Rates of Reactions

Factors and Rate Law

Rates of Reactions

- **Rates of Reaction p.213-273**

· all chemical reactions occur due to particle collisions

· elastic collisions do not result in reactions

· in order for a reaction to occur, INELASTIC collisions are necessary (where there is an exchange of energy)

Rates of Reactions

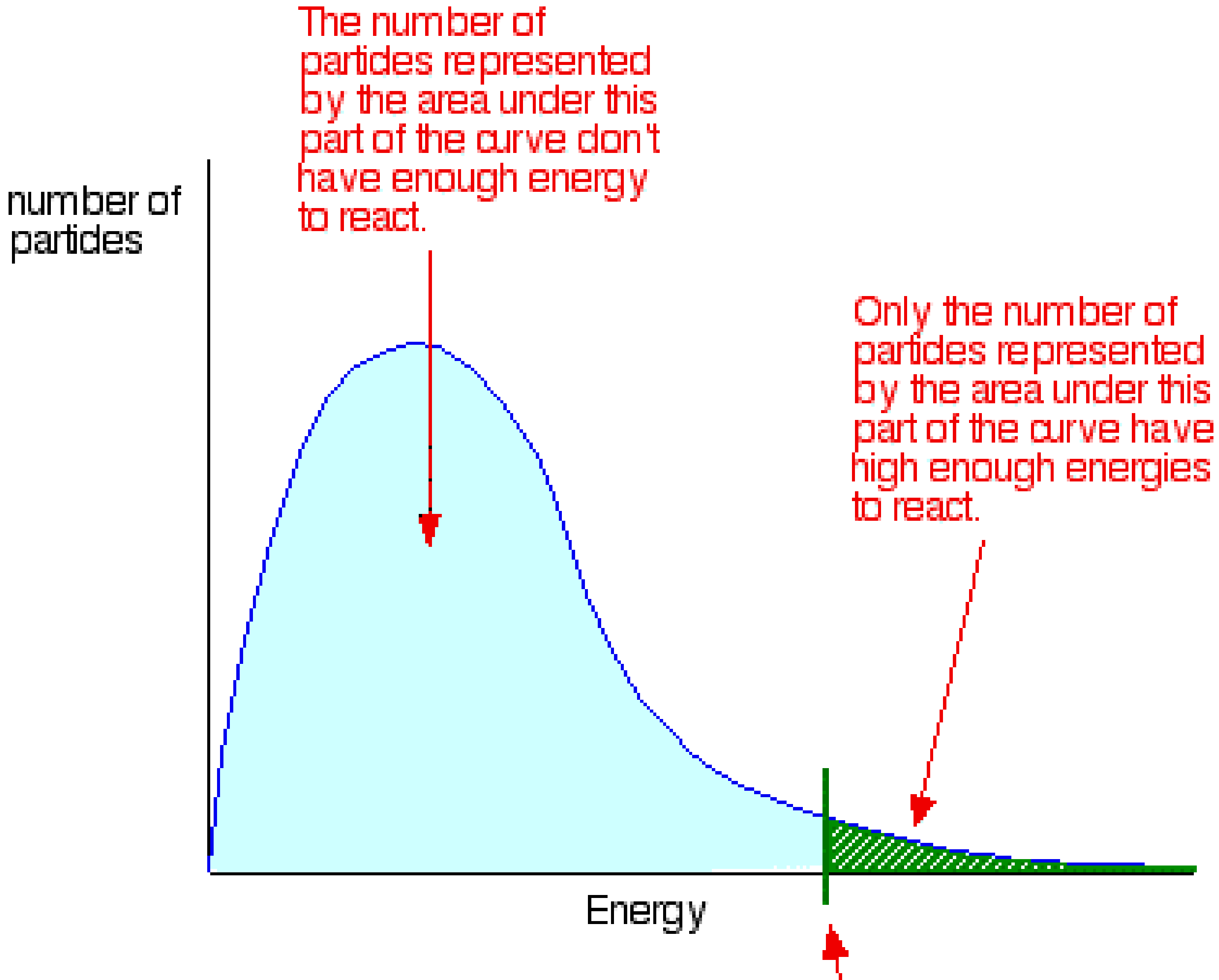
- 3 criteria:

1. particles must collide
2. particles must collide in proper orientation
3. particles must collide with sufficient energy
   (to overcome activation energy barrier)

Rates of Reactions

- **Maxwell-Boltzmann distribution curve**
- a graphical representation of the kinetic energy of particles
- particles in the shaded area have enough energy to
- overcome the E A barrier
- the LARGER the shaded area, the FASTER the reaction

Maxwell-Boltzmann distribution curve



Factors that affect reaction rate

Reaction rate can be changed by increasing or decreasing the number of effective collisions.

