

# Chemistry

## Unit 3

### Area of Study 2 Test Answers:

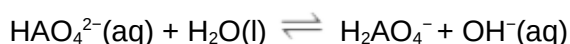
### Acids and bases

#### Section 1: Multiple choice

(16 marks)

##### Question 1

- C** A base is a proton acceptor. When the hydrogen arsenate ion  $\text{HAsO}_4^{2-}$  acts as a base in water, the following reaction occurs:



##### Question 2

- B** Polyprotic refers to an acid that can donate more than one proton.

$\text{CH}_3\text{COOH}$  only donates one proton to form its conjugate base  $\text{CH}_3\text{COO}^-$ .  $\text{NH}_4^+$  also only donates one proton to form its conjugate base  $\text{NH}_3$ .

$\text{H}_2\text{SO}_3$  can donate one or two protons to form  $\text{HSO}_3^-$  or  $\text{SO}_3^{2-}$ .

##### Question 3

- D** Both solutions have the same concentration and volume but nitric acid is a strong acid whereas ethanoic acid is a weak acid. So statement I is not correct.

Therefore, nitric acid is ionised more fully in water releasing more  $\text{H}^+(\text{aq})$ .

So, the pH of the nitric acid will be lower and it will have greater electrical conductivity. So statement II is incorrect but statement III is correct.

Statement IV is also correct because the two solutions contain the same number of moles of acid, which will react fully with a strong base such as NaOH.

##### Question 4

- A** The solution is diluted by a factor of 10 so the pH will change by 1 unit. Because the concentration of the  $\text{OH}^-(\text{aq})$  has decreased, the pH will be less basic by 1 unit.

##### Question 5

- C** A strong acid is one that ionises to a large extent, so I is correct.

The reaction rate of an acid with a carbonate depends on the concentration of  $\text{H}^+(\text{aq})$  present. As trichloroethanoic acid is the stronger acid, the solution will contain a higher concentration of  $\text{H}^+(\text{aq})$  and so will react faster with the carbonate. Therefore, statement II is also correct.

### Question 6

- B** A buffer works best when there are approximately equal concentrations of a weak acid and its conjugate base.
- I** Contains 0.001 mol of the weak acid  $\text{NH}_4^+(\text{aq})$  and 0.001 mol of its conjugate base  $\text{NH}_3(\text{aq})$ . So it has good buffering properties.
- II** Contains 0.001 mol of the strong acid  $\text{HCl}$  mixed with 0.002 mol of the base  $\text{NH}_3(\text{aq})$ . The following reaction will take place:
- $$\text{NH}_3(\text{aq}) + \text{HCl}(\text{aq}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{Cl}^-(\text{aq})$$
- The 0.001 mol of  $\text{NH}_3$  will react with the 0.001 mol of  $\text{HCl}$  to form 0.001 mol of  $\text{NH}_4^+(\text{aq})$ . All the  $\text{HCl}$  will be consumed in the reaction but there will be 0.001 mol of  $\text{NH}_3(\text{aq})$  left over in solution. So the final mixture will contain 0.001 mol of the weak acid  $\text{NH}_4^+(\text{aq})$  and 0.001 mol of its conjugate base  $\text{NH}_3(\text{aq})$  and so will have good buffering properties.
- III** This mixture does contain equal amounts of an acid and its conjugate; however, the acid is a strong acid and its conjugate is a very weak base. So this combination does not form a buffer.

### Question 7

- B** As the dissociation of water is endothermic, an increase in temperature will cause the equilibrium to shift to the right. So the concentration of  $\text{H}^+(\text{aq})$  increases and therefore the pH decreases to a value smaller than 7.

As the equilibrium shifts to the right, the concentration of  $\text{OH}^-(\text{aq})$  ions also increases and does so by the same amount as the  $\text{H}^+(\text{aq})$ . As the  $[\text{H}^+(\text{aq})] = [\text{OH}^-]$ , then the solution is defined as neutral.

### Question 8

- A** If the acid had been a strong acid and therefore completely ionised, the initial pH would have been  $-\log 0.1$  (i.e. 1). However, the initial pH is approximately 4, indicating only partial ionisation and hence a weak acid.

