Chapter 9: Atomic Foundations of Matter

Exercises — Revise, Reflect, Refine

Q1 A particular element (A) has one electron in its third shell. There is another element (B) with six electrons in its second shell.
(i) How many electrons does A tend to give or take to become stable?
(ii) What kind of ion would it form?
(iii) How many electrons does B tend to give or take to become stable?
(iv) What kind of ion would it form?
(v) If A and B were to combine, what kind of bond would be formed?
(vi) What would be the formula for the compound thus formed?

SOLUTION

Element A has electronic configuration 2,8,1 (one electron in its third shell). Element B has electronic configuration 2,6 (six electrons in its second shell).

(i) A has 1 valence electron. It is easier to lose 1 electron than to gain 7. A tends to give away 1 electron to achieve the stable configuration 2,8 (octet).

(ii) By losing 1 electron, A acquires a positive charge. It forms a cation: A^+.

(iii) B has 6 valence electrons. It needs to gain 2 more electrons to complete its octet and achieve the stable configuration 2,8. B tends to take 2 electrons.

(iv) By gaining 2 electrons, B acquires a negative charge of 2. It forms an anion: B^{2-}.

(v) A is a metal-like element (loses electrons) and B is a non-metal-like element (gains electrons). When they combine, electrons transfer from A to B. This produces oppositely charged ions that attract each other: an ionic bond is formed.

(vi) To balance charges: 2 A^+ ions are needed for every 1 B^{2-} ion ($2 \times (+1) + 1 \times (-2) = 0$). The formula of the compound is A_2B.

Answer: A (config 2,8,1) loses 1 electron → A^+ cation. B (config 2,6) gains 2 electrons → B^{2-} anion. They form an ionic bond. Formula of the compound: A_2B.

Q2 An element X has six electrons in its outer shell and forms a diatomic molecule.
(i) Why would that be so?
(ii) What kind of bond would it form?
(iii) Draw the structure of the molecule it would form.
(iv) A certain other element Y has two electrons in its second shell. Draw the structure of the molecule that X would form with Y.

SOLUTION

X has 6 valence electrons; it needs 2 more to complete its octet. Y has 2 electrons in its second shell (electronic configuration 2,2, like beryllium), giving it 2 valence electrons.

(i) X has 6 valence electrons and needs 2 more to complete the octet. Rather than transferring electrons (which would require a large energy), two X atoms each contribute 2 electrons to share, forming a stable X_2 diatomic molecule. This mutual sharing allows both atoms to achieve an 8-electron outer shell.

(ii) Atoms of the same element do not transfer electrons between themselves. They share electrons equally. X forms a covalent bond (specifically a double bond in X_2, since each atom shares 2 of its electrons).

(iii) Structure of X_2: Each X atom has 6 valence electrons. They share 2 pairs of electrons (double bond). Lewis structure: :X::X: (with 2 lone pairs on each X and a double bond between them). Like O=O in oxygen gas.

(iv) Y has 2 valence electrons and X has 6 valence electrons (needs 2 more). Y shares its 2 electrons — one with each of two X atoms. Each X also contributes 1 electron to the bond. This gives both X atoms a complete octet. The molecule formed is YX_2 with two single covalent X–Y–X bonds, similar to the structure of water (H_2O). Lewis structure: X:Y:X with lone pairs on each X atom.

Answer: X (6 valence electrons) and another X share 2 pairs → X=X double covalent bond in X_2. With Y (2 valence electrons, config 2,2), X forms YX_2: two single covalent bonds, one between each X and Y.

Q3 You want to design a new ionic compound where the total positive charge is 6+ and the total negative charge is 6−. Which of the following combinations gives the correct number of ions?
(i) 2 Al^{3+} and 3 Cl^{-}
(ii) 3 Mg^{2+} and 1 PO_4^{3-}
(iii) 2 Fe^{3+} and 3 O^{2-}
(iv) 3 Ca^{2+} and 2 SO_4^{2-}

SOLUTION

A balanced ionic compound requires total positive charge = total negative charge in magnitude.

(i) 2 Al^{3+} and 3 Cl^{-}: Positive charge = 2 × 3 = 6+. Negative charge = 3 × 1 = 3−. 6+ ≠ 3−. Not balanced.

