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Physics 12 AP Kinetic Theory and the Gas Laws

Read 13-7

1] What is Boyle's Law?

$P \propto \frac{1}{V}$ or $V \propto \frac{1}{P}$ at const T or PV = const

2] What is Charles Law?

$V \propto T$ ← a gas volume will expand w/increasing T

3] What is Gay-Lussac's Law?

$P \propto T$ ← a gas pressure will ↑ w/ T↑

Read 13-7

4] List the ideal gas law . (2 forms) What is the value of R?

$PV = nRT$ $\qquad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Study the examples on P 396

STP ← 1 atm (1×10^5 Pa), 0°C / 273 K

5] If 5.00 m^3 of a gas initially at STP is placed under a pressure of 4.0 atm, the temperature of the gas rises to 25 deg C. What is the volume? (1.36 m^3)

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

$$\frac{1(5)}{273} = \frac{4V}{298} \qquad V = 1.36\,m^3$$

6] The pressure in a helium gas cylinder is initially 30 atm. After many balloons have been blown up, the pressure has decreased to 6 atm. What fraction of the original gas remains in the cylinder? (0.2) ↖ $\frac{n_2}{n_1}$

~~$P_1V_1 = P_2V_2$~~

T = cons

$$\frac{30}{6} = \frac{V_2}{V_1}$$

(const, const)

$$P_1V = n_1RT_1 = P_2V = n_2RT_2$$

$$\frac{P_1}{n_1} = \frac{P_2}{n_2} \qquad \frac{n_2}{n_1} = \frac{P_2}{P_1} = \frac{1}{5} = .2$$

22.4 L = 1 mol

7] Calculate the density of oxygen at STP using the ideal gas laws. (1.43 kg/m^3)

mass/vol = mol/vol x kg/mol

$PV = nRT$

$\frac{P}{RT} = \frac{n}{V}$ $\frac{1\times10^5 Pa}{(8.315)(273)} = \frac{44 mol}{m^3} \times \frac{.032 kg}{mol} = 1.41 \frac{kg}{m^3}$

8] A tank contains 28.0 kg of O_2 gas at guage pressure of 6.80 atm. If the oxygen is replaced with He, how many kg of the later will be needed to produce a guage pressure of 8.25 atm? (4.24 kg)

$P_1V_1 = n_1RT_1$

$\frac{P_1}{n_1} = RTV = \frac{P_2}{n_2}$ ← moles

$\frac{6.8}{875} = \frac{8.25}{n_2}$ $n_2 = 1061.6$ mol

$28 kg \times \frac{1 mol}{32 g} = 875 mol$

H: $\frac{4g}{mol} \times$ 15.6 mol = 4246 = 4.25 kg

9] How many moles of water are there in 1.000 L? How many molecules? (55.6 moles, 3.34×10^{25} molecules)

molecular weight : H_2O = 2+16 = 18g/mol

1 L = 1 kg = 1000 g 1000g ÷ 18g/mol = 56 mol

1 mol = 6.02×10^{23} particles

56 mol = 3.34×10^{25} molecules

<u>Read 13-11 Very Carefully</u>

10] What does the term kinetic theory mean?

All matter is made of molecules which are undergoing continuous random motion

11] What are the four postulates of kinetic theory?

1] large #(N) of molecules moving in random directions at various speed

2] molecs are far apart in relation to diam

3] classical mechanics in that the potential energy between molecules is v.small & can be ignored in relation to E_k of molecules

4] perfectly elastic collisions (E_k conserved)

12] How does kinetic theory explain Boyle's Law??

- Press is caused by collisions
- smaller vol = greater collisions/sec = greater P = greater T

13] List the equation that relates temperature to the average kinetic energy of gas molecules.

$$\bar{E}_{k\,ave} = \frac{1}{2} m \bar{v}^2 = \frac{3}{2} k T$$

$k = 1.38 \times 10^{-23}\ \mathrm{J/K}$

Carefully study the examples on P 401

14] a) What is the average kinetic energy of an oxygen molecule at STP?
b) What is the total translational kinetic energy of 1 mole of O_2 molecules at 20 deg C? (5.65 x 10^{-21} J, 3650 J)

one molecule

$$\bar{E}_k = \frac{3}{2} kT = 5.65 \times 10^{-21}\ \mathrm{J}$$

$$\bar{E}_k = \frac{3}{2} kT = \frac{3}{2}(1.38 \times 10^{-23})\, 293\mathrm{K} = 6.07 \times 10^{-21}\ \mathrm{J} \times 6.02 \times 10^{23}\ \frac{\mathrm{molec}}{\mathrm{mol}} = 3.65 \times 10^{3}\ \mathrm{J}$$

