AP* Gas Law Free Response Questions KEY

1971

$P_{CO} = P_{atm} - P_{H2O} = (752 - 19.8)$ torr = 732.2 torr

$$n = \frac{PV}{RT} = \frac{(732.2 torr)(0.242 L)}{(62.4 \frac{L\_torr}{mol\_K})(295.15K)} = 9.62 \infty 10^{-3} \text{ mol}$$

$$9.62 \infty 10^{-3} mol \infty \frac{2 \text{ mol HCOONa}}{2 \text{ mol CO}} \infty \frac{68.0g}{1 \text{ mol}} = 0.654 \text{ g}$$

0.654 g/0.964 g × 100 = 67.9%

1971

(a) $P_{C6H6} = \chi P°_{C6H6} = (^{49}/_{50})(75 \text{ torr}) = 73.5$ torr

(b) $P_T = \chi P°_{tol.} + \chi P°_{benz.}$

$= (^3/_4)(22 \text{ torr}) + (^1/_4)(75 \text{ torr}) = 35.3$ torr.

$$\chi_{benz.} = \frac{(1/4)(75torr)}{35.25torr} = 0.532$$

1972

(a)

$$n = \frac{PV}{RT} = \frac{(\frac{740}{760} atm)(0.249L)}{(0.08205 \frac{L\ atm}{mol\_K})(295K)} = 0.0100 mol\ CO_2$$

$K_2CO_3 + 2 HCl \rightarrow 2 KCl + CO_2 + H_2O$

$$\frac{0.0100 mol\ CO_2}{} \infty \frac{1 \text{ mol } K_2CO_3}{1 \text{ mol } CO_2} \infty \frac{138.2g\ K_2CO_3}{1 \text{ mol } K_2CO_3}$$

$= 1.38$ g K_2CO_3

$$\frac{1.38 \text{ g } K_2CO_3}{5.00 \text{ g mix}} \infty 100\% = 27.7\% K_2CO_3$$

(b) $KOH + HCl \rightarrow K^+ + Cl^- + H_2O$

$$\frac{0.100L\ HCl}{} \infty \frac{2.0 \text{ mol}}{1L} = 0.200 \text{ mol HCl}$$

2(0.0100 mol) = 0.0200 mol HCl reacted with K_2CO_3

1 mol NaOH = 1 mol HCl

$$\frac{0.0866L\ NaOH}{} \infty \frac{1.5 \text{ mol}}{1L} = 0.130 \text{ mol HCl excess}$$

mol HCl reacted = (0.200 - 0.0200 - 0.130)mol = 0.050 mol

$$\frac{0.050mol\ HCl}{} \infty \frac{1mol\ KOH}{1mol\ HCl} \infty \frac{56.1g\ KOH}{1mol\ KOH} = 2.81g$$

$$\frac{2.81 \text{ g KOH}}{5.00 \text{ g mix}} \infty 100\% = 56.2\% \text{ KOH}$$

KCl = (100 - 27.7 - 56.2)% = 16.1% KCl

1973

(a) 6.19 g PCl_5 / 208.22 g/mol = 0.0297 mol PCl_5

$$P = \frac{nRT}{V} = \frac{(0.0297 \text{ mol})(0.08205 \frac{L\_atm}{mol\_K})(525.15K)}{2.00L}$$

= 0.640 atm = 487 mm Hg

(b) $P_{PCl3} = P_{Cl2} = X$; $P_{PCl5} = (0.640 - X)$ mm Hg
$P_T = 1.00$ atm = (0.640 - X) + X + X
X= 0.360 atm = $P_{PCl3} = P_{Cl2}$
P_{PCl5} = (0.640-0.360) atm = 0.290 atm = 220 mm

1976

Useful realtionship is: M= (gRT)/(PV). Significant intermolecular attraction exists at temperatures not far above boiling point.
Therefore, the compressibility of the gas is greater and the value of PV is smaller than predicted.
This would lead to a higher value for the molecular weight than the true value.

1982

a) 2 points

Real molecules exhibit finite volumes, thus excluding some volume from compression.

Real molecules exhibit attractive forces, thus leading to fewer collisions with the walls and a lower pressure.

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b) 3 points

SO_2 is the least ideal gas.

It has the largest size or volume.

It has the stongest attractive forces (van der Waals forces or dipole-dipole interactions).

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c) 3 points

High temperature results in high kinetic energies.

