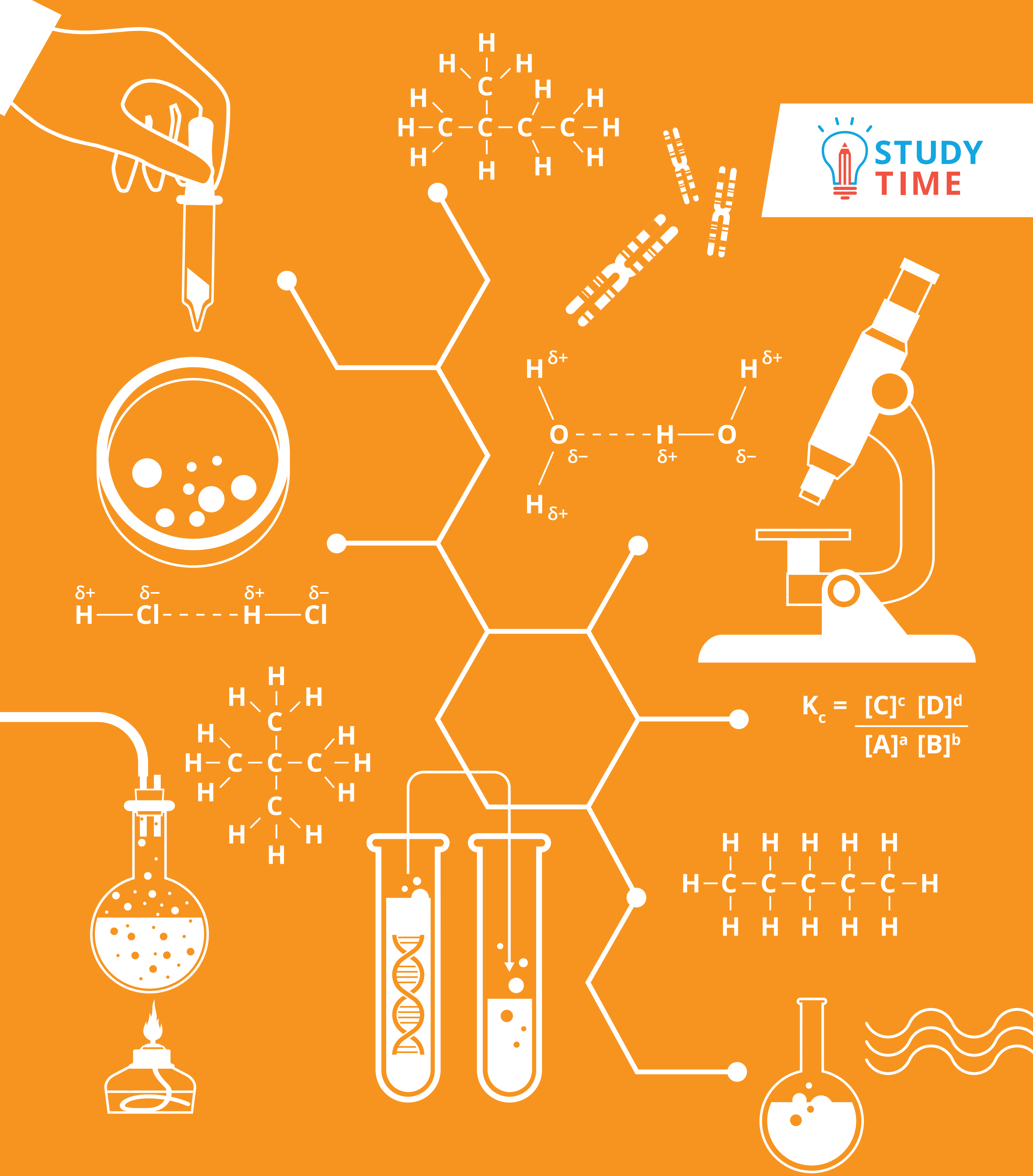
STUDY TIME



LEVEL 2 CHEMISTRY

CHEMICAL REACTIVITY

NCEA Workbook Answers

1. Collision Theory and Rate of Reaction

a. A chemical reaction is a process that changes one or more substances (called the reactants) into new substances (called the products). This involves the breaking of chemical bonds in the reactants and the formation of new chemical bonds as the products form.

b. If a chemical reaction was occurring in a test tube, you might observe some physical changes such as: a colour change in the solution; bubbles forming or the solution fizzing; a change in the temperature of the test tube such as it becoming warmer or cooler; if one or more of the reactants were solid, you might see them dissolving, or a solid (precipitate) might form in the solution.

c. A reactant is a substance that you start with before the chemical reaction takes place. It is the substance that undergoes the reaction and is chemically changed.

d. A product is the outcome of a chemical reaction, the new substance or substances that are formed from the chemical reaction.

e. *i.* Reactants: NaOH + HCl; Products: NaCl + H_2O

ii. Reactants: $CaCO_3$ + H_2SO_4; Products: $CaSO_4$ + H_2O + CO_2

iii. Reactants: $2NaCO_3$ + HCl; Products: 2NaCl + CO_2 + H_2O

iv. The reactants are always on the left-hand side of the arrow and the products are always on the right-hand side.

f. *i.* The '2' in H_2O means that there are two hydrogen atoms are bound to the oxygen atom. A subscript number 2 means two of whatever it comes after. In this case, H.

ii. The '3' in $CaCO_3$ means that there are 3 oxygen atoms bound to the carbon to form the carbonate ion. The '2' in H_2SO_4 means that there are two hydrogen atoms bound to the sulfate (SO_4) and the '4' in SO_4 means that the sulfate has four oxygen atoms bound to the sulfur atom. The '2' in CO_2 means there are two oxygen atoms bound to the carbon; the '2' in H_2O means two hydrogen atoms are bound to the oxygen atom in the molecule.

iii. The '2' at the front of $2NaCO_3$ means that there are two molecules of $NaCO_3$ present. When the '2' comes at the front, it means two of whatever atom or molecule follows. Likewise, the '2' in 2NaCl means there are two sodium chloride molecules. The '3' in $NaCO_3$ means three oxygen atoms are bound to the carbon to form the carbonate ion; the '2' in CO_2 means there are two oxygen atoms bound to the carbon; the '2' in H_2O means there are two hydrogen atoms bonded to the oxygen atom in the molecule.

g. *i.* There is one nitrogen (N) and three hydrogens (H).

ii. There are two ammonia molecules. Altogether, there are two nitrogen atoms (N) and six hydrogen atoms (H).

iii. There are one sulfur (S) and four oxygen atoms (O).

iv. There are two sulfate molecules. Altogether, there are two sulfur atoms (S) and eight oxygen atoms (O).

h. A balanced chemical equation is an equation representing a reaction; if it is 'balanced' there is the same number of each type of element on each side of the equation, i.e. on the products' side and on the reactants' side. For example, if there are 2HCl on the reactant side, there should be 2H and 2Cl on the product side as well, although they may be combined with other, new elements or molecules.

i. *i.* Yes, this is a balanced chemical equation. On the reactant's side:
H = 2, Cl = 1, Na = 1, O = 1; on the product's side: Na = 1, Cl = 1, O = 1, H = 2. So, we can see that there is the same number of each type of element on each side of the equation. Therefore it is balanced.

ii. This is not balanced. On the reactants' side:
P = 4, O = 11, H = 2; on the products' side: P = 1, O = 4, H = 3. There are too few of each element on the products' side for this to be balanced.
If you cannot remember how to balance chemical equations, make sure to revise this from the Level 1 Acids and Bases Walkthrough Guide.

j. A solution consists of one substance (the solute) dissolved in a relatively large quantity of another substance (the solvent). For example, a solution of table salt in water has NaCl (salt) molecules (the solute) dissolved in water (the solvent). The NaCl molecules are dispersed evenly throughout the water.

k. A solute is one substance dissolved in another. For example, if we have a solution of table salt in water like above, the solute is the salt.

l. A solvent is a substance that another is dissolved in. For example, if we have a solution of table salt in water, the solvent is the water.

m. *i.* (s) — s in brackets (s) means solid. This means the reactant, magnesium (Mg), is in solid form at the start of the reaction.

(aq) — aq in brackets (aq) means aqueous. This means the reactant, hydrochloric acid (HCl) is a solution of HCl, rather than a solid.

(g) — g in brackets (g) means gas. This means that the product, H_2, hydrogen, is in gaseous form, so we know that hydrogen gas is produced.

