

Chapter 1

Gas Thermometer and Absolute Zero

Name:_____ Lab Partner:_____ Section:_____

1.1 Purpose

Construct a temperature scale and determine absolute zero temperature (the temperature at which molecular motion ceases).

1.2 Introduction

Temperature is an important property of physical systems. It was not well understood until the late 19th century. Today there are many different types of temperature-measuring devices. In this lab we will experiment with one of the oldest but most straightforward thermometers, a copper bulb containing a gas. The bulb's temperature is determined from the pressure of the enclosed gas. We will then construct a temperature scale and determine the absolute zero temperature at which molecular motion ceases.

1.2.1 Linear Temperature Response

Let X be any thermometric property that varies linearly with temperature. X can be the length of a metal rod, the height of a column of mercury, the electrical resistance of a wire, the pressure of a gas, etc.

$$X \propto T \tag{1.1}$$

Since X has linear variation with T , a plot of X versus T is a straight line:

$$X = C \cdot T + X_0 \tag{1.2}$$

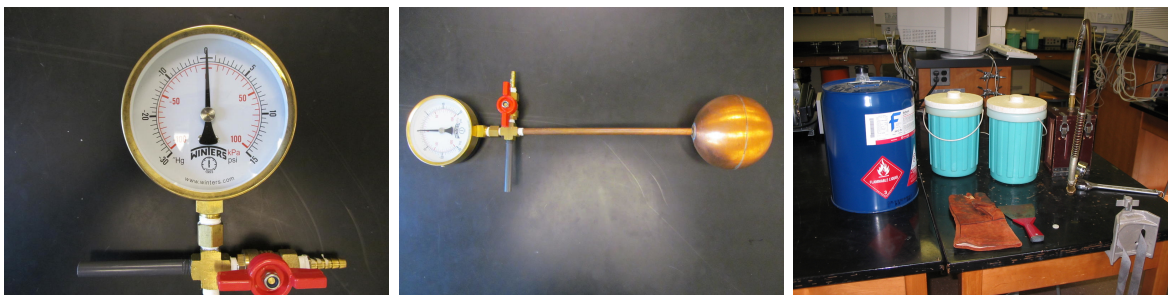


Figure 1.1: The pressure gauge on the gas thermometer, the gas thermometer and the temperature bath equipment

The Pascal:	1 Pa = 1 N/m ²	1 atm = 1.01 x 10 ⁵ Pa
The Torr:	1 Torr = 1 mm Hg	1 atm = 760 Torr
The lb/in ² (psi)	1 lb/in ² = 6870.8 Pa	1 atm = 14.7 lb/in ²

Table 1.1: Units for pressure

where C is the slope of the X -versus- T line. In the Celsius temperature scale, the slope is calculated using the melting temperature for ice and the boiling temperature for water. Hence:

$$C = \frac{X_{boil} - X_{melt}}{T_{boil} - T_{melt}} \quad (1.3)$$

X_0 is the value of X at $T=0$. In the Celsius scale, $T = 0$ is defined to be at T_{melt} .

1.2.2 Gas Thermometer

Shown in Figure 1.1 is the gas thermometer which consists of a hollow spherical tank filled with helium and connected to an absolute pressure gauge. Also shown is the equipment for the four temperature baths

Pressure is the force per unit area that the gas molecules exert on the container as they collide with the walls of the container. Pressure in this experiment will be measured in kPa (1 Kilopascal = 10^3 Pa). A table of common pressure units is shown in Table 1.1.

In a gas bulb thermometer the thermometric property (X) used is the pressure, p , of gas kept at constant volume, $V_{constant}$, by the copper bulb. p increases with temperature, T , according to the ideal gas law:

$$pV_{constant} = nRT \quad (1.4)$$

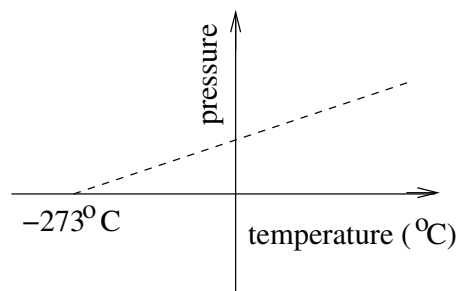


Figure 1.2: Plot of temperature vs pressure for an ideal gas.

