Gas Laws I
The Ideal Gas Law

1. What quantity, in moles, of helium are in a 3.0 L Mickey Mouse balloon at Disneyland if the pressure in the balloon is 754 torr and the temperature is 24.2°C?

$$P = 754 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.9921 \text{ atm}$$

$$V = 3.0 \text{ L}$$

$$T = 24.2°\text{C} + 273.15 \text{ K} = 297.4 \text{ K}$$

$$\frac{PV}{nT} = R \quad \text{so...} \quad n = \frac{PV}{RT} = \frac{(0.9921 \text{ atm})(3.0 \text{ L})}{(0.08206 \frac{\text{L·atm}}{\text{mol·K}})(297.4 \text{ K})} = 0.12 \text{ mol He}$$

2. When measured at STP, what volume will 0.35 moles of oxygen gas occupy?

$$P = 1.00 \text{ atm}$$

$$T = 273.2 \text{ K}$$

$$\frac{PV}{nT} = R \quad \text{so...} \quad V = \frac{nRT}{P} = \frac{(0.35 \text{ mol})(0.08206 \frac{\text{L·atm}}{\text{mol·K}})(273.2 \text{ K})}{1.00 \text{ atm}} = 7.8 \text{ L}$$

When warmed to room temperature (25.0°C) and maintained at standard pressure, what will be the new volume?

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} \quad \text{constant } n \text{ and } P$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{so...} \quad V_2 = V_1\frac{T_2}{T_1} = 7.8 \text{ L}\left(\frac{298.2 \text{ K}}{273.2 \text{ K}}\right) = 8.6 \text{ L}$$

3. Using the following data, determine the molar mass of the unknown compound.

The mass of a 255.5 mL flask is 55.144 g (with the mass of the air subtracted out). After filling the flask with an unknown gas at the laboratory barometric pressure, the mass of the flask and gas was measured to be 55.363 g. The barometric pressure was determined to be 742.5 mm Hg using a mercury barometer. The laboratory temperature was 22.4°C.

What is the molar mass of the gas?

$$V_{\text{flask}} = 0.2555 \text{ L} \qquad P_{\text{gas}} = \frac{742.5 \text{ mm Hg}}{760 \frac{\text{mm Hg}}{\text{atm}}} = 0.9770 \text{ atm}$$

$$m_{\text{flask}} = 55.144 \text{ g} \qquad T = 22.4°\text{C} + 273.2 \text{ K} = 295.6 \text{ K}$$

$$m_{\text{flask+gas}} = 55.363 \text{ g}$$

$$m_{\text{gas}} = 0.219 \text{ g}$$

$$\frac{PV}{nT} = R = \frac{PV}{\left(\frac{m}{M}\right)T} = \frac{MPV}{mT}$$

$$M = \frac{mRT}{PV} = \frac{(0.219 \text{ g})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(295.6 \text{ K})}{(0.9770 \text{ atm})(0.2555 \text{ L})} = 21.3 \text{ g/mol}$$

4. A mountaineer blows up a balloon to 3.00 L at sea level where the pressure is 754 mm Hg. He flies to Tibet with his balloon and runs up to 20,000 feet on the way to the top of Mt. Everest, where the pressure is 371 mm Hg. What is the volume of the balloon? (Assume the temperature didn't change.)

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2} = \frac{(754 \text{ mm Hg})(3.0 \text{ L})}{371 \text{ mm Hg}} = 6.1 \text{ L}$$

5. Your ears are essentially a closed air-space inside your head. Mostly surrounded by bone, there is only one flexible wall enclosing this air-space – the ear drum. The volume inside the air space is not large at only about 1-2 mL. Assuming a volume of 1.0 mL and that you feel pain due to pressure on the ear drum when the volume of the inner ear is reduced by 0.05 mL, what pressure over atmospheric (1.0 atm) is necessary on the ear drum to cause pain? (Report the answer in atm, torr, psi, and Pa)

$$V_1 = 1.0 \text{ mL}$$
$$V_2 = 0.95 \text{ mL}$$
$$P_1 = 1.0 \text{ atm}$$
$$P_2 = \frac{P_1V_1}{V_2} = \frac{(1.0 \text{ atm})(1.0 \text{ mL})}{0.95 \text{ mL}} = 1.05 \text{ atm}$$
$$P \text{ over atmospheric} = 0.05 \text{ atm} \quad \text{(without regard to significant figures)}$$

6. A mountaineer blows up a balloon to 3.00 L at sea level where the pressure is 754 mm Hg and the temperature is 22.0°C. He flies to Tibet with his balloon and runs up to 20,000 feet on the way to the top of Mt. Everest where the pressure is 371 mm Hg and the temperature is -15.5°C. What is the volume of the balloon?

