1. An aqueous solution of which of the following reacts with magnesium metal?
   A. Ammonia  
   B. Hydrogen chloride  
   C. Potassium hydroxide  
   D. Sodium hydrogencarbonate

2. Which is a buffer solution?
   I. $0.01 \text{ mol dm}^{-3} \text{HCl, 0.01 mol dm}^{-3} \text{NaCl}$
   II. $0.01 \text{ mol dm}^{-3} \text{CH}_3\text{COOH, 0.01 mol dm}^{-3} \text{CH}_3\text{COONa}$
   A. I only  
   B. II only  
   C. Both I and II  
   D. Neither I nor II

3. Which one of the following species can act as both a Brønsted-Lowry acid and base in aqueous solution?
   A. CH$_3$COOH  
   B. NO$_3^-$  
   C. H$_2$PO$_4^-$  
   D. OH$^-$

4. The $K_a$ value for an acid is $1.0 \times 10^{-2}$. What is the $K_b$ value for its conjugate base?
   A. $1.0 \times 10^{-2}$  
   B. $1.0 \times 10^{-6}$  
   C. $1.0 \times 10^{-10}$  
   D. $1.0 \times 10^{-12}$

5. Separate 20.0 cm$^3$ solutions of a weak acid and a strong acid of the same concentration are titrated with NaOH solution. Which will be the same for these two titrations?
   I. Initial pH  
   II. pH at equivalence point  
   III. Volume of NaOH required to reach the equivalence point  
   A. I only  
   B. III only  
   C. I and II only  
   D. II and III only

6. Which of the following is/are formed when a metal oxide reacts with a dilute acid?
   I. A metal salt  
   II. Water  
   III. Hydrogen gas  
   A. I only  
   B. I and II only  
   C. II and III only  
   D. I, II and III

7. Four aqueous solutions, I, II, III and IV, are listed below.
   I. 0.100 mol dm$^{-3}$ HCl  
   II. 0.010 mol dm$^{-3}$ HCl  
   III. 0.100 mol dm$^{-3}$ NaOH  
   IV. 0.010 mol dm$^{-3}$ NaOH  
   What is the correct order of increasing pH of these solutions?
   A. I, II, III, IV  
   B. I, II, IV, III  
   C. II, I, III, IV  
   D. II, I, IV, III

8. Which is a conjugate acid-base pair in the following reaction?
   \[ \text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{H}_2\text{NO}_3^+ + \text{HSO}_4^- \]
   A. HNO$_3$ and H$_2$SO$_4$  
   B. HNO$_3$ and H$_2$NO$_3^+$  
   C. HNO$_3$ and HSO$_4^-$  
   D. H$_2$NO$_3^+$ and HSO$_4^-$
9. Which equation represents an acid-base reaction according to the Lewis theory but not the Brønsted-Lowry theory?
   A. NH₃ + HCl ⇌ NH₄Cl  
   B. 2H₂O ⇌ H₃O⁺ + OH⁻  
   C. NaOH + HCl ⇌ NaCl + H₂O  
   D. CrCl₃ + 6NH₃ ⇌ [Cr(NH₃)₆]³⁺ + 3Cl⁻

10. When the following 1.0 mol dm⁻³ aqueous solutions are arranged in order of increasing pH, which is the correct order?
   I. Ammonium chloride  
   II. Ammonium ethanoate  
   III. Sodium ethanoate
   A. I, II, III  
   B. II, I, III  
   C. III, I, II  
   D. III, II, I

11. An acid-base indicator, HIn, dissociates according to the following equation.

\[
\text{HIn}(aq) \rightleftharpoons \text{H}^+(aq) + \text{In}^-(aq)
\]

Which statement about this indicator is correct?
   I. In a strongly acidic solution colour B would be seen.
   II. In a neutral solution the concentrations of HIn(aq) and In⁻(aq) must be equal.
   III. It is suitable for use in titrations involving weak acids and weak bases.
   A. I only  
   B. II only  
   C. III only  
   D. None of the above

12. Which substance can be dissolved in water to give a 0.1 mol dm⁻³ solution with a high pH and a high electrical conductivity?
   A. HCl  
   B. NaCl  
   C. NH₃  
   D. NaOH

13. A buffer solution can be prepared by adding which of the following to 50 cm³ of 0.10 mol dm⁻³ CH₃COOH(aq)?
   I. 50 cm³ of 0.10 mol dm⁻³ CH₃COONa(aq)  
   II. 25 cm³ of 0.10 mol dm⁻³ NaOH(aq)  
   III. 50 cm³ of 0.10 mol dm⁻³ NaOH(aq)
   A. I only  
   B. I and II only  
   C. II and III only  
   D. I, II and III

14. Which equation represents an acid-base reaction according to the Lewis theory but not according to the Brønsted-Lowry theory?
   A. CO₃²⁻(aq) + 2H⁺(aq) → H₂O(l) + CO₂(g)  
   B. Cu²⁺(aq) + 4NH₃(aq) → Cu(NH₃)₄²⁺(aq)  
   C. BaO(s) + H₂O(l) → Ba²⁺(aq) + 2OH⁻(aq)  
   D. NH₃(g) + HCl(g) → NH₄Cl(s)

15. What is the concentration of OH⁻ ions (in mol dm⁻³) in an aqueous solution in which
\[ [H^+] = 2.0 \times 10^{-3} \text{ mol dm}^{-3}; \ (K_w = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}) \]

A. $2.0 \times 10^{-3}$  B. $4.0 \times 10^{-6}$  C. $5.0 \times 10^{-12}$  D. $2.0 \times 10^{-17}$

16. What is the relationship between $K_a$ and $pK_a$?

A. $pK_a = -\log K_a$  
B. $pK_a = \frac{1.0 \times 10^{-14}}{K_a}$  
C. $pK_a = \log K_a$  
D. $pK_a = \frac{1.0}{K_a}$

17. Which curve is produced by the titration of a 0.1 mol dm$^{-3}$ weak base with 0.1 mol dm$^{-3}$ strong acid?

A.  
B.  
C.  
D. 

18. The pH of a solution is 2. If its pH is increased to 6, how many times greater is the [H$^+$] of the original solution?

