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M. S. THESIS.

HEAT OF FORMATION  
OF SOME  
FERRO-CALCIC SINGULO-SILICATES.

BY

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Course III          Option 2

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

1908.

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PART I.

INTRODUCTION.



The investigation<sup>1</sup> of the heat formation of ferro-calcic silicates in general was begun in 1908. On account of many difficulties encountered both in the preparation of ferrous oxide and in the adjustment of the electrical apparatus and calorimeter, the experiments could not be brought to a finish with satisfactory results.

As this work is considered important, not only from a scientific, but also from a practical point of view, the investigation was resumed in the latter part of 1908 and continued until the middle of 1909. The experiments were conducted according to the same method as that of last year, the apparatus, however, was modified and improved, and the former method of preparing ferrous oxide replaced by one that was better.

Many methods have been proposed and recommended for the preparation of ferrous oxide. The leading ones are those of Wackerwoder, Sivert, Moissan, Debray, Berthier, Plattner, Mills, Vogel, Birnie, Tissandier and Steffe. A brief history of their investigations appears to be interesting.

As early as 1843, Wackerwoder<sup>2</sup> began to prepare ferrous oxide by the reduction of ferric oxide at 300 deg. C by hydrogen. This experiment was later repeated by Sivert<sup>3</sup> and Moissan<sup>4</sup>, though at a higher temperature. The latter heated ferric oxide in a stream of hydrogen at 500 deg. C and proved that this method was not very satisfactory.

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1. Wen, Thesis No. 352

2. Wackerwoder and Stromyer "Archiv f. Pharmacie" 1843 36 p. 27

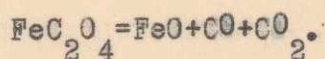
3. Jahresberichte über die Fortschritte der Chemie 1864 17 p. 266

4. Annales de Chimie et de Physique 1880 21 p. 199

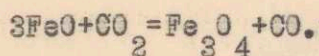
because of the fact that hydrogen, at that high temperature, reduced some ferrous oxide to metallic iron. Moissan, therefore, employed another method for the preparation, which consisted in reducing ferric oxide by a current of carbon monoxide. He found that the results were satisfactory and that the amount of total iron in the product approximated the theoretical one.

Of the work on ferrous oxide, that of Debray<sup>1</sup> should be mentioned. These experiments were conducted by passing a stream of equal volumes of carbon monoxide and carbon dioxide over ferric oxide at <sup>a</sup> red heat. The results obtained proved unsatisfactory.

Another method used was that by Vogel<sup>2</sup>, Moissan<sup>3</sup> and Birnie<sup>4</sup>. It consisted in decomposing ferrous oxalate at an elevated temperature; the decomposition takes place according to the following equation:



Vogel found that the product obtained was not free from metallic iron. Moissan pointed out that the decomposition did not take place exactly as the chemical equation given above, but that there was a secondary reaction, in which the carbon dioxide liberated converted the ferrous oxide first formed into magnetic oxide.



The results of Birnie agree in part with those of Vogel. He

1. Comptes Rendus 1857 45 p. 1018
2. Liebig Annalen der Chemie und Pharmacie 1855 95 p. 116
3. Annales de Chimie et de Physique 1880 21 p. 199
4. Am. Inst. Min. Eng'rs. Trans. 1899 29 p. 684 foot note.

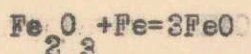


found, however, that the product contained not only a little reduced iron, but also a small quantity of carbon and that the amount of carbon set free depended upon the mode of heating the ferrous oxalate and that the metallic iron was produced by the liberated carbon.

Berthier<sup>1</sup> and Plattner<sup>2</sup> prepared ferrous oxide by heating a mixture of metallic iron and magnetic oxide, or rather, hammer scale.

Tissandier<sup>3</sup> employed another method of making this oxide which consisted in passing carbon dioxide over heated iron wire at 600 deg. C. The experiment was later repeated by Moissan<sup>4</sup> and Steffe<sup>5</sup>. They found that the method gave unsatisfactory results. It was also employed for the preparation of ferrous oxide in our experiment last year<sup>6</sup>, the results obtained proving to be very unsatisfactory.

The best and most successful method is that which was first employed by Mills<sup>7</sup> and then by Steffe, being based upon the method of Berthier and Plattner. It consists in heating, in molecular proportions, a mixture of metallic iron and ferric oxide when FeO is formed according to the chemical formula:



- 
1. Traité des Essais Paris 1834 I p. 430
  2. Merbach Die Anwendung der Erwärmtten Geblässeluft in der Metallurgie 1840 p. 228
  3. Comptes Rendus 1872 74 p.
  4. Annales de Chimie et de Physique 21 p. 199
  5. Doctor Thesis Berlin 1908 p. 7
  6. Wen Thesis 1908 No. 352 p. 6
  7. Deutsches Patentblatt 1895 17 p. 362 German Patent March 31, 1895 12 Klasse No. 86589.

Steffe in 1908 made an investigation on this method and heated the mixture in a current of nitrogen. He found the product to be most satisfactory. Therefore, in our experiments of 1908-09, this method was adopted for the preparation of ferrous oxide. The preparation of FeO formed the first part of the thesis and the determination of the heat formation of ferro-calcic silicates of the second and main part.

The work of this investigation, as planned, was to consist in determining the heat formation of a series of singulo-silicates, and second, of a series of bisilicates of FeO and CaO. On account of the fact that much time was consumed in the adjustment of the electrical apparatus, and that many experimental difficulties were encountered, to overcome which it would have necessitated a new apparatus of larger capacity and a device for keeping the voltage constant, three concordant results of the singulo-silicate series were obtained.



For this experiment silica, calcium carbonate, iron powder, reduced by hydrogen, and ferric oxide were used.

The preparation and analysis of silica and calcium carbonate were given in my thesis<sup>1</sup> of last year.

### 1. Metallic Iron

Iron powder used in the preparation of ferrous oxide was that of Kahlbaum (C.A.L. Kahlbaum Chemical Supply Company, Berlin, S.O.) The iron was first dried in a steam chest at 110 deg. C for three hours, cooled and ground in an agate mortar until the whole passed through a bolting cloth. It was then analysed by the following method: A weighed sample, about 0.2 gm. is dissolved in 100 c.c. of dilute sulphuric acid, (5 parts  $H_2SO_4$ , Sp. gr. 1.84:100 parts  $H_2O$ ) and heated until the solution is complete. The solution is passed through Jones' Reductor<sup>2</sup> while hot, at a rate of not more than 50 c.c. per minute. The beaker in which the solution was contained and the reductor are carefully washed with 300 c.c. of the above sulphuric acid and then with 100 c.c. of hot water. The solution is titrated with potassium permanganate. Two analyses were made and the percentage of iron was found to be 99.10 and 99.08.

Analysis of hydrogen in the ~~electrolytic~~ iron. As ~~electro-deposited~~ <sup>hydrogen reduced</sup> iron usually contains occluded hydrogen, it was therefore important to consider the analysis of this element. Its determination was made by the combustion method. The apparatus used is shown in Figure I.

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1. Wen Thesis 1908 No. 352 pp. 4, 5.

2. H.P. Talbot "Quantitative Analysis" N.Y. Wiley 1902 p. 96

A weighed sample of about 2 gm. of iron powder in a porcelain boat is introduced into the combustion tube of the furnace. The Liebig potash-bulb L, containing potassium hydroxide and the U-tube T containing calcium chloride, are attached to one end of the combustion tube and the weighed Marchand U-tube M which also contains calcium chloride to the other. The heating gas is then turned on and lighted. The oxygen before coming in contact with the iron is freed from carbon dioxide by the bulb L and from moisture by the tube T. The water vapor formed by the combustion of the hydrogen in the sample is absorbed and collected in the tube M. The time of combustion is twenty minutes. The amount of hydrogen from the increased weight is calculated as follows:

18:2=increase of wt.:wt. of hydrogen.

$$\text{wt. of hydrogen} = \frac{\text{increase of wt.}}{9}$$

$$\text{Percentage of hydrogen} = \frac{\text{wt. of hydrogen}}{\text{wt. of sample}} \times 100.$$

Three determinations were made and the percentages of hydrogen in the sample were 0.016, 0.013, and 0.015

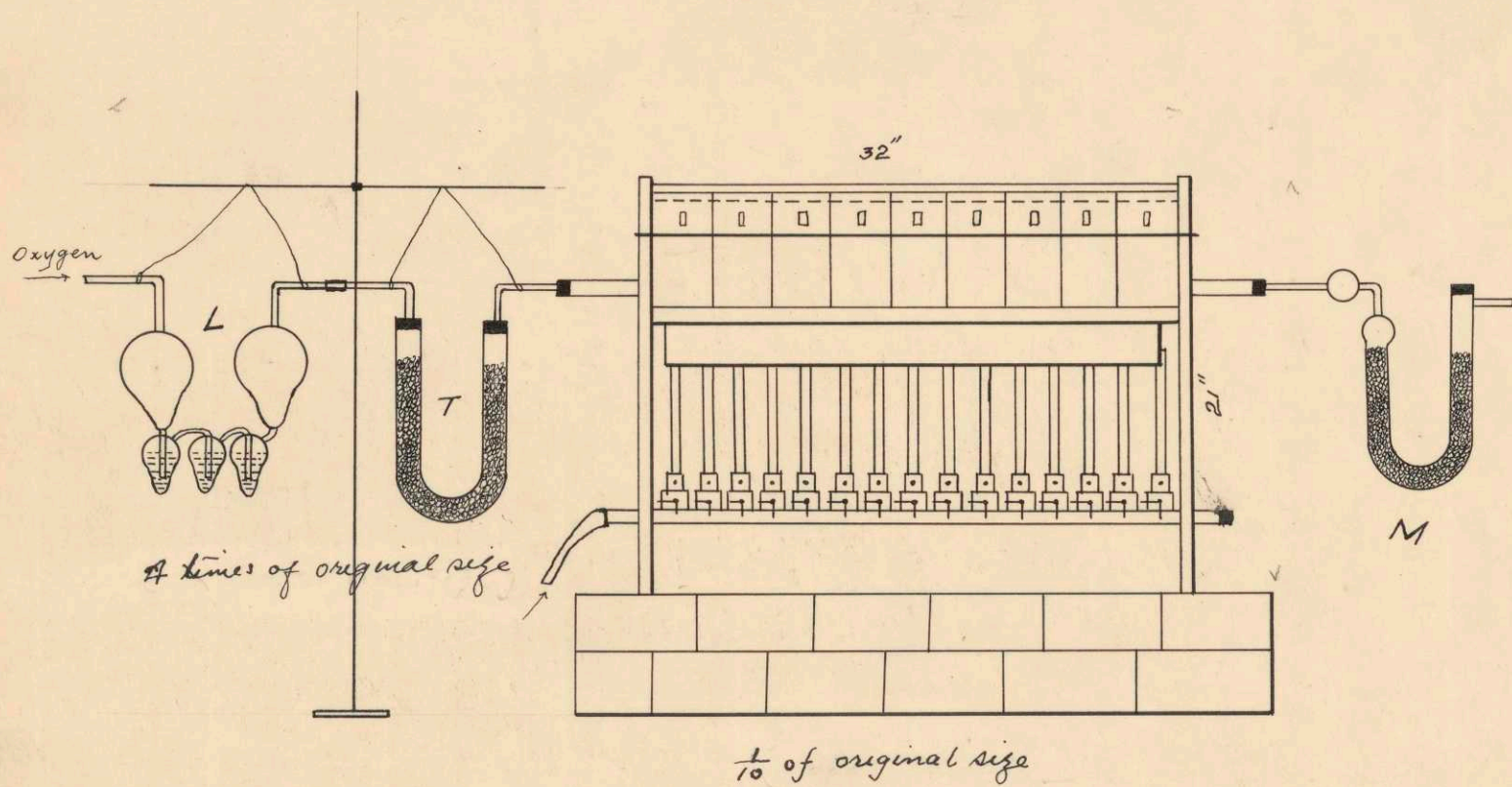
The determination of hydrogen was preceded by a blank test to find out whether the admission of oxygen and the amount of calcium chloride were rightly proportioned to have the oxygen free from H<sub>2</sub>O.

## 2. Ferric Oxide.

The ferric oxide used was that of Kahlbaum. It was first dried in the steam chest at 110 deg. C for three hours and



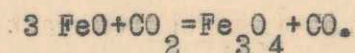
Fig. I  
APPARATUS FOR  
THE DETERMINATION OF HYDROGEN



then analysed according to the following procedure: From 0.2 to 0.3 gm. of ferric oxide is weighed out, placed in a porcelain casserole and dissolved in 30 c.c. of hydrochloric acid (sp. gr. 1.12). It is heated to a temperature below boiling until the solution is complete. The solution is allowed to cool. Five c.c. of concentrated sulphuric acid (Sp. gr. 1.84) is then added carefully and the solution evaporated on the hot plate or on the steam bath, until it becomes nearly colorless. The casserole is covered and heated over the flame of the lamp until a heavy white fume of sulphuric anhydride is freely evolved. The casserole now is cool<sup>ed</sup>, 100 c.c. of distilled water is added. The solution is warmed until all the ferric sulphate is brought into solution. It is then passed through the Jones reductor, as described above, and titrated with a potassium permanganate. The analyses gave the following percentages of Fe: 69.66, 69.72 and 69.71. Taking the average of these analyses we have 69.70 per cent of Fe = 99.57 per cent  $\text{Fe}_2\text{O}_3$ .

### 3. Ferrous Oxide.

The method of preparing ferrous oxide employed last year was that of Tissandier<sup>1</sup>, which consisted in heating metallic iron in a stream of carbon dioxide. This method, was found to give unsatisfactory results, because of the fact that the ferrous oxide first formed was peroxidized by the carbon dioxide and converted into magnetic oxide, according to the following chemical equation:

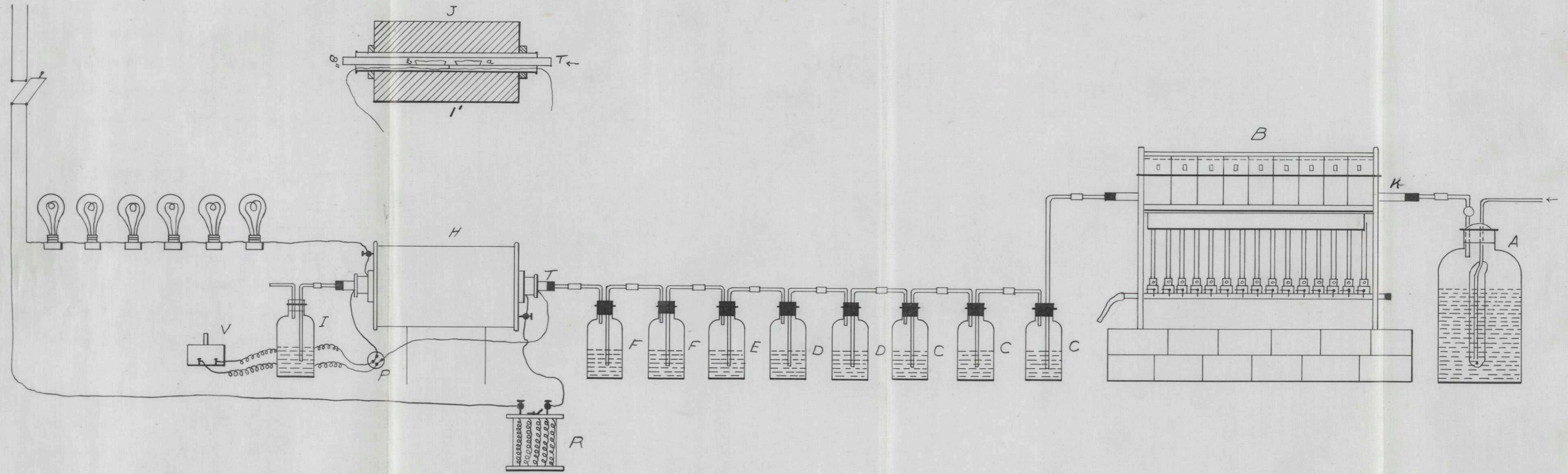



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1. Comptes Rendus 1872 74 p. 541.



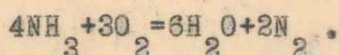
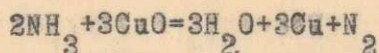
Plate 2  
THE  
ARRANGEMENT  
OF  
APPARATUS FOR THE PREPARATION  
OF  
FERROUS OXIDE





As the method of Tissandier failed to give good results, that of Steffe, discussed above, was adopted. The product formed was satisfactory, the results obtained agreed to those of Steffe.

Preparation of Nitrogen. As the heating of the mixture of iron powder and ferric oxide cannot take place in atmospheric air, it is necessary to heat the mixture in an inert gas. Nitrogen was used in this case and passed over the substance while heating and cooling. It was prepared by passing a mixture of air and ammonia gas over heated cupric oxide contained in the combustion tube. The heated cupric oxide and the free oxygen from the air decompose the ammonia gas; the chemical reactions taking place are represented by the following formulae.



