CIE Chemistry A-Level

Topic 7 - Equilibria

Flashcards

What is a reversible reaction?

What is a reversible reaction?

- A reaction in which reactants form products and products reform reactants.
- This occurs until an equilibrium is reached.

What is dynamic equilibrium?

What is dynamic equilibrium?

The rate of the forward reaction equals the rate of the reverse reaction, hence the concentrations of the reactants and products remains constant.

What is Le Chatelier's principle?

What is Le Chatelier's principle?

If a system in dynamic equilibrium is subjected to a change, then the position of equilibrium will shift to minimise this change.

How does increasing temperature affect the position of equilibrium?

How does increasing the temperature affect the position of equilibrium?

For an equilibrium where the forward reaction is exothermic, increasing the temperature will shift the equilibrium left (so more endothermic reactions occur) to take in more heat energy and reduce the temperature.

The reverse is true when the forward reaction is endothermic.

How does decreasing the temperature affect the position of equilibrium?

How does decreasing the temperature affect the position of equilibrium?

For an equilibrium where the forward reaction is exothermic, decreasing the temperature will shift the position of equilibrium to the right (so more exothermic reactions occur) to release more heat energy and increase the temperature.

The reverse is true when the forward reaction is endothermic.

How does the concentration of reactants affect the position of equilibrium?

How does the concentration of reactants affect the position of equilibrium?

Increasing the concentration of reactants causes the position of equilibrium to shift right in order to reduce the concentration of reactants and form more products.

The reverse occurs if the concentration of reactants is decreased.

How does pressure affect the position of equilibrium?

How does pressure affect the position of equilibrium?

- Increasing the pressure will cause the position of equilibrium to shift to the side with the fewest gaseous molecules in order to increase the pressure.
- The opposite occurs if pressure is decreased.
- If there is an equal number of gaseous molecules on both sides of the equation, changing the pressure will have no effect on the position of equilibrium.

How does the presence of a catalyst affect the position of equilibrium and the magnitude of the equilibrium constant?

How does the presence of a catalyst affect the position of equilibrium and the magnitude of the equilibrium constant?

- The presence of a catalyst doesn't affect the position of equilibrium.
- The magnitude of the equilibrium constant therefore is unaffected.
- It does however increase the rate of the forward and reverse reactions so equilibrium is established sooner.

How does temperature affect the magnitude of the equilibrium constant?

How does temperature affect the magnitude of the equilibrium constant?

- If the forward reaction is **exothermic**, increasing the temperature shifts the position of equilibrium to the **left** so K_c decreases.
- If the forward reaction is **endothermic**, increasing the temperature shifts the equilibrium to the **right** so K_c increases.
- The reverse is true if temperature is decreased.

How does pressure affect the magnitude of the equilibrium constant?

How does pressure affect the magnitude of the equilibrium constant?

K_c remains the same:

- Doubling the pressure will double both the partial pressures and concentrations of the species on both sides of the equation.
- The system is no longer in equilibrium so partial pressures of reactants and products must change to keep K_c the same.
- New equilibrium position will be reached whereby K_c is restored (the ratio of the K_c expression is the same as before).

How does concentration affect the magnitude of the equilibrium constant?

How does concentration affect the magnitude of the equilibrium constant?

- Changing the concentration of a reactant or product means that the system is no longer in equilibrium.
- The concentrations of the reactants and products now must change so the ratio and hence K_c is restored.
- K_c is therefore unaffected by concentration changes.

What does the equilibrium constant tell you?

What does the equilibrium constant tell you?

- The position of equilibrium of a reaction.
- The magnitude indicates whether there are more reactants or products in an equilibrium system.

How would you calculate the equilibrium constant (K_c) for the following equation?

$$3H_2 + N_2 \rightleftharpoons 2NH_3$$

How would you calculate the equilibrium constant (K_c) for the following equation? $3H_2 + N_2 \rightleftharpoons 2NH_3$

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Multiply all the concentrations of the products to the power of their balancing number. Divided this by the product of all the concentrations of the reactants to the power of their balancing number. This is K_c, the equilibrium constant.