15] Calculate the rms speed of helium atoms near the surface of the sun at a temperature of about 6000 deg K. (6120 m/s)

$$\bar{E}_k = \frac{1}{2} m \bar{v}^2 = \frac{3}{2} kT$$

$$\bar{v} = \sqrt{\frac{3kT}{m}} = 6.10 \times 10^{3}\ \frac{\mathrm{m}}{\mathrm{s}}$$

$$= \sqrt{\frac{3 \cdot 1.38 \times 10^{-23} \cdot 6000}{4 \cdot 1.67 \times 10^{-27}}}$$

16] A gas is at 20 deg C. To what temperature must it be raised to double the rms speed of its molecules? ~~(899 deg~~ C)

$$V_{rms} = \sqrt{\frac{3kT}{m}}$$

$$\frac{V_1}{V_2} = \frac{1}{2} = \frac{\sqrt{\frac{3kT_1}{m}}}{\sqrt{\frac{3kT_2}{m}}} \qquad \frac{1}{2} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$$

$$T_2 = 4T_1$$

$$T_2 = 4(293) = 1172\ K$$

17] What is the rms speed of nitrogen molecules contained in an 8.0 m^3 volume at 2.1 atm if the total amount of nitrogen is 1300 mol? (375 m/s)

$$\frac{PV}{nR} = T$$

$$\frac{2.1(1.01\times10^5)\times 8}{(1300)(8.315)} = T = 157\ K$$

$$V_{rms} = \sqrt{\frac{3kT}{m}} = 373\ \frac{m}{s}$$

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Gas Law Problems

1] A helium-filled balloon occupies a volume of 16 m^3 at sea level. The balloon is released and rises to a point in the atmosphere where the pressure is 0.75 atm. What is its volume? (21 m^3)

(1 atm)

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ $1 \times 16 = .75 V_2$ $V_2 = 21.3\ m^3$

Boyle

2] A volume of 5.00 m^3 of neon gas is expanded until its volume becomes 12.5 m^3. The original pressure acting on the gas was 2.00 x 10^2 kPa. What is the final pressure acting on the gas? (80.0 kPa)

$P_1V_1 = P_2V_2$ $5(200) = 12.5 P_2$ $P_2 = 80\ kPa$ $8.0 \times 10^4\ Pa$

3] A volume of 30 m^3 of argon gas is kept under constant pressure. The gas is heated from 20.0 deg C to 293 deg C. What is the new volume? (58 m^3)

Charles

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ $\frac{30}{293} = \frac{V_2}{(293+273)}$ $V_2 = 57.9\ m^3$

4] A gas at 60.0 deg C has a volume of 0.021 m^3. Under constant pressure, it is heated to twice its original volume. What is the temp of the gas? (393 °C)

$\frac{1}{60+273} = \frac{2}{T_2}$ $T_2 = 666\ K$ or $393°C$

5] Two hundred litrers of gas at 0 deg C are kept under a pressure of 150 kPa. The termp of the gas is raised to 273 deg C. The pressure is increased to 350 kPa. What is the final volume? (170 L)

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ $\frac{150\,kPa\,(200)}{273} = \frac{350 V_2}{(273+273)}$ $V_2 = 171\ L$

6] Fifty litres of gas are kept at a temperature of 200 K and under pressure of 15 atm. The temperature of the gas is increased to 400 K. The pressure is decreased to 7.5 atm. What is the volume of the gas? (200 L)

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ $\frac{15(50)}{200} = \frac{7.5 V_2}{400}$ $200L = V_2$

7] A cubic meter of gas at STP is heated to 364 deg C. The pressure acting on the gas is kept constant. What volume does the gas occupy. (2.33 m^3)

(273, 1 atm)

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ $\frac{1}{273} = \frac{V_2}{(273+364)}$

$V_2 = 2.33\ m^3$

8] A balloon contains 2.0×10^2 m^3 of helium while on the surface of the earth. Atmospheric pressure is 1.0 atm. Temperature is 20.0 deg C. The balloon expands freely and rises to a height where the pressure is only 0.67 atm and the temperature is -50 deg C. What is the new volume of the balloon? (230 m^3)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad \frac{1\,(200)}{293} = \frac{.67\,V_2}{223} \qquad V_2 = 227\,m^3$$

9] The pressure acting on 20.0 liters of a gas is 120.0 kPa. If the temperature is 23 deg C, how many molecules are present? (5.88×10^{23} molecules)

$$PV = nRT \quad (n = \text{moles}) \qquad n = \frac{PV}{RT} = \frac{(120\times10^3)(20\times10^{-3})}{(8.315)(296)} \qquad n = .975\,mol$$

$$.975 \times 6.02\times10^{23} = 5.87\times10^{23}\ \text{molec}$$

10] a] What volume does 1.0 g of ammonia (NH_3) occupy at STP. (1.32 L)

