

HEAT OF VAPORIZATION

OBJECT: To measure the heat of vaporization of water, using the method of mixtures.

METHOD: The heat liberated by the condensation of steam is measured by allowing it to condense in cold water in a calorimeter. From the observed temperature change of the water and calorimeter and their known thermal capacities a working equation is set up in which all the quantities involved are known or measurable except the heat of vaporization, which is thereby determined.

THEORY: The evaporation of a liquid is a process in which the material changes state from the liquid to the vapor phase. A large quantity of heat is required to produce this change, this energy going into the potential energy of the molecular state and hot into kinetic energy. When a liquid is boiling, bubbles of its vapor are being formed throughout the volume of the liquid. These bubbles have a pressure within them which is equal to the maximum vapor pressure of the liquid at that temperature. When this pressure of saturated vapor is equal to the outside pressure, the liquid is said to be at its boiling temperature. For water this temperature is 100°C at a pressure of 76cm of mercury.

If a vessel of water has heat supplied to it at a constant rate, its temperature will steadily rise until the water begins to boil. While the water is boiling its temperature remains constant, even though heat is continually being supplied to it. This heat is being used to produce a change of state. The heat necessary to convert one gram of water from the liquid to the vapor phase (without a change of temperature) is about 540 calories. The heat of *condensation* of the vapor into the liquid state is identical with this heat of *vaporization*.

Heat of Vaporization: Technically, the heat of vaporization of a substance is defined as numerically the heat required to change unit mass of the substance from the liquid to the vapor phase (without a change of temperature). The defining equation is

$$L_v = H/M$$
 or $H = L_v M$ (1)

where L_v is the heat of vaporization and H is the heat necessary to change a substance of mass M from the liquid to the vapor state at constant temperature.

In the usual metric units L_v is expressed in calories per gram. In the British system the usual unit is the British thermal unit (Btu) per pound. Because of the manner of defining the calorie and the British thermal unit it follows that the *number* of British thermal units per pound is 9/5 times the number of calories per gram. For example, for water $L_v = 540 \times 9/5 = 972$ Btu per pound.

Measurement of L_v **by the Method of Mixtures**: The technique of the method of mixtures used in this experiment for the measurement of the heat of vaporization of water is based upon the assumption that no heat is gained from or lost to the surroundings, so that the heat transfers are confined to the materials in the calorimeter. The procedure is simply to allow a measurable mass of steam to condense in some cold water in a calorimeter and to observe the resulting increase in temperature of the water and the calorimeter.

Derivation of Working Equation: In deriving working equations for experiments utilizing the method of mixtures it is vital to be sure that every heat transfer is included. In the present case the word statement of the heat exchanges is

Heat given off by steam in condensing + heat given off by water formed by condensed steam = heat gained by cold water + heat gained by calorimeter

A symbolic equation for these terms is

$$L_{v}M_{s} + M_{s}C_{w}(t_{3} - t_{2}) = M_{w}c_{w}(t_{2} - t_{1}) + M_{c}c_{c}(t_{2} - t_{1})$$
⁽²⁾

where M_s = the mass of steam, M_w = mass of cold water, M_c = mass of calorimeter, C_w = specific heat of water, C_c = specific heat of calorimeter, t_1 = initial temperature of calorimeter and cold water, t_2 = final equilibrium temperature of water and calorimeter, t_3 = temperature of the hot water condensed from steam.

Since all of the factors in Eq. (2) except L_v are known or measurable, L_v may be calculated from the known and observed data.

Minimizing Errors Due to Heat Losses: The working equation is based upon the assumption that there are no heat losses or gains to or from the surroundings. This condition is approximated by the

Fig. 1. Simple form of Calorimeter

use of a properly constructed calorimeter and by adjusting the initial and final temperatures of the water in the calorimeter. The calorimeter (Fig. 1) consists of an inner vessel K, the calorimeter proper, made of aluminum (or sometimes copper) of high thermal conductivity, so that the vessel and its contents will quickly reach an equilibrium temperature. The inner vessel is kept from touching the outer jacket A by means of a non-conducting fiber ring H. Thus *conduction* of heat is reduced. *Convection* is minimized by the presence of the "dead" air space between the inner and outer vessels. To prevent *radiation* of heat, the vessels are made of polished metal. A wooden cover L reduces convection currents above the calorimeter cup. A stirrer of the same material as the calorimeter is used to stir the mixture. Its mass should be added to that of the calorimeter.

