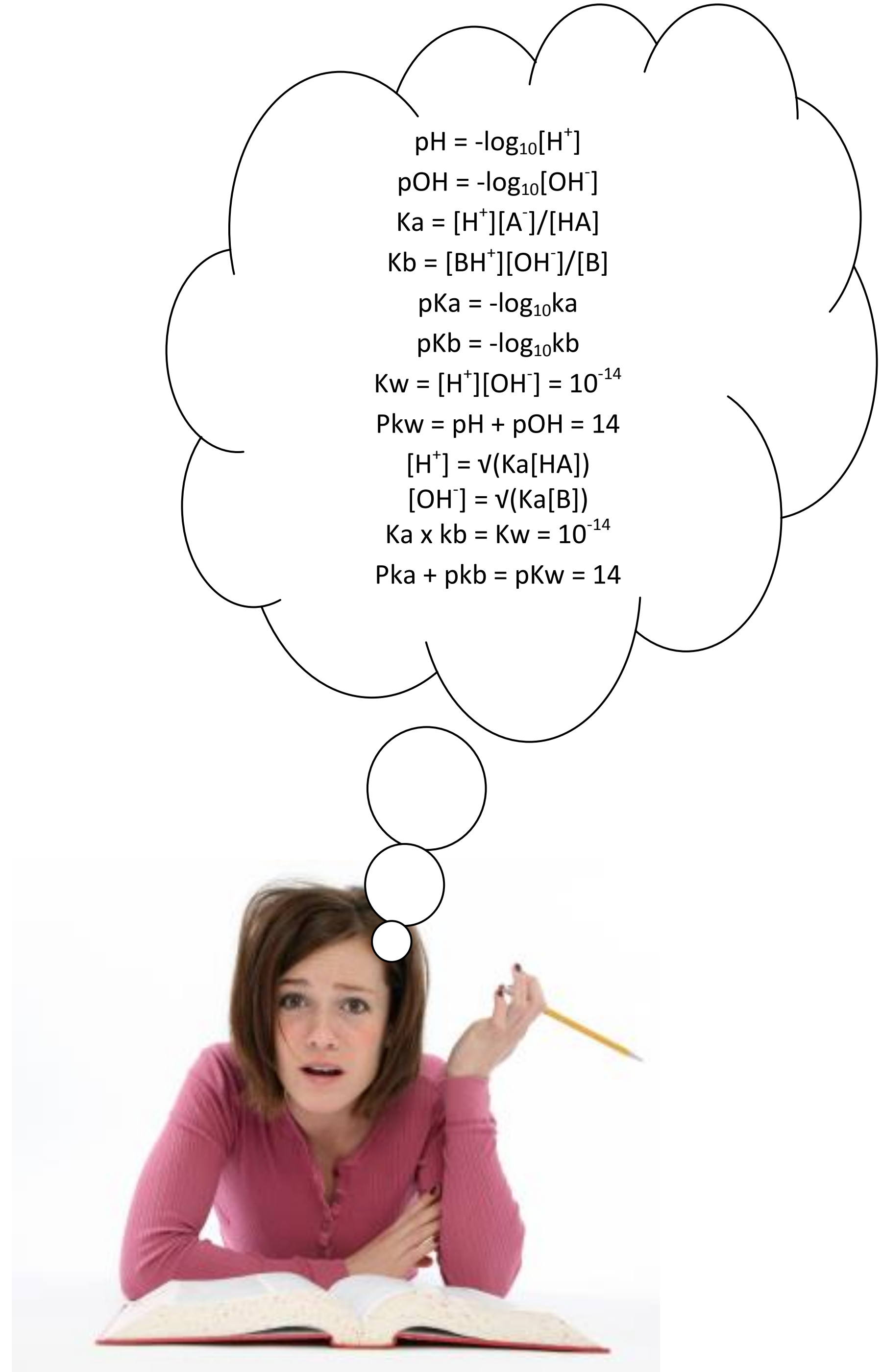
Acid-base equilibrium calculations are often identified by students and teachers as one of the most challenging A-level / IB Chemistry topics…

Why so hard?