Equation 1.4 displays the proportionality between p and T shown in equation 1.1. We can rewrite equation 1.4 as

$$p\left(\frac{V_{constant}}{nR}\right) = T \quad (1.5)$$

This relation is known as Charles' Law. Comparing equations 1.5 and 1.2, we note that

$$C = \frac{nR}{V_{constant}} \quad (1.6)$$

$$X_0 = 0 \quad (1.7)$$

The temperature scale implied in equation 1.4 is significant. In this scale, $p=0$ occurs at $T=0$. This temperature scale is the absolute zero or Kelvin scale.

1.2.3 Absolute Zero

As temperature decreases, molecular velocities decrease. Absolute zero is that temperature for which the molecular velocities reach zero and molecular motion ceases. Figure 1.2 displays the p versus T behavior of equation 1.4: as $p \rightarrow 0$, $T \rightarrow$ absolute zero.

1.3 Procedure

In this experiment we will show the linear dependence of p on T for the gas bulb thermometer. We will also find the numerical value (in degrees Celsius) of absolute zero temperature.

Special Cautions:

- The temperature of liquid nitrogen is 77K (-196°C). Direct contact with skin will burn.
- Do not exceed pressures of 140 kPa in the gas thermometer. Hold the handle firmly while it is in the temperature baths.

	Measurement 1	Measurement 2	Measurement 3	Measurement 4
Initial Gauge Reading				
Initial Absolute Pressure				
Liquid Nitrogen				
Solid CO ₂				
Ice Water				
Boiling Water				

Table 1.2: Table of measurements

- Let the bulb return to room temperature before changing the pressure.

Up to a pressure of ≈ 140 kPa helium behaves as an ideal gas, i.e. the helium molecules collide elastically. At higher pressures molecular collisions are inelastic and p is not linear with T .

Note the pressure gauge on the gas thermometer. The inner red scale is calibrated in kPa. However, with many pressure gauges, the scale is from -100 kPa (vacuum or absolute pressure of zero) to +100 kPa. The zero on the scale corresponds to 1 atmosphere of pressure (an absolute pressure of 101 kPa). To change a gauge reading to absolute pressure **add 100 kPa to the gauge reading**.

- Evacuate the bulb thermometer using the vacuum pump and then fill it with helium to a gauge pressure reading of 40 kPa (an absolute pressure of 140 kPa). Record the pressure gauge reading and the absolute pressure in kPa in Table 1.2.
- Four liquid baths provide constant temperatures for the bulb thermometer experiment. The temperature bath liquids and temperatures are:

Bath	Kelvin (K)	Celsius ($^{\circ}\text{C}$)
Liquid Nitrogen	77	-196
Solid CO ₂	201	-72
Ice Water	273	0
Boiling Water	373	100

- Place the bulb thermometer in each of the four baths beginning with the liquid nitrogen and ending with the boiling water. This avoids formation of a layer of ice around the bulb that would result from first placing the bulb in water and then into CO₂ or liquid nitrogen. Jiggle the bulb around the bath until it reaches thermal equilibrium. Record the reading of the **absolute** pressure in each bath in the data table as measurement 1 in table 1.2.
- Repeat the above procedures for initial bulb absolute pressures of 128 kPa (gauge reading 28 kPa), 114 kPa (gauge reading of 14), and 101 kPa (gauge reading of 0 kPa). By changing the initial pressure, we are changing n , the number of moles of gas in the bulb. Be sure to allow the bulb to return to room temperature before changing the initial pressure. Record your data in table 1.2.

- Plot p versus T (Celsius) for each of the four different initial pressures. This will result in four different calibration lines. Draw a visual linear fit to the plotted points at each pressure.
- Extrapolate each fit line to intercept the temperature axis. All four lines should intercept at approximately the same temperature, T_0 . Calculate the average of the four T_0 values, \bar{T}_0 . Find the percentage error between \bar{T}_0 and the standard value of absolute zero, -273°C .

Average T_0 _____
 Percentage Error for T_0 _____

- As an application of the thermometer you have just calibrated, measure the temperature of the room by using the initial absolute pressure of the gas that you put into the bulb for each measurement. Combine the four measurements together to get an average value for the room temperature:

Average T_{room} _____

Is this value reasonable?

1.3.1 Questions

1. The copper bulb has a radius of 0.05 meters. When the bulb is filled to 101 kPa, there are ≈ 0.021 moles of gas in the bulb. Using the slope of the pressure vs temperature plot, estimate the ideal gas constant (R). Calculate the percentage error with the standard value for R of $8.315 \frac{\text{J}}{\text{molK}}$. Be sure to convert the pressure to Pascal and the temperature to Kelvin

1.4 Conclusion

Write a detailed conclusion about what you have learned. Include all relevant numbers you have measured with errors. Sources of error should also be included.

