• C.J. Overbeck Northwestern University • R.R. Palmer Beloit College • Marsh W. White The Pennsylvania State University

SPECIFIC HEAT OF SOLIDS

OBJECT: To measure the specific heat of several solid specimens, using the method of mixtures.

METHOD: A hot solid specimen is dropped into a calorimeter containing cold water, and the temperature rise of the water and calorimeter is observed. The specific heats of the water and calorimeter are known. From these data and the measured masses, the heat absorbed by the water and calorimeter is determined. This heat is set equal to the heat given up by the hot specimen. From this equation the unknown specific heat is determined.

THEORY: Calorimetry means literally the "metering of calories"; it is thus the science of measuring quantities of heat.

Heat and Temperature: The fact cannot be too strongly emphasized that the terms *heat* and *temperature* mean completely different things. In popular parlance they are very frequently incorrectly used interchangeably, but it is desirable to differentiate between them in scientific and technical work. *Heat is a form of energy possessed by a body, while the temperature of a body determines the direction and rate of heat transfer between the body and its surroundings*. One body has a higher temperature than the other when heat energy flows from the former to the latter. Note that the body having the higher temperature does not necessarily have the greater amount of heat. Thus, if a small piece of hot iron be placed on a large block of iron at room temperature, heat will flow from the hot iron to the colder; the colder iron, however, contains a greater quantity of heat. This statement could easily be verified by successively placing each piece of iron in the same quantities of ice water and observing which one produced the greater heating of the water.

Units of Heat: Although it is now known that heat is a form of energy and hence could be measured in ordinary units of work, it has been found desirable to establish arbitrary units of heat which are based upon the effect of heat in changing the temperature of the universal substance water. In the metric system *the calorie is defined as the heat required to change the temperature of one gram of water by one degree centigrade*. The British unit of heat is *the British thermal unit (Btu), which is the heat necessary to change the temperature of one pound of water by one degree Fahrenheit*. (Hence 1 Btu = 454 x 5/9 calories.) These definitions of the calorie and the British thermal unit are only approximate, as the heat required to change the temperature of water differs somewhat at various temperatures.

Specific Heat: When experiments are made upon various substances, it is found that different amounts of heat are required to produce the same change in temperature in the same mass of different substances. For instance, if 100gm each of lead, iron, aluminum and water are heated to the same temperature, say 100°C, and dropped separately into equal masses of cold water, it will be found that the aluminum will raise the temperature of the cold water twice as much as the iron, the iron about three times as much as the lead, and the hot water about thirty times as much as the lead.
It is found by experience that the quantity of heat given out, or absorbed, while a body is undergoing a temperature change is directly proportional to the mass *m* of the body, directly proportional to the change in temperature $t_2 - t_1$ of the body, and depends upon the particular substance under investigation. Symbolically,

$$H \propto m$$
$$\propto (t_2 - t_1)$$

whence

$$H = mc(t_2 - t_1) \tag{1}$$

where the dimensional quantity *c* is determined by the units of the various quantities involved and by the thermal quality of the substance under consideration. It is called the "specific heat" of the substance and, as may be seen from Eq. (2), is numerically equal to the amount of heat required to change the temperature of unit mass of the substance one degree. Hence in the usual metric system *c* is numerically the heat in calories required to heat 1gm of a substance 1°C, while in the common British system *c* is numerically the heat in British thermal units required to change the temperature of 1lb. of a substance by 1°F.

Water Equivalent: The term *water equivalent* is a useful concept in calorimetric work. As the name suggests, it is the *mass of water* which will absorb or give up the same amount of heat in going through a given temperature change as the *body itself* would in going through the same temperature change. It is numerically equal to the product of the mass of the body by the specific heat of the substance of which the body is made.