- Involves use of **complicated mathematics** (including multistep calculations, logarithms and inverse logarithms- which are not included on the GCSE mathematics syllabus)
- **Information overload**: for IB HL most students have to learn and apply at least 10 mathematical equations (depending on their ability to rearrange / derive other equations)
- Requires students to understand and visualize understanding of **abstract concepts**.
- It is a **synoptic topic**- which draws on many other aspects of Chemistry (including: nature of matter, chemical equilibrium, chemical reaction, stoichiometry, and solutions)
- Requires learning on **multiple levels**: macroscopic, sub-microscopic and symbolic (*Johnstone 1991*)
- Students may have **fundamental misconceptions** (such as the difference between strength and concentration)



How will this approach help?

This resource was designed to make teaching and learning of this subject more effective and rewarding for both teachers and students.

- Fun (interaction and competition)
- Manageable (reduces need for rote memorization)
- Visual (helps students picture a route to solve problems)
- Differentiated (has questions ranging in the level of challenge)

Part 1

Students design an acid-base calculations map. The amount of information you give depends on the level of the students. As a minimum it would be useful to give the equations you would like them to use in at least one form. A template is included in this pack; followed by a complete version of the map. This map only applies to monoprotic acids and monobasic alkalkis.

Part 2

Students work individually and in teams to solve problems of increasing challenge. A points system is suggested in order to make the activity competitive and encourage students to challenge themselves.

Part 1: Design a map

Equations summary:

The following equations are all required for the map. You will also need to rearrange them to their appropriate forms for the map.

$[H^+] = [HA]$
$[OH^-] = [B]$

$pH = -\log_{10}[H^+]$
$pOH = -\log_{10}[OH^-]$

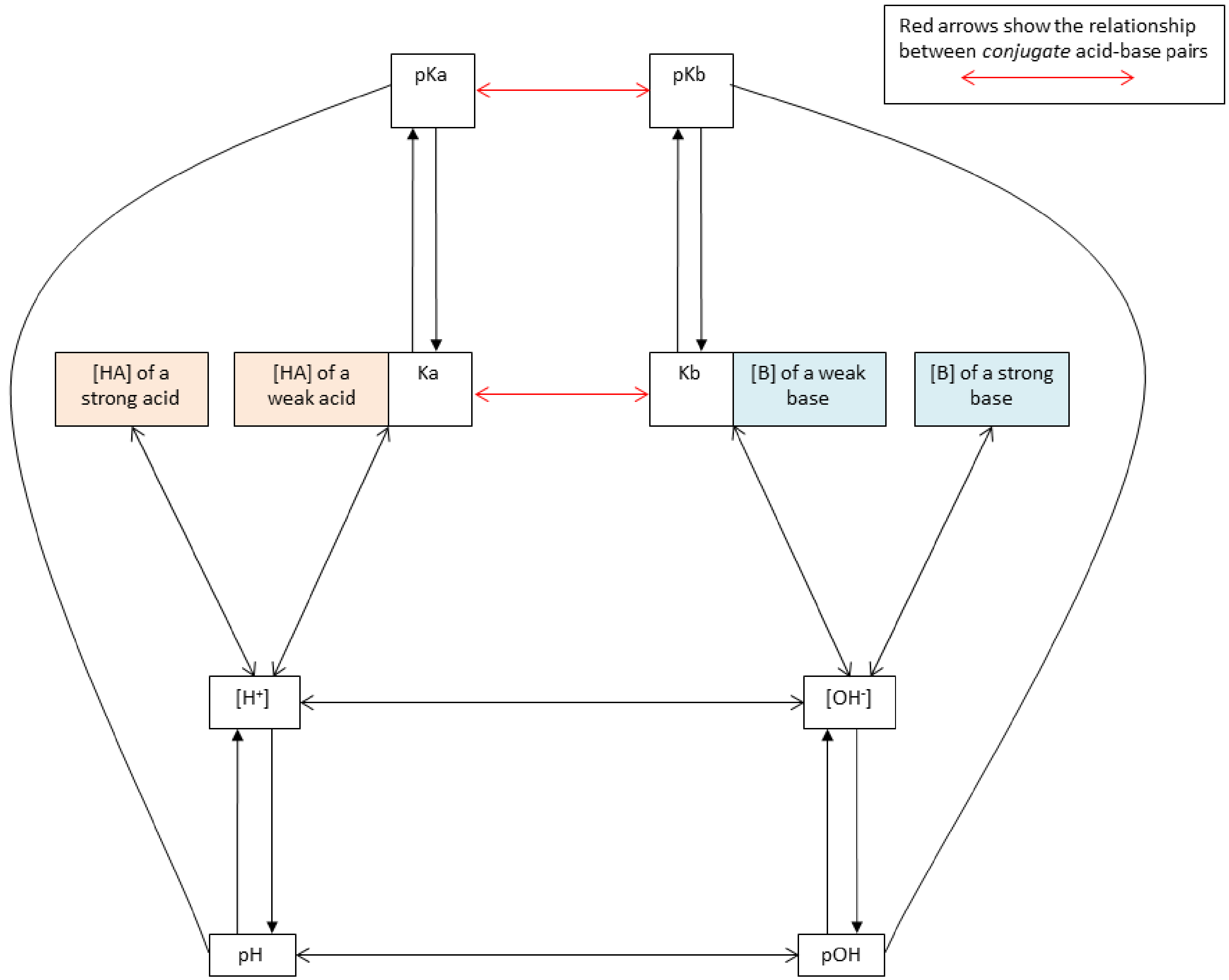
$pKa = -\log_{10}ka$
$pKb = -\log_{10}kb$

