



UNIT 1 : STOICHIOMETRY

LINE CALCULATIONS, UNIT CONVERSIONS, & SIGNIFICANT DIGITS

- for temp value (given on exam):

$$\hookrightarrow T(^{\circ}\text{F}) = 1.8 \times T(^{\circ}\text{C}) + 32$$
$$\bullet T(^{\circ}\text{F}) = \frac{9}{5} T(^{\circ}\text{C}) + 32$$
$$\hookrightarrow T(^{\circ}\text{C}) = \frac{T(^{\circ}\text{F}) - 32}{1.8}$$

$$\hookrightarrow T(\text{K}) = T(^{\circ}\text{C}) + 273.15$$

◦ no conversion factor

$$\hookrightarrow T(^{\circ}\text{R}) = T(\text{K}) \times 1.8$$

$$\hookrightarrow T(^{\circ}\text{R}) = T(^{\circ}\text{F}) + 491.67$$

for change in temp, use conversion factor: $\frac{1\text{ K}}{1.8^{\circ}\text{R}}$, $\frac{1\text{ K}}{1.8^{\circ}\text{F}}$, $\frac{1^{\circ}\text{C}}{1.8^{\circ}\text{F}}$, $\frac{1^{\circ}\text{C}}{1.8^{\circ}\text{R}}$, $\frac{1^{\circ}\text{C}}{1\text{ K}}$, $\frac{1^{\circ}\text{F}}{1^{\circ}\text{R}}$

- significant digits are # of digits believed to be correct

↳ 27 has 2

↳ 0.0582 has 3

↳ 4.36 has 3

↳ 400 has 1

◦ to make it have 3 SD, 4.00 E 2

◦ to make it have 2 SD, 4.0 E 2

- keep all digits for intermediate ans

- when add/subtract, round to smallest # of digits past decimal place

$$\hookrightarrow \text{e.g. } 15.2\text{ g} + 10.9 = 25\text{ g}$$

- when multiply/divide, keep smallest # of SD

$$\hookrightarrow \text{e.g. } 1.02\text{ g/mL} \times 155.5\text{ mL} = 159\text{ g}$$

- rules for determining SD:

- all nonzero digits are significant

↳ e.g. 21.58 has 4 SD

- for quantities < 1 , any 0 preceding 1st non-zero digit is not significant

↳ 0.00237 & 0.00250 have 3 SD

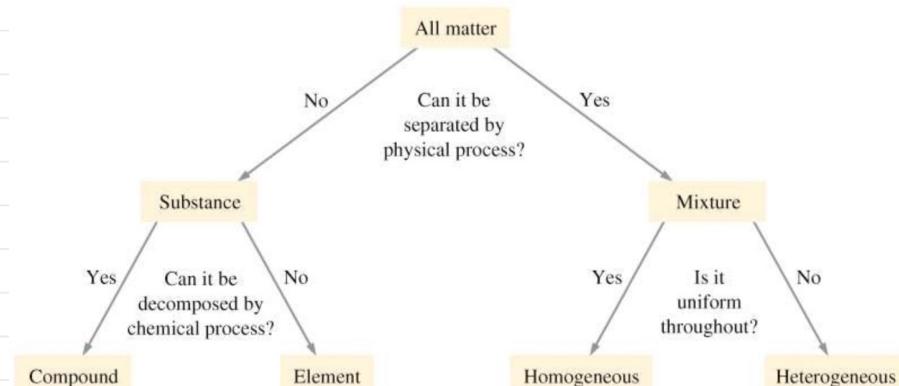
- for quantities > 1 , any 0 following last non-zero digit is not significant unless there's decimal

↳ 200 has 1 SD

↳ 200.0 has 4 SD

ATOMIC THEORY OF MATTER & CHEMICAL COMPOUNDS

- classification of matter:



physical separation techniques include distillation, centrifuge, filter, chromatography

CONCEPT CHECK 1.2

Identify whether each of the following is:

- A) a heterogeneous mixture C) a pure substance
 B) a homogeneous mixture D) cannot say

- i. A piece of metal D (could be pure metal or alloy)
 ii. Distilled water C
 iii. Distilled water ice cubes in distilled water C
 iv. Oil on water A
 v. Your morning cup of coffee D

periodic table of elements:

The periodic table shows the following information for each element:

- Symbol:** The element symbol is enclosed in a box.
- Atomic Number:** The atomic number is written above the symbol.
- Mass Number:** The mass number is written below the symbol.
- Atomic Mass:** The atomic mass is written to the right of the symbol.
- # of protons:** An orange arrow points to the atomic number.
- Relative atomic mass:** An orange arrow points to the atomic mass.
- atomic mass units (u):** An orange arrow points to the atomic mass.

Group	Period	Element	Symbol	Atomic Number	Mass Number	Atomic Mass
1A	1	H	H	1	1.00794	1.00794
2A	1	He	He	2	4.00260	4.00260
3A	2	Li	Li	3	6.941	6.941
4A	2	Be	Be	4	9.01218	9.01218
5A	2	N	N	5	14.011	14.011
6A	2	O	O	6	16.000	16.000
7A	2	F	F	7	19.000	19.000
8A	2	Ne	Ne	8	20.1797	20.1797
13A	3	B	B	13	10.811	10.811
14A	3	C	C	14	12.011	12.011
15A	3	N	N	15	14.0067	14.0067
16A	3	O	O	16	15.9994	15.9994
17A	3	F	F	17	18.9984	18.9984
13	3	Al	Al	13	26.9815	26.9815
14	3	Si	Si	14	28.0855	28.0855
15	3	P	P	15	30.9738	30.9738
16	3	S	S	16	32.066	32.066
17	3	Cl	Cl	17	35.4527	35.4527
18	3	Ar	Ar	18	39.948	39.948
19	4	K	K	19	39.0983	39.0983
20	4	Ca	Ca	20	40.078	40.078
21	4	Sc	Sc	21	44.9559	44.9559
22	4	Ti	Ti	22	47.88	47.88
23	4	V	V	23	50.9415	50.9415
24	4	Cr	Cr	24	51.9961	51.9961
25	4	Mn	Mn	25	54.9381	54.9381
26	4	Fe	Fe	26	55.847	55.847
27	4	Co	Co	27	58.9332	58.9332
28	4	Ni	Ni	28	58.693	58.693
29	4	Cu	Cu	29	63.546	63.546
30	4	Zn	Zn	30	65.39	65.39
31	4	Ga	Ga	31	69.723	69.723
32	4	Ge	Ge	32	72.61	72.61
33	4	As	As	33	74.9216	74.9216
34	4	Se	Se	34	78.96	78.96
35	4	Br	Br	35	79.904	79.904
36	4	Kr	Kr	36	83.80	83.80
37	5	Rb	Rb	37	85.4678	85.4678
38	5	Sr	Sr	38	87.62	87.62
39	5	Y	Y	39	88.9059	88.9059
40	5	Zr	Zr	40	91.224	91.224
41	5	Nb	Nb	41	92.9064	92.9064
42	5	Mo	Mo	42	95.94	95.94
43	5	Tc	Tc	43	(98)	(98)
44	5	Ru	Ru	44	101.07	101.07
45	5	Rh	Rh	45	102.906	102.906
46	5	Pd	Pd	46	106.42	106.42
47	5	Ag	Ag	47	107.868	107.868
48	5	Cd	Cd	48	112.411	112.411
49	5	In	In	49	114.818	114.818
50	5	Sn	Sn	50	118.710	118.710
51	5	Sb	Sb	51	121.757	121.757
52	5	Te	Te	52	127.60	127.60
53	5	I	I	53	128.604	128.604
54	5	Xe	Xe	54	131.29	131.29
55	6	Cs	Cs	55	132.905	132.905
56	6	Ba	Ba	56	137.327	137.327
57	6	*La	*La	57	138.906	138.906
58	6	Hf	Hf	58	178.49	178.49
59	6	Ta	Ta	59	180.948	180.948
60	6	W	W	60	183.84	183.84
61	6	Re	Re	61	186.207	186.207
62	6	Os	Os	62	190.23	192.22
63	6	Ir	Ir	63	192.22	195.08
64	6	Pt	Pt	64	196.967	196.967
65	6	Au	Au	65	200.59	204.383
66	6	Hg	Hg	66	204.383	207.2
67	6	Tl	Tl	67	207.2	208.980
68	6	Pb	Pb	68	208.980	(209)
69	6	Bi	Bi	69	(209)	(210)
70	6	Po	Po	70	(210)	(222)
71	6	At	At	71	(222)	(293)
72	7	Lanthanide series	Lanthanide series	72	140.115	140.908
73	7	Pr	Pr	73	144.24	144.24
74	7	Nd	Nd	74	149.115	149.115
75	7	Pm	Pm	75	150.36	150.36
76	7	Sm	Sm	76	151.965	151.965
77	7	Eu	Eu	77	157.25	157.25
78	7	Gd	Gd	78	158.925	158.925
79	7	Tb	Tb	79	162.50	162.50
80	7	Dy	Dy	80	164.930	164.930
81	7	Ho	Ho	81	167.26	167.26
82	7	Er	Er	82	168.934	168.934
83	7	Tm	Tm	83	173.04	173.04
84	7	Yb	Yb	84	174.967	174.967
85	7	Lu	Lu	85		
86	7			86		
87	8	Actinide series	Actinide series	87	232.038	231.036
88	8	Th	Th	88	238.029	238.029
89	8	Pa	Pa	89	237.048	237.048
90	8	U	U	90	(244)	(244)
91	8	Np	Np	91	(243)	(243)
92	8	Pu	Pu	92	(247)	(247)
93	8	Am	Am	93	(251)	(251)
94	8	Cm	Cm	94	(257)	(257)
95	8	Bk	Bk	95	(258)	(258)
96	8	Cf	Cf	96	(259)	(259)
97	8	Es	Es	97	(260)	(260)
98	8	Fm	Fm	98		
99	8	Md	Md	99		
100	8	No	No	100		
101	8	Lr	Lr	101		
102	8			102		
103	8			103		

$$\hookrightarrow \text{mass #} = \# p^+ + \# n^0$$

$$\hookrightarrow \text{atomic #} = \# p^+$$

CONCEPT CHECK 1.3

The mass number and the atomic number of an atom that contains 15 electrons, 15 protons and 16 neutrons are, respectively:

- A) 46 and 15
 B) 46 and 16
 C) 31 and 15
 D) 30 and 16
 E) None of the above

octet rule: atoms are most stable when their outer shell is completely full/empty

elements combine to form compounds by atomic bonding

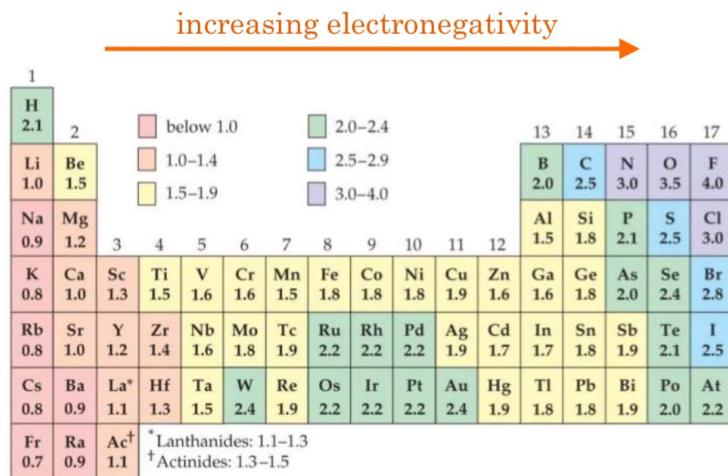
↳ bonding involves e⁻ that are shared (covalent bond) or transferred (ionic bond)

↳ energy is absorbed/released when e⁻ are transferred or shared

electronegativity: measure of how strongly an atom competes for e⁻ in bonds formed w/ other atoms

electron affinity: energy released when e⁻ added to neutral atom

electronegativity trends:



increasing electronegativity ↑

in ionic compounds, one atom donates e^- to another atom

↳ e.g. NaCl is crystal of Na^+ & Cl^- ions

↳ dissociate into ions when dissolved in water

↳ usually metal combined w/ non-metal

in covalent compounds, one or more atoms share e^-

↳ e.g. CH_4 , $\text{C}_6\text{H}_{12}\text{O}_6$

↳ large, organic molecules are usually covalent

↳ 2 or more atoms joined by covalent bonds may form charged polyatomic ion

◦ ammonium NH_4^+

◦ carbonate CO_3^{2-}

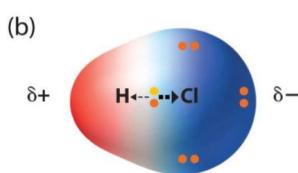
◦ sulfate SO_4^{2-}

· types of atomic bonds:



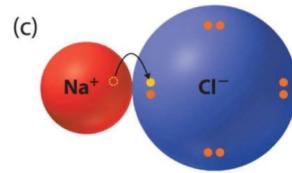
Nonpolar covalent bond

Bonding electrons shared equally between two atoms.
No charges on atoms.



Polar covalent bond

Bonding electrons shared unequally between two atoms.
Partial charges on atoms.



Ionic bond

Complete transfer of one or more valence electrons.
Full charges on resulting ions.

· molecular formula shows acc # of atoms in molecule

↳ e.g. hexene is C_6H_{12}

· empirical formula shows relative # of atoms in molecule

↳ e.g. hexene is CH_2

· molecular formula can be obtained from empirical formula if molecular mass of compound is known

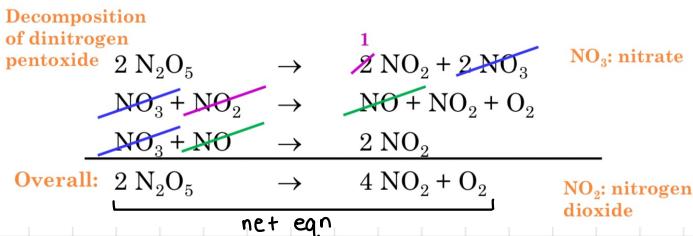
CONCEPT CHECK 1.4

Which of the following compounds has a different empirical formula from the others?