Answers

ii. H_2O_2	H_2O_2 is the molecular formula for hydrogen peroxide. This is on the left-hand side of the equation, so it tells us one of our reactants is hydrogen peroxide.
(l)	An l in brackets (l) means liquid. This means that the reactant, H_2O_2, is in liquid form.
MnO_2	MnO_2 is the molecular formula for magnesium dioxide. This is placed above the arrow, which means that the MnO_2 is a catalyst for this reaction. Its role is to speed up the reaction, but it isn't actually a product or a reactant. Anything placed over the arrow is a catalyst or condition affecting the reaction.
H_2O	H_2O is the molecular formula for water. This is on the right-hand side of the equation, so it tells us one of our products is water. Be careful to read the products and reactants carefully for every reaction. At first glance, this looks like the reactant H_2O_2, making it look like no change has taken place, but that's not true!
$O_{2(g)}$	$O_{2(g)}$ is the molecular formula for molecular oxygen. The g in brackets (g) tells us that this is in gaseous form. It is on the right-hand side of the equation, so we can tell that oxygen gas is produced as a product.
iii. Cu^{2+}	Cu^{2+} is a single copper ion with a +2 charge.
Cu	Cu is a single neutral copper atom.

n. *i.* (aq) — (aq) with aq in brackets means aqueous. This means whatever molecule it is placed after is in an aqueous state, i.e. is in a solution.

ii. (g) — (g) with g in brackets means gaseous. This means whatever molecule it is placed after is in a gaseous state, i.e. is a gas.

iii. (s) — (s) with s in brackets means solid. This means whatever molecule it is placed after is in a solid state, i.e. is a solid.

iv. (l) — (l) with l in brackets means liquid. This means whatever molecule it is placed after is in a liquid state, i.e. is a liquid

o. An aqueous substance (aq) is dissolved in solution, i.e. it is a solute dissolved in a solvent, such as water. A substance that is liquid (l) is not dissolved in a solvent but is in a pure state; it just isn't solid or gaseous.

p. The concentration of a solution is the number or amount of solute particles dissolved per volume of the solvent. For example, there may be 2 mols of solute dissolved per litre of solvent.

q. Mol L^{-1} (moles per litre)

r. A solution with a low concentration has fewer solute particles dissolved per unit of volume than the solution with a higher concentration. The solution with a higher concentration has more solute particles dissolved in the same volume.

2. Collision Theory

a. Collision theory states that a chemical reaction occurs when particles collide with each other under the correct conditions. If the particles do not collide, or collide without the correct conditions, the reaction can't occur.

b. Collision theory states that for a reaction to occur, particles must:

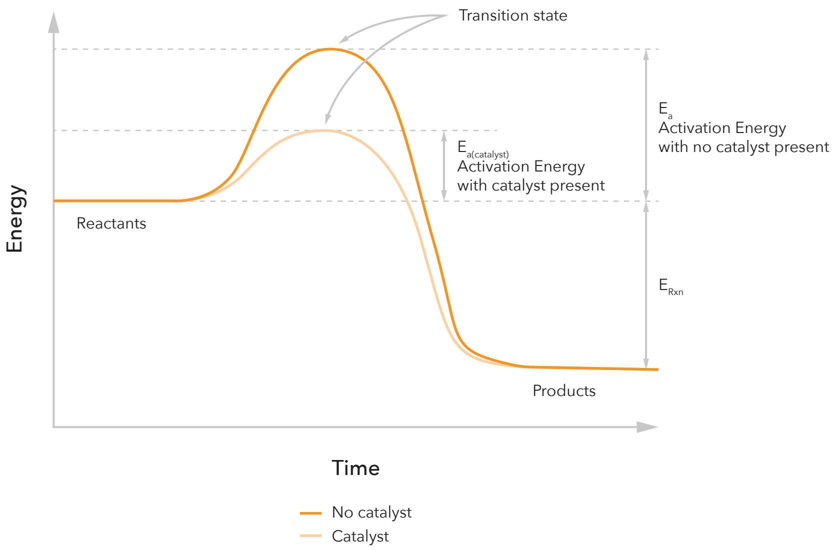
- Collide.
- In the correct orientation.
- With sufficient energy (to overcome the activation energy barrier).

c. The activation energy (E_a) is the minimum amount of energy that a reactant molecule requires to be able to react when it collides with another reactant particle. In other words, it is the minimum amount of energy required by the reactants for the specific reaction to occur. It varies for each reaction.

i. In order to react, particles must collide, and when they collide, they must also have enough energy to react. This means that they must have enough energy to meet the activation energy requirements for the reaction. Otherwise, the reaction will not occur and the collision will be said to be unsuccessful.

d. A catalyst is a substance that speeds up a particular reaction but isn't itself used up. For example, platinum (Pt) can sometimes be a catalyst. For reactions where it is a catalyst, adding it makes the reaction occur more quickly. However, there is still the same amount of platinum present at the end, i.e., it doesn't get converted into anything else. Catalysts speed up reactions by lowering the activation energy of the reaction.

i.



e. The reaction rate is how many individual reactions are occurring each second; this relates to how quickly the overall reaction for the solution or substance progresses. For example, a high reaction rate might convert 5 mols of the reactant to products per second, but a slower reaction might convert just 2 mols of the reactant to products per second.

f. **Concentration of reactants**

A higher concentration of reactants increases the rate of reaction since there are more reactant particles per unit of volume. More reactant particles mean that particles are more likely to bump into each other (collide) and therefore have a reaction.

Surface area for a reactant that is solid

More surface area increases the rate of reaction since there are more reactant particles exposed on the surface of the solid. Those in the centre of the solid can't be accessed/collided with and react as they are shielded from the solution by the outer layers of the solid. Therefore, only those on the surface can react. So, if more are on the surface, there can be more reactions in the same time period and a faster reaction rate.

Temperature

Increasing the temperature increases the reaction rate. The temperature is increased by applying heat energy to the solution; this is transferred to the particles in the solution. This increases the kinetic energy of the particles so they move faster, and therefore collide and react more often in the same time period than they would at a cooler temperature. It also means more of the reactant particles have sufficient energy to meet the activation energy requirements of the reaction so more collisions are successful.

Catalyst

Adding a catalyst increases the reaction rate because a catalyst allows the reaction to proceed with lower activation energy, the minimum amount of energy a reactant particle needs to successfully react if it does collide with another reactant. If it collides but does not have enough energy, it will bounce off and not react. Lowering the activation energy means more reactant particles meet this energy threshold, so more successful collisions take place, leading to more reactions in the same period of time, and therefore a faster reaction rate.

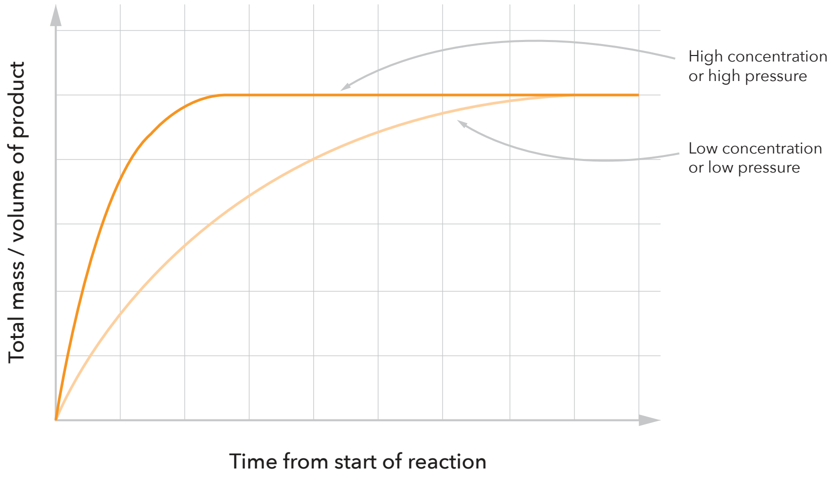
Stirring

Stirring a solution causes the reactant particles to move around more quickly and therefore collide more frequently in the same period of time. This increases the number of reactions per time period, and therefore increases the rate of reaction.

g. The reaction between $CaCO_3$ and HCl is the reaction of a metal carbonate and an acid, which produces a salt, water, and carbon dioxide gas (CO_2). The CO_2 gas rises through the solution, forming bubbles/fizzing.

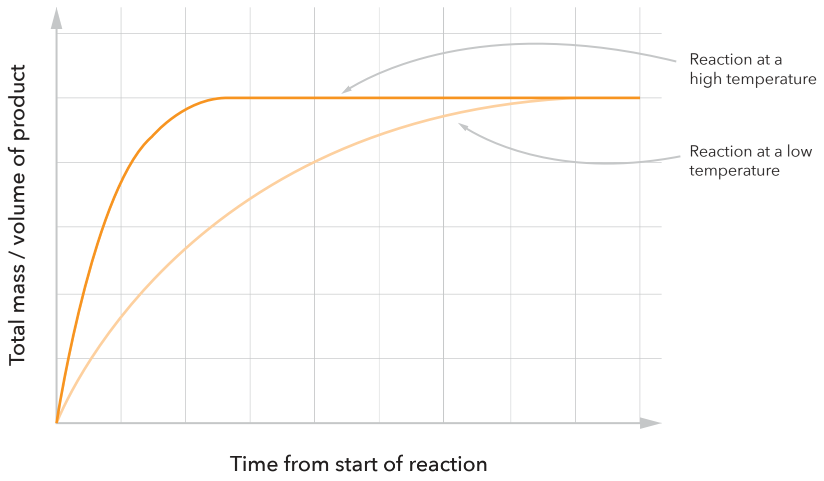
Powdered $CaCO_3$ has more surface area than solid chips. This means more $CaCO_3$ reactant particles are immediately exposed to the solution of HCl and so more collisions occur in a shorter period of time. This means the rate of reaction is faster and CO_2 gas is produced more rapidly, so the bubbling is more vigorous.

h.



i. At the beginning of the reaction, both the high HCl concentration and low HCl concentration solutions have zero products formed, so both lines start at 0 and rise as products are produced. At first, both rise steeply as there are lots of reactant molecules available to collide and react. This is shown by the steep gradient of the lines initially. Many products are formed quickly and the reaction rate is high. However, over time, the reactants are used up and there are fewer and fewer reactant molecules to collide with each other, so fewer reactions occur and the rate of reaction slows down. This is shown by the lines becoming less steep. The solution with a higher HCl concentration rises more steeply initially, showing a faster reaction rate. This is because this solution has more HCl particles in the same volume, so the particles are more likely to collide with the NaOH particles. Therefore more reactions occur in the same amount of time. However, both solutions plateau at the same point because both have the same concentration of NaOH, the second reactant, and once this is used up, no further reactions can take place. This means both solutions will produce the same mass of product at the end, but the higher HCl solution will produce this mass sooner.

