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The Scientific Shop

ALBERT B. PORTER

Scientific Instruments — 324 Dearborn St., CHICAGO

CIRCULAR 350 — MAY, 1907

The Studentia Calorimeters

Patent Applied For

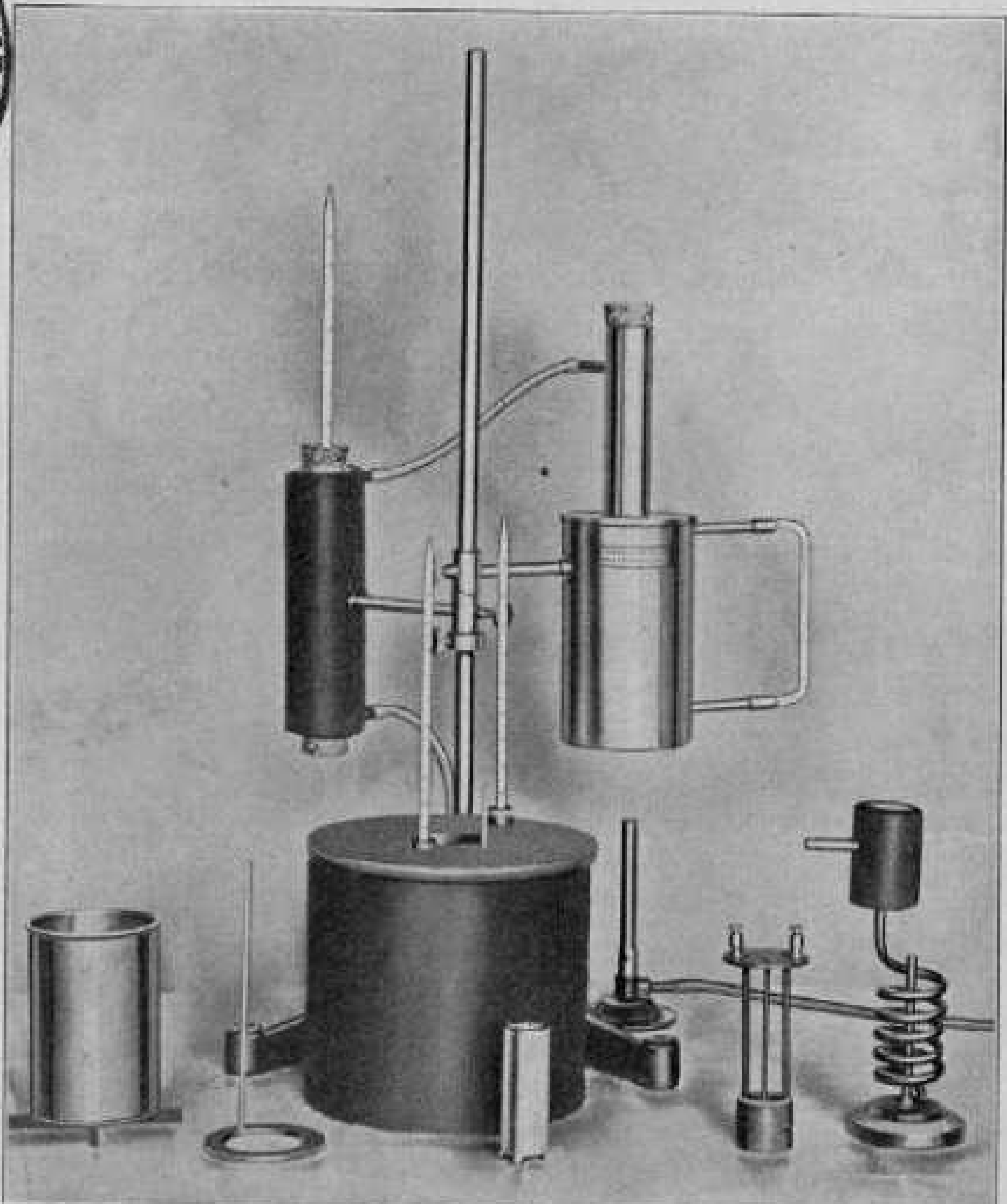


Fig. 1

Showing the apparatus set up for determination of specific heats by method of mixtures, and some of the component parts of the Calorimeters

The Studentia Calorimeters

The "Studentia" Calorimeters were designed for The Scientific Shop by Mr. J. O. Mulvey, mechanician of the Armour Institute of Technology. They owe their inception to the gratifying favor with which the "Scientia" Calorimetric Outfit has been received by scientific men, and to persistent calls for smaller and less expensive but equally well-made apparatus suitable for elementary laboratory work.

The "Studentia" Calorimeters include everything needed to give the beginning student a thorough training in calorimetric methods, while the utensils are so designed and are of such size that reasonably accurate results are assured. The various parts of the "Studentia" outfit are interchangeable and, since all parts are sold separately, the teacher may increase his laboratory equipment at any time.

The "Studentia" Calorimeters are made of the best materials, and with the same attention to details which characterizes the "Scientia" outfit. All the parts of the apparatus whose water-equivalents must be taken into account are made of brass or hard rolled copper, and the exposed metallic surfaces of the calorimetric vessels are nickel plated and polished in order to minimize the radiation corrections.

Fig. 1 shows the apparatus set up for the determination of specific heats of solids by the method of mixtures and, in the foreground, several of the component parts of the "Studentia" outfit. The sectional cuts, Figs. 2 to 5, show the arrangement of the apparatus for several experiments.

Since the greatest errors in calorimetry usually arise in the temperature measurements and in the estimation of the radiation correction, especial attention has been given to these points in designing the apparatus. For the purpose of making the radiation correction as small and as constant as possible, the apparatus includes a water-jacket for shielding the calorimeter from outside temperature changes, and this water-jacket is nickel plated and polished on the inside, and is heavily lagged with felt on the outside. Since the jacket holds between its walls a large mass (1500 g.) of water, these precautions ensure a nearly constant jacket-temperature, and a small and determinate radiation correction.