This can be done by modifying the following factors:

1. Nature of reactants
2. Surface area
3. Concentration
4. Temperature
5. Use of chemical catalysts or inhibitors

1. Nature of reactants

- reaction rate depends on strength of bonds
- rate will increase as the bonds become weaker
- SOLID → LIQUID → GAS → AQUEOUS IONS

SLOW REACTION→ FAST REACTION

2. Surface area of reactants

- frequency of effective collisions increases as more surface area is exposed
- think of lighting a fire, cooking your food

HW p. 250 #1-4,6

1. a) #1
   b) slower
   c) 3,1,4,2
2. a) 1 b) 3 c) 2 d) 4

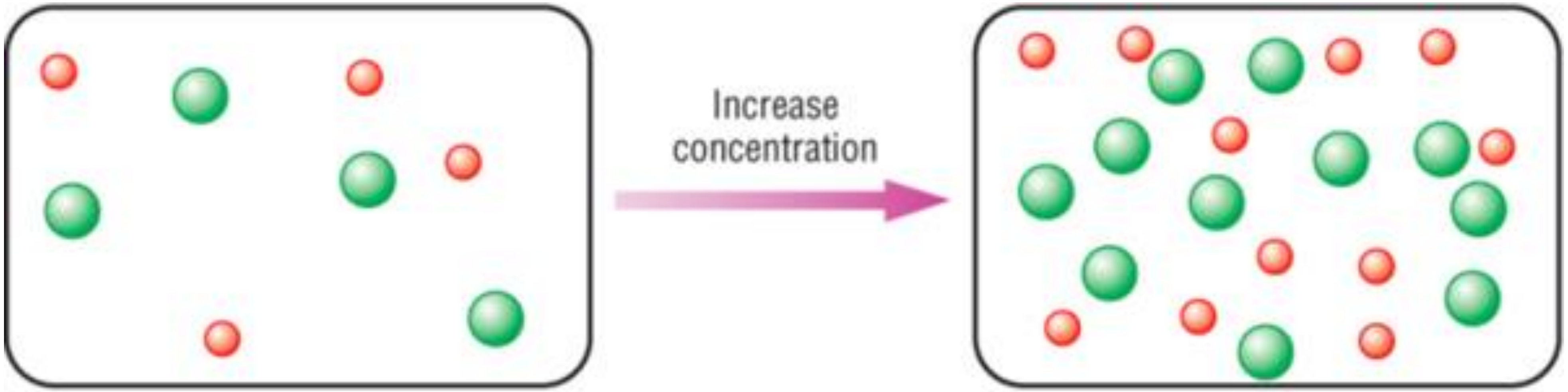
3) C

4) a, d, c, b

6. a) same rate
   b) #1

3. Concentration of reactants

- rate increases with an increase in concentration
- more particles in a given space means collisions are more likely
- statistically, this makes effective collisions more likely
- think of walking in the halls during class as opposed to in between classes



Here we have a few molecules.
There are few collisions.
The rate of reaction is low.

Here we have many molecules.
There are more collisions.
The rate of reaction is greater.