(ii) 3 Mg^{2+} and 1 PO_4^{3-}: Positive charge = 3 × 2 = 6+. Negative charge = 1 × 3 = 3−. 6+ ≠ 3−. Not balanced.

(iii) 2 Fe^{3+} and 3 O^{2-}: Positive charge = 2 × 3 = 6+. Negative charge = 3 × 2 = 6−. 6+ = 6−. Balanced. ✓

(iv) 3 Ca^{2+} and 2 SO_4^{2-}: Positive charge = 3 × 2 = 6+. Negative charge = 2 × 2 = 4−. 6+ ≠ 4−. Not balanced.

Only option (iii) gives total positive charge = 6+ and total negative charge = 6−.

Answer: (iii) 2 Fe^{3+} and 3 O^{2-}. Total positive charge = 2 × 3 = 6+; total negative charge = 3 × 2 = 6−. Charges balance.

Q4 Choose the correct statement(s) and correct the false statement(s).
(i) Elements are made up of molecules and compounds are made up of atoms.
(ii) The molecule of a compound is always made up of two or more atoms of the same kind.
(iii) One molecule of nitrogen gas contains three nitrogen atoms.
(iv) Water is made of two hydrogen atoms, covalently bonded with one oxygen atom.

SOLUTION

(i) FALSE. It is the reverse: elements are made up of atoms (e.g., iron consists of Fe atoms), and compounds are made up of molecules or formula units containing atoms of two or more elements.

Corrected statement: Elements are made up of atoms, and compounds are made up of molecules (or formula units) containing atoms of two or more different elements.

(ii) FALSE. The molecule of a compound contains atoms of two or more different elements (not the same kind). For example, water (H_2O) contains hydrogen and oxygen — atoms of different kinds.
Corrected statement: The molecule of a compound is always made up of atoms of two or more different elements.

(iii) FALSE. Nitrogen gas is diatomic: each molecule is N_2 and contains only two nitrogen atoms, not three.
Corrected statement: One molecule of nitrogen gas contains two nitrogen atoms.

(iv) TRUE. Water (H_2O) is indeed made of two hydrogen atoms and one oxygen atom held together by covalent bonds (electron sharing).

Answer: Only (iv) is correct. Corrections: (i) elements are made of atoms, compounds of molecules; (ii) compound molecules contain atoms of different elements; (iii) N_2 has two (not three) nitrogen atoms.

Q5 Write the chemical formulae for the following compounds.
(i) Aluminium nitrate
(ii) Calcium oxide
(iii) Ferric oxide

SOLUTION

(i) Aluminium nitrate: Al^{3+} and NO_3^- (nitrate ion, charge −1).
Cross-multiply valencies: $Al^{3+} \times 1$ and $(NO_3)^- \times 3$.
Formula: $Al(NO_3)_3$

(ii) Calcium oxide: Ca^{2+} and O^{2-}.
Both have charge magnitude 2; they combine in a 1:1 ratio.
Formula: CaO

(iii) Ferric oxide: Fe^{3+} (ferric = Fe^{3+}) and O^{2-}.
Cross-multiply valencies: Fe × 2 and O × 3 (to balance 2 × 3 = 6+ and 3 × 2 = 6−).
Formula: Fe_2O_3

Answer: (i) $Al(NO_3)_3$ (ii) CaO (iii) Fe_2O_3

Q6 Write the formulae of the compounds formed from the following pairs of ions.
(i) Ca^{2+} and Br^{-}
(ii) Al^{3+} and CO_3^{2-}
(iii) K^{+} and SO_4^{2-}
(iv) NH_4^{+} and Cl^{-}

SOLUTION

(i) Ca^{2+} and Br^{-}: Cross-multiply — Ca × 1, Br × 2. Verify: 1 × 2 = 2+ and 2 × 1 = 2−. Balanced.
Formula: $CaBr_2$

(ii) Al^{3+} and CO_3^{2-}: Cross-multiply — Al × 2, CO_3 × 3. Verify: 2 × 3 = 6+ and 3 × 2 = 6−. Balanced.
Formula: $Al_2(CO_3)_3$

(iii) K^{+} and SO_4^{2-}: Cross-multiply — K × 2, SO_4 × 1. Verify: 2 × 1 = 2+ and 1 × 2 = 2−. Balanced.
Formula: K_2SO_4

(iv) NH_4^{+} and Cl^{-}: Both have charge magnitude 1; combine in 1:1 ratio.
Formula: NH_4Cl

Answer: (i) $CaBr_2$ (ii) $Al_2(CO_3)_3$ (iii) K_2SO_4 (iv) NH_4Cl

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Q7 Which of the following, in Fig. 9.18, correctly represents Cl^{-} ion (Atomic number of chlorine = 17)?

