1. Which pair of elements reacts most readily?
   A. Li + Br₂   B. Li + Cl₂   C. K + Br₂   D. K + Cl₂

2. Which of the following salts form coloured solutions when dissolved in water?
   I. ScCl₃   II. FeCl₃   III. NiCl₂   IV. ZnCl₂
   A. I and II only   B. II and III only   C. III and IV only   D. I, II, III and IV

3. The compounds Na₂O, Al₂O₃ and SO₂ respectively are
   A. acidic, amphoteric and basic.   B. amphoteric, basic and acidic.
   C. basic, acidic and amphoteric.   D. basic, amphoteric and acidic.

4. Which of the following properties of the halogens increase from F to I?
   I. Atomic radius   II. Melting point   III. Electronegativity
   A. I only   B. I and II only   C. I and III only   D. I, II and III

5. Which pair would react together most vigorously?
   A. Li and Cl₂   B. Li and Br₂   C. K and Cl₂   D. K and Br₂

6. Which properties of period 3 elements increase from sodium to argon?
   I. Nuclear charge   II. Atomic radius   III. Electronegativity
   A. I and II only   B. I and III only   C. II and III only   D. I, II and III

7. Which general trends are correct for the oxides of the period 3 elements (Na₂O to Cl₂O)?
   I. Acid character decreases.
   II. Electrical conductivity (in the molten state) decreases.
   III. Bonding changes from ionic to covalent.
   A. I and II only   B. I and III only   C. II and III only   D. I, II and III

8. For which element are the group number and the period number the same?
   A. Li   B. Be   C. B   D. Mg

9. Which of the physical properties below decrease with increasing atomic number for both the alkali metals and the halogens?
   I. Atomic radius   II. Ionization energy   III. Melting point
   A. I only   B. II only   C. III only   D. I and III only

10. Which of the reactions below occur as written?
    I. Br₂ + 2I⁻ → 2Br⁻ + I₂   II. Br₂ + 2Cl⁻ → 2Br⁻ + Cl₂
    A. I only   B. II only   C. Both I and II   D. Neither I nor II

11. Rubidium is an element in the same group of the periodic table as lithium and sodium. It is likely to be a metal which has a
    A. high melting point and reacts slowly with water.
    B. high melting point and reacts vigorously with water.
    C. low melting point and reacts vigorously with water.
    D. low melting point and reacts slowly with water.

12. When the following species are arranged in order of increasing radius, what is the correct order?
A. $\text{Cl}^-$, Ar, $\text{K}^+$  B. $\text{K}^+$, Ar, $\text{Cl}^-$  C. $\text{Cl}^-$, $\text{K}^+$, Ar  D. Ar, $\text{Cl}^-$, $\text{K}^+$

13. What increases in equal steps of one from left to right in the periodic table for the elements lithium to neon?
   A. the number of occupied electron energy levels
   B. the number of neutrons in the most common isotope
   C. the number of electrons in the atom
   D. the atomic mass

14. Which property decreases down group 7 in the periodic table?
   A. atomic radius  B. electronegativity  C. ionic radius  D. melting point

15. Which two elements react most vigorously with each other?
   A. chlorine and lithium  B. chlorine and potassium  C. iodine and lithium  D. iodine and potassium

16. Which is an essential feature of a ligand?
   A. a negative charge  B. an odd number of electrons  C. the presence of two or more atoms  D. the presence of a non-bonding pair of electrons

17. Which properties are typical of most non-metals in period 3 (Na to Ar)?
   I. They form ions by gaining one or more electrons.
   II. They are poor conductors of heat and electricity.
   III. They have high melting points.
   A. I and II only  B. I and III only  C. II and III only  D. I, II and III

18. A potassium atom has a larger atomic radius than a sodium atom. Which statement about potassium correctly explains this difference?
   A. It has a larger nuclear charge.
   B. It has a lower electronegativity.
   C. It has more energy levels occupied by electrons.
   D. It has a lower ionization energy.

19. Which equation represents the third ionization energy of an element M?
   A. $\text{M}^+(g) \rightarrow \text{M}^{2+}(g) + 3\text{e}^-$  B. $\text{M}^{2+}(g) \rightarrow \text{M}^{3+}(g) + \text{e}^-$
   C. $\text{M}(g) \rightarrow \text{M}^{3+}(g) + 3\text{e}^-$  D. $\text{M}^{3+}(g) \rightarrow \text{M}^{4+}(g) + \text{e}^-$

20. Which factors lead to an element having a low value of first ionization energy?
   I. large atomic radius
   II. high number of occupied energy levels
   III. high nuclear charge
   A. I and II only  B. I and III only  C. II and III only  D. I, II and III

21. Which statement about electronegativity is correct?
   A. Electronegativity decreases across a period.
   B. Electronegativity increases down a group.
   C. Metals generally have lower electronegativity values than non-metals.
   D. Noble gases have the highest electronegativity values.