Recognizing the fact that ordinary thermometers are entirely unsuited to the measurement of the small variations of temperature which take place within the calorimeter itself, and that the Beckmann thermometers such as are supplied with the "Scientia" outfit are perhaps too costly and too fragile to be put into the hands of young students, special thermometers have been designed to form a part of the "Studentia" equipment. These thermometers (C1468 and C1469) can be supplied either with the scales etched on the stem, or with enclosed porcelain scales as may be desired. They are made of Jena glass, are 14 inches (35 cm.) long, and are rather slender in the stem so as to have as small a water-equivalent and parallax-error as is consistent with sufficient strength. The scale, which runs from 15°C. to 40°C., thus covering all temperatures which are apt to be met with in the calorimeter itself, is divided to one-twentieth degrees. Since each division is about a half millimetre long, fractions of a division can be estimated with the naked eye, and tenths of a division (1/200°) can be read by aid of a lens. Each thermometer has an expansion chamber at the top to prevent breakage if accidentally overheated, and as an aid in calibration. The lowest division (15°C.) is placed from 4 to 5 inches (9.5 to 12.5 cm.) above the bottom of the bulb so as to be always visible above the cover of the calorimeter when in use. In shipping these thermometers the mercury sometimes runs into the expansion chamber. It can usually be brought back into the tube by rapping the bulb vertically on the palm of the hand, or by rapidly swinging the thermometer at arm's length with the bulb held outward. If this procedure is not effective, the expansion chamber should be cautiously heated in a small flame until it is quite hot to the touch. The mercury can then readily be run back into the tube by rapping or swinging as before.

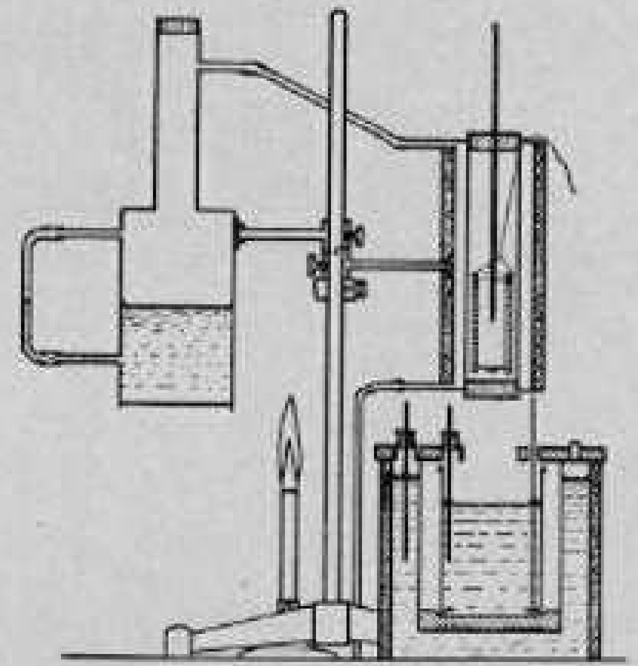


Fig. 2

Showing the apparatus arranged for specific heats by method of mixtures

The Water-Jacket (C1451) shown in the centre of Fig. 1, and in section in Figs. 2 to 5, is a double-walled vessel of hard-rolled brass, nickel plated and polished inside, and covered outside by a removable felt jacket three-eighths of an inch (0.8 cm.) thick. The felt covering serves to protect the vessel from outside temperature changes, while the polished inner surface diminishes the radiation correction of a calorimeter when surrounded by the jacket. The water-jacket is 6 inches (15 cm.) high and 6½ inches (16.5 cm.) in diameter over all; the inner space is 5 inches (13 cm.) deep and 4 inches (10 cm.) in diameter, while the space between the inner and outer walls is 1 inch (2.5 cm.) thick. On top there is a tubulure for the insertion of a thermometer, and for filling the jacket, and a pin which, with the tubulure, holds the cover in position.

The Cover is made of white pine, glued up three ply so as to prevent warping, and is heavily shellaced. It is pierced by a central hole of 1½ inches (3.7 cm.) in diameter, and by four smaller holes for the tubulure, pin, thermometer, and the handle of the stirrer.

The Inner Vessel or Calorimeter (C1452), which is identical with the small inner vessel of the "Scientia" calorimetric outfit, is shown resting on its support at the extreme left of Fig. 1, and in section in Figs. 2, 3, and 5. It is made of hard rolled copper, is nickel plated and polished on the outside, is 4½ inches (11.5 cm.) high, 3 inches (7.5 cm.) in diameter, and has a capacity of 500 cc. With it is supplied a cross-shaped, wooden insulating support for holding it centrally inside the water-jacket and away from the bottom and walls of the latter.

The Stirrer (C1453), shown just to the left of the water-jacket in Fig. 1, is the same as the small stirrer in the "Scientia" outfit. It is made of a flat ring of sheet copper, turned down at the outer edge for stiffness, and has a copper wire handle long enough to pass through a hole in the cover of the water-jacket as shown in Figs. 2, 3, and 5. The inner diameter of the ring is 1⅞ inches (4.8 cm.), which gives ample clearance around the condenser, electric heating coil, etc.

The Tripod, Rod, and Collar (C1455), for supporting the boiler and steam-heater, are shown in Figs. 1, 2, and 3. They are identical with those supplied with the "Scientia" Waterman Calorimeter. The tripod is heavy and rigid, being made of enamelled iron, with legs 6 inches (15 cm.) long. The rod, which screws firmly into the tripod, is made of Bessemer steel, plated and polished. The collar clamps to the vertical rod, as shown in Figs. 1 and 2, so as to permit rotation of the boiler and steam-heater about a vertical axis.

The Boiler (C1456), shown attached to the right of the vertical rod in Fig. 1, and in section in Figs. 2 and 3, is made of heavy brass, nickel plated and polished. It is supplied with a horizontal supporting rod and clamp which interlocks with that on the steam-heater so that the two may be swung together around the vertical rod. The boiler is supplied with a glass water-gauge, and is prolonged above so that it may supply drier steam, and in order that it may be used in testing the boiling points of thermometers. The body of the boiler is 3½ inches (9 cm.) in diameter and 6 inches (15 cm.) high; the upper tube is 5 inches (12.5 cm.) long and 1¼ inches (3 cm.) in diameter.

