Course 3-pH Titres Indicators & pH

Marking scheme

Question 1

(b) Graph: **axes correct and correctly labelled** (*pH axis does not have to start at 0*) (3, 3)
[Note: penalty (–3) if pH on horizontal axis and volume on vertical axis.]
all points correctly plotted (6) {*Allow* (*3*) *for 8 points plotted correctly*} {*not on graph paper* (*– 6*)}
correct graph line (*based on their points – no penalty for not joining the first or the last pair of points*) (6)

Indicator: **bromothymol blue / phenol red / neutral red / cresol purple / thymol blue / phenolphthalein / thymolphthalein** (3)

Use: **range of indicator (indicator colour change) within pH jump on graph** *(unambiguously identified e.g 'within vertical part of graph' or 'between lower and upper pH values of vertical part of their graph' or 'between values from table (6 – 11 or 6 – 11.2) corresponding to vertical part of graph' or 'any range (e.g. 8 – 10) within the vertical part of the graph'.* (4) {*Note: this (4) can be given even if the indicator chosen is incorrect.*}

Question 2

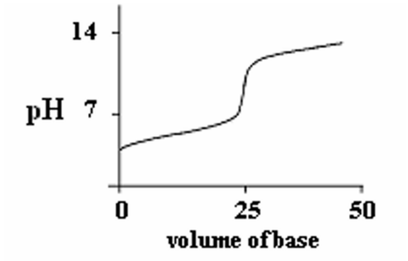
(b) (i) EXPLAIN: the indicator itself dissociates according to the equation

$$\mathbf{HX \rightleftharpoons H^+ + X^-} \quad \textit{or} \quad \mathbf{HX + H_2O \rightleftharpoons H_3O^+ + X^-} \qquad (3)$$

in acid (low pH) equilibrium lies on the left (shifts backward) giving colour of molecules (HX) / in acid (low pH) indicator is associated (undissociated) giving colour of molecules (HX) Associated = present as molecules (3)

in base (alkali / high pH) equilibrium lies on the right (shifts forward) giving colour of ions (X^-) / in base (alkali / high pH) indicator is dissociated giving colour of ions (X^-) Dissociated = present as ions (ionised) (3)

(ii) DRAW:



graph with pH axis labelled at 7 and number over 7 (3)

neutralisation point at about 25 cm^3 (3)

steep rise at about pH = 6.5 to 10.5 (3)

No labelling or numbers required on horizontal axis.

(iii) EXPLAIN: Phenolphthalein has a pH **range from 8.3 – 10 (8 – 10)** / phenolphthalein **changes colour in steep part of graph** (6)
[Allow (3) for ***weak acid-strong base*** *titration*]

Question 3

(a) DEFINE: (i): **Proton (H^+) donor //**

(ii): **Related (produced) by gain of one proton (H^+) / base + H^+** (2 × 4)

DISTINGUISH: Strong acid **dissociates** almost **fully (readily) in** aqueous **solution (water) / good proton donor //**
weak acid **only slightly dissociates in solution / poor proton donor** (2 × 3)

WHAT: **X^-** (3)
[“SA diss fully” *and* “WA diss. slightly” (3); if “in solution (water)” mentioned once, give other (3).

(b) (i) STATE: **Red** colour observed //

EXPL.: **Equilibrium shifted left** by H^+ present / **high H^+ conc. / high [H^+]** (2 × 3)

(ii) STATE: **Yellow** colour observed //

EXPL.: **Equilibrium shifted right** by OH^- removing H^+ / **low H^+ conc. / low [H^+]** (2 × 3)

(c) CALC.: (i): **13** [– log 0.1 = 1 (2) 14 – 1 = 13 (1)] (3)

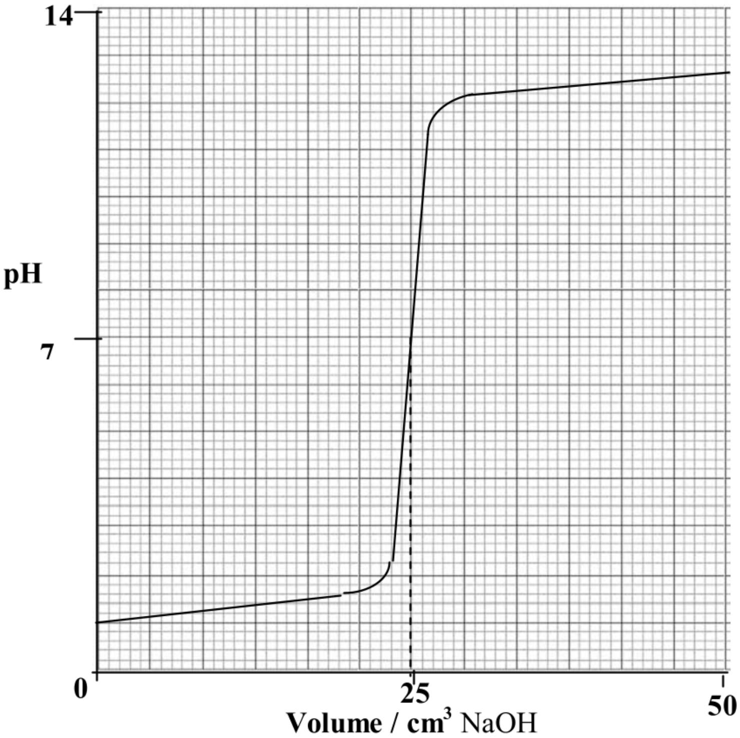
(ii): **2.9** (6)

$[H^+]^2/0.004 = 3.5 \times 10^{-4}$ / $[H^+]^2 = 1.4 \times 10^{-6}$ / $[H^+] = 1.18 \times 10^{-3}$ (3)
pH = $-\log 1.18 \times 10^{-3}$ = 2.9 (3)

OR

pH = $-\log \sqrt{(K_a \times M)}$ / pH = $-\log \sqrt{(3.5 \times 10^{-4} \times 0.004)}$ (3)
pH = 2.9 (3)

DRAW.: **Axes labelled (pH – with 7 or 14, and volume – with 25 or 50) //**
Correct shaped curve with steep rise in pH (minimum: 4 to 10) //
Rise around 25 cm^3 (rise around middle of total addition) (3 × 3)



Curve does not have to be drawn on graph paper.

