

THE GAS STATE

Unit 4

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9.2	Boyles Law $P \propto 1/V$ $PV = \text{Constant}$ $P_1V_1 = P_2V_2$ Pressure Atmospheric Pressure Units of Pressure Pascal, Atmosphere, mm of Hg, torr	Page 428 # 5 to 10
9.22	Charles Law $V \propto T$ Or V/T is a constant $V_1/T_1 = V_2/T_2$ Absolute scale or Kelvin Scale $-273.14 = 0K$ Combined Gas Law $P_1V_1/T_1 = P_2V_2/T_2$ Ideal Gas Equation $PV = nRT$ (9.4)	Page 423 # 16 to 19 Page 438 # 26 to 33
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GAS STATE

THE KINETIC-MOLECULAR THEORY OF GASES CAN BE STATED AS FIVE POSTULATES:

- A gas consists of molecules in constant random motion.
- Gas molecules influence each other only by collision.
- There are no inter molecular forces of attraction.
- All collisions between gas molecules are perfectly elastic; all kinetic energy is conserved.
- The volume actually occupied by the molecules of a gas is negligibly small; the vast majority of the volume of the gas is empty space through which the gas molecules are moving.

EQUATIONS OF STATE FOR GASES

STANDARD STATE:

STP STANDARD TEMPERATURE AND PRESSURE

Temperature = 0° C or 273.14 K

Pressure = 101.325 kPa

Volume = 22.4 L

SATP STANDARD AMBIENT TEMPERATURE AND PRESSURE

Temperature = 25°C or 298 K

Pressure = 100 kPa

Volume = 24.8 L

UNIVERSAL GAS CONSTANT R = 8.314 J/mol K or 8.314 kPa dm³/mol K

COMMONLY USED UNITS OF PRESSURE

Atmosphere atm.

Kilopascal kPa Conversion unit = $\frac{1atm}{101.325kPa}$

Toricelli torr. Conversion unit = $\frac{1atm}{760torr}$

Millimeter mm Conversion unit = $\frac{1atm}{760mm}$

1 mm of Hg = 1 torr

1 atm. = 101.325 kPa = 760 torr = 760 mm of Hg = 76 cms of Hg

TEMPERATURE

Celsius and Kelvin

CONVERSION:

Kelvin = degrees Celsius + 273

K = °C + 273

In all SI metric calculations use only Kelvin values.

BOYLES LAW:

At constant temperature the pressure of a given mass of gas is directly proportional to its volume.

$$P_1V_1 = P_2V_2 \text{ at constant temperature}$$

CHARLES LAW:

At constant pressure the volume of a given mass of gas is inversely proportional to its temperature.

$$V_1T_2 = V_2T_1 \text{ OR } \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

COMBINED GAS LAW:

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

AVOGADRO'S LAW OR HYPOTHESIS:

Equal volumes of all gases under the same conditions of temperature and pressure contain the same number of molecules.

$$V \propto n,$$

$$V = \text{Constant} \times \text{number of moles}$$

IDEAL GAS EQUATION:

Gases that obey Charles and Boyle's law for all temperatures and pressures are called ideal gases

$$PV = nRT$$

REAL GASES:

Most gases do not obey ideal gas laws they are called real gases. The pressure volume relation is better understood and calculated using Van der-waal's equation

$$\boxed{P + \frac{a}{n^2V^2}(V - nb) = nRT}$$

DALTONS LAW OF PARTIAL PRESSURES

The total pressure exerted by a mixture of non reacting gas is the sum of the partial pressures of the individual gases

$$P_{\text{total}} = P_A + P_B + P_C$$

Where $P_A + P_B + P_C$ are partial pressures of gases A, B and C

VAPOUR PRESSURE:

The pressure exerted by volatile liquid molecules above its surface. VP of water at 22 ° C =

GRAHAMS LAW OF DIFFUSION:

At constant temperature and pressure the rate of diffusion of a gas is inversely proportional to the square root of its density.

$$r_1 = \sqrt{\frac{1}{d_1}} \text{ and } r_2 = \sqrt{\frac{1}{d_2}} \text{ or } \frac{r_1}{r_2} = \sqrt{\frac{d_2}{d_1}} \text{ at constant temperature and pressure. Since there is a relation that}$$

molecular mass is twice vapour density of a gas the above equation reduces to $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$

Some practical applications of gas laws in your day to day experience.