The Steam Heater (C1457), shown attached to the left of the vertical rod in Fig. 1, and in section in Fig. 2, serves, in connection with the boiler, to heat pieces of metal, etc., when determining their specific heats by the method of mixtures. It consists of a brass tube 1 7/16 inches (3.5 cm.) in diameter inside and 7¼ inches (18.5 cm.) long, surrounded by an outer brass tube 1¾ inches (4.5 cm.) in diameter, so as to form a steam jacket, the whole being covered by a lagging of felt 5/16 inch (0.8 cm.) thick. Small tubes at the top and bottom connect with the jacket space, and serve as inlet and outlet for the steam. The felt lagging prevents escape of heat and at the same time enables the apparatus to be conveniently handled while hot.

When in use, the bottom and top of the heater are closed by means of corks. A thermometer is passed through the upper cork so that its bulb may be inside the (conveniently) tubular piece of metal whose specific heat is being found, and the latter is supported by means of a thread pinched between the upper cork and the walls of the tube. When the temperature of the piece of metal has risen nearly to 100°C. and has become steady, the steam heater is swung round over the calorimeter, and the metal is lowered into the latter by means of the thread. The apparatus is so designed that, during the process of heating the metal, the boiler, steam heater, and water-jacketed calorimeter lie respectively over the three openings of the tripod as shown in Fig. 1, and so that, when the steam heater is swung round until it strikes the handle of the stirrer, it is centered over the hole in the cover of the calorimeter in such a way that the metal piece may be dropped in quickly and with certainty. The convenience of this feature of the design will be appreciated in the laboratory.

Pieces of Metal (C 1466), made especially for specific heat determinations with the "Studentia" and Scientia" calorimeters, are a convenience which will be appreciated. One of these metal pieces is shown in front of the water-jacket in Fig. 1, and in section inside the steam heater in Fig. 2. The metal pieces are made in tubular form so that they may heat uniformly throughout and readily give up heat to the calorimeter, and so that, when in the steam heater, the bulb of the thermometer may lie inside the metal. Each piece is drilled at the top for suspension, and is cut away at the bottom at four places in order that it may rest firmly on the bottom of the calorimeter and yet allow circulation of water inside as well as outside when the stirrer is moved up and down. In this way they are greatly superior to rolled-up strips of sheet metal. The pieces are of sufficient mass to give a rise of four to five degrees in the calorimeter.

The Condenser (C1458), shown with its water-trap at the extreme right of Fig. 1 and in part section in Fig. 3, is used in determining the heat of vaporization of liquids by the method of condensation. It consists of a stiffened and perforated brass disc 2¾ inches (7 cm.) in diameter, bearing on its upper surface a water-box 1¾ inches (4.5 cm.) in diameter and 5/16 inch (0.8 cm.) deep, from which rise two copper tubes ¼ inch (0.6 cm.) in diameter. One of these tubes, which serves as inlet for the steam or vapor, is bent into a helical coil, and is bored out to a taper at the upper end, fitting the water-trap. The other tube, which rises vertically from the water-box, serves as an outlet for any air which may be driven over from the boiler. The diameter of the steam-coil is 1¾ inches (4.5 cm.), which gives sufficient clearance for the stirrer, as shown in Fig. 3. The condenser

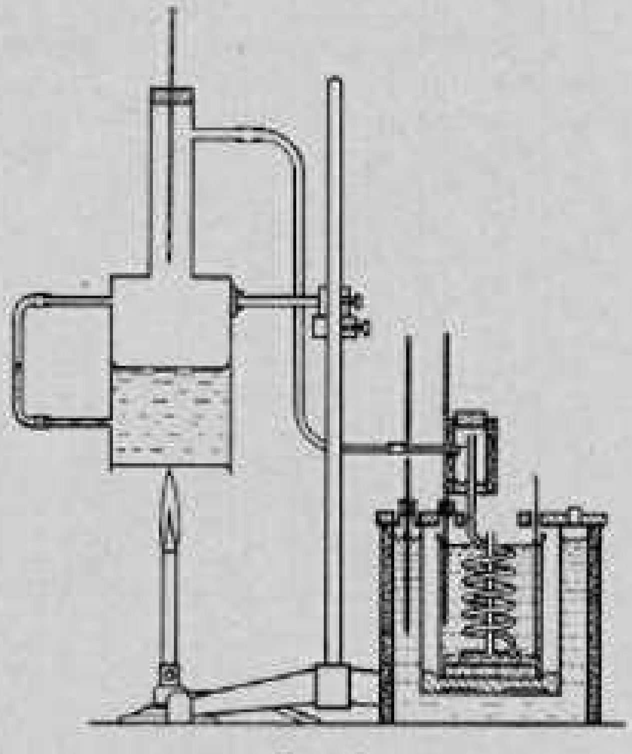


Fig. 3

Showing the apparatus arranged for heat of vaporization

is very efficient, and may be used with any vapor which does not attack copper.

The Water-Trap (C1459), shown in connection with the condenser in Figs. 1 and 3, serves to catch any liquid drops which might otherwise be carried over from the boiler to condenser. It consists of a brass tube 2¼ inches (5.5 cm.) long and 1 inch (2.5 cm.) in diameter, closed at the top by means of a cork so as to be readily emptied. The steam outlet at the bottom is tapered so as to fit the condenser-coil, and extends inside nearly to the top, as shown in Fig. 3. The steam inlet enters at the side, below the outlet, and is so shaped as to prevent an upward rush of vapor which might carry liquid drops into the outlet pipe. The water-trap is lagged with felt to prevent condensation, and to enable it to be comfortably handled while hot.

