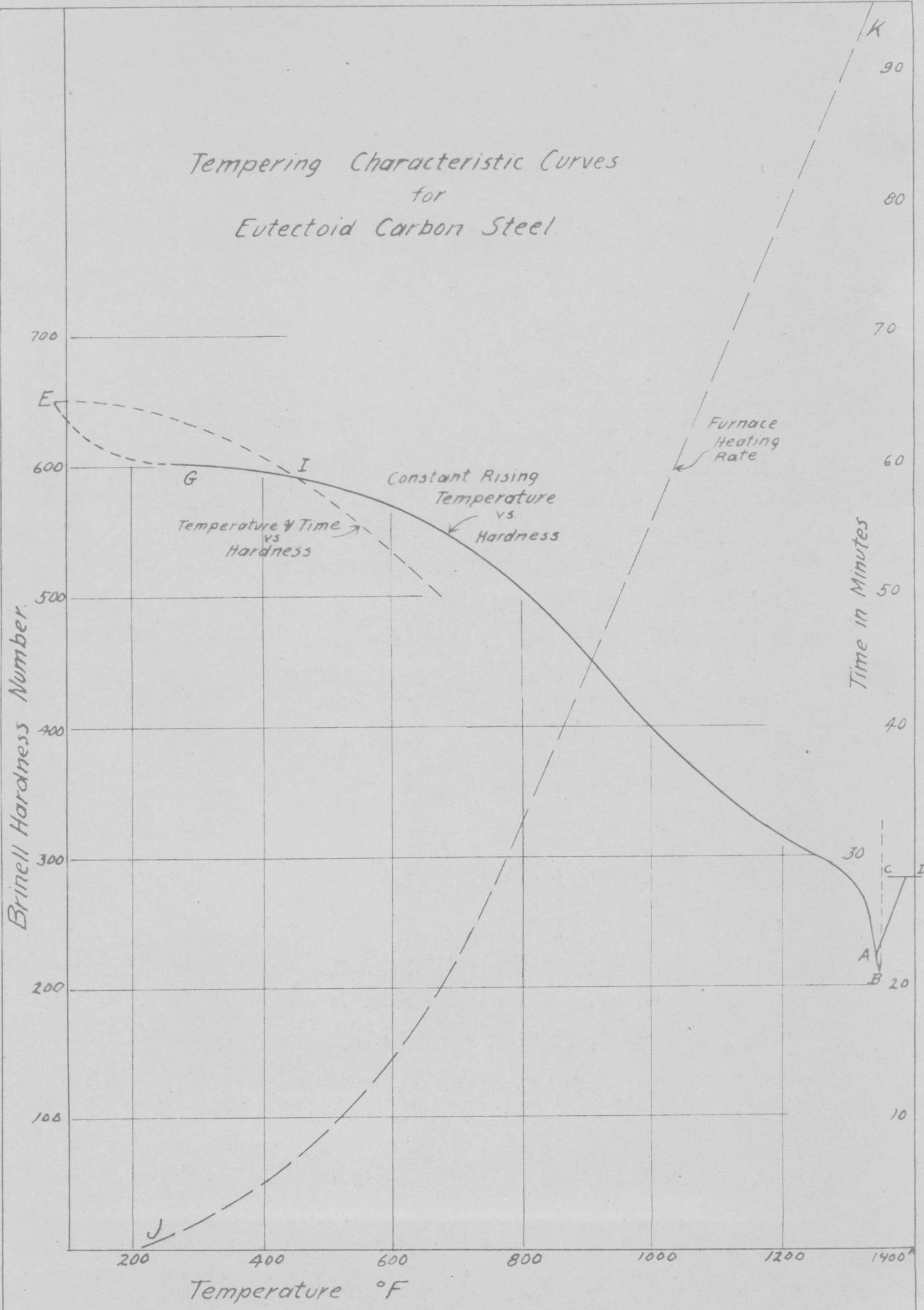
EXPERIMENT NO. 19

THE AUSTEMPERING OF STEEL

OBJECT: To study the method of Austempering and the dif-
ference in properties between austempered steel and tem-
pered or drawn martensite.

APPARATUS: Electric furnace and controls used in Experi-
ment No. 12.

Thermo-Electric pyrometer, (Hoskins, Type HA,

No. O, Serial No. 17060 for C-A thermo-couple).

Chromel-alumel thermo-couple and leads.

Electric furnace, (Vertical tube resistance)

Cast iron crucible, 400 cc.

Hack saw, bench vise, hammer and file.

Brinell hardness testing machine, (120 Kg., 2 mm.)

Rockwell hardness testing machine, (Diamond

cone, 150 Kg., No. 3F-436, with chart).

Alundum disc cut off machine.

MATERIALS: Two specimens of $\frac{1}{4}$" Dia. drill rod, .75% C. steel.

Lead quenching bath.

Ten per cent brine solution.

EXPLANATION OF SET UP: The Hevi-Duty furnace and controls
are standard set up as used in Experiment No. 12.

The vertical tube electric furnace was 110 volt resis-
tance type similar to that used in Experiment No. 1, but of
larger size.

The crucible was cast iron with capacity of about 500 cc.
This crucible, which contained the lead for quenching, was
placed in the furnace tube and the lead held in the molten
state.   The temperature was read with the Thermo-electric
pyrometer and chromel-alumel thermo-couple.   The couple
was immersed in the molten lead.   The temperature of the
furnace was controlled manually by a line rheostat.

