Name ____

POGIL ACTIVITY 4
Gas Laws and Temperature Scales

A. Units of Measurement for Quantity, Pressure and Temperature

1. Quantity

In scientific disciplines, the amount of substance is measured by **mass** or **moles**. To measure mass, common metric mass units are used. The other measurement for quantity is the **mole.** A mole is a collection of particles, similar to a dozen. Just as a dozen represents a number (12 items), a mole represents a number, a very large number. One mole is equal to **6.02×10^{23} particles**. For example, one mole of neon gas contains 6.02×10^{23} neon atoms; one mole of water contains 6.02×10^{23} water molecules.

Quantities are given using either unit, for example, one mole of water has a mass of 18 g. In other words, **amounts can be measured by weight or by counting the number of particles in the sample:**

18 g of water = 6 020 000 000 000 000 000 000 000 = 6.02×10^{23} molecules

The term **molar mass** embodies the relationship between mass and moles. For example, based on the example for water, the molar mass of water is 18 grams per mole (g/mol). *This activity will not explore the mole concept beyond the definitions stated above.*

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2. Pressure

Pressure is defined as a force per unit area. SI units of pressure are atmospheres (atm). Other common units of pressure include: millimeters of mercury (mmHg), torr, inches of mercury (inHg) and pounds per square inch (psi).

Consider placing a 15-pound weight on the last digit of your thumb which has an area of about one square inch; you would experience a pressure of 15 psi. This is approximately the same pressure exerted by a column of air, from sea level to the top of the earth's atmosphere (one atm), under normal atmospheric conditions. More precisely, one atm is equal to 14.7 psi.

There are several units for pressure. The relationship between atm and the most common units are given here. Each mathematical relationship can be used to derive a conversion factor between the various units.

1 atm = 14.7 psi = 29.9 inHg 760 mmHg = 760 torr

3. Temperature

Temperature is a measure of the average kinetic energy of a system or sample. As sample particles collide with the bulb on a thermometer, their kinetic energy is transformed into heat which causes a column of liquid to expand. The liquid is usually mercury or alcohol, both of which expand with heat.

Critical Thinking Questions

CTQ 1

Indicate the type of equipment or device that can be used to measure the following:

a. Temperature ____
b. Volume ____
c. Pressure ____
d. Moles ____
e. Length ____
f. Area ____

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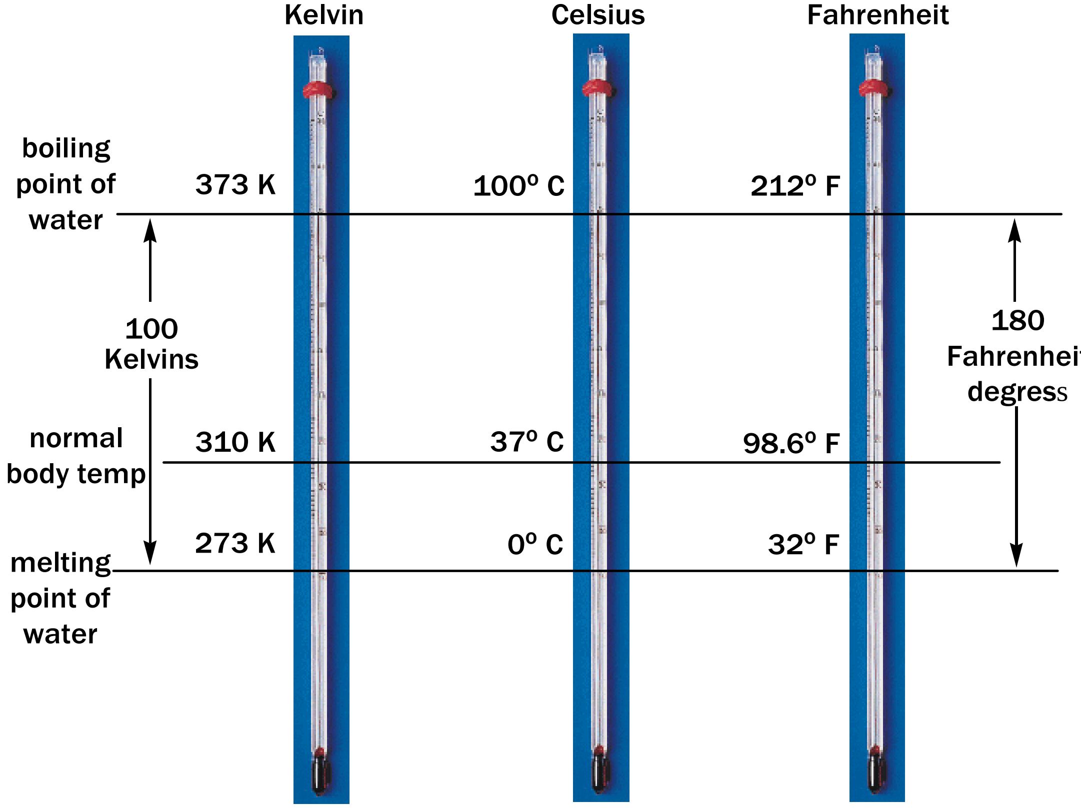
B. Temperature Scales

Temperature is measured using three different scales: Fahrenheit, Celsius and Kelvin. Kelvin is the SI unit for temperature; Celsius is the most widely used temperature scale whereas Fahrenheit is mainly restricted to the U.S. and Britain.