22. Which statement is correct for a periodic trend?
   A. Ionization energy increases from Li to Cs.
   B. Melting point increases from Li to Cs.
   C. Ionization energy increases from F to I.
   D. Melting point increases from F to I.
23. Which compound of an element in period 3 reacts with water to form a solution with a pH greater than 7?
   A. SiO₂   B. SiCl₄   C. NaCl   D. Na₂O

24. Which electrons are lost by an atom of iron when it forms the Fe³⁺ ion?
   A. One s orbital electron and two d orbital electrons
   B. Two s orbital electrons and one d orbital electron
   C. Three s orbital electrons
   D. Three d orbital electrons

25. Which equation represents the first ionization energy of fluorine?
   A. F(g) + e⁻ → F⁻(g)
   B. F⁻(g) → F(g) + e⁻
   C. F⁺(g) → F(g) + e⁻
   D. F(g) → F⁺(g) + e⁻

26. Which properties are typical of d-block elements?
   I. complex ion formation
   II. catalytic behaviour
   III. colourless compounds
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

27. Which statement is correct for the halogen group?
   A. Halide ions are all reducing agents, with iodide ions being the weakest.
   B. Halogens are all oxidizing agents, with chlorine being the strongest.
   C. Chloride ions can be oxidized to chlorine by bromine.
   D. Iodide ions can be oxidized to iodine by chlorine.

28. Which of the following statements are correct?
   I. The melting points decrease from Li → Cs for the alkali metals.
   II. The melting points increase from F → I for the halogens.
   III. The melting points decrease from Na → Ar for the period 3 elements.
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

29. Which element is a transition metal?
   A. Ca   B. Cr   C. Ge   D. Se

30. When Na, K, and Mg are arranged in increasing order of atomic radius (smallest first), which order is correct?
   A. Na, K, Mg
   B. Na, Mg, K
   C. K, Mg, Na
   D. Mg, Na, K

31. Which oxides produce an acidic solution when added to water?
   I. SiO₂
   II. P₂O₅
   III. SO₂
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

32. Which combination of ion charge and ion size produces the greatest lattice enthalpy?
   A. High charge, large size
   B. High charge, small size
   C. Low charge, small size
   D. Low charge, large size

33. Which series is arranged in order of increasing radius?
   A. Ca²⁺ < Cl⁻ < K⁺
   B. K⁺ < Ca²⁺ < Cl⁻
   C. Ca²⁺ < K⁺ < Cl⁻
   D. Cl⁻ < K⁺ < Ca²⁺

34. Which salts form coloured solutions when dissolved in water?
   I. FeCl₃
   II. NiCl₂
   III. ZnCl₂
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
35. Which combination is correct for the complex ion in \([\text{Co(NH}_3\text{)}_4\text{(H}_2\text{O})\text{Cl}]\text{Br}\)?

<table>
<thead>
<tr>
<th>Oxidation state of cobalt</th>
<th>Shape of the complex ion</th>
<th>Overall charge of the complex ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. +2</td>
<td>Octahedral</td>
<td>+2</td>
</tr>
<tr>
<td>B. +3</td>
<td>Octahedral</td>
<td>-1</td>
</tr>
<tr>
<td>C. +2</td>
<td>Octahedral</td>
<td>+1</td>
</tr>
<tr>
<td>D. +2</td>
<td>Tetrahedral</td>
<td>+1</td>
</tr>
</tbody>
</table>

36. Describe the acid-base character of the oxides of the period 3 elements Na to Ar. For sodium oxide and sulfur trioxide, write balanced equations to illustrate their acid-base character.

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37. Table 6 of the Data Booklet lists melting points of the elements. Explain the trend in the melting points of the alkali metals, halogens and period 3 elements.

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38. (i) Explain how the first ionization energy of K compares with that of Na and Ar.

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(ii) Explain the difference between the first ionization energies of Na and Mg.

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(iii) Suggest why much more energy is needed to remove an electron from Na\(^+\) than from Mg\(^+\).

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(Total 8 marks)

39. Define the term ligand. \(\text{Cu}^{2+}(\text{aq})\) reacts with ammonia to form the complex ion

\(\text{Cu(NH}_3\text{)}_4\text{Cl}^+\)
[Cu(NH₃)₄]²⁺. Explain this reaction in terms of an acid-base theory, and outline the bonding in the complex ion formed between Cu²⁺ and NH₃.

