

Atoms, elements and compounds

Mark scheme and worked solutions for 30 questions: 15 multiple choice, 15 structured.

1 Core Elements, compounds and mixtures [1]

Answer: B

Worked solution

The key test for a compound is two things at once: (1) it contains more than one element, and (2) those elements are chemically joined in a fixed ratio, so a sample of the compound cannot be separated back into its elements by physical methods such as filtering or evaporating - only by a chemical reaction. Checking each option against both tests picks out B.

2 Core Atomic structure and the Periodic Table [1]

Answer: A

Worked solution

Picture the atom as a very small, dense nucleus (containing all the protons and neutrons) with electrons moving around it in shells at much greater distances. Almost all of the atom's mass is concentrated in this tiny central nucleus, while the electron shells take up almost all of the atom's volume but almost none of its mass.

3 Core Atomic structure and the Periodic Table [1]

Answer: D

Worked solution

There are only three particles to remember here, and two facts about each: proton (+1 charge, mass 1), neutron (0 charge, mass 1) and electron (0 charge, mass about 1/1840, i.e. negligible). The neutron is the only particle with both "0" for charge and "1" for mass, which is option D.

4**Core**

Atomic structure and the Periodic Table

[1]

Answer: C

Worked solution

Mass number = number of protons + number of neutrons. Rearranging: number of protons = mass number - number of neutrons = $31 - 16 = 15$. It helps to keep the two definitions straight: proton number counts only protons; mass number counts protons and neutrons together.

5**Core**

Atomic structure and the Periodic Table

[4]

Mark scheme**(a)**

[2]

- number of neutrons = 14 (1)
- number of electrons = 13 (1)

ALLOW working shown as $27 - 13 = 14$ for the neutrons

(b)

[1]

- 2,8,3 (1)

REJECT any configuration that does not sum to 13

(c)

[1]

- 3 occupied shells AND period 3 (1)

ALLOW "third period" / "period three"

- both parts of the answer are needed for the mark
-

Worked solution

Aluminium has proton number 13, so a neutral atom has 13 protons and 13 electrons. The mass number (27) is protons + neutrons, so neutrons = $27 - 13 = 14$. To work out the electronic configuration, fill the shells from the nucleus outwards: the first shell holds up to 2 electrons, the second up to 8, and any remaining electrons go into the third shell. With 13 electrons: 2 in the first shell, 8 in the second shell, leaving $13 - 2 - 8 = 3$ in the third shell, giving 2,8,3. The number of occupied shells (3) tells you the period number directly - aluminium is in Period 3.

Mark scheme

(a)

[3]

- protons and neutrons are found in the nucleus, at the centre of the atom (1)
- electrons are arranged in shells (energy levels) around the nucleus (1)
- an atom has no overall charge because the number of (positively charged) protons equals the number of (negatively charged) electrons, so the charges cancel out (1)

(b)

[2]

- all three relative charges correct: proton +1, neutron 0, electron -1 (1)
- all three relative masses correct: proton 1, neutron 1, electron very small / about 1/1840 (1)

Worked solution

An atom is built from three particles. The protons and neutrons are packed together in a tiny central nucleus, while the electrons occupy shells around the outside. Protons carry a charge of +1 and electrons carry a charge of -1; because a neutral atom always has equal numbers of protons and electrons, the total positive charge exactly cancels the total negative charge, leaving no overall charge. For the table: protons and neutrons both have a relative mass of 1 (and neutrons have no charge, matching their name), while electrons have almost no mass (about 1/1840 of a proton's mass) and carry a charge of -1.

Mark scheme

(a) [3]

- number of protons = 16 (1)
- number of electrons = 18 (1)
- reason: the atom has gained 2 electrons, so it now has 2 more electrons than protons ($18 = 16 + 2$) (1)

ALLOW reason expressed as "protons stay the same when electrons are gained/lost"

(b) [1]

- 2,8,8 (1)

(c) [2]

- electronic configuration 2,8,8 (1)
- number of occupied shells = 3 (1)

ECF if (c)'s configuration is wrong but internally consistent, allow the shells mark for the number of groups written**Worked solution**

Gaining or losing electrons never changes the number of protons in the nucleus - only the number of electrons changes. Sulfur has proton number 16, so the S^{2-} ion still has 16 protons, but it has gained 2 extra electrons, giving $16 + 2 = 18$ electrons. Filling the shells with 18 electrons: 2, then 8, then 8, giving 2,8,8. Calcium (proton number 20) loses 2 electrons to form Ca^{2+} , leaving $20 - 2 = 18$ electrons - the same number as the sulfide ion above - so the configuration is also 2,8,8, occupying 3 shells. Notice both ions end up with the same electron arrangement as the noble gas argon.

