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PHYS 231 Lab Exercise: Absolute Zero

Objective: To demonstrate that the pressure of a gas varies linearly with temperature. And to determine the temperature of absolute zero on the Celsius scale.

Introduction: We usually think of temperature as a measure of "hotness" and "coldness," but in terms of the kinetic theory of gases, temperature is a measure of the average kinetic energy of particles in a physical system. It is a "dimension" of the physical system, the same way length, time, or mass are dimensions.

Consider a *system* consisting of air in a container and imagine if you reduced the average kinetic energy of the particles in the system by cooling the air. If your method of cooling the air was extremely efficient, you might eventually be able to reduce the temperature to near *absolute zero* or 0K[3], at which point the particles would have very little kinetic energy, and thus could exert little pressure on any container walls. If instead of cooling the air, you raise the temperature, you would expect the air pressure to rise (assuming constant volume). In this exercise, you will explore the dependence of the pressure of air in a glass bulb as it depends on temperature to see if the *ideal gas law* holds true. You will also use the ideal gas law to estimate the temperature on the Celsius scale of absolute zero.

One version of the *ideal gas law* states:

$$PV = nRT.$$

Notice that for a constant volume container and a fixed amount of gas, the temperature and pressure are proportional to one another

$$P \propto T, \text{ for constant } V \text{ and } n$$

Thus, ***if the ideal gas law holds true, a plot of pressure versus temperature for this system should be a straight line.***

For this exercise, temperatures are measured with a digital thermometer. Pressure is measured using a *strain gauge*, a device in which a flexible membrane moves in response to changing pressure. One side of the membrane is a vacuum and other is exposed to your gas sample. The pressure sensor reports an output voltage that varies in an almost perfectly linear way with pressure and it would therefore be zero if the absolute pressure were truly zero. This pressure sensor is housed in the little black box above the glass tube.

Apparatus:

large beakers, a support stand with various clamps, a digital thermometer, strain gauge pressure sensor, a Bunsen burner, matches, crushed ice, & a supply of water.

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[3] Recall that the Kelvin temperature scale is defined such that 0 Kelvin is defined to be the temperature at which both pressure of a gas drop to zero.

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Procedure: **Part I: Preparations and Calibrations**

a) Begin by plugging in the voltmeter and the black power supply for the pressure sensor. Turn on the voltmeter and be sure it is set to read "DC" voltage. You should get a reading of about 0.5 volts for about 1 atmosphere of pressure. Remember, this voltmeter merely displays the output voltage delivered to it by the pressure sensor and the displayed value is not the value of the pressure but is instead a number (nearly) directly proportional to it. **For this experiment, assume the voltage is a directly proportional of the pressure.**

b) To calibrate the voltage readings to pressure, first record the voltage on the pressure gauge when it is exposed to the atmosphere. Go to the barometer in the back of the room and record the air pressure (in mm of Mercury) at room temperature. Using the conversion factor of 1 mm Hg = 133 Pa, convert the air pressure into units of Pa.

c) Compute a conversion factor (in Pa/V) between air pressure and voltage readings by dividing the air pressure at room temperature by the voltage. Record this conversion factor and use it to convert all your future voltage readings into pressure.

d) Open the little blue valve on the bulb to allow the atmosphere into the glass bulb. Once you have done this, close the blue valve to trap a particular sample of air in the bulb. You will be holding this air in a constant volume (the bulb) for the rest of today's lab.

Part II: Initial Cooling of the Trapped Air

a) Very gently pack the bulb into the beaker surrounded and covered as best you can with cubed ice.

b) Insert the thermometer into the ice packing. **Try to keep the thermometer near the middle of the bulb for the remainder of the experiment.**

c) Wait a few moments until equilibrium is established and record the values of temperature and voltage in a two-column data table (either on the data sheet or in *Excel*). Add a third column and record the corresponding pressures for the voltages. **Record all temperatures in Celsius degrees!**

Part III: Slowly Heating the Trapped Air

a) Carefully remove the bulb from the beaker of ice (by raising the bulb mount).

b) Pour the ice into a spare beaker, and then fill the original beaker two-thirds or so with water.

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c) Put the bulb in the water bath and adjust its temperature (perhaps adding ice) so that it is about 10˚C. Record the temperature and the voltage (remember that voltage is representing pressure in this lab).

d) With the book of matches provided, start the Bunsen burner and introduce heat. Continue heating the bulb, taking readings of the temperature and voltage roughly every 10 degrees until the water is about to boil. **As the temperature rises, you must take the recordings on the fly, so be prepared.**

Part IV: Shutting Down The Equipment

a) Having recorded the data, switch off the Bunsen burner. Do this by turning off the gas at the source.

SAFETY WARNING: TO TURN OFF THE BUNSEN BURNER DO NOT JUST BLOW OUT THE FLAME. THIS WILL ESSENTIALLY RESULT IN A NATURAL GAS LEAK.

b) Turn off the voltmeter, and then unplug the voltmeter and the pressure sensor.

Part V: Data Analysis

Using *Excel*, make a plot of pressure versus the temperature on a Celsius scale. Even though you do not have data much below 0˚C (assuming the ice was at 0˚C), prepare the left edge of the *x*-axis to accommodate temperature all the way down to about –300˚C (you may need to double click on the x-axis and adjust the scale to get this to work).

Now address the following questions.

a) Does the air in the bulb seem to exhibit ideal gas behavior? That is, *do you see a linear relationship between Pressure and Temperature?*

b) If it's linear, use the trendline tool in *Excel* to fit a straight line to your data?

1. Give the value of the slope of your best-fit line (including units) and a brief explanation of what the physical interpretation of the slope is.

2. What is the value of the *y*-intercept of your best-fit line (including units)? *Also provide a brief explanation of what the physical interpretation of the y-intercept is in this case.*

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c) On your graph, extrapolate your line into the region of negative Celsius temperatures and estimate the *x*-intercept. This is an estimate of absolute zero, be sure you understand <u>why</u> this is the case. *Record your estimate below.*

d) Noting that the trendline from problem 2 is fitting the equation $y = mx + b$, where y is the pressure, x is the temperature, m is the slope, and b is the y-intercept. From this equation, estimate the temperature absolute zero by setting $y = 0$ and solving for x. *Show your work and record your estimate for the temperature of absolute zero (in Celsius) below.* How does it compare to your estimate using the graphical method?

e) For both your estimates of absolute zero, compute difference between the result and the theoretical value of absolute zero (-273.15˚C). How well does this experiment support the ideal gas law?

<u>Discussion:</u> Please consider the following questions:

a) What property of matter is critical to most thermometers?

b) What is meant by the statement that "a thermometer measures its own temperature"?

c) Which is larger: 1˚F, 1˚C, or 1K?

d) Why are there no negative numbers on the Kelvin temperature scale?

e) In your experiment, the volume occupied by the gas is fixed. By raising the temperature of the gas you cause the pressure to increase. Explain these changes in pressure using the kinetic theory of gases.

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DATA SHEET

(You may record the data in an *Excel* spreadsheet if you prefer, but please record the same data)

Room Temperature, T (˚C): _____________________

Voltage reading at room temperature, V: _____________________

Atmosphere pressure, P_{atm} : ____________ (in mm Hg) _____________ (in Pa)

Conversion factor between voltage and pressure: _____________________ (in Pa/V)

Temperature (˚C)	Voltage (V)	Pressure (Pa)