EXPLAIN: **Most indicators will change within this pH range (jump in pH)** (3)

Question 4

QUESTION 9

(*a*) DEFINE: (*i*) *Arrhenius acid*: **produces H^+ (hydrogen ion)** by dissociation **in water (aqueous solution)** //
(*ii*) *Brønsted-Lowry acid*: **proton (hydrogen ion, H^+) donor** (2 × 3)

(*b*) DEFINE: **– $\log_{10}[H^+]$ / – $\log_{10}[H_3O^+]$ / negative log** to base ten **of hydrogen (hydronium) ion concentration in moles per litre** (6)

STATE: **reliable (accurate, suitable)** only **for dilute solutions** / only **valid (useful)** in **0 - 14** range / **applies to aqueous solutions** only **/ unreliable (inaccurate, unsuitable) in** very **concentrated solutions / unreliable for negative pH values** (3)
[‘*Temperature dependent / (25 °C)’* acceptable.][‘*Valid range 1 – 14*’ unacceptable but does not cancel.]

(*c*) GRAPH: *See graph on next page.*
both axes correctly labelled (*pH, V, volume, cm^3, NaOH*) (3)
appropriate, correct numeric scales on both axes (3)
smooth curve of correct shape corresponding to 0 -15 cm^3 NaOH added and from 25- 40 cm^3 NaOH added (3)
careful plotting of vertical part (6)
[*Volume versus pH* acceptable.][(3) marks deducted if graph not on graph paper.]

(*d*) (*i*) CALCULATE: **0.014** M **[0.0139 – 0.014** M**]** (9)

$[H^+] = \sqrt{K_a[CH_3COOH]}$ / inverse log (–3.3) / 5.01 × 10^{-4} / $-\log\sqrt{K_a[CH_3COOH]} = 3.3$ / $\log\sqrt{K_a[CH_3COOH]} = -3.3$ (6)

$$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} \Big/ \frac{[H^+]^2}{[CH_3COOH]} \Big/ 1.8 \times 10^{-5} = \frac{[5.01 \times 10^{-4}]^2}{[CH_3COOH]}$$

$[CH_3COOH]$ = **0.014** M **[0.0139 – 0.014** M**]** (3)
Take [acid] or [HA] or *M* to be $[CH_3COOH]$ and $[A^-]$ to be $[CH_3COO^-]$

or

$[H^+] = \sqrt{K_a[CH_3COOH]}$ / inverse log (–3.3) / 5.01 × 10^{-4} / $-\log\sqrt{K_a[CH_3COOH]} = 3.3$ / $\log\sqrt{K_a[CH_3COOH]} = -3.3$ (6)

$K_a[CH_3COOH]$ / $1.8 \times 10^{-5} \times [CH_3COOH] = (5.01 \times 10^{-4})^2$

$$[CH_3COOH] = \frac{(5.01 \times 10^{-4})^2}{1.8 \times 10^{-5}} = \frac{2.51 \times 10^{-7}}{1.8 \times 10^{-5}} = \mathbf{0.014} \quad \mathbf{[0.0139 - 0.014}\ M\mathbf{]} \quad (3)$$

Take [acid] or [HA] or *M* to be $[CH_3COOH]$ and $[A^-]$ to be $[CH_3COO^-]$

[*1 mark deducted for incorrect rounding off.*]

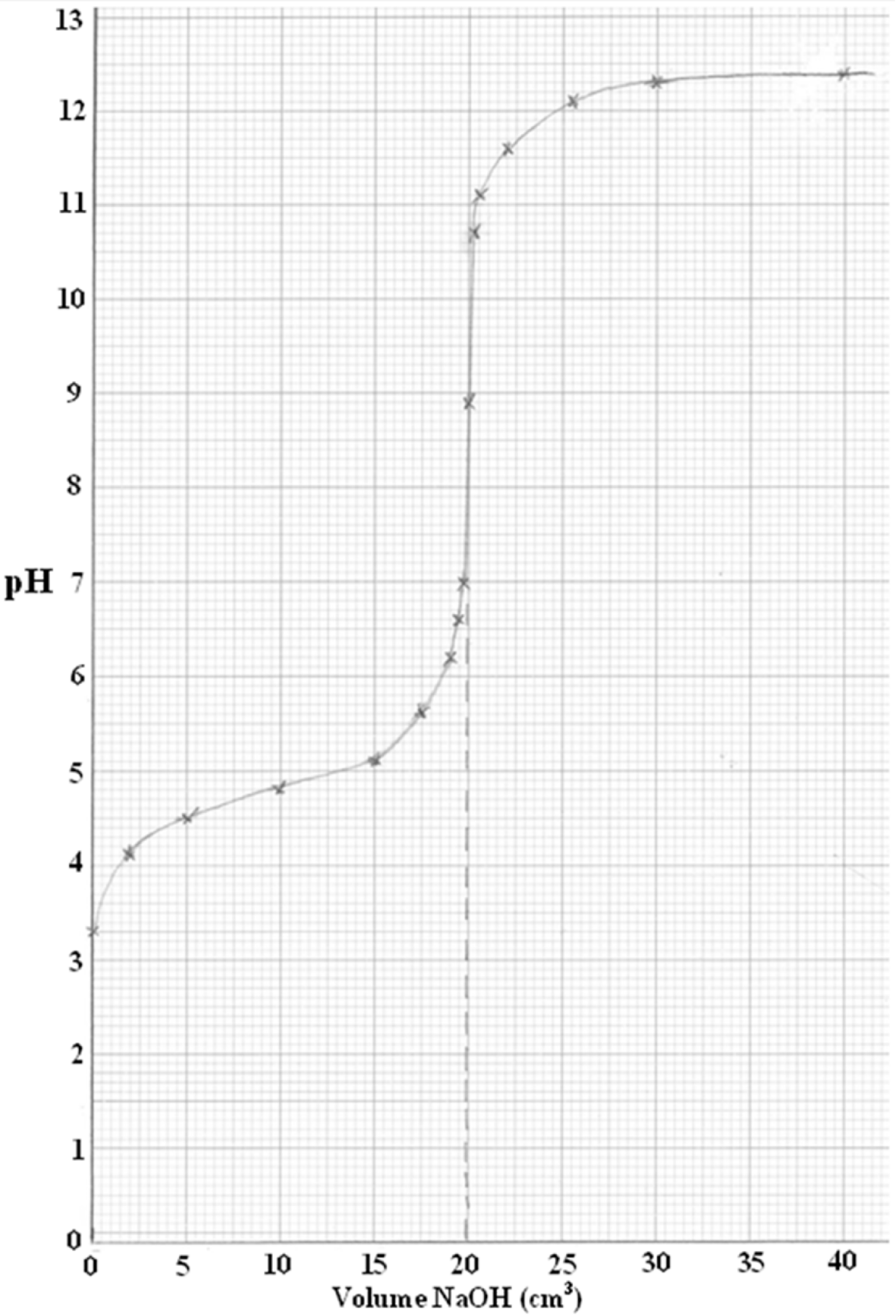
(*ii*) MAKE USE: **20 cm^3** (3)

(*e*) WHAT: **phenolphthalein / thymol blue / cresol purple / thymolphthalein** **(6)**

REFER: **range** of phenolphthalein **coincides with vertical part of graph** / **range (8 -10) within pH jump** / phenolphthalein **changes colour corresponding to steep (vertical) part of graph /** phenolphthalein **changes colour within (coinciding with) pH jump** at end point / phenolphthalein **has one colour at pH = 8 (7, 6, before neutralisation, before vertical part of graph) and another at (after) pH = 10 (11, after neutralisation, after vertical part of graph)** **(2)**

[K_a (K_{In}, pK_a, pK_{In}) value of phenolphthalein acceptable for (4).]