Answer: A**Worked solution**

The word "isotope" only ever describes atoms of the same element - same proton number - that differ in their number of neutrons (and therefore in mass number). Any option that mentions "different elements" or "different numbers of protons" cannot be describing isotopes, which immediately rules out B and C.

9

Supplement

Isotopes

[1]

Answer: C

Worked solution

Chemical reactions happen through the transfer or sharing of electrons, particularly the outer-shell electrons. Because ^{35}Cl and ^{37}Cl both have 17 protons, they both have 17 electrons arranged in exactly the same way (2,8,7). Since their electron arrangements are identical, their chemical behaviour is identical too - only their masses (and physical properties linked to mass) differ.

10

Core

Isotopes

[4]

Mark scheme

(a)

[3]

- protons = 19 (1)
- neutrons = 20 (1)
- electrons = 19 (1)

ALLOW working shown as $39 - 19 = 20$ for the neutrons

(b)

[1]

- both isotopes have 19 protons (the same proton number), which is what makes them both potassium; they have different numbers of neutrons (20 in ^{39}K , 22 in ^{41}K), which is what makes them different isotopes (1)

ALLOW answer that states same proton number and different neutron number/mass number, without giving the specific numbers

Worked solution

The subscript number (19) in $^{39}_{19}\text{K}$ is the proton number and is the same for both isotopes - this is what makes both of them potassium. The superscript number (39 or 41) is the mass number (protons + neutrons). For $^{39}_{19}\text{K}$: protons = 19, so neutrons = $39 - 19 = 20$, and in a neutral atom electrons = protons = 19. Because both isotopes share the same proton number but differ in mass number, they must have different numbers of neutrons - that is exactly the definition of isotopes.

11**Supplement**

Isotopes

[5]

Mark scheme

(a)

[3]

- method: multiply each isotope's mass by its percentage abundance and add the results, then divide by 100 (1)
- correct substitution: $(35 \times 75) + (37 \times 25)$, all over 100 (1)
- final answer: 35.5 (1)

ALLOW 35.5 with no unit; relative atomic mass has no units

(b)

[2]

- yes, consistent (1)
- because the calculated value (35.5) is the same as the Periodic Table value (35.5) / ECF: consistent if the candidate's answer to (a) matches the value they compare it with (1)

Worked solution

Relative atomic mass is a weighted average of the isotopic masses, weighted by how abundant each isotope is. Multiply each isotope's mass by its percentage abundance, add the results together, then divide by 100 (because the abundances are percentages): $(35 \times 75 + 37 \times 25) / 100 = (2625 + 925) / 100 = 3550 / 100 = 35.5$. This matches the value of 35.5 given for chlorine in the Periodic Table, so the calculation is consistent with it. This also shows why chlorine's relative atomic mass is not a whole number: it is an average of two isotopes with different masses.

12**Core**

Ions and ionic bonds

[1]

Answer: B**Worked solution**

Every electron carries a charge of -1. If a neutral atom loses 2 electrons, it loses 2 units of negative charge, so what remains is 2 units more positive than before: a charge of 2+. A positively charged ion is always called a cation (a useful memory link: "cat-ion" - a cation is "paws-itive"). So losing electrons always gives a cation, and here specifically a 2+ cation.

13 Core Ions and ionic bonds

[1]

Answer: D

Worked solution

An ionic bond only exists between ions - particles that already carry a full positive or negative charge - and it is the electrostatic (opposite-charges-attract) force that holds them together. This is different from a covalent bond, which involves sharing electrons rather than transferring them to form separate charged ions.

14 Core Ions and ionic bonds

[1]

Answer: A

Worked solution

Two properties always go together for ionic compounds: a high melting/boiling point (because breaking apart the strong lattice of ions takes a lot of energy) and conduction of electricity only when the ions can move freely - that is, when molten or dissolved in water, but never when solid, since the ions are then locked in fixed positions in the lattice.

15 Supplement Ions and ionic bonds

[1]

Answer: B

Worked solution

Ionic compounds do not exist as individual molecules; instead, huge numbers of positive and negative ions pack together in a regular, repeating three-dimensional pattern (a giant lattice), with each ion attracted electrostatically to the oppositely charged ions around it in every direction. This is what makes ionic lattices so difficult to break apart, giving ionic compounds their high melting points.