Use the K_c expression to work out the units for the equilibrium constant for the equation below:

$$3H_2 + N_2 \rightleftharpoons 2NH_3$$

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$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Substitute in the units and cancel down:

$$K_c = \frac{(mol\ dm^{-3})^2}{mol\ dm^{-3} \times (mol\ dm^{-3})^3} = \frac{mol^2\ dm^{-6}}{mol^4\ dm^{-12}} = dm^6\ mol^{-2}$$

What is K_p?

What is K_p?

- The equilibrium constant for reactions in the gaseous phase.
- Similar to K_c but it uses partial pressures instead of concentrations.

How do you calculate the mole fraction of a gas?

How do you calculate the mole fraction of a gas?

For gas, A:

$$Mole\ fraction,\ X_a = \frac{No.\ of\ moles\ of\ gas\ A}{Total\ no.\ of\ moles\ of\ all\ present\ species}$$

How do you calculate the partial pressure of a gas?

How do you calculate the partial pressure of a gas?

For gas A:

$$Partial\ pressure\ of\ A,\ p(A) = Mole\ fraction,\ X_A \times Total\ pressure$$

Write the K_p expression for the following reaction: $H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$

Write the K_p expression for the following reaction:

$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$

$$K_p = \frac{p(HI)^2}{p(H) \times p(I)}$$

Where *p(X)* is the partial pressure of gas X and the power is the balancing number in the equation.

Use the K_p expression to work out the units for the equilibrium constant for the equation below:

$$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$$

Use the K_p expression to work out the units for the equilibrium constant for the equation below:

$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$

Substitute the units into the K_p expression and cancel any common units, in this case all units cancel out.

$$K_p = \frac{p(HI)^2}{p(H) \times p(I)}$$

$$K_p = \frac{(kPa)^2}{kPa \times kPa} = \frac{kPa^2}{kPa^2} = no\ units$$

$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$$

Initially, a mixture contains 3.00 mol of water and 1.50 mol of methane. At equilibrium, this mixture contains 0.250 mol of carbon dioxide. Calculate the quantity of each compound at equilibrium.

$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$

Initially, a mixture contains 3.00 mol of water and 1.50 mol of methane. At equilibrium, this mixture contains 0.250 mol of carbon dioxide. Calculate the quantity of each compound at equilibrium.

Black- from question
Red - use the stoichiometric ratio in the equation.
Blue - calculated quantities (subtract reacted from initial)

	CH_4 +	$2H_2O$ ⇌	CO_2 +	$4H_2$
Initial amount / mol	**1.50**	**3.00**	0.00	0.00
Amount reacted / mol	0.250	0.500	0.00	0.00
Amount at equilibrium / mol	1.50 - 0.250 = 1.25	3.00 - 0.500 = 2.50	**0.250**	1.00

No products in initial mixture

Calculate K_c using the quantities at equilibrium below. The volume is 4 dm^3.

	CH_4 +	$2H_2O$ ⇌	CO_2 +	$4H_2$
Amount at equilibrium / mol	1.25	2.50	0.250	1.00

Calculate K_c using the quantities at equilibrium below. The volume is 4 dm^3.

Total volume = 4 dm^3

Calculate concentration using c = n ÷ v

	CH_4 +	$2H_2O$ ⇌	CO_2 +	$4H_2$
Amount at equilibrium / mol	1.25	2.50	0.250	1.00
Concentration / mol dm^{-3}	1.25 ÷ 4 = 0.313 mol dm^{-3}	2.50 ÷ 4 =0.625 mol dm^{-3}	0.250 ÷ 4 0.0625 mol dm^{-3}	1.00 ÷ 4 = 0.250 mol dm^{-3}

$$K_c = \frac{[H_2]^4[CO_2]}{[CH_4][H_2O]^2} = \frac{(0.250)^4(0.0625)}{(0.313)(0.625)^2} = 2\ x\ 10^{-3}\ mol^2 dm^{-6}$$

What is the Haber process? Write an equation for this reaction and state the source of the reactants

What is the Haber process? Write an equation for this reaction and state the source of the reactants

- It is a process that produces ammonia:

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ $\Delta H = -92 \text{ kJ mol}^{-1}$

- Nitrogen - fractional distillation of air
- Hydrogen - natural gas

What conditions are used for the Haber process?