Any remaining oxygen is absorbed by pyrogalate of potassium

The apparatus for the preparation of nitrogen is shown in Plate 2

The air under pressure enters the 500 c.c. bottle A which contains concentrated ammonium hydroxide (sp. gr. .90) After passing through the bottle, the air carries a certain amount of ammonium gas and enters the combustion tube K, 3 ft. long and 1/2 in. in diam., containing cupric oxide. B is the gas-heated combustion furnace in which the tube is placed. Bottles of 250 c.c. capacity contain pyrogalate of potassium which is to absorb the oxygen. Bottles D contain potassium hydroxide which is to take away the carbon dioxide from the gas. Bottle E contains ammoniacal cuprous chloride which is to ab-



sorb the carbon monoxide that may be present in the air. F are bottles containing concentrated sulphuric acid (sp. gr. 1.84) which serves to remove any moisture. In order to obtain as pure nitrogen as possible, care was taken both in filling the combustion tube and in heating it. The tube was filled with cupric oxide uniformly, that the ammonia gas might not escape without being decomposed; it was heated barely to redness, for if heated to too high a temperature it would become soft and thus permit the ammonia gas to pass off undecomposed and contaminated.

The nitrogen thus prepared was not absolutely pure, but contained a trace of oxygen which could not be detected by the Orsat apparatus with which the gas was analysed. This trace of oxygen affected the results of ferrous oxide greatly. In order to prevent this, a boat (a) of metallic iron powder was introduced and placed in the tube T, near the end where the nitrogen gas entered (see cross section J, . Plate 2). After an operation, part of the iron powder was found to have become oxidized, the color of the part near the entrance of the nitrogen was black, and the other part near the boat (b) remained unchanged.

As has already been said, the process of preparing ferrous oxide consisted in heating a mixture of metallic iron powder and ferric oxide in a current of nitrogen. The apparatus and its arrangement are shown in Plate 2 drawn approximately to scale. H is the electric furnace  $12'' \overset{\text{long}}{\wedge} 8''$  diameter and T the porcelain combustion tube  $22'' \overset{\text{long}}{\wedge} 5/8''$  diameter in which the substance is introduced in a boat and

and heated. The nitrogen, after passing through bottles C, D, E and F, enters the tube at one end, as is indicated by an arrow, and leaves at the other end to which is attached bottle I containing concentrated sulphuric acid. This is to prevent any air from entering the tube. R is the rheostat which enables us to vary the current as desired. V is the millivoltmeter and P the thermo-junction which serves to measure the temperature of the electric furnace. Six lamps, two of 100 c.p. and four of 32 c.p., are connected in parallel in order that a larger current may be had.

The calculation of iron and ferric oxide necessary for the mixture was carried on as follows:

By analysis, the metallic iron was found to contain 99.10 per cent of Fe and the ferric oxide 99.57 per cent  $\text{Fe}_2\text{O}_3$ . Let X=the wt. of  $\text{Fe}_2\text{O}_3$  required for 1 gm. of the sample of Fe.

$$\text{wt. of iron} : X = \text{mol. wt. Fe} : \text{Fe}_2\text{O}_3$$

$$0.9910 : X = 56 : 160$$

$$X = \frac{160 \times 0.9910}{56} = 2.8314 \text{ gm. Fe}_2\text{O}_3$$

But the  $\text{Fe}_2\text{O}_3$  was only 99.70 per cent pure; the weight of  $\text{Fe}_2\text{O}_3$  corresponding to one gram Fe was corrected as follows:

$$\text{wt. of Fe}_2\text{O}_3 = \frac{2.8314 \times 100}{99.57} = 2.8436 \text{ gm.}$$

One gram of Fe requires 2.8436 gm.  $\text{Fe}_2\text{O}_3$ .

Mode of operating was as follows. The electrolytic iron powder was ground in the agate mortar until it passed through a bolting cloth. A portion of this fine metallic iron and a corresponding portion of ferric oxide were weighed out in two one-inch watch



glasses. The iron and the ferric oxide were mixed and ground in the agate mortar for at least 15 minutes, so that the two substances might be in intimate contact with each other. The mixture was transferred to a piece of glazed paper and then to the iron boat in which the substance was going to be heated. This boat was of black sheet iron, 3in. long, 3/8 in. wide, 1/4 in. deep. It was made by folding a piece of the sheet over a semi-cylindrical piece of wood. The boat containing the mixture was first introduced into the porcelain tube. Another iron boat containing metallic iron followed it. The ends of the porcelain tube were now closed, the gas for the combustion furnace was turned on and lighted. A stream of nitrogen, at a rate of not more than six bubbles per minute, was passed through the porcelain tube. The electric current was now ready to be turned on to heat the electric furnace. It took 2 1/2-3 hr. to bring the electric furnace with a current of not more than 10 Amp. at 110 volt, to about 800 deg. C. The mixture was heated in the furnace at a temperature from 820 to 840 deg. C for two hours. After this period, the electric current was turned off, but the stream of nitrogen was allowed to pass until the temperature had been reduced to the room temperature. The mixture was taken out, the air for the preparation of nitrogen shut off, and the flame extinguished. In order to make the experiment a successful one, the stream of nitrogen was adjusted and so regulated that not more than six, and not less than three, bubbles passed through the sulphuric acid bottle per minute. At the beginning of the operation, when the temperature of the electric furnace was below 200 deg. C, the current of nitrogen was allowed to pass more rapid-

ly. This was to drive out as soon as possible the air in the porcelain tube.

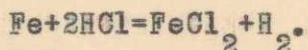
The temperature of the electric furnace was measured by means of the Le Chatelier thermo-electric pyrometer. The hot junction was placed in the middle of the tube and under the porcelain tube, as is shown in the cross section (Plate 2, Fig. J). The thermo-junction was calibrated<sup>1</sup> by means of the boiling points of distilled water, naphthaline and sulphur and the freezing point of aluminum, and a temperature-millivolt curve plotted. In determining the total iron in the ferrous oxide, the method given on page 8 was first used. This, however, consumed much time and was replaced by the following method which consists in dissolving from 0.15 to 0.20 gm. of the sample in a 250 c.c Erlenmeyer flask with 75 c.c. of sulphuric acid, 1  $H_2SO_4$  in 4 parts  $H_2O$ , heating the solution until all the ferrous oxide is dissolved, diluting with 100 c.c. of  $H_2O$ , warming, pouring through the Jones reductor and titrating with a potassium permanganate. The result obtained is tested by comparing with the theoretical value of ferrous oxide, which is 77.70 per cent of Fe.

The analysis of total iron is not, however, sufficient to show that the product is pure ferrous oxide. It is therefore important to find out whether the product contained any metallic iron or ferric oxide, or both. In testing for metallic iron, a small sample is

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boiled in a test-tube with distilled water to drive off any air that may be present, then a few drops of dilute hydrochloric acid are added. If metallic iron is present, small bubbles of hydrogen are set free and rise to the surface of the solution.



In testing for ferric oxide, the substance is heated in dilute hydrochloric acid with exclusion of air, which is accomplished by passing a current of carbon dioxide into the tube while the product is being dissolved. If there is any ferric oxide, the solution becomes yellow; if not, it remains colorless. By the above qualitative methods, it is easy to ascertain the composition of the product.

The results obtained are shown in the following table:

No of tests	Weight of Charge in gm.	Weight of metallic iron in gm.	Weight of ferric oxide in gm.	Temperature in degree Centigrade	Time in hour.	Percent of total iron in product	Remarks
1	3.8436	1.0000	2.8436	600	2	74.40	1 contained much metallic iron and ferric oxide
2	1.9218	0.5000	1.4218	600	2	n. d.	2 contained much metallic iron and ferric oxide
3	1.9218	0.5000	1.4218	750	2	n. d.	3 Results was no better than 2.
4	1.9218	0.5000	1.4218	820-840	2	76.70	4 little metallic iron, much ferric oxide.
+ 5	3.8507	1.0000	2.8507	820-840	2	77.05	5 little metallic iron and <del>some</del> ferric oxide
# 6	3.8436	1.0000	2.8436	820-840	2	77.30	6 trace of metallic iron and some ferric oxide.
7	3.8250	1.0000	2.8250	820-840	2	77.67	7, 8, 9, 10, 11, a trace of metallic iron, no ferric oxide was detected.
8	3.8250	1.0000	2.8250	820-840	2	77.68	
9	3.8250	1.0000	2.8250	820-840	2	77.62	
10	3.8250	1.0000	2.8250	820-840	2	77.65	
11	5.7375	1.5000	4.2375	820-840	2	77.83	

+ The charge contained an amount of  $Fe_2O_3$  allowed for the hydrogen in the metallic iron.

# Here, an iron boat <sup>containing iron powder</sup> was introduced into the porcelain tube to absorb any oxygen contained in the nitrogen before it came in contact with the mixture.



In sample 1 the product contained much metallic iron and ferric oxide and the percentage of total iron was therefore low. In sample 2 a small<sup>er</sup> charge was used, but the product was no better than that obtained in Sample 1. In sample 3 the product, though heated to a high temperature, also contained much metallic iron and ferric oxide. The presence of these was chiefly due to the low temperature to which the mixture was heated. Quantitative analyses of samples 2 and 3 were not made. In sample 4, the mixture was heated to a higher temperature; it appeared to be much improved, but still it contained some metallic iron and much ferric oxide, for it colored the hydrochloric acid solution quite yellow. The presence of metallic iron and ferric oxide in the product and its low percentage of total iron led us to think that this must be due to the small amount of oxygen carried over by the nitrogen. To avoid this, an iron boat filled with metallic iron powder was introduced into the porcelain tube and placed at the end where the current of nitrogen entered, in order to remove all oxygen before the nitrogen came in contact with the mixture. Sample 6 was made under this condition. The product contained only a little metallic iron and some ferric oxide and the percentage of total iron became much higher and better. To further improve the results of the product, a small amount of ferric oxide was taken away from the charge. The results obtained were satisfactory and the value of total iron approximated the theoretical value which is 77.70 per cent. Samples 7, 8, 9, 10 and 11 show these satisfactory results.

In the preparation of ferrous oxide by this method, it appears that the temperature to which the mixture is heated plays an important part. If the temperature is too low, some metallic iron and some ferric oxide remain unchanged. In order to completely convert the mixture into ferrous oxide, it must be given the correct temperature and time. It is observed in the above table that, other conditions being the same, a small increase in the weight of the charge does not affect the character of the product.

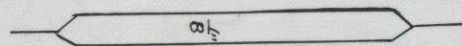
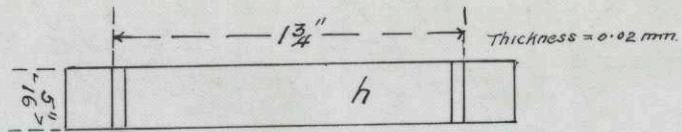
It will be noted that the amount of ferric oxide required for the charge in this case is less than the theoretical. This is perhaps due to the fact that, as the percentage of iron is low (99.10 per cent), the iron is present to a small extent as oxide and consequently the amount of ferric oxide required for the formation of ferrous oxide is less than what it is expected to be.



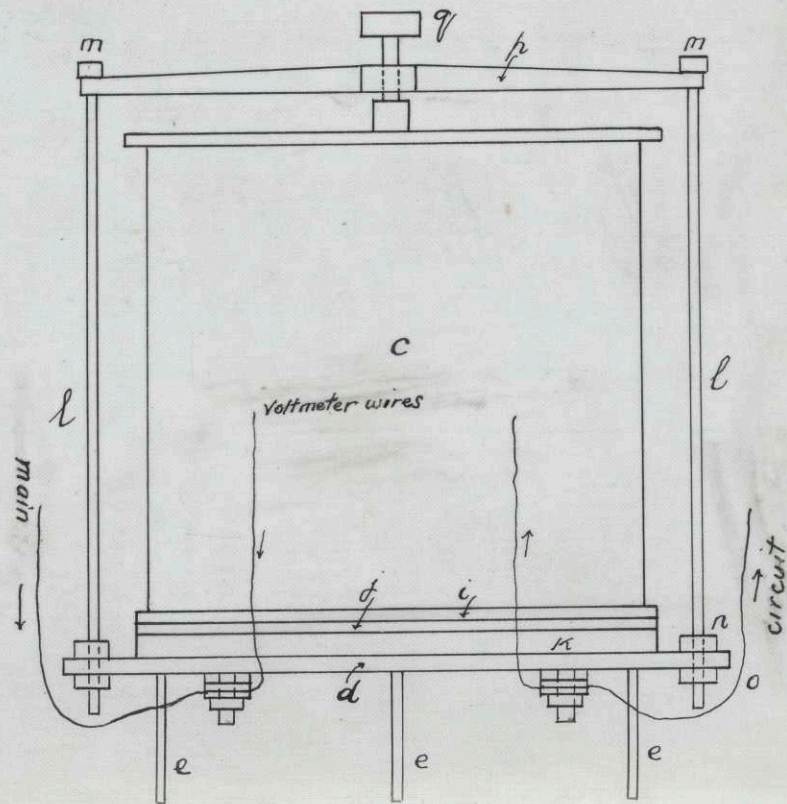
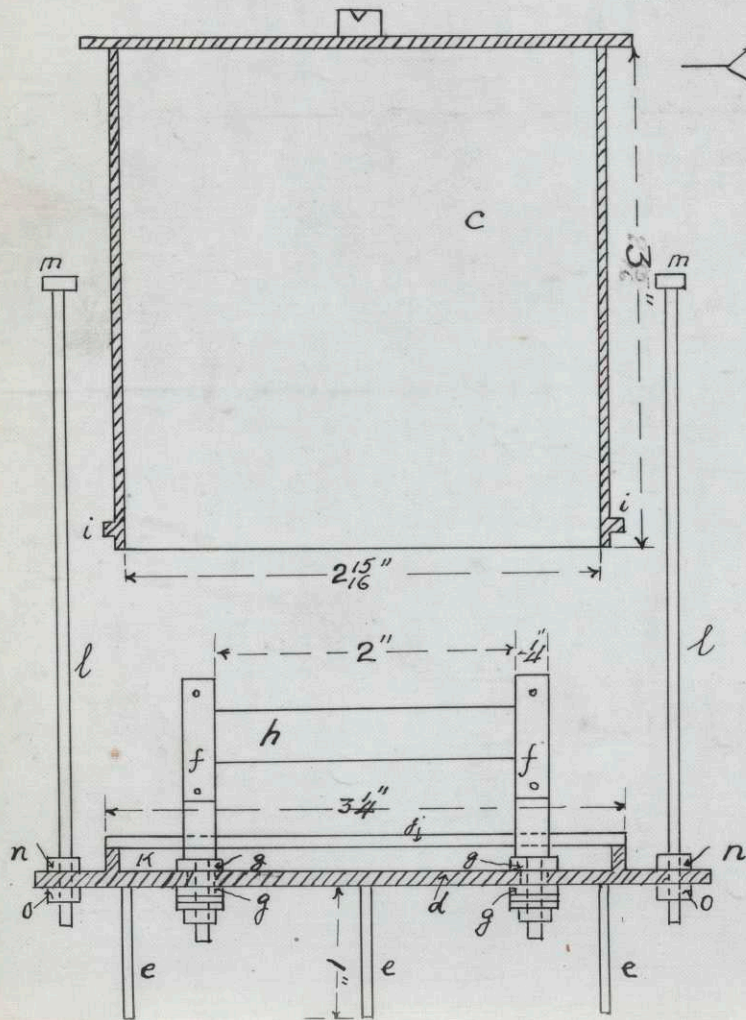
PART II

DETERMINATION OF HEATS OF FORMATION.

IV  
 DETAILS OF  
 COMBUSTION CHAMBER



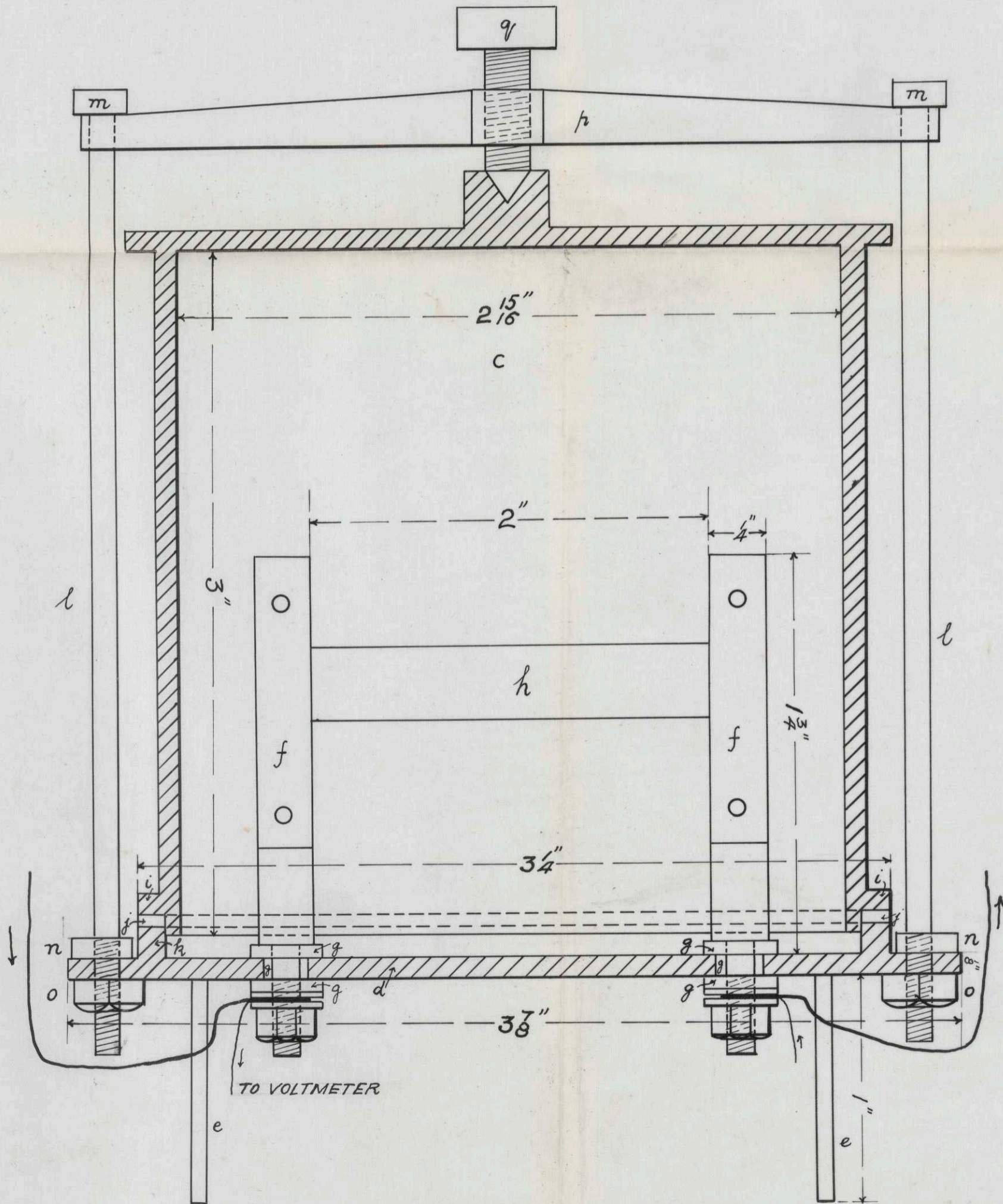
PLATINUM BOAT





IV  
SECTION OF COMBUSTION CHAMBER

SCALE 1 IN. = 1/2 IN.









