Structure and bonding in aluminium chloride

Specification reference

- *2.2.2 a) b) c) d) e) (i) g) h) j) (i)*

Introduction

This activity would make an interesting review or revision exercise at the end of work on bonding and structure in 'Chapter 5: Electrons and bonding'. It may be also be used to introduce higher ability students to the idea that ionic and covalent bonding should not be regarded as discrete types of interaction but represent extremes of bonding type on a continuum. Some of the activities, such as the dot-and-cross diagrams of the ionic compound and the simple $AlCl_3$ molecule are straightforward in themselves, whereas the bonding and structure of Al_2Cl_6 will require more thought. At the end of the activity are some more open-ended questions which may lead interested students into a discussion of the idea of the polarisation of ions by the small, highly charged aluminium ions, although this is beyond the scope of the specification.

Learning outcomes

After completing the worksheet students should be able to:

- construct dot-and cross diagrams for ionic and covalent compounds
- explain the structure of giant ionic lattices, resulting from oppositely charged ions strongly attracted in all directions
- explain the effect of structure and bonding on the physical properties of ionic and covalent compounds
- predict and explain the shapes of molecules, using electron pair repulsion theory
- draw 3D diagrams of molecules.

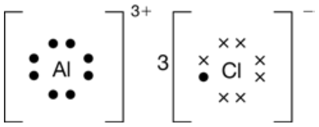
Teacher notes

- Question **1** begins with a straightforward ionic dot-and-cross diagram. The idea of drawing 3D structures to show the arrangement of negative ions around a positive ion in an ionic lattice may not be familiar to all students. It may be helpful for students to be told to represent the 'ionic bond' by a line between the ions much as they do in drawing covalent molecules, although they may need warning that this should be used with caution in other situations. Predicting the number of Al^{3+} ions around the Cl^{-} ion may prove tricky. This goes beyond the requirements of the specification, but would be interesting for students to think about. To support this, teachers could compare the situation to the more familiar sodium chloride lattice where each ion has a co-ordination number of six, consistent with the 1:1 ratio of the ions in the lattice.
- Question **2** should be a very accessible task; students are likely to be familiar already with the analogous compound BF_3.
- The most difficult aspect of question **3** is likely to be the drawing of the 3D structure. It is probably helpful to approach the drawing in three stages, starting by showing a tetrahedral arrangement of bonds around one of the aluminium atoms, then a non-linear arrangement of bonds around the 'bridging' chlorine atoms and finally another tetrahedral arrangement of bonds around the second aluminium. It can be suggested to students that they draw the Al–Cl–Al arrangements in the plane of the paper, leaving the remaining Al–Cl bonds to be shown using the wedge and dotted-line convention. Although electron pair repulsion theory suggests that the structure would have tetrahedral bond angles, published data suggests that the Al–Cl–Al bond angle may be less than 50° and the Cl–Al–Cl bond angles in the range 106–123°.

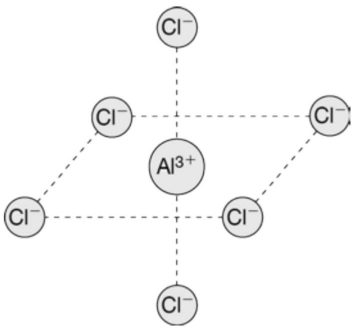
- In question **4**, students apply information provided in the passage to discuss the extent to which aluminium chloride can be considered ionic. The reaction with water could provide some interesting points for discussion with confident students; initially water molecules replace Cl^- ions in the ionic lattice, bonding via dative covalent bonds to the aluminium ion. This may decompose to form HCl, according to the equation:
  $Al(H_2O)_6Cl_3 \rightarrow Al(OH)_3 + 3\ HCl + 3\ H_2O$
- On addition of excess water, $Al(H_2O)_6^{3+}$ (aq) and Cl^-(aq) are released into solution. The $Al(H_2O)_6^{3+}$ is acidic, releasing H^+ and forming $Al(H_2O)_5(OH)^{2+}$.
- The final part of this question, which goes beyond the specification, will require some knowledge of trends in ionic size within the periodic table; students are unlikely to be able to suggest how the small ionic size and high charge may cause covalent character to exist in ionic bonds, but teachers may wish to discuss this with suitable students. Alternatively, it may be left out of the activity or set as a research task.

Answers

1 **a** Both ions correct (*1 mark*)
charges correct on both ions (*1 mark*)

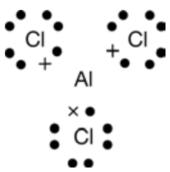


b 6 Cl^- ions around Al^{3+} (*1 mark*)
arrangement is clearly 3-dimensional and octahedral (*1 mark*)



c There are six Cl^- ions around each Al^{3+}. (*1 mark*)
So two Al^{3+} ions surround each Cl^- ion, giving an Cl : Al ratio of 3 : 1 (*1 mark*)
Students may find this difficult to visualise; please see the first bullet point in Teacher notes for guidance.

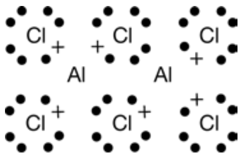
2 **a** Al outer shell correct (*1 mark*)
all Cl atoms correct (*1 mark*)



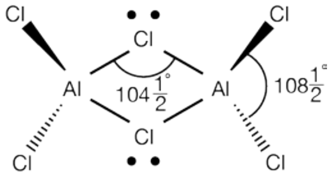
b Trigonal / triangular planar (*1 mark*)
120^o (*1 mark*)

3 **a** Dative (or co-ordinate) bond. (*1 mark*)
A covalent bond in which both electrons are provided by the chlorine atom. (*1 mark*)

b Dative bonds shown correctly from chlorine to aluminium. (*1 mark*)
Rest of structure correct. (*1 mark*)



c Bonds around Al drawn to look tetrahedral (*1 mark*)
one Cl–Al–Cl bond angle marked in range 100–115° (*1 mark*)
one Al–Cl–Al bond marked in range 95–110° (smaller than Cl–Al–Cl angle). (*3 marks*)



4 a

Question	Answer	Marks	Guidance
4 a	**Level 3 (5–6 marks)** One similarity and one difference clearly identified. AND For each difference there is clear link to the behaviour of ions or covalent molecules. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3-4 marks)** One similarity or difference clearly identified. AND Reference to the behaviour of ions / covalent molecules, with an attempt to link to the property under discussion. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1-2 marks)** Reference is made to a similarity or difference, but some details may be missing. AND Some relevant mention of the behaviour of ions / covalent molecules but this is not clearly linked to the similarity / difference. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** *No response or no response worthy of credit*	6	Similar to other ionic compounds: solid soluble in water (as described in passage) OR will conduct when in solution different to other ionic compounds: will not conduct electricity when molten) Discussion: Charged ions are present in solid; Ions will be attracted to water molecules; Ions will move in response to electric field; Covalent molecules / No charged ions present in liquid Will not attract water Will not move in response to electric field

b Aluminium ions (3+) have a higher charge than magnesium ions (2+). (*1 mark*)
Aluminium ions are smaller than magnesium ions. (*1 mark*)

This high 'charge density' means that electrons in the chloride ion can be attracted towards the aluminium ion, causing a distortion of the chloride ion (called polarisation of the ion). As a result, there is some electron density between the aluminium and chloride ions and this creates some covalent character in the bond.