This energy overcomes the attractive forces.

Low pressure increases the distance between molecules. (So molecules comprise a small part of volume or attractive forces are small)

1984

Scoring Standards for Question #7- - - - - - - - - - - - - - - (8 points total)

Constant a is related to the attractive forces that exist between real molecules.	1 point
Constant b is related to the fact that real molecules occupy space or volume.	1 point
H_2S has a larger a value	1 point*
because H_2 is a polar molecule and therefore has stronger intermolecular forces.	2 points
H_2S has a larger b value because of its additional atom.	1 point**
The constant a correlates with the boiling point	1 point*
since it is related to the intermolecular forces which must be overcome in the process of boiling.	1 point

* 1 point granted in the absence of an explanation only if the constant is correctly identified somewhere in the discussion.

** Explanation not required for point provided constant is correctly identified somewhere in the discussion.

Question 3. 9 points. Average score 5.18

1986

Three volatile compounds X, Y, and Z each contain element Q. The percent by weight of element Q in each compound was determined. Some of the data obtained are given below.

Compound	Percent by Weight of Element Q	Molecular Weight
X	64.8%	?
Y	73.0%	104.
Z	59.3%	64.0

(a) The vapor density of compound X at 27°C and 750. mm Hg was determined to be 3.53 grams per liter. Calculate the molecular weight of compound X.

(b) Determine the mass of element Q. contained in 1.00 mole of each of the three compounds.

(c) Calculate the most probable value of the atomic weight of element Q.

(d) Compound Z contains carbon, hydrogen, and element Q. When 1.00 gram of compound Z is oxidized and all of the carbon and hydrogen are converted to oxides, 1.37 grams of CO_2 and 0.281 gram of water are produced. Determine the most probable molecular formula of compound Z.

Part a: PV = (grams/m wt) × RT

m wt = (3.53 grams/liter) (0.0821 liter-atm/mole K) × (300 K) (1/[750/760]) = 88.1 grams/mole (3 points)

OR

(3.53 grams/liter) (760/750) (300/273) × (22.4 liters/mole) = 88.1 grams/mole

OR other equivalent solutions

Part b: gram Q/mole X = 0.648 × 88.1 = 57.1

gram Q/mole Y = 0.730 × 104 = 75.9

gram Q/mole Z × 0.593 × 64.0 = 38.0

One correct (1 point)
All correct (1 additional point)

Part c: Masses in (b) must be integral multiples of atomic weight. Largest common denominator is 19. (1 point)

Note: Credit given for incorrect at. wt. if consistent with values in (b).

Part d: 1.37 grams CO_2 (1 mole/44.0 grams CO_2) = 0.0311 mole CO_2 ≡ 0.0311 mole C

0.281 gram H_2O (1 mole/18.0 grams H_2O) = 0.0156 mole H_2O = 0.0312 mole H (2 points)

1.00 gram Z (1 mole/64 grams) = 0.0156 mole Z

Each mole Z contains 2 moles of CH, or 26 grams, which leaves (64 − 26) = 38 grams, corresponding to 2 moles of Element Q. Mol. formula is $C_2H_2Q_2$. (1 point)

Note: Other equivalent solutions received credit.

1990

number of moles of H_2 and the number of moles of O_2 are equal. The total pressure is 1,146 millimeters mercury. (The equilibrium vapor pressure of pure water at 25° C is 24 millimeters mercury.)

The mixture is sparked, and H_2 and O_2 react until one reactant is completely consumed.

(a) Identify the reactant remaining and calculate the number of moles of the reactant remaining.

(b) Calculate the total pressure in the container at the conclusion of the reaction if the final temperature is 90° C. (The equilibrium vapor pressure of water at 90° C is 526 millimeters mercury.)