A. 3  B. 4  C. 1000  D. 10 000

19. The acid dissociation constant of a weak acid HA has a value of $1.0 \times 10^{-5}$ mol dm$^{-3}$. What is the pH of a 0.10 mol dm$^{-3}$ aqueous solution of HA?

A. 2  B. 3  C. 5  D. 6

20. Which mixture would produce a buffer solution when dissolved in 1.0 dm$^{-3}$ of water?

A. 0.50 mol of CH$_3$COOH and 0.50 mol of NaOH  
B. 0.50 mol of CH$_3$COOH and 0.25 mol of NaOH  
C. 0.50 mol of CH$_3$COOH and 1.00 mol of NaOH  
D. 0.50 mol of CH$_3$COOH and 0.25 mol of Ba(OH)$_2$

21. Which compound, when dissolved in aqueous solution, has the highest pH?

A. NaCl  B. Na$_2$CO$_3$  C. NH$_4$Cl  D. NH$_4$NO$_3$
22. In which reaction is $\text{H}_2\text{PO}_4^-(aq)$ acting as a Brønsted-Lowry base?

A. $\text{H}_2\text{PO}_4^-(aq) + \text{NH}_3(aq) \rightarrow \text{HPO}_4^{2-}(aq) + \text{NH}_4^+(aq)$

B. $\text{H}_2\text{PO}_4^-(aq) + \text{OH}^-(aq) \rightarrow \text{HPO}_4^{2-}(aq) + \text{H}_2\text{O}(l)$

C. $\text{H}_2\text{PO}_4^-(aq) + \text{C}_2\text{H}_5\text{NH}_2(aq) \rightarrow \text{HPO}_4^{2-}(aq) + \text{C}_2\text{H}_5\text{NH}_3^+(aq)$

D. $\text{H}_2\text{PO}_4^-(aq) + \text{CH}_3\text{COOH}(aq) \rightarrow \text{H}_3\text{PO}_4(aq) + \text{CH}_3\text{COO}^-(aq)$

23. The pH of solution X is 1 and that of Y is 2. Which statement is correct about the hydrogen ion concentrations in the two solutions?

A. $[\text{H}^+]$ in X is half that in Y.

B. $[\text{H}^+]$ in X is twice that in Y.

C. $[\text{H}^+]$ in X is one tenth of that in Y.

D. $[\text{H}^+]$ in X is ten times that in Y.

24. Which substances could be added to a solution of ethanoic acid to prepare an acidic buffer solution?

I. Hydrochloric acid
II. Sodium ethanoate
III. Sodium hydroxide

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

25. Which methods will distinguish between equimolar solutions of a strong base and a strong acid?

I. Add magnesium to each solution and look for the formation of gas bubbles.

II. Add aqueous sodium hydroxide to each solution and measure the temperature change.

III. Use each solution in a circuit with a battery and lamp and see how bright the lamp glows.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

26. The equation for the reaction between nitric acid and sulfuric acid is shown below.

$$\text{H}_2\text{SO}_4 + \text{HNO}_3 \leftrightarrow \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$$

Which species are acting as acids in this reaction according to the Brønsted-Lowry theory?

A. $\text{H}_2\text{SO}_4$ and $\text{HNO}_3$

B. $\text{H}_2\text{SO}_4$ and $\text{H}_2\text{NO}_3^+$

C. $\text{HNO}_3$ and $\text{H}_2\text{NO}_3^+$

D. $\text{H}_2\text{NO}_3^+$ and $\text{HSO}_4^-$

27. Which values are correct for a solution of NaOH of concentration 0.010 mol dm$^{-3}$ at 298 K?

$(K_w = 1.0 \times 10^{-14}$ mol$^2$ dm$^{-6}$ at 298 K)$

A. $[\text{H}^+] = 1.0 \times 10^{-2}$ mol dm$^{-3}$ and pH = 2.00

B. $[\text{OH}^-] = 1.0 \times 10^{-2}$ mol dm$^{-3}$ and pH = 12.00

C. $[\text{H}^+] = 1.0 \times 10^{-12}$ mol dm$^{-3}$ and pOH = 12.00
28. Which solution, of concentration 0.10 mol dm$^{-3}$, has the highest pH value?

A. HCl(aq)  
B. MgCl$_2$(aq)  
C. NaCl(aq)  
D. AlCl$_3$(aq)

29. Which statement about indicators is always correct?

A. The mid-point of an indicator’s colour change is at pH = 7.  
B. The pH range is greater for indicators with higher p$K_a$ values.  
C. The colour red indicates an acidic solution.  
D. The p$K_a$ value of the indicator is within its pH range.

30. Lime was added to a sample of soil and the pH changed from 4 to 6. What was the corresponding change in the hydrogen ion concentration?

A. increased by a factor of 2  
B. increased by a factor of 100  
C. decreased by a factor of 2  
D. decreased by a factor of 100

31. When the following 1.0 mol dm$^{-3}$ solutions are listed in increasing order of pH (lowest first), what is the correct order?

