KEY

Chemistry 12

REVIEW – REACTION KINETICS

1. Write expressions with which you could express ***rates*** for the following reactions. (Hint: look at what happens to reactants and products.) Recall that *solid or liquids* can lose or gain *mass*, *gases* can lose or gain *volume* and *aqueous solutions* can increase or decrease in *concentration*. (*"a" is done as an example*.)

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

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{unit time}}$$

or

$$\text{reaction rate} = \frac{\text{volume of } H_2 \text{ produced}}{\text{unit time}}$$

or

$$\text{reaction rate} = \frac{\text{decrease in [HCl]}}{\text{unit time}}$$

or

$$\text{reaction rate} = \frac{\text{increase in } [MgCl_2]}{\text{unit time}}$$

b) $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}$

$$RR = \frac{\text{mass AgCl produced}}{\text{unit time}}$$

$$RR = \frac{\downarrow [Ag^+]}{\text{unit time}} \qquad RR = \frac{\downarrow [Cl^-]}{\text{unit time}}$$

c) $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

$$RR = \frac{\downarrow \text{mass C}}{\text{unit time}} \qquad RR = \frac{\downarrow [O_2]}{\text{unit time}}$$

$$RR = \frac{\uparrow [CO_2]}{\text{unit time}}$$

2. For each of the following reactions find a ***quantity*** or ***property*** which could be monitored in order to measure the rate of reaction. (*"a" is done as an example.*)

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

- *pressure will decrease as reaction proceeds because you are going from **4 moles** of reactants to **2 moles** of products. Assuming you have a constant volume, less moles exert less pressure.*

b) $CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$

- *Two things could be monitored here. Look at the **states** of everything carefully.*

1 – open system: total mass ↓

2 – closed system: total pressure ↑

c) $2NO_{2(g)} \rightarrow N_2O_{4(g)}$

brown colourless

Two things could be monitored here.
*One is obvious. Look at the **states** of everything carefully for the other one.*

1- Δcolour → will lighten

2- ↓pressure → 2 moles of gas Δ 1 mole gas

3. A chemist wishes to determine the rate of reaction of beryllium with hydrochloric acid. The equation for the reaction is:

$$Be_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + BeCl_{2(aq)}$$

A piece of beryllium is dropped into 1.00 L of $HCl_{(aq)}$ and the following data were obtained:

Time	Mass of Beryllium
0 s	0.020 g
4 s	0.018 g
8 s	0.016 g
12 s	0.014 g
16 s	0.012 g
20 s	0.010 g

a) Calculate the ***Rate of Reaction*** in *grams of Be consumed per second.*

$$\frac{(0.020 - 0.010)\,g}{20\,s} = \boxed{5 \times 10^{-4} \frac{g}{s}}$$

b) Calculate the ***Rate of Reaction*** in *moles of Be consumed per second.*

$$\left(\frac{5 \times 10^{-4}\,g}{s}\right)\left(\frac{mol}{9.0\,g}\right) = \boxed{6 \times 10^{-6} \frac{mol\ Be}{s}}$$

c) What will happen to the [HCl] as the reaction proceeds? ↓

4. When *pentane* (C_5H_{12}) is burned in air (*oxygen*), the products *carbon dioxide* and *water* are formed.

a) Write a ***balanced formula equation*** for this reaction.

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

b) If pentane is consumed at an average rate of 2.16 grams/s, determine the rate of consumption of pentane in *moles/s*.

C=5(12)
H=12(1)
72.09/mol

$\left(\frac{2.16\,g}{s}\right)\left(\frac{mol}{72.0\,g}\right) = \boxed{3.00 \times 10^{-2}\ \frac{mol}{s}}$

c) If pentane is consumed at an average rate of 0.030 moles/s, determine the rate of consumption of *oxygen* in moles/s.

$\left(\frac{0.030\,mol\ C_5H_{12}}{s}\right)\left(\frac{8\,mol\ O_2}{1\,mol\ C_5H_{12}}\right) = \boxed{0.24\ \frac{mol}{s}\ O_2}$

d) If pentane is consumed at an average rate of 0.030 moles/s, determine the rate of production of CO_2 in moles/s.