The method chosen for determining the quantity of heat set free or absorbed in the formation of a silicate consists in fusing the substances in a platinum boat by means of electricity in a calorimeter specially designed for this purpose. The difference between the quantity of heat developed by the electrical energy and the quantity of heat obtained by the rise of temperature of the water in the calorimeter when fusing a charge gives the heat of formation of the silicate or silicate mixture.

### 1. The Apparatus

The electrical apparatus used in the experiment and its general arrangement are shown in Plate III. It consists of:

*usual* *bucket* *air-space*  
Two concentric jackets, J, outer jacket 11 in.h. × 8 3/4 in.

*para-petls*  
diameter and an inner jacket 8 1/2 in. h. × 7 3/4 in. diameter, made of non-conducting material, the surfaces of which are burnished, so as to prevent the loss of heat by radiation, or gain of heat by absorption from the surrounding space.

A combustion chamber, C, of rolled brass.

A vessel, D, 6 in.h. × 5 in. diam., of nickel-plated brass, which serves as a calorimeter. The calorimeter contains a weighed quantity of water into which the bulb of the thermometer, T, the stirrer, S, and the combustion chamber, C, are immersed. The thermometer permits reading to a precision of 0.01 deg. C, the stirrer is run by an electric motor mounted on top of it and is used to keep the water in the calorimeter at a uniform temperature.

The combustion chamber, Plate IV, consists of a cylindrical cover, c, and a circular bottom-plate, d, which rests on three



small legs, all made of rolled brass which has been treated with a solution of ammonia and cupric carbonate. This gives the surface a dark appearance and protects it from corrosion. Upon and through the bottom plate are fixed two <sup>slatted</sup> brass poles, f, 1/4 in. diameter, insulated from the bottom plate by rubber washers, g, and set 2 1/4 in. apart, from centre to centre. These two poles are connected by a platinum boat h, 1 3/4 in. long, 5/16 in. high and 1/8 in. wide, made of foil 0.02 mm. thick, in which the charge is held and fused. The shape of the platinum boat is clearly seen in the figure. <sup>IV</sup> Vessel, c, and bottom plate, d, are connected to make a water-tight joint. For this purpose, vessel, c, has a rib, i, which rests on a rubber gasket, j, carried by rib, k, of the bottom plate, d. The latter carries two rods, l, each of which has a head, m, at the top, a lock-nut, n, near the bottom and a thread at the lower end to receive a nut, o. The two rods are connected by a cross piece, p, and tightened by the set screw, q. <sup>curved</sup>

The electric current used to fuse the charge was furnished by a storage battery of light cells, B, plate III, four cells being connected in series and the two series are in parallel. Each cell had eleven electrodes, 8 in. x 8 in. and furnished a current of 10 amperes at 2 volts. The current was measured by the <sup>new</sup> millivoltmeter, A, connected in parallel to the shunt, F, which is in series with the circuit, the instrument permitting to read to an accuracy of 0.1 amperes. The difference in potential was measured by the voltmeter, V, which could be read to 0.001 of a volt.

The disposition of the wire connection is shown in



plate III. The double-throw switch, E, serves to charge and discharge the storage battery. When the switch is in the position, P, the battery is being charged; the current from the supply-main passes along the dotted arrows through six 32 c.p. incandescent lamps, the switch, P, to the battery, B, and thence returns through the resistance wires, r, in the water-tank, K, back to, P, and the return-main.

When the switch is in the position, P', the battery is being discharged. The current leaving the battery follows the full-drawn arrows, passes through the right of the switch, P', the shunt, F, the connector, h, and enters the combustion chamber at the bottom through the + pole, passes through the platinum boat, leaves the combustion chamber at the bottom through the -pole, passes through the left side of the switch, P', the two resistance wires, r, immersed in a large tank of water, K, returns to the battery. For measuring the difference in potential between the two terminals at the bottom of the combustion chamber where the current enters and leaves, there are attached two insulated copper wires which are connected with the voltmeter, V, to the two poles.

As a large current is required for the fusion of the charge, it is of much importance to consider the size of the copper wire used in the circuit. The wire should be large enough to carry 60 or more amperes without heating. With a smaller wire, the circuit would become heated and an increment of resistance could not be avoided; and thus the current is not kept constant. The copper wire was 4.06 mm. diameter, equals No. 8 gauge.

It is a matter of great importance in this experiment to get a constant current. This was effected by the consideration of two points, first, the number of amperes drawn from the storage battery and, second, the external resistance of the circuit. If too large a current is drawn from the battery, this becomes over-discharged and a constant current can never be obtained even if the external resistance is kept absolutely constant. In the present case, a constant current was obtained only when not more than 10 amperes were drawn from <sup>2</sup> each cell.

To get the proper and constant current for the fusion of the charge, a suitable external resistance of the circuit had to be provided. Three iron wires, No. 5 gauge, 2 ft., 8 in. long were first used and connected in parallel. It was found that these wires could not fulfil the required conditions because they offered too much resistance and then did not give either a proper current or a constant one. The iron wires were replaced by No. 14 <sup>a a</sup> I I wire of the Baker Co., Brooklyn, N.Y., which offered a resistance of only 73 ohms per 1000 feet. Two wires, <sup>2 2'</sup> 3 1/2 ft. long, connected in parallel were used, their ends were screwed into 2 brass blocks, b, 1/2 in. sq., 4 in. long. These were screwed onto the board, n, which was supported by two bricks, m. The wires were immersed in a large tank of water, k, to prevent their being heated and thus to obtain a constant current.

When the electric current is turned on, the platinum boat becomes heated; its resistance will increase and the electric current correspondingly decrease. In order to compensate for this, a



slider 0, was used and slid on one of the resistance wires, r, and the current kept thus constant by increasing or decreasing the external resistance of the circuit.

As the experiment was a delicate one, the operations were carried on with the greatest possible care. Every charge was preceded by a duplicate blank test in order to get the constant of the apparatus. In every blank- and charge-determination, the electric current, the quantity of water, 1200 grams, and the time were kept constant. The last was recorded by means of a stop-watch.

## 2. Mode of Operating.

The substances were separately weighed out in one-inch watch glasses, mixed on a piece of glazed paper and transferred into the platinum boat beneath which a small piece of glazed paper had been previously placed, in order to catch any mixture that might fall from the boat. It was essential that the position of the boat in the poles should remain absolutely unchanged after the blank tests had been made, hence this method of filling the boat was adopted. The glazed paper was removed, the cover of the combustion chamber placed on the bottom plate and tightened by turning the screw, g. An experiment consisted of the following operations:

The room-temperature was read, that the temperature of the calorimeter-water might be adjusted so that at the end of a test the water-temperature should be the same as the room-temperature, or perhaps one degree higher, as in this way the cooling correction of the

calorimeter was reduced to a minimum. Usually the calorimeter water, at the start, was 1 degree C lower than the room-temperature.

The combustion chamber was then placed in the weighed water, the stirrer inserted and set in motion by turning on the current, a branch from the supply main. The bulb of the thermometer was immersed, the voltmeter connected to the two poles. The circuit was closed by connecting the combustion chamber with the leads by means of two connections, h. The stirrer was allowed to run for at least five minutes and usually ten minutes, before the preliminary readings of the temperature of the water in the calorimeter were taken. The temperature was read every minute for five minutes, then the current was turned on and allowed to pass for one minute, being timed by a stop-watch. The temperature of the water would rise and continue to do so for three or four minutes more before it reached its highest point. After the current was turned off, readings of the temperature of the water were taken every 30 seconds and this continued until five minutes after the temperature had reached its maximum.

During the passage of the current, readings were taken of the <sup>and</sup> voltmeter and the millivoltmeter, the total current was kept constant by varying the external resistance, r, by means of a slide, O.

It will be observed, in this experiment, that the whole current did not pass through the platinum boat, that a small part of it went through the voltmeter, v. Owing to the high resistance of the voltmeter, the low voltage of the storage battery,



only an inappreciable part of the total current passed through the voltmeter and could be, therefore, neglected.

### 3. Cooling Corrections.

In calorimetric work, one of the most troublesome sources of error is the gain or loss of heat caused by the surroundings. This is due chiefly to conduction and radiation. The conduction can be eliminated by supporting the calorimeter on three corks, but the error due to radiation is great and serious. To reduce this source of error to a minimum, the calorimeter should be enclosed within two concentric vessels of non-conducting material; further, the temperature of the calorimeter should not differ greatly from that of its surroundings, and the duration of the experiment should be as short as permissible.

The error due to radiation may be reduced to its minimum by so adjusting the initial temperature of the calorimeter-water, that the room-temperature lies about half way between its initial and final temperatures. The duration of the passage of the current was fixed at one minute.

The advantages of having such a short period are great and manifold. In the first place, the rise of temperature in the calorimeter is small; then, the initial temperature can be more easily adjusted; further, the heat lost by radiation, or gained by absorption, is small and hence the amount of cooling correction is also small and of smaller influence. If, on the other hand, the duration of the passage of the current is long, the rise of temperature will be high and the initial temperature will have to be adjusted far below the

room-temperature and the final temperature will rise far above it. The result is that the quantity of heat absorbed and radiated is large, and being irregular, makes the cooling correction uncertain.

In the experiments, the current was allowed to pass, at first, five minutes and the initial temperature was about the same as the room-temperature. The idea of doing this was to make the cooling correction a positive amount. The result was that the rise of temperature was far too great and the cooling correction correspondingly too large and therefore irregular. Table II will show the variations of the cooling correction varying from 0.20 to 0.27, average 0.235, with a rise of temperature of 13.30 to 13.99, average 13.645.

Next, the time was reduced to three minutes and the initial temperature lowered, so that the final temperature was about the same as the room-temperature. Since, in this case, heat was absorbed from the surroundings, the cooling correction was negative. The amount of cooling correction, though greatly decreased, was still too large and irregular. Table III, No. 1 to 4, shows results. The correction gives an average 0.145 for a rise of temperature of 6.97.

In the two-minute runs shown in table III, No. 5 and 6, the amount of cooling correction was greatly decreased, amounting to 0.09 for a rise of temperature of 4.95. This is still too large and too uncertain.

In the one-minute runs, the amount of cooling correction was reduced still further, as seen in table IV. Here the correction values are 0.05 for a rise of temperature of 2.71. But the



results of the blank tests still varied greatly. The initial temperature was adjusted in such a manner that the surrounding temperature was about half-way between the initial and final temperatures. Under this condition, the results proved to be much better and more satisfactory as seen in tables V, VI, VII and VIII.

#### 4. Computation of Cooling Correction.

During the operation of a calorimeter, as has already been said, heat is either gained or lost by absorption or radiation, it is, therefore, of main importance to find out this amount of heat. As the conditions under which the experiments were performed were different in each series of runs, the values found will vary; they may be positive or negative. There are three possible cases.

1. The initial temperature of water in the calorimeter is about the same as that of the room.

2. The initial temperature of water in the calorimeter is sufficiently low, that at the end of the experiment the maximum temperature reached is equal to the room-temperature or little lower.

3. The room-temperature lies at half-way between the initial and final temperatures of the water in the calorimeter.

In Case 1, the temperature of water in the calorimeter begins to rise in the surrounding room-temperature and heat is lost by radiation. The corrected rise of temperature is expressed by

$$T = t_2 - t_1 + \frac{r_1 + r_2}{2} (\theta_2 - \theta_1) \quad \text{No. A}$$

where  $t_1$  denotes the temperature at the instant when the current is turned on,  $t_2$  the temperature at the instant when the temperature, after having turned off the current, reaches its highest point;  $r$ , the rate of radiation per minute in deg. C before the current is turned on;  $r_2$ , the rate of radiation per minute after the current is shut off;  $\theta_1$ , the time at which the current is turned on;  $\theta_2$  the time at which the temperature reaches its maximum. The following example will make clear the calculation of rise of the temperature and of cooling correction.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	24.68	24	53	4.600
	30				4.600
1	0	24.68			4.627
	30				4.633
2	0	24.68			4.610
	30				4.637
3	0	24.68			4.630
	30				4.633
4	0	24.68			4.627
	30				4.620
5	0x	24.68			
	30				
6	0				
	30				
7	0				
	30				
8	0				
	30				
					Av. 4.624



Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
9	0				
	30				
10	0#				
	30	37.90			
11	0	38.04			
	30	38.13			
12	0	38.18			
	30	38.19 max.			
13	0	38.18			
	30	38.14			
14	0	38.10			
	30	38.06			
15	0	38.02			
	30	38.00			
16	0	38.97			
	30	38.91			
17	0	38.87			
	30	37.83			
18	0				

Since heat was radiated while the temperature of the water in the calorimeter was rising, the correction will have to be added to the observed rise of temperature.

$$r_1 = 24.68 - 24.68 = 0 \text{ deg. C}$$

$$r_2 = 38.19 - 37.83 = 0.36 = 0.072 \text{ deg. C}; t_2 = 38.19 \text{ deg. C}; t_1 = 24.68$$

deg. C

$$\theta_1 = 5; \theta_2 = 12 \frac{1}{2}; \therefore T = 38.19 - 24.68 + \frac{\theta_2 + 0.072}{2} \times 7 \frac{1}{2} = 13.78 \text{ deg. C}$$

In Case 2, the initial temperature of the calorimeter was far below and the final temperature about the same as that of the room-temperature. Heat was gained, and the amount of cooling correction consequently negative. The general formula assumes this form in which the cooling correction is negative.

$$T = t_2 - t_1 - r \frac{(\theta_2 - \theta_1)}{2} \quad (\text{No. B})$$

The computation is shown by the following example:

Duration of Time		Calorimeter Temperature of water	Avg. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	16.30	23	50	4.160
	30				4.187
1	0	16.33			4.187
	30				4.190
2	0	16.38			4.200
	30				4.200
3	0	16.42			
	30				
4	0	16.48			
	30				
5	0	16.50			
	30				
6	0				
	30				
7	0				
	30				
8	0				
	30	23.12			
9	0	23.35			



Example continued.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	30	23.50			
10	0	23.60	23	50	
	30	23.62			
11	0	23.67			
	30	23.69			
12	0	23.69			
	30	23.70			
13	0	23.70			
	30	23.70			
14	0	23.70			
	30	23.70			
15	0	23.70			
	30	23.70			
16	0	23.70			
	30	23.70			
17	0	23.70			
	30	23.70			
18	0	23.70			

$$r_1 = \frac{16.50 - 16.30}{5} = \frac{0.20}{5} = 0.04 \text{ deg. C}; \quad r_2 = \frac{23.70 - 23.70}{5} = 0;$$

$$t_2 = 23.70; \quad t_1 = 16.50; \quad \theta_2 = 12 \frac{1}{2}; \quad \theta_1 = 5;$$

$$T = 23.70 - 16.50 - \frac{0.04 + 0}{2} \times 7 \frac{1}{2} = 7.05 \text{ deg. C}$$

In Case 3, if the initial temperature of the water in the calorimeter could be brought to just as many degrees below the room-temperature as the final temperature of the water will rise above the room temperature, then the heat gained or lost would be balanced and a cooling correction become unnecessary. But it is practically impossible to so adjust the initial temperature, as the

conditions of the surroundings are changing all the time. The best that can be done in this case is to so adjust the initial temperature of the calorimeter water that the surrounding temperature lies about half-way between the initial and final temperatures of the water. The corrected rise of temperature is calculated by

$$T = t_2 - t_1 \pm \frac{r_1 + r_2}{2} (\theta_2 - \theta_1) \quad (\text{No. C})$$

If  $r_1$  is greater than  $r_2$ , the correction assumes a negative value and the negative sign of the formula is used. If  $r_2$  is greater than  $r_1$ , the positive sign, by arranging the conditions of the experiments to suit Case 3 and with its formula (No. C), is used. It was found that the amount of cooling-corrections was greatly reduced and the results thereby improved. The following example will illustrate this method of computing the amount of cooling-corrections developed by electrical energy.