$[H^+][OH^-] = 10^{-14}$
$pH + pOH = 14$

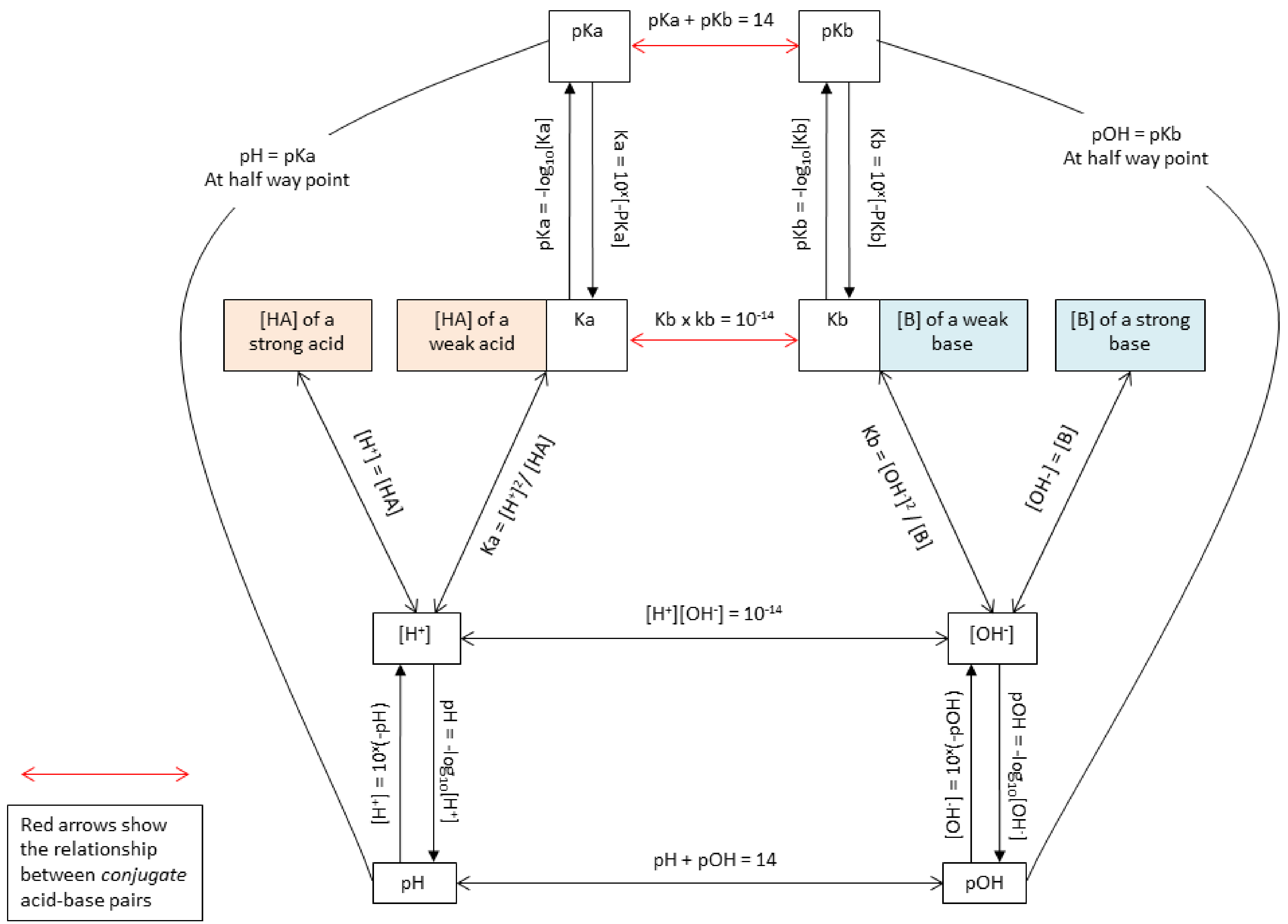
$Ka = [H^+]^2/[HA]$
$Kb = [OH^-]^2/[B]$

$Ka \times kb = 10^{-14}$
$Pka + pkb = 14$

pH = pKa at half way point
pOH = pKb at half way point



Acid-Base calculations map



Part 2: Question cards (pre-cut and clip in sets according to difficulty level):

Easy 1 point	Medium 2 points	Hard 3 points	Very hard 4 points
E1 What is the hydrogen ion concentration of a 2.2moldm^{-3} hydrochloric acid solution?	**M1** What is the pH of a 0.8moldm^{-3} solution of the strong acid nitric acid (HNO_3)?	**H1** What is the pH of a 3.5moldm^{-3} solution of ethanoic acid? Ethanoic acid has a pka of 4.75.	**VH1** 50cm^3 of 1moldm^{-3} NaOH is added to 100cm^3 of 1moldm^{-3} CH_3CH_2COOH and the pH of the solution was measured to be 4.8. Calculate the Ka of CH_3CH_2COOH.
E2 A solution of the strong acid $HClO_4$ has a hydrogen ion concentration of 1moldm^{-3}, what is the concentration of $HClO_4$ in this solution?	**M2** A solution of hydrochloric acid has a hydrogen ion concentration of 7.94 x 10^{-2} moldm^{-3}, what is the pOH of this solution?	**H2** A solution of HCN (pKa = 4.70) has a H^+ concentration of 0.002moldm^{-3}; determine the concentration of HCN in this solution.	**VH2** A 2.5moldm^{-3} solution of phenol (C_6H_5OH) has a hydrogen ion concentration of 1.67 x 10^{-5}moldm^{-3}. Determine the pKb of the phenolate ion ($C_6H_5O^-$).