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(Total 4 marks)

40. Nitrogen is found in period 2 and group 5 of the periodic table.
   (i) Distinguish between the terms period and group.

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(1)

(ii) State the electron arrangement of nitrogen and explain why it is found in period 2 and group 5 of the periodic table.

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(3)

(Total 4 marks)

41. Table 8 of the Data Booklet gives the atomic and ionic radii of elements. State and explain the difference between
   (i) the atomic radius of nitrogen and oxygen.

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(2)

(ii) the atomic radius of nitrogen and phosphorus.

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(1)

(iii) the atomic and ionic radius of nitrogen.

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(Total 5 marks)

42. State and explain the trends in the atomic radius and the ionization energy
   (i) for the alkali metals Li to Cs.
for the period 3 elements Na to Cl.

43. (i) Describe three similarities and one difference in the reactions of lithium and potassium with water.

(ii) Give an equation for one of these reactions. Suggest a pH value for the resulting solution, and give a reason for your answer.

44. (a) Classify each of the following oxides as acidic, basic or amphoteric.

   (i) aluminium oxide

   (ii) sodium oxide

   (iii) sulfur dioxide

(b) Write an equation for each reaction between water and

   (i) sodium oxide

   (ii) sulfur dioxide.

45. By reference to the structure and bonding in the compounds NaCl and SiCl₄
(i) state and explain the differences in conductivity in the liquid state.

...........................................................................................................................(3)

(ii) predict an approximate pH value for a solution formed by adding each compound separately to water.

...........................................................................................................................(4)

(Total 7 marks)

46. Two characteristics of the d-block (transition) elements are that they exhibit variable oxidation states and form coloured compounds.

(i) State two possible oxidation states for iron and explain these in terms of electron arrangements.

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

(ii) Explain why many compounds of d-block (transition) elements are coloured.

...........................................................................................................................(3)

(Total 5 marks)

47. This question is about Period 3 elements and their compounds.

(a) Explain, in terms of their structure and bonding, why the element sulfur is a non-conductor of electricity and aluminium is a good conductor of electricity.

...........................................................................................................................(4)

(b) Explain, in terms of its structure and bonding, why silicon dioxide, SiO_2, has a high melting point.

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

(Total 6 marks)

48. Silicon tetrachloride, SiCl_4, reacts with water to form an acidic solution.

(i) Explain why silicon tetrachloride has a low melting point.

..........................................................................................................................
Write an equation for the reaction of silicon tetrachloride with water.

(2)

49. Explain why
   (i) the first ionization energy of magnesium is lower than that of fluorine.
   (2)
   (ii) magnesium has a higher melting point than sodium.
   (3)

(Total 5 marks)

50. Discuss the acid-base nature of the period 3 oxides. Write an equation to illustrate the reaction of one of these oxides to produce an acid, and another equation of another of these oxides to produce a hydroxide.

(Total 5 marks)

51. Information about the halogens appears in the Data Booklet.
   (i) Explain why the ionic radius of chlorine is less than that of sulfur.
   (2)
   (ii) Explain what is meant by the term electronegativity and explain why the electronegativity of chlorine is greater than that of bromine.
   (3)

(Total 5 marks)

52. Magnesium chloride and silicon(IV) chloride have very different properties.
   (i) Give the formula and physical state at room temperature of each chloride.
   (2)
   (ii) State the conditions under which, if at all, each chloride conducts electricity.
   (2)
   (iii) Each chloride is added to water in separate experiments. Suggest an approximate pH value for the solution formed, and write an equation for any reaction that occurs.
   (3)

(Total 7 marks)

53. The elements in the d-block in the periodic table have several characteristics in common.
   (i) Give the electronic configuration of Ni^{2+}.
   (1)
   (ii) Explain what is meant by a ligand, and describe the type of bond formed between a ligand and a d-block element.
   (2)
   (iii) Determine the oxidation numbers of copper in the species
   \[ [\text{Cu(NH}_3)_4]^2+ \] and \[ [\text{CuCl}_4]^2- \]
   (2)
   (iv) Explain why the species in (iii) are coloured.
   (3)
   (v) Identify the d-block element used as a catalyst in the Haber process and write an equation for the reaction occurring.
   (2)

(Total 10 marks)

54. (a) (i) State the meaning of the term electronegativity and explain why the noble gases are not assigned electronegativity values.
   (2)
   (ii) State and explain the trend in electronegativity across period 3 from Na to Cl.
   (2)
   (iii) Explain why Cl₂ rather than Br₂ would react more vigorously with a solution of I⁻. 
   (2)
(b) State the acid-base properties of the following period 3 oxides.

\[
\text{MgO} \quad \text{Al}_2\text{O}_3 \quad \text{P}_4\text{O}_{10}
\]

Write equations to demonstrate the acid-base properties of each compound.