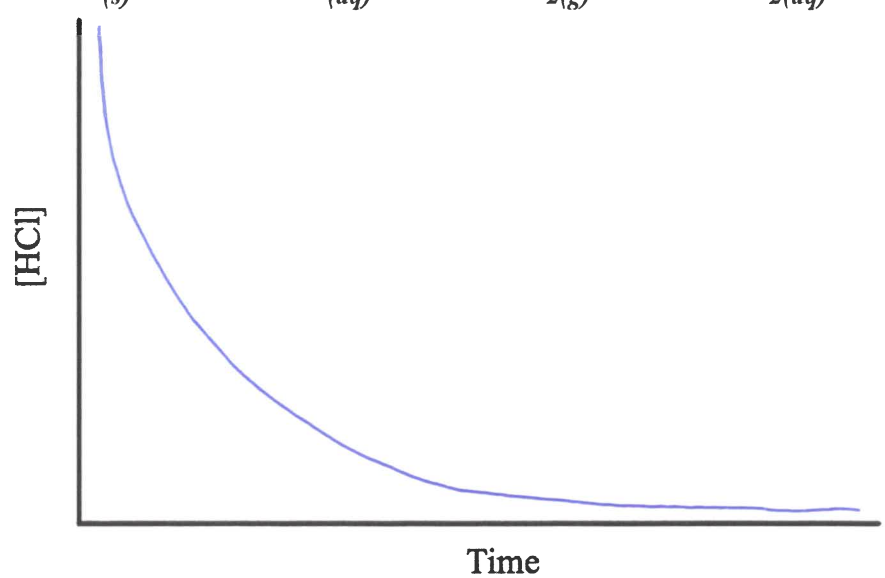
$\left(\frac{0.030\,mol\ C_5H_{12}}{s}\right)\left(\frac{5\,mol\ CO_2}{1\,mol\ C_5H_{12}}\right) = \boxed{0.15\ \frac{mol}{s}\ CO_2}$

e) If pentane is consumed at an average rate of 0.030 moles/s, determine the rate of production of CO_2 in ***grams/s***.

$\left(\frac{0.030\,mol\ C_5H_{12}}{s}\right)\left(\frac{5\,mol\ CO_2}{1\,mol\ C_5H_{12}}\right)\left(\frac{44.0\,g}{mol}\right) = \boxed{6.6\ \frac{g}{s}\ CO_2}$

5. On the following set of axes, draw the shape of the curve you would expect if you plotted the ***[HCl]*** *vs.* ***Time***, starting immediately after the two reactants are mixed. The equation for the reaction is:

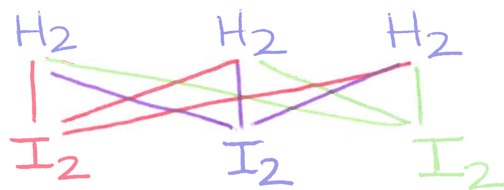
$Zn_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$



Explain how you got that particular shape. Be detailed.

-rate starts high as [HCl] is high + slope is steep
-as rxn proceeds, HCl is used up so [HCl]↓
-rate slows down & slope is less steep

6. How many possible collisions are there between 3 H_2 molecules and 3 I_2 molecules? (*a diagram may help*)



9 possible collisions

7. a) In a room filled with H_2 and O_2 there are about ***10^{32}*** collisions per second. Explain why the reaction between H_2 and O_2 at room temperature is so *slow* as to be unnoticeable!

very few collisions are successful < insufficient KE to overcome Ea / incorrect orientation/geometry

