Topic 4: Chemical bonding and structure

13.5 hours

Essential idea: Ionic compounds consist of ions held together in lattice structures by ionic bonds.

4.1 Ionic bonding and structure

Nature of science:

Use theories to explain natural phenomena—molten ionic compounds conduct electricity but solid ionic compounds do not. The solubility and melting points of ionic compounds can be used to explain observations. (2.2)

Understandings:

- Positive ions (cations) form by metals losing valence electrons.
- Negative ions (anions) form by non-metals gaining electrons.
- The number of electrons lost or gained is determined by the electron configuration of the atom.
- The ionic bond is due to electrostatic attraction between oppositely charged ions.
- Under normal conditions, ionic compounds are usually solids with lattice structures.

Applications and skills:

- Deduction of the formula and name of an ionic compound from its component ions, including polyatomic ions.
- Explanation of the physical properties of ionic compounds (volatility, electrical conductivity and solubility) in terms of their structure.

Guidance:

- Students should be familiar with the names of these polyatomic ions: NH_4^+, OH^-, NO_3^-, HCO_3^-, CO_3^{2-}, SO_4^{2-} and PO_4^{3-}.

Theory of knowledge:

- General rules in chemistry (like the octet rule) often have exceptions. How many exceptions have to exist for a rule to cease to be useful?
- What evidence do you have for the existence of ions? What is the difference between direct and indirect evidence?

Utilization:

- Ionic liquids are efficient solvents and electrolytes used in electric power sources and green industrial processes.

Syllabus and cross-curricular links:
Topic 3.2—periodic trends
Topic 21.1 and Option A.8—use of X-ray crystallography in structural determinations
Physics topic 5.1—electrostatics

Aims:

- **Aim 3**: Use naming conventions to name ionic compounds.
- **Aim 6**: Students could investigate compounds based on their bond type and properties or obtain sodium chloride by solar evaporation.
- **Aim 7**: Computer simulation could be used to observe crystal lattice structures.

Essential idea: Covalent compounds form by the sharing of electrons.

4.2. Covalent bonding

Nature of science:

Looking for trends and discrepancies—compounds containing non-metals have different properties than compounds that contain non-metals and metals. (2.5)

Use theories to explain natural phenomena—Lewis introduced a class of compounds which share electrons. Pauling used the idea of electronegativity to explain unequal sharing of electrons. (2.2)

Understandings:

- A covalent bond is formed by the electrostatic attraction between a shared pair of electrons and the positively charged nuclei.
- Single, double and triple covalent bonds involve one, two and three shared pairs of electrons respectively.
- Bond length decreases and bond strength increases as the number of shared electrons increases.
- Bond polarity results from the difference in electronegativities of the bonded atoms.

Applications and skills:

- Deduction of the polar nature of a covalent bond from electronegativity values.

Guidance:

- Bond polarity can be shown either with partial charges, dipoles or vectors.
- Electronegativity values are given in the data booklet in section 8.

Utilization:

- Microwaves—cooking with polar molecules.

Syllabus and cross-curricular links:
Topic 10.1—organic molecules

Aims:

- **Aim 3**: Use naming conventions to name covalently bonded compounds.

Essential idea: Lewis (electron dot) structures show the electron domains in the valence shell and are used to predict molecular shape.

4.3 Covalent structures

Nature of science:

Scientists use models as representations of the real world—the development of the model of molecular shape (VSEPR) to explain observable properties. (1.10)

Understandings:

- Lewis (electron dot) structures show all the valence electrons in a covalently bonded species.
- The "octet rule" refers to the tendency of atoms to gain a valence shell with a total of 8 electrons.
- Some atoms, like Be and B, might form stable compounds with incomplete octets of electrons.
- Resonance structures occur when there is more than one possible position for a double bond in a molecule.
- Shapes of species are determined by the repulsion of electron pairs according to VSEPR theory.
- Carbon and silicon form giant covalent/network covalent structures.

Applications and skills:

- Deduction of Lewis (electron dot) structure of molecules and ions showing all valence electrons for up to four electron pairs on each atom.
- The use of VSEPR theory to predict the electron domain geometry and the molecular geometry for species with two, three and four electron domains.
- Prediction of bond angles from molecular geometry and presence of non-bonding pairs of electrons.
- Prediction of molecular polarity from bond polarity and molecular geometry.
- Deduction of resonance structures, examples include but are not limited to C_6H_6, CO_3^{2-} and O_3.

