NATIONAL MATH + SCIENCE INITIATIVE

AP CHEMISTRY

Gas Laws

2016 EDITION

Click on the following link or scan the QR code to complete the evaluation for the Study Session
https://www.surveymonkey.com/r/S_SSS

Periodic Table of the Elements

1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 16.00	9 F 19.00	10 Ne 20.179
11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.09	15 P 30.974	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.938	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 93.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.91	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 *La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.21	76 Os 190.2	77 Ir 192.2	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.02	89 †Ac 227.03	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 § (269)	111 § (272)	112 § (277)						

§Not yet named

*Lanthanide Series:	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
†Actinide Series:	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

AP Chemistry Equations & Constants

Throughout the test the following symbols have the definitions specified unless otherwise noted.

L, mL	= liter(s), milliliter(s)	mm Hg	= millimeters of mercury
g	= gram(s)	J, kJ	= joule(s), kilojoule(s)
nm	= nanometer(s)	V	= volt(s)
atm	= atmosphere(s)	mol	= mole(s)

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy

ν = frequency

λ = wavelength

Planck's constant, $h = 6.626 \times 10^{-34}$ J s

Speed of light, $c = 2.998 \times 10^{8}$ m s^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

EQUILIBRIUM

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}, \text{ where } a\,A + b\,B \rightleftarrows c\,C + d\,D$$

$$K_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

$$K_b = \frac{[OH^-][HB^+]}{[B]}$$

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25°C$$

$$= K_a \times K_b$$

$$pH = -\log[H^+],\ pOH = -\log[OH^-]$$

$$14 = pH + pOH$$

$$pH = pK_a + \log\frac{[A^-]]}{[HA]}$$

$$pK_a = -\log K_a,\ pK_b = -\log K_b$$

Equilibrium Constants

K_c (molar concentrations)

K_p (gas pressures)

K_a (weak acid)

K_b (weak base)

K_w (water)

KINETICS

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$t_{1/2} = \frac{0.693}{k}$$

k = rate constant

t = time

$t_{1/2}$ = half-life

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$P_A = P_{total} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

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

$$n = \frac{m}{M}$$

$$K = °C + 273$$

$$D = \frac{m}{V}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

Molarity, M = moles of solute per liter of solution

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
m = mass
M = molar mass
D = density
KE = kinetic energy
v = velocity
A = absorbance
a = molar absorptivity
b = path length
c = concentration

Gas constant, $R = 8.314 \text{ J mol}^{-1}\text{K}^{-1}$
$= 0.08206 \text{ L atm mol}^{-1}\text{K}^{-1}$
$= 62.36 \text{ L torr mol}^{-1}\text{K}^{-1}$
1 atm = 760 mm Hg
= 760 torr
STP = 0.00 °C and 1.000 atm

THERMOCHEMISTRY/ ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta S° = \sum S° \text{ products} - \sum S° \text{ reactants}$$

$$\Delta H° = \sum \Delta H_f° \text{ products} - \sum \Delta H_f° \text{ reactants}$$

$$\Delta G° = \sum \Delta G_f° \text{ products} - \sum \Delta G_f° \text{ reactants}$$

$$\Delta G° = \Delta H° - T\Delta S°$$
$$= -RT \ln K$$
$$= -nFE°$$

$$I = \frac{q}{t}$$

q = heat
m = mass
c = specific heat capacity
T = temperature
$S°$ = standard entropy
$H°$ = standard enthalpy
$G°$ = standard free energy
n = number of moles
$E°$ = standard reduction potential
I = current (amperes)
q = charge (coulombs)
t = time (seconds)

Faraday's constant, F = 96,485 coulombs per mole of electrons

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

AP*Chemistry: Gases

These terms may be used in a question testing your understanding of GASES

pressure; volume; moles; molecular mass; temperature; total pressure; diffusion; effusion; ratio of gases; any non standard temperature/pressure conditions involving gases; molecular motion; kinetic energy; collected over water; O_2; N_2: CO_2; dry gas; root mean square

Key Formulas or Relationships

$PV = nRT$ (this is the most commonly used…try it first)

$R = 0.0821 \frac{\text{L atm}}{\text{mol K}}$ or for ENERGY related calculations $R = 8.31 \frac{\text{J}}{\text{mol K}}$

$MM = \frac{dRT}{P}$

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ Solve for P, V, or T as needed; omit any variable that is constant

$P_{total} = P_1 + P_2 \ldots$ or $P_{gas} = P_{total} - P_{water}$ when a gas is collected over water

Also in a mixture, the partial pressure of gas_1 = mole fraction of gas_1 × total pressure

STP for gases is 0°C or 273 K and 1 atm or 760 mmHg

Key Concepts

Remember to relate molecular mass to molecular motion (smaller = faster) especially when talking about diffusion or movement of gases.