Duration of Time		Calorimeter Temperature of water.	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.77	24.5	54	3.975
	30				4.025
1	0	22.77			4.015
	30				4.000
2	0	22.77			3.985
	30				4.000
3	0	22.77			4.020
	30				4.025
4	0	22.77			4.025
	30				4.000
5+	0	22.78			4.010



Example continued

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy
Min.	Sec.	Deg. C	Deg. C	I. Amp. E. Volt
	30			3.990
6#	0			4.020
	30	24.95		4.010
7	0	25.05		4.025
	30	25.11		4.015
8	0	25.17		4.010
	30	25.19		4.005
9	0	25.20		4.000
	30	25.20		3.990
10	0	25.20		
	30	25.20		Av. 4.009
11	0	25.20		
	30	25.20		
12	0	25.19		
	30	25.19		
13	0	25.19		
	30	25.18		
14	0	25.18		
	30			
15	0			

+ Current turned on. # Current turned off.

$$r_1 = \frac{22.78 - 22.77}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C (absorbed)}; r_2 = \frac{25.20 - 25.18}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C (radiated)}; t_2 = 25.20; t_1 = 22.78; \theta_1 = 5; \theta_2 = 9.$$

$$T = t_2 - t_1 + \frac{r_1 + r_2}{2} (\theta_2 - \theta_1) = 25.20 - 22.78 + \frac{0.002 + 0.004}{2} \times 4 = 2.42 + 0.01 = 2.43^\circ \text{C}$$





The amount of cooling corrections in this case must be added, as the quantity of heat which is radiated is larger than that which was absorbed.

#### 5. Method of Making Preliminary Fusions.

Attempts were first made to determine the heat formation of silicates by comparing the rise of temperature in the blank-test with that in the charge-test and to multiply the difference with the quantity of water. This was done by keeping the electric current constant, the amount of water and the time constant, both in the blank-tests and in the charge-tests. The method did not give true values of the heats of reaction. The current passing through the platinum boat in a blank-test gives a certain value. Passing through a charge-test, the resistance is decreased by the conduction of the charge; if the current is to be kept constant, the voltage must be reduced, but the heat generated  $H = k.I.E.t$ , hence the rise of temperature of the water in the calorimeter will be smaller than the rise of temperature with the blank-test and the two are not comparable.

The results are given in the following table. I

By studying the table, it is found that in every determination the differences between the average rise of temperature of the blank-tests and of the charge-tests vary greatly from one another, and that the heat of formation of the silicates is negative, that is, that heat is absorbed.

#### 6. Final Method of Making Fusions.

In this method, the theoretical quantity of heat

developed by electrical energy is compared with the actual quantity of heat obtained in the calorimeter. In a blank-test, the theoretical quantity of heat should be equal to the actual quantity, but in the experiments this was not found to be the case; as in almost every determination the actual quantity of heat was greater. This deviation was due to the constant error of the instruments and to error from other sources, such as cooling correction, personal factor in the reading of instruments, etc. In order to obtain reliable results, it is of great importance to determine the blank-constant. This was done by running two blank-tests before every charge-test.

The theoretical quantity of heat developed by electrical energy is

$$H = 0.2387 I.E.t. \text{ gm-cal.}$$

in which  $I$  denotes the electric current in amperes,  $E$ , the difference of potential between two poles of the combustion chamber, in volts, and  $t$ , the time in seconds.

In the example given on page ... the electric current was kept constant at 54 amperes, the average difference of potential was 4.009 volts, and the time during which the electric current was turned on was 60 seconds. Therefore the theoretical quantity of heat

$$H = 0.2387 \times 4.009 \times 60 = 3101 \text{ gm-cal.}$$

The actual quantity of heat is  $H_1 = Q.T.$  in which  $Q$  denotes the quantity of water in grams including the water-equivalent of the calorimeter, the stirrer and the combustion chamber, and  $T$  the corrected



Table 2 Blank-Test

No. of tests	Time in second	current in ampere	Averaged difference potential in Volt.	Weight of water in gm.	Temperature in degree Centigrade					Actual amount of heat in gm-cal.	Theoretical amount of heat in gm-cal	Difference
					Initial	Final	Room temp.	Cooling Correction	Rise of Temp.			
1	300	53	4.502	1303	24. <sup>.78</sup> <del>87</del>	37.85	25	+ .23	13.30	17330	17090	240
2	300	53	4.527	1303	25.00	38.10	25	+ .23	13.33	17369	17180	189
3	300	53	4.547	1303	25.21	38.40	26	+ .22	13.41	17473	17260	213
4	300	53	4.564	1303	25.50	38.74	27	+ .21	13.45	17525	17330	195
5	300	53	4.581	1303	25.77	39.08	27	+ .25	13.56	17669	17390	279
6	300	53	4.576	1303	24.64	38.02	24	+ .24	13.62	17747	17370	377
7	300	53	4.582	1303	24.51	37.94	24	+ .23	13.66	17800	17391	411
8	300	53	4.624	1303	24.68	38.19	24	+ .27	13.78	17955	17550	405
9	300	53	4.696	1303	19.24	32.99	22	+ .24	13.99	18229	17920	309
10	300	53	4.715	1303	20.41	34.15	23	+ .20	13.94	18164	17993	171

rise of temperature.

The water-equivalent is obtained by multiplying the sum of the weights of the calorimeter, the stirrer and the combustion chamber by the specific heat of the metal.

Weight of calorimeter .....	211.0 gm.
" " stirrer .....	100.0 "
" " combustion chamber ....	836.0 "

Taking the specific heat of the metal to be 0.09, the water-equivalent of metal parts is equal to  $(836+100+211) \times 0.09 = 108$  gm. water.

Then with 1200 gram water,  $Q = 1200+108=1308$  gm. of water.

The actual quantity of heat

$$H_1 = Q T = 1308 \times 2.48 = 3166 \text{ gm-cal.}$$

In order to ascertain the accuracy of this method, a series of blank-tests was first made. The duration of the operation proper of each test was five minutes; the initial temperature of the water was adjusted about the same as the surrounding temperature. The difference of potential between the two terminals was read every half minute. In this series of tests, heat was lost and the corrected temperature should be calculated as shown on page ...by the formula: A, viz:

$$T = t_2 - t_1 + \frac{r_1 + r_2}{2} (\theta - \theta_1)$$

The difference between the theoretical and the actual quantities, as shown in table II, are great and varied. These



Table 3

NO. of tests	Time in second	Current in ampere	Averaged difference in potential in volt	Weight of water in gram	Temperature of water in degree Cent.					Actual amount of heat in gm.-cal	Theoretical amount of heat in gm.-cal.	Difference	
					Initial	Final	Room Temp	Cooling Correction	Rise of Temp				
1	a	180	50	4.180	1303	16.70	23.79	23.5	-.09	7.00	9121	8980	141
	b	180	50	4.168	1303	16.12	23.29	23	-.20	6.97	9082	8954	128
	c	180	50	4.196	1303	16.50	23.70	23	-.15	7.05	9186	9004	182
2	a	180	50	4.374	1303	16.30	23.87	24	-.17	7.40	9642	9396	246
	b	180	50	4.386	1303	16.24	23.78	24	-.18	7.36	9590	9416	221
3	a	180	50	3.853	1303	17.03	23.79	23	-.17	6.59	8587	8377	210
	b	180	50	3.837	1303	15.73	22.47	23	-.20	6.54	8522	8130	392
4	a	180	52	4.102	1303	15.01	22.39	23	-.17	7.21	9395	9165	230
	b	180	52	4.100	1303	15.02	22.39	24.5	-.18	7.19	9369	9160	209
5	a	120	50	4.202	1303	17.69	22.47	23	-.10	4.68	6098	6018	80
	b	120	50	4.189	1303	17.63	22.50	23.5	-.11	4.76	6202	6000	202
	c	120	50	4.195	1303	17.73	22.53	25	-.11	4.69	6111	6008	103
	d	120	50	4.192	1303	17.96	22.79	23.5	-.10	4.73	6163	6004	159
6	a	120	54	4.217	1303	17.00	22.24	22	-.07	5.17	<sup>6736</sup> <del>6525</del>	6525	211
	b	120	54	4.240	1303	16.50	21.80	23	-.07	5.23	<sup>6824</sup> <del>6534</del>	6534	290

discrepancies are due to many sources of error, but the greatest of all is perhaps the amount of the cooling corrections and the variations in the difference of potential. On account of these, another series of blank-tests was made in which the duration of the operation proper was reduced to three minutes and two minutes. In order to prevent a rapid loss of heat by radiation, the initial temperature was brought down to such a point that the final temperature was about the same as the room-temperature. In these tests, heat was gained, hence the amount of cooling correction should be subtracted from the observed rise of temperature. The one marked "B" on p.27. is used for the correction.

$$T = t_2 - t_1 - \frac{r_1}{2}(\theta_2 - \theta_1)$$

The amount of cooling correction is seen to be greatly reduced and hence better, but the results are still unsatisfactory as shown in table III

By comparing tables II and III, it will be seen that the cooling correction in the three-minute runs is smaller than that in the five-minute runs, and that in the two-minute runs smaller than that in the three-minute runs. But even in the two-minute runs the difference between the theoretical and the actual quantities of heat are too great and varied to be of value, hence a fourth series of blank-tests was made in which the duration of the operation proper was reduced to one minute. The initial temperature was brought sufficiently below the surrounding temperature so that the final temperature was little below it. The difference of potential between the two termi-



nals was read three times a minute, that is, at 15, 30 and 45 seconds. Two examples will show the details of the observations made in all the subsequent tests.

First Example.

Duration of		Calorimeter	Av. Room	Electrical	
Time		Temperature	Temperature	Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	18.90	21	55	4.333
	30				4.340
1	0	18.90			4.390
	30				
2	0	18.91			
	30				
3	0	18.91			
	30				
4	0	18.91			
	30				
5+	0	18.92			
	30				
6*	0				
	30	21.25			
7	0	21.40			
	30	21.50			
8	0	21.52			
	30	21.56			
9	0	21.58			
	30	21.59 max.			
10	0	21.59			
	30	21.59			
11	0	21.59			
	30	21.59			
12	0	21.59			
	30	21.58			

First Example Cont'd.

Duration of Time		Calorimeter Temperature of water.	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
13	0	21.57			
	30	21.56			
14	0	21.55			
	30	21.54			
15	0				

+ Current turned on. \* Current turned off.

The temperature correction is computed as shown on page... as follows:

$$r_1 = 0.004 \text{ deg. C}; r_2 = 0.01 \text{ deg. C}$$

$$t_2 = 21.59; t_1 = 18.92; \theta_1 = 5; \theta_2 = 9 \frac{1}{2};$$

$$T = 21.59 - 18.92 + \frac{0.004 + 0.01}{2} \times 4 \frac{1}{2} = 2.70 \text{ deg. C}$$

The cooling correction should, in this case, be added to the observed rise of temperature as the amount of heat radiated was greater than that which was absorbed.



Second Example.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt.
	0	19.39	25	55	4.357
	30				4.390
1	0	19.40			4.406
	30				
2	0	19.42		Av.	4.384
	30				
3	0	19.44			
	30				
4	0	19.46			
	30				
5+	0	19.48			
	30				
6#	0				
	30	21.90			
7	0	21.99			
	30	22.08			
8	0	22.12			
	30	22.20			
9	0	22.33			
	30	22.25			
10	0	22.27			
	30	22.29 max.			
11	0	22.29			
	30	22.29			
12	0	22.29			
	30	22.29			
13	0	22.30			
	30	22.30			
14	0	22.30			
	30	22.30			
15	0	22.31			

Table 4

NO. of tests	Time in second	Averaged difference potential in volt.	Current in amp.	Weight of water in gram.	Temperature of water in degree Centigrade					Actual amount of heat in gm-cal	Theoretical amount of heat in gm-cal	Difference
					Initial	Final	Room temp.	Cooling correction	Rise of temp.			
1	60	4.353	55	1303	18.69	21.46	23	-.07	2.70	3518	3429	89
2	60	4.352	55	1303	19.25	21.98	23	-.03	2.70	3518	3428	90
3	60	4.374	55	1303	19.09	21.81	23.5	-.05	2.67	3479	3445	34
4	60	4.371	55	1303	19.01	21.78	23	-.05	2.73	3557	3444	113
5	60	4.351	55	1303	18.93	21.64	23	-.03	2.68	3492	3427	65
6	60	4.354	55	1303	18.92	21.59	21.5	+.03	2.70	3518	3430	88
7	60	4.367	55	1303	19.09	21.89	23	-.05	2.75	3583	3440	143
8	60	4.384	55	1303	19.48	22.29	25	-.06	2.75	3583	3453	130



Table 5

No. of tests	Time in second	Current in ampere	Averaged difference potential in volt	Weight of water in gm.	Temperature of water in degree Cent.					Actual amount of heat in gm-cal.	Theoretical amount of heat in gm-cal.	Difference
					Initial	Final	Room temp.	Cooling Correction	Rise of temp.			
1	a	60	4.354	1303	23.68	26.03	25	+0.02	2.37	3088	3056	32
	b	60	4.363	1303	24.51	26.90	26	-0.017	2.380	3107	3062	<del>45</del> 39
2	a	60	3.880	1303	21.21	23.60	23	-0.02	2.37	3088	3001	87
	b	60	3.938	1303	23.60	26.00	25	.00	2.40	3127	3046	81
3	a	60	4.219	1303	24.20	26.74	25.5	+0.02	2.56	3336	3203	133
	b	60	4.222	1303	23.80	26.33	24.5	+0.02	2.55	3323	3206	119
4	a	60	3.981	1303	22.08	24.50	24	.00	2.42	3153	3079	74
	b	60	3.996	1303	22.10	24.52	23.5	+0.015	2.435	3173	3090	83

The temperature correction is:

$$r_1 = 0.018 \text{ deg. C}; r_2 = 0.004 \text{ deg. C}; t_2 = 22.29; t_1 = 19.48; \theta_1 = 5;$$

$$\theta_2 = 11 \frac{1}{2}.$$

$$T = 22.29 - 19.48 - \frac{0.018 + 0.004}{2} (5 \frac{1}{2}) = 2.75 \text{ deg. C}$$

The cooling correction, in this case, should be subtracted from the observed rise of temperature, as heat was gained from the surroundings.

The results obtained in this series of blank-tests are given in table IV.

A perusal of the above results will show that there are still great discrepancies among them. These were due, in greater part, to two chief sources of error, first, that the initial temperature was brought too far below that of the surroundings, which rendered the amount of cooling correction uncertain and varied, and that, on account of the variation of the difference of potential between the two terminals, three readings were not sufficient to give a fair average. In the next series, these two sources of error were mostly eliminated by adjusting the initial temperature just a little below the room-temperature, so that the final temperature was a little above it, and by reading the difference of potential between the two terminals as often and as accurately as possible.

The results given in table V show the value of the change in the mode of operating as the duplicates check within the precision of measuring apparatus.

In this series, different platinum boats were employed in each pair of blank-tests. An inspection of the results



will show that the blank-constants, that is, the differences between the actual amount of heat and the theoretical amount of heat obtained in the blank-tests, agree in each case excellently, and that in every determination the actual amount of heat is greater than the theoretical. Four examples may serve to show the details of observation.

First Example.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy.	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.70	25	49	4.350
	30				4.350
1	0	23.69			4.375
	30				4.375
2	0	23.68			4.350
	30				4.350
3	0	23.68			4.335
	30				4.350
4	0	23.68			4.350
	30				4.350
5+	0	23.68			4.375
	30				4.335
6*	0				<hr/>
	30	25.70		Av.	4.354
7	0	25.85			
	30				
8	0	25.95			
	30	26.00			
9	0	26.01			
	30	26.02			
10	0	26.03 max.			
	30	26.03			

First Example Cont'd.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
11	0	26.03			
	30	26.03			
12	0	26.03			
	30	26.02			
13	0	26.02			
	30	26.01			
14	0	26.01			
	30	26.00			
15	0	26.00			

+ Current turned on    \* Current turned off

The corrected rise of temperature is calculated

as follows:

$$r_1 = 0.004 \text{ deg. C}; \quad r_2 = 0.006 \text{ deg. C}$$

$$t_2 = 26.03; \quad t_1 = 23.68; \quad \theta_1 = 5; \quad \theta_2 = 9 \frac{1}{2}$$

$$T = 26.03 - 23.68 + \frac{0.004 + 0.006}{2} \times 4 \frac{1}{2} = 2.37 \text{ deg. C}$$



Second Example

Duration of Time		Calorimeter Temperature	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt.
	0	24.49	26	49	4.375
	30				4.350
1	0	24.50			4.355
	30				4.350
2	0	24.50			4.360
	30				4.360
3	0	24.50			4.365
	30				4.360
4	0	24.50			4.375
	30				4.370
5+	0	24.51			4.360
	30				4.375
6*	0				
	30	26.51			
7	0	26.70			
	30	26.79			
8	0	26.84			
	30	26.87			
9	0	26.88			
	30	26.90 max.			
10	0	26.90			
	30	26.90			
11	0	26.90			
	30	26.90			
12	0	26.90			
	30	26.90			
13	0	26.89			
	30	26.89			
14	0	26.89			
	30	26.89			
15	0	26.89			

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 Av. 4.363

+ Current turned on. \* Current turned off.

$$r_1 = \frac{24.51 - 24.49}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}; \quad r_2 = \frac{26.90 - 26.89}{5} = \frac{0.01}{5} = 0.002^\circ\text{C}$$

$$t_2 = 26.90; \quad t_1 = 24.51; \quad \theta_1 = 5; \quad \theta_2 = 9 \frac{1}{2}$$

$$\frac{r_1 + r_2}{2} \times 4 \frac{1}{2} = 0.014 \text{ deg. C}$$

This amount should be subtracted from the observed rise of temperature, because the heat gained was greater than that which was lost.