- A) Glucose ($C_6H_{12}O_6$) CH_2O
 B) Ribose ($C_5H_{10}O_5$) CH_2O
 C) Sorbitol ($C_6H_{14}O_6$) $C_3H_7O_3$
 D) Acetic acid ($C_2H_4O_2$) CH_2O
 E) Formaldehyde (CH_2O) CH_2O

CHEMICAL REACTIONS & THE MOLE CONCEPT

- during chemical rxn, atoms rearrange through breaking & formation of chemical bonds
 - chemical eqns describe changes that occur in chemical rxns
 - ↳ must be balanced (atom conservation principle)
 - balancing an equation is done by including stoichiometric coefficients
 - ↳ stoichiometric chemical eqn describes only net changes in rxn
 - actual net equation (unbalanced)
 - ↳ e.g. $2 \text{N}_2\text{O}_5 \rightarrow 4 \text{NO}_2 + \text{O}_2$
 - mechanism eqns describe steps required to go from reactants to products at molecular level

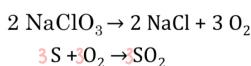


- NO_3 is intermediate product
 - for sequential rxn : 1) $\text{A} + \text{B} \rightarrow \text{C} + \text{D}$
 2) $\text{C} + \text{E} \rightarrow \text{F}$
 - ↳ overall net eqn: $\text{A} + \text{B} + \text{E} \rightarrow \text{D} + \text{F}$

- **Avogadro's constant** : # of elementary entities in 1 mole
↳ $\frac{12\text{ g/mol}}{1.9926 \cdot 10^{-2}\text{ g/atom}}$
 - mole is measurement of quantity : 1 mole = $6.022 \cdot 10^{23}$ un
 - **molar mass**: mass of 1 mole of substance
 - ↳ aka molecular weight
 - ↳ mass on periodic table is molar mass

CONCEPT CHECK 1.5

How many moles of NaClO_3 are needed to produce 6.00 mol of SO_2 in the following two-step reaction?

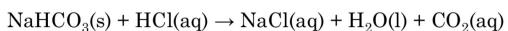


- A) 2.00 mol NaClO₃
 - B)** 4.00 mol NaClO₃
 - C) 3.00 mol NaClO₃
 - D) 18.00 mol NaClO₃
 - E) None of the above

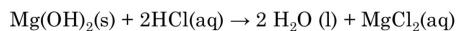
$$\hookrightarrow 6.00 \text{ mol} / 3 = 2$$

CONCEPT CHECK 1.6

Baking soda (NaHCO_3) is often used as an antacid. It neutralizes excess hydrochloric acid secreted by the stomach according to the equation:



Milk of magnesia, which is an aqueous suspension of magnesium hydroxide, is also used as an antacid, as shown below:



Which is the most effective antacid per gram
A) NaHCO_3 or B) Mg(OH)_2 ?

- ↳ more acid (HCl) getting neutralized per mol of antacid
- 1:1 vs 1:2

COMPOSITION OF COMPOUNDS & MIXTURES

- mole fraction: $x_A = \frac{n_A}{n_T} = \frac{n_A}{\sum_i n_i}$
- mole percentage: $x_A \times 100\%$
- mass fraction: $w_A = \frac{m_A}{m_T} = \frac{m_A}{\sum_i m_i}$
- mass percentage: $w_A \times 100\%$
- avg molar mass: mass of 1 mol of mixture of known composition
 - ↳ $\bar{M} = \sum_i x_i M_i$

- solutions are composed of a solvent & one or more solutes
 - ↳ solvent is present in largest amount
 - for aqueous solns, solvent is water
 - ↳ solute is present in smaller amounts & is dissolved in solvent
- solutions are homogenous (i.e. have uniform properties)
- molarity describes concentration of solution
 - ↳ $\frac{\text{amount of solute (moles)}}{\text{volume of soln (litres)}}$
 - ↳ $C = \frac{n}{V}$
 - ↳ M stands for mol/L
- other ways to express concentration:
 - ↳ percentages
 - by mass: 25% ($\frac{w}{w}$) = 25 g solute per 100 g soln
 - by volume: 25% ($\frac{v}{v}$) = 25 mL solute per 100 mL soln
 - weight to volume: 25% ($\frac{w}{v}$) = 25 g solute per 100 mL soln
 - ↳ $\frac{\text{amount of solute (moles)}}{\text{amount of solvent (kg)}}$
 - ↳ molality = $\frac{\text{amount of solute (moles)}}{\text{g solute}}$
 - ↳ parts per million (ppm) = $\frac{1 \text{,}000 \text{,}000 \text{ g soln}}{\text{g solute}}$
 - ↳ parts per billion (ppb) = $\frac{1 \text{,}000 \text{,}000 \text{,}000 \text{ g soln}}{\text{g solute}}$

STOICHIOMETRY CALCULATIONS

- theoretical yield: expected yield from given quantities of reactants
- actual yield: quantity that's acc produced
- percentage yield: ratio of actual yield to theoretical yield, expressed as percent
 - ↳ percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \cdot 100\%$
- limiting reactant is completely consumed
 - ↳ other reactants are called excess reactants
 - ↳ must use limiting reactant as basis
- percentage excess is proportion by which excess reactant exceeds stoichiometric amount

CONCEPT CHECK 1.7 & 1.8

A mixture containing 2.0 moles of A, 2.0 moles of B and 2.0 moles of C is allowed to react. The reaction given by the following balanced equation occurs:



The limiting reactant is...

- A) A B) B C) C

The percent excess of A is...

- A) 50% B) 100% C) 200%

$$\begin{aligned} \text{A:B} &= 2:4 = 1:2 = 1.0 \text{ mol : } 2.0 \text{ mol} \\ \text{excess} &= \frac{2.0 - 1.0}{1.0} \cdot 100\% \\ &= 100\% \end{aligned}$$

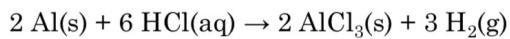
CONCEPT CHECK 1.9

A reaction mixture contains equal moles of calcium (Ca) and sulfur (S). If the percent yield is 80.0%, the mass of calcium sulfide (CaS) produced would be equal to:

- A) The sum of the masses of Ca and S
B) 80.0% of the sum of the masses of Ca and S.
C) 20.0% of the sum of the masses of Ca and S.
D) None of the above.

CONCEPT CHECK 1.10

A solution containing HCl reacts with 125% excess aluminum according to the reaction given by the following equation:



How many moles of Al(s) should be provided for 6 mol HCl?

- A) 2.0 mol Al
B) 2.5 mol Al
C) 3.0 mol Al
D) 4.0 mol Al
E) 4.5 mol Al

$$\begin{aligned} \text{excess 125\%} &\rightarrow \text{mol Al } 2.25 \\ &= 2 \cdot 2.25 \\ &= 4.5 \text{ mol Al} \end{aligned}$$

UNIT 2 : STATES OF MATTER

GAS PRESSURE AND KINETIC MOLECULAR THEORY

postulates of gas behaviour:

- 1) gas is composed of very large # of molecules
- 2) molecules are separated by large distance relative to their own size
- 3) gas is composed of large # of molecules in ceaseless motion

speeds of ideal gas molecules obey Maxwell-Boltzmann speed distribution:

$$f(u) = 4\pi \left(\frac{M}{2\pi RT}\right)^{3/2} u^2 e^{-\left(\frac{Mu^2}{2RT}\right)} = 4\pi \left(\frac{m}{2\pi k_B T}\right)^{3/2} u^2 e^{-\left(\frac{mu^2}{2k_B T}\right)}$$

$$\hookrightarrow \text{Boltzmann constant is } k_B = \frac{R}{n_A} = \frac{8.314 \text{ J/(mol} \cdot \text{K)}}{6.022 \cdot 10^{23} / \text{mol}} = 1.3806 \cdot 10^{-23} \text{ J/K}$$

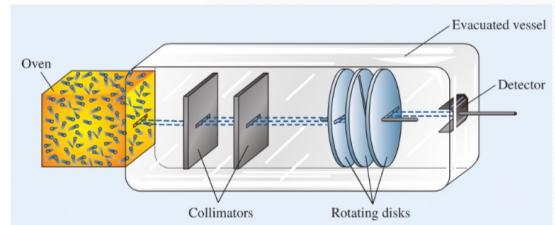
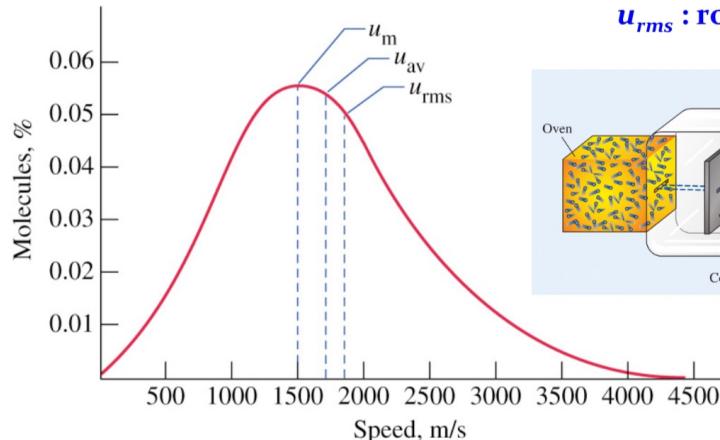
↳

Hydrogen gas at 0 °C

u_m : most probable speed

u_{av} : average speed

u_{rms} : root-mean-square speed



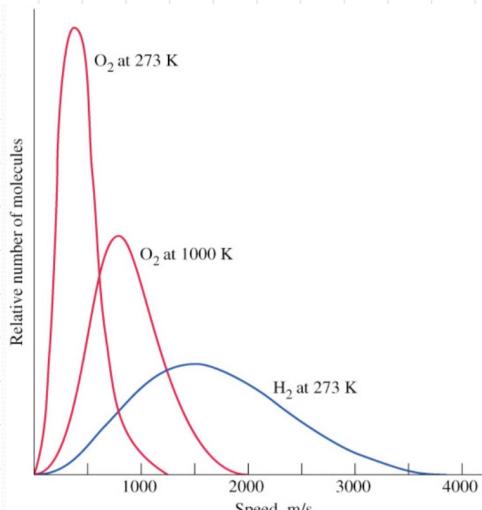
most probable speed: max value of distribution function by setting derivative to 0
 $\hookrightarrow u_{mp} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2k_B T}{m}}$

avg speed: expected value of distribution function by evaluating $\int_0^\infty u f(u) du$
 $\hookrightarrow u_{av} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8k_B T}{\pi m}}$

root-mean-square speed: evaluate integral $\int_0^\infty u^2 f(u) du$ & take square root
 $\hookrightarrow u_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{m}}$

$$R = 8.314 \text{ J/(mol} \cdot \text{K)}$$

effect of temp & mass on speed:



- ↳ higher temp results in broader range of speeds
- ↳ distribution shifts toward higher speeds as temp inc
- ↳ lower molecular weight results in broader range of speeds
- ↳ distribution shifts toward higher speeds for molecules w/lower molecular weight

· force is $F = ma$

- ↳ measured in Newton (N)

$$\circ 1 \text{ N} = 1 \text{ kg} \cdot \frac{\text{m}}{\text{s}^2}$$

· pressure is $P = \frac{F}{A}$

- ↳ A = area

↳ measured in Pascal (Pa)

$$\circ 1 \text{ Pa} = 1 \text{ N/m}^2 = 1 \frac{\text{kg}}{\text{ms}^2}$$

· kinetic-molecular theory postulates:

- ↳ gas is composed of very large # of molecules in ceaseless random straight-line motion

- ↳ molecules are separated by large distance relative to their own size

- ↳ molecules behave like hard spheres that undergo perfectly elastic collisions w/one another & walls of container

- ↳ there are no forces of attraction or repulsion btwn molecules

· $PV = \frac{nMc^2}{3}$ is gas pressure

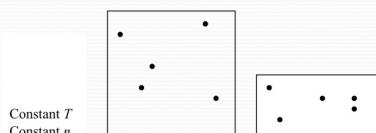
- ↳ $c^2 = \bar{v}^2$

◦ \bar{v}^2 is mean-square speed for 3D

· avg kinetic energy of gas is $\bar{E}_k = \frac{1}{2} mc^2 = \frac{3}{2} nRT$

Concept Check 2.2

Two containers of argon (Ar) gas are illustrated below. Both containers contain the same number of moles of argon and are at the same temperature.



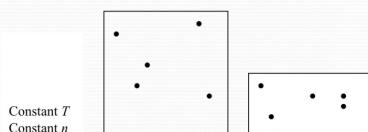
The root-mean-square speed of the argon is the same in both containers.

(A) True

B) False

Concept Check 2.3

Two containers of argon (Ar) gas are illustrated below. Both containers contain the same number of moles of argon and are at the same temperature.



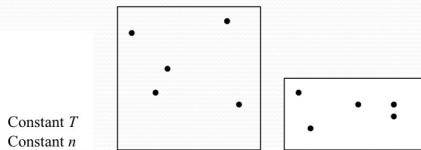
The frequency with which argon atoms collide with the walls is the same in both containers.

A) True

(B) False

Concept Check 2.4

Two containers of argon (Ar) gas are illustrated below. Both containers contain the same number of moles of argon and are at the same temperature.



The average force of each collision between an argon atom and the wall is the same in both containers.