Figure 1. Three Temperature Scales



CTQ 2

Which temp scale does not use the degree sign (°) ?

CTQ 3

For each scale, how many degrees are there between m.p. and b.p. for water?

Celsius = __________ degrees

Fahrenheit = __________ degrees

Kelvin = __________ kelvins

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CTQ 4

How is the size of a single Kelvin related to the size of a single degree Celsius; is it larger, smaller, or the same? Answer using a grammatically complete sentence.

CTQ 5

Derive an equation for converting from Kelvin to Celsius.

°C= ______________________

Information

There are 3 female students in room A and 7 male students in room B. The gender ratio is:

$$\frac{3\text{ F}}{7\text{ M}} \text{ or } \frac{7\text{ M}}{3\text{ F}}$$

CTQ 6

How is the size of a single degree Celsius related to the size of a single degree Fahrenheit; is it larger, smaller, or the same? Answer using a complete sentence.

CTQ 7

Derive reciprocal ratios for the relationship between degrees Celsius and degrees Fahrenheit. (This fraction can be used as a conversion factor.)

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Information

To convert temperatures between Celsius and Fahrenheit, both temperatures must be at the same reference point; for example, the freezing point of water in Fahrenheit and Celsius is 32°C and 0°C, respectively.

To convert from °C to °F, first use the conversion factor, then add 32.
To convert from °F to °C, first subtract 32 from °F then use the conversion factor.

CTQ 8

Derive an equation for converting from °C to °F

CTQ 9

Derive an equation for converting from °F to °C

CTQ 10

Convert the following:

a. Convert 23.5°C to °F

b. Normal body temperature is 98.6°F. Convert to °C

c. Convert -19.5 °F to °C

d. Convert -40°C to °F

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C. Gas Laws

Any gas can be characterized by some combination of pressure **(P)**, volume **(V)**, temperature **(T)** and the amount of gas expressed in moles **(n)**. Moles can be readily calculated if the mass of a sample is known.

In the following discussion, a sample of gas refers to a fixed quantity of gas and if no gas is added or removed from the sample, then mathematically speaking, (n) is a constant (unchanged).

A mathematical constant, represented by a variable, is number whose value does not change; it is a constant value.

A constant may refer to any one of the characteristics of a gas (P, V, T, n) whose value remains unchanged. Or a constant may refer to a number that does not have a meaningful interpretation (such as k) and simply serves to facilitate rearranging a mathematical expression into a more useful form.

If the amount (n) of a sample of gas does not change, then a gas is described by only three variables, P,V and T.

Two empirical gas laws describe the change in volume when pressure is changed (**Boyle's Law)** or when temperature is changed (**Charles' Law**). **The Combined Gas Law** collects all three variables into one equation.

1. Boyle's Law

Boyle's Law states that volume (V) is inversely proportional to pressure (P) as long as T and n do not change. This inverse relationship is expressed as:

$V \sim 1/P$ **(when n, T constant)**

A mathematical constant is used to rearrange the two variables into an equality known as Boyle's Law:

$PV = k$ **(n, T constant) Boyle's Law**

If either variable is changed, the new PV value is still equal to the same constant (k); thus, we can set initial conditions (subscript 1) equal to final conditions (subscript 2):

$P_1V_1 = P_2V_2$ **(n, T constant) another form of Boyle's Law**

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CTQ 11

Consider this form of Boyle's Law, $PV = k$ (n, T constant). Since k is a constant,

a. What is the change in volume if pressure is doubled?

V is unchanged   V is doubled   V decreases by one-half

b. What is the change in P if V is doubled?

P is unchanged   P is doubled   P decreases by one-half

CTQ 12

Consider this form of Boyle's Law, $P_1V_1 = P_2V_2$ (n, T constant).

What is the change in P_2 if V_1 is doubled?

P_2 is unchanged P_2 is doubled P_2 decreases by half

CTQ 13

What happens to k when:

a. P is increased and V is decreased? k increases   k decreases   k is unchanged

b. P is increased and V is increased? k increases   k decreases   k is unchanged

c. P is decreased and V is decreased? k increases   k decreases   k is unchanged

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2. Charles' Law

Charles' Law states that volume (V) is directly proportional to temperature (T) as long as (n) and (P) do not change. This direct relationship is expressed as:

V ~ T (n, P constant)

A mathematical constant is used to rearrange the two variables into an equality known as Charles' Law:

V/T = k (n, P constant) Charles' Law

If either variable is changed, the new quotient is still equal to the same constant (k); thus, we can set initial conditions (subscript 1) equal to final conditions (subscript 2):

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{(n, P constant)} \quad \textbf{Charles' Law}$$

CTQ 14

Consider this form of Charles' Law, V/T = k (n, P constant). Since k is a constant,

a. What is the change in volume if temperature is doubled?