Why do we not inflate car and motorcycle tires to the maximum?

Why do compressed gases when allowed to expand rapidly cause cooling ?

On a summer day why is it that wet clothes dry faster?

Why do we need space suits when we travel to outer space? Astronauts uses space suits while taking space walks?

What are bends? Why is it that deep sea diver's are asked not to surface too quickly?

WORKSHEETS

CELSIUS-KELVIN TEMPERATURE CONVERSIONS WORKSHEET

- Liquid oxygen (sometimes abbreviated LOX) is used in liquid-fuel rockets. Its boiling point is -183°C . What is this temperature in Kelvin?
- A substance is heated from 300 K to 315 K. What is the change in temperature expressed in $^{\circ}\text{C}$?
- Perform the following conversions.
 - 24°C to K
 - 50 K to $^{\circ}\text{C}$
 - 30°C to K
 - 215.15 K to $^{\circ}\text{C}$
 - -37.89°C to K
 - 333.67 K to $^{\circ}\text{C}$
- A clinical thermometer registers a patient's temperature to be 37.13°C . What is this in Kelvin?
- The coldest permanently inhabited place on earth is the Siberian village of Oymyakon in Russia. In 1964 the temperature reached a shivering -71.11°C . What is this temperature in Kelvin?
- Helium has the lowest boiling point of any liquid. It boils at 4 K. What is this in $^{\circ}\text{C}$?
- When an object is heated to high temperature, it glows and gives off light. The color of this light depends upon the temperature of the glowing object. Photographic lighting is described as a temperature in Kelvin. For example, a certain electronic flash gives a color temperature (or color balance) rated at 5800 K. What is this temperature expressed in $^{\circ}\text{C}$?

CHARLES LAW WORKSHEET

- Give the temperature-volume law both in words and in the form of an equation.
- How is the volume of a gas affected by a decrease in temperature?
- What would be the new volume if the temperature on 450 mL of gas is changed from 45°C to -5°C ?
- A sample of gas whose volume at 27°C is 0.127 L, is heated at constant pressure until its volume becomes 317 mL. What is the final temperature of the gas in Celsius and Kelvin?
- To make 300 mL of oxygen at 20.0°C change its volume to 250 mL, what must be done to the sample if its pressure and mass are to be held constant?
- To what temperature must an ideal gas at 27°C be cooled to reduce its volume by 1/3?
- From the data in the following questions calculate the missing quantity.
 - $V_1 = 22.4\text{ L}$; $T_1 = 0^{\circ}\text{C}$; $T_2 = 91^{\circ}\text{C}$; $V_2 = ?\text{ L}$
 - $V_1 = 125\text{ mL}$; $T_1 = ?$; $T_2 = 25^{\circ}\text{C}$; $V_2 = 100\text{ mL}$
 - $V_1 = ?\text{ L}$; $T_1 = 400\text{ K}$; $T_2 = 175\text{ K}$; $V_2 = 6.20\text{ L}$
 - $V_1 = 250\text{ mL}$; $T_1 = 298\text{ K}$; $T_2 = ?\text{ K}$; $V_2 = 273\text{ mL}$
- A 50 cm^3 sample of a gas in a syringe at 15°C is heated to 50°C and the syringe's piston is allowed to move outward against a constant atmospheric pressure. Calculate the new volume of the hot gas.
- What is the final volume if 3.4 L of nitrogen gas at 400 K is cooled to 200 K and kept at the same pressure?
- Determine the final volume of 20 L of a gas whose temperature changes from -73°C to 327°C if the pressure remains constant.
- A partially filled plastic balloon contains $3.4 \times 10^3\text{ m}^3$ of helium gas at 5°C . The noon day sun heats this gas to 37°C . What is the volume of the balloon if atmospheric pressure remains constant?