E3 A sulphuric acid solution has a hydrogen ion concentration 0.32moldm^{-3} what is the pH of this solution?	**M3** What is the hydroxide ion concentration in a 0.5moldm^{-3} solution of the strong acid, nitric acid (HNO_3)?	**H3** Ammonia has a pKb of 4.76 calculate the pOH of a 0.5moldm^{-3} solution of ammonia.	**VH3** The weak acid hydrogen sulphide has a pKa of 7. What is the concentration of hydroxide ions in a 1.8moldm^{-3} solution of hydrogen sulphide?
E4 Benzoic acid has a Ka of 6.3 x 10^{-5}, what is the pKa of Benzoic acid?	**M4** A solution of a weak acid is found to contain a hydrogen ion concentration of 1.3 x 10^{-6}moldm^{-3}, determine the hydroxide ion concentration of this solution.	**H4** A solution of $NaHCO_3$ has an OH^- concentration of 1.5 x 10^{-3}moldm^{-3}, what is the concentration of $NaHCO_3$? The HCO_3^- has a pkb of 6.35	**VH4** The pKa of hydrofluoric acid is 3.17. What is the concentration of hydroxide ions in a 0.1moldm^{-3} solution of hydrofluoric acid?
E5 Citric acid has a Ka of 8.13 x 10^{-4}, what is the pKa of citric acid?	**M5** The carbonate ion has a pKb of 3.67, calculate the Kb of the carbonate ion.	**H5** A sample of rain water was found to have a pH of 5.2. What is the hydroxide ion concentration in this solution?	**VH5** A 0.25moldm^{-3} solution of methylamine (CH_3NH_2) has an OH^- concentration of 9.5 x 10^{-3}moldm^{-3}. Calculate the pKa of the methyl ammonium ion ($CH_3NH_3^+$).