Rate law

- relationship between rate, concentration of reactants and coefficients
- we only consider gaseous and aqueous reactants
    - (concentration of pure liquids and solids remains constant as they density depends less on temperature)
- a proportionality constant (k) between rate and concentration can be determined, this is unique to a particular reaction
- this value is constant because when concentrations are high, so is rate and vice versa

- $r = k\,[A]^x[B]^y$
  - r = rate in mol/Ls
  - k = rate constant
  - [A], [B] = concentration of reactants in mol/L
  - x, y = coefficients in balanced equation
- Therefore: $k = \dfrac{r}{[A]^x[B]^y}$

Example 1

- How does the rate of the following reaction change if the concentration of the two reactants is doubled?

$$2\,A + 3\,B \rightarrow C$$

- Initial rate: $r = k\,[A]^2\,[B]^3$
- New rate: r =
- k = k therefore:

Example 2

- Two gases, A and B, react at a rate of 2.6 mol/Ls according to the following equation.

$$2\,A + B \rightarrow C$$

- If the concentration of A is 0.30 mol/L and that of B is 1.20 mol/L, what is the value of the constant?

Example 3

- Consider the following reaction:
- $AlCl_{3\ (aq)} + 3\ NaOH_{\ (aq)} \rightarrow Al(OH)_{3\ (s)} + 3\ NaCl_{\ (aq)}$
- If the reaction occurs at a rate of 0.050 mol/Ls as a function of $AlCl_3$, the initial concentration of AlCl3 is 3.50 mol/L, what is the concentration of $AlCl_3$ and NaCl after 20 seconds?

Example 3

- If you double the concentration of $AlCl_3$ and you decrease the concentration of NaOH by a factor of 3, what is the new rate? (remember k = k....it's a constant!)

HW p. 258- 259

#4 - 11

4) 8.90×10^7 mol/Ls

5) 0.80

6) 3.1×10^2

7) r2 = 32 r1

8 a) 2.9×10^2 mol/Ls

b) 5.6×10^5 mol/Ls

9 a) 3, 2, 4, 3

b) $r = k[Fe2O3]^2$

10 a) $r = k\,[O2]^8$

b) 4.1×10^6

c) no change (solid)