(c) Calculate the number of moles of water present as vapor in the container at 90° C.

a) $2H_2 + O_2 \longrightarrow 2H_2O$

Moles H_2 = moles O_2 initially but 2 moles of H_2 react for every mole of O_2. ∴ O_2 is left (1)

$P_{Tot} = P_{H_2+O_2} + P_{H_2O}$

$1146 = P_{H_2+O_2} + 24$ (1)

$P_{H_2+O_2} = 1122$ mm Hg

1122 mm/4 = P_{O_2} left (½ of init. O_2 which is ½ total)

$P_{O_2} = 280.5$ mm (1)

$P_1V_1/T_1 = P_2V_2/T_2$ OR $PV=nRT$ (1)

$\frac{(280.5)(.5 l)}{298°} = \frac{(760 mm)V_2}{273°}$ OR $\frac{(280.5/760)atm\ (.5 l)}{.0821 \frac{l\,atm}{mol\,deg}\ 298 deg} = n$ (1)

$V_2 = 0.169 l$

$n = 0.169 l/22.4$

$= 7.55 \times 10^{-3}$ mol

$n = 7.55 \times 10^{-3}$ mol (1)

b) $\frac{P_{O_2}(90°)}{363} = \frac{280.5}{298}$ OR $P = \frac{(7.55\times10^{-3} mol)(.0821)(363)}{0.5}$

$= .450$ atm

$P_{O_2}(90°) = 342$ mmHg $P = 342$ (1)

$P_{tot} = P_{O_2} + P_{H_2O}$

$= 342 + 526$

$= 868$ mm Hg (1)

c) $V_{H_2O}(STP) = \frac{526 mm Hg\ (.5 l)\ 273}{760\ (363)}$ OR $n = \frac{(526/760)atm\ (0.50 l)}{(0.0821 \frac{l\text{-}atm}{mol\,deg})(363 deg)}$

$V_{H_2O} = 0.260 l$ (1)

$n_{H_2O} = 0.260 l/22.4 l\,mol^{-1}$ $n = 0.0116$ mol

$= .0116$ mol

9 1993

STANDARDS

(a) Reducing the temperature of a gas reduces the average kinetic energy (or velocity) of the gas molecules. This would reduce the number (or frequency) of collisions of gas molecules with the surface of the balloon (OR decrease the momentum change that occurs when the gas molecules strike the balloon surface.) In order to maintain a constant pressure vs the external pressure, the volume must decrease. 1 pt. 1 pt

[If other 2 pts not awarded]

(b) The molecules of the gas do have volume 1 pt

When they are cooled sufficiently, the forces of attraction that exist between them cause them to liquefy or solidify. 2 pts

(c) The molecules of a gas are in constant motion so the HCl and NH_3 diffuse along the tube. Where they meet, NH_4Cl is formed. Since HCl has a higher molar mass, its velocity (avg) is lower. Therefore it doesn't diffuse as fast as the NH_3. 1 pt 1 pt

(d) The wind is moving molecules of air that are going mostly in one direction. Upon encountering a flag, they transfer some of their energy (momentum) to it and cause it to move (flap!). 1 pt. 1 pt.

1994

CHEMISTRY

STANDARDS

Question 3

(a) $n = \frac{PV}{RT} = \frac{(721)(0.090)}{(62.4)(298)} = 3.49 \times 10^{-3}$ mol H_2

25°C ⟶ 298 K *(1 pt.)*
745 - 24 = 721 mm Hg *(1 pt.)*
calculation of moles of H_2 *(1 pt.)*

(b) $\frac{(23.8)(0.090)}{(62.4)(298)} = 1.15 \times 10^{-4}$ mol H_2O *(1 pt.)*

$(1.15 \times 10^{-4})(6.03 \times 10^{23}) = 6.92 \times 10^{19}$ molecules H_2O *(1 pt.)*

(c) The average kinetic energies are equal, so

$$(\tfrac{1}{2}mv^2)_{H_2O} = (\tfrac{1}{2}mv^2)_{H_2}\ .$$

$$\frac{v_{H_2}}{v_{H_2O}} = \sqrt{\frac{MM_{H_2O}}{MM_{H_2}}} = \sqrt{\frac{18}{2}} = 3$$

(1 pt.) for formula
(1 pt.) for calculation

Note: credit also given for correct use of $v_{rms} = \sqrt{\frac{3RT}{M}}$.

(d) H_2O deviates more from ideal behavior. *(1 pt.)*

Explanation:

EITHER

i) The volume of the H_2O molecule is larger than that of the H_2 molecule

OR,

ii) The intermolecular forces among H_2O molecules are stronger than those among H_2 molecules

(1 pt.)