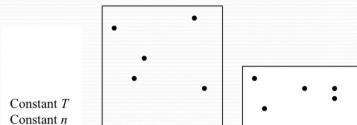
- (A) True B) False

IDEAL GAS LAW

- gas laws relate volume of gas to # moles, temp, & pressure ($V = f(n, T, P)$)
 - ↳ established by holding 2 variables constant & measuring relationship btwn V & individual variable
- in 0°C (273.15K) { 1 atm (pressure), 1 mol gas = 22.414 L}
- 3 laws to get $V = f(n, T, P)$
 - ↳ Boyle's Law: $V \propto \frac{1}{P}$
 - ↳ Charles' Law: $V \propto T$
 - ↳ Avogadro's Law: $V \propto n$
$$\left. \begin{array}{l} V \propto \frac{nT}{P} \\ \text{or } PV \propto nT \end{array} \right\}$$
- ideal gas law is $PV = nRT$
 - ↳ R is gas constant
 - $R = \frac{1 \text{ atm} \cdot 22.414 \text{ L}}{1 \text{ mol} \cdot 273.15 \text{ K}} = 0.08206 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}$
 - ↳ P is in atm
 - ↳ V is in L
 - ↳ n is in mol
 - ↳ T is in K
- $PV = nRT$ can also be expressed as $PV_m = RT$
 - ↳ $V_m = \frac{V}{n}$ (molar volume)
- when using ideal gas law, remember it doesn't account for type of gas present so assume:
 - ↳ no intermolecular forces btwn gas molecules
 - ↳ gas molecules have no molecular volume
- ideal gas law is good apx for many gases at higher temp & low pressure
- empirically, $PV = nRT$
 - ↳ ideal gas law
- theoretically, $PV = \frac{nMc^2}{3}$
 - ↳ KMT
- temp of ideal gas is measure of its avg translational kinetic energy

Concept Check 2.5

Two containers of argon (Ar) gas are illustrated below. Both containers contain the same number of moles of argon and are at the same temperature.



Every argon atom has the same kinetic energy in both containers.

- A) True B) False

Concept Check 2.6

At a temperature of 400 K and pressure of 1 atm, 1 mole of which of the following gases will occupy the largest volume?

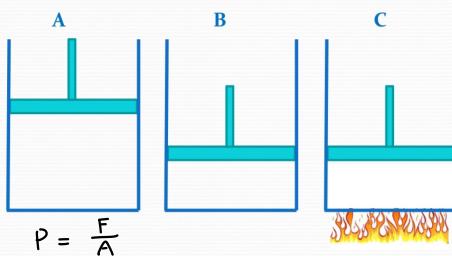
$$V = \frac{P}{nRT}$$

- A) H_2
B) O_2
C) He
D) N_2
 E) all occupy the same volume

Concept Check 2.7

Three samples of an ideal gas are confined in identical cylinders fitted with identical pistons. Correctly rank the following from highest to lowest pressure.

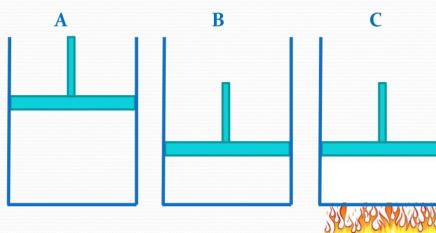
- A) $P_A > P_B > P_C$
B) $P_C > P_A > P_B$
C) $P_B > P_A > P_C$
D) $P_C > P_B > P_A$
 E) $P_A = P_B = P_C$



Concept Check 2.8

Three samples of an ideal gas are confined in identical cylinders fitted with identical pistons. Correctly rank the following from greatest to least number of moles of gas.

- A) $n_A > n_B > n_C$
B) $n_A > n_C > n_B$
C) $n_B > n_A > n_C$
D) $n_C > n_B > n_A$
E) $n_A = n_B = n_C$



$$n = \frac{PV}{RT}$$

gas density is $\rho = \frac{PM}{RT}$

MIXTURES OF GASES

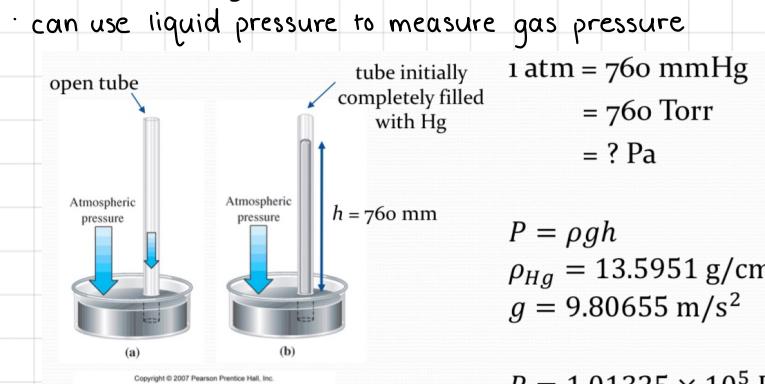
- diff types of gases in mixture act independently of each other
 - according to Dalton's Law of Partial Pressures, $P = P_A + P_B$
 - ↳ P : total pressure of mixture of gases
 - ↳ P_A : partial pressure of gas A
 - ↳ P_B : partial pressure of gas B
 - partial pressures are pressures each gas would have if present alone in container of same volume & at same temp
 - ↳ $P_A = \frac{n_A RT}{V}$
 - ↳ $P_B = \frac{n_B RT}{V}$
 - ↳ assuming $V = V_A = V_B$
 - total volume of mixture of gases is $V = V_A + V_B$
 - ↳ $V_A = \frac{n_A RT}{P}$
 - ↳ $V_B = \frac{n_B RT}{P}$
 - ↳ assuming $P_{\text{tot}} = P_A = P_B$
- 2 forms of Dalton's Law of Partial Pressures where y_A is mole fraction of gas A in mixture
- ↳ $y_A = \frac{n_A}{n} = \left(\frac{P_A V}{RT} \right) / \left(\frac{PV}{RT} \right) = \frac{P_A}{P}$
 - ° assuming gases individually occupy same volume as total volume
 - ↳ $y_A = \frac{n_A}{n} = \left(\frac{PV_A}{RT} \right) / \left(\frac{PV}{RT} \right) = \frac{V_A}{V}$
 - ° assuming gases individually under same pressure as total pressure

INTERMOLECULAR FORCES AND REAL GASES

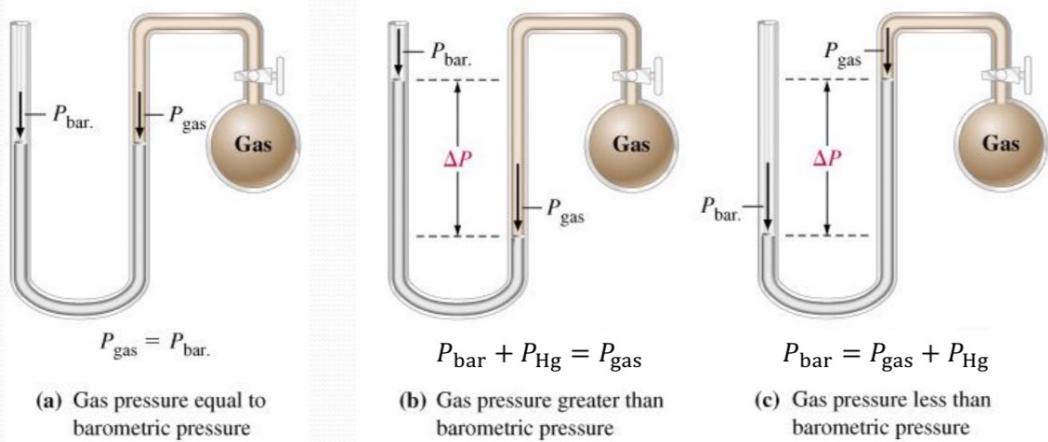
- many gases behave as ideal gases at high temp & low pressure when intermolecular forces don't play large role
 - ↳ intermolecular forces are attraction btwn molecules
- London dispersion forces are weakest intermolecular forces
 - ↳ e⁻ are symmetrically distributed in non-polar molecule
 - ↳ e⁻ may accumulate on 1 side of molecule & create instantaneous dipole
 - ↳ e⁻ in neighbouring molecule attracted to +ve side & form induced dipole
 - ↳ dipoles & attraction are all temporary
- polarizability: tendency of charge distribution to become non-uniform in atom/molecule
- dipole-dipole forces are stronger than London dispersion
 - ↳ polar molecules have permanent dipole moment (+ve end & -ve end)
- both London dispersion & dipole-dipole are Van der Waals forces
- hydrogen bonding: highly electronegative atom pulls e⁻ from H so H is attracted to lone pair of e⁻ on neighbouring molecule
 - ↳ occurs primarily btwn H & O, F, or N
 - ↳ much stronger than Van der Waals forces but much weaker than covalent bonds
- repulsive forces arise due to electrostatic interactions as e⁻ orbitals approach or overlap
 - ↳ very strong & important in short range
- modified version of ideal gas law for real gases: $P = \frac{nRT}{V-bn} - \frac{an^2}{V^2}$ (Van der Waals' eqn)
 - ↳ molecules occupy space so $V = \frac{nRT}{P} + bn$ or $P = \frac{nRT}{V-bn}$
 - ° b is constant that gives volume of molecules depending on gas
→ units are L/mol
 - ↳ intermolecular forces of attraction btwn molecules lower pressure so $P = \frac{nRT}{V-bn} - \frac{an^2}{V^2}$
 - ° a is constant that describes strength of intermolecular attraction
→ units are $\frac{L^2 \cdot atm}{mol^2}$
 - proportional to squared concentration of moles

CONDENSED STATES AND TEMPERATURE

- in liquids, molecules are free to move but held close together by intermolecular forces
- pressure exerted by liquid is proportional to density of liquid & height of liquid in column
 - even w/ diff shapes & volumes, pressure stays the same
 - $P = \rho gh$
 - ρ is density
 - $g = 9.80655 \text{ g/cm}^3$
 - $\rightarrow \text{GPE}$
 - h is height
- can use liquid pressure to measure gas pressure



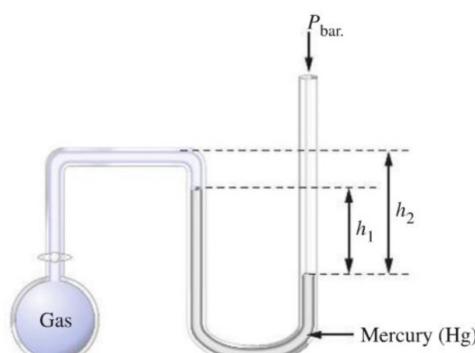
open-end manometer can be used to measure pressure:



$\hookrightarrow \Delta P_{\text{mmHg}} = \Delta h_{\text{Hg}}$

Concept Check 2.9

5. What is the pressure (in mmHg) of the gas inside the apparatus below if $P_{\text{bar.}} = 740 \text{ mmHg}$, $h_1 = 30 \text{ mm}$ and $h_2 = 50 \text{ mm}$?



- A) 690 mmHg
 B) 710 mmHg
 C) 720 mmHg
 D) 760 mmHg
 E) 770 mmHg

$$P_{\text{bar}} = 740 \text{ mmHg}$$

$$\Delta h = 30 \text{ mm}$$

$$P_{\text{gas}} + P_{\text{Hg}} = P_{\text{bar}}$$

$$P_{\text{gas}} = 740 - 30$$

$$= 710 \text{ mmHg}$$

· solids have fixed shape & resist deformation

↳ molecular solids are held together by intermolecular forces

↳ non-molecular solids are networks of bonded atoms / ions

· ionic: ions linked together by ionic bonds

→ e.g. NaCl, CaCl₂

· covalent: atoms linked by covalent bonds

→ e.g. diamond, graphite

· metallic: metal atoms linked together by metallic bonds formed by delocalised sea of e⁻

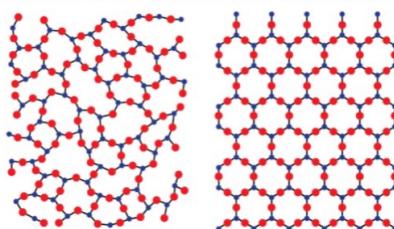
→ e.g. Cu, Mg

· 2 main structures of solids:

↳ amorphous: don't exhibit any long-range order

↳ crystalline: exhibit regular order at long-range

↳ e.g. SiO₂



· temperature is measure of avg translational kinetic energy of molecules

↳ in mixture of gases, both components must have same temp

heat: measure of energy transferred to / from system across its boundary

· thermal equilibrium: no spontaneous energy transfer when 2 systems brought into contact

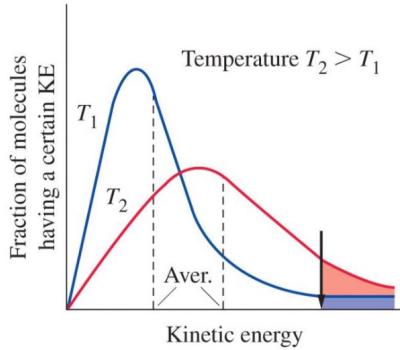
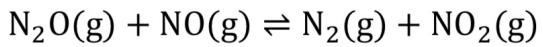
temp of system is measure of its thermal state related to its ability to transfer energy to other systems

UNIT 3 : RATE OF REACTIONS

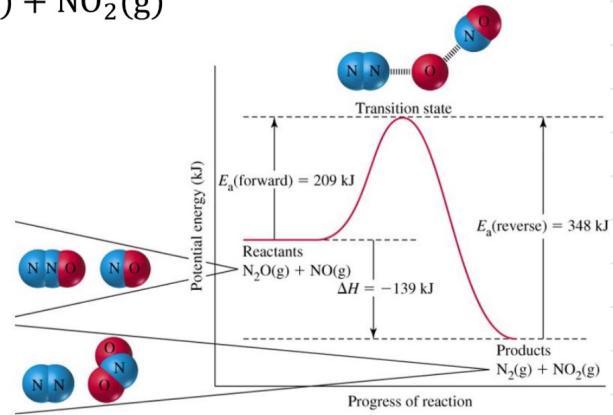
COLLISION THEORY & MEASURING REACTION RATES

- For chemical rxn to occur, chemical bonds must be broken & new bonds formed
 - ↳ molecules must collide w/ sufficient energy & in correct orientation
 - reactant molecules must achieve given energy level (i.e. activation energy) before rxn can happen

↳ e.g.