PROCEDURE: The two specimens of steel were placed in the
Hevi-Duty heat treating furnace, the control set for 1500
°F., and the power turned on.   The temperature was brought
up to 1500°F. and held for 30 minutes.

During this procedure the lead was melted in the iron
crucible placed in the vertical tube furnace.   The tempera-
ture of the lead was brought up to 650°F. and held at this
temperature by manually controlled line rheostat.

Specimen No. 1 was removed from the heat treating
furnace and quenched in 10% brine solution, and then immers-
ed in the lead bath.   No. 2 was removed and quickly immersed
in the lead bath.   Both specimens were held in the lead bath
at 650 °F., for 30 minutes, removed and cooled in air.

Each specimen was tested for comparison of properties by the following procedure:

One end of the specimen was held in the bench vise and the other end struck with a hammer until rupture occurred.

Sections were cut from each specimen and Brinell, Rockwell, and file test applied for hardness determination.

CONCLUSIONS: Both specimens showed very nearly the same hardness by all tests, approximately Brinell, 400.

Specimen No. 1, drawn martensite, appeared to be very brittle, with low elastic limit and extremely low ultimate strength. No permanent bending was possible without rupture.

Specimen No. 2, austempered, showed high elastic limit, great toughness, and extremely high ultimate strength. The specimen could be bent through an angle of about 45 degrees before rupture occurred.

This method of heat treatment is limited to pieces of small cross section since, as the Bain "S" curve shows, extremely rapid cooling must be effected and stopped at high temperature. This is impossible with large sections.
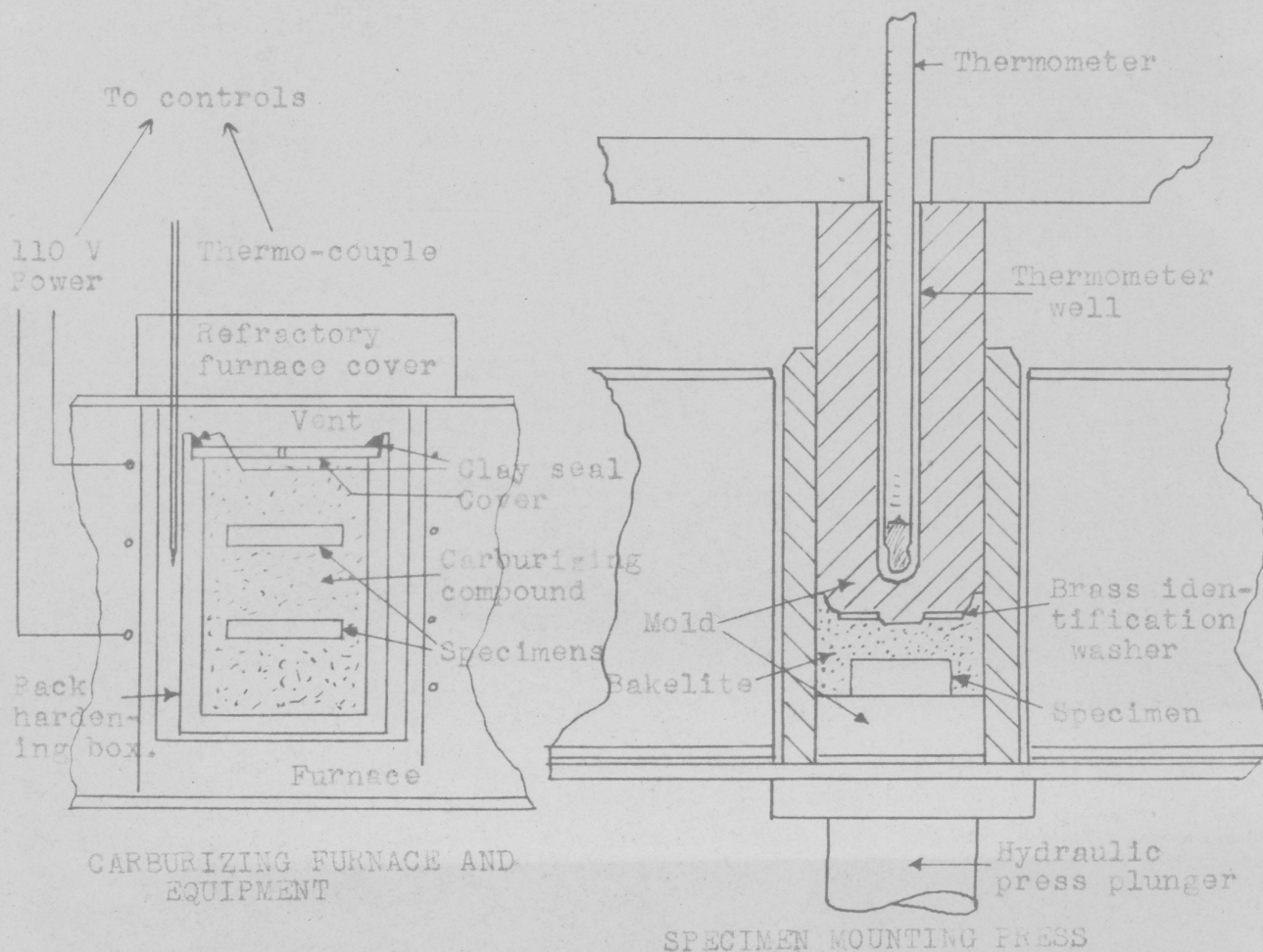
EXPERIMENT NO. 20

CASE CARBURIZING OF LOW CARBON STEEL

OBJECT: To study the method and results of case carburizing of low carbon steel.