What conditions are used for the Haber process?

- 400 - 450℃
- 200 atm
- Iron catalyst

What temperature would you expect to be used for the Haber process and why? Why is the temperature used in industry a compromise?

What temperature would you expect to be used for the Haber process and why? Why is the temperature used in industry a compromise?

- The forward reaction is exothermic so a low temperature would give the greatest yield.
- However, a low temperature gives a slow rate of reaction and so a higher temperature is normally used to strike a balance between yield and rate.

What pressure would you expect to be used for the Haber process and why? Why is the pressure used in industry a compromise?

What pressure would you expect to be used for the Haber process and why? Why is the pressure used in industry a compromise?

- According to Le Chatelier's principle, a high pressure would give the greatest yield of ammonia.
- However, high pressures can be dangerous and expensive to maintain so a lower pressure may be used.

What is the Contact process? Write an equation for this reaction and state the source of the reactants

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- The process for creating sulfur trioxide:

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)} \qquad \Delta H = -196 \text{ kJ mol}^{-1}$$

- Sulfur dioxide - heat sulfur in air
- Oxygen - air

What conditions are used for the Contact process?

What conditions are used for the Contact process?

- 400 - 450℃
- 1 - 2 atm
- V_2O_5 catalyst

What temperature would you expect to be used for the Contact process and why? Why is the temperature used in industry a compromise?

What temperature would you expect to be used for the Contact process and why? Why is the temperature used in industry a compromise?

- The forward reaction is exothermic so a low temperature would give the greatest yield.
- However, a low temperature results in a slow rate of reaction and so a higher temperature may be used to strike a balance between yield and rate.

What pressure would you expect to be used for the Contact process and why? Why is the pressure used in industry a compromise?

What pressure would you expect to be used for the Contact process and why? Why is the pressure used in industry a compromise?

- According to Le Chatelier's principle, a high pressure would give the greatest yield of sulfur trioxide.
- However, even at pressures close to atmospheric pressure, 99.5% of SO_2 is converted into SO_3 so increasing the pressure would only see a minute improvement in yield that wouldn't be economically worthwhile.

What is a Brønsted-Lowry acid?

What is a Brønsted-Lowry acid?

A proton donor

What is a Brønsted-Lowry base?

What is a Brønsted-Lowry base?

A proton acceptor

What is the proton donor and acceptor in this reaction:

$$HNO_{2(s)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO_2^-{}_{(aq)}$$

What is the proton donor and acceptor in this reaction:

$$HNO_{2(s)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO_2^-{}_{(aq)}$$

- Proton donor: $HNO_{2(aq)}$
- Proton acceptor: $H_2O_{(l)}$

What is a conjugate acid-base pair?

Label the conjugate acid-base pairs in the equation below:

$$HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-_{(aq)}$$

What is a conjugate acid-base pair? Label the conjugate acid-base pairs in the equation below:

$HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-_{(aq)}$

- A conjugate acid-base pair is two species that differ from each other by a proton (H^+ ion)
- $HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-_{(aq)}$

  Acid 1 Base 2 Acid 2 Base 1
- **HCl and Cl^- are a conjugate acid-base pair.**
- **H_2O and H_3O^+ are a conjugate acid-base pair.**

What is a strong acid? Write an equation to show that HCl is a strong acid

What is a strong acid? Write an equation to show that HCl is a strong acid

A strong acid is an acid that completely dissociates in solution:

$$HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

Typical pH is 0 - 1

What is a strong base? Write an equation to show that NaOH is a strong base

What is a strong base? Write an equation to show that NaOH is a strong base

A strong base is a base that completely dissociates in solution:

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

Typical pH is close to 14

What is a weak acid? Write an equation to show that ethanoic acid is a weak acid

What is a weak acid? Write an equation to show that ethanoic acid is a weak acid

A weak acid is an acid that only partially dissociates in solution:

$$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$$

Typical pH is 2 - 6

What is a weak base?Write an equation to show that ammonia is a weak base

What is a weak base? Write an equation to show that ammonia is a weak base

A weak base is a base that only partially dissociates in solution:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Typical pH is above 7 but lower than a strong base

What is the acid dissociation constant, K_a? Write the general equation for K_a

(A level only)

What is the acid dissociation constant, K_a? Write the general equation for K_a

(A level only)

A quantitative measure of the strength of an an acid.

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

Write a general equation for pK_a. Why might pK_a be used instead of K_a?

(A level only)

Write a general equation for pK_a. Why might pK_a be used instead of K_a? **(A level only)**

$pK_a = -\log K_a$

pK_a values make it easier to compare relative acidic strengths of substances.

What is pH? (A level only)

What is pH? **(A level only)**

- A way to measure/ compare hydrogen ion concentration.
- There's a large range of $[H^+]$ values with negative powers of 10. pH gives a more manageable scale of 1 to 14 rather than 10^{-1} to 10^{-14}.

How do you calculate the pH of a strong acid? **(A level only)**

How do you calculate the pH of a strong acid?

(A level only)

Strong acid: $HA \rightarrow H^+ + A^-$

Concentration of acid = concentration of H^+ ions.

$pH = -\log[H^+]$

What is K_w?

(A level only)

What is K_w? **(A level only)**

- **The ionic product of water.**
- Water molecules can function as acids and bases.
  $H_2O \rightarrow H^+ + OH^-$
- $K_w = [H^+][OH^-] = 1 \times 10^{-14}\ mol^2\ dm^{-6}$ at RTP
- So little water is ionised at any moment that the concentration of H_2O remains almost constant, thus it doesn't appear in the K_w expression.

How do you calculate the pH of a strong base?

(A level only)

How do you calculate the pH of a strong base?

(A level only)

Strong base: $XOH \rightarrow X^+ + OH^-$

Concentration of base = concentration of OH^- ions.

$K_w = [H^+][OH^-]$ so $[H^+] = K_w/[OH^-]$

$pH = -\log[H^+]$

How do you calculate the pH of a weak acid?

(A level only)

How do you calculate the pH of a weak acid?

(A level only)

Weak acid: $HA \rightleftharpoons H^+ + A^-$

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

We can assume $[H^+] = [A^-]$ so: $$K_a = \frac{[H^+]^2}{[HA]}$$

Rearrange to make $[H^+]$ the subject: $$[H^+] = \sqrt{K_a \times [HA]}$$

$pH = -\log[H^+]$

Write an equation that can be used to calculate the concentration of protons from pH

(A level only)

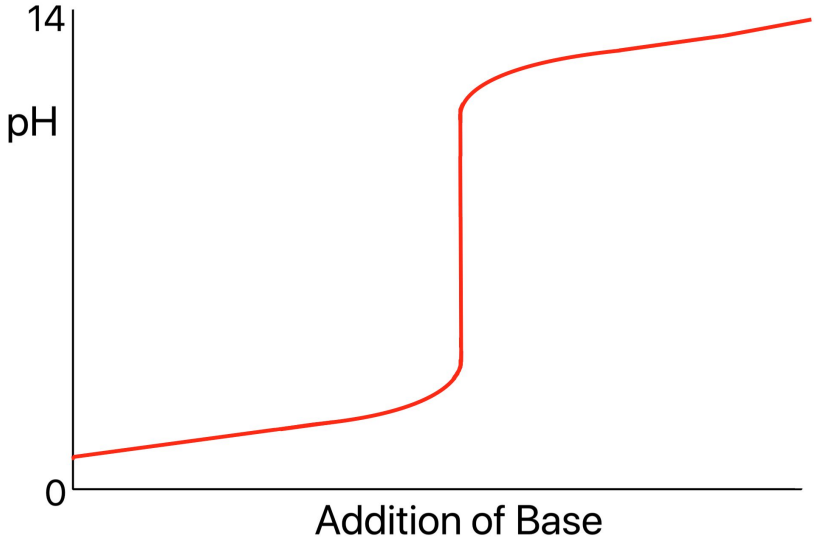
Write an equation that can be used to calculate the concentration of protons from pH **(A level only)**