V is unchanged V is doubled V decreases by one-half

b. What is the change in T if V is doubled?

T is unchanged T is doubled T decreases by one-half

CTQ 15

Consider this form of Charles' Law, $V_1/T_1 = V_2/T_2$ (n, P constant).

a. What is the change in V_2 if T_1 is doubled?

V_2 is unchanged V_2 is doubled V_2 decreases by half

b. What is the change in T_2 if V_1 is doubled?

T_2 is unchanged T_2 is doubled T_2 decreases by half

CTQ 16

What happens to k when:

a. V is increased and T is decreased? k increases k decreases k is unchanged

b. V is increased and T is increased? k increases k decreases k is unchanged

c. V is decreased and T is decreased? k increases k decreases k is unchanged

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3. Combined Gas Law

Since the volume of a gas depends on the pressure and temperature, Boyle's and Charles' Law can be combined into one expression called the Combined Gas Law:

$$\frac{PV}{T} = k \quad \text{and} \quad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \text{(n constant)} \quad \textbf{Combined Gas Law}$$

CTQ 17

What happens to P_2 when:

V_1 is doubled and T_1 is doubled?

P_2 is unchanged $\qquad$ P_2 is doubled $\qquad$ P_2 decreases by half

D. Application of Gas Laws

Any gas is characterized by some combination of P,V, T and n. Solving word problems involving gases requires using the proper units. For a sample of gas (constant n), pressure is measured in atmospheres (atm), volume is measured in liters (L) and temperature is measured in Kelvins (K).

If other units are given in a word problem, they must first be converted into atm, liters and kelvins before using a gas law equation.

Example 1 Using Boyle's Law

A helium balloon at 298 K has a volume of 2.5 L at normal atmospheric pressure (1.0 atm). What is the volume when the balloon is released and floats to an altitude where the pressure is 0.875 atm? Assume the temperature remains constant.

Solution

a. Insert given values into Boyle's Law $P_1V_1 = P_2V_2$ (n, T constant):

$P_1 = 1.0$ atm $\quad V_1 = 2.5$ L $\quad P_2 = 0.875$ atm $\quad V_2 =$ unknown

(1.0 atm) (2.5 L) = (0.875 atm) V_2

b. Rearrange equation to isolate unknown variable (simple algebra):

$$\frac{(1.0 \text{ atm})(2.5 \text{ L})}{(0.875 \text{ atm})} = V_2$$

c. Solve for unknown variable:

$$\frac{(1.0 \cancel{\text{atm}})(2.5 \text{ L})}{(0.875 \cancel{\text{atm}})} = 2.85714 \ldots = 2.9 \text{ L} \quad \text{[two sig figs]}$$

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Example 2 Using Charles' Law

A helium balloon at 298 K has a volume of 2.5 L at normal atmospheric pressure (1.0 atm). What happens to the volume if the balloon is cooled in dry ice to a temperature of 198 K? In the absence of any more information, assume pressure remains constant.

Solution

a. Insert given values into Charles' Law $V_1/T_1 = V_2/T_2$ (n, P constant):

$V_1 = 2.5$ L $T_1 = 298$ K $V_2 =$ unknown $T_2 = 198$ K
2.5 L / 298 L = V_2 / 198 K

b. Rearrange equation to isolate unknown variable:

$$\frac{2.5\text{ L } 198\text{ K}}{298\text{ K}} = V_2$$

c. Solve for unknown variable:

$$\frac{2.5\text{ L } 198\,\cancel{\text{K}}}{298\,\cancel{\text{K}}} = 1.66107\ldots = 1.7\text{ L}$$

Example 3 Converting units for Gas Law equation

A balloon filled with nitrogen gas has a volume of 3425 mL and a temperature of 25.5°C. What is the volume if the sun warms the balloon to 38.5°C?

Solution

V & T given; must be Charles' Law

a. Convert into proper units:

V_1 = 3425 mL = 3.425 L V_2 = unknown
T_1 = 25.5°C = 298.5 K T_2 = 38.5 °C = 311.5 K

b. Rearrange and solve for unknown:

$$\frac{(3.425\text{ L})(311.5\text{ K})}{(298.5\text{ K})} = V_2 = 3.574\text{ L}$$

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CTQ 18

Rearrange Charles' Law to solve for T_2

CTQ 19

Rearrange the Combined Gas Law to solve for:

a. $P_2 =$

b. $V_2 =$

c. $T_2 =$

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Exercises

1. A sample of chlorine gas has a volume of 0.765 L and exerts a pressure of 0.760 atm. What is the volume at constant temperature if the pressure is decreased to 0.625 atm?

2. A sealed syringe contains 2.00 cc of oxygen gas at a pressure of 14.7 psi. If the plunger is depressed and the volume is reduced to 1.75 cc, what is the pressure inside the syringe?

3. A cylinder fitted with a moveable piston has a volume of 2.5 L. What happens to the piston if the temperature of the gas inside the cylinder is increased? (Think about the engine in your automobile).

4. A sample of krypton gas with a volume of 10.00 L has a temp of 303 K and exerts a pressure of 2.47 atm. What is the final volume if the temp increases to 450 K and pressure remains constant?