$14+3 = 17\,\frac{g}{mol}$

$$1g \div 17\frac{g}{mol} = .0588\,mol \qquad V = \frac{nRT}{P} = 1.32\times10^{-3}\,m^3 \text{ or } 1.32\,L$$

b] What volume does it occupy at 100 deg C and a pressure of 1.2 atm? (1.5 L)

$$\text{Still } .0588\,mol \qquad V = \frac{nRT}{P} = \frac{(.0588)(8.315)(373)}{(1.2\times1.01\times10^5)} = 1.5\times10^{-3}\,m^3 \text{ or } 1.5\,L$$

11] What is the mass of 40 L of uranium hexafluoride (UF_6) at 500 deg C and 4 atm of pressure? (887g)

$237 + 6\times19 = 351\,\frac{g}{mol}$

$$PV = nRT$$

$$\frac{(4\times1.01\times10^5)(40)}{(8.315)(773)} = 2514\,mol \times 351\frac{g}{mol} = 882\,g$$

12] Find the density in g/L of ethylene (C_2H_4) at STP. (1.25 g/L)

$12\times2+4 = 28\,g/mol$

$$PV = nRT$$

$$\frac{P}{RT} = \frac{n}{V} = \frac{1.01\times10^5}{(8.315)(273)} = 44\frac{mol}{m^3} \times \frac{28g}{mol} = 1245\frac{g}{m^3} \text{ or } 1.25\frac{g}{L}$$

13] What is the density of oxygen at 20 deg C and 5 atm of pressure? (6.66 g/L)

$$\frac{5\times1.01\times10^5}{(8.315)(293)} = \frac{n}{V} = 207\frac{mol}{m^3} \times \frac{32g}{mol} = \frac{6.63g}{L}$$

14] A sample of an unknown gas has a mass of 28.1 g and occupies 4.8 L at STP. What is its molecular mass? (131u)

$$\frac{PV}{RT} = n \qquad \frac{(1.01\times10^5)(4.8)}{(8.315)(273)} = n = 214\,mol$$

$$\frac{28.1\,g}{214\,mol} = .131\frac{g}{mol} = 131\frac{amu}{mol}$$

15] What is the average kinetic energy of the molecules of any gas at 100 deg C? (7.72×10^{-21} J)

$\bar{E}_k = \frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$

$E_k = 7.72 \times 10^{-21}$ J

16] What is the average velocity of the molecules in a smaple of oxygen at 100 deg C? The mass of an oxygen molecule is 5.3×10^{-26} kg. (540 m/s)

$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$

$(32 \times 1.67 \times 10^{-27})\bar{v}^2 = 3(1.38 \times 10^{-23})373$ $\bar{V} = 538\frac{m}{s}$

17] A gas sample at 200 K is heated until its temperature is 400 K. If the original average velocity of the gas molecules was v, their new average velocity is (b)

$\frac{\bar{V}_1}{\bar{V}_2} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$ $\sqrt{2}\,\bar{V}_1 = \bar{V}_2$

a] v   b] $\sqrt{2}$ v   c] 2v   d] 4v

$E_k \propto T$ [kelvin]

$2 = 2T = 2(283) = 566K$

$566 - 273 = 293°C$

18] The molecules of a gas at 10 deg C would have twice as much KE at (b)

a] 20 deg C   b] 293 deg C   c] 566 deg C   d] 859 deg C

19] An oxygen molecule has 16 times the mass of a hydrogen molecule. A sample of hydriogen gas whose molecules have the sam average KE as the molecules in a sample of oxygen at 400 K is at a temperature of (b)

$E_k = \frac{3}{2}kT$ — mass not needed

a] 25K   b] 400 K   c] 1600 K   d] 6400 K

20] A gas sample at 0 deg C is heated until:
a] the average KE doubles . What is the new temperature? (273 deg C)

$E_k \propto T \therefore T$ doubles $= 2 \times 273\,k = 546\,K = 273°C$

b] the average velocity of its molecules doubles. What is its new temp? (819 deg C)

$\frac{V_1}{V_2} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$ $\frac{1}{2} = \frac{\sqrt{273}}{\sqrt{T_2}}$ $T_2 = 1092\,k = 819°C$

21] Mercury is a gas at 500 deg C. What is the average velocity of mercury atoms at this temp? The mass of a mercury atom is 3.3×10^{-25} kg. (311 m/s)

$\frac{1}{2}mv^2 = \frac{3}{2}kT$

$200(1.67 \times 10^{-27})v^2 = 3(1.38 \times 10^{-23})(773)$

$\bar{V} = 309\frac{m}{s}$