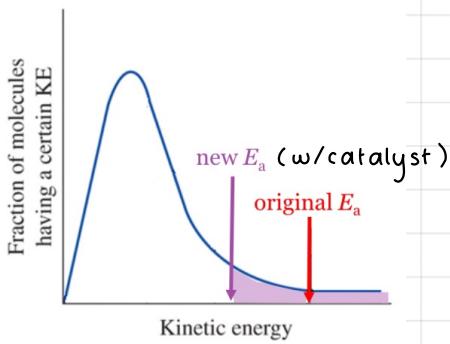
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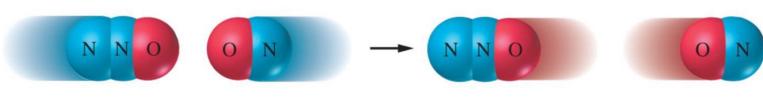
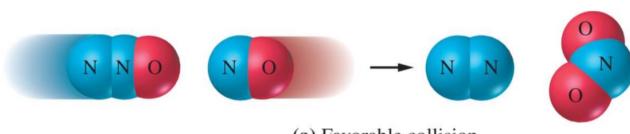
• E_a is activation energy

catalyst inc rate of rxn by providing diff rxn path w/ lower activation energy

↳



- participates in rxn but isn't altered by it
- doesn't appear in overall rxn as reactant or product
- classified as homogeneous or heterogeneous
- make it possible to avoid high temp for rxns w/ high E_a
- collision orientation matters when determining if rxn goes thru:



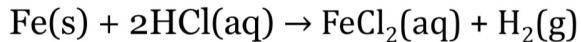
(b) Unfavorable collisions

• factors that affect rxn rate:

- ↳ concentration of reactants
- ↳ rxn temp
- ↳ presence of catalysts
- ↳ physical nature of reactants

Concept Check 3.1

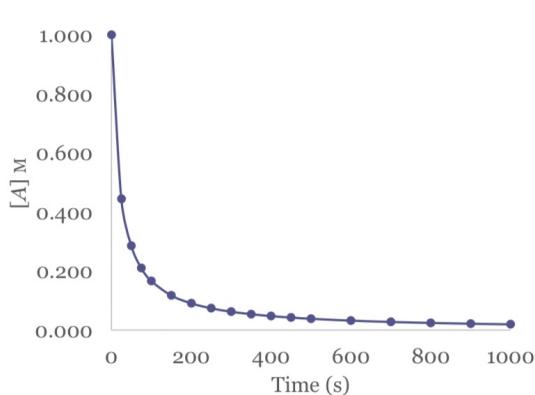
The chemical equation for the reaction of iron (Fe) metal with hydrochloric acid (HCl) is:



Will the rate of this reaction (A) increase, (B) decrease or (C) remain the same when:

- i) the temperature is increased? A
- ii) the solution is stirred? A
- iii) the concentration of the acid is increased? A
- iv) the iron is ground into a powder? A

• measuring rxn rates from raw data:



$$\dot{R}_A \approx \frac{c_A(t_2) - c_A(t_1)}{t_2 - t_1}$$

$$\dot{R}_A = \frac{d[A]}{dt} = \text{slope of tangent line}$$

• for generic equation $aA + bB \rightarrow cC + dD$, $\dot{R} = -\frac{1}{a} \frac{d[A]}{dt} = -\frac{1}{b} \frac{d[B]}{dt} = \frac{1}{c} \frac{d[C]}{dt} = \frac{1}{d} \frac{d[D]}{dt}$

↳ \dot{R} is volumetric rxn rate

• +ve value
• units are $\frac{\text{mol}}{\text{Ls}}$

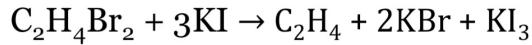
↳ - means consumption

↳ + means production

• rates of rxn must be determined experimentally

Concept Check 3.2

For the reaction



the rate of reaction is 2.0×10^{-5} M/s. What is the rate of change of KI concentration (M/s)?

- A) -0.7×10^{-5} (D) -6.0×10^{-5}
B) 0.7×10^{-5} E) 6.0×10^{-5}
C) -2.0×10^{-5}

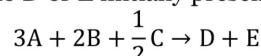
$$2.0 \cdot 10^{-5} = -\frac{\dot{R}_{\text{KI}}}{3}$$
$$\dot{R}_{\text{KI}} = -6.0 \cdot 10^{-5} \text{ M/s}$$

DEPENDENCE OF REACTION RATE ON CONCENTRATION AND TEMPERATURE

- rate laws relate rate of rxn to concentration of reactants
 - ↳ empirically determined (i.e. exponents don't necessarily equal stoichiometric coeffs)
- for rxn $aA + bB \rightarrow \text{products}$, $\dot{R} = -\frac{1}{a} \frac{d[A]}{dt} = -\frac{1}{b} \frac{d[B]}{dt} = k[A]^m[B]^n$
 - ↳ m: order of rxn wrt A
 - ↳ n: order of rxn wrt B
 - ↳ m+n: overall order of rxn
 - ↳ k: rxn rate constant (function of temp)
- units for k depend on overall rate of rxn:
 - ↳ zero order: M/s
 - ↳ 1st order: 1/s
 - ↳ 2nd order: 1/Ms
- consider rxn rate $\dot{R} = k[A]^m[B]^n$ & double concentration A
 - ↳ m=0: overall rate doesn't change
 - ↳ m=1: rate x2
 - ↳ m=2: rate x4
- instantaneous rate of rxn is determined at beginning of rxn before reactant concentrations have changed significantly
 - ↳ to get differential rate law, use data from multiple exp
- when finding order of rxn wrt reactant from experimental data, use 2 exp where concentration of reactant changes but others stay constant

Concept Check 3.3

Experiments were performed using different initial concentrations of reactants A, B and C (no D or E initially present) for the reaction:



Initial rates of reaction were determined as given below:

Experiment	[A] _o (M)	[B] _o (M)	[C] _o (M)	\dot{R} (M/s)
1	1.0	1.0	2.0	0.16
2	9.0	1.0	2.0	0.48
3	9.0	0.5	2.0	0.12
4	1.0	1.0	4.0	0.16

What is the order of the reaction with respect to A?

- A) 0 (B) 0.5 C) 1 D) 1.5 E) 2

$$\dot{R} = k[A]^m[B]^n[C]^l$$

$$0.16 = k[1.0]^m x \leftarrow \text{exp 1}$$

$$0.48 = k[9.0]^m x \leftarrow \text{exp 2}$$

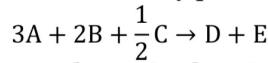
$$\frac{0.48}{0.16} = \frac{k[9.0]^m x}{k[1.0]^m x}$$

$$3 = (9)^m$$

$$m = 0.5$$

Concept Check 3.4

Experiments were performed using different initial concentrations of reactants A, B and C (no D or E initially present) for the reaction:



Initial rates of reaction were determined as given below:

Experiment	[A] _o (M)	[B] _o (M)	[C] _o (M)	\dot{R} (M/s)
1	1.0	1.0	2.0	0.16
2	9.0	1.0	2.0	0.48
3	9.0	0.5	2.0	0.12
4	1.0	1.0	4.0	0.16

What is the order of the reaction with respect to B?

- A) 0 B) 0.5 C) 1 D) 1.5 E) 2

$$0.48 = k[1.0]^n x \leftarrow \text{exp 2}$$

$$0.12 = k[0.5]^n x \leftarrow \text{exp 3}$$

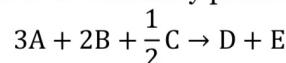
$$\frac{0.48}{0.12} = \frac{k[1.0]^n x}{k[0.5]^n x}$$

$$4 = [2]^n$$

$$n = 2$$

Concept Check 3.5

Experiments were performed using different initial concentrations of reactants A, B and C (no D or E initially present) for the reaction:



Initial rates of reaction were determined as given below:

Experiment	[A] _o (M)	[B] _o (M)	[C] _o (M)	\dot{R} (M/s)
1	1.0	1.0	2.0	0.16
2	9.0	1.0	2.0	0.48
3	9.0	0.5	2.0	0.12
4	1.0	1.0	4.0	0.16

What is the numerical value of the rate constant?

- A) 0.16 B) 1.50 C) 350 D) 4520 E) 120 000

$$\dot{R} = k[A]^m[B]^n[C]^l$$

$$0.16 = k[2.0]^l x \leftarrow \text{exp 1}$$

$$0.16 = k[4.0]^l x \leftarrow \text{exp 4}$$

$$\frac{0.16}{0.16} = \frac{k[4.0]^l x}{k[2.0]^l x}$$

$$1 = [2]^l$$

$$l = 0$$

Using exp 1:

$$0.16 = k[A]^{0.5}[B]^2[C]^0$$

$$0.16 = k[1.0]^{0.5}[1.0]^2[2.0]^0$$

$$0.16 = k(1)$$

$$k = 0.16$$

when all except one reactant are in large excess, $aA \rightarrow \text{products}$, then

$$\dot{R} = -\frac{1}{a} \frac{d[A]}{dt} = k[A]^n$$

integrate equation to determine $[A]$ as function of time

half-life of reactant is amount of time it takes for half of reactant to react

from integrated rate laws, can determine half-life since $t = t_{\frac{1}{2}} \Rightarrow [A] = \frac{1}{2} [A]_0$

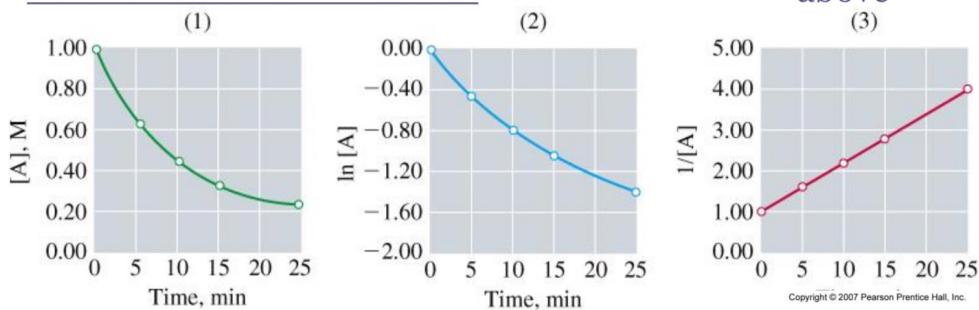
to determine order of rxn from time plots, look for equation that results in graph having linear relationship

Order	Differential rate law	Integrated rate law	Units of k	$t_{1/2}$
0	$-\frac{1}{a} \frac{d[A]}{dt} = k$	$[A] = -akt + [A]_0$	M/s	$\frac{[A]_0}{2ak}$
1	$-\frac{1}{a} \frac{d[A]}{dt} = k[A]$	$\ln[A] = -akt + \ln[A]_0$	1/s	$\frac{\ln 2}{ak}$
2	$-\frac{1}{a} \frac{d[A]}{dt} = k[A]^2$	$\frac{1}{[A]} = akt + \frac{1}{[A]_0}$	1/(M·s)	$\frac{1}{ak[A]_0}$
n ($n \neq 1$)	$-\frac{1}{a} \frac{d[A]}{dt} = k[A]^n$	$\frac{1}{[A]^{n-1}} = (n-1)akt + \frac{1}{[A]_0^{n-1}}$	$\frac{1}{M^{n-1} \cdot s}$	$\frac{2^{n-1} - 1}{ak(n-1)[A]_0^{n-1}}$

Concept Check 3.6

$A \rightarrow \text{products}$

Time, min	[A], M	$\ln[A]$	$1/[A]$
0	1.00	0.00	1.00
5	0.63	-0.46	1.6
10	0.46	-0.78	2.2
15	0.36	-1.02	2.8
25	0.25	-1.39	4.0



- A) zero C) second
 B) first D) none of the above

- Arrhenius equation describes relationship btwn rxn rate constant & temp:
- $k = A \exp\left(-\frac{E_a}{RT}\right)$
- ↳ A: pre-exponential factor
- ↳ E_a : activation energy (J/mol)
- ↳ T: temp (K)
- ↳ R: 8.314 J/mol · K
- ↳ A & E_a are two constants that depend on rxn type
- ↳ alternative form: $\ln k = -\frac{E_a}{RT} + \ln A$
- graph of $\ln k$ vs $\frac{1}{T}$ will be linear w/slope $-\frac{E_a}{R}$
- ↳ can calculate E_a by knowing 2 points on this line: $\ln \frac{k_2}{k_1} = -\frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

phase equilibrium

PHASE TRANSITIONS, PHASE EQUILIBRIUM, & VAPOUR PRESSURE

· phase is region of space throughout which state of aggregation (i.e. spatial organization of atoms/molecules) & chemical composition of matter are both uniform

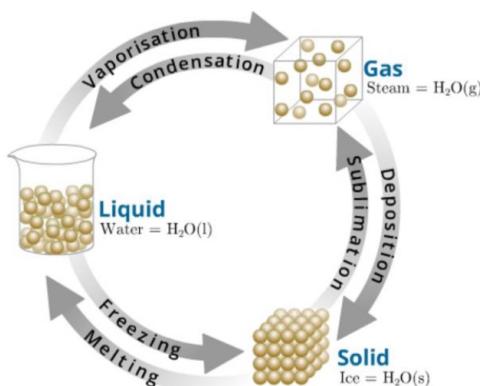
↳ not analogous w/ state of matter

phase transition: when matter changes from 1 phase to another due to changes in temp and/or pressure

↳ changes from 1 solid phase to another are also phase transitions

↳

Phase Transitions of a Single-Component (H_2O) System



© University of Waterloo

· vapourization: passage of molecules from surface of liquid into vapour state

· condensation: passage of molecules from vapour to liquid state

enthalpy of vapourization/condensation: amount of heat that must be absorbed/released to keep liquid at constant temp when given quantity is vapourized/condensed

↳ $\Delta H_{\text{vap}} = H_{\text{vapour}} - H_{\text{liquid}} = -\Delta H_{\text{cond}}$

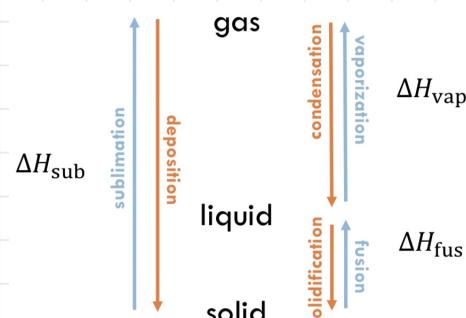
↳

TABLE 13.1 Some Enthalpies of Vaporization at 298 K^a

Liquid	ΔH_{vap} , kJ/mol	
Diethyl ether, $(\text{C}_2\text{H}_5)_2\text{O}$	29.1	dispersion
Methyl alcohol, CH_3OH	38.0	dispersion + hydrogen bond
Ethyl alcohol, $\text{CH}_3\text{CH}_2\text{OH}$	42.6	dispersion + hydrogen bond
Water, H_2O	44.0	4 hydrogen bonds!