16 Core Ions and ionic bonds

[5]

Mark scheme

(a) [2]

- the potassium atom loses one electron to form a K^+ ion (1)
- the fluorine atom gains one electron to form an F^- ion (1)

(b) [2]

- K^+ : 2,8,8 (1)
- F^- : 2,8 (1)

(c) [1]

- the K^+ and F^- ions have opposite charges and are held together by a strong electrostatic force of attraction (1)

Worked solution

Potassium (2,8,8,1) has just one electron in its outer shell, so it is easiest for it to lose that one electron and reach the stable configuration 2,8,8 (the same as argon), becoming a K^+ ion. Fluorine (2,7) has seven outer electrons, so it is easiest for it to gain one more electron to complete its outer shell, reaching 2,8 (the same as neon), becoming an F^- ion. The electron lost by potassium is the same electron gained by fluorine. The resulting K^+ and F^- ions carry opposite charges, so they attract each other strongly - this electrostatic attraction between oppositely charged ions is the ionic bond.

17 Core Ions and ionic bonds

[4]

Mark scheme

(a) [2]

- any two from: high melting point (1); high boiling point (1); hard but brittle (1)

ALLOW any two genuine physical properties typical of ionic compounds

(b) [2]

- solid sodium chloride does not conduct electricity (1)
- molten sodium chloride does conduct electricity (1)

Worked solution

Ionic compounds like sodium chloride have high melting and boiling points because a great deal of energy is needed to overcome the strong electrostatic forces holding the giant lattice of ions together. For conductivity, what matters is whether the ions can move: in the solid, the ions are held tightly in fixed positions in the lattice and cannot move to carry charge, so solid sodium chloride does not conduct electricity. Once melted, the ions are free to move throughout the liquid, so molten sodium chloride does conduct electricity.

Mark scheme

(a) [2]

- the magnesium atom loses two electrons to form a Mg^{2+} ion (1)
- the oxygen atom gains two electrons to form an O^{2-} ion (1)

(b) [2]

- Mg^{2+} : 2,8 (1)
- O^{2-} : 2,8 (1)

(c) [2]

- each magnesium atom loses exactly 2 electrons and each oxygen atom gains exactly 2 electrons (1)
- the number of electrons lost by magnesium must equal the number gained by oxygen, so one Mg^{2+} ion (charge 2+) balances exactly one O^{2-} ion (charge 2-), giving a 1:1 ratio (1)

Worked solution

Magnesium (2,8,2) has two outer electrons, which it loses to reach the stable configuration 2,8 (like neon), forming Mg^{2+} . Oxygen (2,6) has six outer electrons, needing two more to complete its outer shell, so it gains two electrons to reach 2,8, forming O^{2-} . Because electrons cannot simply disappear, the number transferred must balance exactly: the 2 electrons lost by one magnesium atom are gained by one oxygen atom. This means the ions produced, Mg^{2+} and O^{2-} , have charges that are equal and opposite, so they combine in a simple 1:1 ratio to give overall zero charge in MgO .

Mark scheme

(a) [2]

- calcium oxide consists of a regular, repeating (three-dimensional) arrangement of alternating Ca^{2+} and O^{2-} ions (1)
- the ions are held together by strong electrostatic forces of attraction acting in all directions throughout the lattice (1)

(b) [2]

- there are strong electrostatic forces of attraction between the oppositely charged Ca^{2+} and O^{2-} ions throughout the giant lattice (1)
- a large amount of (thermal) energy is needed to overcome/break these strong forces before the lattice can melt (1)

(c) [2]

- when molten, the ions are free to move (throughout the liquid) and so can carry electrical charge (1)
- when solid, the ions are held in fixed positions in the lattice and cannot move, so they cannot carry electrical charge (1)

Worked solution

Calcium oxide is a giant ionic lattice: enormous numbers of Ca^{2+} and O^{2-} ions arranged in a regular, repeating pattern, each attracted electrostatically to its oppositely charged neighbours in every direction. Melting this lattice means overcoming all of these strong attractive forces at once, which needs a large amount of energy - this is why calcium oxide has such a high melting point. Electrical conductivity depends on charged particles being able to move: in the solid, the ions are locked into fixed positions and cannot carry charge from place to place, so it does not conduct; once molten, the lattice breaks down and the ions become free to move, so they can now carry charge and the liquid conducts electricity.