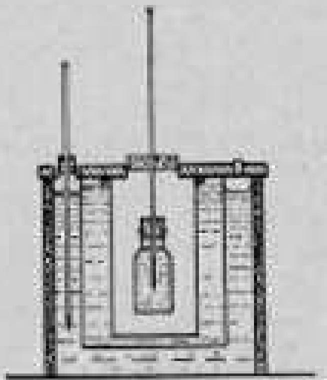


Fig. 4

Showing the apparatus arranged for specific heats by method of cooling

The Inner Vessel With Rim (C1461) and **Nickeled Cooling Bottle** (C1462), which are identical with those supplied with the "Scientia" calorimeters, are used in determining the specific heats of liquids by the method lar 331, at **K** and **J**. The inner vessel is 2½ inches (6.3 cm.) in diameter and 5 inches (12.5 cm.) high; it is nickel plated and polished on the outside, and is finished dead black inside; a bayonet catch in the rim holds the vessel firmly attached to the cover. The nickeled cooling bottle is 1 inch (2.5 cm.) in diameter, 2¼ inches (5.7 cm.) high, and has a capacity of 25 cc; the bottle is supported in use by a thermometer passing through the cork and through a second perforated cork fitted to the central hole in the cover.

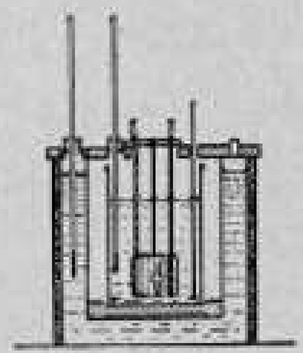


Fig. 5

Showing the apparatus arranged for heat equivalent of electrical energy

The Electrical Heating Coil (C1464), shown next to the condenser in Fig. 1, and in part section in Fig. 5, is intended for measurement of Joule's thermal equivalent of electrical energy, and may also be used for comparing the specific heats of liquids by the method of electric heating. The heating coil is designed to be directly connected across 110-volt direct or alternating current mains without the interposition of other resistances. It is made of thin wire of small temperature coefficient, wound in a screw thread cut in the outside surface of a "lava" tube, the whole being enclosed in a water-tight copper casing. The casing is attached to the fibre disc, which bears the binding posts, by means of a copper rod and two copper tubes through which the wires pass which connect the coil to the terminals. These connecting wires are insulated by means of tubular "lava" bushings. The apparatus is 5 inches (12.5 cm.) high over all; the copper casing of the coil is 1¼ inches (3.2 cm.) high, 1¼ inches (3.2 cm.) in diameter, and the diameter of the central hole is ¾ inch (2 cm.). The resistance of the coil is about 100 ohms, so that it carries a current of about 1.1 amperes and consumes about 120 watts, thus liberating sufficient heat to raise the temperature of 400 grams of water in the calorimeter 4°C. per minute. The approximate resistance of each coil is stamped on the fibre disc; hence rough measurements can be made, without using an ammeter and voltmeter, by assuming the voltage of the current supply as known. Although intended only to be used when immersed in a liquid, the coil may be left in circuit when exposed to air; it will then reach a dull red heat, but will deteriorate only very slowly.

An Apparatus for Mechanical Equivalent of Heat, simpler and less expensive than the "Scientia" apparatus, is in preparation. Details and prices will be published when ready.

Examples of Results Obtained with the Studentia Calorimeters

Before putting the Studentia Calorimeters on the market, the whole of the apparatus was tested in the laboratory of The Scientific Shop to determine what degree of accuracy the instruments might be expected to give in the hands of an intelligent student, and to see whether the design of the apparatus could be materially improved. The experiments recorded below suggested several modifications of construction which are embodied in the calorimeters now offered. No effort was made to attain exceptionally precise results in these experiments, but merely to get a fair idea of the working accuracy of the apparatus in the hands of the student. For this reason no especial care was taken in making the readings, nor in applying the corrections, beyond that which may be reasonably required of the beginning student. Radiation corrections could have been considerably reduced by always starting with the calorimeter below room temperature as in Experiment I, but it was in general thought best, for the purpose in view, to make no effort to reduce the radiation.

I. Specific Heat of a Solid by the Method of Mixtures

The apparatus was connected as shown in Figs. 1 and 2. The solid used was a tubular piece of brass, considerably smaller and lighter than the pieces now regularly supplied with the "Studentia" Calorimeters. It was weighed, hung inside the steam-heater by means of a thread, the thermometer (C 843) and corks were inserted as in Fig. 2, taking care that the bulb of the thermometer lay inside the bore of the tubular piece of brass. The burner was then started under the boiler, and steam was allowed to pass until the temperature of the brass piece became very nearly constant. Meanwhile, the double walls of the water-jacket were filled with water at about room temperature, and a second thermometer (C 843) was passed through a perforated cork fitting the tubulure of the water-jacket. A weighed quantity of water slightly below room-temperature was placed in the calorimeter, and a thermometer (C 849), graduated to 1/10°, was passed through a perforated cork and thrust through the cover so as to dip into the water. The water in the calorimeter was kept well stirred, and temperature readings were taken at five-minute intervals, as follows:

Time P. M.		**Temperatures**		
Hours	Minutes	Calorimeter	Water-Jacket	Heater
1	45	47.50°C	18.5°C	98.2°C
1	50	17.53	18.6	98.4
1	55	17.57	18.8	98.4

The thermometers in the heater and jacket were read to tenths of degrees, that in the calorimeter was read to hundredths; parallax-errors were avoided by holding the eye and lens in such position that the graduations on the thermometer tube hid their reflections in the mercury thread.

The temperature having become practically constant in the heater, the corks at top and bottom were loosened, and at 1:56 P. M., the lower cork was removed, the heater was swung round until it touched the handle of the stirrer, and the brass piece was quickly lowered into the calorimeter. The heater was then immediately swung back into its former position, and the boiler was allowed to run throughout the remainder of the experiment so that the temperature-environment should remain constant. Readings of the thermometers could not, of course, be made at the instant the brass piece was lowered into the calorimeter, but the following values were obtained by exterpolation from those given above.