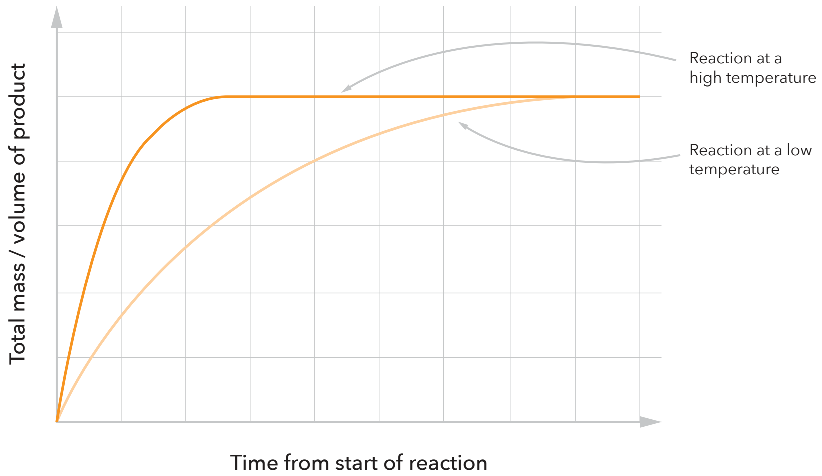
j.



i. At the beginning of the reaction, both reactions have zero products formed, so both lines start at 0. The lines rise as products are produced. At first, they both rise steeply as there are lots of reactant molecules available to collide and react, so many products are formed quickly. The reaction rate is high. However, over time, the reactants are used up and there are fewer and fewer reactant molecules to collide with each other, so fewer reactions occur and the rate of reaction slows down. In the solution with a higher temperature, the line rises more steeply initially, showing a faster reaction rate. This is because the particles in this solution have been given more heat energy; this causes them to have more kinetic energy, move faster, and therefore collide more often. As a result, more collisions occur in the same amount of time compared with the lower temperature solution, so the reaction rate is faster. Also, in the higher temperature solution, more particles will have enough energy to meet the activation energy, which is the minimum amount of energy needed for them to react if they do collide. Therefore, more of the reactions will be successful.

However, both solutions plateau at the same point because both have the same concentrations of reactants, and once these are used up, no further reactions can take place. This means both solutions will produce the same mass of product at the end, but the warmer solution will produce this product sooner.

k.



l. At the beginning of the reaction, both reactions have zero products formed, so both lines start at 0. The lines rise as products are produced. At first, they both rise steeply as there are lots of reactant molecules available to collide and react, so many products are formed quickly. The reaction rate is high. However, over time, the reactants are used up and there are fewer and fewer reactant molecules to collide with each other, so fewer reactions occur, and the rate of reaction slows down. In the solution with powdered $CaCO_3$, the line rises more steeply initially, showing a faster reaction rate. This is because when powdered, there is more surface area and more particles exposed to the solution are able to react. As a result, more collisions occur in the same amount of time compared with the solution with the solid chips, and so the reaction rate is faster. In the solution with the solid chips, the particles on the inside of the chip are shielded by the outer layers of particles and not exposed to the solution, so they cannot react until those on the outside have. This slows down the rate of reaction. However, both solutions plateau at the same point because both have the same concentrations of reactants, and once these are used up, no further reactions can take place. This means both solutions will produce the same mass of product at the end, but the solution with the powder will produce this mass sooner.

m. At first, at time 0 on the graph, there are only reactant molecules and no product molecules because the reaction has not started yet. As the reaction begins, the reactant molecules react to form the products. The reactants are converted into the products (used up) so the number of reactant molecules decreases, but the number of product molecules begins to increase. We can see that as the reactant molecules decrease, the product molecules increase by the same amount, which indicates that this is a 1:1 relationship, i.e., one reactant molecule is needed to make each product molecule. At first, the number of reactant molecules decreases rapidly, as there are many reactant molecules present to collide with each other; therefore collisions occur more often and the reaction proceeds quickly. At time = 10 seconds, there are more slightly more products than reactants, and from around this point, the number of reactant molecules decreases more slowly and the number of product particles also increases more slowly. This is because there are now fewer reactant particles present in the solution, so they collide less frequently, and therefore react less frequently. Therefore, products are produced less frequently. At time = 20, 30, 40 and 50s, the reaction continues, albeit at a slower and slower rate as the reactant molecules are used up. At time = 60s, all reactant molecules are used up and there are zero left; all have been converted into products. At this point, the number of products and reactants is constant. The reaction stops and is said to have gone to completion.

n. At first, the lines showing the decrease of reactants and increase of products are very steep, with a high gradient, indicating that the reaction is occurring quickly, there is a high rate of reaction. Over time, the lines become less steep, indicating that the rate of reaction is slowing down. By 60s, the lines become horizontal and flat with a constant gradient of zero. This indicates that the reaction has stopped.

3. Equilibrium

a. When a reaction has gone to completion, all of the reactants have reacted to produce the products. The reaction has stopped because all or one or more of the reactants has been used up.

b. A reversible chemical reaction is one where, once the products have formed, they can be converted back into reactants. For example, the reaction is $A + B \rightleftharpoons C$, if the reaction is reversible, this means C can be converted back into A and B.

c. This means that N_2 and $3H_2$ react together to form $2NH_3$, however, since the reaction is reversible, $2NH_3$ can also react to break back down into N_2 and $3H_2$.

d. The forward reaction is the initial reaction and the one that the chemical equation shows reading from left to right. In the above example, this is $N_2 + 3H_2 \rightarrow 2NH_3$. The reverse or back reaction is the one going in the opposite direction, which takes the product 2NH3 and converts it back into the original reactants, $N_2 + 3H_2$. This can be written like this: $N_2 + 3H_2 \leftarrow 2NH_3$ with the arrow reversed to show the reaction is going in the other direction.

e. Some examples include reactions where one of the products can escape, such as CO_2 gas leaving a solution as bubbles; this means the reverse reaction can't occur because the product is no longer present to react and be converted back. These reactions may still be reversible in a closed environment where the products can't escape, such as a reaction occurring with a lid on the test tube so CO_2 can't escape.

Some other examples are combustion reactions, many precipitation reactions, and reactions between very strong acids and bases that completely dissociate in water.

f. Many chemical reactions are reversible. A lot of these are organic reactions, such as a weak organic acid dissociating in water and other reactions involving weaker acids and bases, the formation of esters from alcohol and carboxylic acids, etc.

Others include industrial processes such as the formation of ammonia from nitrogen and hydrogen gas, the formation of sulfur dioxide from sulfur and oxygen gas, etc.

g. When the reaction begins, there are only reactants and no products, so the concentration of reactants is high and the concentration of products is zero. As the forward reaction occurs, products are made from the reactants so the concentration of reactants decreases while the concentration of products increases. Since the reaction is reversible, after some products have formed they begin to react with each other to reform the reactants, and the reverse reaction starts. This causes some of the products to turn back into reactants. Both forward and reverse reactions continue simultaneously, so they now oppose each other. Eventually, a point is reached where the forward and reverse reactions occur at the same rate so that for every one forward reaction, one reverse reaction occurs, and the concentrations of products and reactants stop changing and become constant. This is shown on the graph where the lines plateau and become horizontal; this shows the concentrations are no longer changing. At this point, the reaction is said to have reached equilibrium.

h. Equilibrium is reached for a reversible reaction when the rates of forward and reverse reactions become equal so that the concentrations of products and reactants become constant.

i. Equilibrium is said to be dynamic because both forward and reverse reactions continue in the solution; there is still ongoing activity in the solution at equilibrium.

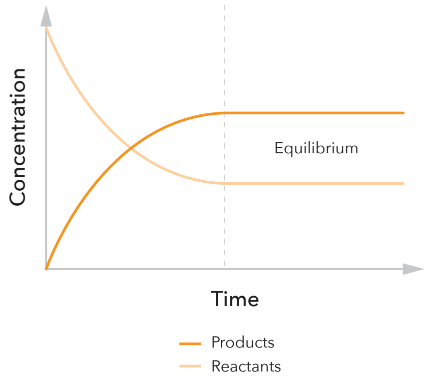
j. The concentrations of the products and reactants become constant and stop changing. In terms of physical observations, this may be the point when the colour or temperature stops changing or no more solid will dissolve for a chemical reaction.

k. Once equilibrium is reached, for every forward reaction that produces products, a reverse reaction occurs that converts them back. At this point, the forward and reverse reactions directly oppose each other so even though both are continuing, the concentrations of products and reactants no longer change.

l. The position in equilibrium for a reversible reaction is the relative proportions of reactants and products at equilibrium. For example, one reversible reaction might have a higher concentration of products than reactants when equilibrium is reached, or vice versa.

m. In the first graph, at equilibrium, the concentration of products is higher than the concentration of reactants. In the second graph, at equilibrium, the concentration of reactants is higher than the concentration of products.

n.



o. A closed system is one where none of the products can escape. For example, if the reaction takes place in a closed test tube, or if all of the products and reactants are dissolved in solution (and none is a gas that might escape by fizzing/bubbling). An open system is one where the products can escape. For example, an open test tube where any gases produced can escape to the atmosphere. For equilibrium to occur, the products and reactants need to be in a closed system.