[REFER marks available only if WHAT marks awarded.]


pH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
0
5
10
15
20
25
30
35
40
Volume NaOH (cm³)

Question 5

QUESTION 9

(*a*) DEFINE: (*i*) **proton (H^+) acceptor //**
(*ii*) two species that **differ by a proton (H^+)** (2 × 3)
[Examples insufficient on their own.]

WHAT: **H_3O^+ / hydronium ion** (3)

(*b*) DEFINE: pH = **$-\log_{10}$ [H^+]** / **$-\log_{10}$ [H_3O^+]** / **minus log** base 10 **hydrogen ion concentration** expressed in moles per litre (3)

ACCOUNT: [Allow *'hydrochloric'* for HCl, *'sulfuric' for* H_2SO_4 and *'methanoic'* for HCOOH. Allow *H^+, proton, H_3O^+* or *hydronium ion* for*' hydrogen ion'*.]

(*i*) & (*ii*) First (9) marks available from **one** of the boxes below.

RELEVANT HCl information
0.10 M **HCl produces 0.10** M **H^+** ion **/ pH HCl = –log (0.10)** (6)
or
HCl monoprotic (monobasic) / one molecule **HCl produces one H^+** ion **//**
HCl is **strong (fully dissociated** into H^+ ions, **a good proton donor)** (2 × 3)
and
RELEVANT H_2SO_4 information
0.10 M **H_2SO_4 produces 0.20** M **H^+** ion **/**
pH H_2SO_4 = –log (0.20) /
H_2SO_4 diprotic (dibasic) /
one molecule **H_2SO_4 produces two H^+** ions **/**
H_2SO_4 produces (has) more (twice as many) H^+ ions as HCl (3)

or

RELEVANT H_2SO_4 information
0.10 M **H_2SO_4 produces 0.20** M **H^+** ion **/ pH H_2SO_4 = –log (0.20)** (6)
or
H_2SO_4 diprotic (dibasic) /
one molecule **H_2SO_4 produces two H^+** ions **/**
H_2SO_4 produces (has) more (twice as many) H^+ ions as HCl (3)
and
RELEVANT HCl information
0.10 M **HCl produces 0.10** M **H^+** ion **/ pH HCl = –log (0.10)** (3)

and

RELEVANT HCOOH information
0.10 M **methanoic acid** (**HCOOH**) solution **produces 4.27 × 10^{-3}** M **(less than 0.10** M**) H^+** ion **/**
pH HCOOH = inverse log (–2.37) {antilog (–2.37)} /
HCOOH is **weak {slightly (not fully) dissociated** into H^+ ions, **a poor proton donor} /**
HCOOH weaker than HCl (3)

USE: (*iii*) K_a = **1.8**2 **× 10^{-4}** (6)

[H$^+$] = **inverse log (–2.37) */ antilog (–2.37)* / 4.27 × 10^{-3} / 10$^{-2.37}$** (3)
***Omission of minus loses this (3)**

$\Rightarrow K_a = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]} \left(\frac{[\mathrm{H^+}]^2}{[\mathrm{HA}]}, \frac{[\mathrm{H^+}]^2}{[0.1]} \right)$ /
[H$^+$] = $\sqrt{K_a[\mathrm{HA}]}$ / 4.27 × 10^{-3} = $\sqrt{K_a[0.1]}$ / [H$^+$]^2 = $K_a[\mathrm{HA}]$ / (4.27 × 10^{-3})$^2 = K_a(0.1)$]

K_a = **1.8**2 **× 10^{-4}** (3)

[acid] = [HA] = [HX] = *M* = *M$_a$*

(*iv*) pH = **2.5**2 (3)

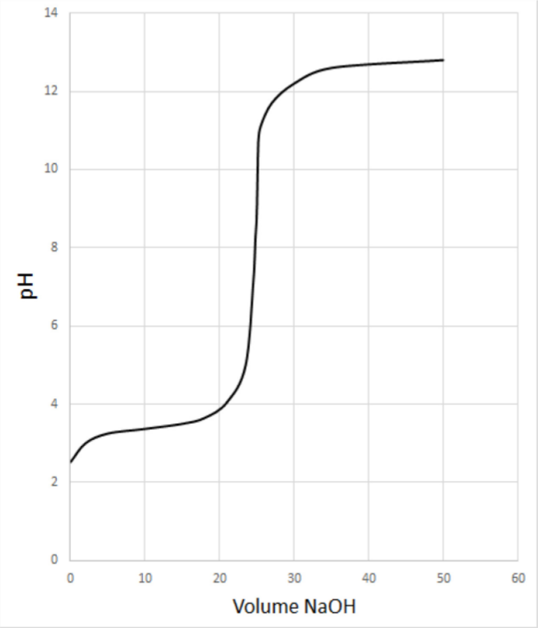
pH = –log $\sqrt{K_a[\mathrm{HA}]}$*****= –log $\sqrt{1.82 \times 10^{-4}[0.05]}$* = **2.5**2 (3)
***Omission of minus loses this (3)**

[acid] = [HA] = [HX] = *M* = *M$_a$*

(*c*) DRAW: **axes labelled (pH and volume) //**
curve of correct shape with steep rise at 25 cm^3 **//**
vertical part mostly above pH = 7 //
steep rise coincides with 25 cm^3 NaOH

ANY THREE: (3 × 3)

[Allow correct work with volume scale increasing from right to left or pH decreasing on *y*-axis towards 0.]
[Allow volume on *y*-axis.]



NAME: **phenolphthalein** (6)

EXPLAIN: **colour change (**indicator **range) coincides with sharp rise on graph / colour change occurs > 7 /colour change occurs between 7 and 10 /** indicator **range** is **8.**3 **– 10** **(2)**
[NAME and EXPLAIN linked]

Question 6

(*b*) WHAT: substance that **dissociates into OH$^-$ (hydroxyl ions, hydroxide ions) in water (aqueous solution) /** substance that **produces OH$^-$ (hydroxyl ions, hydroxide ions) in water (aqueous solution) /** substance that **increases concentration of OH$^-$ (hydroxyl ions, hydroxide ions) in aqueous solution** (3)

WHY: NH_3 **accepts a proton (H$^+$)** (3)
[Allow '*ammonia (NH_3) accepts protons*'.]