Molar volume 1 mol = 22.4 L at STP only. Don't use 22.4 if not at STP!

Understand conceptually that variables are either direct (P/T and V/T) and inverse (P/V) relationships

Van der Waals equation – adjusts ideal gas equation for IMF (*a* factor) and particle volume (*b* factor) Gases will deviate more from ideal behavior at high pressure and low temperature. Also, more electrons = greater IMFs and particle volume and thus more deviation from ideal behavior [key phrase to use for points!].

Connections to Other Chapters

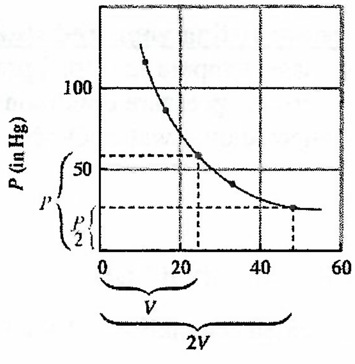
Stoichiometry
Thermodynamics
Equilibrium
Bonding

Potential Pitfalls and Unit Warnings

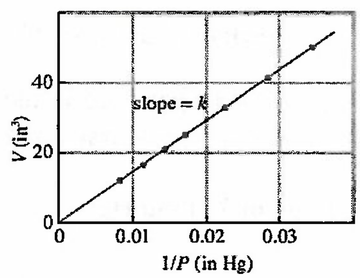
KELVINS, KELVINS, KELVINS
Make sure units match with constants
"Collected over water" -- adjust P by subtracting vapor pressure of water at the given temperature before continuing with calculations

Figures or Graphs you may need to interpret

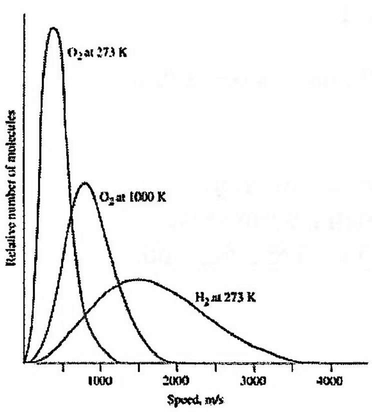
- o The data Boyle collected is graphed on (a) above.
- o $PV = k$
- o Therefore, $V = \frac{k}{P} = k\frac{1}{P}$ which is the equation for a straight line of the type
- o $y = mx + b$ where m = slope, and b is the y-intercept
- o In this case, $y = V$, $x = 1/P$ and $b = 0$. Check out the plot on the right (b).
- o $P_1V_1 = P_2V_2$ is the easiest form of Boyle's law to **memorize**
- o Boyle's Law has been tested for over three centuries. It holds true ***only at low pressures***.



(a)

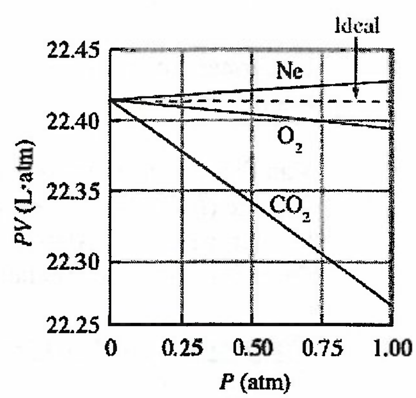


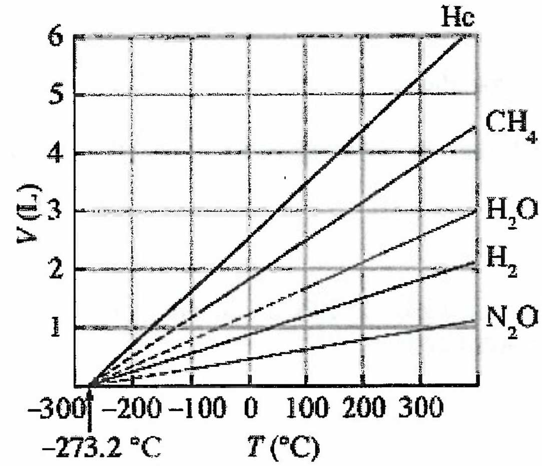
(b)



As temperature increases the average speed of molecules increases but the *variation* in molecule speeds decreases

An **ideal** gas is expected to have a constant value of *PV*, as shown by the dotted line. CO_2 shows the largest change in PV, and this change is actually quite small: *PV* changes from about 22.39 L·atm at 0.25 atm to 22.26 L·atm at 1.00 atm. Thus Boyle's Law is a good approximation at these relatively low pressures.