Third Example.

Duration of Time		Calorimeter Temperature of water.	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.18	23	54	3.750
	30				3.950
1	0	21.19			3.950
	30				3.945
2	0	21.20			3.930
	30				3.925
3	0	21.20			3.935
	30				3.945
4	0	21.20			3.945
	30				3.940
5+	0	21.21			3.925
	30				3.945
6#	0				3.940
	30	23.35			3.930
7	0	23.45			3.925
	30	23.50			3.930
8	0	23.54			3.925
	30	23.57			3.925
9	0	23.58			3.920
	30	23.59			3.930
10	0	23.60 max.			3.925
	30	23.60			3.925
11	0	23.60			<hr/>
	30	23.60		Av.	3.880
12	0	23.60			
	30	23.60			
13	0	23.60			
	30	23.60			
14	0	23.60			
	30	23.60			
15	0	23.60			

+ Current turned on. # Current turned off.

Third Example Cont'd.

$$r_1 = 0.006; r_2 = 0.000;$$

$$t_2 = 23.60; t_1 = 21.21; \theta_1 = 5; \theta_2 = 10$$

$$T = 23.60 - 21.21 - \frac{0.006}{2} \times 5 = 2.37 \text{ deg. C}$$

The amount of cooling correction should be added,  
for heat was gained at the beginning of the experiment.



Fourth Example.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.60	25 deg. C	54	3.875
	30				3.925
1	0	23.60			3.950
	30				3.940
2	0	23.60			3.930
	30				3.930
3	0	23.60			3.940
	30				3.930
4	0	23.60			3.945
	30				3.930
5+	0	23.60			3.925
	30				3.935
6*	0				3.975
	30	25.75			3.940
7	0	25.85			3.955
	30	25.92			3.955
8	0	25.98			3.950
	30	25.99			3.940
9	0	26.00 max.			3.950
	30	26.00			3.940
10	0	26.00			3.940
	30	26.00			3.935
11	0	26.00			
	30	26.00			Av. 3.938
12	0	26.00			
	30	26.00			
13	0	26.00			
	30	26.00			
14	0	26.00			
	30	26.00			
15	0	25.99			

+ Current turned on. # Current turned off.

Fourth Example Cont'd.

$$r_1 = 0; r_2 = 0.002$$

$$t_2 = 26.00; t_1 = 23.60; \theta_1 = 5; \theta_2 = 9$$

$$T = 26.00 - 23.60 + \frac{0.002}{2} \times 4 = 2.40 \text{ deg. C}$$



## 7. Fusion Tests.

It is seen that the conditions of the blank-tests have been greatly improved by the reduction of the amount of the cooling correction and by the more frequent readings of the voltmeter and that the results thus obtained were satisfactory. As in every blank-test there is a difference between the actual and the theoretical amount of heat, it is important to make a blank-test before a charge-test under the same conditions accurately. A duplicate blank-test was made in every case.

The heat formations of three singulo silicates of ferrous oxide and lime were determined and it was found that in every determination the formation evolved heat.

The results obtained in studying the heat formation of the singulo-silicate of the composition, 70.80 per cent FeO and 29.20 per cent  $\text{SiO}_2$ , are given in table VI.

In every test, the charge was well fused, except in No. 1, where there was a small quantity at the two ends of the platinum boat which remained unfused. The result of Test No. 2 appears to be too high and should be discarded. Tests No. 3, 4, and 5 are in excellent agreement with one another. If the average of the last three results be taken, the amount of heat evolved by the formation of the silicate is 107 gram-calories per gram of charge.





Details of the observations leading to the results assembled in table VI are given in the following:

Blank-Test No. 1 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.05	23.5	50	4.100
	30				4.125
1	0	22.05			4.125
	30				4.115
2	0	22.06			4.150
	30				4.100
3	0	22.06			4.125
	30				4.125
4	0	22.07			4.125
	30				4.125
5+	0	22.07			4.125
	30				4.115
6#	0				4.110
	30	24.14			4.110
7	0	24.25			4.110
	30	24.30			4.100
8	0	24.32			4.115
	30	24.35			4.115
9	0	24.37 max.			4.110
	30	24.37			4.100
10	0	24.37			
	30	24.37		Av.	4.116 ✓
11	0	24.37			
	30	24.37			
12	0	24.36			
	30	24.36			

Blank-Test No. 1 a cont'd.

Duration of Time		Calorimeter Temperature of water.	Room Temperature	Electrical Energy
Min.	Sec.	Deg. C		
13	0	24.35		
	30	24.34		
14	0	24.34		

‡ Current turned on.    \* Current turned off.

$$r_1 = \frac{22.07 - 22.05}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r_2 = \frac{24.37 - 24.34}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$\text{Corrected temperature} = 24.37 - 22.07 + \frac{0.004 + 0.006}{2} \times 4 = 2.32 \text{ deg. C}$$

$$= 2.30 + .004 = 2.304 \text{ C}$$



Blank-Test No. 1 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.67	24	50	4.150
	30				4.135
1	0	22.67			4.150
	30				4.125
2	0	22.68			4.125
	30				4.130
3	0	22.68			4.130
	30				4.110
4	0	22.68			4.115
	30				4.125
5+	0	22.68			4.135
	30				4.110
6*	0				4.125
	30	24.76			4.085
7	0	24.85			4.125
	30	24.90			4.120
8	0	24.93			4.115
	30	24.96			4.115
9	0	24.97			
	30	24.98 max.			
10	0	24.98			
	30	24.98			
11	0	24.98			
	30	24.98			
12	0	24.97			
	30	24.97			
13	0	24.97			
	30	24.96			
14	0	24.95			
	30	24.94			
				Average	4.125 ✓

Blank-Test No. 1 b cont'd.

Duration of Time		Calorimeter Temperature of water	Avg. Room Temperature	Electrical Energy
Min.	Sec.	Deg. C	Deg. C	I. Amp. E. Volt
15	0	24.94		

+ Current turned on.    # Current turned off.

$$r_1 = \frac{22.68 - 22.67}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = \frac{24.98 - 24.94}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 24.98 - 22.68 + \frac{0.002 + 0.008}{2} \times 4.5 = 2.323 \text{ deg. C}$$

$$= 2.30 + 0.018 = \underline{\underline{2.318 \text{ C}}}$$



Charge-Test No. 1

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.11	24	50	3.600
	30				3.850
1	0	23.11			3.885
	30				3.935
2	0	23.12			4.000
	30				4.075
3	0	23.12			4.025
	30				4.100
4	0	23.12			4.100
	30				4.130
5+	0	23.12			4.125
	30				4.125
6#	0				4.115
	30	25.10			
7	0	25.28			
	30	25.33			
8	0	25.38			
	30	25.40			
9	0	25.41			
	30	25.42			
10	0	25.43			
	30	25.43			
11	0	25.43			
	30	25.42			
12	0	25.42			
	30	25.41			
13	0	25.41			
	30	25.41			
14	0	25.40			
	30	25.40			

Av. 4.014 ✓

Charge-Test No. 1 Cont'd.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
15	0	25.39			

+ Current turned on. \* Current turned off.

$$r_1 = \frac{23.12 - 23.11}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = \frac{25.43 - 25.39}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.43 - 23.12 + \frac{0.01}{2} \times 5 = 2.335 \text{ deg. C}$$

$$25.43 - 23.12 + \frac{0.002 + 0.008}{2} \times 5 = 2.335 \text{ deg. C}$$

$$= 2.31 + .02 = \underline{\underline{2.330 \text{ C}}}$$



Blank-Test No. 2 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	25.24	26.5	50	3.900
	30				3.875
1	0	25.25			3.875
	30				3.850
2	0	25.26			3.875
	30				3.900
3	0	25.26			3.875
	30				3.875
4	0	25.27			3.875
	30				3.865
5+	0	25.28			3.875
	30				3.860
6#	0				3.860
	30	27.20			3.855
7	0	27.33			3.850
	30	27.39			3.850
8	0	27.42			
	30	27.45			Av. 3.870 ✓
9	0	27.48 max.			
	30	27.48			
10	0	27.48			
	30	27.48			
11	0	27.48			
	30	27.48			
12	0	27.48			
	30	27.48			
13	0	27.48			
	30	27.48			

Blank-Test No. 2 a cont'd.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
14	0	27.47			
	30	27.47			
15	0				

+ Current turned on. \* Current turned off.

$$r_1 = \frac{25.28 - 25.24}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C} \quad \checkmark$$

$$r_2 = \frac{27.48 - 27.47}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C} \quad +$$

$$\text{Corrected temperature} = 27.48 - 25.28 - \frac{0.008 + 0.002}{2} \times 4 = 2.18 \text{ deg. C}$$

$$= 2.20 - .012 = \underline{\underline{2.188 \text{ C}}}$$



Blank-Test No. 2 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	24.28	25.5	50	3.850
	30				3.875
1	0	24.29			3.860
	30				3.850
2	0	24.30			3.850
	30				3.850
3	0	24.30			3.860
	30				3.850
4	0	24.31			3.860
	30				3.860
5+	0	24.32			3.875
	30				3.875
6*	0				3.875
	30	26.28			3.875
7	0	26.38			3.870
	30	26.45			
8	0	26.47			Av. 3.862 ✓
	30	26.49			
9	0	26.50			
	30	26.51 max.			
10	0	26.51			
	30	26.51			
11	0	26.51 ←			
	30	26.50			
12	0	26.50			
	30	26.49			
13	0	26.49			
	30	26.48			
14	0	26.48			
	30	26.48			

Blank-Test No. 2 b cont'd.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
15	0	26.48			

+ Current turned on. # Current turned off.

$$r_1 = \frac{24.32 - 24.28}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C} \quad \checkmark$$

$$r_2 = \frac{26.51 - 26.48}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C} \quad + 0.0075$$

$$\text{Corrected temperature} = 26.51 - 24.32 - \frac{0.008 + 0.006}{2} \times 4.5 = 2.16 \text{ deg. C} \quad + 0.0075 \quad \times$$

$$= 2.19 - 0.001 = \underline{\underline{2.189}} \text{ C}$$



Charge-Test No. 2

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.11	50	24	3.450
	30				3.500
1	0	23.11			3.625
	30				3.650
2	0	23.11			3.675
	30				3.700
3	0	23.11			3.750
	30				3.800
4	0	23.11			3.850
	30				3.850
5+	0	23.11			3.875
	30				
6 $\frac{1}{2}$	0				
	30	24.85			
7	0	25.05			
	30	25.15			
8	0	25.21			
	30	25.27			
9	0	25.28			
	30	25.30			
10	0	25.30			
	30	25.30			
11	0	25.30			
	30	25.30			
12	0	25.30			
	30	25.30			
13	0	25.29			
	30	25.29			
14	0	25.29			
	30	25.28			
15	0	25.28			
				Av.	3.702 ✓

Charge-Test No. 2 cont'd.

+ Current turned off    \* Current turned on.

$$r_1 = 0 \quad \checkmark$$

$$r_2 = \frac{25.30 - 25.28}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C} \quad \checkmark$$

$$\text{Corrected temperature} = 25.30 - \overset{23.11}{28.11} + \frac{0.004 + 0}{2} \times 4.5 = 2.20 \text{ deg. C} \quad \checkmark$$



Blank-Test No. 3 a

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.47	25	52	4.050
	30				4.050
1	0	23.48			4.035
	30				4.050
2	0	23.48			4.050
	30				4.055
3	0	23.49			4.055
	30				4.050
4	0	23.49			4.025
	30				4.050
5+	0	23.50			4.050
	30				4.025
6 $\frac{1}{2}$	0				4.035
	30	25.60			4.050
7	0	25.71			4.050
	30	25.78			4.035
8	0	25.84			4.035
	30	25.87			4.025
9	0	25.88			4.025
	30	25.89			<hr/>
10	0	25.89			Av. 4.042 ✓
	30	25.89			
11	0	25.89			
	30	25.89			
12	0	25.89			
	30	25.88			
13	0	25.88			
	30	25.88			
14	0	25.88			
	30	25.88			
15	0	25.88			

Blank-Test No. 3 a cont'd.

+ Current turned on \* Current turned off

$$r_1 = \frac{23.50 - 23.47}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C} \quad \checkmark$$

$$r_2 = \frac{25.89 - 25.88}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.89 - 23.50 + \frac{0.002 + 0.006}{2} \times 4.5 = 2.37 \text{ deg. C} \quad \times$$

$$= 2.39 - .009 = \underline{\underline{2.381}} \text{ C}$$



Blank-Test No. 3b

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.54	25	52	3.950
	30				4.000
1	0	23.54			4.000
	30				4.025
2	0	23.55			4.000
	30				3.975
3	0	25.56			4.000
	30				4.025
4	0	23.57			4.020
	30				4.010
5+	0	23.58			3.985
	30				4.025
6#	0				4.000
	30	25.70			4.015
7	0	25.79			4.010
	30	25.88			4.015
8	0	25.90			4.020
	30	25.97			4.035
9	0	25.94			4.035
	30	25.95			
10	0	25.95			Av. 4.007
	30	25.95			
11	0	25.95			
	30	25.95			
12	0	25.95			
	30	25.95			
13	0	25.95			
	30	25.95			
14	0	25.95			
	30	25.94			
15	0	25.94			

Blank-Test No. 3 b Cont'd.

+ Current turned on # Current turned off.

$$r_1 = \frac{23.58-23.54}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$r_2 = \frac{25.95-25.94}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.95 - 23.58 - \frac{0.008+0.002}{2} \times 4.5 = 2.35 \text{ deg. C}$$

2.356 C



Charge-Test No. 3.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.48	25	52	3.450
	30				3.750
1	0	23.49			3.800
	30				3.875
2	0	23.50			3.900
	30				3.925
3	0	23.50			3.935
	30				3.950
4	0	23.51			3.950
	30				3.965
5+	0	23.51			3.990
	30				4.000
6*	0				4.015
	30	25.45			4.015
7	0	25.65			4.025
	30	25.75			4.035
8	0	25.82			4.040
	30	25.86			
9	0	25.89			
	30	25.90			
10	0	25.91			
	30	25.91			
11	0	25.91			
	30	25.91			
12	0	25.91			
	30	25.91			
13	0	25.91			
	30	25.91			
14	0	25.90			
	30	25.90			
15	0	25.90			

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 Av. 3.911

Charge-Test No. 3 Cont'd.

+ Current turned on. \* Current turned off.

$$r_1 = \frac{23.51 - 23.48}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$r_2 = \frac{25.91 - 25.90}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.91 - 23.51 - \frac{0.002 + 0.006}{2} \times 5 = 2.38 \text{ deg. C}$$

$$= 2.40 - .01 = \underline{2.390} \text{ C}$$



Blank-Test No. 4 a

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.41	23	52	4.100
	30				4.075
1	0	22.41			4.075
	30				4.085
2	0	22.40			4.100
	30				4.085
3	0	22.40			4.085
	30				4.085
4	0	22.40			4.065
	30				4.080
5+	0	22.40			4.075
	30				4.075
6*					4.090
	30	24.50			4.090
7	0	24.61			4.080
	30	24.68			4.075
8	0	24.73			
	30	24.74			Av. 4.082 ✓
9	0	24.75			
	30	24.76			
10	0	24.76			
	30	24.76			
11	0	24.76			
	30	24.75			
12	0	24.75			
	30	24.75			
13	0	24.74			
	30	24.73			
14	0	24.72			
	30	24.72			
15	0	24.72			

Blank-Test No. 4 a Cont'd.

+ Current turned on.      \* Current turned off.

$$r_1 = \frac{22.40 - 22.41}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = \frac{24.76 - 24.72}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 24.76 - 22.40 + \frac{0.002 + 0.008}{2} \times 4.5 = 2.38 \text{ deg. C}$$

$$= 2.36 + .027 = \underline{\underline{2.387^\circ \text{C}}}$$



Blank-Test No. 4 b

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.58	25	52	3.950
	30				4.050
1	0	23.58			4.050
	30				4.035
2	0	23.58			4.020
	30				4.025
3	0	23.58			4.025
	30				4.050
4	0	23.58			4.025
	30				4.025
5+	0	23.59			4.050
	30				4.040
6%	0				4.045
	30	25.70			4.040
7	0	25.80			4.055
	30	25.88			4.055
8	0	25.91			
	30	25.93			Av. 4.040 ✓
9	0	23.95			
	30	23.96			
10	0	23.96			
	30	23.96			
11	0	23.96			
	30	23.96			
12	0	23.96			
	30	23.96			
13	0	23.96			
	30	23.96			
14	0	23.96			
	30	23.96			
15	0	23.96			

25.96

Blank-Test No. 4 b Cont'd.