A. HNO$_3$ < H$_2$CO$_3$ < NH$_3$ < Ba(OH)$_2$  
B. NH$_3$ < Ba (OH)$_2$ < H$_2$CO$_3$ < HNO$_3$  
C. Ba (OH)$_2$ < H$_2$CO$_3$ < NH$_3$ < HNO$_3$  
D. HNO$_3$ < H$_2$CO$_3$ < Ba (OH)$_2$ < NH$_3$

32. Which compound will dissolve in water to give a solution with a pH greater than 7?

A. sodium chloride  
B. potassium carbonate  
C. ammonium nitrate  
D. lithium sulfate

33. An aqueous solution has a pH of 10. Which concentrations are correct for the ions below?

\[
[H^+(aq)] \text{ mol dm}^{-3} \quad [\text{OH}^- (aq)] \text{ mol dm}^{-3}
\]

<table>
<thead>
<tr>
<th></th>
<th>[H^+(aq)]</th>
<th>[\text{OH}^- (aq)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$10^{-4}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>B</td>
<td>$10^{-4}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>C</td>
<td>$10^{-10}$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>D</td>
<td>$10^{-10}$</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>

34. Which graph shows how the pH changes when a weak base is added to a strong
35. When the following acids are listed in decreasing order of acid strength (strongest first), what is the correct order?

<table>
<thead>
<tr>
<th>Acid</th>
<th>pK_a</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzoic</td>
<td>6.31×10^{-5}</td>
</tr>
<tr>
<td>chloroethanoic</td>
<td>1.38×10^{-3}</td>
</tr>
<tr>
<td>ethanoic</td>
<td>1.74×10^{-5}</td>
</tr>
</tbody>
</table>

A. chloroethanoic > benzoic > ethanoic  
B. benzoic > ethanoic > chloroethanoic  
C. chloroethanoic > ethanoic > benzoic  
D. ethanoic > benzoic > chloroethanoic

36. Which change in [H^+] causes the biggest increase in pH?

A. A change in [H^+](aq) from 1×10^{-3} to 1×10^{-2} mol dm^{-3}  
B. A change in [H^+](aq) from 1×10^{-3} to 1×10^{-4} mol dm^{-3}  
C. A change in [H^+](aq) from 1×10^{-4} to 1×10^{-2} mol dm^{-3}  
D. A change in [H^+](aq) from 1×10^{-4} to 1×10^{-6} mol dm^{-3}

37. The strengths of organic acids can be compared using K_a and pK_a values. Which acid is the strongest?

<table>
<thead>
<tr>
<th>Acid</th>
<th>pK_a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid A</td>
<td>6</td>
</tr>
<tr>
<td>Acid B</td>
<td>3</td>
</tr>
<tr>
<td>Acid C</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>Acid D</td>
<td>1×10^{-4}</td>
</tr>
</tbody>
</table>

38. Which methods can distinguish between solutions of a strong monoprotic acid and a weak monoprotic acid of the same concentration?
I. Add magnesium to each solution and measure the rate of the formation of gas bubbles.
II. Add aqueous sodium hydroxide to each solution and measure the temperature change.
III. Use each solution in a circuit with a battery and lamp and see how bright the lamp glows.

A. I and II only  B. I and III only  C. II and III only  D. I, II and III

39. Which species are a conjugate pair according to the Brønsted-Lowry theory?
A. CH₃COOH and CH₃CHO  
B. NH₃ and BF₃  
C. H₂NO₃⁺ and NO₃⁻  
D. H₂SO₄ and HSO₄⁻

40. Which is the correct statement about the pH and pOH values of an aqueous solution at 25°C?
A. pH + pOH =14.0  
B. pH + pOH =1.0 ×10⁻¹⁴  
C. pH × pOH =14.0  
D. pH × pOH =1.0 ×10⁻¹⁴

41. Which salt, when dissolved in water to form a 1.0 mol dm⁻³ solution, produces the lowest pH value?
A. Ammonium chloride  
B. Ammonium ethanoate  
C. Sodium ethanoate  
D. Sodium chloride

42. Which is not a strong acid?
A. Nitric acid  
B. Sulfuric acid  
C. Carbonic acid  
D. Hydrochloric acid

43. Lime is added to a lake to neutralize the effects of acid rain. The pH value of the lake water rises from 4 to 7. What is the change in concentration of H⁺ ions in the lake water?
A. An increase by a factor of 3  
B. An increase by a factor of 1000  
C. A decrease by a factor of 3  
D. A decrease by a factor of 1000

44. Which solution has the lowest pH value?
A. Aluminium sulfate  
B. Sodium nitrate  
C. Potassium chloride  
D. Sodium ethanoate

45. Which is a Brønsted-Lowry acid-base pair?
A. H₂O and O²⁻  
B. CH₃COOH and CH₃COO⁻  
C. NH₄⁺ and NH₂⁻  
D. H₂SO₄ and SO₄²⁻

46. Which neutralization reaction could use phenolphthalein (pKₐ = 9.3) and not methyl orange (pKₐ = 3.7) as an indicator?
A. NaOH(aq) and HNO₃(aq)  
B. NH₃(aq) and CH₃COOH(aq)  
C. NaOH(aq) and CH₃COOH(aq)  
D. NH₃(aq) and HNO₃(aq)

47. Water dissociates according to the equation

\[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \quad \Delta H = +56 \text{ kJ} \]
At 25°C water has a pH of 7. Which of the following occurs when water is heated to 30°C?

A. It remains neutral and its pH decreases.  B. It becomes acidic and its pH decreases.
C. It remains neutral and its pH increases.  D. It becomes acidic and its pH increases.