SOLUTION

Chlorine (Cl) has atomic number 17. Its electronic configuration as a neutral atom is 2,8,7 (three shells).

When chlorine gains one electron to form the Cl^{-} ion, it has 18 electrons total. Configuration of Cl^{-}: 2,8,8 (three shells — 2 electrons in shell 1, 8 in shell 2, 8 in shell 3).

The correct diagram must show: 3 concentric shells, with 2 electrons in the first, 8 in the second, and 8 in the outermost (third) shell.

From Fig. 9.18, diagram (ii) shows exactly this configuration — three shells with the outermost shell containing 8 electrons (a complete octet). The other diagrams either show the wrong number of shells or the wrong number of electrons in the outermost shell.

Therefore, diagram (ii) correctly represents the Cl^- ion.

Answer: Diagram (ii) correctly represents Cl^-. Cl^- has 18 electrons with configuration 2,8,8 — three shells with a complete octet in the outermost shell.

Q8 Determine the formula unit mass of the following substances.
(i) Ammonium nitrate (NH_4NO_3), used as a nitrogen fertiliser, which is essential for plant growth.
(ii) Phosphoric acid (H_3PO_4), used to make phosphate fertiliser and detergents.
(iii) Sodium hydrogencarbonate ($NaHCO_3$), used to relieve acidity and helps in digestion.

SOLUTION

Atomic masses used: H = 1 u, C = 12 u, N = 14 u, O = 16 u, Na = 23 u, P = 31 u.

(i) NH_4NO_3:
N = 14, H × 4 = 4, N = 14, O × 3 = 48.
Formula unit mass = 14 + 4 + 14 + 48 = 80 u.

(ii) H_3PO_4:
H × 3 = 3, P = 31, O × 4 = 64.
Formula unit mass = 3 + 31 + 64 = 98 u.

(iii) $NaHCO_3$:
Na = 23, H = 1, C = 12, O × 3 = 48.
Formula unit mass = 23 + 1 + 12 + 48 = 84 u.

Answer: (i) NH_4NO_3 = 80 u (ii) H_3PO_4 = 98 u (iii) $NaHCO_3$ = 84 u

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Q9 Write the formulae for the compounds formed by the reaction of:
(i) Magnesium and nitrogen
(ii) Lithium and nitrogen
(iii) Sodium and sulfur
(iv) Aluminium and oxygen

SOLUTION

(i) Magnesium (Mg^{2+}) and nitrogen (N^{3-}):
Cross-multiply: Mg × 3, N × 2. Verify: 3 × 2 = 6+ and 2 × 3 = 6−. Balanced.
Formula: Mg_3N_2

(ii) Lithium (Li^+) and nitrogen (N^{3-}):
Cross-multiply: Li × 3, N × 1. Verify: 3 × 1 = 3+ and 1 × 3 = 3−. Balanced.
Formula: Li_3N

(iii) Sodium (Na^+) and sulfur (S^{2-}):
Cross-multiply: Na × 2, S × 1. Verify: 2 × 1 = 2+ and 1 × 2 = 2−. Balanced.
Formula: Na_2S

(iv) Aluminium (Al^{3+}) and oxygen (O^{2-}):
Cross-multiply: Al × 2, O × 3. Verify: 2 × 3 = 6+ and 3 × 2 = 6−. Balanced.
Formula: Al_2O_3

Answer: (i) Mg_3N_2 (ii) Li_3N (iii) Na_2S (iv) Al_2O_3

Q10 Complete Table 9.3 by writing the formulae of the compounds formed by the cations on the left and the anions at the top. $LiNO_3$ is given as an example.