^a ΔH_{vap} values are somewhat temperature-dependent (see Exercise 96).

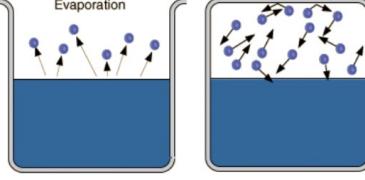
· other phase changes:

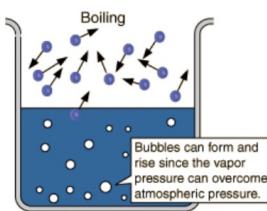


- ↳ $\Delta H_{\text{fus}} + \Delta H_{\text{vap}} = \Delta H_{\text{sub}}$
- during phase equilibrium, there's no net conversion of one phase to another
- vapour pressure is pressure measured when system reaches equilibrium
 - ↳ weak intermolecular forces → more likely to evaporate → high vapour pressure (volatile)
 - ↳ strong intermolecular forces → less likely to evaporate → low vapour pressure (non-volatile)
- ↳ $P_{\text{vap}} = f(T, \text{type of liquid})$
- ↳

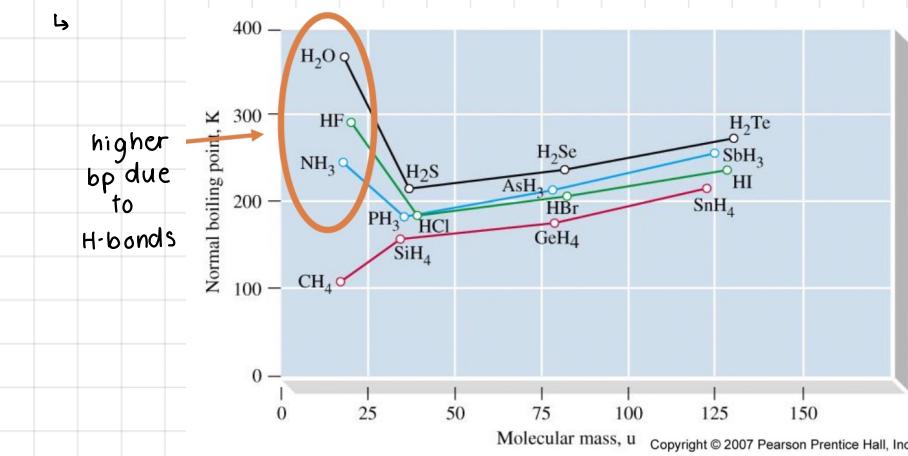
TABLE 13.2 Vapor Pressure of Water at Various Temperatures

Temperature, °C	Pressure, mmHg	Temperature, °C	Pressure, mmHg	Temperature, °C	Pressure, mmHg
0.0	4.6	29.0	30.0	93.0	588.6
10.0	9.2	30.0	31.8	94.0	610.9
20.0	17.5	40.0	55.3	95.0	633.9
21.0	18.7	50.0	92.5	96.0	657.6
22.0	19.8	60.0	149.4	97.0	682.1
23.0	21.1	70.0	233.7	98.0	707.3
24.0	22.4	80.0	355.1	99.0	733.2
25.0	23.8	90.0	525.8	100.0	760.0
26.0	25.2	91.0	546.0	110.0	1074.6
27.0	26.7	92.0	567.0	120.0	1489.1
28.0	28.3				

<ul style="list-style-type: none"> · Evaporation <ul style="list-style-type: none"> ↳ occurs at surface ↳ occurs at any temp ↳ some molecules at surface have enough energy to overcome intermolecular forces 	<ul style="list-style-type: none"> Boiling
<ul style="list-style-type: none"> ↳ 	<ul style="list-style-type: none"> ↳ occurs throughout liquid ↳ occurs at specific temp known as boiling point ↳ $P_{\text{vap}} = \text{surrounding atmospheric pressure}$

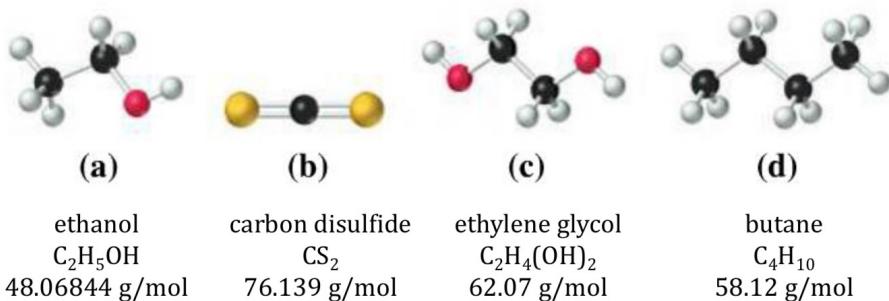


- boiling point temp is when vapour pressure is equal to external pressure P
 - ↳ $P_{\text{vap}}(T_{\text{bp}}) = P$
 - ↳ normal boiling temp is when vapour pressure is equal to 1 atm
- when looking at normal bp of some hydrides, higher molecular mass → higher polarizability → stronger intermolecular force → higher bp

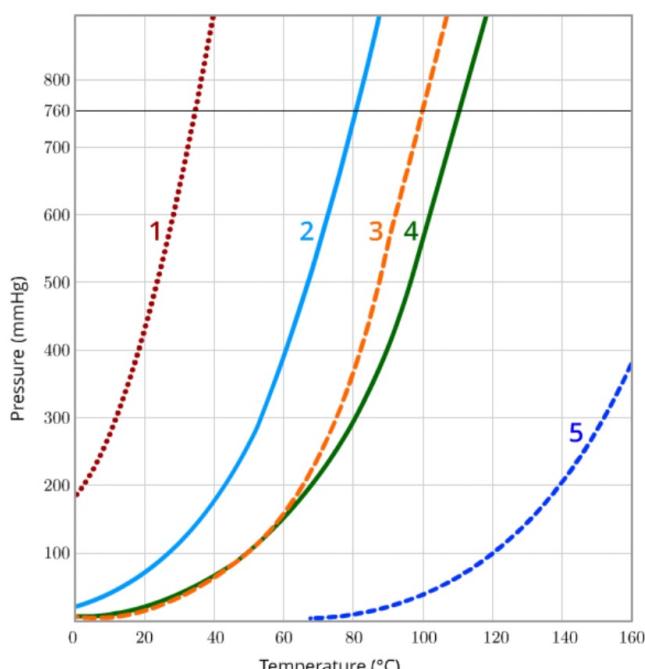


Concept Check 4.1

- Which of the following molecules has the highest normal boiling point? **c**
- Which of the following molecules has the lowest boiling point? **d**



vapour pressure curves of several liquids:



- diethyl ether, C₄H₁₀O
- benzene, C₆H₆
- water, H₂O
- toluene, C₇H₈
- aniline, C₆H₅N

These kind of look like exponential functions!

$$P_{\text{vap}} \propto e^T$$

or

$$\ln P_{\text{vap}} \propto T$$

Clausius - Clapeyron equation: $\ln \left(\frac{P_2}{P_1} \right) = - \frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$

$$R = 8.314 \text{ J/mol} \cdot \text{K}$$

assumes ΔH_{vap} doesn't vary w/ temp

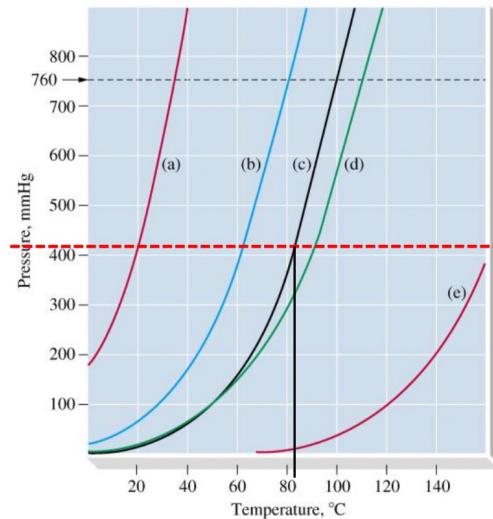
↳ applies to other phase changes when proper enthalpy is used

Concept Check 4.2

Mont Blanc, the highest elevation in the French Alps, is 15 771 ft above sea level. The barometric pressure on Mont Blanc is approximately 420 mmHg. To make a decent cup of tea, the water temperature must be at least 90 °C. Could you make a decent cup of tea on Mont Blanc?

A) Yes

B) No

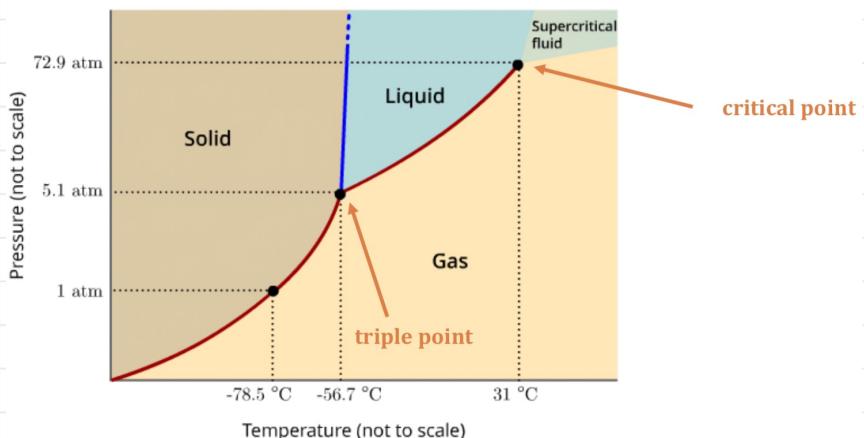


(c) vapour pressure of water

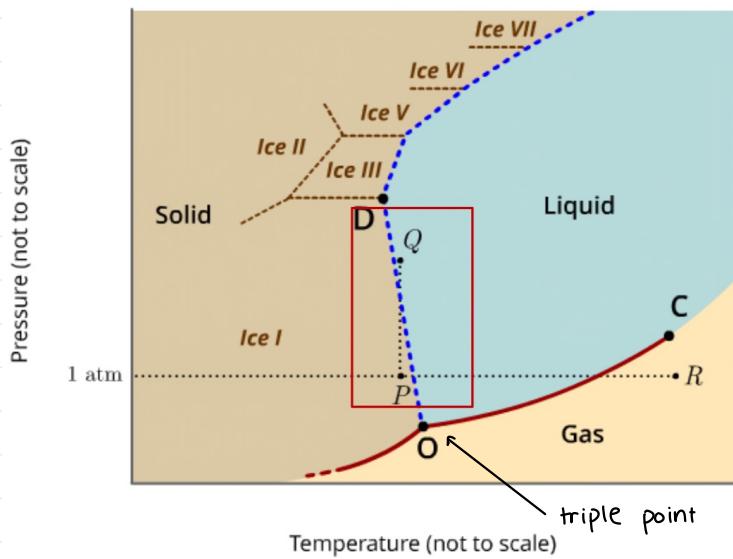
- relative humidity (RH) is $\% \text{ RH} = \frac{P_{\text{H}_2\text{O}} \text{ g}}{P_{\text{H}_2\text{O}}^{\text{vap}}(T)} \times 100\%$
- dew point temp (T_{dp}): temp at which humid air reaches saturation & condenses to form first drop of liquid water
↳ % saturation = $\frac{P_A \text{ g}}{P_A^{\text{vap}}(T)} \times 100\%$

PHASE DIAGRAMS

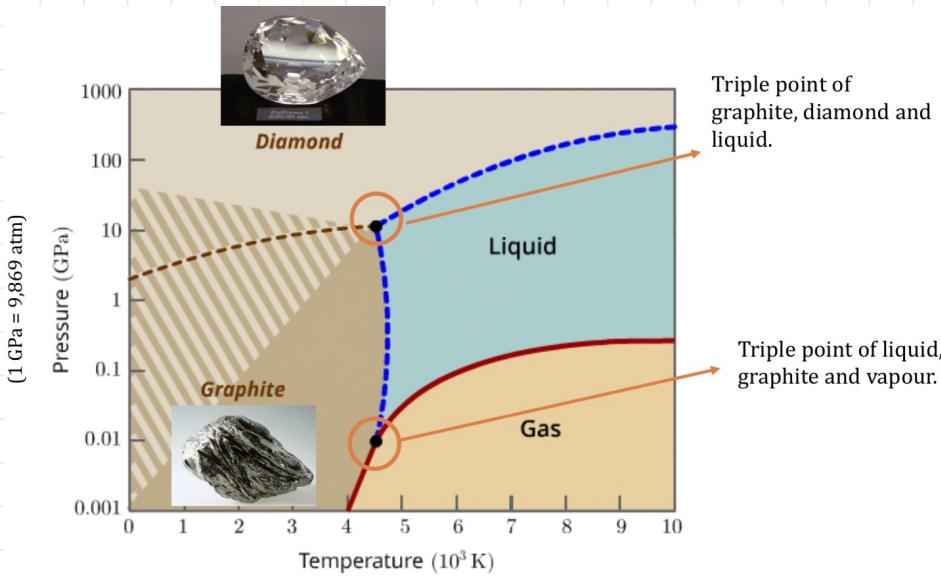
- phase diagram shows regions where several phases of a substance are in equilibrium
↳ e.g. CO_2



- critical point: no phase boundary btwn liquid & vapour exist
↳ heat of vapourization is 0
- supercritical fluids have properties of both gases & liquids
↳ better ability to dissolve substances than in gas phase
↳ better ability to diffuse into substance than in liquid phase
- polymorphism: existence of a solid in more than 1 form
↳ i.e. substance has ability to crystallize into diff forms
↳ e.g. water has diff types of ice



↳ e.g. phase diagram for carbon



Concept Check 4.3

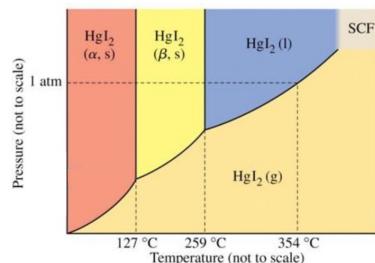
Identify whether each statement is A) TRUE or B) FALSE:

- I. A one-component phase diagram has a single triple point where solid, liquid and vapour phases co-exist. T
- II. A one-component phase diagram has a single critical point above which the liquid phase does not exist. T
- III. A liquid will boil (i.e. the vapour pressure above the liquid equals the total pressure) at a single temperature. F
- IV. At a given pressure, above the triple point pressure, the solid phase melts at a single temperature. T
- V. At a given temperature (between the triple point and the critical temperature) vapour will begin to condense to liquid at a single pressure. T

Concept Check 4.4

Identify whether each statement is A) TRUE or B) FALSE:

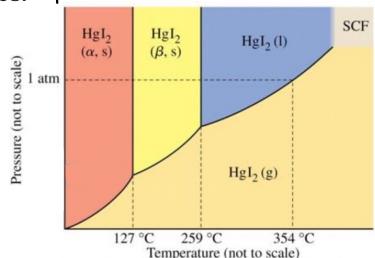
- I. There is a single triple point at which three phases are in equilibrium. F
- II. Mercury(II) iodide has a normal boiling point. T
- III. At temperatures below 259 °C, mercury(II) iodide does not melt. T



Concept Check 4.4 cont.