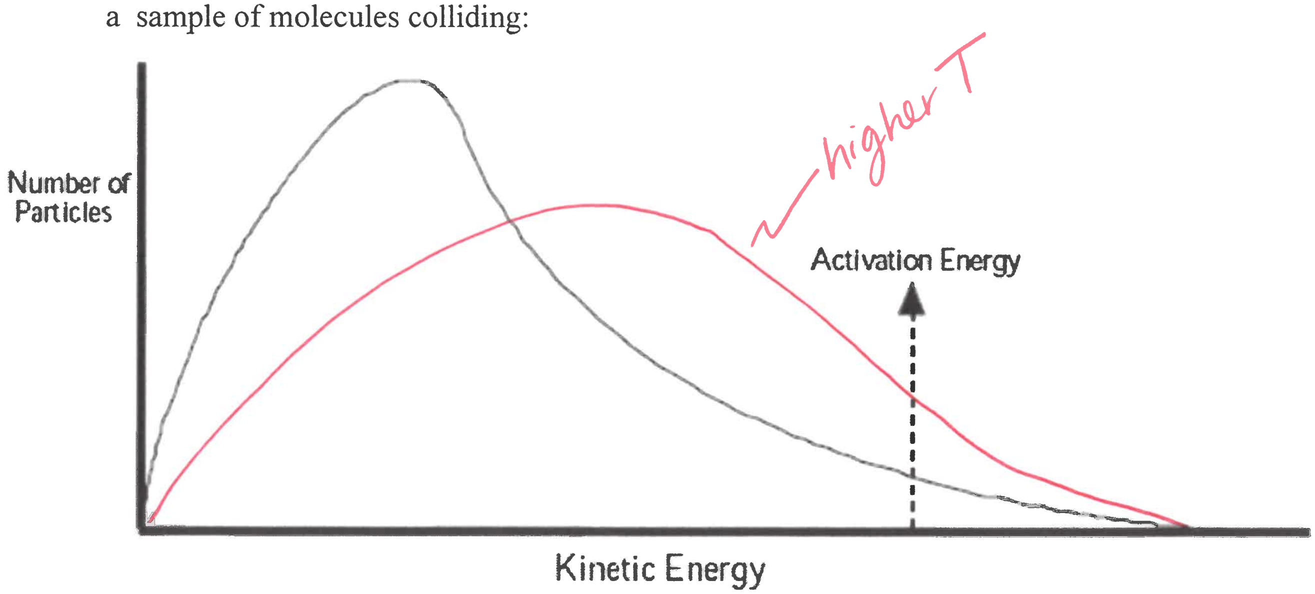
b) Suggest ***two*** ways in which the reaction in question "7a" could be *speeded up*.

1. ↑T
2. add a catalyst (Pt)

8. What might be done to a *solid catalyst* in order to make it more efficient?

grind into a powder

9. a) The following diagram shows a graph of *Number of Particles* vs. the *Kinetic Energy* for a sample of molecules colliding:



Approximately what fraction of the molecules in the sample have enough energy for an effective collision?

~ 1/10th to 1/15th

b) On the diagram in question "a", draw the curve you would expect at a higher temperature in which the rate of the reaction is ***doubled***. *Be careful to be accurate! Label it.*

10. a) When *two moles of A* react with *one mole of B*, a reaction occurs in which *three moles of C* are formed and *34.5 kJ of heat* are *given off*. Write an equation for this reaction showing the heat of reaction (ΔH) at the right of the equation.

$2A + B \rightarrow 3C \quad \Delta H = -34.5\,kJ$

b) Write a ***thermochemical equation*** for the reaction in (a) *(ie. the Heat Term is right in the equation.)*

$2A + B \rightarrow 3C + 34.5\,kJ$

c) Write a thermochemical equation which shows what happens when *3 moles of C decompose* to form *two moles of A* and *1 mole of B. (See the reaction in "b")*