55. (i) Define the term ionization energy.

(ii) Write an equation for the reaction of lithium with water.

(iii) State and explain the trend in the ionization energy of alkali metals down the group.

(iv) Explain why the electronegativity of phosphorus is greater than that of aluminium.

(v) Table 8 in the Data Booklet contains two values for the ionic radius of silicon. Explain, by reference to atomic structure and electron arrangements, why the two values are very different.

(Total 13 marks)

56. Explain why sulfur has a lower first ionization energy than oxygen, and also a lower first ionization energy than phosphorus.

(Total 11 marks)

57. With reference to the types of bonding present in period 3 elements:

(i) explain why Mg has a higher melting point than Na.

(ii) explain why Si has a very high melting point.

(iii) explain why the other non-metal elements of period 3 have low melting points.

(Total 6 marks)

58. (i) Explain why complexes of Zn\(^{2+}\) are colourless whereas complexes containing Cu\(^{2+}\) are coloured.

(ii) Give the formula and describe the shape of the complex ion formed between Fe\(^{3+}\) and the ligand CN\(^{-}\).

(Total 5 marks)

59. Describe the acid-base character of the oxides of the period 3 elements Na to Ar. For sodium oxide and sulfur trioxide, write balanced equations to illustrate their acid-base character.

(Total 3 marks)

60. Consider the transition metal complex, K\(_3\)[Fe(CN)\(_6\)].

(i) Define the term ligand, and identify the ligand in this complex.

(ii) Write the full electron configuration and draw the orbital box diagram of iron in its oxidation state in this complex, and hence, determine the number of unpaired electrons in this state.

(iii) Explain why many transition metal d-block complexes are coloured.

(Total 7 marks)

61. By reference to the structure and bonding in NaCl and SiCl\(_4\):

(i) State and explain the differences in electrical conductivity in the liquid state.

(ii) Predict an approximate pH value for the solutions formed by adding each compound separately to water. Explain your answer.

(Total 7 marks)
62. Explain the following statements.

(a) The first ionization energy of sodium is
   (i) less than that of magnesium. (2)
   (ii) greater than that of potassium. (1)

(b) The electronegativity of chlorine is higher than that of sulfur. (2)

63. The following table shows values that appear in the Data Booklet.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Covalent (atomic) radii /10^{-12} m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Na</td>
<td>70</td>
</tr>
<tr>
<td>Mg</td>
<td>160</td>
</tr>
<tr>
<td>Al</td>
<td>143</td>
</tr>
<tr>
<td>Si</td>
<td>117</td>
</tr>
<tr>
<td>P</td>
<td>110</td>
</tr>
<tr>
<td>S</td>
<td>104</td>
</tr>
<tr>
<td>Cl</td>
<td>99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Ionic radii/10^{-12} m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N^{3-}</td>
</tr>
<tr>
<td>Na^{+}</td>
<td>171</td>
</tr>
<tr>
<td>Mg^{2+}</td>
<td>65</td>
</tr>
<tr>
<td>Al^{3+}</td>
<td>98</td>
</tr>
<tr>
<td>Si^{4+}</td>
<td>212</td>
</tr>
</tbody>
</table>

Explain why
(i) the magnesium ion is much smaller than the magnesium atom. (2)
(ii) there is a large increase in ionic radius from silicon to phosphorus. (2)
(iii) the ionic radius of Na^{+} is less than that of F^{-}. (2)

64. Elements with atomic number 21 to 30 are d-block elements.

(a) Identify which of these elements are not considered to be typical transition elements. (1)

(b) Complex ions consist of a central metal ion surrounded by ligands. Define the term ligand. (2)

(c) Complete the table below to show the oxidation state of the transition element. (3)

<table>
<thead>
<tr>
<th>ion</th>
<th>Cr_{7}O_{7}^{2-}</th>
<th>[CuCl_{4}]^{2-}</th>
<th>[Fe(H_{2}O)_{6}]^{3+}</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxidation state</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(d) Identify two transition elements used as catalysts in industrial processes, stating the process in each case. (2)

(e) Apart from the formation of complex ions and apart from their use as catalysts, state two other properties of transition elements. (2)

65. (a) (i) Define the term ionization energy. (2)
   (ii) Write an equation, including state symbols, for the process occurring when measuring the first ionization energy of aluminium. (2)

(b) The first ionization energies of the elements are shown in Table 7 of the Data Booklet. Explain why the first ionization energy of magnesium is greater than that of sodium. (2)

(c) Lithium reacts with water. Write an equation for the reaction and state two observations that could be made during the reaction. (2)
66. (a) State the meaning of the term *electronegativity*.