To further minimize heat losses arrange to have the original temperature of the water in the calorimeter as much lower than room temperature as the final equilibrium temperature will be above the temperature of the room. In this way the heat lost to the room while the temperature is above room temperature will be almost counterbalanced by the heat gained from the surroundings while the temperature is below room temperature.

There is often considerable error made because the "steam" admitted to the calorimeter contains some liquid water which has condensed en route from the boiler to the cold water. This error can be reduced by placing a trap, Fig. 2, as near as possible to the water, the design of the trap being such as to catch much of the condensed steam which would otherwise enter the calorimeter as water. Since each gram of this condensed steam would represent an error of 540 calories it is obvious that this source of uncertainty must be carefully avoided.



Fig. 2. Water Trap, to prevent drops of condensed steam from passing into the Calorimeter. The tube at the lower left is an outlet tube for drainage.

APPARATUS: Calorimeter (Fig. 1), water trap (Fig. 2), steam generator (Fig. 3), thermometer 0-50°C graduated in tenths, ice, Bunsen burner, balance with weights, vessels for ice and water, rubber tubing, pinch clamp, and barometer are required.



Fig. 3. Steam Generator

PROCEDURE: In a separate vessel cool some water, by means of ice, to about 5°C. Weigh the inner vessel of the calorimeter (without the ring). Add about 150gm of cold water (at about 5°C) to the calorimeter. When the water in the steam generator is boiling freely, stir the cold water, take its exact temperature in the calorimeter and begin passing steam from the boiler, through the trap, into the cold water. The rubber tube leading from the trap into the water should

be as short as conveniently possible. Continue stirring the water and watching the temperature, permitting the steam to enter until the temperature of the mixture in the calorimeter is as much above room temperature as the initial temperature was below the temperature of the room. Carefully measure the final temperature.

Weigh the calorimeter and contents and by subtraction from the former value, observed before the steam was admitted, the mass of the condensed steam is obtained. Calculate L_v from the working equation. To determine the boiling point of the water read the barometer and consult steam tables (boiling points versus pressures) for the temperature at that pressure. (Why is this better than using a thermometer?) Repeat the series of observations if time allows. Note the percentage difference between the average of the observed values of L_v and the standard value.

The data may be tabulated as follows:

| M _c = mass of calorimeter | _ |
|--|---|
| <i>M</i> ₁ = mass of calorimeter and cold water | |
| M _w = mass of cold water | |
| M_2 = mass of calorimeter and contents at end | |
| of experiment | |
| M _s = mass of steam | |
| c _w = specific heat of water | |
| c _s = specific heat of calorimeter | |
| t ₁ = temperature of cold water | |
| t ₂ = equilibrium temperature of calorimeter | |
| and contents at end of experiment | |
| B = barometer reading | |
| t ₃ = temperature of steam | |
| L_{y} = experimentally determined heat of | |
| vaporization | |
| Percentage error between experimentally | |
| determined and standard values of Ly | |

QUESTIONS: 1. Are burns caused by steam any more severe than those caused by hot water at the same temperature? Why?

2. Will potatoes cook faster (after the water has started boiling) if the flame under the vessel is increased? Why?

3. Explain why liquid air in a Dewar flask can maintain itself at a temperature of -191°C.

4. How much coal having a heat of combustion of 12,000 Btu/lb. is necessary to change 80kg of water at 20° to steam, if 75% of the energy is wasted in the process?

5. In the measurement of the heat of vaporization of water by the method of mixtures the following data were taken: 6.1gm of steam were admitted into a calorimeter weighing 125gm and containing 130gm of water at 20°C, the specific heat of the calorimeter being 0.10cal/gm/°C. The final temperature of the water was 45°C. Calculate the heat of vaporization of water from these data and note the percentage error from the standard value.

6. Two hundred grams of water in an aluminum calorimeter, mass 50gm, both at 20.0°C, are brought to 30.0° C by the introduction of some steam at standard atmospheric pressure. How much steam is required? How much ice at its melting point is required to bring the 200gm of water in the calorimeter at 30°C to 20.0°C? (The specific heat of aluminum = 0.22 cal/gm/°C.) What would be the best room temperature for the above experiment? Why?