E6 Hydrogen fluoride has a ka of 6.76 x 10^{-4} what is its pKa?	**M6** A solution of potassium hydroxide has a pOH of 1. What is the hydroxide ion concentration of this solution?	**H6** A weak acid has a hydroxide ion concentration of 1.5 x 10^{-9}moldm^{-3}. What is the pH of this solution?	**VH6** A solution of the weak base sodium ethanoate has a pH of 9 and a pKb of 9.25 what is the concentration of this solution?
E7 What is the hydrogen ion concentration [H^+] of a 0.5moldm^{-3} of the strong acid, hydrochloric acid?	**M7** What is the hydroxide ion concentration in a solution of dilute carbonic acid which has a pH of 6.5?	**H7** The pOH of a solution of drain cleaner is 2, calculate the hydrogen ion concentration in this solution.	**VH7** The pH of a 1.349 x 10^{-2} moldm^{-3} solution of the weak acid, carbonic acid (H_2CO_3) was found to be 6.1. What is the pKb of the hydrogen carbonate ion?
E8 The hydrogen ion concentration dilute vinegar is 1.3 x 10^{-6}. What is the pH of this solution?	**M8** What is the pOH of a 0.6moldm^{-3} solution of the strong base potassium hydroxide?	**H8** The ammonium ion (NH_4^+) is an acid with a Ka of 5.75 x 10^{-10}. What is the pKb of ammonia (NH_3)?	**VH8** The pKb of the hydrogen phosphate ion ($H_2PO_4^-$) is 11.88. What is the pH of a 0.75moldm^{-3} solution of phosphoric acid?
E9 What is the hydroxide ion concentration in a 2moldm^{-3} solution of sodium hydroxide? Sodium hydroxide is a strong base.	**M9** A weak acid has a hydroxide ion concentration of 2.3 x 10^{-9}moldm^{-3}. What is the hydrogen ion concentration in this solution?	**H9** What is the pH of a 1.1moldm^{-3} solution of the strong alkali sodium hydroxide?	**VH9** The pOH of a 3.63 moldm^{-3} ammonia solution (NH_3) is 2.1. What is the pKa of the ammonium ion NH_4^+?
E10 What is the concentration of the strong base, potassium hydroxide, if the hydroxide ion concentration of the solution is 0.63moldm^{-3}?	**M10** What is the pH of a solution of the weak base, ammonia, if the hydroxide ion concentration is 1.3 x 10^{-6} moldm^{-3}?	**H10** A solution of carbonic acid has a pH of 5.5, what is the concentration of carbonic acid in this solution? Carbonic acid is a weak acid with a Ka of 4.47 x 10^{-7}.	**VH10** A 0.25 moldm-3 solution of the weak aciid HCN has a pH of 5. What is the pKb of the CN^- ion?