Time	**Calorimeter**	**Water-Jacket**	**Heater**
1.56	17.58°C	18.8°C	98.4°C

The water in the calorimeter was now vigorously stirred, and readings were taken at half-minute intervals until the temperature began to fall, and then at longer intervals, as follows:

Time	**Calorimeter**	**Water-Jacket**
1.56½	20.06°C	18.8°C
1.57	20.06	....
1.57½	20.06	18.8
1.58	20.06	....
1.58½	20.05	18.8
1.59	20.05	
1.60	20.04	18.9

The radiation correction was estimated by Regnault's method (see e. g. Watson's "Text Book of Practical Physics," pp. 218-220), but, being found to be less than 0.005°C, was neglected. The water equivalents of calorimeter and stirrer were found by multiplying their weights by the specific heat of copper, viz., 0.0927. The water equivalent of the thermometer was found by placing the calorimeter with its contained water in the pan of the balance, holding the thermometer in a retort clamp, and immersing its bulb in the water to the same depth as when in use. The apparent gain in weight of the calorimeter in grammes is then (Archimedes' principle) equal to the volume of the immersed portion of the thermometer in cubic centimetres. This, multiplied by 0.45, the mean heat capacity in calories per cc. of glass and of mercury, gives the required water equivalent. All weighings were made to the nearest decigramme on a trip scale, since closer weighings would not increase the accuracy of the final result.

The following summary gives the experimental results and indicates the method of calculation:

Weight of calorimeter	144.5g.
" of stirrer	24.0g.
" of calorimeter, stirrer, and water	564.6g.
" of " " " " with thermometer immersed	565.3g.
Weight of brass test piece	138.9g.
Temperature of water	17.58°C.
" of brass piece	98.4°C.
" of mixture	20.06°C.
Weight of water=564.6—(144.5 + 24.0)=	396.1g.
Water equivalent of calorimeter and stirrer = (144.5 + 24.0) × 0.0927	15.6g.
Water equivalent of thermometer = (565.3 — 564.6) × 0.45	0.3g.
Total water equivalent of calorimeter and its contents =15.6 + 0.3 + 396.1 =	412.0g.
Rise of temperature of water=20.06—17.58=	2.48°C.
Fall in temperature of brass=98.4—20.06=	78.34°C.

Hence the specific heat of the brass piece is

$$S = \frac{412.0 \times 2.48}{138.9 \times 78.34} = 0.0939$$

Two more experiments with the same piece of brass gave the following results:

	Expt. 2.	Expt. 3.
Weight of water	379.9g.	359.5g.
Temperature of water	15.41°C.	19.77°C.
Temperature of brass	98.4°C.	98.4°C.
Temperature of mixture	18.08°C.	22.40°C.
Specific heat of brass	0.0942	0.0936

The three values obtained were thus:

Experiment 1	0.0939
Experiment 2	0.0943
Experiment 3	0.0936
Mean	0.0939

II. Specific Heat of a Liquid by the Method of Mixtures

(**First Method**)

The liquid used in the following two experiments was alcohol purchased as "95 per cent." It replaced the water in the calorimeter in the previous experiment. To determine its specific heat the brass piece previously used was heated in the steam heater and lowered into the alcohol.

The specific heat of the liquid was then determined from its rise in temperature, using the value 0.0939 just found for the brass. The chief experimental data were:

	Expt. 1.	Expt. 2.
Weight of alcohol used	287.5g.	247.8g.
Temperature of alcohol	19.73°C.	14.32°C.
Temperature of brass	98.3°C.	98.0°C.
Temperature of mixture	24.47°C.	20.12°C.
Radiation correction	0.04°C.	0.04°C.
Corrected temperature of mixture	24.51°C.	20.16°C.

The specific heat of the "95 per cent." alcohol is hence, using data obtained in Ex. 1:

$$\text{Expt. 1.}\quad S=\left\{\frac{138.9\times 0.0939\times(98.3-24.51)}{24.51\;-\;19.73}-(15.6+0.3)\right\}\div 287.5$$

$$=0.645$$

$$\text{Expt. 2.}\quad S=0.638$$

$$\text{Mean,}\quad 0.642$$

III. Specific Heat of a Liquid by Mixtures

(Second Method)

A liquid which would attack the calorimeter may be enclosed in a small bottle, warmed in the steam heater, and lowered bottle and all into water in the calorimeter. A separate experiment gives the water equivalent of the bottle. The following experiment with mercury illustrates the method.

(a.) Water Equivalent of the Bottle.

Weight of water in the calorimeter	315.7g.
Temperature of bottle	98.5°C.
Initial temperature of water	16.48°C.
Final temperature of water	17.82°C.
Radiation correction	0.00°C.

Hence the water equivalent of the bottle is

$$W=\frac{(15.9+325.7)(17.82-16.48)}{98.5-17.82}=5.51\text{g.}$$

(b.) Specific Heat of Mercury.

Weight of water in calorimeter	300.6g.
Weight of mercury	270.9g.
Temperature of mercury	98.3°C.
Initial temperature of water	17.42°C.
Final temperature of water	20.96°C.
Radiation correction	0.03°C.
Corrected final temperature	20.99°C.

Hence the specific heat of mercury is

$$S=\left\{\frac{(15.9+300.6)(20.99-17.42)}{98.3-20.99}-5.51\right\}\div 270.9=0.0336$$

IV. Heat of Vaporization of Water

Using the apparatus set up as in Fig. 3, two experiments gave the following data for the heat of vaporization of water. The weight of the condensed water was found by carefully drying the condenser externally, weighing it and the contained water of condensation to a centigramme,

	Expt. 1.	Expt. 2.
Weight of condenser	139.84g.	139.84g.
Water equivalent of condenser (139.84 × 0.0927) equals	13.0g.	13.0g.
Weight of water in calorimeter	405.5g.	373.4g.
Weight of water condensed	19.66g.	10.59g.
Temperature of steam	99.0°C.	98.9°C.
Initial temperature of water	17.10°C.	15.22°C.
Final temperature of water	43.42°C.	30.61°C.
Radiation correction	0.30°C.	0.18°C.
Corrected final temperature	43.72°C.	30.79°C.