Identify whether each statement is A) TRUE or B) FALSE:

- IV. The vapour pressure of mercury(II) iodide at any given temperature could be determined from this phase diagram, if the axis were drawn to scale. T
- V. As pressure increases the sublimation temperature of mercury(II) iodide increases. T



HENRY'S LAW & RAOULT'S LAW

solution formation:

1) solvent molecules are separated from each other

2) solute molecules are separated from each other

3) solvent & solute molecules become attracted to each other

$$\Delta H_{\text{soln}} = \underbrace{\Delta H_{\text{separate solvent}} + \Delta H_{\text{separate solute}}}_{\Delta H > 0 \text{ (endothermic)}} + \underbrace{\Delta H_{\text{attraction}}}_{\Delta H < 0 \text{ (exothermic)}}$$

in an ideal soln, forces are similar btwn all components of soln

↳ $\Delta H_{\text{soln}} = 0$

↳ volumes are strictly additive

↳ mixing is always complete

e.g. acetone & CS₂ is non-ideal soln b/c acetone has dp-dp forces but CS₂ has London dispersion forces

↳ interaction btwn them:

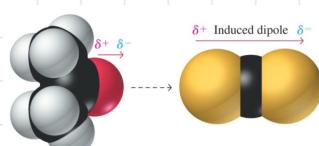


TABLE 14.1 Some Common Solutions

Solution	Components
Gaseous solutions	
Air	N ₂ , O ₂ , and several others
Natural gas	CH ₄ , C ₂ H ₆ , and several others
Liquid solutions	
Seawater	H ₂ O, NaCl, and many others
Vinegar	mL of H ₂ O, HC ₂ H ₃ O ₂ (acetic acid)
Soda pop	H ₂ O, CO ₂ , C ₁₂ H ₂₂ O ₁₁ (sucrose), and several others
Solid solutions (alloys)	
Yellow brass	Cu, Zn
Palladium-hydrogen	Pd, H ₂

↳ liquid solns are most common

· Henry's law states that solubility of gas inc when pressure inc

↳ generally applies to gas-liquid solns

$$\hookrightarrow P_A = H_A x_A$$

- P_A is partial pressure of gas above soln

- H_A is Henry's constant

- depends on solute/solvent pair & temp

- units of pressure

- x_A is mole frac in liquid

↳ another common form is C_A = k_A P_A

- C_A is concentration in liquid soln

- k_A is Henry's constant (unit: $\frac{\text{concentration}}{\text{pressure}}$)

- P_A is partial pressure above soln

- any measures of concentration can be used as long as k_A is given in correct units

· most of time, inc temp dec solubility of gases in liquids

Henry's law constants in aq. solns:

H _A (T) (10 ⁴ atm)					
T (°C)	CO ₂	O ₂	N ₂	CH ₄	CO
0	0.0728	2.55	5.29	2.24	3.52
10	0.104	3.27	6.68	2.97	4.42
20	0.142	4.01	8.04	3.76	5.36
30	0.186	4.75	9.24	4.49	6.20
40	0.233	5.35	10.4	5.20	6.96

· presence of dissolved solute lowers vapour pressure of solvent

· Raoult's law is P_A = x_A P_A^{vap} (i.e. P_{vap} of soln \propto P_{vap} of pure solvent)

↳ P_A is partial pressure above soln

↳ x_A is mole frac of component in soln

↳ P_A^{vap} is vapour pressure of pure component

↳ applies to all volatile components of ideal solns

↳ applies reasonably well to nonideal dilute solns

- x_{solv} > 0.98

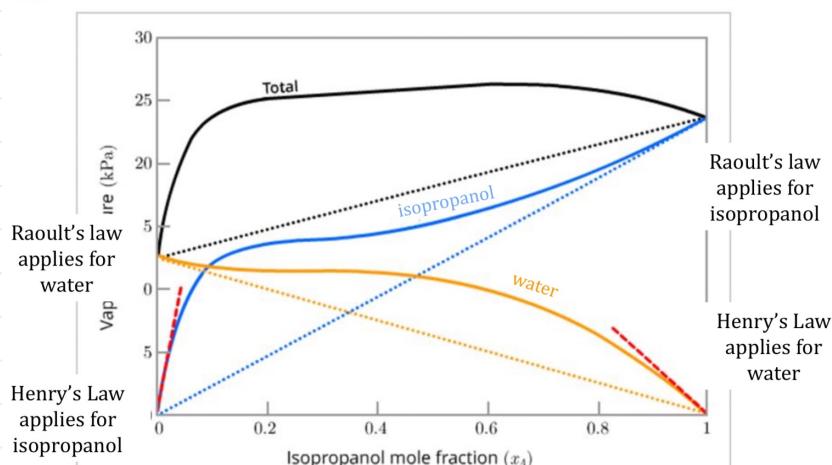
- Henry's law describes behaviour of solute in soln but Raoult's law describes behaviour of solvent in soln
- for an ideal soln, both laws apply

Concept Check 4.5

An ideal solution contains 50 mol-% A and 50 mol-% B. You know that A is more volatile than B. Which of the following is true of the vapour in equilibrium with this solution?

- A) $y_A = y_B = 0.50$
- B) $y_A > y_B$
- C) $y_A < y_B$
- D) Not enough information provided

Deviations from Ideal Behaviour



Concept Check 4.6

A non-ideal mixture is formed of two species A and B having pure vapour pressures of 100 and 200 mmHg, respectively. The total pressure of vapour above the mixture is found to be 205 mmHg.

The system shows a _____ deviation from Raoult's law.

- A) positive
- B) negative
- C) cannot tell

The normal boiling point of the mixture is higher than the boiling point of either pure A or pure B.

- A) True
- B) False

↳ higher P_{vap} means lower boiling point temp

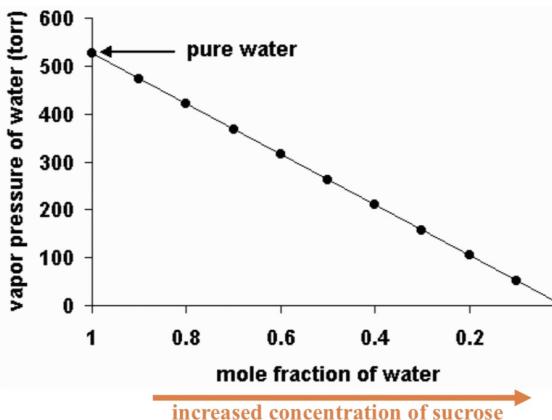
COLLIGATIVE PROPERTIES

colligative properties are physical changes that result from adding solute to solvent & depend on ratio of solute to solvent particles but not identity of solute

- ↳ vapour pressure lowering
- ↳ boiling point elevation
- ↳ freezing point depression
- ↳ osmotic pressure

vapour pressure is lowered when non-volatile solute is present

- ↳



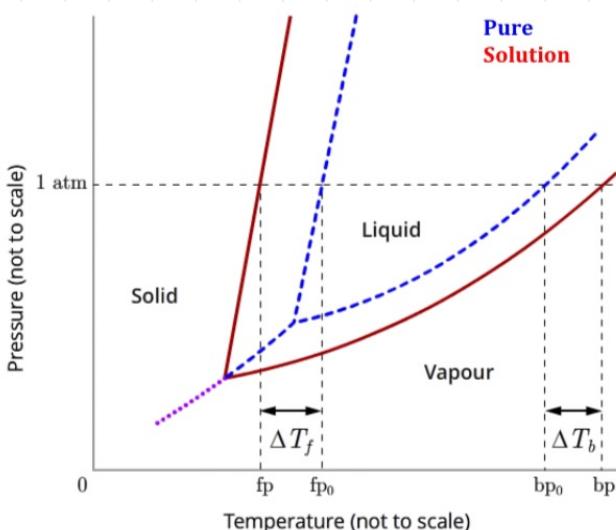
$$\Delta P_{\text{solvent}} = -x_{\text{solute}} P_{\text{solvent}}^{\text{vap}}$$

can use to est molar mass of unknown solid dissolved in known liquid

$$M_{\text{solid}} = - \frac{M_{\text{liquid}} m_{\text{solid}}}{m_{\text{liquid}}} \left(\frac{P_{\text{liquid}}^{\text{vap}}}{\Delta P_{\text{liquid}}} + 1 \right)$$

normal T_{bp} is when $P_{\text{vap}} = 1 \text{ atm}$ since P_{vap} of soln \neq P_{vap} of pure solvent, temp must be inc to reach P_{vap} of 1 atm

- ↳



normal freezing point is temp at which liquid crystallizes at 1 atm

- ↳ lowered T_{fp} due to presence of solute

bp elevation & fp depression: $\Delta T_{\text{bp}} = K_b m$ & $\Delta T_{\text{fp}} = -K_f m$

m is solute molality of soln ($\frac{\text{mol solute}}{\text{kg solvent}}$)

K_b is bp elevation constant

K_f is fp depression constant

K_b & K_f depend only on solvent type

some molecules dissociate into ions when dissolved

e.g. $\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$

since colligative properties depend on ratio of solute to solvent particles, include van't Hoff factor i to account for inc # of solute particles

- $\Delta T_{bp} = i K_b m$
- $\Delta T_{fp} = -i K_f m$
- notes regarding van't Hoff factor i :
 - ↳ i rep # of particles released into soln per formula unit of solute
 - ↳ min value is 1
 - implies no dissociation
 - ↳ max value is # ions formed through complete dissociation
 - e.g. 2 for NaCl
 - ↳ since aq. ions of opp charges associate into ion-pairs, value of i varies btwn min & max value depending on soln concentration

TABLE 14.3 Variation of the van't Hoff Factor, i , with Solution Molality

Solute	Molality, m					
	1.0	0.10	0.010	0.0010	...	Inf dil*
NaCl	1.81	1.87	1.94	1.97	...	2
MgSO ₄	1.09	1.21	1.53	1.82	...	2
Pb(NO ₃) ₂	1.31	2.13	2.63	2.89	...	3

*The limiting values: $i = 2$, 2, and 3 are reached when the solution is infinitely dilute. Note that a solute whose ions are singly charged (for example, NaCl) approaches its limiting value more quickly than does a solute whose ions carry higher charges. Interionic attractions are greater in solutes with more highly charged ions.

Concept Check 4.7

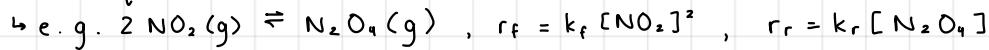
Four different aqueous solutions are made by dissolving 1 mol of either KI, LaCl₃, MgBr₂, or CaF₂ in 1 L of water. Assuming complete dissociation, which solution has the highest boiling point?

- A) KI
- B) LaCl₃ → $i = 4$
- C) MgBr₂
- D) CaF₂
- E) Not enough information provided

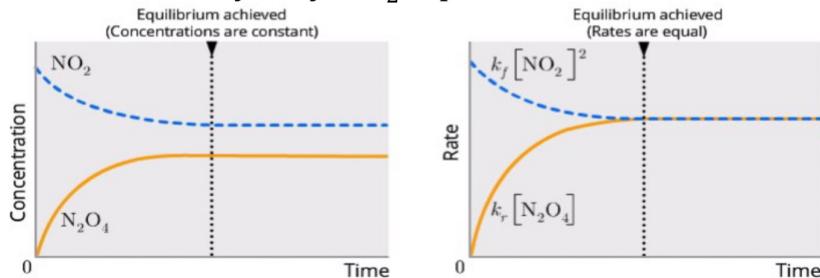
chemical equilibrium

CHEMICAL EQUILIBRIUM AND EQUILIBRIUM CONSTANTS

chemical equilibrium is when the rate of fwd rxn = rate of reverse rxn



- Assume initially only NO_2 is present



$$\text{at equilibrium: } k_f [\text{NO}_2]_{\text{eq}}^2 = k_r [\text{N}_2\text{O}_4]_{\text{eq}}$$

$$\frac{k_f}{k_r} = \frac{[\text{N}_2\text{O}_4]_{\text{eq}}}{[\text{NO}_2]_{\text{eq}}^2} = K_c$$

$$\text{for general eqn } aA + bB \rightleftharpoons cC + dD, K_c = \frac{[\text{C}]^c [\text{D}]^d}{[\text{A}]^a [\text{B}]^b}$$

$[]$ rep equilibrium concentration in mol/L

K_c is equilibrium constant for given temp using equilibrium concentrations

- indep of initial concentration of reactants & products

Concept Check 5.1

Identify the TRUE statement:

- A) The value of an equilibrium constant is calculated using the initial concentration of reactants and products.
- B) The value of an equilibrium constant is calculated using the final concentration of reactants and products.
- C) At equilibrium, the rates of the forward and reverse reactions become zero.
- D) At equilibrium, reactant concentrations are equal to product concentrations.
- E) More than one of the statements is correct.