Part 2: Answer cards (pre-cut):

Easy 1 point	Medium 2 points	Hard 3 points	Very hard 4 points
E1 2.2 moldm^{-3}	M1 0.097	H1 2.10	VH1 1.58 x 10^{-5}
E2 1 moldm^{-3}	M2 12.9	H2 0.2 moldm^{-3}	VH2 4.05
E3 0.49 moldm^{-3}	M3 2 x 10^{-14} moldm^{-3}	H3 2.53	VH3 2.36 x 10^{-11} moldm^{-3}
E4 4.20	M4 7.69 x 10^{-9} moldm^{-3}	H4 5.04 moldm^{-3}	VH4 1.22 x 10^{-12} moldm^{-3}
E5 3.09	M5 2.14 x 10^{-4}	H5 1.58 x 10^{-9} moldm^{-3}	VH5 10.56
E6 3.17	M6 0.1 moldm^{-3}	H6 5.18	VH6 0.178 moldm^{-3}

E7 $0.5 moldm^{-3}$	M7 $3.16 \times 10^{-8} moldm^{-3}$	H7 $1.0 \times 10^{-12} moldm^{-3}$	VH7 3.67
E8 5.89	M8 0.22	H8 4.76	VH8 1.12
E9 $2 moldm^{-3}$	M9 $4.35 \times 10^{-6} moldm^{-3}$	H9 14.04	VH9 9.24
E10 $0.63 moldm^{-3}$	M10 8.11	H10 $2.24 \times 10^{-5} moldm^{-3}$	VH10 9.60

Part 2: Student instruction sheet

Place the cards face down in 4 piles (based on difficulty). You may shuffle them in their groups if you wish.

Each student in the group draws a card from the top of the pile of their choice and then the whole group has 2 minutes to try and answer their question. After this time you may find your answer card:

- If your answer is correct you receive the number of points based on how challenging the question is (easy = 1, medium = 2, hard = 3, very hard = 4)
- If you answer incorrectly you lose the number of points that the question is worth… yes, you can have negative points in this game! The key to success is being realistic about your own current level of ability.
- If you answer correctly without the map you gain double the number of points for the question. If you use the map and you are incorrect your loss is not doubled.

After each attempt at an answer you may find your answer card. You will then have a further 2 minutes to try and work out the correct method to get the answer.

Part 2: Descriptors

Skill assessed	E	M	H	VH
Solve problems with 1 step	✓	✓	✓	✓
Converting between $[H^+]$ and $[OH^-]$ and concentration of strong acids and bases respectively	✓	✓	✓	✓
Working out negative logs ($\log_{10}$) to find pH from $[H^+]$ and pKa from Ka.	✓	✓	✓	✓
Solve problems with up to 2 steps		✓	✓	✓
Working out inverse logs of negative values (10^x-Y)		✓	✓	✓
Working out negative logs ($-\log_{10}$) to find pOH from $[OH^-]$, and pKb from Kb.		✓	✓	✓
Convert between $[H^+]$ and $[OH^-]$ and pH and pOH of a solution.		✓	✓	✓
Solve problems with up to 3 steps			✓	✓
Convert between ka, $[H^+]$ and [HA] for weak acids and kb, $[OH^-]$ and [B] for weak bases			✓	✓
Covert between ka and kb or pka and pkb for conjugate acid-base pairs.			✓	✓
Solve problems that seem to have "two starting points" on the map.			✓	✓
Solve problems with up to 4 steps				✓
Spot a solution at its half way point and use this to solve problems				✓

Tips for the teacher:

Students work in groups of 2 – 4 (in which case they may be able to answer up to 10-20 *different* questions each)

Make sure groups are mixed in terms of confidence level of the students, so that one difficulty level is not used up too quickly.

Ask each student to keep their cards and answers. You will then have a record of each student's confidence (look at the distribution of colored cards that each student has on the desk) and student's answers.

It may be worth setting students the full set of questions at a hardness level one above the one they successfully reach in the lesson (therefore enabling progress)

Notes

- The purpose of the map is to help students start to solve acid-base calculation problems and eventually solve them without the map.
- Only mono-protic acids and mono-basic alkalis can be used on the map (some of the equations for diprotic acids and dibasic alkalis are different).
- Buffers and indicator calculations have not been included.
- Some routes around the map are nonsensical (For example, if you calculated the $[H^+]$ of a weak acid, it would not make sense to assume that this is equal to the [HA] of a different strong acid). Students do not need to recognize invalid questions like this; the map is intended as a tool to help students solve valid questions.