4. Equilibrium Expressions

a. *i.* $K_c = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$

ii. The square brackets indicate the concentration of that particular reactant or product in mol per litre, at equilibrium. For example, [C] means the concentration of the reactant C, in mol per litre, when the reaction has reached equilibrium.

b. *i.* On the top; in the numerator of the fraction.

ii. On the bottom; in the denominator of the fraction.

c. *i.* No. Leave these out of the K_c expression. The concentration of solids does not change during the reaction, so we do not include them in the K_c.

ii. Yes, include these in the K_c expression.

iii. Yes, include these in the K_c expression.

iv. No. Leave these out of the K_c expression. The concentration of solvents does not change during the reaction, so we do not include them in the K_c.

d. *i.* $K_c = \frac{[NH_3]^2}{[N_2] \times [H_2]^3}$

ii. $K_c = \frac{[CO] \times [H_2]^3}{[CH_4] \times [H_2O]}$

iii. $K_c = \frac{[HCN]^2}{[H_2] \times [N_2]}$

Remember not to include products and reactants that are solids in the K_c expression.

iv. $K_c = \frac{[Cl^-] \times [H_3O^+]}{[HCl]}$

Remember not to include solvents like H_2O in the K_c expression.

v. $K_c = \frac{[H^+] \times [CH_3COO^-]}{[CH_3COOH]}$

vi. $K_c = \frac{[C]^3 \times [D]^3}{[A] \times [B]^2}$

vii. $K_c = \frac{[C_2D_2]}{[A] \times [B]}$

viii. $K_c = \frac{[C]^3 \times [D]}{[B]^2}$

Remember not to include products and reactants that are solids in the K_c expression.

e. An equilibrium constant (K_c) is a measurement of the ratio between the concentrations of the products and concentrations of the reactants for a reversible reaction, at equilibrium when equilibrium has been reached.

f. The equilibrium constant actually does not have units because it is a ratio.

g. If K_c is very large, e.g. greater than 1000, then this means that the reaction is close to going to completion. This means the reaction produced a very large amount of products compared to reactants. Remember that the concentration of products goes on top in the K_c expression, so if the concentration of products is very large, this number is very large, and the K_c is also large. If the K_c is very small, e.g. 0.0001, then this means the reaction didn't produce very many products at all. Since product concentrations go on the top for K_c, if there are few products but many reactants left, then this means we divide a relatively small number by a larger number for the K_c, so we get a small K_c of less than 1.

If the K_c is exactly 1, this means that the concentrations of products and reactants were the same as equilibrium.

h. *i.* Reaction: $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$

$$K_c = \frac{[SO_3]}{[SO_2] \times [O_2]}$$

$$= \frac{(0.200)^2}{(0.150)^2 \times 0.150}$$

$$= 11.85$$

The K_c is larger than 1. This means there are more products than reactants at equilibrium. However, it is not above 1000 so is not significantly product favoured.

ii. Reaction: $CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$

$$K_c = \frac{[H^+] \times [CH_3COO^-]}{[CH_3COOH]}$$

$$= \frac{0.05 \times 0.05}{0.100}$$

$$= 0.025$$

The K_c is small. This means there are fewer products than reactants at equilibrium.

i. $K_c = \frac{[NO_2]^2}{[N_2] \times [O_2]^2}$

$$7.5 \times 10^{-10} = \frac{[NO_2]^2}{[0.100] \times [0.250]^2}$$

$$7.5 \times 10^{-10} = \frac{[NO_2]^2}{[0.100] \times [0.0625]^2}$$

$$7.5 \times 10^{-10} = \frac{[NO_2]^2}{0.00625}$$

$$7.5 \times 10^{-10} \text{ x } 0.00625 = [NO_2]^2$$

$$\sqrt{(7.5 \times 10^{-10} \times 0.00625)} = [NO_2]$$

$$2.165 \text{molL}^{-1} = [NO_2]$$

j. $K_c = \frac{[CO] \times [H_2]^3}{[H_2O] \times [CH_4]}$

$$4.7 = \frac{0.200 \times (0.300)^3}{0.05 \times [CH_4]}$$

$$4.7 = \frac{0.200 \times 0.027}{0.05 \times [CH_4]}$$

$$4.7 = \frac{0.0054}{0.05 \times [CH_4]}$$

$$\frac{0.0054}{4.7} = 0.05 \times [CH_4]$$

$$\frac{0.0054}{0.05} = [CH_4]$$

$$[CH_4] = 0.023 \text{molL}^{-1}$$

k. $K_c = [H_3O^+] \times [OH^-]$ (since H_2O is a solvent, we don't include its concentration)

$1 \times 10^{-14} = [0.100] \times [OH^-]$

$\frac{1 \times 10^{-14}}{0.0010} = [OH^-]$

$[OH\text{-}] = 1.0 \times 10^{-11} molL^{-1}$

l. $K_c = \frac{[C_2]^2}{[B]^2 \times [A]^3}$

$22 = \frac{(0.025)^2}{(0.100)^2 \times [A]^3}$

$22 = \frac{0.000625}{0.01^2 \times [A]^3}$

$\frac{0.000625}{22} = 0.01 \times [A]^3$

$2.841 \times 10^{-5} = 0.01 \times [A]^3$

$\frac{2.841 \times 10^{-5}}{0.01} = [A]^3$

$[A]^3 = 0.00284$

$\sqrt[3]{0.00284} = [A]$

$[A] = 0.142 molL^{-1}$

Answers

m. The pressure inside a container is the force that the particles of gas or liquid inside exert on the walls of the container as they move around and collide with them. The more particles of gas or liquid in the container, the higher the pressure, since with more particles, there will be more frequent collisions with the walls and therefore more force exerted. If there are fewer particles, the pressure will be less. For equilibrium systems, pressure is important if the chemical reaction involves substances in a gaseous state.

n. One: add more gaseous particles to the container, e.g add more gas.
Two: shrink the volume of the container, so the same amount of gas is in less volume.

o. When the volume is reduced but the number of gaseous particles inside the container stays the same, the pressure in the container increases. Reducing the volume of the container means the gaseous particles have a shorter distance to travel before colliding with the walls of the container, so they collide more often and therefore exert more force on the container and therefore the pressure is greater.

p. A chemical reaction that is endothermic absorbs heat energy from the surroundings as it progresses, therefore cooling the surroundings. The products of the reaction have more energy than the reactants did at the start.

A chemical reaction that is exothermic releases heat energy to the surroundings as it progresses, therefore heating up the surroundings. The products of the reaction have less energy than the reactants did at the start.

q. ΔH means a change in enthalpy or change in heat energy. This refers to the change in the heat energy of the products compared to the reactants. This is an expression of whether the reaction is endothermic (absorbs energy, with products having more energy than the reactants) or exothermic (releases energy, with products having less energy than the reactants.) ΔH is followed by a number, e.g $\Delta H = 2400 Jmol^{-1}$, which represents the amount of heat energy lost or gained by the products. It is sometimes also written $\Delta_r H$.

r. If ΔH is negative, e.g. ΔH = −250J, this means heat energy is released and the reaction is exothermic. If ΔH is positive, e.g. $\Delta H = 100 Jmol^{-1}$, this means heat energy is absorbed and the reaction is endothermic. The ΔH value given refers to the forward reaction unless otherwise indicated.

s. For reversible reactions, if the forward reaction is exothermic, the reverse reaction will be endothermic and vice versa, they are always the opposite of each other.

t. *i.* The reaction is exothermic because ΔH is negative.

ii. The reaction is exothermic because ΔH is negative.

iii. The reaction is endothermic because ΔH is positive.

u. When a change, such as an increase in temperature or decrease in the concentration of a product, is applied to a system at equilibrium, the system will respond to the change so that the effects of the change are minimised. In effect, the system will oppose the change. For example, if the concentration of a reactant is increased when the system is at equilibrium, the forward reaction will increase to try and use up that extra reactant.

v. Concentration

If the concentration of a product or reactant is reduced or extra product or reactant is added, the system will act to oppose this change to either use up the extra reactant or product or to replace the removed reactant or product, by increasing either the forward or reverse reaction.

Pressure

Increasing or decreasing the pressure can affect the equilibrium reaction if some or all reactants or products involved are gases. This only occurs if there are different numbers of moles of gas on the products' and reactants' sides of the chemical equation. For example, if the reaction is $2A_{(g)} + B_{(aq)} \rightleftharpoons 3C_{(g)}$, there are 2 moles of gas on the reactants' side and 3 moles of gas on the products' side. If the pressure was increased, the reverse reaction would increase to decrease the number of moles of gas in the system and therefore reduce the pressure, opposing the change. Likewise, if the pressure was reduced, the opposite would occur where the system would act to increase and restore the pressure by increasing the forward reaction and producing more moles of gas and increasing the pressure.