Answer: C**Worked solution**

The defining feature of covalent bonding, unlike ionic bonding, is that electrons are shared rather than transferred completely from one atom to another. Two atoms each contribute one electron to a shared pair, and both atoms are attracted to this shared pair, holding them together.

Answer: D

Worked solution

Simple molecular substances consist of individual molecules held together by weak intermolecular forces, so relatively little energy is needed to separate the molecules from each other, giving low melting and boiling points. Because the molecules themselves are electrically neutral and there are no ions or delocalised electrons free to move and carry charge, these substances are poor conductors of electricity.

Mark scheme

(a) [2]

- 4 covalent bonds (1)
- 2 electrons shared in each bond / 1 shared pair of electrons per bond (1)

(b) [2]

- the carbon atom shares one electron with each of the four hydrogen atoms, giving the carbon atom 8 electrons in its outer shell (1)
- each hydrogen atom shares one electron with the carbon atom, giving each hydrogen atom a full outer shell of 2 electrons (1)

Worked solution

Carbon has 4 electrons in its outer shell and needs 4 more to complete it (a full outer shell of 8); each hydrogen atom has 1 electron and needs 1 more to complete its outer shell of 2 (hydrogen's shell only holds 2 electrons). Methane solves both needs at once: the carbon atom forms one covalent bond with each of four hydrogen atoms, and each bond is a shared pair of 2 electrons. Counting the carbon atom's outer shell: its own 4 electrons plus 1 shared electron from each of the 4 hydrogen atoms gives 8 electrons in total - a full outer shell. Counting each hydrogen atom: its own 1 electron plus 1 shared electron from carbon gives 2 electrons - also a full outer shell.

Mark scheme

(a)

[3]

- the carbon atom shares a total of 4 electrons, 2 with each oxygen atom (1)
- each oxygen atom shares 2 electrons with the carbon atom, so 2 shared pairs of electrons (a double bond) form between the carbon atom and each oxygen atom (1)
- as a result, both the carbon atom and each oxygen atom end up with a full outer shell of 8 electrons (1)

(b)

[2]

- 6 electrons shared / 3 shared pairs of electrons (1)
- triple (covalent) bond (1)

Worked solution

Carbon has 4 outer electrons and needs 4 more; each oxygen atom has 6 outer electrons and needs 2 more. In CO_2 , the carbon atom forms a double bond with each oxygen atom: it shares 2 of its electrons with each oxygen atom (using all 4 of its outer electrons in total), and each oxygen atom shares 2 of its own electrons back with carbon. Each double bond is therefore 2 shared pairs (4 electrons). To count outer electrons, each atom counts every electron in every shared pair around it. Carbon has 2 shared pairs with each oxygen atom, so 4 shared pairs (8 electrons) in total - a full outer shell. Each oxygen atom has 2 shared pairs with carbon (4 electrons) plus its own 4 unshared electrons, giving 8 - also a full outer shell. So all three atoms achieve a noble gas electronic configuration. In N_2 , each nitrogen atom has 5 outer electrons and needs 3 more, so the two atoms share 3 pairs of electrons (6 electrons in total) between them - a triple bond - giving each nitrogen atom a full outer shell of 8.

Mark scheme

(a) [3]

- iodine molecules are held together by weak intermolecular forces (forces between molecules) (1)
- the covalent bonds within each iodine molecule are strong (1)
- on melting or boiling, only the weak intermolecular forces need to be overcome, and this requires only a small amount of energy, so melting and boiling points are low (1)

(b) [2]

- iodine molecules are electrically neutral / have no overall charge (1)
- there are no free ions and no delocalised electrons present that are free to move and carry charge (1)

(c) [1]

- the covalent bond within the molecule is much stronger than the (intermolecular) forces between molecules

ALLOW any correct statement that the intramolecular covalent bond is much stronger than the intermolecular forces

Worked solution

It is important not to confuse the strong covalent bonds holding the two atoms together within an iodine molecule with the much weaker forces of attraction between separate iodine molecules. When iodine melts or boils, the molecules themselves do not break apart - the covalent bonds stay intact. Instead, only the weak forces between neighbouring molecules are overcome, which takes relatively little energy, giving iodine (and simple molecular substances generally) low melting and boiling points compared with giant structures. Because each iodine molecule is overall electrically neutral, and there are no ions or delocalised electrons free to move through the substance, iodine cannot carry an electric current, so it is a poor conductor.

Answer: A**Worked solution**

Diamond's structure is a giant covalent lattice in which each carbon atom uses all four of its outer electrons to form four single covalent bonds to four other carbon atoms, building a rigid three-dimensional network. This is different from graphite, where each carbon atom bonds to only three others within flat layers.