APPARATUS: Electric furnace, (Vertical tube resistance).

Wheelco Capacitrol. (Used in Experiment No. 12)

Alundum disc cut off wheel.

Bench grinder.

Marking dies.

Iron pack hardening box and cover.

Surface polishing plates.

Cincinnati Horizontal Disc Polishing Machine.

Bausch and Lomb Routine Metallograph, No. 215.

Bakelite specimen mounting press.

MATERIALS: Two inch specimens cut from $\frac{1}{2}$" round stock bar.

(1- No. J, (1020), .20% C., Cold rolled)

(1- No. K, (1112), .12% C., Bessemer screw)

Houghton's "Pearlite" Pack hardening compound.

Special laboratory granulated pack Hd. compound.

Ten per cent brine solution.

Norton polishing papers, 2 through 3/0.

600 grain alundum powder.

Nital etching solution, (1$\frac{1}{2}$%).

Bakelite, (Granulated, raw).

Brass identification washers.

EXPLANATION OF SET UP: The furnace was set up for case-hardening as shown in the diagram below. The specimens were packed in the pack hardening box with the case hardening compound so that no specimen touched another or the side of the box. The thermo-couple was placed between the side of the box and the lining of the furnace. Through this thermo-couple the temperature was controlled by the Wheelco Capacitrol on the control board.

The important features of the bakelite press are shown in the diagram below. The bakelite was heated with the electric tube furnace and 2500 pounds pressure applied.

To controls

110 V Power   Thermo-couple

Refractory furnace cover

Vent

Clay seal
Cover

Carburizing compound

Specimens

Pack hardening box

Furnace

CARBURIZING FURNACE AND EQUIPMENT

Thermometer

Thermometer well

Brass identification washer

Mold

Bakelite

Specimen

Hydraulic press plunger

SPECIMEN MOUNTING PRESS

PROCEDURE: The specimens were cut from stock bar as shown on page 79, stamped for identification and packed with the case hardening compound in the iron pack hardening box, (See diagram, page, 80.)

The temperature control was set for 1700 °F. and the power turned on. After this temperature was reached, one hour was allowed for soaking. Eight hours at constant temperature, 1700 °F. was then allowed for carburizing.

At the end of this run the furnace power was shut off and the specimens removed and quenched in 10% brine solution. A cross section specimen was cut from near the middle of each piece, polished, etched and examined by the procedure employed in Experiment No. 11. Specimens were mounted in bakelite in order that polishing might be carried to the extreme edges.

CONCLUSIONS: Examination of the case hardened specimens under the microscope revealed the following:

Specimen, J, (1020), showed, at the outer surface, the needle like structure of high carbon martensite, Fig. 9, page 103. This was due to the absorption of carbon from the carburizing compound and the drastic quenching from austenite. As the field of study was shifted toward the center of the surface of the specimen, a gradation toward a lighter color was noted. This was due to lighter etching of martensite less rich in carbon. When the field was shifted further toward center and out of the zone of carbu-

rization, very fine pearlite, or sorbite, lean in carbon, appeared, with negligible traces of precipitated ferrite. It was possible to see the faint lammelar structure of pearlite.

Specimen, K, (1112), appeared very similar to J with only the following differences:

K showed slightly more precipitated ferrite in the non-carburized core. This was due to the much lower carbon content of the original stock metal, Fig. 10, page 103.

Specimen, K, showed minute apparent nodular material interspersed through all fields. These were the cross sections of threads of manganese sulphide which were stretched out in the rolling process of the stock steel.

Case hardening is the process of carburizing the outer surface of a low carbon steel as used in this experiment and quenching it to form martensite which is an extremely hard unstable structure.

EXPERIMENT NO. 21

THE McQUAID-EHN TEST FOR GRAIN SIZE IN STEEL

OBJECT: To determine the grain size in steels by the Mc-
Quaid-Ehn test.

APPARATUS: Electric furnace, used in Experiment No. 20,

Wheelco Capacitrol, used in Experiment No. 12.

Alundum disc cut off machine.

Bench grinder.

Marking dies.

Iron pack hardening box and cover.

Surface polishing plate.

Cincinnati Horizontal Disc Polishing Machine.

Bausch and Lomb Routine Metallograph, No. 215.

Bakelite specimen mounting press.

MATERIALS: Two inch specimens cut from $\frac{1}{2}$" round stock bar.

(1- No. J, (1020), .20% C., Cold rolled)

(1- No. K, (1112), .12% C., Bessemer screw stock)

(1- No. L, (1095), .95% C., Hot rolled)

Houghton's "Pearlite" Pack hardening compound.

Special Lab. granulated pack hardening compound.

Ten per cent brine solution.

Polishing papers, (Norton, No. 2 through 3/0)

600 grain alundum powder.

Nital etching solution, ($1\frac{1}{2}$%)

Bakelite, (Granulated, raw.)

Brass identification washers.

PROCEDURE: The apparatus was set up as explained in Experiment No. 20. The specimens were cut from stock bar as shown on page 83, stamped for identification and packed for case hardening as in Experiment No. 20.