Temperature

Increasing or decreasing the temperature will affect the equilibrium reaction. If the temperature is increased, whichever reaction is endothermic and absorbs energy will increase to use up the extra heat energy. If the temperature is decreased, whichever reaction is exothermic and releases energy will increase to release more heat energy and replace the lost heat energy.

w. *i.* If the concentration of a reactant is increased when the system is at equilibrium, the forward reaction will increase to use up the reactant.

ii. If the concentration of a reactant decreases, the reverse reaction will increase to make more reactant and replace the lost reactant.

iii. If the concentration of a product increases, the reverse reaction will increase to use up the extra product.

iv. If the concentration of a product is decreased, the forward reaction will increase to replace the lost product.

v. The reaction that decreases the pressure will increase in rate. This will be the reaction that results in fewer moles of gas being present. If the reaction does not involve substances in a gaseous state or there are the same number of moles of gas on the reactants' and products' side, then increasing the pressure will have no effect on the equilibrium.

vi. The reaction that increases the pressure will increase in rate. This will be the reaction that results in more moles of gas being present. If the reaction does not involve substances in a gaseous state or there are the same number of moles of gas on the reactants' and products' side, then decreasing the pressure will have no effect on the equilibrium.

vii. The reaction which is endothermic and absorbs heat energy will increase to absorb the excess heat energy.

viii. The reaction which is exothermic and releases heat energy will increase to release more heat energy and replace that lost.

x. A catalyst will speed up both the forward and reverse reactions. This will cause the equilibrium to be reached faster, however, it will not alter the concentrations of the products or the reactants at equilibrium since it acts on both forward and reverse reactions. A catalyst will not change the position of equilibrium, but make it reach equilibrium faster.

y. *i.* There are 2mols of gas on each side of the chemical equation and so equal numbers of moles of gas, which means that there will be no effect from increasing the pressure on the system.

ii. The forward reaction will increase to use up the extra reactant and convert it into the product, so the concentration of NO_2 will increase. However, the K_c value will not change as only changes in temperature change the K_c value.

iii. The ΔH value is negative which tells us that the forward reaction is exothermic and releases energy. If the temperature is decreased, this forward reaction will increase to release more heat energy and replace the lost heat energy, which will result in more products being formed. As a result of the change in temperature, the K_c value will change to become larger as the concentration of products is now higher and the equilibrium position shifts to favour the products more.

z. *i.* If the forward reaction is exothermic, the reverse reaction is the endothermic reaction, so it will increase to use up the excess heat energy. This will produce more reactants. When equilibrium is reestablished now, there will be more reactants than in the previous equilibrium. As a result, K_c will decrease because we will be dividing by a bigger number. ($K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$).

ii. The forward reaction is endothermic and absorbs heat energy, so it will increase to use up the excess heat energy supplied. This will produce more of the products. When equilibrium is reestablished now, there will be more products than in the previous equilibrium. As a result, K_c will increase because we will be dividing a larger number. ($K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$).

iii. The forward reaction is exothermic and so releases heat energy. If the temperature is decreased, the forward reaction will increase so that more heat energy is released to replace the lost heat energy. This will cause more products to be formed. When equilibrium is reestablished now, there will be more products than in the previous equilibrium. As a result, K_c will increase because we will be dividing a larger number. ($K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$).

iv. The forward reaction is endothermic and so absorbs heat energy. This means that the reverse reaction is exothermic and releases heat energy. If the temperature is decreased, the reverse reaction will increase so that more heat energy is released to 'replace' the lost heat energy. This will cause more reactants to be formed. When equilibrium is reestablished now, there will be more reactants than in the previous equilibrium. As a result, K_c will decrease because we will be dividing by a bigger number. ($K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$).

v. The catalyst will speed up the rates of both the forward and reverse reactions so equilibrium will be reached sooner, however, it will not change the concentrations of the products and reactants at equilibrium, so it will have no effect on the K_c value.

vi. If the concentration of a product is reduced, the forward reaction will temporarily increase to create more product to replace the product. However, the original equilibrium will eventually be re-established once the concentration of the product is restored to what it was. As a result, the K_c value will not change. This is the same for increasing or decreasing the concentration of any product or reactant.

vii. Changing the pressure may increase or decrease the forward or reverse reactions if there are unequal numbers of moles of gas on either side of the chemical equation, otherwise, it will not affect the reactions. In either case, the equilibrium will eventually be re-established with the same K_c value.

aa. This means that the K_c value has changed. This occurs when the system at equilibrium undergoes a temperature change and the K_c value will permanently shift. It may shift to be more in favour of the products (e.g. higher concentration of products at equilibrium) or in favour of the reactants (e.g. higher concentration of reactants at equilibrium). Only changing the temperature permanently changes the K_c; changes in concentration of the reactants and products, pressure, or the addition of a catalyst do not affect the K_c for a reaction at a particular temperature.

5. Acids and Bases

a. Acid + base ⟶ salt + water
Acid + metal carbonate ⟶ salt + water + carbon dioxide gas
Acid + hydrogen metal carbonate ⟶ salt + water + carbon dioxide gas

b. An acidic substance is one that donates hydrogen ions (H^+) to water when it is added to a solution (is a proton donor). An acid will dissociate in water (break apart) to release hydrogen ions. For example, when HCl is added to water, it breaks apart and the H^+ and Cl^- ions separate so that it has added more H^+ ions to the solution.

i. Three examples from L1 Acids and Bases are HCl (hydrochloric acid) H_2SO_4 (sulfuric acid) and HNO_3 (nitric acid). Common examples of everyday acids are lemon juice and vinegar.

c. A basic substance is one which is a proton acceptor, it removes hydrogen ions (H^+) from water (accepts and binds to them) when it is added to solution. For example, a base may interact with hydrogen ions, attracting them and binding to them, or it may release OH^- ions into the solution, and the OH^- ions then attract and bind the H^+ ions, neutralising them to form water.

i. Examples of bases from Level 1 Acids and Bases include NaOH (sodium hydroxide), carbonates (and hydrogen carbonates). Examples of basic substances from everyday life include soap and other cleaning products, baking soda, bleach. At Level 2, amines can also be used as weak bases.

d. A basic solution has a higher concentration of OH^- ions than H^+ ion; an acidic solution has a higher concentration of H^+ ions than OH^- ions and a neutral solution contain equal concentrations of H^+ and OH^- ions.

e. Dissociate means to break apart or separate.

f. A proton is a single hydrogen ion (H^+) in solution. A hydrogen ion has one proton but no electrons, hence why it can be referred to as a proton. When acids are added to water and dissociate, they release protons into the solution. Bases in solution will accept protons, binding to them and removing them from the solution.

i. The H^+ ion binds to H_2O molecules in the solution to produce the hydronium ion, H_3O^+
$H^+ + H_2O \longrightarrow H_3O^+$

g. The H^+ ions released into solution by an acid that has dissociated attach themselves to the water molecules to form hydronium ions, H_3O^+.

i. A strong acid is one that completely dissociates in water. All, or most of the acid molecules break apart when the acid is dissolved in the water. After the reaction, the solution contains virtually no intact acid molecules. A weak acid is one that only partially dissociates in water. Only a few of the acid molecules break apart when dissolved in water, but many don't. This means fewer protons are added to the solution. After the reaction, the solution contains mostly intact acid molecules.

ii. A strong acid is an acid that completely dissociates when added to water, e.g. there are none, or almost no, intact acid molecules left after the dissolving has taken place. Concentration refers to the number of moles of a substance dissolved in a solution. A concentrated acid has many moles dissolved in the volume of liquid, whereas a dilute acid has fewer mols dissolved.

iii. HCl - hydrochloric acid, HNO_3 - nitric acid, and H_2SO_4 - sulfuric acid.

iv. Ethanoic acids, hydrogen carbonates, and other organic acids, the ammonium ion NH_4^+

h. A strong base is one that completely dissociates in water. All, or most of the base molecules break apart when the base is dissolved in the water. After the reaction, the solution contains virtually no intact base molecules. A weak base is one that only partially dissociates in water. Only a few of the base molecules break apart when dissolved in water, but many don't. This means fewer protons are removed from the solution by the base. After the reaction, the solution contains mostly intact base molecules.

i. NaOH and other metal hydroxides, KOH, $Ca(OH)_2$

ii. Ammonia, NH_3, the acetate ion, CH_3COO^- and other organic carboxylate ions.

i. An alkali is a base that will dissolve in water (is soluble in water). An alkaline solution is one that is basic because it has a base dissolved in it.

j. An amphiprotic substance is one that can act as either an acid or as a base. This means that it could either accept a hydrogen ion (acting as a base) or donate a hydrogen ion (acting as an acid).

i. HCO_3^- is an amphiprotic substance because it can act either as a base or as an acid in solution. This means that it can accept another hydrogen ion (and therefore act as a base) or donate its hydrogen ion (and therefore act as an acid). If it was to donate its H^+, acting as an acid, the reaction would be:

$HCO_3^- + H_2O \rightarrow H_3O^+ + CO_3^{2-}$

If it were to accept an H^+, acting as a base, the reaction would be:

$HCO_3^- + H_2O \rightarrow OH^- + H_2CO_3$

k. When Na_2CO_3 is added to water, the salt dissociates into its respective ions, $2Na^+$ and CO_3^{2-}:
$Na_2CO_3 \rightarrow 2Na^+ + CO_3^{2-}$

The CO_3^{2-} carbonate ion produced can interact with hydrogen ions, H^+, in solution to form hydrogen carbonates:
$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$
$HCO_3^- + H_2O \rightarrow H_2CO_3 + OH^-$

As a result, the carbonate ion can accept H^+ ions from water, so it is acting as a (weak) base.

l. When a base accepts an H^+ ion, it becomes an acid, since it now has an H^+ ion that it could donate back to the solution. When a base accepts an H^+ ion and becomes an acid like this, we call it conjugate acid. For example, SO_4^{2-} ion can accept an H^+ to become HSO_4^-. SO_4^{2-} is a base, since it can accept an H^+; HSO_4^- is its conjugate acid.

m. When an acid donates an H^+ ion, it becomes a base, since it could now accept an H^+ ion back. When the acid donates an H^+ ion, it becomes a conjugate base. For example, HCl is an acid that can donate an H^+ ion to form Cl^-, while Cl^- can accept an H^+ to form HCl. HCl is an acid and Cl^- is its conjugate base.