The final pH of the mixture is close to 13 and the pH at equivalence point is higher than 7. Both these observations point to the base being strong.

### End of section 1

## Section 2: Short answer

(23 marks)

\* Indicates 1 mark

### Question 9

(5 marks)

- a** Arrhenius described acids as substances that produce  $\text{H}^+(\text{aq})$  ions in water.\*
- b** Brønsted-Lowry defined an acid as a proton donor\* thus extending the definition of an acid to include substances that are not dissolved in water.\*
- c** Correct examples might include:
- $\text{HCl(g)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})^*$
  - $\text{HCl(g)} + \text{NH}_3(\text{g}) \rightleftharpoons \text{NH}_4\text{Cl(s)}^*$

### Question 10

(8 marks)

| Compound in solution     | Solution acidic or basic or neutral | Equation   | Explanation  |
|--------------------------|-------------------------------------|--|--|
| NaCl                     | Neutral*                            | —  | Neither $\text{Na}^+$ nor $\text{Cl}^-$ undergo further hydrolysis.*   |
| $\text{NH}_4\text{Cl}$   | Acidic*                             | $\text{NH}_4^+(\text{aq}) + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{NH}_3(\text{aq})^*$ | The ammonium ion is hydrolysed to produce $\text{H}_3\text{O}^+(\text{aq})$ .<br>The chloride ion is a very weak base and so is not hydrolysed in water.*<br>As $[\text{H}_3\text{O}^+] > [\text{OH}^-]$ , the solution is acidic. |
| $\text{Na}_2\text{CO}_3$ | Basic*                              | $\text{CO}_3^{2-}(\text{aq}) + \text{H}_2\text{O(l)} \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{OH}^-(\text{aq})^*$    | The carbonate ion is hydrolysed to produce $\text{OH}^-(\text{aq})$ .<br>The sodium ion is a very weak acid and so is not hydrolysed in water.*<br>As $[\text{H}_3\text{O}^+] < [\text{OH}^-]$ , the solution is basic.            |

### Question 11

(4 marks)

- a** Propanoic acid is a weak acid so it is partially ionised.\* Therefore, the concentration of  $\text{H}^+(\text{aq})$  ions in a propanoic acid solution is lower than in solutions of nitric and sulfuric acids, strong acids with the same concentration as propanoic acid. Because the concentration of  $\text{H}^+(\text{aq})$  ions is lower, the pH of the propanoic acid solution is higher.\*
- b** Sulfuric acid is diprotic. In water, one hydrogen ion is completely donated to water.  
In addition, there is partial hydrolysis of the  $\text{HSO}_4^-(\text{aq})$  ion to release a second hydrogen ion.\* So the concentration of  $\text{H}^+(\text{aq})$  ions is higher overall than in a solution of the monoprotic nitric acid of the same concentration, and the pH of the sulfuric acid solution is lower.\*

**Question 12****(6 marks)****a** pH = 5.2 so

$$[\text{H}_3\text{O}^+] = 10^{-5.2} = 6.31 \times 10^{-6} \text{ mol L}^{-1*}$$

$$[\text{OH}^-] = \frac{10^{-14}}{6.31 \times 10^{-6}} = 1.58 \times 10^{-9} \text{ mol L}^{-1*}$$

**b**  $n(\text{HCl}) = 0.075 \times 0.0150 = 0.001125 = n(\text{H}^+)$ 

$$n(\text{NaOH}) = 0.125 \times 0.0100 = 0.00125 = n(\text{OH}^-)*$$

The  $\text{OH}^-$  ions are in excess by  $0.00125 - 0.001125 \text{ mol} = 0.000125 \text{ mol}$ .