48. Which mixture would produce a buffer solution when dissolved in 1.0 dm$^3$ of water?

A. 0.30 mol of NH$_3$(aq) and 0.30 mol of HCl(aq)
B. 0.30 mol of NH$_3$(aq) and 0.15 mol of HCl(aq)
C. 0.30 mol of NH$_3$(aq) and 0.60 mol of HCl(aq)
D. 0.30 mol of NH$_3$(aq) and 0.15 mol of H$_2$SO$_4$(aq)

49. Solutions of hydrochloric acid (HCl(aq)) and ethanoic acid (CH$_3$COOH(aq)) of the same concentration reacted completely with 5.0 g of calcium carbonate in separate containers. Which statement is correct?

A. CH$_3$COOH(aq) reacted slower because it has a lower pH than HCl(aq).
B. A smaller volume of CO$_2$(g) was produced with CH$_3$COOH(aq) than with HCl(aq).
C. A greater volume of CO$_2$(g) was produced with CH$_3$COOH(aq) than with HCl(aq).
D. The same volume of CO$_2$(g) was produced with both CH$_3$COOH(aq) and HCl(aq).

50. Solutions of hydrochloric acid (HCl(aq)) and ethanoic acid (CH$_3$COOH(aq)) of the same concentration reacted completely with 5.0 g of calcium carbonate in separate containers. Which statement is correct?

A. CH$_3$COOH(aq) reacted slower because it has a lower pH than HCl(aq).
B. A smaller volume of CO$_2$(g) was produced with CH$_3$COOH(aq) than with HCl(aq).
C. A greater volume of CO$_2$(g) was produced with CH$_3$COOH(aq) than with HCl(aq).
D. The same volume of CO$_2$(g) was produced with both CH$_3$COOH(aq) and HCl(aq).

51. Ammonia (NH$_3$) is a weak base in aqueous solution with an ionization constant $K_b$. What expression is equal to the ionization constant for the following reaction?

$$\text{NH}_4^+(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_3(aq) + \text{H}_3\text{O}^+(aq)$$

A. $\frac{K_w}{K_a}$  B. $\frac{K_a}{K_w}$  C. $\frac{K_w}{K_b}$  D. $\frac{K_b}{K_w}$

52. The $pK_a$ values of four acids are as follows.

|   | W 4.87 | X 4.82 | Y 4.86 | Z 4.85 |

What is the correct order when these acids are arranged in order of increasing acid strength?


53. 10 cm$^3$ of 0.01 mol dm$^{-3}$ nitric acid (HNO$_3$) is diluted with 90 cm$^3$ of water. What is the pH of the resulting solution?
A. 1  B. 2  C. 3  D. 4

54. A base of concentration 0.10 mol dm\(^{-3}\) is titrated with 25 cm\(^3\) of an acid of concentration 0.10 mol dm\(^{-3}\). Which base-acid pair would have the highest pH at the equivalence point?

A. NaOH(aq) and CH\(_3\)COOH(aq)  B. NaOH(aq) and HNO\(_3\)(aq)
C. NH\(_3\)(aq) and HNO\(_3\)(aq)  D. NH\(_3\)(aq) and CH\(_3\)COOH(aq)

55. Which acids are strong?

I. HCl(aq)  II. HNO\(_3\)(aq)  III. H\(_2\)SO\(_4\)(aq)
A. I and II only  B. I and III only  C. II and III only  D. I, II and III

56. The pH of a solution changes from pH = 1 to pH = 3. What happens to the [H\(^+\)] during this pH change?

A. It increases by a factor of 100.  B. It decreases by a factor of 100.
C. It increases by a factor of 1000.  D. It decreases by a factor of 1000.

57. What is the conjugate base of the HSO\(_4\)^–(aq) ion?

A. H\(_2\)SO\(_4\)(aq)  B. SO\(_4^{2-}\)(aq)  C. H\(_2\)O(l)  D. H\(_3\)O\(^+\)(aq)

58. What is the value of [H\(^+\)] in a buffer solution in which [CH\(_3\)COOH] = 2.0 mol dm\(^{-3}\) and [CH\(_3\)COO\(^-\)] 1.0 mol dm\(^{-3}\)? For CH\(_3\)COOH, \(K_a = 1.8 \times 10^{-5}\) mol dm\(^{-3}\).

A. 6.0\times10^{-3}  B. 3.6\times10^{-5}  C. 1.8\times10^{-5}  D. 9.1\times10^{-6}

59. Which salt forms the most acidic solution when added to water?

A. NaCl  B. MgSO\(_4\)  C. Al(NO\(_3\))\(_3\)  D. KHCO\(_3\)

60. An acid-base indicator has a p\(K_a\) value of 4.0. At what pH will this indicator change colour?

A. 2.0  B. 4.0  C. 8.0  D. 12.0

61. Which species can act as a Lewis acid?

A. BF\(_3\)  B. OH\(^-\)  C. H\(_2\)O  D. NH\(_3\)

62. Which substance, when dissolved in water, to give a 0.1 mol dm\(^{-3}\) solution, has the highest pH?

A. HCl  B. NaCl  C. NH\(_3\)  D. NaOH

63. Which methods will distinguish between equimolar solutions of a strong base and a strong acid?

I. Add magnesium to each solution and look for the formation of gas bubbles.
II. Add aqueous sodium hydroxide to each solution and measure the temperature change.
III. Use each solution in a circuit with a battery and lamp and see how bright the lamp glows.