i. HCl and Cl^-, H_2SO_4 and HSO_4^-, HNO_3 and NO_3^-, NH_4^+ and NH_3, CH_3COOH and CH_3COO^- these all differ by just one proton.

ii. OH^- and H_2O, CO_3^{2-} and HCO_3^-, H_2O and H_3O^+, NH_3 and NH_4^+, these should all differ by just one proton.

n. The stronger the acid, the weaker the conjugate base. The stronger the base, the weaker the conjugate acid.

o. A neutralisation reaction is a reaction between an acid and a base that generates water, a neutral product, and a salt. The H^+ ions from the acid react with OH^- ions from the base to make H_2O.

p. Acidic and basic solutions have H^+ and OH^- ions dissolved in the solution and these ions are free to move in the solution and can conduct the electric charge through the solution.

i. A strong acid or base will generally make a solution that will conduct electricity better. This is because the strong acid or base will completely dissociate in water and so will produce higher concentrations of ions, such as H^+ and OH^- ions, than the weaker acid or base which only partially dissociates. The greater the concentration of ions in the solution, the more easily the solution can conduct electricity and the more conductive it will be.

q. When added to water, the sodium carbonate salt first dissociates into its ions, $2Na^+$ and CO_3^{2-}. The CO_3^{2-} ions can react with water, accepting H^+ ions to become hydrogen carbonates and therefore acting as weak bases according to the following equations:
$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$
$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$

However, when the sodium carbonate dissolves in water and dissociates, the charged Na^+ ions are also able to conduct electricity and so add to the overall conductivity, so the conductivity of the solution is not solely dependent on the concentration of OH^-, CO_3^{2-} or HCO_3^- ions in the solution.

6. pH and pH Calculations

a. The pH scale measures the relative concentration of H^+ ions in a solution. The more H^+ ions, the more acidic the solution is, and the lower the pH is. The fewer H^+ ions, the more basic the solution is, and the higher the pH is.

b. A pH of 1–6 is acidic, meaning there is a greater concentration of H^+ ions than OH^- ions in the solution. A pH of 7 is neutral, meaning that the concentrations of H^+ ions and OH^- are equal. A pH of 7+ is basic, meaning there is a greater concentration of OH^- ions than H^+ ions.

c. When added to water, a strong acid or base (more or less) completely dissociates into ions, such as OH^- and H^+ ions. However, a weak acid or base only partially dissociates in water, meaning it doesn't fully break up and produces a lower concentration of H^+ or OH^- ions. As a result, a strong acid produces more H^+ ions than a weak acid, and a strong base produces more OH^- ions than a weak base. This means that strong acids will tend to have a lower pH than weak acids, while strong bases will tend to have a higher pH than weak bases.

d. An acidic solution will turn blue litmus paper red, there will be no change with red litmus paper, and when a universal indicator is added, the solution will change colour to be red (very acidic, pH 1-2), orange (acidic, pH 3-4), or yellow (slightly acidic, pH 5-6).

A basic solution will turn red litmus paper blue, there will be no change with blue litmus paper, and when a universal indicator is added, the solution will change colour to be blue-green (slightly basic, pH 8-9), blue (basic, pH 10-11) or purple (very basic, pH 12+).

e. Since HCl is a strong acid, it dissociates completely in water into H^+ and Cl^-. If there is $0.100 molL^{-1}$ of HCl, once it dissociates, we would expect there to be $0.100 molL^{-1}$ of H^+ ions in the solution, and so the concentration of HCl to H^+ ions should be 1:1. This is the case for all strong acids.

f. Since NaOH is a strong base, it dissociates completely in water into Na^+ and OH^-. If there are $0.500 molL^{-1}$ of NaOH, once it dissociates, we would expect there to be $0.500 molL^{-1}$ of OH^- ions in the solution, and so the concentration of NaOH to OH^- ions should be 1:1. This is the case for all strong bases.

g. The ionic product of water, K_w, is the equilibrium constant for water. It gives the relationship between the concentrations of OH^- and H_3O^+ ions in water when at equilibrium. $K_w = 1 \times 10^{-14}$ and is equivalent to $[OH^-] \times [H_3O^+]$. This can be found by writing a K_c expression for water:
$2H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$.
The K_c (K_w) expression is $[H_3O^+] \times [OH^-]$. The concentration of H_2O is not included as it is a solvent.

h. $pH = -\log[H_3O^+]$

i. $pH = -\log[H_3O^+]$
$pH = -\log[0.100]$
$pH = 1$

j. We are given the concentration of OH^-. We need to know the concentration of H_3O^+ to find the pH, but we can use the concentration of OH^- to find the concentration of H_3O^+ for the solution using K_w, the ionic product:
$K_w = 1 \times 10^{-14}$
$K_w = [OH^-] \times [H_3O^+]$
$[H_3O^+] = \frac{K_w}{[OH^-]}$
$[H_3O^+] = \frac{1 \times 10^{-14}}{[0.100]}$
$[H_3O^+] = 1 \times 10^{-13}$
$pH = -\log[H_3O^+]$
$pH = -\log[1 \times 10^{-13}]$
$pH = 13$

k. $pH = -\log[H_3O^+]$
$pH = -\log[0.500]$
$pH = 0.3$

l. HCl is a strong acid and so fully dissociates in water. Therefore, 0.100mol of HCl will produce 0.100mol of H_3O^+ in water. The concentration is mol per litre, so if 0.100mol is dissolved in 1 litre, it will produce 0.100molL^{-1} of H_3O^+
$pH = -\log[H_3O^+]$
$pH = -\log[0.100]$
$pH = 1$

m. H_2SO_4 is a strong acid and so fully dissociates in water. However, each H_2SO_4 molecule has two H^+ ions to contribute, so there will be twice the concentration of H_3O^+ produced as it is H_2SO_4 originally. Therefore, there will be $0.100 \times 2 = 0.200$mol of H_3O^+ produced, and since it is in 1 litre of water, the concentration of H_3O^+ will be 0.200molL^{-1}.
$pH = -\log[H_3O^+]$
$pH = -\log[0.200]$
$pH = 0.70$

n. The concentration of NaOH is $\frac{0.500}{2} = 0.250$molL^{-1}. Since NaOH is a strong base, it will completely dissociate in water to produce 0.250molL^{-1} of OH^-.

We need to know the concentration of H_3O^+ to find the pH, but we can use the concentration of OH^- to find the concentration of H_3O^+ for the solution using K_w, the ionic product:

$K_w = 1 \times 10^{-14}$
$K_w = [OH^-] \times [H_3O^+]$
$[H_3O^+] = \frac{K_w}{[OH^-]}$
$[H_3O^+] = \frac{1 \times 10^{-14}}{[0.250]}$

$[H_3O^+] = 4 \times 10^{-14}$
$pH = -\log[H_3O^+]$
$pH = -\log[4 \times 10^{-14}]$
$pH = 13.4$

o. First, use the pH to calculate the concentration of H_3O^+ ions. Then, use K_w and the concentration of H_3O^+ ions to calculate the concentration of OH^- ions

$pH = -\log[H_3O^+]$
$12.8 = -\log[H_3O^+]$
$10^{-12} = [H_3O^+]$
$[H_3O^+] = 1.58 \times 10^{-13}$
$K_w = 1 \times 10^{-14}$
$K_w = [OH^-] \times [H_3O^+]$
$1 \times 10^{-14} = [1.58 \times 10^{-13}] \times [OH^-]$
$\frac{1.58 \times 10^{-13}}{1 \times 10^{-14}} = [OH^-]$
$[OH^-] = 0.0633 molL^{-1}$

p. $pH = -\log[H_3O^+]$
$0.7 = -\log[H_3O^+]$
$10^{-0.7} = [H_3O^+]$
$[H_3O^+] = 0.200 molL^{-1}$
Since HNO_3 is a strong acid, it dissociates completely, so 0.200mol of HNO_3 will produce 0.200molL^{-1} of H_3O^+ so we need to dissolve 0.200mol of HNO_3 in 1 litre of water to get a pH of 0.7.

Question One: Reaction Rates

a. *i.* At point A in the reaction, the gradient of the line is steepest. This shows that the volume of hydrogen gas being produced is increasing over time. Since hydrogen gas is one product of the reaction, this shows that the rate of reaction is increasing and that the reaction is occurring quickly. The rate of reaction is high at point A because this is early in the reaction. There is still a high concentration of the reactants (zinc and sulfuric acid) because they have not all had an opportunity to react yet. This means there are more reactant particles in the volume of solution to bump into each other, so they collide more frequently. For a reaction to occur, the particles must collide, so the more collisions, the more reactions, and the faster the reaction rate.

However, over time, the reactants begin to be used up as they are converted to H_2. At point B, we see the gradient of the line is becoming less steep and that less H_2 is being produced per second. Since many of the reactant particles have now reacted already, there are fewer of them in the solution, so they collide less frequently. As a result, there are fewer reactions, and the reaction rate slows down. By point C, the volume of H_2 becomes constant. No more H_2 is produced after this point, which means the reaction has stopped. All of the reactant particles have reacted to form H_2 now and there are none left to collide and react. The flat horizontal line indicates the reaction has finished.

Notice how we described what the graph was showing us in terms of the gradient, then what this meant for the reaction rate/number of reactions occurring, and then how this linked to the particles in solution and collision theory for each point. We used words like "Since", "As a result", "because" and "this means" to connect together our ideas and sentences. This helps to show that you understand the links between ideas and makes your answer easier to read, so you should do this too!

ii. Increasing the temperature for the reaction means that extra heat energy is added to the solution and to the particles. This means that the particles have more kinetic energy so they move faster in solution. As a result, the sulphuric acid particles collide more frequently with the zinc particles. Chemical reactions occur when particles collide and collide with sufficient energy to meet the activation energy needed for the reaction.