BOYLE'S LAW WORKSHEET

- State the pressure-volume law both in words and in the form of an equation.
- To compress nitrogen at 1 atm from 750 mL to 500 mL, what must the new pressure be if the temperature is kept constant?
- If oxygen at 128 kPa is allowed to expand at constant temperature until its pressure is 101.3 kPa, how much larger will the volume become?
- A sample of nitrogen at 101.3 kPa with a volume of 100 mL is carefully compressed at constant temperature in successive changes in pressure, equaling 5 kPa at a time, until the final pressure is

- 133.3 kPa. Calculate each new volume and prepare a plot of P versus V, showing P on the horizontal axis.
- A sample of nitrogen at 20°C was compressed from 300 mL to 0.360 mL and its new pressure was found to be 400.0 Pa. What was the original pressure in kPa?
 - The pressure on 6.0 L of a gas is 200 kPa. What will be the volume if the pressure is doubled, keeping the temperature constant?
 - What would be the new volume if the pressure on 600 mL is increased from 90 kPa to 150 kPa?
 - A student collects 25 mL of gas at 96 kPa. What volume would this gas occupy at 101.325 kPa. There is no change in temperature or mass.
 - A gas measuring 525 mL is collected at 104.66 kPa. What volume does this gas occupy at 99.33 kPa?
 - A mass of gas occupies 1 L at 1 atm. At what pressure does this gas occupy?
 - 2 litres,
 - 0.5 litres?
 - From the data in the following table calculate the missing quantity (assuming constant temperature).
 - $V_1 = 22.4 \text{ L}$; $P_1 = 1 \text{ atm}$; $P_2 = ? \text{ atm}$; $V_2 = 2.8 \text{ L}$
 - $V_1 = 60 \text{ mL}$; $P_1 = ? \text{ kPa}$; $P_2 = 101.3 \text{ kPa}$; $V_2 = 16 \text{ mL}$
 - $V_1 = ? \text{ m}^3$; $P_1 = 40 \text{ Pa}$; $P_2 = 100 \text{ kPa}$; $V_2 = 1.0 \text{ L}$
 - $V_1 = 2.50 \text{ L}$; $P_1 = 7.5 \text{ atm}$; $P_2 = ? \text{ atm}$; $V_2 = 100 \text{ mL}$

COMBINED GAS LAW WORKSHEET

- Helium in a 100 mL container at a pressure of 66.6 kPa is transferred to a container with a volume of 250 mL. What is the new pressure if no change in temperature occurs? What is the new pressure if the temperature changes from 20°C to 15°C?
- What will have to happen to the temperature of a sample of methane if 1000 mL at 98.6 kPa and 25°C is given a pressure of 108.5 kPa and a volume of 900 mL?
- A gas has a volume of 225 mL at 75°C and 175 kPa. What will be its volume at a temperature of 20°C and a pressure of $1.0 \times 10^5 \text{ kPa}$?
- A gas is heated to 80°C and a pressure of 180 kPa. If the container expands to hold a volume of 800 mL, what was the volume of the gas, (in litres), at a temperature of 50°C and 120 kPa pressure?
- A 200 mL sample of gas is collected at 50 kPa and a temperature of 271°C. What volume would this gas occupy at 100 kPa and a temperature of -14°C?
- Correct the following volumes at STP and at SATP:
 - 24.6 L at 25°C and 104 kPa
 - 150000 mm³ at 100°C and 75.00 kPa
 - 0.045 L at -45.0°C and 140.0 kPa
 - 0.5 L at 115°C and 148000 Pa
- A certain sample of gas has a volume of 0.452 L measured at 87°C and 0.620 atm. What is its volume at 1 atm and 0°C?
- Natural gas is usually stored in large underground reservoirs or in above ground tanks. Suppose that a supply of natural gas is stored in an underground reservoir of volume $8.0 \times 10^5 \text{ m}^3$ at a pressure of 360 kPa and a temperature of 16°C. How many above ground tanks of volume $2.7 \times 10^4 \text{ m}^3$ at a temperature of 6°C could be filled with the gas at a pressure of 120 kPa?
- The human lung has an average temperature of 37°C. If one inhales Alaskan air at 1 atm and -28.9°C and then holds it, to what pressure will the air in the lungs rise? (The bursting strength of the human lung is over 2 atm. Will they burst?)
- A cylindrical coffee can is welded shut at 20°C at sea level. Its height is 20 cm and its radius is 15 cm. If the bursting strength of its "tin" plate is 3.75 atm, to what temperature may it be heated before bursting?