+ Current turned on \* Current turned off

$$r_1 = \frac{23.59 - 23.58}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = 0$$

$$\text{Corrected temperature} = 25.96 - 23.59 - \frac{0.002 + 0}{2} \times 4.5 = 2.37 \text{ deg. C}$$

$$= 2.37 - .005 = \underline{2.365 \text{ C}}$$



Charge-Test No. 4

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.00	25	52	3.650
	30				3.800
1	0	23.01			3.850
	30				3.900
2	0	23.01			3.950
	30				3.985
3	0	23.02			4.010
	30				4.025
4	0	23.03			4.115
	30				4.125
5	0 x	23.04			4.200
	30				4.250
6	0 #				4.300
	30	25.00			4.325
7	0	25.28			
	30	25.35			Av. 4.038 ✓
8	0	25.40			
	30	25.44			
9	0	25.48			
	30	25.50			
10	0	25.50			
	30	25.50			
11	0	25.50			
	30	25.50			
12	0	25.50			
	30	25.50			
13	0	25.50			
	30	25.50			
14	0	25.50			
	30	25.50			
15	0	25.50			

Charge-Test No. 4 a Cont'd.

× Current turned on    \* Current turned off

$$r_1 = \frac{23.04 - 23.00}{5} = \frac{0.04}{5} = 0.008 \text{ deg. } ^\circ\text{C}$$

$$r_2 = 0$$

$$\text{Corrected temperature} = 25.50 - 23.04 - \frac{(0.008)}{2} \times 4.5 = 2.44 \text{ deg. } ^\circ\text{C}$$



Blank-Test No. 5 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.60	24	53	4.050
	30				3.975
1	0	22.60			3.850
	30				3.850
2	0	22.60			3.825
	30				3.825
3	0	22.60			3.850
	30				3.835
4	0	22.60			3.825
	30				3.850
5+	0	22.60			3.825
	30				3.800
6#	0				3.810
	30	24.65			3.825
7	0	24.76			3.815
	30	24.80			3.825
8	0	24.84			3.825
	30	24.87			<u>3.825</u>
9	0	24.88			Av. 3.851 ✓
	30	24.89			
10	0	24.89			
	30	24.89			
11	0	24.89			
	30	24.88			
12	0	24.88			
	30	24.88			
13	0	24.87			
	30	24.87			
14	0	24.86			
	30	24.85			
15	0	24.85			

+ Current turned on. # Current turned off.

$$r = 0 \checkmark$$

1

$$r = \frac{24.89 - 24.85}{2} = \frac{.04}{5} = 0.008 \text{ deg. C} \checkmark$$

$$\text{Corrected temperature} = 24.89 - 22.60 + \frac{.008 + 0}{2} \times 4.5 = 2.31 \text{ deg C} \checkmark$$

Blank-Test No. 5 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.80	25.5	53	3.850
	30				3.850
1	0	22.80			3.825
	30				3.825
2	0	22.80			3.825
	30				3.825
3	0	22.80			3.815
	30				3.800
4	0	22.80			3.815
	30				3.815
5	0	22.81			3.825
	30				3.840
6	0				3.825
	30	24.86			3.815
7	0	24.95			3.825
	30	25.00			3.815
8	0	25.02			3.825
	30	25.05			3.815
9	0	25.07			3.825
	30	25.08 max.			3.810
10	0	25.08			<u>3.800</u>
	30	25.08			
11	0	25.08			Av. 3.822 ✓
	30	25.08			
12	0	25.07			
	30	25.07			
13	0	25.06			
	30	25.05			
14	0	25.05			
	30	25.04			
15	0	25.04			

$$r = \frac{22.81 - 22.80}{1} = \frac{0.01}{5} = .002 \text{ deg. C}$$

$$r = \frac{25.08 - 25.04}{2} = \frac{.04}{5} = .008 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.08 - 22.81 + \frac{.01}{5} \times 4.5 = 2.29 \text{ deg. C}$$



Charge-Test No. 5

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.50	23.5	53	3.050
	30				3.450
1	0	22.50			3.500
	30				3.550
2	0	22.51			3.565
	30				3.600
3	0	22.51			3.625
	30				3.700
4	0	22.52			3.700
	30				3.725
5+	0	22.52			3.725
	30				3.750
6#	0				3.765
	30	24.45			3.765
7	0	24.58			3.800
	30	24.68			3.800
8	0	24.72			3.825
	30	24.76			
9	0	24.78			
	30	24.80 max.			
10	0	24.80			
	30	24.80			
11	0	24.80			
	30	24.80			
12	0	24.80			
	30	24.79			
13	0	24.79			
	30	24.79			
14	0	24.79			
	30	24.79			
15	0	24.79			

Av. 3.641 ✓

+ Current turned on. # Current turned off.

$$r = \frac{22.52 - 22.50}{1} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r = \frac{24.80 - 24.79}{2} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 24.80 - 22.52 - \frac{0.004 + 0.002}{2} \times 4.5 = 2.271 \text{ deg C}$$

The heat of formation of two other singulo-silicates were next determined, their compositions were 12 per cent CaO + 57.58 per cent FeO + 30.42 per cent SiO<sub>2</sub>, and 28 per cent CaO + 40.30 per cent FeO + 31.70 per cent SiO<sub>2</sub>.

For the determination of the heat formation of these two silicates, calcium carbonate (CaCO<sub>3</sub>) was used, instead of calcium oxide (CaO), for the latter absorbs moisture and carbonic-acid very readily. The amount of calcium carbonate required for the corresponding portion of calcium oxide was computed as follows:

Mol. wt. of CaO: Mol. wt. of CaCO<sub>3</sub> = wt. of CaO: wt. of CaCO<sub>3</sub>.

The amount of CaCO<sub>3</sub> corresponding 0.12 gm. CaO is

$$\frac{100.1 \times 0.12}{56.1} = 0.2141 \text{ gm.}$$

The amount of CaCO<sub>3</sub> corresponding 0.28 gm. CaO is

$$\frac{100.1 \times 0.28}{56.1} = 0.4996 \text{ gm.}$$

The results of the heat formation of the above two silicates are given in the following tables VII and VIII.

Tables VII and VIII show ~~show~~ the quantity of heat evolved by the formation of these silicates. The amount of calcium carbonate used for the formation of the first silicate was 0.2141 gm. and the quantity of heat required to decompose it into CaO and CO<sub>2</sub> is 96<sup>\*</sup> gram-calories. The amount of calcium carbonate for the formation of the sec-

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\* J. W. Richards, Metallurgical Calculations Part I, p. 29 Ed. 2



Table 7

No. of tests	Condition of blank and Charge-tests		Blank-tests										Charge-tests														
			Charge CaO 12.00%										FeO 57.58% SiO <sub>2</sub> 30.42%														
			Current amp.	Time Second	Weight of water gm.	Difference Potential volt.	Room temp.	Temperature of water degree Centigrade				Actual amount of heat gm-cal.	Theoretical amount of heat gm-cal.	Difference	Weight of Charge gds.	Difference potential volt.	Room temp.	Temperature of water degree Centigrade				Actual amount of heat gm-cal.	Theoretical amount of heat gm-cal.	Difference	Averaged blank const.	Difference	Amount of heat required to decompose CaCO <sub>3</sub>
Initial	Final	Cooling Correction						Rise Temp	Initial	Final	Cooling Correction							Rise Temp									
1	a	53	60	1303	3.975	22	20.41	22.80	-0.1	2.38	3101	3017	84	1	3.830	23	21.90	24.21	-0.1	2.30	2997	2907	90	77	+13	96	109
	b	53	60	1303	4.060	23	21.12	23.52	+0.2	2.42	3153	3082	71				21.90	24.21	-0.1	2.30	2997	2907	90	77	+13	96	109
2	a	58	60	1303	3.681	24	22.42	24.83	+0.1	2.42	3153	3058	95	1	3.424	25	23.00	25.31	-0.1	2.30	2997	2844	153	106	+47	96	143
	b	58	60	1303	3.702	25	23.01	25.44	+0.2	2.45	3192	3075	117				23.00	25.31	-0.1	2.30	2997	2844	153	106	+47	96	143
3	a	57	60	1303	3.681	23	20.90	23.27	+0.1	2.38	3101	3005	96	1	3.554	23	20.90	23.23	-0.1	2.32	3023	2901	122	89	+33	96	129
	b	57	60	1303	3.700	23	20.82	23.21	-0.1	2.38	3101	3020	81				20.90	23.23	-0.1	2.32	3023	2901	122	89	+33	96	129
4	a	59	60	1303	3.607	24	21.60	24.00	-0.1	2.39	3114	3052	62	1	3.424	24	21.81	24.14	-0.15	2.315	3016	2896	120	62	+58	96	154
	b	59	60	1303	3.594	24	21.81	24.20	-0.1	2.38	3102	3041	61				21.81	24.14	-0.15	2.315	3016	2896	120	62	+58	96	154
5	a	58	60	1303	3.618	23	21.00	23.38	-0.1	2.365	3083	3008	83	1	3.427	22.5	21.01	23.29	+0.1	2.29	2984	2847	137	88	+49	96	145
	b	58	60	1303	3.618	23	21.40	23.79	-0.15	2.375	3095	3002	93				21.01	23.29	+0.1	2.29	2984	2847	137	88	+49	96	145
6	a	57	60	1303	3.694	23	21.22	23.60	-0.1	2.37	3088	3016	72	1	3.542	23	21.22	23.55	-0.1	2.32	3023	2892	131	79	+52	96	148
	b	57	60	1303	3.711	23	21.12	23.57	-0.1	2.39	3114	3029	85				21.22	23.55	-0.1	2.32	3023	2892	131	79	+52	96	148



Table 8

No. of tests	Condition of blank and Charge-tests				Blank - tests										Charge - tests																	
	Current Amp	Time Second	Weight of water gm.	Difference potential volt.	Room Temp	Charge CaO 28.00%				FeO 40.30%			SiO <sub>2</sub> 31.70%			Actual amount of heat gm.-cal.	Theoretical amount of heat gm.-cal.	Difference	Weight of Charge gm.	Difference potential Volt.	Room Temp.	Temperature of water degree Centigrade				Actual amount of heat gm.-cal.	Theoretical amount of heat gm.-cal.	Difference	Averaged blank Const.	Difference	Amount of heat required to decompose CaCO <sub>3</sub>	Amount of heat evolved by slag-formation.
						Initial	Final	Cooling correction	Rise Temp.	Initial	Final	Cooling correction	Rise temp.	Initial	Final							Cooling correction	Rise temp.									
1	a	54	60	1303	4.009	24.5	22.78	25.20	+0.1	2.43	3166	3101	65	1	3.833	25	23.19	25.50	-0.15	2.295	2997	2964	27	68	-41	224	183					
	b	54	60	1303	4.020	24.5	22.89	25.34	.00	2.45	3182	3110	72																			
2	a	54	60	1303	4.061	26	24.11	26.63	-0.25	2.495	3251	3141	110	1	3.885	26	24.28	26.63	+0.25	2.475	3095	3005	90	115	-25	224	199					
	b	54	60	1303	4.053	27	23.59	26.06	+0.3	2.50	3257	3136	121																			
3	a	52	60	1303	4.049	24	22.68	25.02	+0.2	2.36	3075	3015	60	1	3.880	24.5	23.30	25.51	+0.1	2.20	2867	2890	-23	65	-88	224	136 <sup>#</sup>					
	b	52	60	1303	4.070	24	22.80	25.19	-0.1	2.38	3101	3031	70																			
4	a	55	60	1303	4.090	25.5	23.91	26.48	+0.3	2.60	3388	3222	166	1	3.854	25.5	24.71	27.11	+0.3	2.43	3166	3036	130	159	-29	224	195					
	b	55	60	1303	4.091	25.5	24.21	26.77	+0.3	2.59	3375	3223	152																			

# a small amount at the two ends of the boat remained unfused.



ond was 0.4996 gm. and the quantity of heat necessary to decompose it is 224 gram-calories. These quantities of heat should be added to the difference between the actual amount of heat and the theoretical amount obtained in the charge-tests, and the differences between the sums and the averaged blank constants give the heats of formation of the two silicates.

The amount of heat evolved by the formation of one-gram mixture, 12 per cent CaO+57.58 per cent FeO+30.42 per cent SiO<sub>2</sub> is given in the last column of table VII. As the result of test No. 1 is too low and does not come within the precision of the method, it should be disregarded. Taking the average of tests No. 2 - 6, the heat of formation is 145 gram-calories for 1 gr. of mixture.

The quantity of heat evolved by the formation of one-gram mixture, 28 per cent CaO+40.30 per cent FeO+31.70 SiO<sub>2</sub>, is shown in table VIII. The result of test No. 3 is low; this was due largely to a portion of the charge remaining unfused. The results of tests No. 1, 2 and 4, appear to be satisfactory, and the average of these results gives the heat of formation 192 gram-calories.

In performing the experiment, it often happened that when the fusion took place, the platinum boat fused at the instant when the charge became fused. This proved that the heat evolved raised the temperature locally to above the melting point of platinum.

An inspection of tables VI, VII, and VIII will make it evident that:

1. The actual amounts of heat in the blank-tests do not exactly agree with the theoretical, but are larger in every case.

2. The differences of these two quantities vary with the platinum boats used in making the blank-tests.

These discrepancies and variations are due to sources of error from various instruments. These sources, though eliminated as much as possible, may be caused by

1. the reading of the voltmeter
2. The reading of the ammeter
3. The reading of the stop-watch
4. The reading of the thermometer
5. The weighing of the water
6. The specific heat of the calorimeter, the combustion chamber and the stirrer.

7. The radiation of heat.

As the experimental errors may come in from numerous sources, exact agreement of results cannot be secured.

#### 8. Conclusion.

The amount of heat evolved by the formation of the three ferro-calcic singulo silicates given in tables VI, VII and VIII, appears to increase with an increment of the percentage of CaO, and shows that a smooth curve would result if adequate data were obtained. On account of the fact that many difficulties were encountered and that the capacity of the apparatus was too small, data for the singulo silicates between 0 and 12 per cent CaO, and between 12 and 28 per cent



CaO were not determined. In order to carry on such experiments with greater speed and accuracy, it would be necessary to have apparatus of larger capacity and instruments of greater delicacy. The charge might weigh 5 gm. as the amount of heat evolved would be sufficiently large to give characteristic values. This would require a larger platinum boat and a larger combustion chamber, hence also a larger number of cells in the storage battery in order to furnish a larger current. The amount of water used is an important factor. In order to eliminate the loss of heat by radiation, the quantity of water ought to be such as to obtain a rise of temperature of only a few tenths of a degree C. This small rise of temperature will require a thermometer sensitive to 0.001 deg. C. Another important factor is that the current should be kept constant by an automatic device, instead of shifting the slider by hand. If the above conditions are fulfilled, this method used will give accurate results with ferro-calcic silicates without including many failures, as was the case in the present investigation.

Attempts were made to determine the heat of formation of the bi-silicate,  $2\text{FeO} + \text{SiO}_2$ . They were not successful, because the mixture required such a high temperature for fusing, that the platinum boat melted in every case before the charge was completely fused. With another metal whose melting-point is a few hundred degrees higher than that of the platinum and whose conductivity is about the same, the determination of the heat formation of the bi-silicate series ought to be carried to a successful end.

The details of the observations leading to the results assembled in Table 7 are given in the following:

Blank-Test No. 1 a.

Duration of Time		Calorimeter Temperature of water Deg. C	Av. Room Temperature Deg. C	Electrical Energy	
Min	Sec.			I. Amp.	E. Volt
	0	20.39	22	53	3.800
	30				3.925
1	0	20.39			3.975
	30				4.000
2	0	20.40			4.015
	30				3.975
3	0	20.40			3.950
	30				3.975
4	0	20.41			3.975
	30				3.975
5+	0	20.41			4.000
	30				3.975
6#	0				4.000
	30	22.52			4.010
7	0	22.63			4.025
	30	22.70			3.975
8	0	22.74			3.985
	30	22.77			3.985
9	0	22.78			3.990
	30	22.79			4.000
10	0	22.80 max.			3.960
	30	22.80			3.985
11	0	22.80			
	30	22.80			Av. 3.975
12	0	22.80			
	30	22.80			
13	0	22.80			
	30	22.80			
14	0	22.80			
	30	22.80			
15	0	22.80			

+ Current turned on. # Current turned off.