If the particles collide more often, there will be more opportunities for a reaction to occur, more successful collisions will occur per second, and therefore, the rate of reaction will increase. In addition, more of the reactant particles will have enough energy to meet the activation energy requirement, so more of the collisions will be successful and result in a reaction, causing the reaction rate to increase.

You'll notice that we came up with two reasons why increasing the temperature increases the rate of reaction, and wrote about both of them. When answering questions, always stop and think whether there are any other explanations. If there are two or more reasons why they are relevant, make sure you include them all. Don't just settle for one, or you might limit your marks.

b. *i.* The platinum in catalytic converters acts as a catalyst for the reaction between carbon monoxide and oxygen, to create carbon dioxide. For a reaction to occur successfully, particles must collide at the right orientation and with sufficient energy. A catalyst increases the rate of reaction without being involved in the reaction by lowering the activation energy required for it to go ahead. By this, more CO_2 is converted in the same amount of time when platinum is present, as shown by the results in the table above where a high amount of carbon dioxide is produced in the presence of the catalytic converter.

ii. A high temperature indicates an increase in the kinetic energy of the system. For a reaction to successfully occur, particles must collide with sufficient energy and at the correct orientation, so increasing the temperature provides more energy for the particles to collide. This is demonstrated through the information on the table as at 100°C the amount of carbon dioxide produced is low, whereas at 200°C it is high. In the higher temperature, it is easier for particles to overcome the activation energy to react, and therefore the rate of reaction increases

Question Two: Equilibrium

a. *i.* $K_c = \frac{[NH_2]^2}{[N_2][H_2]^3}$

ii. We are given the K_c value. The K_c is calculated using the concentrations of the products and reactants when the reaction is at equilibrium. Therefore, if the reaction is at equilibrium, we should get this same K_c value if we calculate the K_c expression using the concentrations given to us. If we do not, we know the reaction isn't at equilibrium. Using the concentrations given and the equilibrium expression we wrote earlier:

$$K_c = \frac{[NH_2]^2}{[N_2] \times [H_2]^3}$$

$$K_c = \frac{[0.100]^2}{[0.01] \times [0.1]^3}$$

$$K_c = \frac{0.01}{0.01 \times 0.001}$$

$$K_c = 1000$$

The reaction is not at equilibrium, because the K_c value for this reaction when it is at equilibrium at 25°C is 640 but the value we get using these concentrations is not 640.

iii. A system at equilibrium will act to oppose any change and lessen the impact of the change. Nitrogen gas is a reactant in this reaction. Therefore, adding more nitrogen gas and increasing the concentration of nitrogen gas when the system is at equilibrium will cause the forward reaction to increase in rate to use up the extra nitrogen gas. This will cause more ammonia gas to be produced.

When the pressure is increased, a system at equilibrium will act to decrease the pressure if possible by increasing the rate of reaction for the reaction that would result in fewer moles of gas. In this case, there are 4 moles of gas on the reactant's side and 2 moles of gas on the product's side. Therefore, the forward reaction will increase in rate to convert more of the N_2 and H_2 into NH_2 and therefore reduce the overall moles of gas in the system.

b. *i.* $K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$

ii. High pressure means that the equilibrium reaction means the system will try to decrease the pressure, so it will favour the reaction that produces the fewest moles of gas. There are 3 moles of gas on the reactants side and 1 mole on the products side, so the forward reaction will be favoured and more methanol is produced from the hydrogen and carbon monoxide.

iii. As methanol is removed, $[CH_3OH]$ is decreased, so the equilibrium will work to oppose this change by shifting towards the forward reaction in order to produce more methanol. This increases the total amount of methanol produced which is beneficial for manufacturers.

iv. Increasing the temperature will favour the endothermic reaction as the equilibrium acts to minimise the change by absorbing the added heat energy. Decreasing the temperature will favour the exothermic reaction as the equilibrium acts to minimise the change by releasing more heat energy to compensate for the loss. Because the enthalpy change for this reaction is negative, that means the forward reaction is exothermic and the reverse reaction is endothermic, so to increase the yield of methanol, the equilibrium should favour the forward reaction, meaning the reaction should be performed at a low temperature.

c. *i.* $K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$

ii. $K_c = \frac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$

$K_c = \frac{[0.35]^2}{[0.15]^2 \times [0.095]}$

$K_c = \frac{0.1225}{0.0225 \times 0.095}$

$K_c = 57.3$

iii. Increasing the pressure of the vessel will cause the equilibrium to act to oppose the change by favouring the reaction that produces the fewest moles of gas. There are 3 moles of gas on the reactants side of the reaction and only 2 moles on the products side, so the forward reaction will be favoured. This means that more sulfur trioxide will be produced, so there is a higher concentration of SO_3 in the vessel.

Question Three: Acids and Bases

a. *i.* $HSO_4^- + H_2O \longrightarrow H_3O^+ + SO_4^{2-}$ (acting as an acid, donating hydrogen to water and increasing the concentration of H^+ in solution).

$HSO_4^- + H_2O \longrightarrow H_2SO_4 + OH^-$ (acting as a base, accepting hydrogen from water and increasing the concentration of OH^- in solution).

ii. KOH is a strong base. In water, it completely dissociates into a K^+ ion and the OH^- ion, according to the following equation:

$KOH \rightarrow K^+ + OH^-$

This adds charged OH^- ions to the solution. Since the KOH dissociates completely, it adds a lot of OH^- ions to the solution. This means that KOH is basic and has a very high pH of 13.

CH_3COOH is a weak acid. In water, it partially dissociates into CH_3COO^- and H^+ ions, according to the following equation:

$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$

This adds a few H^+ ions to the solution, but since the ethanoic acid does not dissociate completely, it does not add very many H^+ ions to the solution. This means that it is only weakly acidic and has a low (but not very low) pH of 3.44.

Charged particles that are free to move in solution are needed for the solution to conduct electricity. The greater the number of charged particles, the more readily the solution will conduct electricity, i.e., the more conductive it is. Since the KOH dissociates completely and produces a lot of charged ions in the solution, the solution of KOH is very conductive. However, since the ethanoic acid does not dissociate completely, it produces lower concentrations of charged ions in the solution, so the solution of ethanoic acid is much less conductive.

b. *i.* $CH_3CH_2COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3CH_2COO^-_{(aq)} + H_3O^+_{(aq)}$

ii. Propanoic acid is acting as an acid in this reaction because it donates a proton/hydrogen forming the conjugate base $CH_3CH_2COO^-$. The water receives the hydrogen and so it is a base that forms the conjugate acid H_3O^+.

c. *i.* When sodium propanoate dissolves in water it separates into ions.

$CH_3CH_2COONa_{(s)} \rightarrow CH_3CH_2COO^-_{(aq)} + Na^+_{(aq)}$

The propanoate ions react with the water.

$CH_3CH_2COO^-_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3CH_2COOH_{(aq)} + OH^-_{(aq)}$

The OH^- ions being produced means that the solution is basic.

ii. Sodium propanoate is a salt. In water, it fully dissociates into $CH_3CH_2COO^-$ and Na^+ ions.

$CH_3CH_2COONa_{(s)} \rightarrow CH_3CH_2COO^-_{(aq)} + Na^+_{(aq)}$

This means that there is a high concentration of free-moving charged particles to carry charge through the solution resulting in high conductivity.

NaOH is a strong base. In water, it fully dissociates into Na^+ and OH^- ions.

$NaOH_{(s)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

The high concentration of free-moving ions in the solution makes it highly conductive.

CH_3CH_2COOH is a weak acid. In water, it only partially dissociates into $CH_3CH_2COO^-$ and H^+ ions.

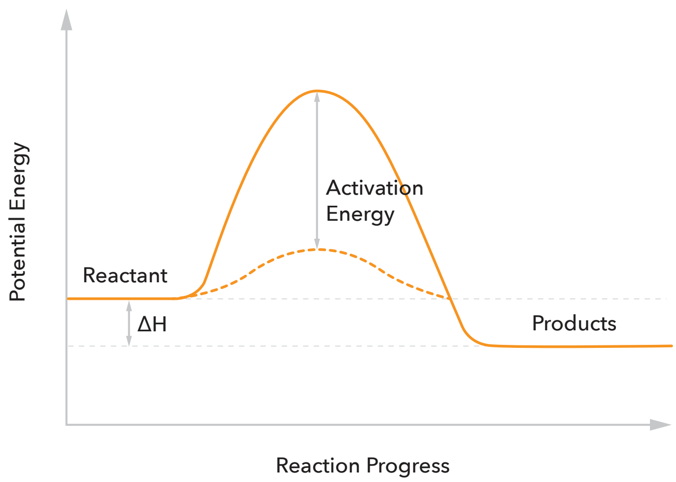
$CH_3CH_2COOH_{(s)} \rightarrow CH_3CH_2COO^-_{(aq)} + H^+_{(aq)}$

The lower concentration of free-moving charged particles in the solution means it is not as conductive.

