

Ideal Gas and Latent Heat

Objectives:

- To understand the significance of the ideal gas law.
- To determine the value of absolute zero on the Centigrade scale.
- To design an experiment to measure the latent heat of melting of ice

Equipment: Hollow metal bulb with pressure gauge and large thermometer, stirring rod for containers, hot plate, metal container, plastic container, ice, beaker, ball of twine. Styrofoam cup, computer temperature probe.

Background:

Absolute Zero: On the Centigrade temperature scale $T = 0$ is the melting temperature of ice. This point is arbitrarily chosen. We could just as well have set $T = 0$ at the boiling point of water. However, there is one temperature that has important physical meaning and is a logical point to call zero. This point is called **absolute zero** (T_0) and is the temperature at which all thermal motion stops, **-273° C**. A body cannot be cooled below absolute zero. (In practice, matter cannot be cooled all the way to absolute zero, although temperatures within about .000001 degree of absolute zero have been reached.)

The **Kelvin temperature scale** is based on absolute zero, $T_0(\text{Kelvin}) = 0^\circ \text{K}$. The size of the degree for the Kelvin scale is the same as the Centigrade degree and the two scales are related by the equation:

$$T(\text{K}) = T(\text{C}) + 273.$$

The pressure that a gas exerts on the walls of a container is caused by the collisions of the gas molecules with the wall. As the gas is cooled, the molecular speed decreases, the force of the collisions with the walls decreases and the pressure drops. At absolute zero the motion ceases and the pressure drops to zero. According to the ideal gas law, for a constant volume of gas, the pressure is linearly related to temperature:

$$P = \frac{nR}{V}T,$$

where n is the number of moles of gas in the volume V and $R = 8.31 \text{ J/mole.K}$ is the universal gas constant. [A mole is the quantity of material whose mass in grams is numerically equal to its molecular mass (weight). One mole contains 6×10^{23} particles.] In this lab you will measure the pressure P of a container of gas at several temperatures T and extrapolate to zero pressure to estimate the value of absolute temperature.

Latent Heat. The latent heat is defined as the amount of heat needed to melt a unit amount of material from its solid state to liquid state. It's often given in units of J/kg. You will measure the latent heat of ice by melting it in a cup of warm water. When the ice of mass M at temperature T_{ice} is added to the water of mass m at temperature T_i and completely melts, the final temperature of the whole system decreases to T_f . Then, applying conservation of energy the heat added to M equals the heat released by m :

$$\begin{aligned} \text{Heat (added to ice)} &= \text{Heat(given up by water)} \\ c_{ice} M (0 - T_{ice}) + L M + c_{water} M (T_f - 0) &= c_{water} m (T_i - T_f), \end{aligned}$$

where L is the latent heat of ice per unit mass, c_{ice} is the specific heat of ice and c_{water} is the specific heat of water.

Activity 1.

Experimentally determine the value of absolute zero T_0 in $^{\circ}\text{C}$.

A. With the pressure bulb at room temperature carefully record the temperature and pressure. Then immerse the bulb in ice water so that at least two inches of water cover the top of the bulb. After the bulb has cooled, record the temperature and pressure. Repeat for very hot water and several intermediate temperatures.

B. Enter your temperature-pressure data into the data sheet in the program "Graphical Analysis". Have the program plot your data and make a best straight line fit to your data. Reread the appendix "graphing" in Newton's Second Law lab and reformat your graph to clearly convey as much information as possible about your experiment. Print copies of your data sheet and graph for yourself and your partners.

C. From the plot of the best fit determine the temperature in Centigrade where the pressure of the gas goes to zero. This is your estimate of absolute zero. What is the percent discrepancy with the accepted value of -273°C ? Estimate your experimental error by deleting one or more data points in your graph (keep at least two) and see how much the Graphical Analysis fit changes.

Activity 2.

A. What is the significance of the slope of the graph you obtained in Activity 1?

B. Estimate the number of moles and the mass of the air in the metal pressure bulb and use this estimate to get a theoretical value for the slope of the graph from Activity 1. [Air is 21% oxygen and 79% other gases, mostly nitrogen. Use the average molecular weight in your calculation.]

Activity 3.

The latent heat of melting of ice. Given a cup of "warm" water at an initial temperature T_i and a piece of ice at $T_{ice} = 0^{\circ}\text{C}$, create an experimental procedure to measure the latent heat of ice. State carefully what quantities you need to measure. State the conditions under which the quantities are to be measured. Express the latent heat to be measured in terms of the measured quantities.

Ideal Gas and Latent Heat (preliminary questions)

Name: _____ Section: _____

1. Estimate the number of air molecules in the classroom of this lab. Assume the dimensions are 15m x 15 m x 4 m. (Do not use the density of air in this step. The density will be determined in step 2.) How many moles is this?

2. Use your answer to question 1 to estimate the density of the air in the lab in kg/m^3 . (The mass of one mole of air is $0.21 \times 32 \text{ gram} + 0.79 \times 28 \text{ gram}$)

3. The specific heat of air is $22 \text{ J}/(\text{mole}\cdot\text{C}^\circ)$. How much energy would be required to increase the air temperature in the lab by 3°C ?

4. 40 cc of milk at 5°C is added to 100 cc of coffee at 60°C . If the specific heat of milk is $3.5 \text{ J}/\text{g}\cdot^\circ\text{C}$ and the density of milk is $1.1 \text{ g}/\text{cc}$, what is the final temperature of the coffee?

Report -- Ideal Gas and Latent Heat

Name: _____ Section: _____
Partner: _____ Partner: _____

Activity 1: Absolute zero.

A. (Carefull, Hot Plate Requires a Metal Container, NOT a Plastic Container!)

Record your P versus T data in the table below. Note that some P-indicators have an unusual scale division. Choose T in roughly 5 degree intervals. You will need all the spaces of the table since you will have at least 15 temperatures. Be sure to label the entries and indicate the units.

T(C) -- P(mm Hg)			

B. Using “Graphical Analysis”, make a plot of P versus T. Include proper axis-labels with units. Give the graph a title. Be sure to extend the T axis (and P axis) to low enough negative temperatures to include absolute zero T_0 .

Make a linear fit to the data, reformat your graph to be as informative as possible, and print copies of the graph for yourself and your partners.

C. Estimate the error in T_0 by selectively deleting points and recording how the fit changes.

# of points fitted	T_0

Also record the value of T_0 found in part B with error and units.

$T_0 =$ _____ \pm _____ Centigrade

Activity 2.

A. What is the significance of the slope of the graph?

B. Measure the circumference of the bulb with a piece of twine.
Estimated volume of the metal bulb: _____

Estimated number of moles of air in the metal bulb: _____

Show your work for these estimations.

Theoretical slope of the graph (from gas law): _____

Observed slope of the graph: _____

Show your work.

Estimated mass of air in the metal bulb: _____

Activity 3.

Given a cup, water, ice, computer temperature probe, design an experiment to measure **the latent heat of melting of ice.**

If using a glass thermometer, be extra carefull not to break it!!!!

Which quantities do you need to measure.

Indicate the order in which each quantity needs to be measured. For example, the mass of the ice must be measured before it melts, but not too early, since the ice keeps melting.

NOTE—If you put too much ice (or too little water), the ice will not all melt, as intended.

STEPS OF PROCEDURE:

Quantities to be measured	symbol	how to measure it and in which sequence
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1.

2.

3.

4.

5.

6.

How are the above quantities related?

Find the latent heat of ice (in units of J/kg)?