CALCULATE: (*i*) pH = **0.3**0 (3)

pH= –log [H$^+$] = –log 0.50 = **0.3**0 (3)

[–0.3 loses this (3).]

(*ii*) pH = **2.5**2 (6)

pH = –log$\sqrt{K_a[\text{HA}]}$ **/ pH = –log**$\sqrt{1.8 \times 10^{-5} \times 0.50}$ (3)

pH = **2.5**2 (3)

[–2.52 loses this (3).] [acid] = [HA] = [HX] = *M* = *M$_a$*

WHICH : **ethanoic** acid **/ CH_3COOH** (3)

STATE: initial **pH is 2.5**2 **/** starts at **2.5**2 **/** initial **pH is not** 0.30 **/** does **not** start at 0**.3 //**
vertical part (steep rise) of graph is mostly **above** pH = **7 (between 7 and 11) //**
buffering (no pH rise) between 12 and 35 cm^3 NaOH added ANY TWO: (3 + **1**)
[STATE marks only available if WHICH marks awarded.]

WHAT: **changes colour (pH range) between** pH = **6 (7, 8) and** pH = **9 (10, 11) /**
colour change (pH range of indicator**) coincides with steep (vertical) part of graph /**
does not change colour before pH = **6 (7, 8)** (3)

Question 7

QUESTION 9

(*a*) DEFINE: pH = **$-\log_{10}[H^+]$ /** pH = **$-\log_{10}[H_3O^+]$ /**
minus log base 10 **hydrogen ion concentration** expressed **in moles per litre**
[Deduct 1 for brackets not square.]

WRITE: K_w = **$[H_3O^+][OH^-]$ /** K_w = **$[H^+][OH^-]$**
[Deduct 1 for brackets not square.]

[6 + 2]

(*b*) STATE: **only** for **aqueous solutions /**
only for **dilute solutions /**
not effective (reliable, accurate, suitable) in **concentrated solutions /**
temperature dependent (pH scale 0 - 14 only at **25 °C)** (6)

(*c*) CALCULATE:

(*i*) $[H_3O^+]$ = **$2.2 \times 10^{-6} - 2.24 \times 10^{-6}$** moles per litre (6)

$[H_3O^+]$ = **inverse log (-5.65) /** $[H_3O^+]$ **= antilog(-5.65) /** $[H_3O^+]$ = **$10^{-5.65}$** (3)

$\Rightarrow$ $[H_3O^+]$ = **$2.2 \times 10^{-6} - 2.24 \times 10^{-6}$** moles per litre (3)

(*ii*) $[OH^-]$ = **$4 \times 10^{-9} - 5 \times 10^{-9}$** moles per litre (6)

$K_w = [H_3O^+][OH^-]$ / $K_w = 2.2 \times 10^{-6}\,[OH^-]$
$\Rightarrow$ $[OH^-]$ **= $1.0 \times 10^{-14} \div 2.2 \times 10^{-6}$** (3)
= $4 \times 10^{-9} - 5 \times 10^{-9}$ moles per litre (3)

or

pOH = 14 – 5.65 = **8.35** (3)

$[OH^-]$ = inverse log (-8.35) / $[OH^-]$ = antilog(-8.35) / $[OH^-] = 10^{-8.35}$

$\Rightarrow$ $[OH^-]$ = **$4 \times 10^{-9} - 5 \times 10^{-9}$** moles per litre (3)

(*d*) (*i*) WHAT: **20**.0 cm^3 (3)

(*ii*) DEDUCE: A: **1**.0 M
B: 0.**5** M
C: **1**.0 M
D: **1**.0 M (4 × 3)
[Take order of the question unless responses are clearly labelled.]

(*iii*) WHICH: **C** (3)

JUSTIFY: **lower initial pH (D has higher initial pH, greater initial H^+ concentration,**
$[H^+]$ higher initially) / from graph **1.8 – 1.9 < 2.2 – 2.3 /**
***Ka* of C > *Ka* of D shown by calculation using pH = $-\log\sqrt{Ka[\text{acid}]}$ /**
first part of **C** curve **below D** curve **/**
C curve **becomes steep (vertical) first /**
C has longer vertical part to its pH curve **/**
C curve **closer to** strong **A** curve (3)
[JUSTIFY marks only available if WHICH marks awarded.]

(*iv*) WHAT: **CH_3COO^-** (3)

Question 8

QUESTION 7

(*a*) (*i*) DEFINE: **proton (hydrogen ion, H^+) donor** (3)

(*ii*) WHAT: is a **good proton (H^+) donor /** has a **weak conjugate base / fully dissociated /** has **large (complete) degree of dissociation** into ions **/ K_a value large** (3)

(*iii*) IDENTIFY: **OCl^-** (3)

(*iv*) IDENTIFY: **H_2SO_4** (3)

(*b*) CALCULATE: (*i*) pH = **1.1** (6)

$[H^+]$ = 0**.08**	(2)
pH = **– $\log_{10}[H^+]$ /** pH = **– $\log_{10}[H_3O^+]$**	(2)
pH = **1.1**	(2)

CALCULATE: (*ii*) pH = **4.5** (6)

pH = **$-\log\sqrt{K_a[HA]}$ (**pH = **$-\log\sqrt{1.2\times10^{-9}}$,** pH = **$-\log(3.5\times10^{-5})$)**	(3)
pH = **4.5**	(3)

Question 9

QUESTION 7

(*a*) DEFINE: (*i*) **dissociates in water (aqueous solution) //**
to produce protons (hydrogen ions, H^+) (2 × 2)
[Allow H_3O^+ (hydronium ions)]

(*ii*) **proton (hydrogen ion, H^+) donor** (4)

(*iii*) STATE: **protons (H^+** ions**) do not exist** alone in solution **/**
protons (H^+ ions**)** from dissociation **donated (become attached, transferred)**
to water (some other species) /
protons (H^+ ions**) become H_3O^+ (hydronium ions) /**
water must always be **involved** (theory **confined to aqueous solutions) /**
NH_3 can**not** be considered **a base /**
water can**not** be considered **amphoteric (amphoteric substances not explained)** (6)

(*iv*) WHAT: two species (two substances, an acid and a base) that **differ by a proton (H^+) /**
base accepts proton to become its conjugate acid /
acid donates proton to become its conjugate base (3)

(*b*) DISTINGUISH: **greater the tendency of** an **acid to donate protons (more** the **acid**
tends to dissociate into ions) the stronger it is /
less the tendency of an **acid to donate protons (less** the **acid**
tends to dissociate into ions) the weaker it is (6)

or

strong *acid:*
is a **good proton (H^+) donor /** has a **weak conjugate base / fully dissociated /**
has **large (complete) degree of dissociation** into ions **/ K_a value large //**

weak *acid*:
is a **poor proton (H^+) donor /** has a **strong conjugate base /**
dissociated into ions **to small extent / slightly* dissociated / K_a value small**
(2 × 3)