Calorimetric Measurements: For different thermal measurements various types of calorimeters are used. One of the commonest and simplest of these consists of a thin polished vessel *K*, Fig. 1, of high thermal conductivity held centrally within an outer jacket *A* by means of a non-conducting support *H*. Thus conduction of heat is minimized,

Fig. 1. Simple design of Calorimeter.

while the "dead" air space between the inner and outer vessels helps to prevent heat transfers by convection currents. Radiation of heat is reduced by having the vessels highly polished. A wooden cover L minimizes convection currents above the calorimeter cup.

Method of Mixtures: In the determination of thermal constants, the method that is most commonly used is known as the "method of mixtures." This method is based upon the fact that if two or more bodies, originally at different temperatures, are placed in thermal contact and exchange of heat takes place exclusively between these bodies, the heat given up by one part of the system is equal to that gained by the other. One of the simplest experimental determinations of specific heat by the method of mixtures consists essentially in dropping a known mass of the specimen at a known high temperature into a known mass of water at a known low temperature and determining the resulting temperature. The heat absorbed by the water and the containing vessel can be easily computed and equated to the heat given up by the hot metal. From this equation the unknown specific heat can be computed.

Derivation of Working Equation: If m_s grams of the "unknown" specimen at a temperature t_1 be poured into a calorimeter of mass m_e and known specific heat c_s, containing m_ω grams of water at a temperature t_2, the temperature of the specimen will fall and that of the calorimeter and water will rise, so that the resulting mixture will finally come to some intermediate equilibrium temperature t_3. The change in temperature of the specimen (t_1 - t_3) and that of the water and calorimeter (t_3 - t_2). If no heat has been gained or lost from or to the surrounding objects, it follows that

Heat given off by specimen = heat gained by water + heat gained by calorimeter

Substituting the above symbolic values for these quantities there results the equation

$$c_s m_s (t_1 - t_3) = c_\omega m_\omega (t_3 - t_2) + c_e m_e (t_3 - t_2) \tag{3}$$

Solving for c_s gives a working equation in which all the quantities may be experimentally determined.

Errors Due to Heat Transfer: As previously stated, the working equation, as derived, holds true only as long as there is no heat transfer to or from the room. This condition is approximated by the use of a properly constructed calorimeter and by having the water at an initial temperature about as much below room temperature (say 2°) as the resulting mixture will be above room temperature after the specimen has been poured in. In this way the error due to the little heat that is gained from the room, while the temperature of the water is below room temperature, will be compensated for by the error due to heat lost to the room, while the temperature of the mixture is above room temperature. With reasonable care, the specific heat of substances can be determined by the method of mixtures with an error not exceeding one per cent. Comparisons of experimental values with those found in tables are often misleading on account of the wide variations in the purity and temperature of the materials used.

TABLE OF SPECIFIC HEATS

(Specific heats in calories per gram per degree centigrade)

Substance	Specific Heat	Substance	Specific Heat
Air (const. vol.)	0.168	Iron	0.11
Air (const. press.)	0.237	Lead	0.031
Alcohol	0.65	Mercury	0.033
Aluminum	0.22	Nickel	0.109
Brass	0.090	Platinum	0.0323
Copper	0.093	Steel	0.118
Ether	0.56	Tin	0.055
Glass, crown	0.16	Turpentine	0.46
Glass, flint	0.12	Water	1.000
Gold	0.031	Zinc	0.092
Ice, 0°C	0.5		

APPARATUS: Calorimeter (Fig. 1), double boiler for heating specimens (Fig. 2), Bunsen burner, lead, aluminum and copper specimens, thermometer 0-100˚C, thermometer 0-50˚C, glass rod to stir shot, large cork to cover boiler dipper, trip scales and weights, vessel for water, trays or pans for drying shot, and paper toweling are required.

PROCEDURE: Fill the boiler about one third full of water and start heating it. Be particularly careful throughout the progress of the experiment to keep enough water in the boiler so that it will show in the gage. Weigh out several hundred grams of dry lead shot, pour the shot into the cup, and place it in the boiler. Cover it with a cork. Heat the shot until the temperature is about 95˚C. It is best to use a separate thermometer in the shot and calorimeter. Keep the shot well stirred (it is expensive to use the thermometer for this).