d) 21.1 mol/Ls

11\. a) 8.0×10^5

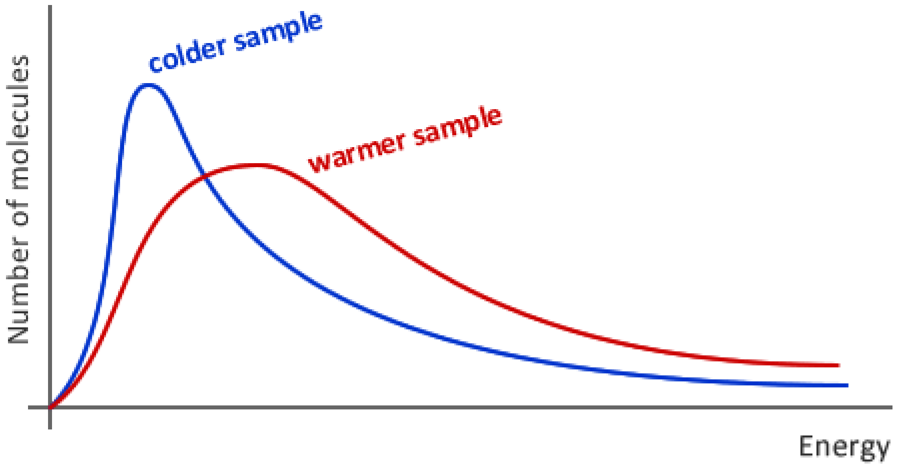
b) 3.4×10^5 mol/Ls

4.Temperature

Temperature is directly proportional to Ek

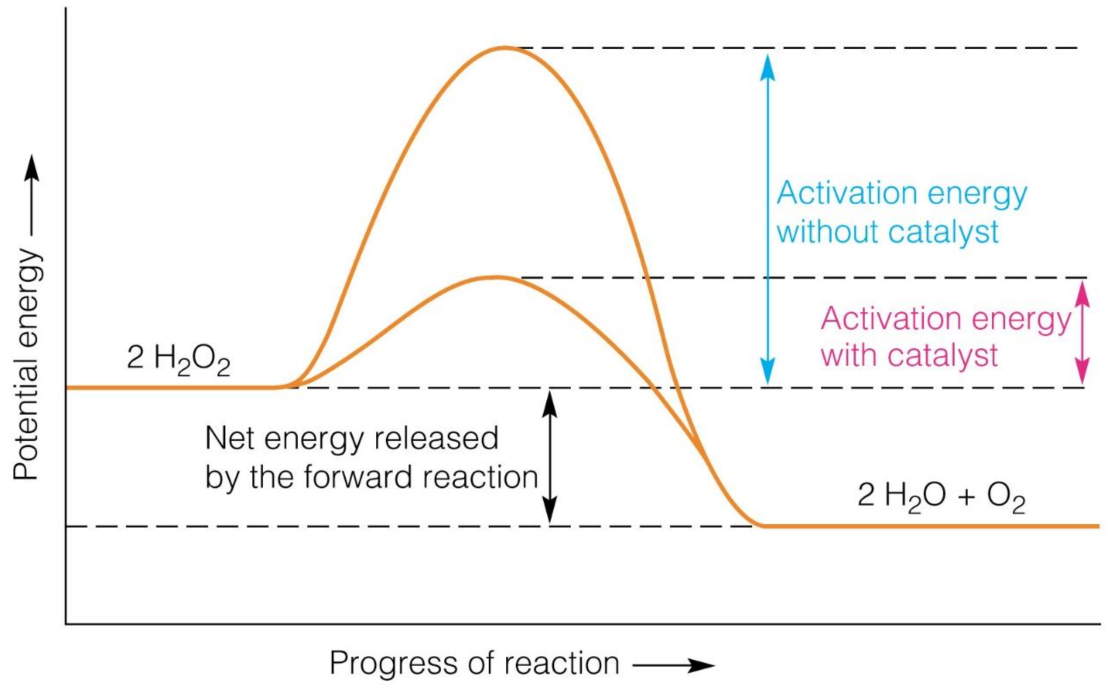
As temperature goes up, particles collide with greater force