The furnace temperature control was set for 1700°F. and the power turned on. After this temperature was reached one hour was allowed for soaking. Eight hours at constant temperature, 1700 °F. was then allowed for carburizing.

At the end of this run the furnace power was shut off and the specimens allowed to cool in the furnace.

A cross section specimen was cut from near the middle of each specimen, polished, etched, and examined by the procedure employed in Experiment No. 11.

Specimens were mounted in bakelite in order that polishing might be carried to the extreme edges.

The images of the fields which showed grains were projected on the ground glass of the metallograph and comparison made with the A. S. T. M. standard.

CONCLUSIONS: In a coarse grain steel the grain size is proportional to the temperature to which the steel is heated above the critical point. Upon cooling the size of the grain remains that of the austenite formed at this temperature.

In a fine grain steel, deoxidized or killed by aluminum or some other element, the grain size is not directly proportional to temperature, but remains almost constant with rising temperature to about 1700 °F. and then grows very rapidly with further rise in temperature to a size even greater than that of a coarse grain steel.

The grain size of steels of very low carbon content can be determined by etching the grain boundaries of the ferrite, and examining under the microscope. That of hyper-eutectoid steels can be determined by examining the boundaries of pearlite separated by precipitated cementite. Eutectoid steels do not show grain boundaries because there is no precipitation between the grains. Medium carbon or high hypoeutectoid steels precipitate ferrite within the grains, thus not showing the boundaries.

The McQuaid-Ehn test consists of raising the carbon content of the outer surface of the steel by carburizing to hypereutectoid composition, cooling to form pearlite, and precipitate cementite on the boundaries, examining the crystals and determining the size by comparison with a standard.

The test in this experiment showed a grain size of about 1.5 by the A. S. T. M. Standard. If the carburizing temperature was not carried above 1700 °F. this indicates that the specimens were of coarse grain steel.

Fig. 11 and 12, page 203 show sketches of the specimens as seen under the microscope. The field was taken in each case from the outside to the center of the specimen.

Specimen K, is not shown but differs from J only in that cross sections of threads of manganese sulphide appear.

Grain size is important due to the fact that fracture is always made along the grain boundaries or through slip planes within the grain. Small grains thus tend to give greater ultimate strength in the steel.

EXPERIMENT NO. 22

THE SIMPLE TIME-TEMPERATURE CURVE FOR EUTECTOID CARBON STEEL

OBJECT: To plot from experimental data the simple Time-Temperature curve, and study the cooling characteristics of eutectoid carbon steel.

APPARATUS: Electric furnace.

Chromel-Alumel thermo-couples and leads.

Two 22.5 ohm adjustible rheostats.

Brown potentiometer pyrometer.

Stop watch.

MATERIALS: Four pieces of steel, (Sample B), $\frac{1}{2}$" square X 1$\frac{1}{2}$" bound together.

EXPLANATION OF SET UP: Each specimen had one corner at the center of the batch beveled to form a hole for receiving the thermo-couple. The specimens with inserted thermo-couple were placed in the furnace and the leads connected to the potentiometer. The two rheostats were connected in series with the furnace and the 110 V. source of power.

PROCEDURE: The apparatus was set up as explained above. With all resistance cut out of the power circuit, the power was turned on and the temperature brought up to about 1500°F. The rheostats were then adjusted for about 35 ohms. This was found to give a reasonable cooling rate.

Readings were taken of temperature and time in intervals of 30 seconds from $1000°F.$ through about $1200°F.$ These data were recorded and the cooling curve, page 90, plotted between temperature of the sample, as ordinate, and time, as abscissa.

CONCLUSIONS: The maximum cooling rate was found to be, at the beginning of the run, about 20 degrees per minute. As the temperature gradient between the furnace and the room was lowered, the rate was decreased to about 4 $°F.$ per minute at the critical point.

The specimen being of eutectoid composition, the A_1, A_2 and A_3 are common. The curve shows this point to be at 1284 $°F.$ as shown by the horizontal section at A which indicates zero cooling rate. Heat was here given off during transformation, causing no further decrease in temperature until transformation was complete.

The theoretical curve is carried out by dotted lines. Points B and C fall off the theoretical curve due to under cooling and time necessary to conduct heat through the specimen.

The eutectoid temperature for plain carbon steel is 1333 $°F.$ The curve shows a 46 degree depression of the critical point. This depression is due to the cooling rate and the presence of manganese in the steel.

DATA: Specimen, .85% C.,   .72% Mn. steel

Cooling rate, beginning of run, 20 °F. per min.

Cooling rate, end of run, 4 °F. per min.