A. I and II only  B. I and III only  C. II and III only  D. I, II and III

9
64. Which values are correct for a 0.010 mol dm$^{-3}$ solution of NaOH(aq) at 298 K? ($K_w = 1.0 \times 10^{-14}$ mol$^2$ dm$^{-6}$ at 298 K)
   A. $[H^+] = 1.0 \times 10^{-12}$ mol dm$^{-3}$ and pH = 12.00
   B. $[OH^-] = 1.0 \times 10^{-12}$ mol dm$^{-3}$ and pH = 12.00
   C. $[H^+] = 1.0 \times 10^{-12}$ mol dm$^{-3}$ and pOH = 12.00
   D. $[OH^-] = 1.0 \times 10^{-12}$ mol dm$^{-3}$ and pOH = 12.00

65. At 25°C, $K_a$ for an acid is $1.0 \times 10^{-2}$. What is the value of $K_b$ for its conjugate base?
   A. $1.0 \times 10^2$
   B. $1.0 \times 10^{-2}$
   C. $1.0 \times 10^{12}$
   D. $1.0 \times 10^{-12}$

66. Which statement about indicators is always correct?
   A. The mid-point of the pH range of an indicator is 7.
   B. The pH range is greater for indicators with higher $pK_a$ values.
   C. The colour red indicates an acidic solution.
   D. The $pK_a$ value of the indicator is within its pH range.

67. Define the terms strong acid and weak acid. Using hydrochloric and ethanoic acid as examples, write equations to show the dissociation of each acid in aqueous solution.
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………

68. (i) Calcium carbonate is added to separate solutions of hydrochloric acid and ethanoic acid of the same concentration. State one similarity and one difference in the observations you could make.
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   (2)

(ii) Write an equation for the reaction between hydrochloric acid and calcium carbonate.
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   (2)

(iii) Determine the volume of 1.50 mol dm$^{-3}$ hydrochloric acid that would react with exactly 1.25 g of calcium carbonate.
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   (3)
(iv) Calculate the volume of carbon dioxide, measured at 273 K and 1.01\times10^5 Pa, which would be produced when 1.25 g of calcium carbonate reacts completely with the hydrochloric acid.

69. The graph below shows the change in pH when aqueous sodium hydroxide is added to 20 cm$^3$ of aqueous hydrochloric acid.

![Graph showing pH change](image)

By reference to the graph

(i) state the [H$^+$] before any alkali is added.

(ii) state by how much the [H$^+$] changes after the addition of 20 cm$^3$ of aqueous sodium hydroxide.

(iii) determine the volume of the same sodium hydroxide solution needed to neutralize 20 cm$^3$ of aqueous ethanoic acid of the same concentration as the hydrochloric acid.

70. Predict whether each of the following solutions would be acidic, alkaline or neutral. In each
case explain your reasoning.

(i) 0.1 mol dm$^{-3}$ FeCl$_3$(aq)

(ii) 0.1 mol dm$^{-3}$ NaNO$_3$(aq)

(iii) 0.1 mol dm$^{-3}$ Na$_2$CO$_3$(aq)

71. The following graph shows how the pH changes during the titration of 10 cm$^3$ of a solution of a weak acid (HA) with 0.10 mol dm$^{-3}$ NaOH.

(i) State the pH at the equivalence point and explain why the pH changes rapidly in this region.

(ii) Calculate the initial concentration of the acid (HA).
(iii) Calculate the $[H^+]$ of the acid before any sodium hydroxide is added. Use this value to determine the $K_a$ value and the $pK_a$ value of the acid.

72. A buffer solution can be made by dissolving 0.25 g of sodium ethanoate in 200 cm$^3$ of 0.10 mol dm$^{-3}$ ethanoic acid. Assume that the change in volume is negligible.

(i) Define the term *buffer solution*.

(ii) Calculate the concentration of the sodium ethanoate in mol dm$^{-3}$.

(iii) Calculate the pH of the resulting buffer solution by using information from Table 16 of the Data Booklet.

73. The strength of an organic acid can be considered in terms of the breaking of the O–H bond in the molecule.

(a) State how the strength of an acid is related to the dissociation constant, $K_a$, of the acid, and to its $pK_a$ value.

(b) By referring to their structures, explain the difference in the acid strengths of ethanol and phenol.

74. Use the Data Booklet to find the $pK_a$ values of the following acids. State how the presence of substituent’s in carboxylic acids affects their acid strengths. For each pair, explain the difference in acid strength by referring to the substituent.
- Ethanoic acid and propanoic acid
- Chloroethanoic acid and dichloroethanoic acid
- Chloroethanoic acid and fluoroethanoic acid
- Chloroethanoic acid and dichloroethanoic acid
- Chloroethanoic acid and fluoroethanoic acid

76. State and explain whether each of the following solutions will form a buffer solution.

(i) A 1.0 dm$^3$ solution containing 0.10 mol NH$_3$ and 0.20 mol HCl

(ii) A 1.0 dm$^3$ solution containing 0.20 mol NH$_3$ and 0.10 mol HCl

An experiment was carried out to determine the concentration of an aqueous solution of ammonia by titrating it with a solution of sulfuric acid of concentration 0.150 mol dm$^{-3}$. It was found that 25.0 cm$^3$ of the ammonia solution required 20.1 cm$^3$ of the sulfuric acid solution for neutralization.

(a) Write the equation for the reaction and calculate the concentration, in mol dm$^{-3}$, of the ammonia solution.

(b) Several acid-base indicators are listed in Table 17 of the Data Booklet. State and explain which one of the following indicators should be used for this experiment:

- bromocresol green
- phenol red
- phenolphthalein

(c) Determine the pOH of a solution with an ammonia concentration of 0.121 mol dm$^{-3}$. (p$K_b$ of ammonia is 4.75.)
78. (i) Calculate the pH of a mixture of 50 cm$^3$ of ammonia solution of concentration 0.10 mol dm$^{-3}$ and 50 cm$^3$ of hydrochloric acid solution of concentration 0.050 mol dm$^{-3}$.