(b) State and explain the trend in electronegativity across period 3 from Na to Cl.

(c) Explain why Cl₂ rather than Br₂ would react more vigorously with a solution of I⁻.
67. D
68. B
69. D
70. B
71. C
72. B
73. C
74. B
75. B
76. A
77. C
78. B
79. C
80. B
81. B
82. D
83. A
84. C
85. B
86. A
87. C
88. D
89. D
90. B
91. D
92. A
93. D
94. A
95. B
96. D
97. C
98. B
99. C
100. A
101. C

102. oxides of: Na, Mg: basic;
    Al: amphoteric;
    Si to Cl: acidic;
    Ar: no oxide;
    All four correct [2], two or three correct [1].

    \[
    \text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH};
    \]
    \[
    \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4;
    \]

    *Must be balanced for marks.*
    Award marks for alternative correct equations such as \text{SO}_3 with \text{NaOH}.

103. *alkali metals:*
    metallic bonding/a bed of cations in a sea of electrons;
    as radius increases down the group, valence electrons are further away from
    nucleus (and strength of metallic bonding decreases);

    *halogens:*
    non-polar/van der Waals’ forces between molecules;
    as size increases van der Waals’ forces increase (and melting point increases);

    *period 3 elements:
increase in melting points of metals (Na, Mg, Al) due to increase in number of
valence electrons and decrease in size/the way atoms are packed as solids;
Award mark just for “increased number of delocalized or valence electrons”.
silicon:
network covalent solid (with very high melting point);
Award mark also for “many or strong covalent bonds”.

P → Ar:
simple molecular (atomic in case of Ar) substances with weak van
der Waals’ forces (and lower melting points);
trend in P₄, S₈, Cl₂, Ar due to size/mass of particles;
Award mark for “decreasing mass or size”.
Molecular formulae not necessary.

104. (i) and (ii) marked together.

K less than Na because
electron removed (from K) is from higher energy level/further from
nucleus/in n = 4 compared to n = 3;
this is more important than the extra 8 protons in K/OWTTE;
increase repulsion by extra shell of electrons/greater shielding effect;
so less strongly attracted by nucleus;

K less than Ar because
electron removed (from K) is from higher energy level/further from nucleus/
in n = 4 compare to n = 3;
and has only one more proton;
increase repulsion by extra shell of electrons/greater shielding effect;
so less strongly attracted by nucleus;

Mg greater than Na because
(Mg has) greater nuclear charge/one more proton/12 protons compare to 11;
electron removed is in same (main) higher energy level/shell;
smaller (atomic) radius;
so more strongly attracted by nucleus;
Accept opposite worded arguments, i.e. why Na is
greater than K.
Award [7] for any seven correct but accept less/more
strongly attracted to nucleus once only.

(iii) second electron in Na removed from n = 2, whereas second electron in Mg
removed from n = 3

105. ligand: a molecule or ion that can bond to a (central) metal ion
(to form a complex);
NH₃: Lewis base and Cu²⁺: Lewis acid (need both for mark);
each NH₃/ligand donates an electron pair (to Cu²⁺);
forming coordinate covalent/dative covalent bond;

106. (i) period is a horizontal row in the periodic table and a group is a
vertical column/OWTTE;
(ii) 2.5;
electrons in two energy levels/shells;
five outer/valence electrons;

107. (i) atomic radius of N > O because O has greater nuclear charge;
greater attraction for the outer electrons/OWTTE;
(ii) atomic radius of P > N because P has outer electrons in an energy
level further from the nucleus/OWTTE;
(iii) N³⁻ > N/ionic radius > atomic radius because N³⁻ has more electrons
than protons; so the electrons are held less tightly/OWTTE;
Award [1] for greater repulsion in N³⁻ due to more electrons (no reference to
protons).

108. (i) Li to Cs
atomic radius increases;
because more full energy levels are used or occupied/outer electrons
Further from nucleus/outer electrons in a higher shell; ionization energy decreases; because the electron removed is further from the nucleus/increased repulsion by inner-shell electrons; 

Accept increased shielding effect.

(ii) Na to Cl
atomic radius decreases; because nuclear charge increases and electrons are added to same main (outer) energy level; ionization energy increases; because nuclear charge increases and the electron removed is closer to the nucleus/is in the same energy level;

Accept “core charge” for “nuclear charge”.

In (i) and (ii) explanation mark dependent on correct trend.