TIME MIN.	TEMP °F.	TIME MIN.	TEMP °F.	TIME MIN.	TEMP °F.	TIME MIN.	TEMP °F.
0.	1400	8.5	1285	17.0	1281	25.5	1246
.5	1390	9.0	1282	17.4	1281	26.0	1243
1.0	1382	9.5	1279	18.0	1280	26.5	1240
1.5	1372	10.0	1277	18.5	1279	27.0	1247
2.0	1265	10.5	1277	19.0	1278	27.5	1234
2.5	1357	11.0	1280	19.5	1277	28.0	1230
3.0	1349	11.5	1283	20.0	1276	28.5	1226
3.5	1342	12.0	1284	20.5	1275	29.0	1223
4.0	1335	12.5	1284	21.0	1274	29.5	1220
4.5	1328	13.0	1284	21.5	1272	30.0	1217
5.0	1322	13.5	1284	22.0	1270	30.5	1214
5.5	1316	14.0	1284	22.5	1268	31.0	1212
6.0	1310	14.5	1284	23.0	1265	31.5	1208
6.5	1305	15.0	1284	23.5	1261	32.0	1206
7.0	1300	15.5	1284	24.0	1257	32.5	1204
7.5	1295	16.0	1283	24.5	1254	33.0	1202
8.0	1390	16.5	1282	25.0	1250	33.5	1199

Time-Temperature Cooling Curve
for
Carbon Steel
(.85 % C.; .72 % Mn.)
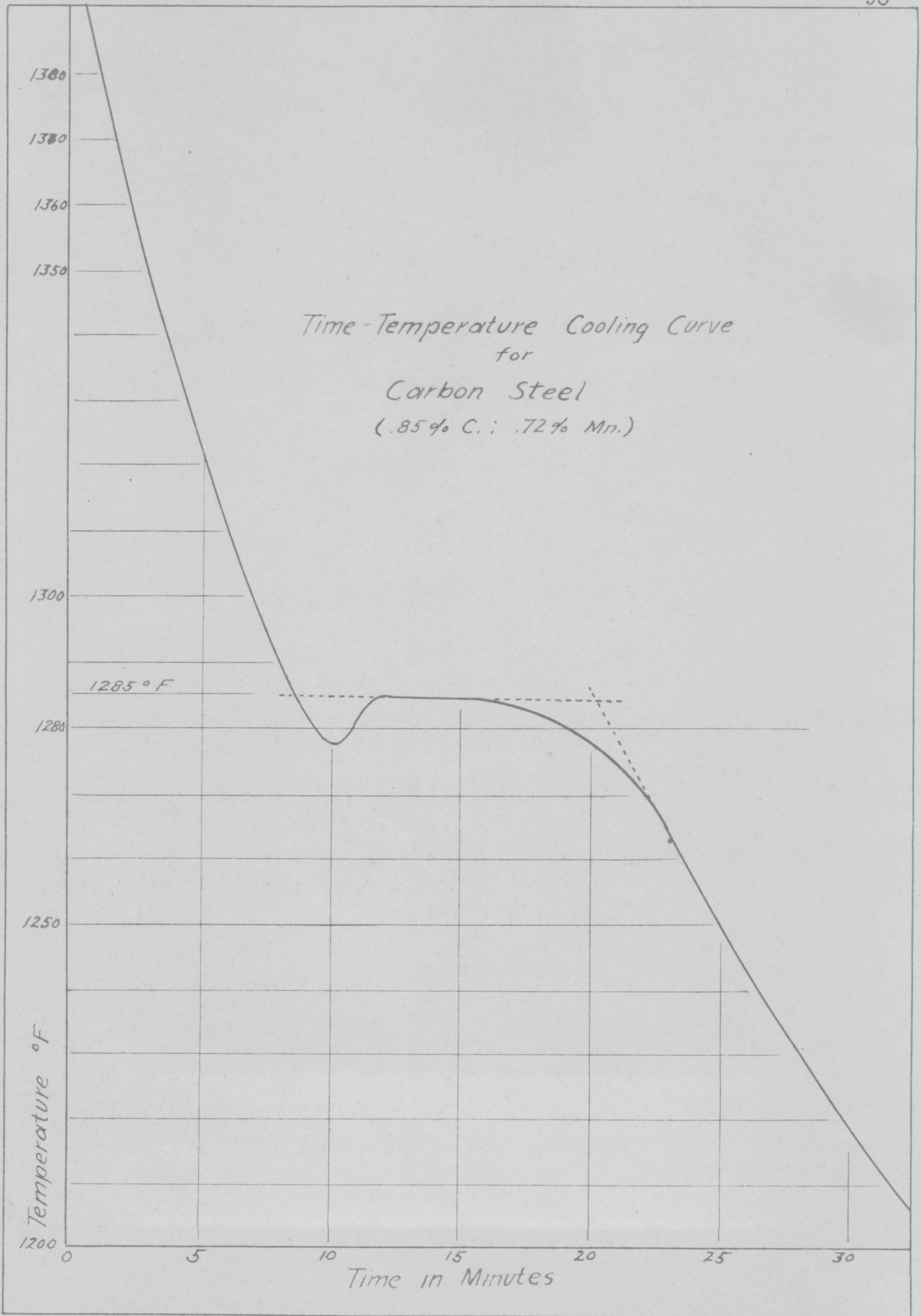
EXPERIMENT NO. 23

THE INVERSE RATE CURVE FOR CARBON STEEL

OBJECT: To plot, from experimental data, the Inverse Rate curve for .26% carbon steel and locate the critical points.

APPARATUS: Equipment used in Experiment No. 22.

Two stop watches.

MATERIALS: Four pieces of .26% C., .52% Mn., .16% Si. steel $\frac{1}{2}$" square by $1\frac{1}{2}$", prepared as in Experiment No. 22.

EXPLANATION OF SET UP: The apparatus was set up as in Experiment No. 22. Two stop watches were used alternately for time readings.

PROCEDURE: The specimens were heated to about 1600 °F. with full power on the furnace. The rheostats were then adjusted for about 35 ohms in series with the power circuit. When cooling began, readings of time and temperature were taken as follows:

Alternating with the two stop watches, time was recorded for each temperature drop of 10 °F. from 1600 °F. through about 1200 °F.