79. The pH values of solutions of three organic acids of the same concentration were measured.

<table>
<thead>
<tr>
<th>Acid</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>5</td>
</tr>
<tr>
<td>Y</td>
<td>2</td>
</tr>
<tr>
<td>Z</td>
<td>3</td>
</tr>
</tbody>
</table>

(i) Identify which solution is the least acidic. 

(ii) Deduce how the [H$^+$] values compare in solutions of acids Y and Z.

(iii) Arrange the solutions of the three acids in decreasing order of electrical conductivity, starting with the greatest conductivity, giving a reason for your choice.

80. The equilibrium reached when ethanoic acid is added to water can be represented by the following equation:

\[
\text{CH}_3\text{COOH}(l) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{H}_3\text{O}^+(aq)
\]

Define the terms Brønsted-Lowry acid and Lewis base, and identify two examples of each of these species in the equation.

81. The pH of a solution is 4.8. Using information from Table 17 of the Data Booklet, deduce and explain the colours of the indicators bromophenol blue and phenol red in this solution.

82. Calculate the pH of a buffer solution containing 0.0500 mol dm$^{-3}$ of ethanoic acid ($K_a = 1.74 \times 10^{-5}$) and 0.100 mol dm$^{-3}$ of sodium ethanoate.

83. Identify one example of a strong acid and one example of a weak acid. Outline three different methods to distinguish between equimolar solutions of these acids in the laboratory. State how the results would differ for each acid.

84. Vinegar has a pH of approximately 3 and some detergents have a pH of approximately 8. State and explain which of these has the higher concentration of H$^+$ and by what factor.

85. Describe the composition and behaviour of a buffer solution.

86. (i) Define the term pH.
(ii) A 25.0 cm³ sample of 0.100 mol dm⁻³ hydrochloric acid was placed in a conical flask, and 0.100 mol dm⁻³ sodium hydroxide is added until a total of 50.0 cm³ had been added. Sketch a graph of pH against volume of NaOH(aq) added, clearly showing the volume of NaOH(aq) needed for complete reaction and the pH values at the start, the equivalence point and finish.

(iii) The experiment in (ii) was repeated, but with a 25.0 cm³ sample of 0.100 mol dm⁻³ ethanoic acid in the conical flask instead of the hydrochloric acid. Use information from Table 16 of the Data Booklet to calculate the pH at the start of the experiment. State the approximate pH value at the equivalence point.

(4)(Total 10 marks)

87. (i) Describe how an indicator, HIn, works.

(ii) Name a suitable indicator for the reaction between ethanoic acid and sodium hydroxide. Use information from Table 17 in the Data Booklet to explain your choice.

(3)(Total 5 marks)

88. (i) Identify two substances that can be added to water to form a basic buffer solution.

(ii) Describe what happens when a small amount of acid solution is added to the buffer solution prepared in (i). Use an equation to support your explanation.

(1)(Total 3 marks)

89. Define the terms Brønsted-Lowry acid and Lewis acid. For each type of acid, identify one example other than water and write an equation to illustrate the definition.

(Total 5 marks)

90. Predict and explain whether an aqueous solution of 0.10 mol dm⁻³ AlCl₃ will be acidic, alkaline or neutral.

(Total 2 marks)

91. A titration was carried out to determine the concentration of 25.0 cm³ of an aqueous solution of nitric acid. The pH value of the liquid in the flask was measured as 0.100 mol dm⁻³, aqueous sodium hydroxide was added. The results are shown on the graph below.
(i) Use the graph to determine the value of \([H^+]\) of the nitric acid solution. (1)

(ii) Determine the pH value when the value of \([H^+]\) has decreased to \(1\times10^{-3}\) mol dm\(^{-3}\). (1)

(iii) Use the graph to determine the volume of 0.100 mol dm\(^{-3}\) aqueous sodium hydroxide solution needed to exactly neutralize the nitric acid. (1)

(iv) Calculate the concentration, in mol dm\(^{-3}\), of the nitric acid. (2)

(Total 5 marks)

92. The pH values of three acidic solutions, X, Y and Z, are shown in the following table:

<table>
<thead>
<tr>
<th>Solution</th>
<th>Acid</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>HCl(aq)</td>
<td>2</td>
</tr>
<tr>
<td>Y</td>
<td>HCl(aq)</td>
<td>4</td>
</tr>
<tr>
<td>Z</td>
<td>CH(_3)COOH(aq)</td>
<td>4</td>
</tr>
</tbody>
</table>

(i) Solutions X and Z have the same acid concentration. Explain, by reference to both acids, why they have different pH values. (2)

(ii) Deduce by what factor the values of \([H^+]\) in solutions X and Y differ. (1)

(Total 3 marks)

93. In aqueous solution at 298 K, ammonia is a weak base with a \(pK_b\) value of 4.75 and a \(K_b\) value of \(1.7\times10^{-5}\) mol dm\(^{-3}\).

(a) Write an equation for the reaction of ammonia with water.

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......................................................................................................................................................... (1)

(b) State the ionization constant expression, \(K_b\), for ammonia.

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......................................................................................................................................................... (1)

(c) Calculate the pH of a 0.25 mol dm\(^{-3}\) solution of ammonia.

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......................................................................................................................................................... (1)
94. (a) Explain why a 1.0 mol dm\(^{-3}\) solution of sodium hydroxide has a pH of 14 whereas 1.0 mol dm\(^{-3}\) ammonia solution has a pH of about 12. Use equations in your answer.

(b) 20.0 cm\(^3\) of a known concentration of sodium hydroxide is titrated with a solution of nitric acid. The graph for this titration is given below.

(i) State an equation for the reaction between sodium hydroxide and nitric acid.