The heat of vaporization according to Expt. 1 is hence

$$L = \frac{(15.9+13.0+405.5)(43.72-17.10)-19.66(99.0-43.72)}{19.66}$$
$$= 532 \text{ cal./gm.}$$

The result according to the second experiment is

$$L = 524 \text{ cal./gm.}$$

V. Heat of Fusion of Ice

The experiment is made by introducing a known weight of dry ice into water in the calorimeter, and vigorously stirring the water until the ice is entirely melted. It is best to wrap up a single smooth piece of ice in several folds of filter paper to absorb the surface-water, weigh the whole to a centigram, slip the ice into calorimeter, and immediately weigh the moist filter paper. The difference between the two weights gives the weight of the dry ice.

The results of two experiments made in this way are given below.

	Expt. 1.	Expt. 2.
Weight of water in calorimeter	365.6g.	383.3g.
Weight of ice added	17.56g.	15.65g.
Initial temperature of water	23.15°C.	18.54°C.
Final temperature of water	18.62°C.	14.91°C.
Radiation correction	0.07°C.	0.00°C.
Corrected final temperature	18.69°C.	14.91°C.

The heat of fusion according to the first experiment is hence

$$L = \frac{(15.9+365.6)(23.15-18.69)-17.56\times 18.69}{17.56}$$
$$= 78.2 \text{ cal./gm.}$$

and according to the second experiment

$$L = 77.7 \text{ cal./gm.}$$

VI. Equivalence of Heat and Electrical Energy; the Electrical Method of Finding the Mechanical Equivalent of Heat

This experiment consists in heating a known mass of water in the calorimeter for a definite time by means of the electrical heating coil (C 1464), noting the rise of temperature, and noting also any two of the following three quantities: the current passing, the voltage at the terminals of the coil, and the resistance of the coil. From these data one may calculate the number of joules of electric energy spent in the calorimeter, the number of calories of heat developed, and hence the number of joules equivalent to a calorie.

It is necessary first to determine the water equivalent of the heating coil by heating the coil in the steam heater and then proceeding as with the bottle in III. The coil may be thrust into the heater from below, so that the bulb of a thermometer passing through the cork at the top may lie inside the coil. The coil absorbs and gives up heat rather slowly; hence it is well to keep it in the steam heater for about five minutes after the thermometer has ceased to rise. The coil is then withdrawn and quickly dropped into the calorimeter. Two experiments made in this manner gave 6.8 g. and 6.6 g. for the water equivalent of one of the coils. The mean of these values, viz., 6.7 g., is used in what follows.

The data obtained in four experiments on the mechanical equivalent of heat are given below. The voltage at the terminals of the coil was 104 in each case. The resistance of the coil used was 93.3 ohms, so that the rate at which energy was liberated in the calorimeter was $104^2 \div 93.3 = 116.0$ watts, or 116.0 joules per second. The heating coil was allowed in each case to remain in the calorimeter throughout the experiment, the current being turned on for a definite time. Readings of the temperature in the calorimeter were taken at one-minute intervals for some time before turning on the current, and were continued on breaking the circuit, for five minutes after the temperature began to fall, to enable the radiation correction to be estimated. The calculation of the result of the first experiment from the data given below is

$$J = \frac{116.0 \times 3 \times 60}{(347.7+15.9+6.7)(28.35-15.95)} = 4.24 \text{ joules per calorie}$$

	Ex. 1.	Ex. 2.	Ex. 3.	Ex. 4.
Water in calorimeter..........	374.7g.	346.5g.	390.8g.	313.5g.
Initial temperature	15.95°C.	9.32°C.	11.89°C.	10.13°C.
Final temperature	28.08°C.	22.46°C.	27.76°C.	19.84°C.
Radiation correction	0.27°C.	0.13°C.	0.24°C.	0.06°C.
Corrected final temperature.....	28.35°C.	22.59°C.	28.00°C.	19.90°C.
Time of heating................	3 min.	3 min.	4 min.	2 min.
Mechanical equivalent	4.24	4.26	4.18	4.24

The mean of the four values obtained for the mechanical equivalent is thus:

$$J = 4.23 \text{ joules per calorie,}$$
$$= 4.23 \times 10^7 \text{ ergs per calorie.}$$

VII. Specific Heat of a Liquid by the Method of Electrical Heating

From VI we find the rate at which heat is developed by the heating coil to be $116.0 \div 4.23 = 27.4$ calories per second. Knowing this constant, the specific heat of a liquid may be determined by heating some of it in the calorimeter by means of the heating coil, precisely as in VI. The following data were obtained in an experiment with "95 per cent." alcohol.

Weight of alcohol..................................	236.2g.
Initial temperature	15.26°C.
Final temperature	28.70°C.
Radiation correction	0.59°C.
Corrected final temperature.........................	29.29°C.
Time of heating.....................................	90 sec.

Hence the specific heat of the alcohol is found to be:

$$\left(\frac{27.4 \times 90}{\ldots} \ldots \right) \ldots$$

VIII. Specific Heat of a Liquid by the Method of Cooling

The arrangement of apparatus for this purpose is shown in Fig. 4. The blackened inner vessel is held to the cover by the bayonet catch, and is immersed in water in the jacket vessel, the cover being held down by a ring-shaped weight not shown in the cut. The nickeled cooling bottle is partly filled with the liquid, closed by a perforated cork through which passes a thermometer supporting the bottle. A second and larger perforated cork fits the hole in the cover, so that the bottle is held centrally inside the blackened vessel. The liquid in the bottle is gently heated over a burner until the thermometer indicates (say) 36° or 37°C. The bottle is then inserted in the blackened vessel, and readings of the thermometer are taken at intervals of (say) one minute until the temperature has fallen perhaps ten or twelve degrees. Readings of the jacket temperature are also made from time to time. A similar set of readings are then made with warm water in the bottle.

The data given below were obtained in an experiment with "95 per cent." alcohol.

Weight of bottle....................................	38.47g.
Water equivalent of bottle = 38.47 × 0.0927 = ...	3.57g.
Water equivalent of thermometer.................	0.31g.
Weight of alcohol....................................	21.93g
Weight of water......................................	17.67g.