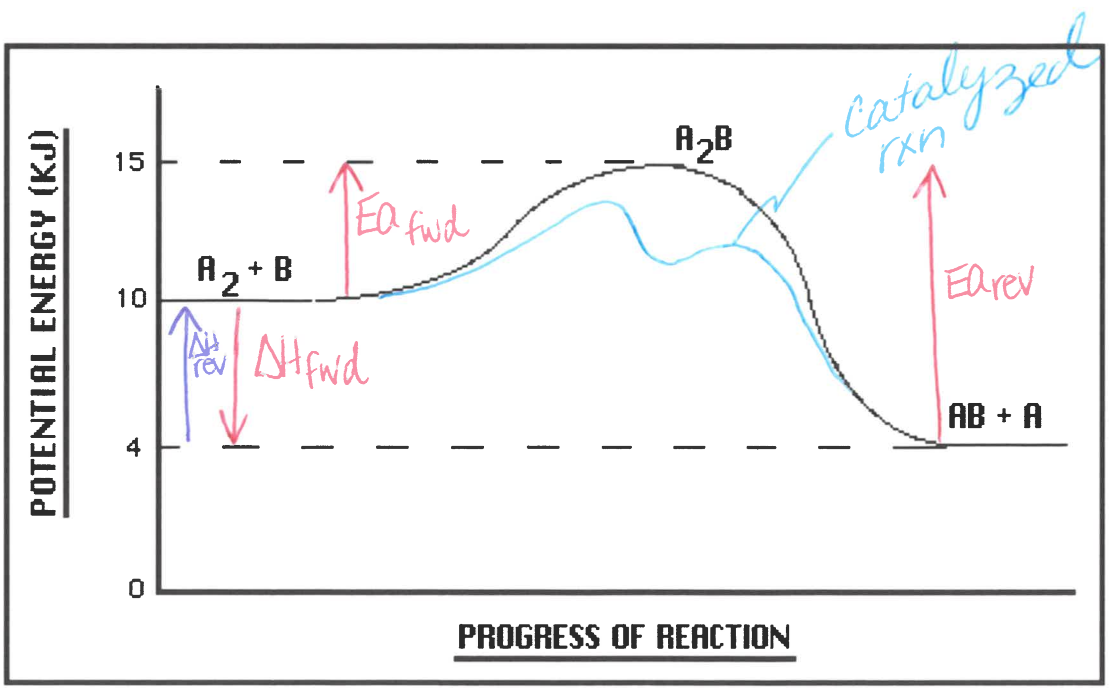
$34.5\,kJ + 3C \rightarrow 2A + B$

d) What would happen to the ***temperature*** of the surroundings if the reaction mentioned in "a" was carried out? get warmer This type of reaction which ***releases heat*** is called exothermic.

e) In the reaction mentioned in question "a" which has *more* ***enthalpy***, the reactants or the products? reactants

f) What is meant by ***enthalpy***? total E in the system

11. Use the following ***Potential Energy Diagram*** to answer all the questions below:



a) What is the value of ΔH for the *forward* reaction ? -6 kJ

b) What is the value of the ***activation energy*** for the *forward* reaction? 5kJ

c) What is the value of the ***activation energy*** for the *reverse* reaction? 11 kJ

d) Which is a *stronger* bond, A--A or A--B ? A-B

e) Explain your answer to (d)
takes more E to break A-B bond than A_2

f) Which species is the ***activated complex***? A_2B

g) Which set of species has the ***lowest potential energy***? AB + A

h) Is the reaction as written *endothermic* or *exothermic*? exo

i) What is the *minimum energy needed* to *start* the reaction $\boldsymbol{AB + A \rightarrow A_2 + B}$?
11kJ (Earev)

j) What happens to the ***kinetic energy*** (speed) of AB and A as the reaction on as shown on the graph proceeds past the activated complex and toward the products?
KE↑

k) For A_2 and B to form the *activated complex* they must have the proper *energy* and the proper orientation/geometry

l) If a catalyst C is used in this reaction, it takes place by means of a different mechanism. This one involves two steps.

$$A_2 + C \rightarrow AC + A \quad \text{(slow)}$$

$$AC + B \rightarrow AB + C \quad \text{(fast)}$$

*Draw another curve on the graph with another colour showing the **catalyzed** reaction. (Remember it has two steps so it should have two bumps! Also be aware that one of the bumps is higher than the other!)*

m) Which step in question (l) is the rate determining step? Step 1

n) Looking at only the equations for the steps in question "*l*", how could one tell that "C" is a catalyst?
it is used up in step 1 & regenerated again in step 2

o) What is ΔH for the reverse reaction to what is shown on the graph? +6kJ

p) What effect did the *catalyst* have on the *activation energy* for the *forward* reaction? ↓ Ea fwd

For the reverse reaction? ↓ Ea rev

q) What effect did the catalyst have on the ΔH of the forward reaction? no effect

The reverse reaction? no effect

12. Name four instances in which ***catalysts*** are used in industry or everyday life and tell *which catalysts* are used.