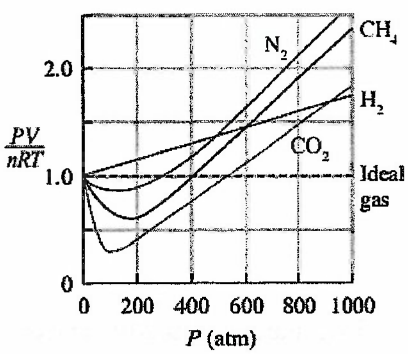




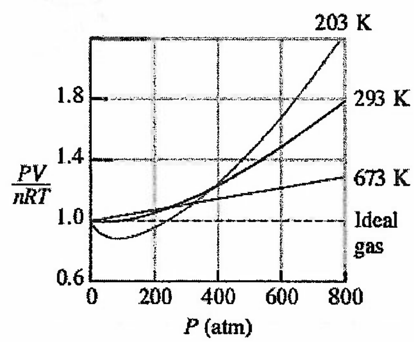
Jacques Charles was a French physicist and the first person to fill a hot "air" balloon with hydrogen gas and made the first solo balloon flight!

- o $V \propto T$ plot = straight line
- o $V_1T_2 = V_2T_1$
- o Temperature ∝ Volume **at constant pressure**
- o This figure shows the plots of V vs. T (Celsius) for several gases. The solid lines represent experimental measurements on gases. The dashed lines represent extrapolation of the data into regions where these gases would become liquids or solids. Note that the samples of the various gases contain different numbers of moles.
- o What is the temperature when the Volume extrapolates to zero?

These graphs are also classics and make great multiple choice questions on the AP exam.



When $PV/nRT = 1.0$, the gas is ideal
All of these are at 200K.
Note the P's where the curves cross the dashed line [ideality].



This graph is just for nitrogen gas.
Note that although nonideal behavior is evident at each temperature, the deviations are smaller at the higher Ts.

Don't underestimate the power of understanding these graphs. We love to ask question comparing the behavior of ideal and real gases. It's not likely you'll be asked an entire free-response gas problem on the real exam in May. Gas Laws are tested extensively in the multiple choice since it's easy to write questions involving them! You will most likely see $PV = nRT$ as one part of a problem in the free-response, just not a whole problem!

2004B

Answer the following questions related to hydrocarbons.

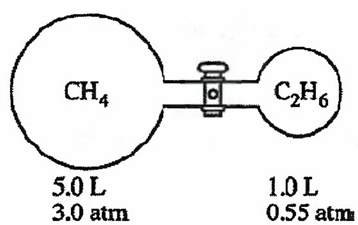
(a) Determine the empirical formula of a hydrocarbon that contains 85.7 percent carbon by mass.

(b) The density of the hydrocarbon in part (a) is 2.0 g L^{-1} at 50°C and 0.948 atm.

(i) Calculate the molar mass of the hydrocarbon.

(ii) Determine the molecular formula of the hydrocarbon.

(c) Two flasks are connected by a stopcock as shown below. The 5.0 L flask contains CH_4 at a pressure of 3.0 atm, and the 1.0 L flask contains C_2H_6 at a pressure of 0.55 atm. Calculate the total pressure of the system after the stopcock is opened. Assume that the temperature remains constant.



(d) Octane, $C_8H_{18}(l)$, has a density of 0.703 g mL^{-1} at 20°C. A 255 mL sample of $C_8H_{18}(l)$ measured at 20°C reacts completely with excess oxygen as represented by the equation below.

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$$

Calculate the total number of moles of gaseous products formed.

2002B

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 127°C.

(a) Calculate the total pressure in the flask.

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

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

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.

2009B

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$$

The mass of an aqueous solution of H_2O_2 is 6.951 g. The H_2O_2 in the solution decomposes completely according to the reaction represented above. The $O_2(g)$ produced is collected in an inverted graduated tube over water at 23.4°C and has a volume of 182.4 mL when the water levels inside and outside of the tube are the same. The atmospheric pressure in the lab is 762.6 torr, and the equilibrium vapor pressure of water at 23.4°C is 21.6 torr.

(a) Calculate the partial pressure, in torr, of $O_2(g)$ in the gas-collection tube.

(b) Calculate the number of moles of $O_2(g)$ produced in the reaction.

(c) Calculate the mass, in grams, of H_2O_2 that decomposed.

(d) Calculate the percent of H_2O_2, by mass, in the original 6.951 g aqueous sample.

(e) Write the oxidation number of the oxygen atoms in H_2O_2 and the oxidation number of the oxygen atoms in O_2 in the appropriate cells in the table below.

Substance	Oxidation Number of Oxygen Atoms
H_2O_2	
O_2	

(f) Write the balanced oxidation half-reaction for the reaction.