

EXPERIMENT 2

THE CONSTANT-VOLUME AIR THERMOMETER

The pressure of air in the bulb of a constant-volume air thermometer is calibrated at various temperatures from the ice point of water to the steam point of water. From these data, the temperature in Celsius degrees corresponding to absolute zero is evaluated.

THEORY

When a gas is confined to a specific volume and is heated or cooled, the pressure exerted by the gas changes. This dependence of the pressure on temperature allows one to use the pressure value in order to measure temperature. In this case, the pressure is the thermometric property of the thermometer. If the pressure is relatively low and the temperature range to be measured is far from the temperature at which the gas liquefies, then the gas can be considered to be an ideal gas. In this case, the relationship between temperature and pressure is linear, that is,

$$P = \alpha T + b. \quad (1)$$

where T is the temperature and P is the pressure, and α and b are constants.

When the pressure versus temperature data is graphed, (1) indicates that this is a straight line. (Refer Figure 1.) By extrapolating the line to zero pressure, the temperature corresponding to absolute zero can be found. On the graph, this is represented by the position where the extrapolated pressure versus temperature line crosses the temperature axis. Absolute zero corresponds to a temperature of -273.15°C . (Note that the constant a in (1) represents the slope on the temperature versus pressure graph.)

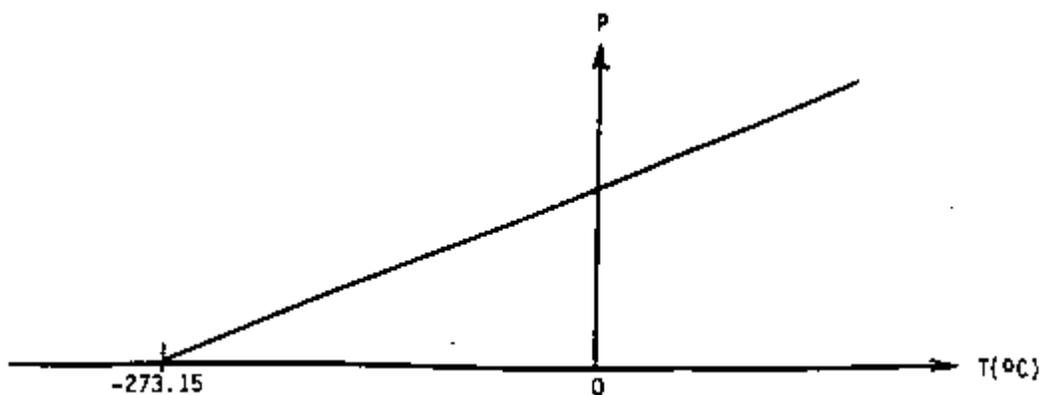


Figure 1. Graph of temperature versus pressure for an ideal gas.

A constant-volume air thermometer consists of a glass bulb filled with air and connected by a glass tube to one arm of a flexible U-tube filled with mercury. The other arm of the U-tube is open to the atmosphere and may be raised or lowered to adjust the mercury levels. The volume of the enclosed air is kept constant by adjusting the mercury level to a fixed position h_0 , on the side of the U-tube connected to the bulb. The bulb is immersed in water contained in a metal can, and the temperature of the confined air is varied by heating or cooling the water in the can. The variation of pressure with temperature is studied by measuring the pressure of the enclosed air at different temperatures.

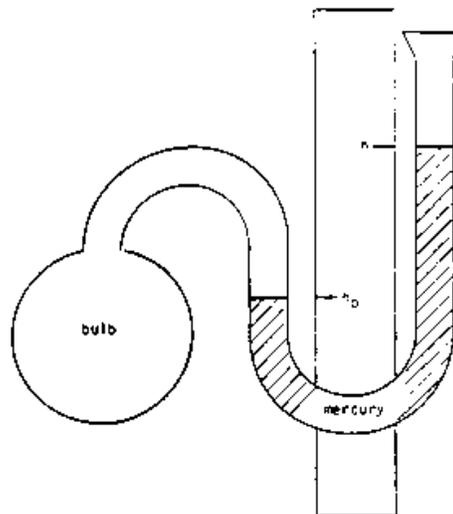


Figure 2. The constant-volume air thermometer

The pressure exerted by the air in the bulb may be calculated from the barometer reading of atmospheric pressure and the difference in the levels of the mercury in the two arms of the U-tube,

$$P = P_{atm} + (h - h_0), \quad (2)$$

where P_{atm} is atmospheric pressure in centimeters of mercury, and h_0 and h are the heights of the mercury columns in the U-tube in centimeters.