V_2O_5 - used in making H_2SO_4
maltase - to break down maltose → glucose
Ni - to hydrogenate saturated fats
Pt, Pd, Rh - used in catalytic converter to break down NO_2 in exhaust

13. Describe what happens to the ***kinetic energy***, ***potential energy*** and the ***total energy*** of reactant molecules as they approach each other.

KE ↓ , PE ↑ , total E - constant

14. Explain *why* a lower ***activation energy*** for a reaction leads to a greater reaction rate at a given temperature.

- greater % of collisions will have sufficient E to overcome required Ea

15. A small piece of zinc reacts with 2.0 M HCl to produce 12.0 mL of H_2 gas in 30.0 seconds at STP. Calculate the ***rate of reaction*** @ STP

a) In mL of H_2/second

$$\frac{12.0\,mL\ H_2O}{30.0\,s} = \boxed{0.400\ \frac{mL}{s}}$$

b) In ***moles of H_2/second***

$$\left(\frac{0.400\,mL}{s}\right)\left(\frac{10^{-3}\,L}{1\,mL}\right)\left(\frac{mol}{22.4\,L}\right) = \boxed{1.76\times10^{-5}\ \frac{mol\ H_2}{s}}$$

16. Which of the following reactions is ***most likely*** to have the *greatest rate* at room temperature?

a) $Ag^+{}_{(aq)} + I^-{}_{(aq)} \rightarrow AgI_{(s)}$

b) $H_{2\,(g)} + Cl_{2\,(g)} \rightarrow 2HCl_{(g)}$

c) $C_3H_{8\,(g)} + 5O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + 4H_2O_{(g)}$

d) $Fe_{(s)} + S_{(s)} \rightarrow FeS_{(s)}$

Explain how you arrived at your answer. both aqueous ions; no bonds to break; floating freely in solution

17. State whether the following are ***endothermic*** or ***exothermic*.**

a) $S + O_2 \rightarrow SO_2 \quad \Delta H = -297\ kJ$ exo

b) $NO_2 + 33.8\ kJ \rightarrow 1/2\ N_2 + O_2$ endo

c) $N_2 + O_2 + 90.4\ kJ \rightarrow 2NO$ endo

d) $N_2H_4 + O_2 \rightarrow N_2 + H_2O + 627.6\ kJ$ exo

18. Consider the reaction:

$Ca_{(s)} + 2HBr_{(aq)} \rightarrow H_{2\,(g)} + CaBr_{2\,(aq)} + \text{heat}$

State whether the following changes would ***increase the rate*** or not?:

a) Let the $CaBr_2$ solution evaporate without changing the temperature. no effect

b) Allow the $H_{2\,(g)}$ to escape .... no effect

c) Decrease the temperature. .... ↓ rate

d) Increase the temperature. .... ↑ rate

e) Increase the [HBr] . ... ↑ rate

19. Consider the *rate* of the following reaction:

$$\boldsymbol{Sn_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + SnCl_{2(aq)}}$$

a) Is it dependent on *temperature*? yes. Explain your answer.
most rxns dependent on T