The following table gives the readings: the numbers in columns 6 and 7 refer to Experiment IX below.

Reading	Alcohol		Water		Water	
No.	Bottle	Jacket	Bottle	Jacket	Smoked Bottle	Jacket
1	36.83°C.	....	36.97°C.	....	37.05°C.	....
2	36.36	....	36.52	....	36.48	....
3	35.88	16.5	36.11	16.5	35.94	15.6
4	35.41	....	35.70	....	35.41	....
....	....	....	....	....	....	....
28	27.48	....	28.67	....	26.70	....
29	27.24	....	28.46	....	26.46	....
30	27.02	16.8	28.25	17.0	26.22	16.3
31	26.80	....	28.05	....	26.00	....
32	26.57	....	27.85	....		
33	26.36	....	27.65	....		
34	....	....	27.46	....		
35	....	....	27.28	....		
36	....	....	27.10	....		
37	....	....	26.92	....		
38	....	....	26.75	17.1		
39	....	....	26.58			
40	....	....	26.26			

Choosing for the purpose of calculation the ten-degree range of temperature from 36.50° to 26.50°, a simple interpolation from the readings given above shows that the alcohol was at the former temperature at 1.70 min., and at the latter at 32.33 min., or that it took the liquid 30.63 minutes to cool through the specified ten degrees. Similarly, it is found that the water cooled through the same ten degrees in 37.36 minutes. Further, it will be noted that the temperature of the jacket was, in the average, 0.15° cooler in the case of the alcohol than in the case of the water, and that this amounts to about 0.98 per cent. of the average difference in temperature between the alcohol and the jacket. Hence, if the jacket temperatures had been the same as in the case of the water, the time of cooling of the alcohol would have been, by Newton's law of cooling, 30.63 × 100.98 = 30.93 minutes.

Since the radiating surfaces and the temperatures were the same with water and alcohol, the heat given out per minute must be equal in the two cases. Hence, if **S** represents the specific heat of alcohol, we have:

$$\frac{17.67+3.57+0.31}{37.36} = \frac{21.98\mathbf{S}+3.57+0.31}{30.93}$$

The specific heat of the alcohol is thus found to be:

$$\mathbf{S} = 0.637$$

The experiment as carried out was evidently defective in that the jacket temperatures were not more accurately determined; the thermometer used in the jacket should be as sensitive as the one in the bottle.

IX. Comparison of Radiation from a Polished and from a Blackened Surface

In this experiment, the surface of the cooling bottle was lightly covered with lampblack by holding it for a moment in a smoky gas flame. The bottle was then filled with the same quantity of water used in VIII, heated to nearly 40°C., inserted into the blackened inner vessel as before, and temperature readings were taken each minute until the temperature had fallen to 26°. These readings are given in columns 6 and 7 in VIII. Interpolation shows that the temperature fell from 36.50° to 26.50° in 26.87 minutes. Correcting this, by Newton's law, to the jacket temperatures, observed in the case of water in the polished bottle in VIII, the time of cooling under these conditions is found to be 28.49 minutes. The radiation being inversely as the time of cooling, the radiation from the polished surface is to that from the blackened surface as 28.49 is to 37.36, or as 1 is to 1.24.

X. Newton's Law of Cooling

Newton's law, that the rate of cooling of a body is proportional to the difference in temperature between the body and its surroundings, has been used several times in what precedes. This law only holds, even approximately, when the difference of temperature is very small. The following experiment shows the failure of the law at relatively large temperature differences.

A 100°C. thermometer (C 843) was inserted in a small quantity of hot water in the smoked cooling bottle. The bottle was inserted into the blackened inner vessel, as in VIII and IX, and the temperature of the bottle was read every minute and of the jacket every two minutes for about an hour. A few of the readings are given below.

Reading No.	Bottle	Jacket	Difference	Fall per Minute	Ratio
1	94.4	17.2	77.2		....
2	92.0	......	74.8	2.30	33
3	89.8	17.3	72.5	2.15	34
4	87.7	......	70.4	2.05	34
5	85.7	17.4	68.3	1.95	35
....	......	......	......	......	....
19	64.1	18.0	46.1	1.20	38
20	62.9	......	44.9	1.15	39
21	61.8	18.1	43.7	1.10	40
22	60.7	......	42.6	1.10	39
....	......	......	......	......	....
35	41.9	18.4	30.7	.75	41
36	48.4	......	30.0	.70	43
37	47.7	18.5	29.2	.70	42
38	47.0	......	28.5	.65	44
....	......	......	......	......	....
51	40.0	18.7	21.3	.45	47
52	39.5	......	20.8	.50	42
53	39.0	18.8	20.2	.45	45

The fourth column contains the differences between bottle temperatures and jacket temperatures. The fall of bottle temperature per minute is in the fifth column. The sixth column gives the ratio of the numbers in the fourth and fifth columns, which, according to Newton's law, should be constant. The numbers in the sixth column, being ratios of two differences, are greatly affected by accidental errors, but the general upward trend of the numbers, as the temperature difference grows less, is sufficient to show the failure of Newton's law.

Price List

The prices given below are not subject to discount. No charge is made for boxing on orders amounting to ten dollars or more.

Component Parts of the "Studentia" Calorimeters

C 1451.	**Water Jacket,** with felt lagging and wooden cover	$ 6.00
C 1452.	**Inner Vesel or Calorimeter,** with wooden support	.75
C 1453.	**Stirrer**	.25
C 1455.	**Tripod, Rod, and Collar**	2.00
C 1456.	**Boiler,** with water gauge, etc., complete	3.00
C 1457.	**Steam Heater,** with felt lagging	3.00
C 1458.	**Condenser**	2.50
C 1459.	**Water Trap,** for use with the condenser	.50
C 1461.	**Inner Vessel, with Rim**	1.50
C 1462.	**Nickeled Cooling Bottle**	1.00
C 1464.	**Electrical Heating Coil**	3.00
C 1466.	**Tubular Pieces of Metal** for specific heat determinations: Aluminum, Brass, Copper, Lead, Iron, Tin, and Zinc. Each	.50
C 1468.	**Special Calorimetric Thermometer,** Jena Glass, 14 inches long, scale from + 15°C. to + 40°C. in 1/20°, etched on stem	1.50
C 1469.	**Same,** with enclosed porcelain scale	1.50
C 843.	**Thermometer,** Jena Glass, 11 inches long, scale from — 5° to 110°C. in 1°, etched on stem	.60
C 843a.	**Same,** with enclosed porcelain scale	.60

For other thermometers, see Circular 331.