APPARATUS

- | | |
|-----------------------------------|---|
| o constant-volume air thermometer | o 0-100°C thermometer, $\pm 2\text{ C}^\circ$ |
| o electric hot plate | o stirring rod |
| o large metal container | o crushed ice |
| o ring stand | o ring clamp |

Be very careful when handling the constant-volume air thermometer. The constant-volume air thermometer consists of a mercury-filled U-shaped tube open to the atmosphere on the right side and connected to a glass bulb on the left side. Air is trapped inside the bulb, and the pressure inside the bulb can be varied by raising and lowering the right side. The bulb is placed inside a metal container filled with water which can be cooled by ice or heated with an electric hot plate. Do not use the thermometer as a stirring rod.

PROCEDURE

- a) Record atmospheric pressure in centimeters of mercury.
- b) Set up the apparatus as shown in Figure 3. The left side of the U-tube must be lowered until the bulb sits inside the metal container. When lowering the left side, the right side may also need to be lowered in order to prevent mercury from spilling into the bulb. Raise or lower the right side of the U-tube until the level of the mercury on the left side is located at a convenient and easily-read position on the scale. Record this value as the reference height, h_0 , and estimate the uncertainty in this reading, Δh .
- c) Fill the metal container with ice and pour water into the container until the ice-water mixture covers the bulb. Stir the mixture. The ice-water mixture lowers the pressure in the bulb by lowering the temperature of the air in the bulb, and thus, the level of mercury in the left side of the U-tube will rise. When the level of mercury in the left side no longer changes, the temperature of the air in the bulb is at approximately 0°C . Adjust the right side of the U-tube until the left side is again at the reference level, h_0 . Record the temperature with the thermometer. Record the height, h , of the mercury level on the right side and its uncertainty, Δh . The uncertainty of this reading should be the same as Δh .
- d) Empty the ice-water mixture and replace with water from the tap. Add ice to the water or heat the water with the bunsen burner until the temperature of the water is approximately 20°C . Wait until thermal equilibrium is established. Raise the right side of the U-tube until the level in the left side is again at the reference level, h_0 . Record the temperature and the height of the mercury column on the right side.
- e) Continue in the above manner, raising the temperature of the water in 20°C increments until the boiling point is reached. (Be very careful as the temperature is raised.)
- f) Allow the apparatus to cool before dismantling.

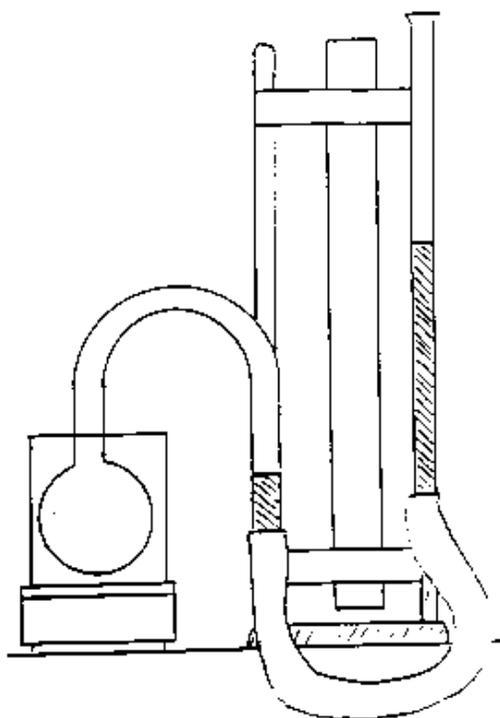


Figure 3. The experimental arrangement.

ANALYSIS

For each temperature at which measurements were made, calculate the pressure of the air in the bulb using (2). Also find the uncertainty in the pressure values. Clearly show the calculations that were performed.

Construct a graph with temperature in Celsius degrees as the abscissa and, pressure in centimeters of mercury as the ordinate. Plot the values of $P \pm \Delta P$ against $T \pm \Delta T$. Each data point is no longer a point with error bars, but a point with error boxes.

Draw two lines through the data boxes, one with maximum slope and one with minimum slope. Calculate the values of these slopes and label them as α_{\max} and α_{\min} (Use these values together with (1) to find the experimental maximum and minimum values of absolute zero, b_{\max} and b_{\min}). Also calculate the best experimental value of absolute zero. Report these values in a table.

On a one-dimensional graph, plot the experimental range of absolute zero and the true value. Displace the true value vertically above the values from the experimental range.

QUESTIONS

1. When using the constant-volume air thermometer to measure temperature, (1) holds. What do the constants a and b represent? (Don't just say slope and intercept.)
2. Because the bulb also expands upon heating, the volume of air in the bulb is not held constant. Explain how the expansion of the bulb affects the determination of the temperature corresponding to absolute zero. That is, does the experimental value of absolute zero increase, decrease, or remain the same. Explain.
3. Some of the air considered to be in the bulb is actually in the tube connecting the bulb to the manometer. This air is then not at the same temperature as the air in the bulb. If the air in the bulb is at a higher temperature than the air in the connecting tube, is the experimental pressure higher or lower than the value it should be? Explain.