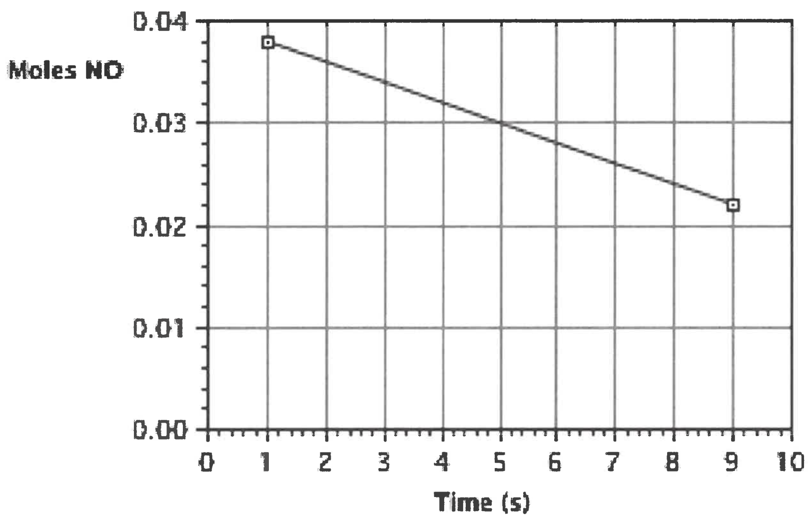
b) Is it dependent on *pressure*? no. Explain your answer.
no gaseous reactants

c) Is it dependent on *surface area*? yes. Explain your answer.
heterogeneous reactants - s & aq

20. Consider the following reaction:

$$2NO_{(g)} \ + \ 2H_{2(g)} \ \rightarrow \ N_{2(g)} \ + \ 2H_2O_{(g)}$$

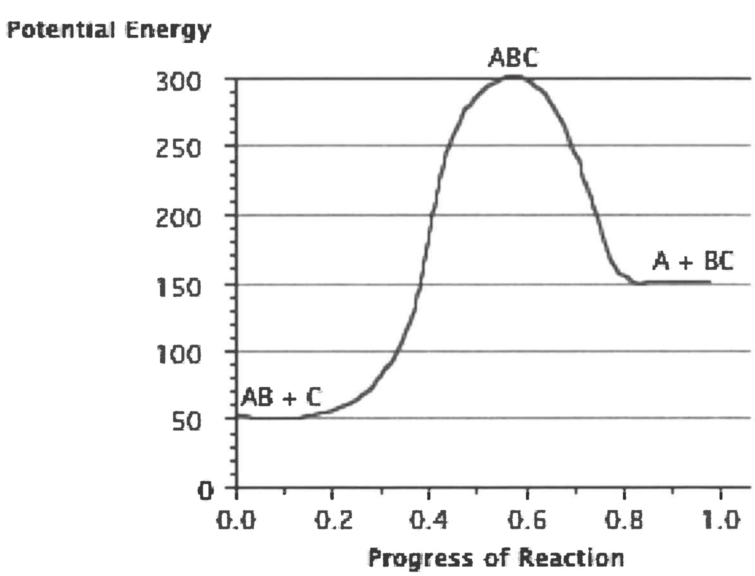
Data collected for the above reaction was used to construct the following graph:



From this graph, determine the ***rate of reaction*** in *moles of NO consumed per second.*

$$\frac{\Delta mol}{\Delta t} = \frac{(0.038-0.022)}{(9-1)} = \frac{0.016}{8} = \boxed{0.002\frac{mol}{s}}$$

21. Use the following ***Potential Energy Diagram*** to answer the questions below:



a) Determine the ***Activation Energy*** for the *forward* reaction... 250 kJ

b) Determine the ***Activation Energy*** for the *reverse* reaction.... 150 kJ

c) What is the ***Enthalpy Change*** (ΔH) for the *forward* reaction?.. + 100 kJ

d) What is the ***Enthalpy Change*** (ΔH) for the *reverse* reaction?.. - 100 kJ

e) The *forward* reaction is endo thermic.

f) The *reverse* reaction is exo thermic.

g) Which species or set of species forms the ***Activated Complex***? ABC

h) Which bond is *stronger*, A--B or B--C? A-B. Give a reason for your answer. takes more E to break A-B bond (250kJ) than B-C bond (150kJ)

i) Particles from which species or set of species is moving the *fastest*? AB + C
State how you arrived at your answer. lowest PE = highest KE