The data were recorded and a curve plotted, page 94, between temperature, as ordinate, and inverse cooling rate, (Time for unit drop in temperature) as abscissa.

CONCLUSIONS: The Inverse Rate curve shows critical points which are difficult to detect in the Time-Temperature curve. It is noted that the Ar_3 point is depressed more than the Ar_1. This due to the higher rate of cooling through the upper critical point. The Ar_2 point is not detected.

DATA

The inverse cooling rate for carbon steel.

Specimen, .25% C., .52% Mn., .16% Si. steel.

Temperature increments, 10 °F.

Cooling rate, Beginning of run, 28.5 °F. per min.

     End of run,   4.0 °F. per min.

For 10 °F. drop to corresponding temperature.

TIME SEC.	TEMP. °F.	TIME SEC.	TEMP. °F.	TIME SEC.	TEMP. °F.
21	1580	30	1440	70	1310
21	1570	43	1430	74	1300
21	1560	67	1420	86	1290
21	1550	54	1410	87	1280
24	1540	51	1400	83	1270
23	1530	58	1390	370	1260
23	1520	62	1380	95	1250
24	1510	54	1370	86	1240
25	1500	61	1360	100	1230
26	1490	64	1350	105	1220
26	1480	64	1340	130	1210
27	1470	62	1330	150	1200
26	1460	72	1320	240	1190
30	1450				

Inverse-Rate Cooling Curve
for
.26% C. – .52% Mn. Steel.
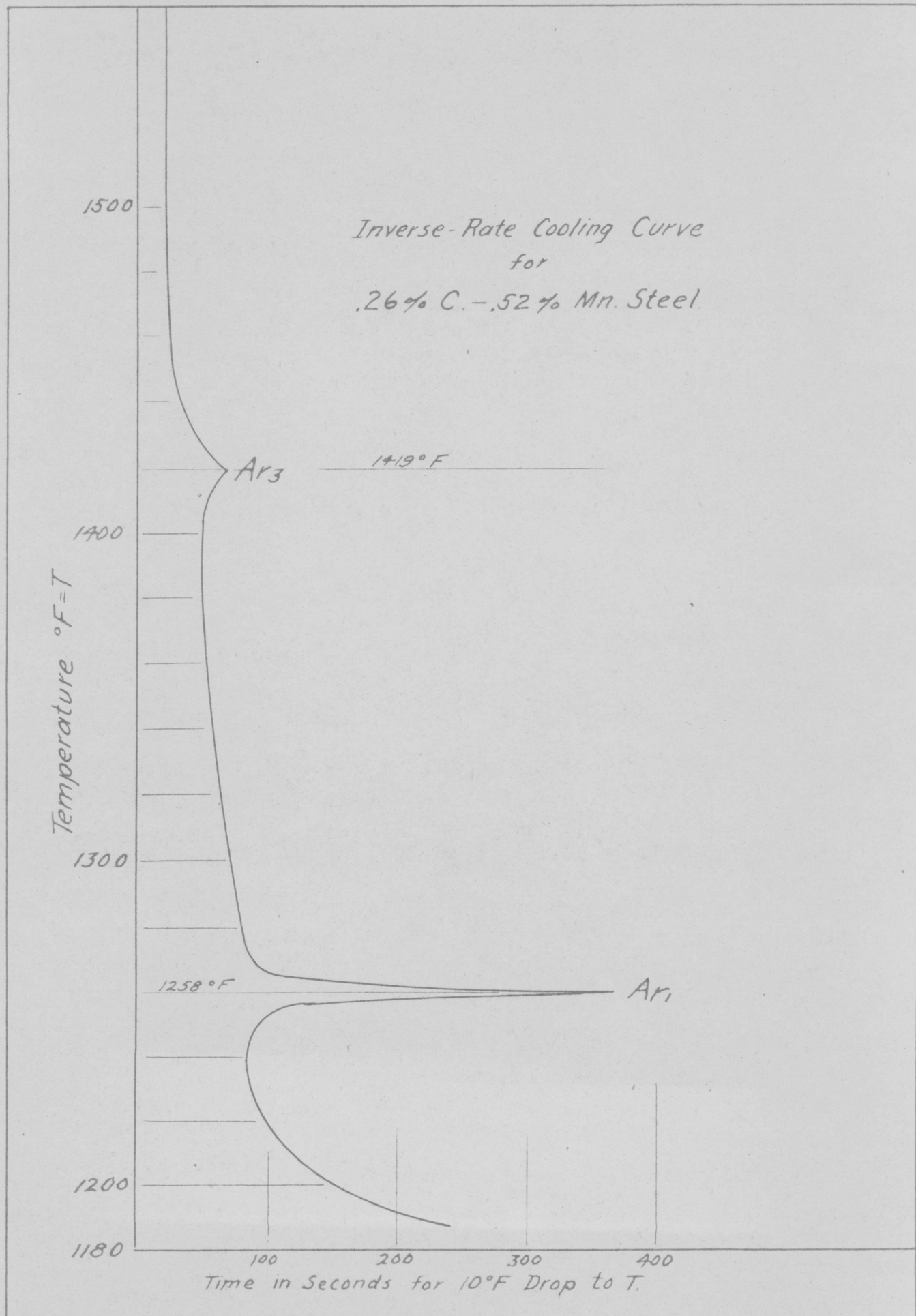
EXPERIMENT NO. 24

THE EFFECT OF TEMPERATURE ON GRAIN SIZE IN CARBON STEELS

OBJECT: To locate the upper limit of the critical range in hypoeutectoic carbon steel of more than .45% carbon, and to study the effect of temperature on grain size.