Concept Check 5.2

If at equilibrium, nearly all the reactants have been consumed, the equilibrium constant would be expected to have a

- A) very small numerical value.
- B) very large numerical value.
- C) numerical value slightly greater than 1.0.
- D) numerical value slightly less than 1.0.
- E) No correct response.

$$K_c = \frac{[\text{products}]}{[\text{reactants}]}$$

for rxn $aA + bB \rightleftharpoons cC + dD$, we can use ideal gas law to express K_c in terms of partial pressure

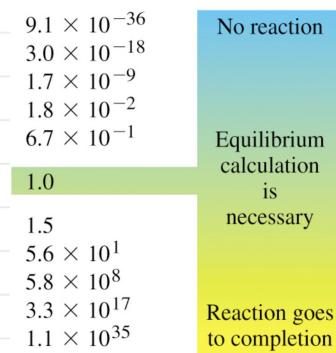
$$\hookrightarrow K_c = K_p (RT)^{-\Delta n} \quad \text{or} \quad K_p = K_c (RT)^{\Delta n}$$

$$\bullet \Delta n = c + d - (a + b)$$

$$\bullet R = 0.08314 \frac{\text{L} \cdot \text{bar}}{\text{mol} \cdot \text{K}}$$

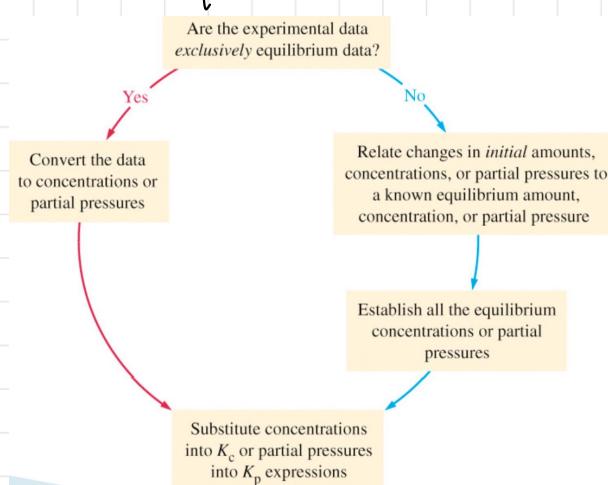
$$\bullet \text{for general eqn } aA + bB \rightleftharpoons cC + dD, K_p = \frac{(P_c)^c (P_d)^d}{(P_A)^a (P_B)^b}$$

- K_p is equilibrium constant for given temp using equilibrium partial pressures
- units of bar for pressures
- when writing expressions for equilibrium constant, pure liquids & solids are not included b/c their concentrations stay constant
- for general eqn $aA + bB \rightleftharpoons cC + dD$, $K = \frac{\alpha_c^c \alpha_p^d}{\alpha_A^a \alpha_B^b}$
- ↳ $\alpha = r \frac{c}{c^\circ}$ for aqueous components
 - $c^\circ = 1 \text{ M}$
 - ↳ $\alpha = r \frac{P}{P^\circ}$ for gaseous components
 - $P^\circ = 1 \text{ bar}$
 - ↳ $\alpha = 1$ for pure liquids & solids
 - ↳ $r = 1$ for ideal gas mixtures & ideal solns
- for rxns in aqueous phase, $K = K_c (\frac{1}{c^\circ})^{\Delta n}$
- ↳ use mol/L for K_c
- for rxns in gaseous phase, $K = K_p (\frac{1}{P^\circ})^{\Delta n}$
- ↳ use bar for K_p
- looking at magnitude of K
 - ↳ if $K > 10^{10}$, rxn goes to completion
 - ↳ if $K < 10^{-10}$, rxn doesn't occur in fwd dir
 - ↳ K



PROPERTIES OF EQUILIBRIUM CONSTANTS AND CALCULATIONS INVOLVING EQUILIBRIUM CONSTANT

- properties of K :
 - ↳ when rxn is multiplied by constant, K is raised to power of constant
 - ↳ K_s for a rxn & its reverse are inverses
 - ↳ when 2+ rxns are added, K for overall rxn is determined by multiplying the separate K s
- to calculate equilibrium constant:



DETERMINING THE NET DIRECTION OF CHEMICAL CHANGE

reaction quotient measures relative amounts of products & reactants present during rxn at particular point in time

$$\hookrightarrow \text{for rxn } aA + bB \rightleftharpoons cC + dD, Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

$\hookrightarrow Q_c \& Q_p$ have same eqns as K_c & K_p but don't have to be calc at equilibrium

Q_c can help us determine dir of change

$$\hookrightarrow Q_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

\hookrightarrow

(a) Pure reactants	(b) "Left" of equilibrium	(c) Equilibrium	(d) "Right" of equilibrium	(e) Pure products

$= K_c$

◦ if reactants are in excess, shift right to reach new equilibrium

→ reactant concentration dec

→ product concentration inc

◦ if products are in excess, shift left to reach new equilibrium

→ reactant concentration inc

→ product concentration dec

Concept Check 5.3

A 40.0 L reactor is initially charged with 0.80 mol N₂, 2.40 mol H₂ and 0.40 mol NH₃. Nitrogen and hydrogen react to form ammonia according to the following reaction:



What will happen as the system moves towards equilibrium?

- A) NH₃ will decompose.
- B) More NH₃ will be formed.
- C) There will be no change in the concentration of reactants and products.

$$Q_c = \frac{[0.4/40]^2}{[0.8/40][2.4/40]^3} \\ = 23.148148$$

Must inc concentration of reactants so shift left

Ie Chatelier's Principle : when equilibrium system is subjected to change in T, P, or C of reacting species, system responds by attaining new equilibrium that partially offsets impact of change

effects of a change in concentration

\hookrightarrow adding reactant at constant volume inc concentration of reactant

◦ $Q_c < K_c$

◦ net dir of chemical change is in fwd dir (i.e. shift right) so more products are formed until $Q_c = K_c$

\hookrightarrow adding product at constant volume inc concentration of reactant

◦ $Q_c > K_c$

◦ net dir of chemical change is in rev dir (i.e. shift left) so more reactants are formed until $Q_c = K_c$

effects of a change in volume :

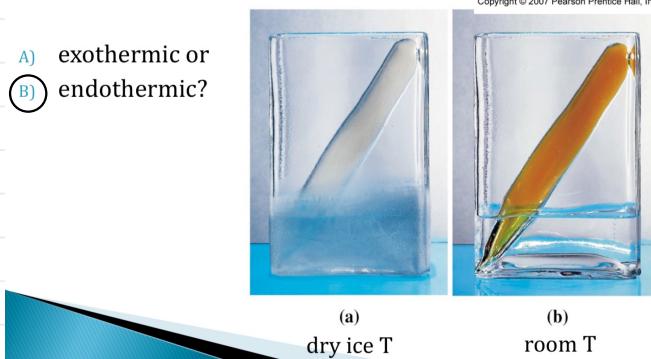
\hookrightarrow when volume of reactive mixture is reduced, chemical equilibrium shifts fwd

- side w/ fewer gas molecules
- ↳ effect of volume change involving condensed phases (i.e. liquids & solids) is generally negligible b/c those phases aren't significantly compressible
- effects of a change in pressure:
 - ↳ add / remove gaseous reactant / product
 - refer to change in concentration notes
 - ↳ change pressure by changing volume
 - may affect chem equilibrium when gas phase is present
 - won't have effect if there's equal # mol of gas on both sides of equation
 - ↳ adding an inert gas to constant volume rxn inc total pressure but doesn't alter other partial pressures
 - no effect on chem equilibrium
- effects of changes in temp:
 - ↳ equilibrium constant will change b/c it's temp dependent
 - ↳ for endothermic rxn ($\Delta H > 0$): energy + reactants \rightleftharpoons products
 - $K_p \uparrow$ & K_c inc when T inc
 - rxn shifts right when T inc
 - ↳ for exothermic rxn ($\Delta H < 0$): reactants \rightleftharpoons products + energy
 - $K_p \downarrow$ & K_c dec when T inc
 - rxn shifts left when T inc
 - ↳ chem equilibrium shifts away from side w/energy term when T inc

Concept Check 5.4

Is the reaction $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

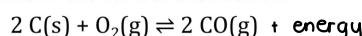
- A) exothermic or
 B) endothermic?



- Van't Hoff eqn can be used to est K_c / K_p at given T , provided that K_c / K_p is known at some other T
- ↳ $\ln \frac{K_2}{K_1} = -\frac{\Delta H}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$

Concept Check 5.5

One of the reactions that occurs in a blast furnace is the partial oxidation of coke (carbon) to form carbon monoxide. This reaction is exothermic in the forward direction:



If a vessel contains an equilibrium mixture of all three reactants, indicate the effect of each of the following disturbances will have on the amount of carbon monoxide in the mixture:

- | | | |
|---|----------------------------------|--------------|
| A) increase | B) decrease | C) no effect |
| i. Adding more O_2 . | iii. Increasing the temperature. | |
| ii. Adding more C. | iv. Decreasing the volume. | |
| iv. Adding an inert gas such as nitrogen while maintaining a constant volume and temperature. | | |

- i) A
- ii) C (addition of solid doesn't affect partial pressure)
- iii) B
- iv) B
- v) C

ELECTROCHEMISTRY

OXIDATION STATES AND REDOX REACTIONS

- oxidation state / number is related to #e⁻ that atom gains, loses, or appears to use in joining w/ other atoms in compounds
 - ↳ i.e. charge each atom would have if all bonds were completely ionic
 - ↳ concept developed for convenience & not measurable property of fundamental significance
- rules for assigning OS:
 - ↳ OS of individual atom in free elem is 0
 - e.g. Cu(s), H₂(g)
 - ↳ for monatomic ion, OS is ion charge
 - e.g. Cu²⁺ OS = +2
 - ↳ sum of OS of all atoms in neutral species is 0
 - ↳ sum of OS of all atoms in ion is charge of ion
 - ↳

The periodic table shows the atomic number, symbol, and mass number for each element. The table is color-coded by group:

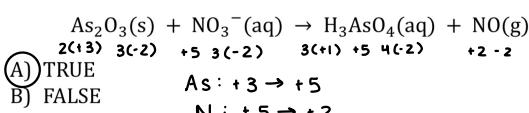
- Group 1 (1A):** Red box highlights H and Li.
- Group 2 (2A):** Blue box highlights Be.
- Groups 3-12 (B):** Green boxes highlight Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Kr, and Po.
- Group 13 (3A):** Orange box highlights Al.
- Group 14 (4A):** Yellow box highlights Si.
- Group 15 (5A):** Purple box highlights P.
- Group 16 (6A):** Magenta box highlights S.
- Group 17 (7A):** Teal box highlights Cl.
- Group 18 (8A):** Light blue box highlights He.

Below the table, oxidation states are indicated for groups 1, 2, 3, 4, 5, 6, 7, and 8. The values are: +1, +2, +3, +4, +5, +6, +7, and -1 respectively.

- exceptions to OS rules occur when 2 rules contradict each other
 - ↳ OS of H is -1 when in hydrides of active metals
 - e.g. LiH
 - ↳ OS of O is -1 in peroxides
 - e.g. H₂O₂
- chemical substance is reduced when OS is reduced thru gain of e⁻
 - ↳ e.g. Cu²⁺(aq) + 2e⁻ → Cu(s)
 - OS: 0 → +2
- ↳ oxidizing agent is substance that causes oxidation of another
- chemical substance is oxidized when OS is inc thru loss of e⁻
 - ↳ e.g. Zn(s) → Zn²⁺(aq) + 2e⁻
 - OS: +2 → 0
- ↳ reducing agent is substance that causes reduction of another

Concept Check 6.1

The following unbalanced reaction is a redox reaction:

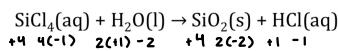


In the reaction above, nitrogen is _____

- A) oxidized
- B) reduced
- C) neither oxidized or reduced

Concept Check 6.2

The following reaction is a redox reaction:



- A) TRUE
 B) FALSE

In the reaction above, chlorine is _____

- A) oxidized
 B) reduced
 C) neither oxidized or reduced

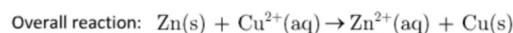
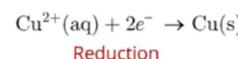
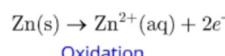
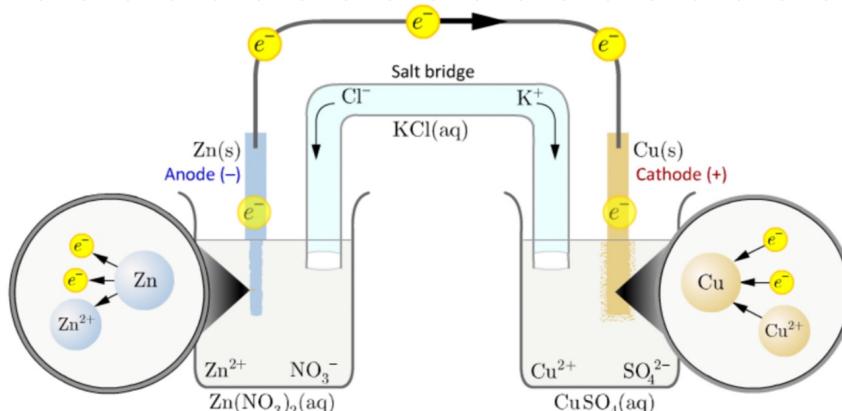
to balance redox rxns:

- 1) write separate half-rxns for oxidation & reduction
- 2) balance all atoms except H & O
- 3) balance O atoms by adding H_2O
- 4) balance H atoms by adding H^+
 - for basic mediums, add same # OH^- to both sides of eq & simplify by combining $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$
- 5) balance charges by adding e^- where needed
- 6) add 2 half-rxns to cancel e^-
 - multiply each eqn by appropriate factor
- ↳ final eqn should be balanced for both # atoms & charges
- ↳ for non-redox rxns, only need steps 2-4

GALVANIC CELL AND FARADAY'S LAW

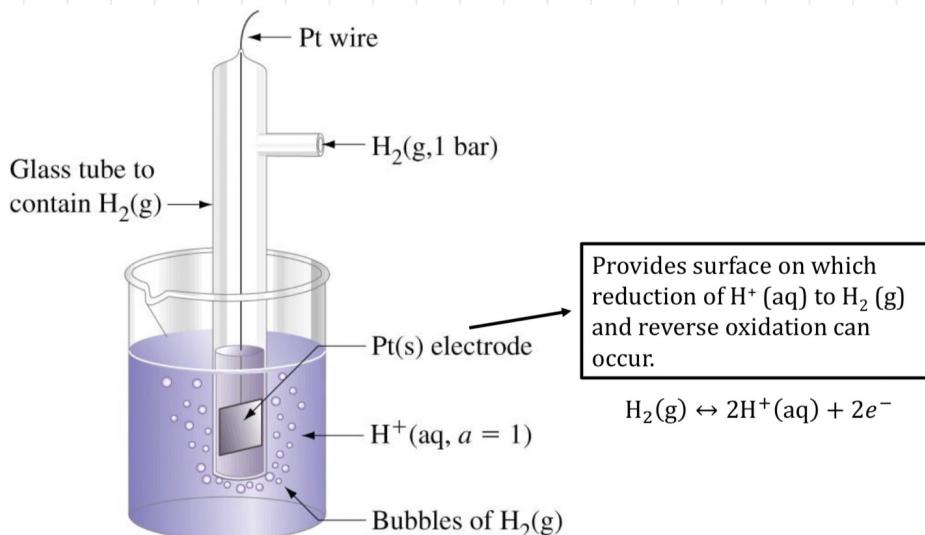
galvanic cell derives electrical energy from spontaneous redox rxns

↳ e.g.