(ii) Calculate the concentration of the sodium hydroxide solution before the titration.

(iii) From the graph determine the volume of nitric acid required to neutralize the sodium hydroxide and calculate the concentration of the nitric acid.

(iv) Predict the volume of ethanoic acid of the same concentration as the nitric acid in (b) (iii), required to neutralize 20.0 cm\(^3\) of this sodium hydroxide solution.

(Total 11 marks)

95. State and explain two methods, other than measuring pH, which could be used to distinguish between 1.0 mol dm\(^{-3}\) solutions of nitric acid and ethanoic acid.

(Total 4 marks)

96. Nitric acid and ammonia may be used to make a buffer solution.

(i) Describe the behaviour of a buffer solution.

(ii) Describe how you could prepare a buffer solution using 0.100 mol dm\(^{-3}\) solutions of nitric acid and ammonia.

(Total 5 marks)

97. Propanoic acid is classified as a weak acid.
(a) State the meaning of the term weak acid.

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............................................................................................................................... (1)

(b) State, giving a reason in each case, two methods other than measuring pH, that could be used to distinguish between 0.100 mol dm\(^{-3}\) propanoic acid and 0.100 mol dm\(^{-3}\) nitric acid.

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(Total 3 marks)

98. State an equation for the reaction of propanoic acid with water. Identify one conjugate Brønsted-Lowry pair.

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............................................................................................................................... (Total 2 marks)

99. With reference to Table 16 in the Data Booklet, determine the pH of a 0.100 mol dm\(^{-3}\) solution of propanoic acid.

...............................................................................................................................
............................................................................................................................... (Total 3 marks)

100. 0.100 mol dm\(^{-3}\) hydrochloric acid solution is added to 25.0 cm\(^3\) 0.100 mol dm\(^{-3}\) ammonia solution and the pH is recorded until a total of 35.0 cm\(^3\) hydrochloric acid has been added.

(i) Sketch a graph to show how the pH changes as hydrochloric acid is added to the ammonia solution. Use a pH scale of 0–14, and an acid volume scale of 0–35 cm\(^3\). Explain the shape of the curve.

...............................................................................................................................
............................................................................................................................... (6)

(ii) Use table 17 of the Data Booklet to suggest an indicator that could be used in the titration, explaining your choice.

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............................................................................................................................... (2)

(Total 8 marks)

101. (i) State the composition of an acidic buffer solution.

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............................................................................................................................... (1)
(ii) Suggest the identity of an acid and its amount that could be added to a solution containing 0.10 mol ammonia in order to prepare a buffer.

(2)

(iii) Explain how the solution you prepare in (ii) can act as a buffer solution when a strong acid and a strong base are added to separate portions of it. Write an equation to illustrate the buffer action in each case.

(4)

(iv) Write an equation for the reaction of ammonia with water, and write its $K_b$ expression.

(2)

(Total 9 marks)

102. (a) Predict and explain, using equations where appropriate, whether the following solutions are acidic, alkaline or neutral.

(i) 0.1 mol dm$^{-3}$ FeCl$_3$(aq)

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(1)

(ii) 0.1 mol dm$^{-3}$ NaNO$_3$(aq)

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...........................................................................................................................

(1)

(iii) 0.1 mol dm$^{-3}$ Na$_2$CO$_3$(aq)

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...........................................................................................................................

(1)

(b) Acidic gases can be released into the atmosphere that have an environmental impact when they are deposited as acid rain. State two elements that form the acidic gases and describe two impacts they have on the natural environment.

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(3)

(Total 6 marks)

103. An experiment was carried out to determine the concentration of aqueous ammonia by titrating it with a 0.150 mol dm$^{-3}$ sulfuric acid solution. It was found that 25.0 cm$^3$ of the aqueous ammonia required 20.1 cm$^3$ of the sulfuric acid solution for neutralization.

(a) Write the equation for the reaction and calculate the concentration, in mol dm$^{-3}$, of the aqueous ammonia.

(4)

(b) Several acid-base indicators are listed in Table 16 of the Data Booklet. Identify one indicator that could be used for this experiment. Explain your answer.

(3)

(c) (i) Determine the pOH of 0.121 mol dm$^{-3}$ aqueous ammonia ($pK_b = 4.75$).
(ii) State what is meant by the term buffer solution, and describe the composition of an acid buffer solution in general terms.

(iii) Calculate the pH of a mixture of 50.0 cm$^3$ of 0.100 mol dm$^{-3}$ aqueous ammonia and 50.0 cm$^3$ of 0.0500 mol dm$^{-3}$ hydrochloric acid solution.

104. Propanoic acid, CH$_3$CH$_2$COOH is a weak acid.

(a) Give the equation for the ionization of propanoic acid in water and deduce the expression for the ionization constant, $K_a$, of propanoic acid.

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(b) Calculate the $K_a$ value of propanoic acid using the $pK_a$ value in the Data Booklet.

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(c) Use your answer from (b) to calculate the [H$^+$] in an aqueous solution of propanoic acid of concentration 0.0500 mol dm$^{-3}$, and hence the pH of this solution.

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105. (a) Aqueous XO$_4^{3–}$ ions form a precipitate with aqueous silver ions, Ag$^+$. Write a balanced equation for the reaction, including state symbols.

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(b) When 41.18 cm$^3$ of a solution of aqueous silver ions with a concentration of 0.2040 mol dm$^{-3}$ is added to a solution of XO$_4^{3–}$ ions, 1.172 g of the precipitate is formed.

(i) Calculate the amount (in moles) of Ag$^+$ ions used in the reaction.

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(ii) Calculate the amount (in moles) of the precipitate formed.