Frequency of effective collisions increases

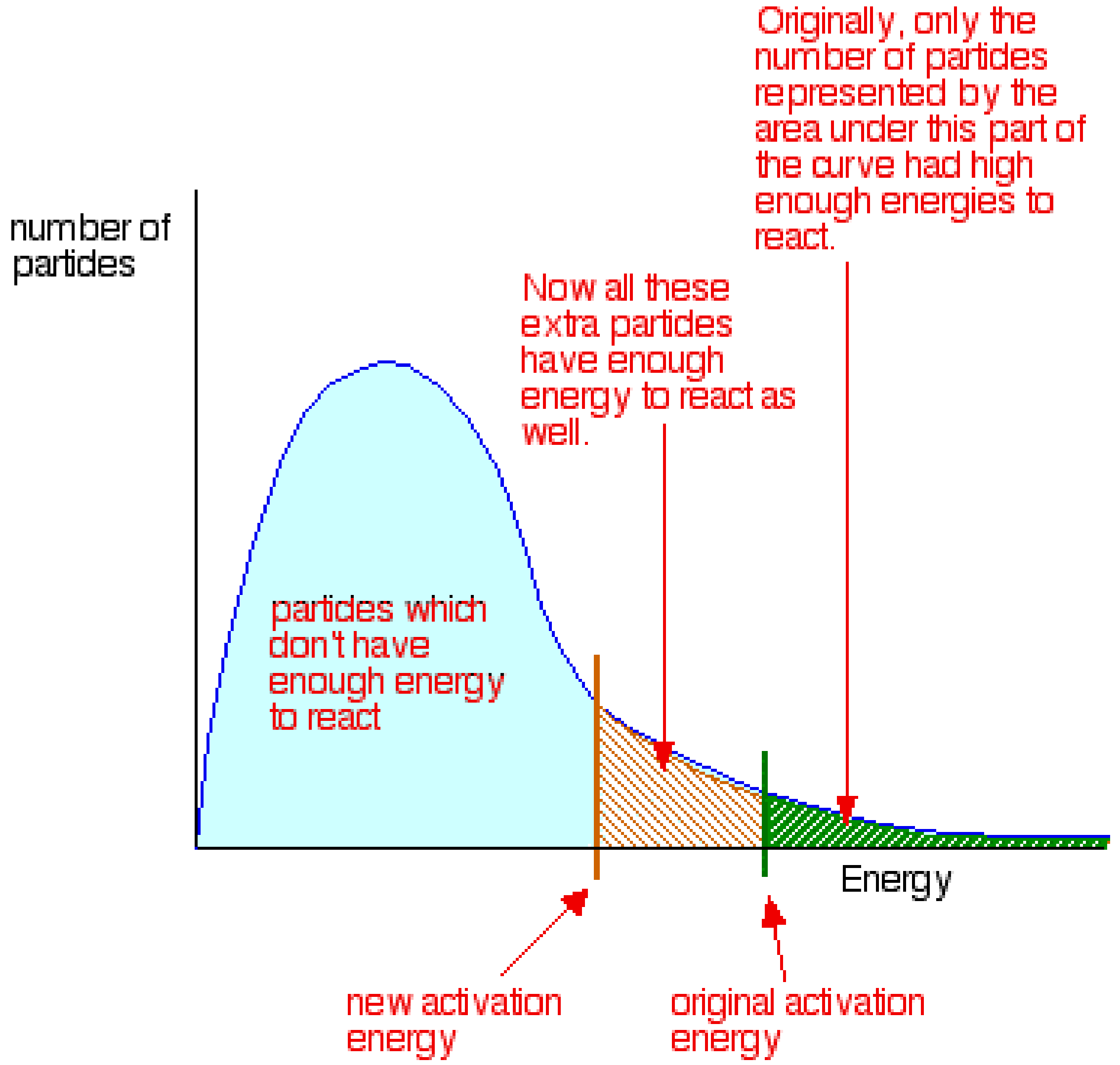


Catalysts (and inhibitors)

- catalysts increase rate by lowering activation energy, essentially providing an alternate energy pathway
- this way, more particles have the energy necessary to react
- catalysts do not change ΔH for a reaction
- catalysts do not get used up in a reaction



Potential energy
2 H_2O_2
Activation energy without catalyst
Activation energy with catalyst
Net energy released by the forward reaction
2 H_2O + O_2
Progress of reaction



number of particles
Originally, only the number of particles represented by the area under this part of the curve had high enough energies to react.
Now all these extra particles have enough energy to react as well.
particles which don't have enough energy to react
Energy
new activation energy
original activation energy

HW p. 267 #2, 5 - 7

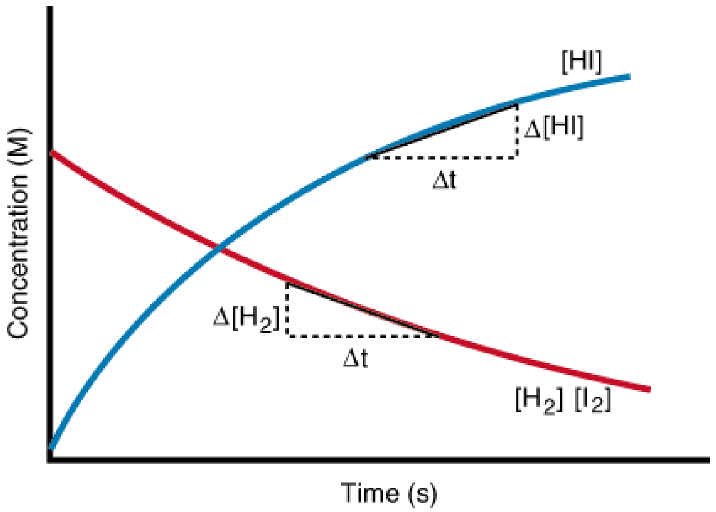
- 2) 3
- 5 a) 2   b) 3
- 6) dotted line shifts to the right

  7 a) 1: inhibitor   2: neither   3: catalyst

  b) 3

Expressing reaction rate

- Rate is a positive value indicating the change in the amount of reactant or product over time
- When reaction begins only reactants are present
- As reactant particles collide effectively, product particles are produced
- Over time, rate decreases as fewer reactant particles remain



General reaction rate

Rate is linked to stoichiometric coefficients

Consider the following reaction:

$$2\ N_2O_{5(g)} \rightarrow 4\ NO_{2(g)} + O_{2(g)}$$

In this reaction, NO_2 is formed at twice the rate that N_2O_5 is consumed

Similarly, O_2 is formed at half the rate that N_2O_5 is consumed

General reaction rate:

Change in concentration over time divided by coefficients

General Reaction Rate

- $r = -1/2 \dfrac{\Delta[N_2O_5]}{\Delta t}$ OR $1/2\ r\ N_2O_5$
- $r = 1/4 \dfrac{\Delta[NO_2]}{\Delta t}$ OR $1/4\ rNO_2$
- $r = 1 \dfrac{\Delta[\ 0_2\ ]}{\Delta t}$ OR $1\ rO_2$

r = general rate in mol/Ls

Example 1

In the following reaction, the rate of ammonia (NH_3) production is

4.80×10^{-4}mol/Ls.