Theory of knowledge:

- Does the need for resonance structures decrease the value or validity of Lewis (electron dot) theory? What criteria do we use in assessing the validity of a scientific theory?

Utilization:

Syllabus and cross-curricular links:
Option A.7—biodegradability of plastics
Biology topic 2.3—3-D structure of molecules and relating structure to function

Aims:

- **Aim 7**: Computer simulations could be used to model VSEPR structures.

4.3 Covalent structures	
• Explanation of the properties of giant covalent compounds in terms of their structures. **Guidance:** • The term “electron domain” should be used in place of “negative charge centre”. • Electron pairs in a Lewis (electron dot) structure can be shown as dots, crosses, a dash or any combination. • Allotropes of carbon (diamond, graphite, graphene, C_{60} buckminsterfullerene) and SiO_2 should be covered. • Coordinate covalent bonds should be covered.	

Essential idea: The physical properties of molecular substances result from different types of forces between their molecules.

4.4 Intermolecular forces

Nature of science:

Obtain evidence for scientific theories by making and testing predictions based on them—London (dispersion) forces and hydrogen bonding can be used to explain special interactions. For example, molecular covalent compounds can exist in the liquid and solid states. To explain this, there must be attractive forces between their particles which are significantly greater than those that could be attributed to gravity. (2.2)

Understandings:

- Intermolecular forces include London (dispersion) forces, dipole-dipole forces and hydrogen bonding.
- The relative strengths of these interactions are London (dispersion) forces < dipole-dipole forces < hydrogen bonds.

Applications and skills

- Deduction of the types of intermolecular force present in substances, based on their structure and chemical formula.
- Explanation of the physical properties of covalent compounds (volatility, electrical conductivity and solubility) in terms of their structure and intermolecular forces.

Guidance:

- The term “London (dispersion) forces” refers to instantaneous induced dipole-induced dipole forces that exist between any atoms or groups of atoms and should be used for non-polar entities. The term “van der Waals” is an inclusive term, which includes dipole–dipole, dipole-induced dipole and London (dispersion) forces.

Theory of knowledge:

- The nature of the hydrogen bond is the topic of much discussion and the current definition from the IUPAC gives six criteria which should be used as evidence for the occurrence of hydrogen bonding. How does a specialized vocabulary help and hinder the growth of knowledge?

Utilization:

Syllabus and cross-curricular links:
Option A.5—using plasticizers
Option A.7—controlling biodegradability
Option B.3—melting points of *cis-/trans-* fats
Biology topics 2.2, 2.3, 2.4 and 2.6—understanding of intermolecular forces to work with molecules in the body

Aims:

- **Aim 7**: Computer simulations could be used to show intermolecular forces interactions.

Essential idea: Metallic bonds involve a lattice of cations with delocalized electrons.

4.5 Metallic bonding	
Nature of science: Use theories to explain natural phenomena—the properties of metals are different from covalent and ionic substances and this is due to the formation of non-directional bonds with a “sea” of delocalized electrons. (2.2)	
Understandings: • A metallic bond is the electrostatic attraction between a lattice of positive ions and delocalized electrons. • The strength of a metallic bond depends on the charge of the ions and the radius of the metal ion. • Alloys usually contain more than one metal and have enhanced properties. **Applications and skills:** • Explanation of electrical conductivity and malleability in metals. • Explanation of trends in melting points of metals. • Explanation of the properties of alloys in terms of non-directional bonding. **Guidance:** • Trends should be limited to s- and p-block elements. • Examples of various alloys should be covered.	**International-mindedness:** • The availability of metal resources, and the means to extract them, varies greatly in different countries, and is a factor in determining national wealth. As technologies develop, the demands for different metals change and careful strategies are needed to manage the supply of these finite resources. **Utilization:** Syllabus and cross-curricular links: Option A.6—use of metals in nanotechnology Biology topic 2.2—water **Aims:** • **Aim 1**: Global impact of value of precious metals and their extraction processes and locations. • **Aim 7**: Computer simulations could be used to view examples of metallic bonding.