$$[H^+] = 10^{-pH}$$

Draw a pH curve for a strong acid-strong base reaction

(A level only)

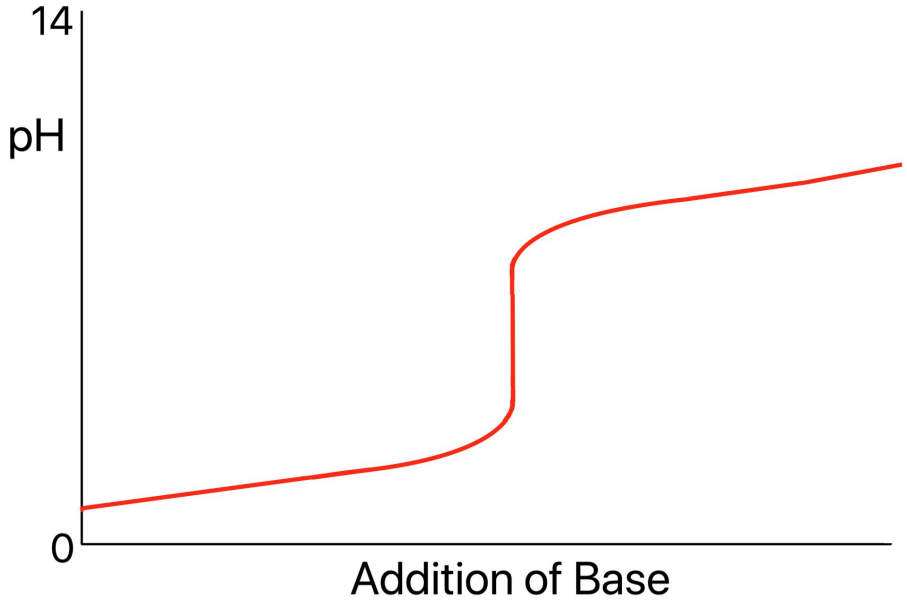
Draw a pH curve for a strong acid-strong base reaction **(A level only)**



Draw a pH curve for a strong acid-weak base reaction

(A level only)

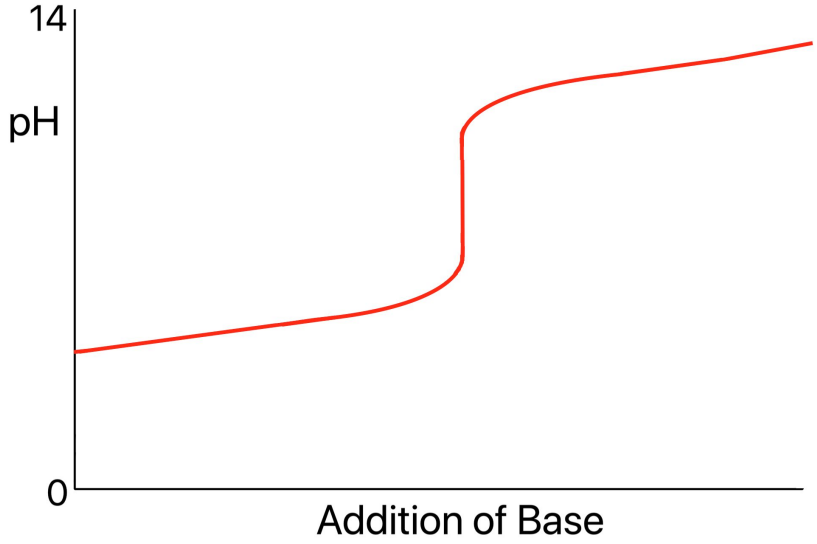
Draw a pH curve for a strong acid-weak base reaction **(A level only)**