Blank-Test No. 1 a Con'd.

$$r = \frac{20.41 - 20.39}{1 \quad 5} = \frac{.02}{5} = 0.004 \text{ deg. C.} \quad \checkmark$$

$$r = 0 \quad \checkmark$$

$$\text{Corrected temperature} = 22.80 - 20.41 - \frac{0.004 + 0}{2} \times 5 = 2.38 \text{ deg. C} \quad \checkmark$$

Blank-Test No. 1 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp	E. Volt
	0	21.10	23	53	4.040
	30				4.050
1	0	21.10			4.060
	30				4.050
2	0	21.11			4.050
	30				4.055
3	0	21.11			4.060
	30				4.060
4	0	21.12			4.060
	30				4.060
5+	0	21.12			4.040
	30				4.060
6#	0				4.060
	30	23.27			4.040
7	0	23.37			4.060
	30	23.44			4.050
8	0	23.49			4.060
	30	23.50			4.075
9	0	23.51			4.065
	30	23.51			4.075
10	0	23.52 max.			4.050
	30	23.52			4.060
11	0	23.52			4.075
	30	23.52			4.075
12	0	23.52			4.075
	30	23.51			4.075
13	0	23.51			
	30	23.50			Av. 4.060 ✓
14	0	23.50			
	30	23.50			
15	0	23.50			

+ Current turned on. # Current turned off.

$$r = \frac{21.12 - 21.10}{5} = \frac{.02}{5} = 0.004 \text{ deg. C}$$

$$r = \frac{23.52 - 23.50}{5} = \frac{.02}{5} = 0.004 \text{ deg. C}$$

$$\text{Corrected temperature} = 23.52 - 21.12 + \frac{0.004 + 0.004}{2} \times 5 = 2.42 \text{ deg. C}$$

$$= 2.40 \text{ C}$$



Charge-Test No. 1

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.88	23.5	53	3.200
	30				3.500
1	0	21.88			3.650
	30				3.750
2	0	21.89			3.750
	30				3.750
3	0	21.89			3.735
	30				3.775
4	0	21.90			3.850
	30				3.925
5+	0	21.90			3.925
	30				3.925
6#	0				3.925
	30	23.90			3.925
7	0	24.00			3.935
	30	24.07			3.935
8	0	24.14			3.935
	30	24.17			3.950
9	0	24.19			3.950
	30	24.20			3.950
10	0	24.21 max.			3.940
	30	24.21			3.955
11	0	24.21			3.960
	30	24.21			
12	0	24.21		Av.	3.830 ✓
	30	24.21			
13	0	24.21			
	30	24.21			
14	0	24.21			
	30	24.21			
15	0	24.21			

+ Current turned on. # Current turned off.

$$r = \frac{21.90 - 21.88}{1} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 24.21 - 21.90 - \frac{0.004}{2} + 0 \times 5 = 2.30 \text{ deg. C}$$

Blank-Test No. 2 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.41	24	58	3.650
	30				3.700
1	0	22.41			3.675
	30				3.675
2	0	22.41			3.675
	30				3.675
3	0	22.41			3.685
	30				3.675
4	0	22.42			3.675
	30				3.675
5+	0	22.42			3.675
	30				3.675
6#	0				3.680
	30	24.55			3.685
7	0	x			3.685
	30	24.72			3.685
8	0	24.78			3.685
	30	24.80			3.675
9	0	24.81			3.695
	30	24.82			3.695
10	0	24.83 max.			<u>3.700</u>
	30	24.83			
11	0	24.83			
	30	24.83			Av. 3.681 ✓
12	0	24.83			
	30	24.83			
13	0	24.83			
	30	24.82			
14	0	24.82			
	30	24.82			
15	0	24.82			

+ Current turned on. # Current turned off.

$$r = \frac{22.42 - 22.41}{5} = \frac{.01}{5} = \bar{0.002} \text{ deg. C}$$

$$r = \frac{24.83 - 24.82}{5} = \frac{.01}{5} = +0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 24.83 - 22.42 + \frac{\bar{0.002} + 0.002}{2} \times 5 = \cancel{2.42} \text{ deg. C}$$

$$= \underline{2.41} \text{ C}$$



Blank-Test No. 2 b.

Duration of Temperature		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.99	25	58	3.700
	30				3.700
1	0	22.99			3.685
	30				3.700
2	0	23.00			3.700
	30				3.690
3	0	23.00			3.710
	30				3.700
4	0	23.00			3.720
	30				3.715
5+	0	23.01			3.700
	30				3.685
6#	0				3.700
	30	25.16			3.710
7	0	25.28			3.710
	30	25.35			3.710
8	0	25.39			3.700
	30	25.40			3.685
9	0	25.41			3.685
	30	25.43			3.700
10	0	25.44 max.			3.700
	30	25.44			3.710
11	0	25.44			<u>3.725</u>
	30	25.44			
12	0	25.44			Av. 3.702 ✓
	30	25.44			
13	0	25.43			
	30	25.43			
14	0	25.42			
	30	25.42			
15	0	25.42			

+ Current turned on. # Current turned off.

$$r = \frac{23.01 - 22.99}{1} = \frac{.02}{5} = 0.004 \text{ deg. C}$$

$$r = \frac{23.44 - 23.42}{2} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.44 - 23.01 + \frac{0.004 + 0.004}{2} \times 5 = 2.45 \text{ deg. C}$$

$$= \underline{\underline{2.43}} \text{ C}$$

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.98	25	58	2.600
	30				3.050
1	0	22.98			3.300
	30				3.400
2	0	22.98			3.415
	30				3.415
3	0	22.99			3.400
	30				3.410
4	0	22.99			3.425
	30				3.400
5+	0	23.00			3.400
	30				3.400
6#	0				3.475
	30	24.90			3.500
7	0	25.10			3.525
	30	25.18			3.535
8	0	25.24			3.575
	30	25.28			3.575
9	0	25.29			3.575
	30	25.30			3.575
10	0	25.31 max.			3.600
	30	25.31			3.600
11	0	25.31			3.600
	30	25.31			<u>3.600</u>
12	0	25.31		Av.	3.424 ✓
	30	25.31			
13	0	25.31			
	30	25.31			
14	0	25.31			
	30	25.31			
15	0	25.31			

+ Current turned on. # Current turned off.

$$r = \frac{23.00 - 22.98}{1} = \frac{.02}{5} = .004 \text{ deg. C}$$

$$r = \frac{0}{2}$$

$$\text{Corrected temperature} = 25.31 - 23.00 - \frac{0.004 + 0}{2} \times 5 = 2.30 \text{ deg. C}$$



Blank-Test No. 3 a

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	20.89	23	57	3.635
	30				3.650
1	0	20.89			3.660
	30				3.660
2	0	20.89			3.665
	30				3.660
3	0	20.89			3.665
	30				3.660
4	0	20.90			3.650
	30				3.650
5+	0	20.90			3.620
	30				3.700
6#	0				3.700
	30	23.00			3.685
7	0	23.10			3.700
	30	23.18			3.700
8	0	23.21			3.710
	30	23.24			3.710
9	0	23.26			3.710
	30	23.27 max.			3.710
10	0	23.27			3.710
	30	23.27			3.710
11	0	23.27			3.710
	30	23.27			3.710
12	0	23.27			<u>3.710</u>
	30	23.27			Av. 3.681 ✓
13	0	23.27			
	30	23.27			
14	0	23.26			
	30	23.26			
15	0	23.26			

+ Current turned on. # Current turned off.

$$r = \frac{20.90 - 20.89}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r = \frac{23.27 - 23.26}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 23.27 - 20.90 + \frac{0.002 + 0.002}{2} \times 4.5 = 2.38 \text{ deg. C}$$

$$= 2.370 \text{ C}$$

Blank-Test No. 3 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	20.80	23	57	3.650
	30				3.675
1	0	20.80			3.675
	30				3.675
2	0	20.81			3.675
	30				3.685
3	0	20.81			3.685
	30				3.685
4	0	20.82			3.685
	30				3.685
5+	0	20.82			3.725
	30				3.725
6#	0				3.725
	30	22.93			3.715
7	0	23.03			3.715
	30	23.12			3.715
8	0	23.18			3.710
	30	23.19			3.710
9	0	23.20			3.710
	30	23.21			3.715
10	0	23.21			3.715
	30	23.21			3.710
11	0	23.21			3.710
	30	23.21			3.710
12	0	23.21			3.710
	30	23.21			3.710
13	0	23.21			3.710
	30	23.21			3.710
14	0	23.21			3.710
	30	23.21			3.710
15	0	23.21			3.710
				Av.	3.700 ✓

+ Current turned on. # Current turned off.

$$r = \frac{20.82 - 20.80}{1} = \frac{.02}{5} = .004 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 23.21 - 20.82 - \frac{.004 + 0}{2} \times 4 = 2.38 \text{ deg. C} \quad \checkmark$$



Charge-Test No. 3

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C.	I. Amp.	E. Volt
	0	20.88	23	57	3.100
	30				3.450
1	0	20.88			3.475
	30				3.465
2	0	20.89			3.410
	30				3.425
3	0	20.89			3.465
	30				3.475
4	0	20.90			3.510
	30				3.525
5+	0	20.90			3.555
	30				3.575
6#	0				3.610
	30	22.83			3.625
7	0	23.00			3.675
	30	23.09			3.685
8	0	23.14			3.675
	30	23.18			3.675
9	0	23.20			3.675
	30	23.21			3.675
10	0	23.23 max.			3.675
	30	23.23			3.675
11	0	23.23			3.675
	30	23.23			
12	0	23.23		Av.	3.554 ✓
	30	23.23			
13	0	23.23			
	30	23.23			
14	0	23.23			
	30	23.23			
15	0	23.23			

+ Current turned on. # Current turned off.

$$r = \frac{20.90 - 20.88}{1} = \frac{.02}{5} = .004 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 23.23 - 20.90 - \frac{.004 + 0}{2} \times 5 = 2.32 \text{ deg. C}$$

Blank-Test No. 4 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.58	24	59	3.625
	30				3.625
1	0	21.58			3.615
	30				3.625
2	0	21.59			3.625
	30				3.615
3	0	21.59			3.625
	30				3.625
4	0	21.60			3.620
	30				3.615
5+	0	21.60			3.610
	30				3.610
6#	0				3.635
	30	23.72			3.625
7	0	23.83			3.610
	30	23.90			3.610
8	0	23.94			3.600
	30	23.97			3.600
9	0	23.98			3.585
	30	23.99			3.590
10	0	24.00 max.			3.600
	30	24.00			3.575
11	0	24.00			3.550
	30	24.00			<u>3.545</u>
12	0	24.00			
	30	24.00		Av.	3.607 ✓
13	0	24.00			
	30	24.00			
14	0	24.00			
	30	24.00			
15	0	24.00			

+ Current turned on. # Current turned off.

$$r = \frac{21.60 - 21.58}{1} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 24.00 - 21.60 - \frac{0.004 + 0}{2} \times 5 = 2.39 \text{ deg. C}$$



Blank-Test No. 4 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.78	24	59	3.550
	30				3.625
1	0	21.78			3.600
	30				3.625
2	0	21.79			3.610
	30				3.600
3	0	21.80			3.610
	30				3.585
4	0	21.80			3.575
	30				3.575
5+	0	21.81			3.585
	30				3.590
6#	0				3.590
	30	23.90			3.585
7	0	24.01			3.585
	30	24.10			3.585
8	0	24.14			3.585
	30	24.18			3.590
9	0	24.19			3.590
	30	24.20 max.			3.585
10	0	24.20			3.610
	30	24.20			3.600
11	0	24.20			3.585
	30	24.20			3.610
12	0	24.20			3.610
	30	24.20			3.615
13	0	24.20			
	30	24.20			
14	0	24.20			
	30	24.20			
15	0	24.20			
				Av.	3.594 ✓

+ Current turned on. # Current turned off.

$$r = \frac{21.81 - 21.78}{1} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 24.20 - 21.81 - \frac{0.006 + 0}{2} \times 4.5 = 2.38 \text{ deg. C}$$

Charge-Test No. 4.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.78	24.5	59	3.000
	30				3.200
1	0	21.78			3.300
	30				3.400
2	0	21.79			3.375
	30				3.350
3	0	21.80			3.400
	30				3.475
4	0	21.80			3.450
	30				3.435
5+	0	21.81			3.450
	30				3.460
6#	0				3.465
	30	23.78			3.475
7	0	23.91			3.485
	30	24.01			3.485
8	0	24.05			3.490
	30	24.09			3.490
9	0	24.10			3.510
	30	24.12			3.510
10	0	24.14			3.515
	30	24.14			3.515
11	0	24.14			3.515
	30	24.14			3.515
12	0	24.14		Av.	3.424 ✓
	30	24.14			
13	0	24.14			
	30	24.14			
14	0	24.14			
	30	24.14			
15	0	24.14			

+ Current turned on. # Current turned off.

$$r = \frac{21.81 - 21.78}{1} = \frac{.03}{5} = .006 \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 24.14 - 21.81 - \frac{.006 + 0}{2} \times 5 = 2.315 \text{ deg. C}$$



Blank-Test No. 5 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	20.98	23	58	3.625
	30				3.635
1	0	20.98			3.625
	30				3.625
2	0	20.99			3.625
	30				3.625
3	0	20.99			3.620
	30				3.610
4	0	20.99			3.610
	30				3.610
5+	0	21.00			3.620
	30				3.615
6#	0				3.610
	30	23.10			3.610
7	0	21.20			3.610
	30	23.27			3.610
8	0	23.31			3.625
	30	23.33			3.610
9	0	23.35			3.610
	30	23.37			3.610
10	0	23.38 max.			3.600
	30	23.38			3.590
11	0	23.38			3.590
	30	23.38			3.590
12	0	23.38			3.585
	30	23.38			3.585
13	0	23.37			
	30	23.37			
14	0	23.37			
	30	23.37			
15	0	23.37			
				Av.	3.611 ✓

+ Current turned on. # Current turned off.

$$r = \frac{21.00 - 20.98}{1} = \frac{.02}{5} = -.004 \text{ deg. C}$$

$$r = \frac{23.38 - 23.37}{2} = \frac{.01}{5} = +.002 \text{ deg. C.}$$

$$\text{Corrected temperature} = 23.38 - 21.00 - \frac{0.004 + 0.002}{2} \times 5 = 2.365 \text{ deg. C}$$

2.375°C

Blank-Test No. 5 b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.38	23	58	3.675
	30				3.665
1	0	21.38			3.650
	30				3.625
2	0	21.39			3.615
	30				3.610
3	0	21.39			3.610
	30				3.600
4	0	21.40			3.595
	30				3.585
5+	0	21.40			3.600
	30				3.610
6#	0				3.610
	30	23.60			3.610
7	0	23.68			3.590
	30	23.71			3.610
8	0	23.76			3.610
	30	23.78			3.610
9	0	23.78			3.610
	30	23.79 max.			3.610
10	0	23.79			3.610
	30	23.79			3.610
11	0	23.79			3.600
	30	23.79			3.600
12	0	23.79			3.610
	30	23.79			3.610
13	0	23.79			3.610
	30	23.79			3.610
14	0	23.78			3.610
	30	23.78			3.610
15	0	23.78			3.610
				Av.	3.613

+ Current turned on. # Current turned off.

$$r_1 = \frac{21.40 - 21.38}{5} = \frac{.02}{5} = -.004 \text{ deg. C}$$

$$r_2 = \frac{23.79 - 23.78}{5} = \frac{.01}{5} = +.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 23.79 - 21.40 - \frac{0.004 + 0.002}{2} \times 4.5 = 2.375 \text{ deg. C}$$



Duration of Time		Calorimeter Temperature of water Deg. C	Av. Room Temperature Deg. C	Electrical Energy	
Min.	Sec.			I. Amp.	E. Volt
	0	21.00	23	58	2.950
	30				3.200
1	0	21.00			3.300
	30				3.400
2	0	21.00			3.375
	30				3.375
3	0	21.00			3.400
	30				3.425
4	0	21.01			3.435
	30				3.450
5+	0	21.01			3.460
	30				3.475
6#	0				3.500
	30	22.88			3.475
7	0	23.05			3.485
	30	23.15			3.535
8	0	23.21			3.525
	30	23.24			3.525
9	0	23.27			3.525
	30	23.28			3.525
10	0	23.29 max.			3.525
	30	23.29			3.525
11	0	23.29			
	30	23.29		Av.	3.427 ✓
12	0	23.29			
	30	23.29			
13	0	23.29			
	30	23.29			
14	0	23.28			
	30	23.28			
15	0	23.28			

+ Current turned on. # Current turned off.

$$r_1 = \frac{21.01 - 21.00}{1} = \frac{.01}{5} = -.002 \text{ deg. C}$$

$$r_2 = \frac{23.29 - 23.28}{2} = \frac{.01}{5} = +.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 23.29 - 21.01 + \frac{+.002 + 0.002}{2} \times 5 = 2.29 \text{ deg. C}$$

$$= 2.28 \text{ C}$$

Blank-Test No. 6 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.20	23	57	3.700
	30				3.700
1	0	21.20			3.700
	30				3.685
2	0	21.21			3.675
	30				3.700
3	0	21.21			3.700
	30				3.700
4	0	21.22			3.685
	30				3.685
5+	0	21.22			3.685
	30				3.685
6#	0				3.700
	30	23.29			3.700
7	0	23.40			3.700
	30	23.49			3.650
8	0	23.52			3.675
	30	23.57			3.710
9	0	23.58			3.710
	30	23.60 max.			3.710
10	0	23.60			3.710
	30	23.60			3.710
11	0	23.60			
	30	23.60		Av.	3.694 ✓
12	0	23.60			
	30	23.60			
13	0	23.60			
	30	23.60			
14	0	23.60			
	30	23.60			
15	0	23.60			

+ Current turned on. # Current turned off.

$$r = \frac{21.22 - 21.20}{1} = \frac{.02}{5} = \frac{.004}{5} \text{ deg. C}$$

$$r = 0$$

$$\text{Corrected temperature} = 23.60 - 21.22 - \frac{.004 + 0}{2} \times 4.5 = 2.37 \text{ deg. C}$$



## Blank-Test--6b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
1	0	21.10	23	57	3.700
	30				3.725
1	0	21.10			3.710
	30				3.710
2	0	21.11			3.710
	30				3.710
3	0	21.11			3.710
	30				3.700
4	0	21.12			3.710
	30				3.710
5+	0	21.12			3.710
	30				3.700
6#	0				3.700
	30	23.22			3.635
7	0	23.32			3.710
	30	23.41			3.710
8	0	23.47			3.710
	30	23.49			3.700
9	0	23.50			3.710
	30	23.51			3.710
10	0	23.52 max.			3.710
	30	23.52			3.725
11	0	23.52			3.725
	30	23.52			3.725
12	0	23.52			3.725
	30	23.52			3.725
13	0	23.52			3.725
	30	23.52			3.725
14	0	23.52			3.725
	30	23.52			3.725
15	0	23.52			3.725
					Av. 3.711

Blank-Test 6b Cont'd.