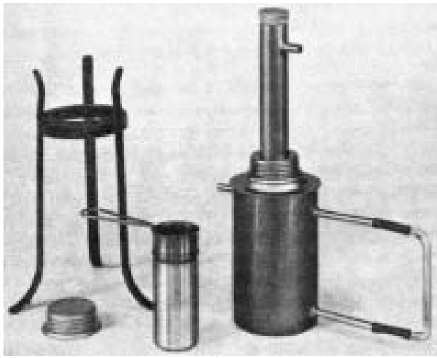

Fig. 2. Double boiler for heating specimen.

Weigh the inner vessel of the calorimeter (without the fiber ring but with the stirrer). Add about 100gm of water at about 2˚C below room temperature.

Having carefully observed the temperature of the water, quickly pour the hot shot into the calorimeter. Stir the shot with another stirrer. Be careful not to let the bulb of the thermometer get into the shot, but hold the bulb in the water. Note carefully the highest (equilibrium) temperature of the water. In all cases, estimate the readings of the thermometer between the division marks on the scale in order to obtain as accurate a reading as possible. Using Eq. (3), calculate the specific heat of the shot. Repeat, using a different metal. (If the results were not accurate, it is better to take other observations with the same material.)

Before leaving the laboratory pour out the shot onto the paper toweling in a pan to dry. Do not mix the wet shot in other pans containing dry shot. At the end of the period be sure to mop up all spilled water and leave things in good condition for the next group.

The data may be tabulated as follows:

Material of specimen……………………..			
m_1 *= mass of heater dipper…………………*			
m_2 *= mass of dipper and shot………………*			
m_s *= mass of shot……………………………*			
m_e *= mass of inner calorimeter vessel…….*			
m_3 *= mass of calorimeter and water……….*			
m_w *= mass of water…………………….......*			
t_1 *= temperature of hot shot………………...*			
t_2 *= initial temperature of water and calorimeter……………………………..*			
t_3 *= final temperature of water, shot and calorimeter…………………….........*			
c_w *= specific heat of water…………………...*			
c_c *= specific heat of calorimeter……………*			
c_s *= specific heat of specimen……………....*			
Percentage differences from value in tables……………………………….........			

QUESTIONS: 1. In a determination of specific heat, the temperature change of the hot shot was 80˚ ± 1˚C, and the temperature change of the water was 4.5. ± 0.2˚C. Compare the uncertainties which each of these factors introduced into the determination of the specific heat. What error, in grams, would be allowable in the measurement of the 300gm of shot in order that this uncertainty may be negligible in comparison with the others?

2. In an experiment on specific heat there is used a calorimeter of copper weighing 100gm and containing 200gm of water. What error is introduced by neglecting the heat capacity of the thermometer if it contains 0.8cc of mercury and 3gm of glass?

3. Justify the statement that the value of specific heat in calories per gram per decree centigrade is identical with the value in British thermal units per pound per degree Fahrenheit.

4. To measure the specific heat of a material, 300gm of water are used in a calorimeter of mass 200gm and specific heat 0.10cal/gm/˚C. If 500gm of the material are heated to 99˚C and the room temperature is 25˚C, what should be the initial temperature of the water so that the initial temperature will be as much below room temperature as the final temperature is above? (A preliminary rough experiment has indicated that the specific heat of the specimen is about 0.22cal/gm/˚C.)

5. A closed copper vessel of 300gm mass has a volume of 600cc and contains air at a pressure of 988cm of mercury. What is the water equivalent of the whole?

6. Look up, in some textbook or handbook, data on the specific heat of water, and plot a curve showing its variation from 0˚ to 100˚C.

7. In a typical experiment performed to measure the specific heat of metal shot by the method of mixtures the following data were obtained: mass of shot, 200gm; initial temperature of shot, 100˚C; mass of water, 100gm; mass of calorimeter, 100gm; specific heat of calorimeter, 0.1cal/gm/˚C; initial temperature of water, 16˚C. Calculate the specific heat of the shot from these data.