[*Accept **weak** acid only **partly dissociated.**]

(*c*) WRITE: $\mathbf{HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+}$
FORMULAE: (3) BALANCING: (3)
[non equilibrium arrow acceptable here]

(*d*) (*i*) WRITE: $\mathbf{HA + H_2O \rightleftharpoons H_3O^+ + A^-}$ FORMULAE: (3) BALANCING: (3)
[non equilibrium arrow unacceptable….(–1)]

(*ii*) FIND: $[H_3O^+] = [A^-]$ = **1.5×10^{-3} (3/2000, 0.0015)** M (3)

> $[H_3O^+] = [A^-]$
>
> 1.5% of 0.1 = **1.5×10^{-3} (3/2000, 0.0015)** M (3)

(*iii*) CALCULATE: pH = **2.8**2 (6)

pH = **– log$_{10}$[H$^+$] /** pH = **– log$_{10}$[H$_3$O$^+$] /** pH = **– log$_{10}$(1.5 × 10^{-3})** (3)

pH = **2.8**2 (3)

(*iv*) CALCULATE: K_a = **2.25 × 10^{-5} – 2.55 × 10^{-5}** (6)

K_a = $\frac{[\mathbf{H_3O^+}][\mathbf{A^-}]}{[\mathbf{HA}]}$ / Allow K_a = $\frac{[\mathbf{H^+}][\mathbf{A^-}]}{[\mathbf{HA}]}$ (3)

$= \frac{(1.5\times10^{-3})^2}{0.10}$ = **2.25 × 10^{-5}** (3)

or

pH = –log$\sqrt{K_a[\mathrm{HA}]}$ / antilog(– pH) = $\sqrt{K_a[\mathrm{HA}]}$ /
2.82 **= –log$\sqrt{K_a[\mathrm{HA}]}$ / antilog(–2.8**2**) = $\sqrt{K_a[\mathrm{HA}]}$ / 10$^{-2.82}$ = $\sqrt{K_a[\mathrm{HA}]}$ /**
2.82 **= –log$\sqrt{K_a[0.10]}$ / antilog(–2.8**2**) = $\sqrt{K_a[0.10]}$ / 10$^{-2.82}$ = $\sqrt{K_a[0.10]}$ /**

[H$_3$O$^+$] = $\sqrt{K_a[\mathrm{HA}]}$ / 1.5 × 10^{-3} = $\sqrt{K_a[\mathrm{HA}]}$ / Allow **[H$^+$] = $\sqrt{K_a[\mathrm{HA}]}$ /**
[H$_3$O$^+$] = $\sqrt{K_a[0.10]}$ / 1.5 × 10^{-3} = $\sqrt{K_a[0.10]}$ / Allow **[H$^+$] = $\sqrt{K_a[\mathrm{HA}]}$** (3)

2.29 × 10^{-6} = K_a × 0.10
⇒ K_a = **2.25 × 10^{-5} – 2.51 × 10^{-5}** (3)

Accept [HA] after dissociation taken as 0.10 – 1.5 × 10^{-3} = 0.0985 M

Question 10

a	b	c	d	e	f
8	6	6	12	6	12

(*a*) WHAT: **proton (H^+) donor** (4)

HOW: **greater the tendency of** an **acid to donate protons (more** the **acid tends to dissociate into ions) the stronger it is /**
less the tendency of an **acid to donate protons (less** the **acid tends to dissociate into ions) the weaker it is** (4)

or

strong *acid:*
is a good proton (H^+) donor / has a **weak conjugate base /**
has **large (complete) degree of dissociation** into ions **/ K_a value large //**

weak *acid*:
is a **poor proton (H^+) donor /** has a **strong conjugate base /**
dissociated into ions **to small extent / slightly (**only **partly) dissociated / K_a value small**
(2 × 2)

(*b*) WHAT IS: (*i*) **H_2SO_4** (3)

(*ii*) **SO_4^{2-}** (3)

(*c*) DESCRIBE: **add (mix) barium chloride ($BaCl_2$)** solution dropwise to (with) few cm^3 of sample (water) in test-tube **//**
white (cloudiness, precipitate, solid) insoluble in HCl (remains after addition of HCl) when sulfate present (positive result) (2 × 3)

(*d*) CALCULATE:

(*i*) $[H_3O^+]$ = **2.5×10^{-6} – 2.512×10^{-6}** moles per litre (6)

$[H_3O^+]$ = **inverse log(–5.6) /** $[H_3O^+]$ = **antilog(–5.6) /** $[H_3O^+]$ = **$10^{-5.6}$** (3)

⇒ $[H_3O^+]$ = **2.5**119 **× 10^{-6}** moles per litre (3) (*ii*) $[\mathrm{OH}^-] = \mathbf{1.58 \times 10^{-7} - 1.6 \times 10^{-7}}$ moles per litre (6)

pOH = 14 – 7.2 = **6.8** (3)

$[\mathrm{OH}^-]$ = inverse log (–6.8) / $[\mathrm{OH}^-]$ = antilog(–6.8) / $[\mathrm{OH}^-] = 10^{-6.8}$

$\Rightarrow$ $[\mathrm{OH}^-] = \mathbf{1.58 \times 10^{-7} - 1.6 \times 10^{-7}}$ moles per litre (3)

or

$[\mathrm{H_3O^+}]$ = inverse log (–7.2) / $[\mathrm{H_3O^+}]$ = antilog(–7.2) / $[\mathrm{H_3O^+}] = 10^{-7.2}$

$[\mathrm{H_3O^+}] = \mathbf{6.31 \times 10^{-8}}$ (3)
$\Rightarrow$ $[\mathrm{OH}^-] = 1.0 \times 10^{-14} \div 6.31 \times 10^{-8} = \mathbf{1.58 \times 10^{-7} - 1.6 \times 10^{-7}}$ moles per litre (3)

(*e*) CALCULATE:

pH = **3.1 – 3.12** (6)

pH = –log$\sqrt{K_a[\mathrm{HA}]}$ / pH = –log$\sqrt{(4.0 \times 10^{-4}) \times (1.5 \times 10^{-3})}$ (3)

pH = **3.1 – 3.12** (3)

[negative answer is not a slip error here]
[HA] = [HX] = *M* = M_a = [acid] =[indicator]

(*f*) (*i*) WRITE: **$\mathrm{HA + H_2O \rightleftharpoons H_3O^+ + A^-}$** (3)
[Do not penalise if equilibrium arrow not used]

(*ii*) WHAT: **yellow (orange)** colour observed **/** red changes to **yellow (orange) / yellow (orange)** colour intensifies **/ colour of $\mathbf{A^-}$** observed (3)

EXPLAIN: **$\mathbf{H_3O^+}$ ($\mathbf{H^+}$) ions removed** by $\mathrm{OH^-}$ ions of base to form water **/ $\mathbf{H_3O^+ + OH^-}$** $\rightarrow$ 2**$\mathbf{H_2O}$ /**
$\mathbf{H^+ + OH^-}$ $\rightarrow$ **$\mathbf{H_2O}$ / lower** **$\mathbf{[H^+]}$ / lower $\mathbf{[H_3O^+]}$ //**
equilibrium (reaction) moves to right (products, yellow side) /
more $\mathbf{A^-}$ at new **equilibrium** (2 × 3)
[WHAT must be correct for EXPLAIN to be awarded marks.]