Studentia Calorimetric Combinations for Special Purposes

C 1471. **Studentia Water-Jacketed Calorimeter,** complete .... $ 7.00

This comprises the following parts:

C 1451.	**Water-Jacket,** with felt lagging and wooden cover	$ 6.00
C 1452.	**Inner Vessel,** with support	.75
C 1453.	**Stirrer**	.25
		$ 7.00

C 1473. **Studentia Apparatus for Specific Heat by Method of Mixtures, complete with Thermometers, etc** **$18.70**

This comprises the following parts:

C 1471.	**Water-Jacketed Calorimeter**, complete	$ 7.00
C 1455.	**Tripod, Rod, and Collar**	2.00
C 1456.	**Boiler**, with water gauge	3.00
C 1457.	**Steam Heater**, with felt lagging	3.00
C 1466.	**Two Pieces of Metal** for specific heat determinations, @ 50c	1.00
C 1468.	**Special Calorimeteric Thermometer** in 1/20° ...	1.50
C 843.	**Two Thermometers**, @ 60c	1.20
		$18.70

C 1475. **Studentia Apparatus for Heat of Vaporization, Complete with Thermometers** **$17.70**

This comprises the following parts:

C 1471.	**Water-Jacketed Calorimeter**, complete	$ 7.00
C 1455.	**Tripod, Rod, and Collar**	2.00
C 1456.	**Boiler**, with water gauge	3.00
C 1458.	**Condenser**	2.50
C 1459.	**Water Trap**	.50
C 1468.	**Special Calorimetric Thermometer** in 1/20°	1.50
C 843.	**Two Thermometers**, @ 60c	1.20
		$17.70

C 1477. **Studentia Cooling Calorimeter**, complete with Thermometers **$11.50**

This comprises the following parts:

C 1451.	**Water-Jacket**, with felt cover and wooden top ..	$ 6.00
C 1461.	**Inner Vessel, with Rim**	1.50
C 1462.	**Nickeled Cooling Bottle**	1.00
C 1468.	**Two Special Calorimetric Thermometers**, @ $1.50	3.00
		$11.50

C 1480. **Studentia Apparatus for Heat Equivalent of Electrical Energy, complete with Thermometers** **$12.10**

This comprises the following parts:

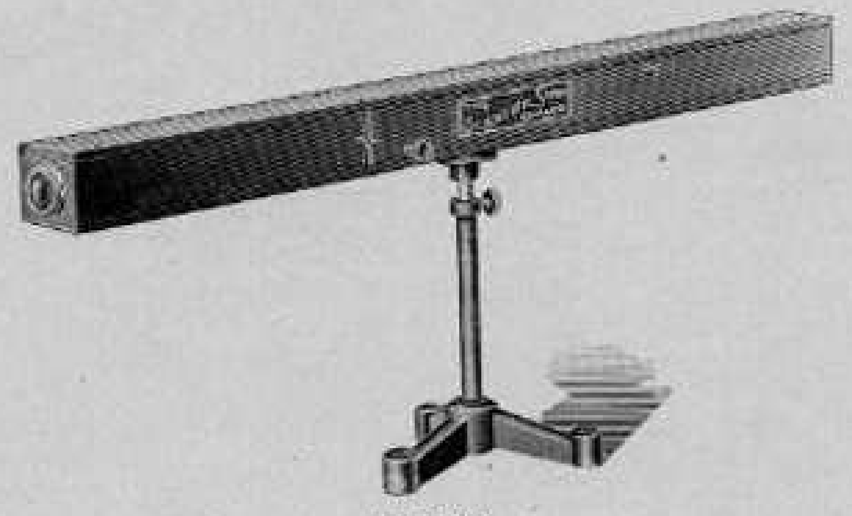
C 1471.	**Water-Jacketed Calorimeter**, complete	$ 7.00
C 1464.	**Electrical Heating Coil**	3.00
C 1468.	**Special Calorimetric Thermometer** in 1/20°	1.50
C 843.	**Thermometer**	.60
		$12.10

C 1485. **Studentia Calorimeters, complete set,** for **Specific Heat** by **Mixtures** and **Cooling, Heats of Vaporization** and **Fusion of Ice, Electrical Heat Equivalent,** etc., **including Thermometers** $28.70

This comprises the following parts:

C 1471.	**Water-Jacketed Calorimeter,** complete	$ 7.00
C 1455.	**Tripod, Rod, and Collar**	2.00
C 1456.	**Boiler,** with water gauge	3.00
C 1457.	**Steam Heater,** with felt lagging	3.00
C 1458.	**Condenser**	2.50
C 1459.	**Water Trap**	.50
C 1461.	**Inner Vessel, with Rim**	1.50
C 1462.	**Nickeled Cooling Bottle**	1.00
C 1464.	**Electrical Heating Coil**	3.00
C 1466.	**Two Pieces of Metal,** @ 50c	1.00
C 1468.	**Two Special Calorimetric Thermometers** in 1/20°, @ $1.50	3.00
C 843.	**Two Thermometers,** @ 60c	1.20
		$28.70

Porter's Fresnel's Biprism Apparatus



C 1500

This consists of a conveniently mounted, light-tight wooden box, about 26 inches long, having a simple slit at one end, an eyepiece at the other, and a built-up biprism with adjusting screw in the middle. The interference fringes come into view when the instrument is pointed toward the sky, or toward a gas flame, and may be made very sharp and clear by turning the adjusting screw, which serves to bring the prism into parallelism with the slit.

C 1500. Porter's Fresnel's Biprism Apparatus .... $ 9.50

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