Question One: Reaction Rates

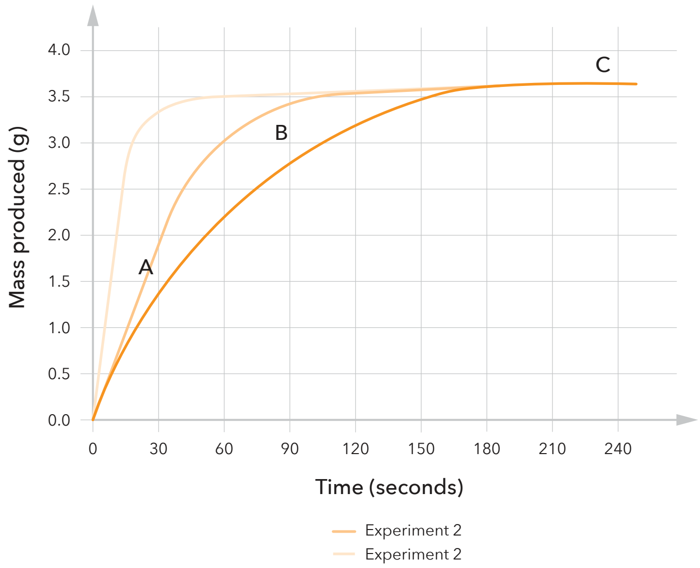
a. According to collision theory, for a reaction to occur, the reactant particles must collide with each other and they must collide with sufficient energy to meet the activation energy requirements for the reaction so that the reaction can occur. If they do not collide with enough energy, the reaction won't occur. In Experiment 2, the only change from Experiment 1 is that the temperature is increased. When the temperature is increased, more heat energy is added to the solution and the particles in the solution. As a result, the reactant particles have more kinetic energy and move faster. This means they collide more frequently and therefore reactions happen more often. As a result, more reactions happen per second so the reaction rate is faster. In addition, since they have greater energy, more of the reactant particles will have sufficient energy to meet the activation energy requirements and so more of the collisions that do occur will be successful. This causes the reaction to reach completion sooner and the fizzing to stop sooner in Experiment 2.
In Experiment 3, the only change from Experiment 1 is the addition of copper which causes the reaction to reach completion sooner. The copper acts as a catalyst which speeds up the rate of reaction so that reactants are all converted into products sooner and the reaction reaches completion sooner. The copper, as a catalyst, works to speed up the reaction by lowering the activation energy of the reaction so that more of the reactant particles have sufficient energy to react successfully. Therefore there are more successful reactions per second and the reaction rate is faster than in Experiment 1.

b. The diagram shows the difference in energy between the reactants (a) and the products (c). The bump is the activation energy (b), E_a, needed for the reaction to occur. The dotted line shows the difference in activation energy when the catalyst is added, the activation energy is lower.



c. *i.* At the beginning of the reaction, the concentration and volume of products like H_2 gas is low and the concentration of the reactants (zinc and sulfuric acid) is high because none or very few have reacted yet to form the products. However, over time as the reaction proceeds, the reactants are converted into products, and the concentration and volume of products increases while the concentration of reactants decreases. This is shown in Section A when the line rises, which indicates that H_2 gas is being produced. Initially, the rate of production of H_2 gas is high and the reaction rate is therefore high, which is shown by the steepness of the line in section A being greater than the other sections. This is because the concentration of reactants is still high. A reaction occurs when the reactant particles collide, so when they have a higher concentration and there are more of them, they are more likely to collide, more collisions happen per second and so the number of reactions per second (the reaction rate) is higher. This means the H_2 increases rapidly at the start. However, as the reactants are used up, their concentration decreases and collisions and therefore reactions become less frequent. As a result, the reaction rate and the production of H_2 slow. This is seen in Section B. Finally, by Section C, all of the reactant particles have been converted into products and so no more reactions take place, since there is no reactant left to react. As a result, the production of H_2 stops and the line plateaus, showing that the volume of H_2 is now constant and no longer increasing.

ii.



iii. Experiment 2 and 3 reach completion sooner than Experiment 1 due to the increased temperature (for Experiment 2) and the presence of a catalyst (Experiment 3). This causes the reaction rate to be higher in both cases so that more hydrogen is produced in a shorter amount of time. This increased reaction rate is shown by the lines being steeper than for Experiment 1. The reaction reaches completion fastest for Experiment 3 due to the catalyst speeding up the reaction, so this has the steepest line. After 30s, the reaction for Experiment 2 reaches completion and stops fizzing and for Experiment 3, this point is reached at 15s. At this point, no more hydrogen gas is produced and the volume of hydrogen becomes constant. The line for Experiment 2, therefore, plateaus after 30s and the line for Experiment 3 plateaus after 15s. The lines for Experiment 2 and 3 reach the same height as that for Experiment 1 because the concentration of reactants has not changed, so the total concentration of products produced, and therefore the volume of hydrogen gas produced, also is the same across the three solutions. All that changes is how quickly this volume of gas is reached.

Question Two: Equilibria

a. *i.* $K_c = \frac{[D] \times [C]^3}{[B] \times [A]^2}$

ii. $K_c = \frac{[D] \times [C]^3}{[B] \times [A]^2}$

The K_c value represents the ratio of the concentrations of the products and reactants when the reaction is at equilibrium. So, if the reaction is at equilibrium, the concentrations of the products and reactants should produce the K_c value when put into the equilibrium constant expression above.

$$K_c = \frac{[0.100] \times [0.050]^3}{[0.100] \times [0.250]^2}$$

$$K_c = \frac{[0.100] \times [0.000125]}{[0.100] \times [0.0625]}$$

$$K_c = \frac{0.0000125}{0.00625}$$

$$K_c = 0.002$$

This value is less than the K_c value of 0.5 at 600°C so the reaction is not at equilibrium.

iii. This is a decrease in the temperature that the reaction is performed at. In this equilibrium system, the forward reaction is exothermic because it releases heat energy, causing the solution to warm and the ΔH to be -450kJmol^{-1}. When chemical systems are at equilibrium, any change to the system will affect the rates of reaction as the system will try to oppose the change. In this case, decreasing the temperature will cause the forward reaction, which is exothermic and releases heat energy, to increase, so as to counteract the loss of heat energy. This will result in a higher concentration of products being formed. Since changes in temperature permanently alter K_c values, when the equilibrium is reestablished it will be re-established with the greater concentration of products (favouring the forward reaction/production of products) and the K_c value will be larger as the concentration of products, which is the numerator in the K_c expression, will now be larger.

iv. $2A_{(g)} + B_{(g)} \rightleftharpoons 3C_{(g)} + D_{(g)}$

There are 3 moles of gas on the reactants' side and 4 moles of gas on the products' side. Since there are different numbers of moles of gas on each side of the chemical equation, changing the pressure will affect the equilibrium. Decreasing the volume of the container will increase the pressure inside the container. When the pressure increases, the system will act to oppose this change by decreasing the pressure if possible. This means that the reaction which results in fewer moles of gas will be favoured; in this case, this is the reverse reaction, which converts 4 moles of gas (the products) into 3 moles of gas (the reactants). This means that when the volume is decreased, the reverse reaction will increase in rate and the concentration of reactants will increase. The equilibrium will eventually reestablish. The K_c value will not change because only changes in temperature change the K_c value.

Question Three: Acids and Bases

a. NH_4Cl dissociates into its ions in solution according to the following equation:
$NH_4Cl \rightarrow NH_4^+ + Cl^-$

The ammonium ion, NH_4^+, can react with water:
$NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3$

The ammonium ion donates a proton to a water molecule in solution to form the hydronium ion, H_3O^+. In this way, it acts as an acid. The NH_3 molecule that results is the conjugate base of the NH_4^+ acid since it could accept an H^+ ion (therefore acting as a base) to reform NH_4^+. The H_3O^+ ion is the conjugate acid of water since it could donate a proton (acting as an acid) to reform H_2O.

b. CH_3COOH is a weak acid, so when it is added to a solution, it only partially dissociates. This means that it produces a low concentration of H_3O^+ ions and most of the CH_3COOH molecules remain intact. To be conductive, a solution needs to have free ions to carry the charge in the solution. Since CH_3COOH produces few ions, the solution does not conduct electricity well. When NH_4Cl is added to a solution, it dissociates into its ions NH_4^+ and Cl^-. The NH_4^+ is only a weak acid, which only partially dissociates to form a few H_3O^+ ions and NH_3 ions. However, the NH_4^+ itself and the Cl^- are already charged ions that can carry charge in the solution, and therefore increase the conductivity of the solution. Therefore, the NH_4Cl solution has a greater concentration of ions in the solution so it conducts electricity better.

c. $pH = -\log[H_3O^+]$
$10^{-ph} = [H_3O^+]$

For CH_3COOH:
$10^{-2.88} = 0.00132 molL^{-1}$
$[H_3O^+] = 0.00132 molL^{-1}$

For HCl:
$10^{-1} = 0.100 molL^{-1}$
$[H_3O^+] = 0.100 molL^{-1}$

HCl is a strong acid because it fully dissociates in water:
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$
As a result, there is a 1:1 ratio between the concentration of the acid in the solution and the concentration of H_3O^+ ions.
However, CH_3COOH is a weak acid that only partially dissociates in water:
$CH_3COOH \rightleftharpoons H_3O^+ + CH_3COO^-$
Therefore, a lower H_3O^+ concentration is produced for the CH_3COOH solution despite it having the same concentration as the HCl solution. This means that the pH of the CH_3COOH solution is higher than that of the HCl solution.

Both acids will react with the cleaned Mg ribbon; this will be a metal + acid $\rightarrow$ salt + hydrogen gas reaction. However, the HCl has a higher concentration of H_3O^+, so it will react faster as there are more reactant particles to collide with, whereas the CH_3COOH solution will react with the Mg ribbon more slowly because there are fewer H_3O^+ ions in solution to collide with and react with the Mg.

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