- linear notation is $\text{Zn(s)} | \text{Zn}^{2+}(\text{aq}) || \text{Cu}^{2+}(\text{aq}) | \text{Cu(s)}$
- ↳ anode: electrode in oxidation half-cell (-)
- ↳ cathode: electronode in reduction half-cell (+)
- ↳ e⁻ flow dir is opp of current flow
- ↳ salt bridge is needed to maintain charge neutrality of each half-cell by allowing flow of ions w/ minimal mixing of 2 solns
 - w/o it, charge buildup would stop e⁻ flow
- ↳ Faraday's Law states that electric current (I) is amount of charge (Q) flowing thru circuit per unit time (t): $I = \frac{Q}{t}$
 - ↳ units are amperes
 - $A = \frac{\text{coulomb(C)}}{\text{second(s)}}$

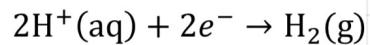
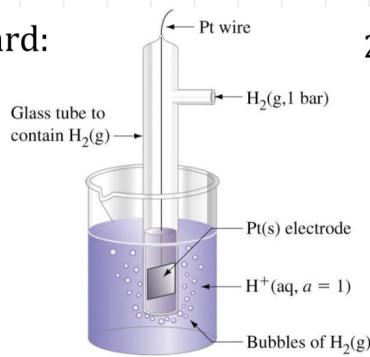
- ↳ quantity of charge that passes thru cell is directly proportional to amount of e⁻ that pass thru cell
 - $Q \propto n$
- ↳ charge of e⁻ = $1.6021773 \cdot 10^{-19}$ C
- Faraday's constant is charge of 1 mol of e⁻
 - ↳ $F = (6.022137 \cdot 10^{23} \text{ e}^-/\text{mol}) (1.6021773 \cdot 10^{-19} \text{ C/e}^-)$
 - $F = 96485 \text{ C/mol}$
 - ↳ # mol of e⁻ flowing thru circuit: $Q = nF$
 - $n = \frac{Q}{F} = \frac{It}{F}$
- from # mol of e⁻ passing thru circuit, can determine # mol substance produced / consumed at electrode
 - ↳ e.g. Cu(s) | Cu²⁺(aq) || Ag⁺(aq) | Ag(s)
 $\text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$
 $\text{Ag}^+(\text{aq}) + 1\text{e}^- \rightarrow \text{Ag(s)}$
 - for every 1 mol e⁻ that passes thru circuit:
 - $\frac{1}{2}$ mol Cu(s) is oxidized so 31.75 g Cu dissolves at anode
 - 1 mol Ag⁺(aq) is reduced so 107.9 g Ag is deposited at cathode
- gas electrode:



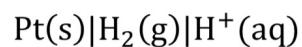
STANDARD CELL POTENTIAL AND THE NERNST EQUATION

- cell potential is electrical potential diff (i.e. voltage) btwn 2 electrodes measured by voltmeter in V ($\frac{J}{C}$)
 - ↳ for galvanic cell, this depends reactants used in half-cells, concentration of reactants, & temp
- to compare voltages of diff cells (E°_{cell}), define standard state:
 - ↳ 1.0 M concentration for dissolved species
 - ↳ 1 bar pressure for gases
 - ↳ 25°C
- to determine E°_{cell} , measure 2 electrode potentials relative to standard electrode
 - ↳ $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$
 - ↳ std electrode has $E^\circ = 0\text{V}$

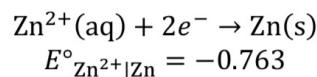
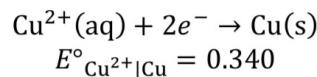
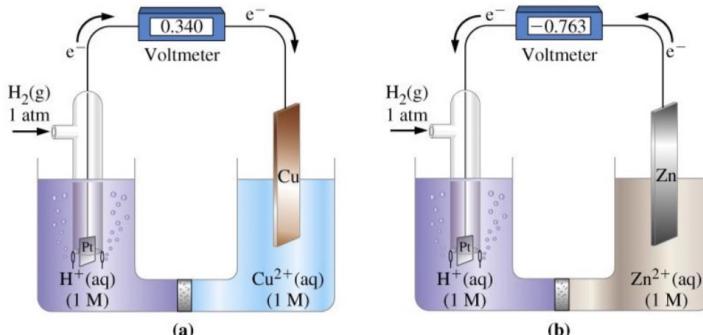
The standard:



$$E^\circ = 0 V$$



e.g. to determine E°_{cell} :



$$\begin{aligned} E^\circ_{\text{cell}} &= E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} \\ &= 0.340V - (-0.763V) \\ &= 1.103V \end{aligned}$$

to determine spontaneous dir of rxn:

- ↳ e⁻ travel from low to high electrode potential
- ↳ anode is electrode w/ lower E°
- ↳ cathode is electrode w/ higher E°
- ↳ $E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}} > 0$

weak oxidizing agent
strong oxidizing agent
(gets reduced, cathode)

Reduction Half-Reaction	E° (V)
$Au^{3+}(aq) + 3e^- \rightarrow Au(s)$	+1.520
$Cl_2(g) + 2e^- \rightarrow 2Cl(aq)$	+1.358
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	+1.229
$Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$	+1.065
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.800
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.771
$I_2(s) + 2e^- \rightarrow 2I^-(aq)$	+0.535
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.340
$S(s) + 2H^+(aq) + 2e^- \rightarrow H_2S(g)$	+0.140
$2H^+(aq) + 2e^- \rightarrow H_2(g)$	0
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	-0.125
$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$	-0.137
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	-0.440
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	-0.763
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	-1.676
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	-2.370
$Na^+(aq) + e^- \rightarrow Na(s)$	-2.713

weak reducing agent
strong reducing agent
(gets oxidized, anode)

Concept Check 6.4

Consider the following standard potentials (E°):

Reduction Half-Reaction	E° (V)
$\text{Au}^+(\text{aq}) + e^- \rightarrow \text{Au(s)}$	1.680
$2\text{Hg}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Hg}_2^{2+}(\text{aq})$	0.905
$\text{I}_2(\text{s}) + 2e^- \rightarrow 2\text{I}^-(\text{aq})$	0.535
$\text{Cu}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Cu(s)}$	0.340
$\text{Cu}^{2+}(\text{aq}) + e^- \rightarrow \text{Cu}^+(\text{aq})$	0.158

When $\text{Au}^+|\text{Au}$ and $\text{Cu}^{2+}|\text{Cu}$ half-cells are combined under standard conditions the $\text{Au}^+|\text{Au}$ half-cell functions as the anode.

- A) TRUE B) FALSE

Concept Check 6.5

Consider the following standard potentials (E°):

Reduction Half-Reaction	E° (V)
$\text{Au}^+(\text{aq}) + e^- \rightarrow \text{Au(s)}$	1.680
$2\text{Hg}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Hg}_2^{2+}(\text{aq})$	0.905
$\text{I}_2(\text{s}) + 2e^- \rightarrow 2\text{I}^-(\text{aq})$	0.535
$\text{Cu}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Cu(s)}$	0.340
$\text{Cu}^{2+}(\text{aq}) + e^- \rightarrow \text{Cu}^+(\text{aq})$	0.158

The E° value for $\text{Hg}^{2+}(\text{aq}) + e^- \rightarrow \frac{1}{2}\text{Hg}_2^{2+}$ is 0.4525 V.

- A) TRUE B) FALSE

↳ reactants, concentration, & temp stay the same

Concept Check 6.6

Consider the following standard potentials (E°):

Reduction Half-Reaction	E° (V)
$\text{Au}^+(\text{aq}) + e^- \rightarrow \text{Au(s)}$	1.680
$2\text{Hg}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Hg}_2^{2+}(\text{aq})$	0.905
$\text{I}_2(\text{s}) + 2e^- \rightarrow 2\text{I}^-(\text{aq})$	0.535
$\text{Cu}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Cu(s)}$	0.340
$\text{Cu}^{2+}(\text{aq}) + e^- \rightarrow \text{Cu}^+(\text{aq})$	0.158

Based on the standard potentials listed above, Cu^+ would be the best reducing agent. (anode)

- A) TRUE B) FALSE

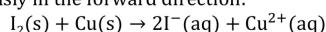
↳ reducing agent must be oxidised so they're products of half-reactions

Concept Check 6.7

Consider the following standard potentials (E°):

Reduction Half-Reaction	E° (V)
$\text{Au}^+(\text{aq}) + e^- \rightarrow \text{Au(s)}$	1.680
$2\text{Hg}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Hg}_2^{2+}(\text{aq})$	0.905
$\text{I}_2(\text{s}) + 2e^- \rightarrow 2\text{I}^-(\text{aq})$	0.535
$\text{Cu}^{2+}(\text{aq}) + 2e^- \rightarrow \text{Cu(s)}$	0.340
$\text{Cu}^{2+}(\text{aq}) + e^- \rightarrow \text{Cu}^+(\text{aq})$	0.158

Under standard conditions, the following reaction proceeds spontaneously in the forward direction:



- A) TRUE B) FALSE

$$E^\circ_{\text{cell}} = 0.535 - 0.340 = 0.195 > 0$$

if cell isn't in std state, use Nernst eqn which is $E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{nF} \ln Q$

$$\hookrightarrow R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\hookrightarrow T : \text{temp (K)}$$

- ↳ $F = 96485 \text{ C/mol}$
- ↳ Q : rxn quotient
 - use M for aq
 - use bar for gas
 - for $aA \rightarrow bB$, $Q = \frac{\alpha^b}{\alpha^a}$
- ↳ n : # e^- transferred in rxn
- other forms of Nernst eqn.
 - ↳ using log instead of ln: $E_{cell} = E^\circ_{cell} - \frac{2.3026RT}{nF} \log Q$
 - ↳ at 25°C : $E_{cell} = E^\circ_{cell} - \frac{0.0592}{n} \log Q$
- concentration cell is galvanic cell that contains same material at anode & cathode
 - ↳ for metals, half-cell w/ higher concentration acts as cathode

NERNST EQUATION AT EQUILIBRIUM AND ELECTROLYTIC CELL

Concept Check 6.8

Based on the Nernst equation, as the reaction proceeds in the spontaneous direction, does E_{cell} increase or decrease?

A) Increase

B) Decrease

$$Q = \frac{[\text{prod}]}{[\text{reac}]}$$

$$E_{cell} = E^\circ_{cell} - \frac{RT}{nF} \ln Q$$

dec inc ↓
 ↑ ↑ inc
smaller - bigger

- when galvanic cell reaches equilibrium, Nernst eqn becomes

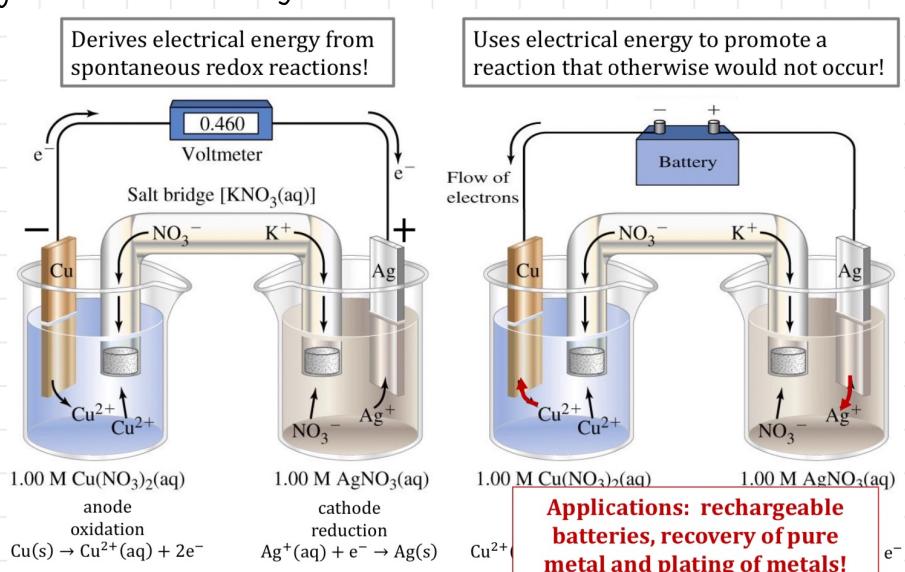
$$0 = E_{cell} = E^\circ_{cell} - \frac{RT}{nF} \ln K$$

↳ at equilibrium, there's no spontaneous rxn

$$Q = K$$

↳ can rearrange to solve for $K = e^{\frac{E^\circ_{cell} n F}{RT}}$

- galvanic vs electrolytic cells:



- oxidation always occurs at anode of electrochemical cell

↳ in galvanic cell, e^- are freed by oxidation half-rxn (-)

↳ in electrolytic cell, e^- are withdrawn from electrode (+)

- reduction always occurs at cathode of electrochemical cell

↳ in galvanic cell, e^- are removed by reduction half-rxn (+)

↳ in electrolytic cell, e^- are forced onto electrode (-)