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(4 marks)

(Total 18 marks)

(4)

(3)

(4)

(Total 6 marks)

(Total 18 marks)
(iii) Calculate the molar mass of the precipitate.

(iv) Determine the relative atomic mass of X and identify the element.

106. (a) (i) Calculate the $K_a$ value of methanoic acid, HCOOH, using table 16 in the Data Booklet.

(ii) Based on its $K_a$ value, state and explain whether methanoic acid is a strong or weak acid.

(iii) Calculate the hydrogen ion concentration and the pH of a 0.010 mol dm$^{-3}$ methanoic acid solution. State one assumption made in arriving at your answer.

(b) Explain how you would prepare a buffer solution of pH 3.75 starting with methanoic acid.
107. The value of the ionic product constant of water, $K_w$, at 60°C is $5.60 \times 10^{-14}$ mol$^2$ dm$^{-6}$.

(a) State the expression for $K_w$.

(b) Calculate the values of $[H^+]$ and pH in water at 60°C.

(c) The value of $[OH^-]$ in water at 60°C is greater than the value at room temperature. Explain why water is not alkaline at 60°C.

108. The formula and $pK_a$ value of chloroethanoic acid appear in Table 16 of the Data Booklet. Use this information to answer the following questions.

(a) Write the equation for the dissociation of chloroethanoic acid in aqueous solution.

(b) Deduce the $K_a$ expression for the dissociation.

(c) Calculate the value of $K_a$ for chloroethanoic acid.

(d) Arrange the following acids in increasing order of acid strength (starting with the weakest).
chloroethanoic acid  ethanoic acid  iodoethanoic acid

Order ....................................................................................................................................................... (Total 4 marks)

109. The indicator bromophenol blue, HIn(aq), has a form that is yellow and an In⁻(aq) form that is blue.

(a) Write an equation to show how bromophenol blue acts as an indicator.
........................................................................................................................................................................ (1)

(b) State and explain the colour of bromophenol blue

(i) on the addition of a strong acid.
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(ii) at the equivalence point of a titration.
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........................................................................................................................................................................
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........................................................................................................................................................................ (3)

(Total 4 marks)

110. (a) The dissociation of water takes place as follows:

\[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \]

(i) State the expression for the ionic product constant of water, \( K_w \).
........................................................................................................................................................................ (1)

(ii) The value of \( K_w \) is \( 2.4 \times 10^{-14} \) mol\(^2\) dm\(^{-6}\) at 310 K. Calculate the [H\(^+\)] at 310 K.
........................................................................................................................................................................ (1)

(b) Lactic acid CH\(_3\)CH(OH)COOH is a weak monoprotic acid
(\( pK_a = 3.85 \) and \( K_a = 1.4 \times 10^{-4} \) mol dm\(^{-3}\)).

(i) Write an equation for the reaction of lactic acid with water.
........................................................................................................................................................................ (1)

(ii) State the ionization constant expression, \( K_a \), for lactic acid.
(iii) Calculate the pH of a 0.20 mol dm$^{-3}$ solution of lactic acid.

(iv) Determine the pH of a solution containing 0.10 mol dm$^{-3}$ of lactic acid and 0.10 mol dm$^{-3}$ of sodium lactate.

111. (a) (i) Write the equation for the reaction of ammonia with water.

(ii) Derive the expression for $K_b$ for this reaction.

(b) Using information from Table 16 in the Data Booklet, determine the pOH of a 0.20 mol dm$^{-3}$ solution of ammonia.

112. Discuss how the acidic strength of 2,2-dimethylpropanoic acid and trichloroethanoic acid compare with ethanoic acid.
113. Benzoic acid, \( \text{C}_6\text{H}_5\text{COOH} \), is a weak acid.

(a) Deduce the equation for the ionization of benzoic acid in water.

(1)

(b) Use information from Table 16 in the Data Booklet to calculate a value for the dissociation constant, \( K_a \), for benzoic acid.

(1)

(c) Derive the ionization constant expression for benzoic acid and use it to determine the pH of a 0.20 mol dm\(^{-3}\) aqueous solution of benzoic acid.

(3)

114. Table 16 in the Data Booklet contains \( pK_a \) values for organic compounds.

(a) Write an equation for the dissociation of 2-nitrophenol in aqueous solution. Explain, with reference to its structure and this equation, why 2-nitrophenol is a stronger acid than phenol.

(3)

(b) Write an equation to show how methylamine acts as a base in aqueous solution. Explain, with reference to its structure and this equation, why dimethylamine is a stronger base than methylamine.

(3)

115. (a) (i) A solution of hydrochloric acid has a concentration of 0.10 mol dm\(^{-3}\) and a pH
value of 1. The solution is diluted by a factor of 100. Determine the concentration of the acid and the pH value in the diluted solution.

(ii) Explain why 0.10 mol dm\(^{-3}\) ethanoic acid solution and the diluted solution in (a) (i) have similar [H\(^+\)] values.

(b) Suggest one method, other than measuring pH, which could be used to distinguish between solutions of a strong acid and a weak acid of the same concentration. State the expected results.

116. The hydrogen ion concentration in pure water varies with temperature. At a particular temperature \([H^+] = 1.7 \times 10^{-7}\) mol dm\(^{-3}\).

(a) State the expression for the ionic product constant of water, \(K_w\), and calculate the value of \(K_w\) at this temperature.

(b) Calculate the pH of water at this temperature.

(c) State and explain whether water at this temperature is acidic, neutral or alkaline.
117. The pK_b values of some amines are shown in Table 15 of the Data Booklet. Write an equation for the reaction of ethylamine with water. State and explain how the basicity of ethylamine compares to that of ammonia.