Draw a pH curve for a weak acid-strong base reaction

(A level only)

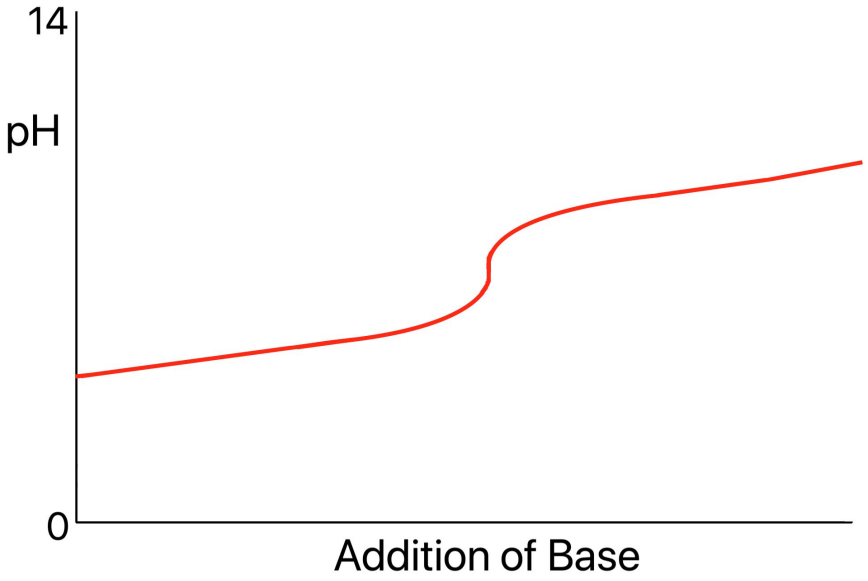
Draw a pH curve for a weak acid-strong base reaction **(A level only)**



Draw a pH curve for a weak acid-weak base reaction

(A level only)

Draw a pH curve for a weak acid-weak base reaction **(A level only)**



How would you use a pH curve to determine a suitable indicator for an acid-base titration?

(A level only)

How would you use a pH curve to determine a suitable indicator for an acid-base titration?

(A level only)

- The pH range of the indicator must be within the vertical section of the pH curve.
- Weak acid-weak base reactions have no suitable indicator because they have no vertical region.

Why must an indicator change colour within the vertical section of pH curve for an acid-base titration?

(A level only)

Why must an indicator change colour within the vertical section of pH curve for an acid-base titration? **(A level only)**

Within the vertical section, the volume of acid (or alkali) added changes very little. When the indicator changes colour, this is the end point of the titration which should show when the correct volumes of acid and alkali have been combined so that neither reactant is in excess. If the indicator changes colour outside the vertical sections, the volumes of acid and alkali won't be close to the actual volumes required for the neutralisation reaction.

What is a buffer?

(A level only)

What is a buffer? **(A level only)**

A system that minimises pH changes on addition of small amounts of an acid or base.

Describe how the system below can act as a buffer:

$$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$$

(A level only)

Describe how the system below can act as a buffer:

$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$ **(A level only)**

- Upon addition of **acid**, the concentration of H^+ ions increases. H^+ ions combine with $CH_3COO^-_{(aq)}$ to form CH_3COOH. The **reverse** reaction is favoured and the position of equilibrium shifts to the **left.**
- Upon addition of **base**, the concentration of OH^- ions increases. OH^- ions combine with H^+ to form H_2O. The **forward** reaction is favoured and the position of equilibrium shifts to the **right.**

What is a weak acid buffer?

(A level only)

What is a weak acid buffer? **(A level only)**

A mixture of a weak acid and its conjugate base (usually in the form of one of its salts i.e. $CH_3COO^-Na^+$).