Cations: NH_4^+, Li^+ (example: $LiNO_3$), Al^{3+}, Cu^{2+}
Anions: NO_3^-, SO_4^{2-}, PO_4^{3-}

SOLUTION

To form each compound, cross-multiply the charge magnitudes of cation and anion to get the number of ions, then simplify if possible.

NH_4^+ (charge +1):
+ NO_3^- (−1): 1:1 ratio => NH_4NO_3
+ SO_4^{2-} (−2): 2 NH_4^+ per 1 SO_4^{2-} => $(NH_4)_2SO_4$
+ PO_4^{3-} (−3): 3 NH_4^+ per 1 PO_4^{3-} => $(NH_4)_3PO_4$

Li^+ (charge +1):
+ NO_3^- (−1): $LiNO_3$ (given as example)
+ SO_4^{2-} (−2): 2 Li^+ per 1 SO_4^{2-} => Li_2SO_4
+ PO_4^{3-} (−3): 3 Li^+ per 1 PO_4^{3-} => Li_3PO_4

Al^{3+} (charge +3):
+ NO_3^- (−1): 1 Al^{3+} per 3 NO_3^- => $Al(NO_3)_3$
+ SO_4^{2-} (−2): 2 Al^{3+} per 3 SO_4^{2-} (LCM of 3 and 2 = 6) => $Al_2(SO_4)_3$
+ PO_4^{3-} (−3): 1:1 ratio => $AlPO_4$

Cu^{2+} (charge +2):
+ NO_3^- (−1): 1 Cu^{2+} per 2 NO_3^- => $Cu(NO_3)_2$

+ SO_4^{2-} (−2): 1:1 ratio => $CuSO_4$
+ PO_4^{3-} (−3): 3 Cu^{2+} per 2 PO_4^{3-} (LCM of 2 and 3 = 6) => $Cu_3(PO_4)_2$

Answer: NH_4^+: NH_4NO_3, $(NH_4)_2SO_4$, $(NH_4)_3PO_4$ | Li^+: $LiNO_3$, Li_2SO_4, Li_3PO_4 | Al^{3+}: $Al(NO_3)_3$, $Al_2(SO_4)_3$, $AlPO_4$ | Cu^{2+}: $Cu(NO_3)_2$, $CuSO_4$, $Cu_3(PO_4)_2$

Q11 5.3 g of sodium carbonate and 6.0 g of acetic acid react to produce 2.2 g of carbon dioxide, 0.9 g of water, and 8.2 g of sodium acetate. Verify whether the law of conservation of mass is valid.

SOLUTION

Law of Conservation of Mass states: in a chemical reaction, the total mass of reactants equals the total mass of products.

Total mass of reactants = mass of sodium carbonate + mass of acetic acid
= 5.3 g + 6.0 g = 11.3 g

Total mass of products = mass of CO_2 + mass of water + mass of sodium acetate
= 2.2 g + 0.9 g + 8.2 g = 11.3 g

Total mass of reactants (11.3 g) = Total mass of products (11.3 g).

The masses are equal, confirming the Law of Conservation of Mass.

Answer: Total reactant mass = 5.3 + 6.0 = 11.3 g. Total product mass = 2.2 + 0.9 + 8.2 = 11.3 g. Both are equal, so the Law of Conservation of Mass is verified.

Q12 If a species has 11 protons, 12 neutrons and 10 electrons then:
(i) what is its atomic number and mass number?
(ii) is it neutral, a cation or an anion? Explain.
(iii) write its electronic configuration.
(iv) name the species.

SOLUTION

(i) Atomic number = number of protons = 11.
Mass number = number of protons + number of neutrons = 11 + 12 = 23.

(ii) For a neutral atom, number of protons = number of electrons.
Here, protons = 11 but electrons = 10.
Since protons > electrons, the species has more positive charges than negative: it carries a net charge of +1.

It is a cation (positively charged ion).

(iii) Electronic configuration with 10 electrons:
Shell 1 (K): 2 electrons.
Shell 2 (L): 8 electrons.
Total: 2 + 8 = 10 electrons. Configuration: 2,8.