1995

QUESTION 2

(9 pts.)

a) $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ *(1 pt.)*

Notes: ignore phases (even when wrong)
multiples are OK
if balanced wrong, parts b and c should be consistent

b) $10.0\text{ g } C_3H_8 \times \dfrac{1\text{ mol } C_3H_8}{44.1\text{ g } C_3H_8} = 0.227\text{ mol } C_3H_8$ *(1 pt.)*

$0.227\text{ mol } C_3H_8 \times \dfrac{5\text{ mol } O_2}{1\text{ mol } C_3H_8} = 1.13\text{ mol } O_2$ *(1 pt.)*

$V = \dfrac{(1.13\text{ mol } O_2)(0.0821\text{ L·atm·mol}^{-1}\text{·K}^{-1})(303\text{ K})}{1.00\text{ atm}} = 28.1\text{ L } O_2$ *(1 pt.)*

$28.1\text{ L } O_2 \times \dfrac{100\text{ L air}}{21.0\text{ L } O_2} = 134\text{ L air}$ *(1 pt.)*

Note: answer must be consistent with part a

c) $\Delta H^0_{rxn} = \sum \Delta H^0_f\,(products) - \sum \Delta H^0_f\,(reactants)$

$-2{,}220.1\text{ kJ} = [4(-285.3\text{ kJ}) + 3(-393.5\text{ kJ})] - [5(0\text{ kJ}) + \Delta H^0_f(C_3H_8)]$ *(1 pt.)*
$-2{,}220.1\text{ kJ} = -1{,}141.2\text{ kJ} - 1{,}180.5\text{ kJ} - \Delta H^0_f(C_3H_8)$
$-2{,}220.1\text{ kJ} = -2{,}321.7\text{ kJ} - \Delta H^0_f(C_3H_8)$
$-101.6\text{ kJ} = \Delta H^0_f(C_3H_8)$ *(1 pt.)*

Notes: answer should be consistent with part a
1 point deducted if negative sign missing from answer
1 point deducted if $-2{,}220.1$ kJ substituted for $\Delta H^0_f(C_3H_8)$
no points earned if coefficients are inconsistent and not set equal to ΔH^0

d) $30.0\text{ g } C_3H_8 \times \dfrac{1\text{ mol } C_3H_8}{44.1\text{ g } C_3H_8} \times \dfrac{2{,}220.1\text{ kJ}}{1\text{ mol } C_3H_8} = 1.51 \times 10^3\text{ kJ}$ *(1 pt.)*

$1.51 \times 10^3\text{ kJ} = 1.51 \times 10^6\text{ J} = (8{,}000\text{ g})(4.18\text{ J·g}^{-1}\text{·K}^{-1})(\Delta T)$

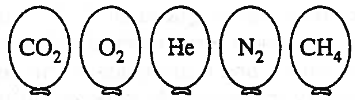
$45.1\text{ K (or °C)} = \Delta T$ *(1 pt.)*

Notes: must correctly substitute into $q = mc\Delta T$ for 1 point
1 point earned if q value wrong but ΔT consistent

1996

QUESTION 5
(8 points)

5.



Represented above are five identical balloons, each filled to the same volume at 25°C and 1.0 atmosphere pressure with the pure gases indicated.

(a) Which balloon contains the greatest mass of gas? Explain.

(b) Compare the average kinetic energies of the gas molecules in the balloons. Explain.

(c) Which balloon contains the gas that would be expected to deviate most from the behavior of an ideal gas? Explain.

(d) Twelve hours after being filled, all the balloons have decreased in size. Predict which balloon will be the smallest. Explain your reasoning.

Scoring Guide

Question 5

(a) CO_2 — *1 point*

because all contain same number of molecules (moles), and CO_2 molecules are the heaviest — *1 point*

(<u>Note:</u> total of 1 point earned if CO_2 not chosen but same number of molecules (moles) is specified)

(b) All are equal — *1 point*

because same temperature ⇒ same average kinetic energy — *1 point*
(<u>Note:</u> just restatement of "same conditions, etc." does not earn second point)

(c) CO_2 — *1 point*

it has the most electrons, hence is the most polarizable
it has the strongest intermolecular (London) forces
} *either <u>one</u>* — *1 point*

(<u>Note:</u> also allowable are "polar bonds", "inelastic collisions"; claiming larger size or larger molecular volume does not earn second point)

(d) He — *1 point*

greatest movement through the balloon wall
smallest size
greatest molecular speed
most rapid effusion (Graham's law)
} *any <u>one</u>* — *1 point*

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Question 2

10 points

2. A rigid 8.20 L flask contains a mixture of 2.50 moles of H_2, 0.500 mole of O_2, and sufficient Ar so that the partial pressure of Ar in the flask is 2.00 atm. The temperature is 127ºC.