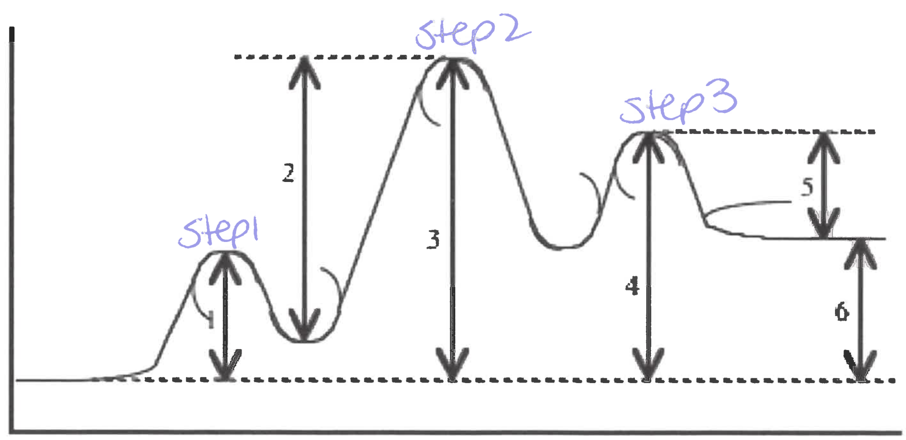
j) Particles from which species or set of species is moving *most slowly*? ABC
State how you arrived at your answer. highest PE = lowest KE

k) The compound "AB" is a gas and the element "C" is a solid. What effect would grinding "C" into a fine powder have on the graph shown here?
no effect ⇒ doesn't change E

22. What two requirements must be met before a collision between two reactant particles is ***effective***?
1. sufficient E ≥ Ea
2. proper collision geometry

23. Describe what happens to two reactant particles which collide with *less* energy than the ***Activation Energy***.
bounce off one another unchanged

24. Given the following *Potential Energy Diagram* for a 3 step reaction, answer the questions below



a) Which arrow indicates the *activation energy* for the *first* step of the reverse reaction? 5

b) Which arrow indicates the *activation energy* for the *first* step of the forward reaction? 1

c) Which arrow indicates the *activation energy* for the *second* step of the forward reaction? 2

d) Which arrow indicates the *enthalpy change* (ΔH) *or "heat of reaction"* for the *overall* **forward** reaction? 6

e) Which arrow indicates the *enthalpy change* (ΔH) *or "heat of reaction"* for the *overall* **reverse** reaction? 6

f) Which arrow indicates the *activation energy* for the ***overall*** forward reaction? 3

g) Which step would be the ***rate determining step*** in the *forward* reaction? Step 2

25. Given the reaction: $HCOOH \rightarrow CO + H_2O$

a) This reaction, without a catalyst, is *very slow* at room temperature. Suggest why.

high Ea

b) This reaction is thought to take place by means of the following mechanism when the catalyst H^+ is added:

Step 1: $HCOOH + H^+ \rightarrow \cancel{HCOOH_2^+}$ (fast)

Step 2: $\cancel{HCOOH_2^+} \rightarrow H_2O + \cancel{HCO^+}$ (slow)

Step 3: $\cancel{HCO^+} \rightarrow CO + H^+$ (fast)

c) Identify the two ***intermediates*** $HCOOH_2^+$, HCO^+

d) Identify the ***catalyst*** in this mechanism H^+

e) Another catalyst is discovered which increases the rate of only *Step 1*. How will this affect the rate of the *overall reaction*? no effect