109. (i) similarities [3 max]
the metal floats/moves on the surface; fizzing/effervescence/bubbles; (accept sound is produced) solution gets hot; solution becomes alkaline/basic; they react to form the metal hydroxide; hydrogen is evolved;
differences [1 max]
flame/hydrogen burns with potassium (and not with lithium)/reaction faster/more vigorous with potassium/slower or less vigorous with lithium;

(ii) 

2Li + 2H₂O → 2Li⁺ + 2OH⁻ + H₂ / 2K + 2H₂O → 2K⁺ + 2OH⁻ + H₂;

Accept LiOH/KOH.

pH ≥ 11; LiOH/KOH is a strong base/strong alkali/high concentration of OH⁻;

110. (a) (i) aluminium oxide
amphoteric;
(ii) sodium oxide
basic;
(iii) sulfur dioxide
acidic;

(b) (i) Na₂O + H₂O → 2Na⁺ + 2OH⁻;
(ii) SO₂ + H₂O → H₂SO₃;

Accept NaOH and H⁺ + HSO₃⁻ / 2H⁺ + SO₃²⁻.

111. (i) NaCl conducts and SiCl₄ does not; NaCl ionic and SiCl₄ covalent; ions can move in liquid (in NaCl)/OWTTE;

(ii) NaCl pH = 7;
salt of strong acid and strong base/Na⁺ and Cl⁻ not hydrolysed; SiCl₄ pH = 0 to 3;
HCl is formed/strong acid formed;

112. (i) +2 and +3/Fe²⁺ and Fe³⁺; both s electrons are lost giving Fe²⁺ and one more d electron is also lost to form Fe³⁺;

(ii) presence of unpaired electrons;
the d orbitals are split into two energy levels; electrons move between these energy levels; electrons can absorb energy from light of visible wavelength /OWTTE;

Award [1] each for any three.

113. (a) sulfur is (simple) molecular; (contains) covalent bonds/no delocalized electrons/all (outer) electrons used in bonding; aluminium contains positive ions and delocalized electrons;
(delocalized) electrons move (when voltage applied or current flows);  

(b) silicon dioxide is macromolecular/giant covalent;  
many/strong covalent bonds must be broken;  

Award max [1] if no mention of covalent.  
Do not accept weakened instead of broken.

114. (i) van der Waals’ forces (between molecules);  

Accept London or dispersion forces or temporary dipole-dipole attractions.  

(these forces are) weak/easily overcome;  

(ii) $\text{SiCl}_4 + 4\text{H}_2\text{O} \rightarrow \text{Si(OH)}_4 + 4\text{HCl}$;  

Ignore state symbols, accept $\text{SiO}_2.2\text{H}_2\text{O}$ or $\text{H}_4\text{SiO}_4$ as product.  

115. (i) electron removed from higher energy level/further from nucleus/  
greater atomic radius;  
increased repulsion by extra inner shell electrons/increased shielding effect;  

(ii) Mg has twice as many/more delocalized electrons (compared to Na);  
the ionic charge is twice as big/greater in Mg (than Na);  
(electrostatic) attraction between ions and electrons is much greater;  

116. oxides of Na, Mg are basic  
Al is amphoteric  
Si, P, S and Cl are acidic  

Award 7 correct [3], 6/5 correct [2] and 4/3 correct [1].  

$\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3/\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$  

$\text{P}_2\text{O}_{10} + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4/\text{P}_2\text{O}_4 + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4$;  

$\text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH}/\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg(OH)}_2$;  

Accept equation using $\text{P}_2\text{O}_5$ or $\text{P}_2\text{O}_3$.  

117. (i) (chlorine has) an extra proton/more protons/greater nuclear charge/  
greater atomic radius;  
out electrons attracted more strongly;  

(ii) ability of atom to attract bonding pair of electrons/electrons in a  
covalent bond;  
chlorine has a smaller radius/(electrons) closer to nucleus/in lower  
energy level;  
repelled by fewer inner electrons/decreased shielding effect;  

118. (i) MgCl$_2$ and SiCl$_4$;  
MgCl$_2$ solid and SiCl$_4$ liquid;  

(ii) MgCl$_2$ (conducts electricity) when molten/dissolved in water;  
SiCl$_4$ does not conduct (under any conditions);  

(iii) MgCl$_2$ pH value in range 5.0 to 6.9/just under 7;  
SiCl$_4$ pH value in range 0 to 3;  

SiCl$_4 + 4\text{H}_2\text{O} \rightarrow \text{Si(OH)}_4 + 4\text{HCl}/\text{SiO}_2.2\text{H}_2\text{O} + 4\text{HCl}$;  

Do not accept SiCl$_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl}$.  

119. (i) Ni$^{2+}$ $1s^22s^22p^63s^23p^6$ $[\text{Ar}]3d^8$;  

(ii) species with lone pair of electrons used to bond with the ion;  
co-ordinate bond/dative (covalent) bond;  

(iii) +2;  

Accept 2+ but not 2 or II.  