How would you calculate the pH of the weak acid buffer solution shown below?

$$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$$

(A level only)

How would you calculate the pH of the weak acid buffer solution shown below?

$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$ **(A level only)**

- Write K_a expression: $K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$
- Make $[H^+]$ the subject: $[H^+] = \frac{K_a \times [CH_3COOH]}{[CH_3COO^-]}$
- Calculate $[H^+]$ and substitute into $pH = -\log[H^+]$

How do buffers control the pH of blood?

(A level only)

How do buffers control the pH of blood? **(A level only)**

- It is important that blood remains within a specific pH range to prevent disastrous effects on enzymes and proteins in the blood that could put our life at risk.
- One way that blood pH is maintained is with the carbonic acid-hydrogen carbonate buffer system:

  $H_2CO_{3(aq)} \rightleftharpoons H^+_{(aq)} + HCO_3^-{}_{(aq)}$
- If small amounts of acid or base are added, the position of equilibrium shifts to minimise this pH change.

Explain how to calculate the pH of a buffer

(A level only)

Explain how to calculate the pH of a buffer **(A level only)**

General equation for a buffer: $HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$

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

Do not assume that $[H^+] = [A^-]$ like other weak acids.

Assume that [HA] at equilibrium = [HA] at start

Rearrange K_a to find $[H^+]$ (K_a will be given, may need to work out equilibrium quantities and concentrations) then substitute $[H^+]$ into $pH = -\log_{10}[H^+]$

What is solubility product?

(A level only)

What is solubility product? **(A level only)**

- The solubility product constant, K_{sp}, is an equilibrium constant for a solid dissolving in (aqueous) solution.
- The higher its K_{sp}, the more soluble a substance is and hence the more solute that dissolves.

How do you calculate K_{sp}?

(A level only)

How do you calculate K_{sp}? **(A level only)**

For reaction: $aA_{(s)} \rightleftharpoons cC_{(aq)} + dD_{(aq)}$

$K_{sp} = [C]^c[D]^d$

Solids are not included as their concentrations don't affect the expression and are hence insignificant.

How does K_{sp} affect whether a precipitate will form?

(A level only)

How does K_{sp} affect whether a precipitate will form? **(A level only)**

A precipitate will only form if the ionic concentrations give a give a value that is greater than the solubility product. If not, the solution is not saturated.

What is the common ion effect?

(A level only)

What is the common ion effect? **(A level only)**

- The extent of which a solute dissolves in solution is affected by the presence of a common ion.
- This prevents dissociation due to shifting the position of equilibrium towards the solid reactant.

What is meant by the partition coefficient? Write an equation for K_{pc}

(A level only)

What is meant by the partition coefficient? Write an equation for K_{pc} **(A level only)**

- A dynamic equilibrium is established between two immiscible layers in a separating funnel when a substance (X) is dissolved in the liquids:
  X(in more dense liquid) ⇋ X(in less dense liquid)

- $$K_{pc} = \frac{[\text{X in less dense liquid}]}{[\text{X in more dense liquid}]}$$

- There are no units as they cancel out.

1.00g of X is in 100cm^3 of water and 5cm^3 of ether. K_{pc} is 40. Calculate the mass of X dissolved in ether.

(A level only)

1.00g of X is in 100cm^3 of water and 5cm^3 of ether.

K_{pc} is 40. Calculate the mass of X dissolved in ether.

(A level only)

- Concentration of X in ether: m/5 g cm^{-3}
- Concentration of X in water: (1.00 - m)/100 g cm^{-3}

$$K_{pc} = \frac{[\text{X in less dense liquid}]}{[\text{X in more dense liquid}]}$$

$$40 = \frac{m/5}{(1.00 - m)/100}$$

$$\frac{40(1.00 - m)}{100} = \frac{m}{5}$$

$$200 - 200m = 100m$$

$$300m = 200$$

$$m = 0.67g$$