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} \quad n \text{ is constant}$$
$$P_1 = 754 \text{ mm Hg}$$
$$V_1 = 3.00 \text{ L}$$
$$T_1 = 22.0°\text{C} + 273.2 \text{ K} = 295.2 \text{ K}$$
$$P_2 = 371 \text{ mm Hg}$$
$$T_2 = -15.5°\text{C} + 273.2 \text{ K} = 257.7 \text{ K}$$
$$V_2 = \frac{P_1V_1T_2}{P_2T_1} = \frac{(754 \text{ mm Hg})(3.00 \text{ L})(257.7 \text{ K})}{(371 \text{ mm Hg})(295.2 \text{ K})} = 5.32 \text{ L}$$

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Additional Problems

1. In an experiment involving Boyle's law, a graph of which data produces a straight line; *P* vs. *V* or *P* vs. 1/V?

$$P \propto \frac{1}{V} \text{ so a plot of } P \text{ vs. } \frac{1}{V} \text{ is a straight line.}$$

2. When a high-diver enters the water after jumping from a diving board, she may descend at much as 10 feet (or more) deep into the pool. At 10 feet, the total pressure on the diver will be 1.3 atm. Assuming that the diver took a deep breath (7.0 L of air in her lungs) at 1.0 atm just before entering the water, what will be the volume of air in her lungs when she gets to 10 feet of depth? Assume that the diver's air spaces (lungs) are completely flexible and she did not exhale while descending.

$$P_1 = 1.0 \text{ atm}$$
$$P_2 = 1.3 \text{ atm}$$
$$V_1 = 7.0 \text{ L}$$
$$V_2 = \frac{P_1 V_1}{P_2} = \frac{(1.0 \text{ atm})(7.0 \text{ L})}{1.3 \text{ atm}} = 5.4 \text{ L}$$

3. In an experiment involving Amonton's law, a graph of which data produces a straight line; *P* vs. *T* or *P* vs. 1/T?

$$P \propto T \text{ so a plot of } P \text{ vs } T \text{ will be linear.}$$

4. Scuba tanks are given a "Maximum Working Pressure" (MWP) rating (which represents the highest pressure the tank can safely hold at a given temperature) and a “Hydrostatic Test Pressure” (HTP) rating (which represents the highest pressure the tank can hold before it may rupture, and is five-thirds the MWP). In the U.S., the MWP for a tank with an international yoke valve is 206.8 bar at 20.0°C. If the tank is filled to 200.0 bar at 20.0°C, what is the maximum pressure that the tank reaches if left in the sun on a boat, if the tank temperature increases to 39.0°C?

   Does the pressure exceed either (or both) the MWP or HTP? Will the scuba tank rupture?

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_1 = 200.0 \text{ bar}$$
$$T_1 = 20.0°\text{C} + 273.2 \text{ K} = 293.2 \text{ K}$$
$$T_2 = 39.0°\text{C} + 273.2 \text{ K} = 312.2 \text{ K}$$
$$P_2 = P_1 \frac{T_2}{T_1} = 200.0 \text{ bar}\left(\frac{312.2 \text{ K}}{293.2 \text{ K}}\right) = 213.0 \text{ bar}$$

P_2 exceeds MWP

5. A football is inflated to a pressure of 1.00 x 10^3 torr in a room at 25°C. If the game is played at 10°C, what will the pressure in the ball be, neglecting any volume change in the ball and assuming that it doesn't leak?

$$P_1 = 1000 \text{ torr}$$
$$T_1 = 25°\text{C} + 273 \text{ K} = 298 \text{ K}$$
$$T_2 = 10°\text{C} + 273 \text{ K} = 283 \text{ K}$$
$$P_2 = P_1 \frac{T_2}{T_1} = 1000 \text{ torr}\left(\frac{283 \text{ K}}{298 \text{ K}}\right) = 950 \text{ torr (neglecting significant figures)}$$