(iv) d orbitals/sub-levels (in complexes) split (into two sets at different  
energy levels);  
energy difference corresponds to frequency/wavelength of (part of)  
visible light;  
part of visible spectrum absorbed by electrons;  
when they move between energy levels;
OWTTE for all of the above.

Award [1] each for any two of the last three.

(v) iron:
\[ \text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3; \]

No penalty for \[ \rightarrow \].

120. (a) (i) the ability of an atom to attract a bonding pair of electrons; inert/do not react/do not attract electrons/stable electron configuration/full outer electron shell/do not form bonds; 2

(ii) electronegativity increases (along period 3 from \( \text{Na to Cl} \)); number of protons increases/nuclear charge increase/core charge increase/size of atom decreases;

\[ \text{Do not accept } \text{“greater nuclear attraction”.} \]

(iii) \( \text{Cl}_2 \) stronger oxidising agent;
\( \text{Cl}_2 \) has greater attraction for electrons/has a higher electron affinity;

Accept converse statements for \( \text{Br}_2 \). 2

(b) \( \text{MgO} \) – basic oxide/alkali;
\( \text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O} \);
\( \text{Al}_2\text{O}_3 \) – amphoteric oxide/acidic and basic oxide;
\( \text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2\text{O}; \)
\( \text{P}_2\text{O}_5 \) – acidic oxide;
\( \text{P}_2\text{O}_5 + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4; \]

All equations must be balanced.

State symbols not required

121. (i) minimum energy required to remove one (mole of) electron(s) from (one mole of) (a) gaseous atom(s) OWTTE; 1

(ii) \( 2\text{Li(s)} + 2\text{H}_2\text{O(1)} \rightarrow 2\text{LiOH(aq)} + \text{H}_2(\text{g}); \)
\( + 1/2\text{H}_2(\text{g}); \)

\[ \text{State symbols not required} \]

(iii) (ionization energy) decreases;

radius increases/valence electrons further away from nucleus/electron removed from higher shell;
(nuclear charge increases but) shielding/screening effect increases/more electrons between nucleus and valence electron/lower effective nuclear charge/\( Z_{\text{eff}} \);

(iv) phosphorus has a higher (effective) nuclear charge/\( Z_{\text{eff}} \);

radius of \( \text{P} \) is smaller;
electron pair/bonding electrons attracted more strongly; 2

(v) both have same number of protons/14 protons/nuclear charge/core charge;
\( \text{Si}^{4+} \) formed by electron loss, \( \text{Si}^{4+} \) formed by electron gain;
\( \text{Si}^{4+} : 2.8 \) arrangement/2 (complete) energy levels/electrons in \( n = 2; \)
\( \text{Si}^{4+} : 2.8.8 \) arrangement/3 (complete) energy levels/electrons in \( n = 3; \)

explanation of proton : electron ratio;

higher effective nuclear charge/\( Z_{\text{eff}} \) in \( \text{Si}^{4+} \); 4

122. \( \text{IE}_3 < \text{IE}_0 \):

valence electron in \( \text{S} \) in \( n = 3; \) in \( \text{O} \) in \( n = 2; \) further away/\( \text{S} \) has another electron shell/atomic radius of \( \text{S} \) greater than that of \( \text{O}; \)

less attracted to nucleus/experiences greater screening from inner electrons;

\( \text{IE}_3 < \text{IE}_0 \);

electron removed from \( \text{S} \) is paired;
greater repulsion due to two electrons in the same (p) orbital/paired electrons in \( \text{S}; \) 4

123. (i) \( \text{Mg} \) has greater nuclear charge/greater charge on cation/more valence \( e^- \)/greater number of delocalized electrons/\( \text{Na} \) has lesser nuclear charge/lesser charge on cation/less valence \( e^- \)/lesser number of delocalized electrons; stronger attraction between cation and delocalized/electrons.
free/valence electrons; 2
If neither mark scored, accept stronger metallic bonding in Mg for [1 max].

(ii) giant/network/lattice/macromolecular structure; 2
many/strong covalent bonds (need to be broken);

(iii) (simple) molecular substances; 2
weak van der Waals'/dispersion/London forces between molecules;
“Weak intermolecular forces” not sufficient for second mark

124. (i) Zn$^{2+}$ has full d sub-shell / Zn$^{2+}$ does not have partially filled d sub-shell/orbitals; 3
d orbitals are split (into two sets of different energy levels);
colour due to electron transition between (split) d orbitals;

(ii) [Fe(CN)$_6$]$^{3-}$; 2
octahedral/suitable diagram;
Accept square bipyramidal

125. Oxides of: Na and Mg are basic;
Al is amphoteric;
Si to Cl are acidic;
Ar has no oxide;
All four correct award [2], two or three correct award [1].