APPARATUS: Buffalo Dental Furnace.

Abrasive disc cut off machine.

Horse-shoe magnet, tongs, vise and hammer.

MATERIALS: Bar of steel, D, $\frac{1}{2}$" sq., (.50% C., .90% Mn.)

Pyrofax gas and compressed air.

EXPLANATION OF SET UP: The Buffalo Dental Furnace is a small cylindrical fireclay lined furnace, gas fired.

PROCEDURE: Specimen No. 1, 2 inches was cut from the bar. Specimen No. 2, the same length was obtained by nicking the bar about half way through and breaking to reveal the fracture. By means of the cut off wheel, each specimen was nicked about half way through to be broken in half.

Both specimens were placed in the furnace and heated to a white heat, about 2200 °F., soaked for a few minutes, removed from the furnace and cooled in air.

Specimen No. 2 was placed back in the furnace and, during slow heating, was removed at short intervals, tested with the magnet, and quickly replaced in the furnace. When the steel was found to be non-magnetic it was removed and cooled in air.

Each specimen was then held in the vise and broken with the hammer to reveal the fracture.

CONCLUSIONS: The fracture before heat treatment showed the initial grain to be of medium size.

Specimen No. 1, cooled from high temperature, showed fracture revealing a very coarse grain. The specimen was much more easily broken than specimen No. 2.

Specimen No. 2, which had been reheated to just above the Ac_{23} point, as shown by the loss of magnetism, was hard to break, and the fracture revealed a very fine grain structure.

The experiment showed that the upper critical range of hypoeutectoid steels of more than .45% carbon can be located by means of the simple horse-shoe magnet.

The magnet cannot be used to locate the Ac_3 point in steels of less than 45% carbon since, as shown by the Iron-carbon diagram, the Ac_2 line drops below the Ac_3 for steels of lower carbon content.

To refine the grain in hypereutectoid steels, it is necessary to heat to just above the Acm line. This is above the Ac_{123} line, therefore the magnet test cannot be used.

EXPERIMENT NO. 25

THE TEMPERATURE DIFFERENCE AND DERIVED DIFFERENTIAL

COOLING CURVES

OBJECT: To locate the critical points for a sample of
metal from the Temperature difference and Derived Differ-
ential cooling curves.

APPARATUS: Brown potentiometer Pyrometer.

Rubicon galvanometer and 50 ohm shunt.

Two adjustible rheostats, total 45 ohms.

Electric furnace.

Chromel-alunel straight and difference

thermo-couples and leads.

Nickel bar, $\frac{1}{2}$" Sq. X 3/4" drilled for couple.

MATERIALS: Steel bar, $\frac{1}{2}$" Sq. X 3/4", drilled for couple.

EXPLANATION OF SET UP: The specimens and thermo-couples
were set up as shown in the diagram below.

To potentiometer   To galvanometer

Chromel   Alunel

Specimen   Neutral body, (Nickel)

Furnace
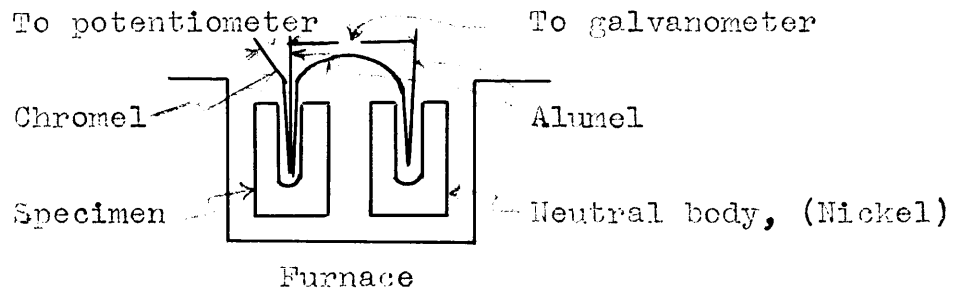
With the set up above, the potentiometer shows the tempera-
ture of the specimen. The galvanometer deflection is
proportional to the difference in temperature between the
specimen and the neutral body.

PROCEDURE: The specimen and neutral body were placed in the furnace and the thermo-couples inserted and leads connected as shown in the diagram. The power circuit was closed on the furnace with the resistance out and the temperature brought up to about 1500 °F. The rheostats were then adjusted for full resistance of 45 ohms in series with the furnace power circuit and cooling began.

Deflection of the galvanometer indicated a lag in the cooling of the nickel behind that of the specimen. When this deflection became constant the galvanometer was adjusted to read about 10 mm.

Readings were taken of temperature of the specimen in increments of 5 °F. and corresponding galvanometer deflection. Maximum deflection of the galvanometer was also read. The cooling range was taken from about 1400 °F. to 1140 °F.

The data were recorded and curves plotted as follows: page 101.

(1) The Temperature-difference curve, between temperature of the specimen, as ordinate, and galvanometer deflection, as abscissa.