The volume of the mixture is  $200 \text{ mL} = 0.200 \text{ L}$ .

$$[\text{OH}^-] = \frac{0.000125}{0.200} = 0.000625 \text{ mol L}^{-1*}$$

$$[\text{H}^+] = \frac{10^{-14}}{0.000625} = 1.6 \times 10^{-11} \text{ mol L}^{-1*}$$

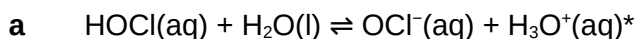
$$\text{pH} = 10.8*$$

## Section 3: Extended answer

(25 marks)

### Question 13

(9 marks)



**b i** A weak acid is one that does not readily donate a proton (to a base).\*

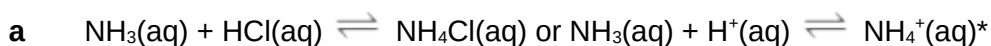
**ii** A monoprotic acid can only donate one proton (to a base).\*

**c**

|   |   |
|---|---|
| <b>i</b> Formula of acid with the higher $K_a$ value<br>HCl*  | <b>Justification</b><br>For an acid HA<br>$K_a = \frac{[\text{H}^+] \times [\text{A}^-]}{[\text{HA}]}$ The stronger the acid, the higher the degree of ionisation and the higher $[\text{H}^+]$ and $[\text{A}^-]$ and the smaller $[\text{HA}]$ . So the $K_a$ fraction will be higher for a strong acid and so will the value of $K_a$ .* |
| <b>ii</b> Formula of acid that forms a 0.5 mol L <sup>-1</sup> solution with the higher pH<br>HOCl* | <b>Justification</b><br>HOCl is a weak acid, so is only partially hydrolysed in water. $[\text{H}^+]$ is lower and so the pH is higher.*  |
| <b>iii</b> Formula of acid with the stronger conjugate base<br>HOCl*                                | <b>Justification</b><br>The weaker an acid, the stronger its conjugate base. So HOCl has the stronger base.*  |

### Question 14

(16 marks)



b  $n(\text{HCl}) = 0.0950 \times 0.01740 = 0.00165 = n(\text{NH}_3)$  in the 20.00 mL titre\*

$n(\text{NH}_3)$  in 100 mL diluted cleaner =  $5 \times 0.00165 = 0.00827 = n(\text{NH}_3)$  in 10.00 mL original cleaner\*

$c(\text{NH}_3)$  in cleaner =  $\frac{0.00827}{0.010} = 0.8265 \text{ mol L}^{-1}$ \* (4 sf)

c  $m(\text{NH}_3)$  in 1 L cleaner =  $0.8265 \times 17.034 = 14.08 \text{ g}^*$

$m(\text{NH}_3)$  in 750 mL bottle =  $\frac{14.08 \times 750}{1000} = 10.6 \text{ g}$  (3 sf)\*

d At the equivalence point the solution contains  $\text{NH}_4^+(\text{aq})$  ions\* (and  $\text{Cl}^-(\text{aq})$  ions).  $\text{NH}_4^+(\text{aq})$  ions hydrolyse to give  $\text{H}_3\text{O}^+$  ions thus making the pH of the solution slightly acidic at the end point.\* This coincides with the pH range at which methyl orange changes colour.\*

Colour change: from yellow at the start of the titration, to orange at equivalence point and then pink when excess acid is present.\*

e

|  | Result would be higher/lower/the same as the actual concentration of ammonia | Explanation  |
|--|--|--|
| Added 20.00 mL of water to the 20.00 mL of diluted cleaner solution in the conical flask prior to titration.                                       | Same*  | The amount, in mole, of ammonia in the flask is unchanged by the addition of water so the same titre of HCl would be needed for the reaction.*   |
| Phenolphthalein indicator was used instead of methyl orange. Phenolphthalein is colourless at a pH less than 8.3 and pink at a pH higher than 9.5. | Lower*   | Phenolphthalein indicator would change colour before equivalence point is reached. So the titre of HCl would be smaller than it should be. Hence the calculated concentration of ammonia would be lower than the actual one.*        |
| The conical flask was washed, then rinsed with the diluted cleaner solution before using it.   | Higher*  | The flask would contain some drops of diluted cleaner as well as the 20.00 mL of it measured out. More HCl would be needed to reach equivalence. Hence the calculated concentration of ammonia would be higher than the actual one.* |

End of answers