Question 11

QUESTION 7

(*a*) DISTING: *strong acid*: **good proton (H^+) donor / readily donates proton (H^+) //**
weak acid: **poor (weak) proton donor** **(5 + 3)**
[‘Does not readily donate a proton’ or references to dissociation not acceptable and cancellation applies.]

(*b*) IDENTIFY: $\mathbf{H_2O}$ **//** $\mathbf{NO_2^-}$ (2 × 3)

(*c*) DEFINE: $\mathbf{-\log_{10}[H^+]}$ **/** $\mathbf{-\log_{10}[H_3O^+]}$ (3)
[Square brackets essential.][Mathematical definition expressed in words is acceptable.]

CALCULATE: **0.01** M (3)

$[H_3O^+]$ = inverse $\log_{10}(-2)$ = **0.01** M (3)

EXPLAIN: **concentration of hydronium (hydrogen) ions {$[H_3O^+]$, $[H^+]$} lower** than 0.2 M /

small (low, 5%) level of **dissociation** (only **slightly dissociated (ionised), almost undissociated, only 0.01 M dissociated)** /

a strong monobasic **acid with concentration 0.2 M would have a concentration of hydronium (hydrogen) ions {$[H_3O^+]$, $[H^+]$} = 0.2** /

a strong monobasic acid with concentration 0.2 M would have a pH = 0.7 /

$\boldsymbol{K_a}$ **of nitrous acid** from data supplied is **only** $[0.01]^2 \div [0.2]$ = $\mathbf{5 \times 10^{-4}}$ and is consistent with weak acid
(3)

WHAT: **0.01** M (3)

CALCULATE: 1 × $\mathbf{10^{-12}}$ M (6)

$\mathbf{[H_3O^+][OH^-] = 1 \times 10^{-14}}$ (3)
$[OH^-]$ = $1 \times 10^{-14} \div 0.01$ = 1 × $\mathbf{10^{-12}}$ M (3)

pH + pOH = 14 / pOH = 12 (3)
$[OH^-]$ = inverse $\log_{10}(-12)$ = 1 × $\mathbf{10^{-12}}$ M (3)

(*e*) EXPLAIN: causes **rapid growth of** water **plants (algae)** / causes **algal blooms //**
decay of these plants **by** aerobic **microorganisms (bacteria, decomposers) /**
respiration by decomposers (bacteria, microorganisms) of these plants uses up oxygen /
surface plants block light **preventing (reducing) photosynthesis** (2 × 3)

Question 12

(b) DEFINE: **proton (hydrogen ion, H^+) donor**

WHAT: acid and base that **differ by a proton (hydrogen ion, H^+)** (4 + 3)

STATE: **purple //**

EXPLAIN: **hydroxyl (hydroxide) ions (OH^-) remove hydrogen ions (H^+) causing the reaction (equilibrium) to shift forward (to the right)** (2 × 3)

CALC: *(i)* pH =**13.7** (6)

$pOH = -\log 0.5 = \mathbf{0.3}$ (3)
$pH = 14 - 0.3 = \mathbf{13.7}$ (3)

$[H^+] = 10^{-14} \div 0.5 = \mathbf{2 \times 10^{-14}}$ (3)
$pH = -\log 2 \times 10^{-14} = \mathbf{13.7}$ (3)

(ii) pH =**2.85** (6)

$pH = -\log\sqrt{\mathbf{2.0 \times 10^{-5} \times 0.1}}$ (3)
$= \mathbf{2.85}$ (3)

$[H^+] = \sqrt{\mathbf{2.0 \times 10^{-5} \times 0.1}}$ (3)
$pH = -\log [H^+] = \mathbf{2.85}$ (3)

Question 13

QUESTION 7

(a) (i) *acid*: **proton (hydrogen ion, H^+) donor** (4)

(ii) *conjugate pair*: acid & base that **differ by a proton (hydrogen ion, H^+)** (4)

IDENTIFY: **HNO_2 & NO_2^- // H_2O & H_3O^+** (2 x 3)

DISTING: *strong*: **good proton donor / completely (high) dissoc.** into ions in dil. aq.soln. (3)

weak: **poor proton donor / slightly (low) dissoc.** into ions in dil. aq. soln. (3)
[Accept "does not readily dissoc." but not "does not completely (fully) dissoc."]

(b) CALC: *pH* = **2.15** [or answers that give 2.15 when corrected to two decimal places.] (9)

$pH = -\log\sqrt{K_a \times M}$ (3)
$= -\log\sqrt{5 \times 10^{-4} \times 0.1}$ (3)
$= 2.15$ (3)

$K_a = \dfrac{[H^+][NO_2^-]}{[HNO_2]} = \dfrac{[H^+]^2}{0.1} = 5 \times 10^{-4}$
$[H^+]^2 = 5 \times 10^{-5}$ (3)
$[H^+] = 0.007$ (3)
$pH = 2.15$ (3)

WHAT: **1** (6)

$pH = -\log [H^+] = -\log [0.1$ (3)
$= 1$ (3)

Question 14

QUESTION 8

(a) DEFINE: (i) *acid*: **proton (hydrogen ion, H^+) donor** (4)
(ii) *base*: **proton (hydrogen ion, H^+) acceptor** (4)

(b) IDENTIFY: **acid** (3) **its conjugate base** (3)

acid = H_2F^+ (3) its conjugate base = HF (3)
acid = HCl (3) its conjugate base = Cl^- (3)

[If not specified as acid and conjugate base, take the order in the question to be the intended order. Accept if indicated correctly on the equation.]