Explain your answer. not the rate determining step

f) Which step has the greatest ***activation energy***? Step 2

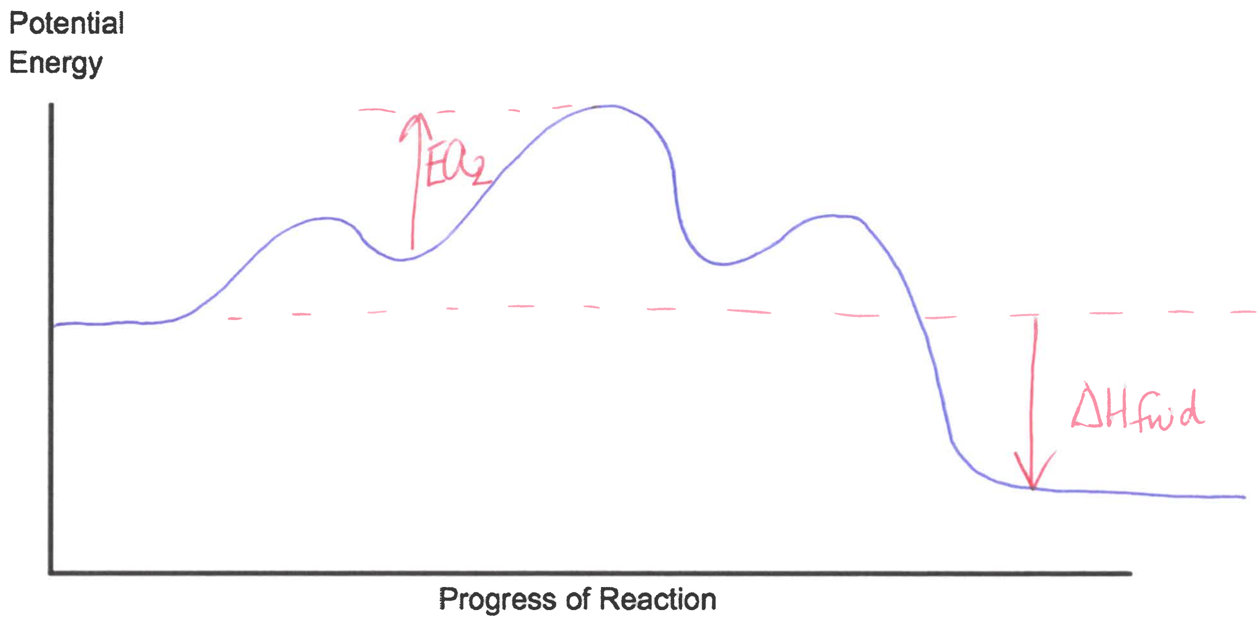
g) How many "bumps" will the potential energy diagram for the catalyzed reaction have?

3

h) Which step is called the ***rate determining step*** in this mechanism? Step 2

i) In order to have successful collisions, the colliding particles must have **both** the proper amount of *energy* and the proper collision geometry

f) On the set of axes below, draw the shape of the curve you might expect for the reaction in this question. The overall reaction is *exothermic*! Make sure you get the "bumps" the correct relative sizes.



26. Given the following mechanism, answer the questions below:

Step 1: $O_3 + NO \rightarrow \cancel{NO_2} + O_2$ (slow)

Step 2: $\cancel{NO_2} + O \rightarrow NO + O_2$ (fast)

a) Give the equation for the ***overall reaction***. $O_3 + O \rightarrow 2O_2$

b) What could the ***catalyst*** be in this mechanism? NO

c) What is an ***intermediate*** in this mechanism? NO_2

28. The equation for an ***overall*** reaction is: $I^- + OCl^- \rightarrow IO^- + Cl^-$

a) The following is a proposed *mechanism* for this reaction. One of the species has been left out. ***Determine what that species is and write it in the box.*** Make sure the *charge* is correct if it has one!

Step 1: $OCl^- + H_2O \rightarrow HOCl + \cancel{OH^-}$ (fast)

Step 2: $I^- + \boxed{HOCl} \rightarrow \cancel{IOH} + Cl^-$ (slow)

Step 3: $\cancel{IOH} + \cancel{OH^-} \rightarrow IO^- + H_2O$ (fast)

b) Which species in the mechanism above acts as a ***catalyst***? H_2O

c) Which three species in the mechanism above are ***intermediates***? $HOCl, OH^-, IOH$

d) Step 2 is the ***rate determining step.***

e) On the set of axes below, draw the shape of the curve you might expect for the reaction in this question. The overall reaction is *endothermic*! Make sure you get the "bumps" the correct relative sizes.