(2) The Derived-differential between temperature of the specimen, as ordinate, and change in deflection for each 5 °F. temperature drop, as abscissa.

CONCLUSIONS: The temperature drop in the neutral body lagged behind that of the specimen due to the difference between the two in specific heat, conductivity, and radiation.

The Ar_1 point is shown by the curve to fall at about 1234 °F. This critical point for eutectoid steel is 1333 °F. The depression in the critical point shown in this experiment was due to body the rapid cooling rate and the presence of .90% manganese in the specimen.

The Ar_{23} point is not as pronounced as the Ar_1 due to the fact that the precipitation of alpha ferrite from austenite takes place through a temperature range from Ar_3 to the Ar_1 point.

At the Ar_1 point all of the remaining austenite transforms to pearlite at constant temperature, causing an abrupt turn in the curve.

DATA: Difference and Derived differential cooling curves.

Specimen. .50% Carbon, .90% Manganese Steel.

Neutral body, Nickel. Temperature in degrees F.

TEMP. SPEC.	GALV. DEF.	CHANGE IN DEF.	TEMP. SPEC.	GALV. DEF.	CHANGES IN DEF.
1400	6.8	0.2	1280	13.5	2.5
1395	6.5	0.3	1275	17.0	3.5
1390	6.8	0.2	1270	20.2	3.2
1385	6.8	0.0	1265	23.0	2.8
1380	6.5	0.3	1260	25.0	2.0
1372	6.3	0.2	1255	26.0	1.0
1370	5.2	0.1	1250	26.0	0.0
1365	6.0	0.2	1245	26.0	0.0
1360	6.0	0.0	1240	26.0	0.0
1355	6.0	0.0	1235	26.5	0.5
1350	6.0	0.0	Max.Def. 79.0		52.5
1345	6.0	0.0	1230	77.0	2.0
1340	6.0	0.0	1225	73.0	4.0
1335	6.0	0.0	1220	68.0	5.0
1330	6.0	0.0	1215	62.0	6.0
1325	6.0	0.0	1210	57.0	5.0
1320	6.0	0.0	1205	52.0	5.0
1315	6.0	0.0	1200	47.0	5.0
1310	6.0	0.0	1195	43.0	4.0
1305	7.0	1.0	1190	38.0	5.0
1300	7.0	0.0	1185	34.0	4.0
1295	8.0	1.0	1180	30.0	4.0
1290	9.0	1.0	1175	27.0	3.0
1285	11.0	2.0	1170	24.0	3.0

Cooling Curves For Carbon Steel
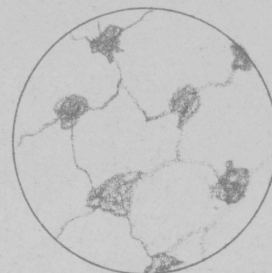
.50 % C., .90 % Mn.
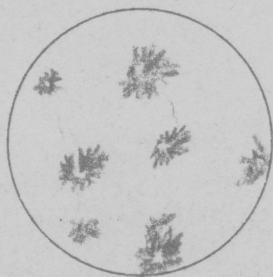
No 1.

Fig. 1.

No 5

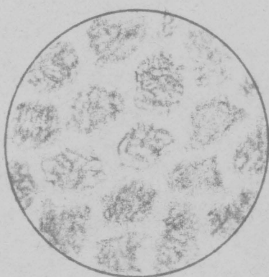Fig. 2.

No 8

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7

Fig. 8

Microscopic appearance of specimens examined in Experiment

No. 11, 14, and 15.

EXPERIMENT NO. 20.

MARTENSITE
Hypereutectoid   Hypereutectoid

Hypoeutectoid

Sorbite

Percipitated Ferrite

Manganese sulphide

Fig. 9.   Fig. 10

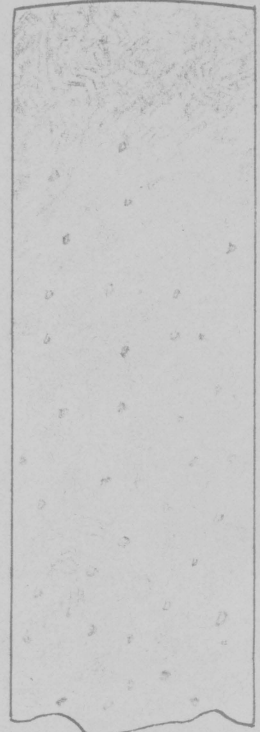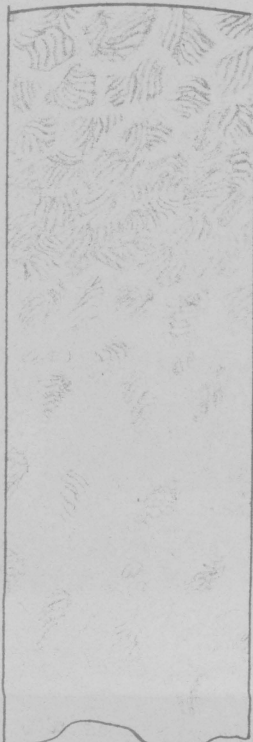Specimen J.   Specimen, K

EXPERIMENT NO. 21.

Hypereutectoid by
  Carburization

Grains, Pearlite

Cementite

Eutectoid   Original Stock
                     Hypereutectoid

Pearlite

Ferrite   Cementite

Fig. 11   Fig. 12
Specimen, J   Specimen, L