Na$_2$O + H$_2$O $\rightarrow$ 2NaOH and SO$_3$ + H$_2$O $\rightarrow$ H$_2$SO$_4$; 3
Must be balanced for mark.
Award marks for alternative correct equations such as SO$_3$ with NaOH.

126. (i) an ion or molecule, with a lone pair of electrons that coordinates to a metal atom or to a metal ion to form a complex/(OWTTE) and cyanide/CN$^-$; 1

(ii) Fe$^{3+}$ = 1$s^2$, 2$s^2$, 2$p^6$, 3$s^2$, 3$p^6$, 3$d^5$;
[Ar] $\uparrow\uparrow\uparrow\uparrow\uparrow\uparrow$ ; 2 max
5 unpaired electrons;

(iii) presence of unpaired electrons; 3
the d orbitals are split into two energy levels;
electrons move between these energy levels;
absorb energy from light of visible wavelength/OWTTE;
Award [1] each for any three.

127. (i) NaCl conducts and SiCl$_4$ does not;
NaCl ionic and SiCl$_4$ covalent;
ions can move in liquid (in NaCl); 3

(ii) NaCl pH = 7;
salt of strong acid and strong base/Na$^+$ and Cl$^-$ not hydrolysed;
SiCl$_4$ pH = 0 to 3;
HCl is formed/strong acid formed; 4

128. (a) (i) Na has lower nuclear charge/number of protons; electrons being removed are from same energy level/shell;
or Na has larger radius/electron further from nucleus; 2 max
Award this mark if both electron arrangements are given.

(ii) Na electron closer to nucleus/in lower energy level/Na has less shielding effect; 1
Allow counter arguments for Mg in (i) and K in (ii).

(b) chlorine has a higher nuclear charge; 2
attracts the electron pair/electrons in bond more strongly;

129. (i) loss of 2 electrons/outer electrons; 2 max
3 shells to 2;
net attractive force increases;

(ii) P$^3$ has one more shell than Si$^{4+}$; 2 max
some justification in terms of electron loss/gain;
net attractive forces;
(iii) same electron arrangement/both have two complete shells;  
extra protons in Na\(^+\) (attract the electrons more strongly);  
\[6\]  
130. (a) scandium and zinc/Sc and Zn;  
Both needed for the mark.  
Accept copper/Cu if given in addition to Sc and Zn i.e. all three needed for the mark.  
(b) species/neural molecules/anions which contain a non-bonding pair of electrons; able to form coordinate/dative covalent bonds;  
(c)  
<table>
<thead>
<tr>
<th>ion</th>
<th>oxidation state</th>
<th>Cr(_2)O(_7)(^{2-})</th>
<th>2[CuCl(_4)](^{2-})</th>
<th>[Fe(H(_2)O)(_6)]^{3+})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>+6</td>
<td>+2</td>
<td>+3</td>
</tr>
</tbody>
</table>
Accept 6+, 2+, 3+. If given as 6, 2, 3 or (VI), (II), (III), Award [2] only.  
(d) V/V\(_2\)O\(_3\) in the contact process;  
Fe in the Haber process;  
Ni in the conversion of alkenes to alkanes/hydrogenation reactions;  
Award [1] each for any two.  
Accept any other suitable examples.  
(e) variable oxidation states; coloured compounds;  
Accept any other suitable examples.  
131. (a) (i) the (minimum) energy required/needed for the removal of one electron; from a gaseous/isolated atom;  
(ii) Al(g) \(\rightarrow\) Al\(^+(g) + e;\)  
Do not penalize the answer if (g) is after e.  
(b) greater nuclear charge/greater number of protons/atom radius g is smaller;  
stronger attraction (for electron);  
(c) 2Li + 2H\(_2\)O \(\rightarrow\) 2LiOH + H\(_2\);  
effervescence/fizzing/bubbles/OWTTE;  
lithium moves around/decrease in size of piece;  
Accept dissolves or disappears.  
heat produced;  
Award [1] each for any two of last three observations.  
132. (a) the ability of an element/atom/nucleus to attract a bonding pair of electrons;  
(b) electronegativity increases (along period 3 from Na to Cl);  
number of protons increases/nuclear charge increases/core charge increases  
size of atoms decreases;  
Do not accept greater nuclear attraction.  
(c) Cl\(_2\) is a stronger oxidizing agent/Chlorine’s outer shell closer to nucleus;  
Cl\(_2\) has greater attraction for electrons/has a higher electron affinity;  
Accept converse argument for Br\(_2\).  
[5]