IDEAL GAS LAW WORKSHEET

1. Using the information from STP or SATP conditions determine the value of the ideal gas constant.
2. A sample of 1.00 moles of oxygen at 50°C and 98.6 kPa occupies what volume?
3. A sample of 4.25 moles of hydrogen at 20.0°C occupies a volume of 25.0 L. Under what pressure is this sample?
4. If a steel cylinder with a volume of 1.50 L contains 10.0 moles of oxygen, under what pressure is the oxygen if the temperature is 27.0°C?
5. When the pressure in a certain gas cylinder with a volume of 4.50 L reaches 500 atm, the cylinder is likely to explode. If this cylinder contains 40.0 moles of argon at 25.0°C, is it on the verge of exploding? Calculate the pressure in atmospheres.
6. At 22.0°C and a pressure of 100.6 kPa, a gas was found to have a density of 1.14 g/L. Calculate its molecular mass.
7. A gas was found to have a density of 1.76 mg/mL at 24.0°C and a pressure of 98.8 kPa. What is its molecular mass?
8. How many milliliters of nitrogen, N₂, would have to be collected at 99.19 kPa and 28°C to have a sample containing 0.015 moles of N₂?
9. The density of a certain gas at 27.0°C and 98.66 kPa is 2.53 g/L. Calculate its molecular mass.
10. What volume is occupied by 0.25 grams of O₂ measured at 25.0°C and 100.66 kPa?
11. What is the molecular mass of a gas if 2.82 grams of the gas occupies 3.16 litres at STP?
12. A balloon is to be filled with 30.0 kg of helium gas. What volume can be filled to a pressure of 1.15 atm if the temperature is 20.0°C?
13. In a gas thermometer, the pressure needed to fix the volume of 0.20 g of helium at 0.50 L is 113.30 kPa. What is the temperature?
14. A gaseous compound has the empirical formula CHCl. At 100°C, its density at 99.97 kPa is $3.12 \times 10^{-3} \text{ g cm}^{-3}$. What is the molecular formula of this compound?
15. The pressure exerted on a diver by the water increases by about 100 kPa for every 10 m of depth. A scuba diver uses air at the rate of 8 L/min at a depth of 10 m where the pressure is 200 kPa (100 kPa due to the atmosphere and 100 kPa due to the water pressure) and the temperature 8°C. If the diver's 10 L air tank is filled to a pressure of $2.1 \times 10^4 \text{ kPa}$ at a dockside temperature of 32°C, how long can the diver remain safely submerged?
16. You want to send chlorine gas, Cl₂, safely from Vancouver to Kingston. Chlorine gas is very poisonous and corrosive. You have a 5000 L truck cylinder that will withstand a pressure of 100 atm. The cylinder will be kept at 2°C throughout the trip. How many moles of chlorine gas can you safely ship?

VAPOR PRESSURE

1. When nitrogen is prepared and collected over water at 30°C and a total pressure of 98.4 kPa, what is its partial pressure in atm?
2. If you were to prepare oxygen and collect it over water at 10°C and a total pressure of 100.1 kPa, what is its partial pressure in atm, kPa and torr?
3. A sample of carbon monoxide was prepared and collected over water at a temperature of 20°C and a total pressure of 99.8 kPa. It occupied a volume of 275 mL. Calculate the partial pressure of this gas in the sample in kPa and its dry volume in mL under a pressure of 101.3 kPa.
4. A sample of hydrogen was prepared and collected over water at a temperature of 25°C and a total pressure of 98.1 kPa. It occupied a volume of 295 mL. Calculate its partial pressure, in atm, and what its dry volume would be in mL under a pressure of 101.3 kPa.
5. What volume of "wet" methane would you have to collect at 20°C and 98.6 kPa to be sure the sample contained 240 mL of dry methane at the same pressure?

6. What volume of "wet" oxygen would you have to collect if you needed the equivalent of 260 mL of dry oxygen at 101.3 kPa and the atmospheric pressure in the lab that day was 99.4 kPa? The oxygen is to be collected over water at a temperature of 15.0°C.
7. Exactly 100 mL of oxygen are collected over water at 25°C and 106.66 kPa. What is the pressure being exerted by the pure oxygen at 25°C.
8. In an experiment, a student collects 107 mL of hydrogen over water at a pressure of 104.8 kPa and a temperature of 31°C. What volume would this hydrogen occupy at SATP?
9. If 80.0 mL of oxygen are collected over water at 20°C and 95.0 kPa. What volume would the dry oxygen occupy at STP?
10. If 450 mL of hydrogen at STP occupy 511 mL when collected over water at 18°C, what is the atmospheric pressure?
11. In an experiment a student collects 58 mL of oxygen gas by the downward displacement of water at 18°C and 105 kPa pressure. What would the mass of the dry oxygen be?