(c) CALCULATE: **3.22** / **3.2** (12)

pH = $-\log\sqrt{K_a \times M}$ (3)

pH = $-\log\sqrt{1.8 \times 10^{-4} \times 0.002}$ / $-\log\sqrt{3.6 \times 10^{-7}}$ / $-\log 0.0006$ / $-\log 6 \times 10^{-4}$ (3)

pH = 3.22 (6)

OR

$[H^+]^2$ = $K_a.M$ / $1.8 \times 10^{-4} \times 0.002$ / 3.6×10^{-7} (3)*

$[H^+]$ = $\sqrt{1.8 \times 10^{-4} \times 0.002}$ / $\sqrt{3.6 \times 10^{-7}}$ / 0.0006 / 6×10^{-4} (3)*

pH = 3.22 (6)

*$[H^+]^2$ and $[H^+]$ are required in the case of these marks.

Question 15

(a) (i) **proton donor / donor of hydrogen ions (H^+)** (4)

(ii) **proton acceptor / acceptor of hydrogen ions (H^+)** (4)

Identify: **H_2S** (3) **OH^-** (3)

Note: both are acids; both are also conjugate acids. Therefore, the order does not matter.

(b) pH = **$-\log_{10}[H^+]$ / $-\log_{10}[H_3O^+]$ / negative log** to base ten **of hydrogen (hydronium) ion concentration** (6)

Calc: pH = **2.37 – 2.4** (12)

6 % (w/v) = 6 g in 100 cm^3 = 60 g l^{-1} (3)
60 g l^{-1} ÷ 60 = 1 mol l^{-1} (3)
$[H^+]^2 = 1.8 \times 10^{-5}$ / $[H^+] = \sqrt{1.8 \times 10^{-5}}$ / 0.0042 (3)
$pH = -\log [H^+] = -\log\sqrt{1.8 \times 10^{-5}} = 2.37 - 2.4$ (3)

OR

6 % (w/v) = 6 g in 100 cm^3 = 60 g l^{-1} (3)
60 g l^{-1} ÷ 60 = 1 mol l^{-1} (3)
$pH = -\log \sqrt{K_a \times M}$ / $-\log \sqrt{1.8 \times 10^{-5} \times 1}$ (3)
$= -\log\sqrt{1.8 \times 10^{-5}} = 2.37 - 2.4$ (3)

For second (3) use the number coming from the first point even if that number is 6. However, division by a number other than 60 loses this (3) unless there is clear evidence of a slip.

As above.

Question 16

(a) (i) *strong*: almost **completely dissociated to give hydrogen ions (H^+)** in solution //
[*Accept 'readily,' 'fully' for 'completely'*.]

weak: only **slightly dissociated to give hydrogen ions (H^+)** in solution (2 × 3)
[*Accept 'partially' for 'slightly.' Do not accept 'not fully' for 'slightly.'*]

(ii) *strong*: **good proton (hydrogen ion, H^+) donor** //
weak: **poor proton (hydrogen ion, H^+) donor** (2 × 3)

(b) (i) *sulfuric acid*: **HSO_4^-** (3)

(ii) *HA*: **A^-** (3)

WHICH: **A^- / conjugate** base **of weak acid** (3)

EXPL: **conjugate** base **of weak acid / weak acids (HA) exist(s) in undissociated (associated, unionised, molecular) form** in water / **A^- more likely to accept a proton / strong acids (H_2SO_4) remain dissociated (ionised)** in water (3)

(c) EXPL: **$HSO_4^- + H_2O \rightarrow SO_4^{2-} + H_3O^+$** (6)

[*If incomplete, mark as:* $HSO_4^- \rightarrow SO_4^{2-}$ // $H_2O \rightarrow H_3O^+$ (2 × 3)]

(d) DEF: **minus log (negative log)** to base 10 **of hydrogen (hydronium) ion concentration /**

$$-\log_{10}[H^+] \ / -\log_{10}[H_3O^+] \ / \ \log_{10}\frac{1}{[H^+]} \ / \ \log_{10}\frac{1}{[H_3O^+]}$$ (6)

CALC: pH = **2.45** (9)

$K_a = \frac{[H^+][A^-]}{[HA]} \ / \ \frac{[H^+]^2}{0.2} = 6.3 \times 10^{-5}$ / $[H^+]^2 = 1.26 \times 10^{-5}$ (3)

$\Rightarrow$ **$[H^+]$ = 3.5×10^{-3}** (3)

$\Rightarrow$ pH = **2.45** (3)

or

pH = $-\log_{10}\sqrt{K_a[M]}$
= $-\log_{10}\sqrt{[6.3 \times 10^{-5}].[0.2]}$
pH = 2.45

$[H^+]$ = $\sqrt{K_a[M]}$
= $\sqrt{[6.3 \times 10^{-5}].[0.2]}$
pH = 2.45

CONC: **1.75×10^{-3}** – **1.77×10^{-3}** (5)

$[H^+]$ / inv. log – pH / inv. log – 2.45 = 3.55×10^{-3} / 3.5×10^{-3} (3)

$\Rightarrow$ M = $3.55 \times 10^{-3} \div 2$ = **1.77×10^{-3} / 1.75×10^{-3}** (2)

Question 17

(2 × 3)

(b) DEFINE: *(i)* *Arrhenius*: dissociates to produce **hydroxyl (hydroxide) ions (OH^-) in aqueous solution (water)** //

(ii) *Brønsted-Lowry*: **proton (hydrogen ion, H^+) acceptor** (4 + 3)

GIVE: *(i)* $\mathbf{H_2PO_4^-}$ // *(ii)* $\mathbf{PO_4^{3-}}$ (2 × 3)

CALCULATE: **11.28 (11.3)** (12)

7 g of NH_4OH = 7 ÷ 35 = 0.2 mol ⇒ **0.2** M NH_4OH (3)

$[OH^-] = \sqrt{1.8 \times 10^{-5} \times 0.2}$ / 1.9×10^{-3} (3)

pOH = – log 1.9×10^{-3} = **2.72 (2.7)** (3)

pH = 14 – 2.72 (2.7) = **11.28 (11.3)** (3)

$[OH^-] = \sqrt{1.8 \times 10^{-5} \times 0.2}$ / 1.9×10^{-3} (3)

$[H^+] = \dfrac{1 \times 10^{-14}}{\sqrt{1.8 \times 10^{-5} \times 0.2}}$ / $\dfrac{1 \times 10^{-14}}{1.9 \times 10^{-3}}$ / 5.3×10^{-12} (3)

pH = – log 5.3×10^{-12} = **11.28 (11.3)** (3)

Question 18

QUESTION 8

(a) (i) WRITE: $\mathbf{2H_2O \rightleftharpoons H_3O^+ + OH^-}$ / $\mathbf{H_2O \rightleftharpoons H^+ + OH^-}$

[Accept with = or →] FORMULAS: (3) BALANCING: (2)

(ii) DEFINE: **$[H^+][OH^-]$ / $[H_3O^+][OH^-]$ / product of concentrations of hydrogen** ions **(H^+) and hydroxyl (hydroxide) ions (OH^-)** in water (3)