What is the general reaction rate and what are the rates of reaction of nitrogen and hydrogen?

$$N_{2\,(g)} + 3\,H_{2\,(g)} \rightarrow 2\,NH_{3\,(g)}$$

Example 2

- What is the rate of hydrogen formation if the concentration of ammo nia (NH_3) decreases from 0.400 mol/L to 0.120 mol/L in 45 seconds?

$$CH_{4\,(g)} + NH_{3\,(g)} \rightarrow HCN_{(g)} + 3\,H_{2(g)}$$

HW p. 219 #3 -7

3) 0.10 mol/Ls

4) $-1/4 \frac{\Delta[HBr]}{\Delta t} = 1/2 \frac{\Delta [Br2]}{\Delta t}$

5) a) 9.1 x 10-4 mol/Ls

b) 0.011 mol/Ls

6) a) 0.133 mol/s

b) $-1/4 \frac{\Delta[B]}{\Delta t} = 1/3 \frac{\Delta [D]}{\Delta t}$

c) 150 L

7) a) 7.94 x 10-3 mol/min
b) 0.198 mol/min
c) 84 ml/s
d) 0.203 g

Ways to measure rate

- unit depends on state of matter
- reaction rate for solids, liquids, gases can be measure in g/s or mol/s
- reaction rate for liquids and gases can also be measured in ml/s
- reaction rate for gases and aqueous solutions can be measured in mol/Ls (change in concentration over time)

Example

Calculate the rate of reaction in g/s and mol/s if 16.0 mg of magnesium react in 3 minutes and 45 seconds.

$$Mg_{(s)} + 2\ HCl_{(aq)}\quad MgCl_{2\ (aq)} + H_{2\ (g)}$$

HW p. 225 #4, 7- 11

4) 4.8 x 104 mol/Ls OR 1.717 mol/Lh

7) 1.182 x 10^6 g
   6.57 x 10^5 L

8) 0.045 mol/Ls

9) 2.78 x 103 mol/Ls   1.78 g

10) a) 1.6 x 103 g/s   b) 6.6 x 10^{-5} mol/s   c) 9.6 x 102 g/min

11) 12 000 g/s

Average reaction rate
Instantaneous reaction rate

- Average rate is the change in reactant or product over a given period of time (SECANT to curve)
- Instantaneous rate is the rate at a specific point during the reaction (changes over time, TANGENT to curve)

Example

- Given the following reaction and table of values for the concentration of gas C, calculate the average rate of reaction between 5.0 and 15 seconds and the instantaneous rate at time 10.0 seconds.

$$A_{(g)} + B_{(g)} \rightarrow C_{(g)}$$

Time (s)	[C] (mol/L)
0.0	0.00
5.0	3.12×10^{3}
10.0	4.41×10^{3}
15.0	5.40×10^{3}
20.0	6.24×10^{3}

HW p. 228 #35, p. 232 #16, p. 233 #21 a-d

3) 1.1 x 106 mol/Ls

4) a) reactant
b) 0.3 mol/Ls
c) 10: 0.5 mol/Ls   20: 0.25 mol/Ls   50: 0.0667 mol/Ls
d) 0 - 10 seconds

5) a) 6.6 x 103 mol/Ls   b) 2.0 x 103 mol/Ls   c) 4.25 x 103 mol/Ls
16) a) 0.6 mol/min   b) 0.25 mol/min

c) 0.10 mol/min   d) 0.3 mol/min   e) rate decreases

21) a) 1.56 x 10^6 mol/Ls   b) 2.3 x 10^6 mol/s

c) 1.8 x 10-7 mol/Ls   d) rate decreases