+ Current turned on. \* Current turned off.

$$r_1 = \frac{21.12 - 21.10}{5} = \frac{.02}{5} = .004 \text{ deg. C}$$

$$r_2 = 0 \quad \checkmark$$

$$\text{Corrected temperature} = 23.52 - 21.12 + \frac{.004 + 0}{2} \times 5 = 2.39 \text{ deg C} \quad \checkmark$$



Charge-Test No. 6

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	21.20	23	57	3.250
	30				3.375
1	0	21.20			3.500
	30				3.575
2	0	21.20			3.450
	30				3.560
3	0	21.21			3.560
	30				3.540
4	0	21.21			3.540
	30				3.560
5+	0	21.22			3.560
	30				3.560
6#	0				3.575
	30	23.15			3.585
7	0	23.30			3.585
	30	23.39			3.600
8	0	23.44			3.600
	30	23.49			3.600
9	0	23.51			3.600
	30	23.52			3.600
10	0	23.54			<u>3.600</u>
	30	23.55 max.		Av.	3.542
11	0	23.55			
	30	23.55			
12	0	23.55			
	30	23.55			
13	0	23.55			
	30	23.55			
14	0	23.55			
	30	23.55			
15	0	23.55			

Charge-Test No. 6 Cont'd.

+ Current turned on. \* Current turned off.

$$r_1 = \frac{21.22-21.20}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r_2 = 0$$

$$\text{Corrected temperature} = 23.55 - 21.22 - \frac{0.004+0}{2} \times 5.5 = 2.32 \text{ deg. C}$$



Details of the observations leading to the results assembled in table VIII.

Blank-Test 1 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I amp.	E. Volt
	0	22.77	24.5	54	3.975
	30				4.025
1	0	22.77			4.015
	30				4.000
2	0	22.77			3.985
	30				4.025
3	0	22.77			4.020
	30				4.025
4	0	22.77			4.000
	30				4.010
5+	0	22.78			3.990
	30				4.020
6#	0				4.010
	30	24.95			4.025
7	0	25.05			4.015
	30	25.11			4.010
8	0	25.17			4.005
	30	25.19			4.000
9	0	25.20 max.			3.990
	30	25.20			<hr/>
10	0	25.20		Av.	4.009
	30	25.20			
11	0	25.20			
	30	25.20			
12	0	25.19			
	30	25.19			
13	0	25.19			
	30	25.18			
14	0	25.18			

Blank-Test 1 a Cont'd.

Duration of Time		Calorimeter Temperature of water	Average Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	30	25.18			
15	0	25.18			

+ Current turned on. \* Current turned off.

$$r_1 = \frac{22.78 - 22.77}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = \frac{25.20 - 25.18}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.20 - 22.78 + \frac{0.002 + 0.004}{2} \times 4 = 2.424 \text{ deg. C}$$



Blank-Test No. 1 b

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	22.88	24.5	54	4.025
	30				4.025
1	0	22.88			4.010
	30				3.995
2	0	22.88			4.050
	30				4.025
3	0	22.88			4.035
	30				4.020
4	0	22.88			4.025
	30				4.015
5+	0	22.89			4.010
	30				4.005
6*	0				4.040
	30	25.10			4.040
7	0	25.20			4.015
	30	25.28			4.015
8	0	25.31			4.005
	30	25.33			4.000
9	0	25.34			<u>4.000</u>
	30	25.34			Av. 4.020
10	0	25.34			
	30	25.34			
11	0	25.34			
	30	25.34			
12	0	25.34			
	30	25.34			
13	0	25.34			
	30	25.34			
14	0	25.34			
	30	25.34			
15	0	25.34			

Blank-Test No. 1 b cont'd.

+ Current turned on. \* Current turned off.

$$r_1 = \frac{22.89 - 22.88}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = 0$$

$$\text{Corrected temperature} = 25.34 - 22.89 - \frac{0.002 + 0}{2} \times 4 = 2.45 \text{ deg. C}$$

Charge-Test No. 1

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.17	25	54	3.500
	30				3.600
1	0	23.18			3.750
	30				3.800
2	0	23.18			3.875
	30				3.990
3	0	23.18			3.885
	30				3.800
4	0	23.19			3.700
	30				3.850
5+	0	23.19			3.900
	30				3.925
6#	0				3.975
	30	25.00			3.975
7	0	25.21			3.975
	30	25.33			<u>3.975</u>
8	0	25.39			Av. 3.833 ✓
	30	25.43			
9	0	25.48			
	30	25.49			
10	0	25.50 max.			
	30	25.50			
11	0	25.50			
	30	25.50			
12	0	25.50			
	30	25.50			
13	0	25.50			
	30	25.50			
14	0	25.50			
	30	25.49			
15	0	25.49			



Charge-Test No. 1 Cont'd.

+ Current turned on. # Current turned off.

$$r_1 = \frac{23.19 - 23.17}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r_2 = \frac{25.50 - 25.49}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$\text{Corrected temperature} = 25.50 - 23.19 - \frac{0.004 + 0.002}{2} \times 5 = 2.295 \text{ deg. C}$$

<sup>0</sup>  
2.305

Blank-Test No. 2 a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	24.08	26	54	3.950
	30				4.075
1	0	24.08			4.075
	30				4.050
2	0	24.09			4.050
	30				4.045
3	0	24.09			4.075
	30				4.075
4	0	24.10			4.065
	30				4.065
5+	0	24.11			4.060
	30				4.060
6#	0				4.075
	30	26.39			4.075
7	0	26.49			4.065
	30	26.55			4.065
8	0	26.59			4.060
	30	26.60			4.065
9	0	26.62			4.060
	30	26.62			4.060
10	0	26.63 max.			4.060
	30	26.63			4.075
11	0	26.63			4.075
	30	26.62			4.075
12	0	26.62			4.075
	30	26.62			Av. 4.061 ✓
13	0	26.62			
	30	26.62			
14	0	26.61			
	30	26.61			
15	0	26.61			

+ Current on. # Current off.

Blank-Test No. 2 a Cont'd.

$$r_1 = \frac{24.11 - 24.08}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$r_2 = \frac{26.63 - 26.61}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$\text{Corrected temperature} = 26.63 - 24.11 + \frac{0.004 + 0.006}{2} \times 5 = 2.495 \text{ deg. C}$$

$$= 2.52 - .005 = 2.515 \text{ C}$$



Duration of Time		Calorimeter Temperature of water.	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.57	27	54	4.000
	30				4.050
1	0	23.57			4.050
	30				4.050
2	0	23.58			4.050
	30				4.075
3	0	23.58			4.050
	30				4.040
4	0	23.59			4.060
	30				4.060
5+	0	23.59			4.050
	30				4.060
6#	0				4.060
	30	25.81			4.055
7	0	25.91			4.045
	30	25.99			4.050
8	0	26.01			4.050
	30	26.04			4.055
9	0	26.05			4.060
	30	26.06 max.			4.060
10	0	26.06			4.060
	30	26.06			4.060
11	0	26.06			4.060
	30	26.05			4.060
12	0	26.05			4.058 ✓
	30	26.04			
13	0	26.04			
	30	26.03			
14	0	26.03			
	30	26.02			
15	0	26.02			

+ Current on

# Current off

Blank-Test No. 2 b Cont'd.

$$r_1 = \frac{23.59 - 23.57}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r_2 = \frac{26.06 - 26.02}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 26.06 - 23.59 + \frac{0.004 + 0.008}{2} \times 4.5 = 2.50 \text{ deg. C}$$

$$= 2.47 + 0.009 = 2.479 \text{ C}$$

Charge-Test No. 2

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy
Min.	Sec.	Deg. C	Deg. C	I. Amp.      E. Volt
1	0	24.26	26	54      3.250
	30			3.300
1	0	24.26		3.375
	30			3.925
2	0	24.26		3.950
	30			3.900
3	0	24.27		3.900
	30			3.875
4	0	24.28		3.875
	30			3.835
5+	0	24.28		3.900
	30			3.950
6#	0			3.950
	30	26.30		3.965
7	0	26.43		3.975
	30	26.51		3.975
8	0	26.53		3.975
	30	26.60		3.985
9	0	26.61		Av. 3.885 ✓
	30	26.62		
10	0	26.63 max.		
	30	26.63		
11	0	26.63		
	30	26.63		
12	0	26.62		
	30	26.62		
13	0	26.61		
	30	26.61		
14	0	26.60		
	30	26.60		
15	0	26.60		



Charge-Test No. 2 Cont'd.

± Current turned on. # Current turned off.

$$r_1 = \frac{24.28 - 24.26}{5} = \frac{.02}{5} = -.004 \text{ deg C}$$

$$r_2 = \frac{26.63 - 26.60}{5} = \frac{.03}{5} = +.006 \text{ deg C}$$

$$\text{Corrected temperature} = 26.63 - 24.28 + \frac{-0.004 + 0.006}{2} \times 5 = 2.475 \text{ deg C}$$

$$= 2.35 + .125 = \underline{2.475 \text{ C}}$$

Blank-Test No. 3a.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
1	0	22.67	24	52	4.050
	30				4.060
1	0	22.67			4.075
	30				4.055
2	0	22.63			4.055
	30				4.075
3	0	22.63			4.025
	30				4.060
4	0	22.63			4.035
	30				4.040
5+	0	22.63			4.035
	30				4.040
6#	0				4.035
	30	24.30			4.035
7	0	24.39			4.045
	30	24.95			4.040
8	0	24.99			4.040
	30	25.00			4.035
9	0	25.01			4.060
	30	25.02 max.			4.065
10	0	25.02			4.065
	30	25.02			Av, 4.049
11	0	25.02 -			
	30	25.02			
12	0	25.02			
	30	25.01			
13	0	25.01			
	30	25.02			
14	0	25.00			
	30	24.99			
15	0	24.99			

Blank-Test No. 3a Cont'd.

+ Current turned on. # Current turned off.

$$r_1 = \frac{22.63 - 22.67}{5} = \frac{0.01}{5} = 0.002 \text{ deg C}$$

$$r_2 = \frac{25.02 - 24.99}{5} = \frac{.03}{5} = 0.006 \text{ deg C}$$

$$\text{Corrected temperature} = 25.02 - 22.63 + \frac{0.002 + 0.006}{2} \times 4.5 = 2.36 \text{ deg C}$$

$$= 2.34 + .01 = \underline{\underline{2.35 \text{ C}}}$$



Blank-Test No. 3b.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy
Min.	Sec.	Deg. C	Deg. C	I. Amp      E. Volt
1	0	22.78	24	52      4.100
	30			4.075
1	0	22.78		4.075
	30			4.065
2	0	22.78		4.065
	30			4.060
3	0	22.79		4.060
	30			4.065
4	0	22.79		4.060
	30			4.065
5+	0	22.80		4.060
	30			4.075
6#	0			4.070
	30	24.95		4.065
7	0	25.05		4.075
	30	25.10		4.080
8	0	25.14		4.075
	30	25.13		4.075
9	0	25.19 max.		4.075
	30	25.19		4.065
10	0	25.19		-----
	30	25.19		Av. 4.070 ✓
11	0	25.19		
	30	25.19		
12	0	25.19		
	30	25.19		
13	0	25.19		
	30	25.13		
14	0	25.13		
	30	25.13		
15	0	25.13		

Blank-Test No. 3b Cont'd.

+ Current turned on. # Current turned off.

$$r_1 = \frac{22.80 - 22.78}{5} = \frac{0.02}{5} = 0.004 \text{ deg C}$$

$$r_2 = \frac{25.19 - 25.13}{5} = \frac{0.06}{5} = 0.012 \text{ deg C}$$

$$\text{Corrected temperature} = 25.19 - 22.80 - \frac{0.004 + 0.012}{2} \times 4 = 2.386 \text{ deg C}$$

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Charge-Test No. 3.

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.28	24.5	52	3.750
	30				3.800
1	0	23.28			3.900
	30				3.915
2	0	23.29			3.935
	30				3.900
3	0	23.29			3.885
	30				3.885
4	0	23.29			3.855
	30				3.890
5+	0	23.30			3.885
	30				3.885
6*	0				3.890
	30	25.16			3.915
7	0	25.32			<hr/>
	30	25.40		Av.	3.880 ✓
8	0	25.46			
	30	25.49			
9	0	25.50			
	30	25.51 max.			
10	0	25.21			
	30	25.51			
11	0	25.51			
	30	25.51			
12	0	25.51			
	30	25.51			
13	0	25.51			
	30	25.51			
14	0	25.51			
	30	25.51			
15	0	25.51			

+ Current turned on. \* Current turned off



Charge-Test No. 3 Cont'd.

$$r_1 = \frac{23.30 - 23.28}{5} = \frac{0.02}{5} = 0.004 \text{ deg. C}$$

$$r_2 = 0$$

$$\text{Corrected temperature} = 25.51 - 23.30 - \frac{0.004 + 0}{2} \times 4.5 = 2.20 \text{ deg. C}$$

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	23.88	25.5	55	4.125
	30				4.100
1	0	23.88			4.090
	30				4.090
2	0	23.89			4.085
	30				4.075
3	0	23.89			4.085
	30				4.100
4	0	23.90			4.085
	30				4.085
5+	0	23.91			4.085
	30				4.085
6#	0				4.085
	30	26.20			4.085
7	0	26.30			4.085
	30	26.39			4.085
8	0	26.43			4.085
	30	26.45			4.085
9	0	26.47			4.085
	30	26.47			4.085
10	0	26.48 max.			4.085
	30	26.48			4.085
11	0	26.48			4.085
	30	26.48			4.085
12	0	26.48			4.085
	30	26.47			4.085
13	0	26.47			4.085
	30	26.46			4.085
14	0	26.46			4.085
	30	26.45			4.085
15	0	26.45			4.085
				Av.	4.090 ✓

+ Current turned on. # Current turned off.

Blank-Test No. 4 a Cont'd.

$$r_1 = \frac{23.91 - 23.88}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$r_2 = \frac{26.48 - 26.45}{5} = \frac{0.003}{5} = 0.0006 \text{ deg. C}$$

$$\text{Corrected temperature} = 26.48 - 23.91 + \frac{0.006 + 0.0006}{2} \times 5 = 2.60 \text{ deg. C}$$

$$= 2.57 \text{ C}$$



Blank-Test No. 4 b

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	24.18	25.5	55	4.100
	30				4.100
1	0	24.18			4.085
	30				4.100
2	0	24.18			4.085
	30				4.090
3	0	24.19			4.085
	30				4.085
4	0	24.20			4.100
	30				4.085
5+	0	24.21			4.085
	30				4.075
6*	0				4.110
	30	26.50			4.110
7	0	26.60			4.090
	30	26.68			4.090
8	0	26.71			4.090
	30	26.74			4.085
9	0	26.76			
	30	26.77 max.		Av.	4.091 ✓
10	0	26.77			
	30	26.77			
11	0	26.77			
	30	26.77			
12	0	26.76			
	30	26.76			
13	0	26.75			
	30	26.75			
14	0	26.74			
	30	26.74			
15	0	26.73			

+ Current on \* Current off

Blank-Test No. 4 b Cont'd.

$$r_1 = \frac{24.21 - 24.18}{5} = \frac{0.03}{5} = 0.006 \text{ deg. C}$$

$$r_2 = \frac{26.77 - 26.73}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 26.77 - 24.21 + \frac{0.006 + 0.008}{2} \times 4.5 = 2.43 \text{ deg. C}$$

$$= 2.56 + 0.08 = 2.64 \text{ C}$$

Charge-Test No. 4

Duration of Time		Calorimeter Temperature of water	Av. Room Temperature	Electrical Energy	
Min.	Sec.	Deg. C	Deg. C	I. Amp.	E. Volt
	0	24.70	25.5	55	3.400
	30				3.550
1	0	24.70			3.900
	30				3.900
2	0	24.71			3.885
	30				3.950
3	0	24.71			3.875
	30				3.865
4	0	24.71			3.775
	30				3.775
5+	0	24.71			3.850
	30				3.900
6#	0				3.925
	30	26.80			3.925
7	0	26.92			4.000
	30	27.00			3.975
8	0	27.04			3.975
	30	27.08			3.950
9	0	27.09			
	30	27.10			Av. 3.854 ✓
10	0	27.11 max.			
	30	27.11			
11	0	27.11			
	30	27.10			
12	0	27.10			
	30	27.10			
13	0	27.09			
	30	27.09			
14	0	27.08			
	30	27.08			
15	0	27.07			

+ Current on. # Current off.



Charge-Test No. 4 Cont'd.

$$r_1 = \frac{24.71 - 24.70}{5} = \frac{0.01}{5} = 0.002 \text{ deg. C}$$

$$r_2 = \frac{27.11 - 27.07}{5} = \frac{0.04}{5} = 0.008 \text{ deg. C}$$

$$\text{Corrected temperature} = 27.11 - 24.71 + \frac{0.002 + 0.008}{2} \times 5 = 2.48 \text{ deg. C}$$

$$= 2.40 + \text{diff} = 2.415 \text{ C}$$