(a) Calculate the total pressure in the flask.

$P_{H_2} = \left(\frac{n_{H_2}RT}{V}\right) = \left(\frac{(2.50\text{ mol})(0.0821\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(400K)}{8.20\text{ L}}\right) = 10.0\text{ atm}$	1 point earned for the partial pressure of H_2
$P_{O_2} = \left(\frac{n_{O_2}RT}{V}\right) = \left(\frac{(0.500\text{ mol})(0.0821\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(400\text{ K})}{8.20\text{ L}}\right) = 2.00\text{ atm}$ $P_{Ar} = 2.0\text{ atm}$	1 point earned for the partial pressure of O_2
$P_T = P_{H_2} + P_{O_2} + P_{Ar} = 10.0\text{ atm} + 2.0\text{ atm} + 2.0\text{ atm} = 14.0\text{ atm}$	1 point earned for the total pressure

(b) Calculate the mole fraction of H_2 in the flask.

$\text{Mol fraction}_{H_2} = \left(\frac{\text{mol}_{H_2}}{\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar}}\right)$ $\text{mol}_{H_2} = 2.50\text{ mol}$ $\text{mol}_{O_2} = 0.500\text{ mol}$ $\text{mol}_{Ar} = \left(\frac{PV}{RT}\right) = \left(\frac{(2.00\text{ atm})(8.20\text{ L})}{(0.0821\frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(400\text{ K})}\right) = 0.500\text{ mol Ar}$	1 point earned for mol Ar
$\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar} = 2.50\text{ mol} + 0.500\text{ mol} + 0.500\text{ mol}$ $= 3.50\text{ mol total}$ $\text{Mol fraction}_{H_2} = \left(\frac{\text{mol}_{H_2}}{\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar}}\right) = \left(\frac{2.50\text{ mol}}{3.50\text{ mol}}\right) = 0.714$	1 point earned for mol fraction of H_2

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Question 2 (cont'd.)

(c) Calculate the density (in g L^{-1}) of the mixture in the flask

$2.50 \text{ mol } H_2 \left(\frac{2.016 \text{ g } H_2}{1 \text{ mol } H_2}\right) = 5.04 \text{ g } H_2$ $0.500 \text{ mol } O_2 \left(\frac{32.0 \text{ g } O_2}{1 \text{ mol } O_2}\right) = 16.0 \text{ g } O_2$ $0.500 \text{ mol Ar} \left(\frac{40.0 \text{ g Ar}}{1 \text{ mol Ar}}\right) = 20.0 \text{ g Ar}$	1 point earned for mass of all species
total mass = 5.04 g + 16.0 g + 20.0 g = 41.0 g $\text{density} = \left(\frac{\text{total mass}}{\text{volume}}\right) = \left(\frac{41.0 \text{ g}}{8.20 \text{ L}}\right) = 5.00 \text{ g L}^{-1}$	1 point earned for density

The mixture in the flask is ignited by a spark, and the reaction represented below occurs until one of the reactants is entirely consumed.

$$2\, H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

(d) Give the mole fraction of all species present in the flask at the end of the reaction.

$2\, H_2(g) + O_2(g) \rightarrow 2\, H_2O(g)$ I: 2.50, 0.500, 0 C: – 1.00, – 0.500, 2(+0.500) E: 1.50, 0, 1.00	1 point earned for 1.00 mol H_2O
total moles after reaction = $\text{mol}_{H_2} + \text{mol}_{H_2O} + \text{mol}_{Ar}$ = 1.50 mol + 1.00 mol + 0.500 mol = 3.00 mol total	1 point earned for total moles
$\text{mol fraction}_{H_2} = \left(\frac{1.50 \text{ mol } H_2}{3.00 \text{ mol}}\right) = 0.500$ $\text{mol fraction}_{O_2} = \left(\frac{0 \text{ mol } O_2}{3.00 \text{ mol}}\right) = 0$ (not necessary) $\text{mol fraction}_{Ar} = \left(\frac{0.500 \text{ mol Ar}}{3.00 \text{ mol}}\right) = 0.167$ $\text{mol fraction}_{H_2O} = \left(\frac{1.00 \text{ mol } H_2O}{3.00 \text{ mol}}\right) = 0.333$	1 point earned for any <u>two</u> mol fractions, excluding O_2