SHOW: in pure water = **$[H^+]$ ($[H_3O^+]$) = $[OH^-]$ / $[H^+]^2$ ($[H_3O^+]^2$) = 1×10^{-14}** (3)

=> **$[H^+]$ ($[H_3O^+]$) = $\sqrt{1 \times 10^{-14}}$ = 1×10^{-7}** (3)

pH = **$-\log 1 \times 10^{-7}$ = 7** [Accept without '1 ×'] (3)

(iii) STRONG: **0.3** (3)

$\boxed{\text{pH} = -\log 0.5 = 0.3 \quad (3)}$

WEAK: **2.52 (2.5)** (9)

$$\frac{[H^+]^2}{0.5} = 1.8 \times 10^{-5} \;/\; [H^+]^2 = 9.0 \times 10^{-6} \quad (3)$$

$$\Rightarrow [H^+] = \sqrt{9.0 \times 10^{-6}} = 3.0 \times 10^{-3} \quad (3)$$

$$\text{pH} = -\log 3.0 \times 10^{-3} = 2.52 \quad (3)$$

OR

$$\boxed{\text{pH} = -\log\sqrt{K_a \times M}\ (3) = -\log\sqrt{1.8 \times 10^{-5} \times 0.5}\ (3) \Rightarrow \text{pH} = 2.52\ (3)}$$

Question 19

(*a*) (*i*) DISTNG: *stong acid:* **good proton donor / readily donates protons /** almost **fully dissociated** //
weak acid: **poor proton donor / slightly (poorly, weakly) dissociated** (2 × 3)
[Allow *'Partly (partially, not fully) dissociated' and 'does not readily donate protons' for weak acid description.*]

(*ii*) CALCULATE: **0.005** M (6)

pH= –log [H⁺] ⇒[H⁺] = inverse log (–2) = **0.01** (3)

0.01 ÷ 2 (dibasic) = **0.005** M (3)

CALCULATE: **5/9 (0.556)** M [**0.55 – 0.56** M] (6)

pH= –log [H⁺] ⇒[H⁺] = inverse log (–2) = **0.01**

$\Rightarrow \boldsymbol{K_a}\ \mathbf{(1.8 \times 10^{-4}) = \frac{[H^+][A^-]}{[HA]} \left(\frac{[H^+]^2}{[HA]}, \frac{(0.01)^2}{[HA]} \right)}$ / $\mathbf{[HA] = \frac{(0.01)^2}{1.8 \times 10^{-4}}}$ / $\mathbf{[HA] = \frac{(0.01)^2}{\mathit{K}a}}$ /
$[H^+] = \sqrt{\boldsymbol{K}a[HA]}$ / $0.01 = \sqrt{\mathbf{1.8 \times 10^{-4}}[HA]}$ / $[H^+]^2 = \boldsymbol{K}a[HA]$ / $(0.01)^2 = \mathbf{1.8 \times 10^{-4}}[HA]$ (3)

[HA] = **= 5/9 (0.55555)** M **[0.5556 – 0.56** M**]** (3)

[acid] = [HA] = [HX] = *M* = M_a

(*iii*) DEFINE: K_w = **[H⁺][OH⁻]** / K_w = **[H₃O⁺][OH⁻] / product of molar concentrations of hydrogen (hydronium) ions (H⁺, H₃O⁺) and hydroxide (hydroxyl) ions (OH⁻) in water** (3)

WHAT: $\mathbf{3.0 \times 10^{-7}}$ M (4)

$K_w\ (9.0 \times 10^{-14}) = [H^+]^2$ / $[H^+] = \sqrt{K_w}$ $(\sqrt{9.0 \times 10^{-14}})$ / $[H^+] = [OH^-]$

⇒ $[H^+] = \mathbf{3.0 \times 10^{-7}}$ M **(4)**

Question 20

(*a*) USE: (*i*) **H_2O + HCl $\rightleftharpoons$ H_3O^+ + Cl^-** (3)

[Accept any style arrow, equals sign or equilibrium indicator.]

(*ii*) **H_2O + NH_3 $\rightleftharpoons$ NH_4^+ + OH^-**

[Accept any style arrow, equals sign or equilibrium indicator.] (3)

EXPLAIN: (*iii*) **strong acid / good proton donor / equilibrium lies on right / forward reaction favoured / Cl^- cannot readily accept protons / Cl^- poor proton acceptor**

[Accept 'fully dissociated'.]

(3)

(*iv*) **weak base / poor proton acceptor / equilibrium lies on left / reverse reaction favoured / NH_4^+ readily donates protons / NH_4^+ good proton donor**

[Accept 'not fully dissociated'.] (3)

(*b*) (*i*) WRITE: K_w = **$[H_3O^+][OH^-]$ / K_w = $[H^+][OH^-]$** (6)

[Allow 3 if $[H_2O]$ appears in expression]

[Deduct 3 for brackets not square.]

(*ii*) ARE: **endothermic** (3)

JUSTIFY: **more ions at higher temperature (when heated) / K_w bigger at higher temperature (when heated) / forward reaction favoured (equilibrium moves to the right) at higher temperature (when heated)**

[ARE and JUSTIFY linked.]

Temperature (°C)	K_w
0	0.1×10^{-14}
10	0.3×10^{-14}
20	0.7×10^{-14}
30	1.4×10^{-14}
40	2.9×10^{-14}
50	5.3×10^{-14}
60	9.3×10^{-14}

(*iii*) PLOT: A: **one axis labelled temperature (°C)** (3)

B: **appropriate correct numeric scales on both axes** (3)

C: careful **plotting of 7 points to give** smooth **curve** of correct shape (8)

[Deduct (1) in C for <u>each</u> of the following:
poor curve;
all pairs of points connected with straight lines;
graph not on graph paper.]
[Temperature *versus* K_w graph acceptable.]

(*iv*) USE: **2.3×10^{-14} [2.1×10^{-14} – 2.5×10^{-14}]** (6)

(*v*) USE: **1.51×10^{-7} [1.44×10^{-7} – 1.59×10^{-7}]** (3)

$[H^+] = \sqrt{K_w}$ / $[H^+] = \sqrt{2.3 \times 10^{-14}}$ ⇒

$[H^+]$ = **1.51×10^{-7}** (3)

(*vi*) FIND: **40** °C (3)

$[H^+]$ = **inverse log (–6.77) /** $[H^+]$ = **antilog(–6.77) /** $[H^+]$ = **$10^{-6.77}$ /** $[H^+]$ = **1.69×10^{-7} – 1.7×10^{-7}** (2)

$K_w = 2.9 \times 10^{-14}$ ⇒ **40** °C (1)

Accept for 3 marks trial and error testing by getting square root of K_w values and pH of corresponding $[H^+]$ values if correct temperature is deduced.