(iv) Atomic number 11 = Sodium (Na). The species has lost 1 electron.
The species is the sodium ion: Na^+.

Answer: Atomic number = 11, Mass number = 23. It is a cation (Na^+): more protons (11) than electrons (10), net charge +1. Electronic configuration: 2,8. Species: sodium ion (Na^+).

Q13 Two elements, A and B, have the following configurations — A: 2, 8, 5 and B: 2, 8, 7.
(i) Which element is more reactive?
(ii) Will A and B form ionic or covalent bonds when they combine? Explain using electron transfer or sharing.
(iii) Predict the formula of the compound they would form.

SOLUTION

(i) A has 5 valence electrons (needs to gain 3 or lose 5 to reach a stable octet).
B has 7 valence electrons (needs to gain only 1 electron to complete its octet).
B is more reactive because it is closer to a full outer shell — it needs just one more electron to achieve the stable octet, making it highly electronegative and reactive (like halogens).

(ii) Both A and B are non-metals (A has 5 valence electrons, B has 7). Non-metals combine with each other by sharing electrons (electron sharing), not by transferring electrons.
Therefore, A and B form a covalent bond.
A contributes 5 valence electrons and B contributes 7. Each A–B bond shares one electron from A and one from B. A needs 3 more electrons to complete its octet, so it forms 3 covalent bonds with 3 B atoms.

(iii) A needs 3 more electrons to complete its octet; each B atom can provide 1 electron (through sharing). Therefore, 1 atom of A bonds with 3 atoms of B.
Formula: AB_3

Answer: B is more reactive (7 valence electrons, needs only 1 more). Both are non-metals, so they form covalent bonds by electron sharing. Formula: AB_3.

Q14 Assertion (A): Copper sulfate conducts electricity in the molten state but not in the solid state.
Reason (R): Copper and sulfate ions are fixed in the lattice in molten state, while in solid state they can move freely.
Choose the correct option:
(i) Both A and R are true, and R is the correct explanation of A.
(ii) Both A and R are true, but R is not the correct explanation of A.
(iii) A is true, but R is false.
(iv) A is false, but R is true.

SOLUTION

Evaluating the Assertion (A): Copper sulfate ($CuSO_4$) is an ionic compound. In the solid state, the Cu^{2+} and SO_4^{2-} ions are held rigidly in a fixed crystal lattice and cannot move — so it does not conduct electricity. In the molten state, the lattice structure breaks down and the ions become free to move — so it does conduct electricity. Assertion A is TRUE.

Evaluating the Reason (R): The Reason states that ions are fixed in the molten state and free to move in solid state. This is the exact opposite of what actually happens. In SOLID state, ions are fixed (no conduction). In MOLTEN state, ions are FREE to move (conduction occurs). The Reason is FACTUALLY INCORRECT (FALSE).

Therefore: A is true, but R is false.

Answer: (iii) A is true, but R is false. The Reason has the states reversed: ions are fixed in the SOLID state (no conductivity) and free to move in the MOLTEN state (conducts electricity).

Q15 The species ^{27}Al, $^{80}Br^-$ and $^{201}Hg^{2+}$ have 13, 35 and 80 protons, respectively. How many electrons and neutrons do they have?

SOLUTION

For each species: neutrons = mass number − atomic number (protons). Electrons = protons ± ionic charge.

^{27}Al (neutral aluminium atom):

Protons = 13 (given). Mass number = 27.
Neutrons = 27 − 13 = 14.
Electrons = 13 (neutral atom, no charge).

$^{80}Br^{-}$ (bromide ion, charge −1):
Protons = 35 (given). Mass number = 80.
Neutrons = 80 − 35 = 45.
Electrons = 35 + 1 = 36 (gained 1 electron to form the −1 ion).

$^{201}Hg^{2+}$ (mercury(II) ion, charge +2):
Protons = 80 (given). Mass number = 201.
Neutrons = 201 − 80 = 121.
Electrons = 80 − 2 = 78 (lost 2 electrons to form the +2 ion).

Answer: ^{27}Al: 13 electrons, 14 neutrons. $^{80}Br^{-}$: 36 electrons, 45 neutrons. $^{201}Hg^{2+}$: 78 electrons, 121 neutrons.