Answer: B

Worked solution

An electrode needs to conduct electricity and must not melt or break down under the conditions of electrolysis. Graphite conducts electricity because, within each layer, each carbon atom bonds to only three others, leaving one electron per atom delocalised and free to move along the layers. Graphite also has a high melting point because breaking its many strong covalent bonds takes a large amount of energy. Together, these properties make it a good, stable electrode material.

Mark scheme

(a) [2]

- each carbon atom forms 4 strong covalent bonds to 4 other carbon atoms (1)
- forming a rigid giant covalent (three-dimensional) structure/lattice (1)

(b) [2]

- graphite consists of carbon atoms arranged in layers (of hexagonal rings), each carbon atom bonded to 3 others, with weak forces between the layers (1)
- because the forces between the layers are weak, the layers can slide over each other easily, allowing graphite to be used as a lubricant (1)

(c) [2]

- graphite: as an electrode, because it conducts electricity / has delocalised electrons that are free to move (1)
- diamond: in cutting tools (or drill tips), because it is very hard due to its rigid giant covalent structure with strong covalent bonds throughout (1)

REJECT graphite as a lubricant (already used in (b))

- each mark needs both the use and a correctly linked property

Worked solution

Diamond and graphite are both forms of carbon but have very different structures. In diamond, every carbon atom forms four strong covalent bonds to four neighbours, producing a rigid three-dimensional lattice with no weak points - this rigidity is why diamond is extremely hard and is used in cutting tools. In graphite, each carbon atom bonds to only three neighbours, forming flat layers of hexagonal rings; the covalent bonds within each layer are strong, but the forces between separate layers are weak, so the layers can slide over one another - this is why graphite feels slippery and is used as a lubricant, and also, because one electron per carbon atom is left delocalised and free to move along the layers, why graphite conducts electricity and can be used as an electrode.

Mark scheme

(a)

[2]

- each silicon atom is covalently bonded to 4 oxygen atoms, and each oxygen atom is covalently bonded to 2 silicon atoms (1)
- forming a giant covalent (three-dimensional) lattice/structure (1)

(b)

[3]

- silicon(IV) oxide has many strong covalent bonds throughout its giant lattice, which must all be broken to melt it (1)
- breaking these strong covalent bonds requires a large amount of energy, giving a very high melting point (1)
- there are no ions and no free/delocalised electrons present, so there is nothing free to carry electrical charge, meaning it does not conduct electricity (1)

Worked solution

Silicon(IV) oxide has a giant covalent structure much like diamond: instead of individual molecules, every atom is linked to its neighbours by strong covalent bonds that extend throughout the whole structure (each silicon atom bonded to four oxygens, each oxygen bridging two silicons). Melting this structure means breaking a huge number of these strong covalent bonds at once, which needs a very large amount of energy - this is why silicon(IV) oxide, like diamond, has such a high melting point. It does not conduct electricity because, unlike a metal or a graphite layer, it has no delocalised electrons free to move, and unlike an ionic compound, it contains no ions - there is simply nothing present that is free to carry an electric charge.

Answer: C**Worked solution**

In a metal, each metal atom loses its outer electrons to the whole structure; these electrons become delocalised, meaning they are no longer attached to any one atom and are free to move throughout the metal. What is left behind is a regular lattice of positive metal ions, held together by their electrostatic attraction to this surrounding "sea" of delocalised electrons.

Mark scheme

(a) [2]

- positive metal ions are arranged in a regular giant lattice (1)
- the ions are surrounded by a "sea" of delocalised electrons, which are free to move throughout the structure (1)

(b) [2]

- the delocalised electrons are free to move throughout the metal lattice (1)
- these mobile electrons can carry electrical charge through the structure, allowing an electric current to flow (1)

(c) [2]

- the layers of positive metal ions can slide over each other when a force is applied (1)
- the delocalised electrons are not fixed in position and move with the ions, continuing to hold the structure together as the ions slide, so the metallic bond is not broken and the metal bends/changes shape rather than shattering (1)

Worked solution

A metal is a giant lattice of positive metal ions surrounded by a sea of delocalised electrons - electrons that have left their original atoms and are free to move anywhere throughout the structure. This mobility explains both key properties. Electrical conductivity: because the delocalised electrons can move freely, they can flow through the metal and carry an electric current when a voltage is applied. Malleability and ductility: when a force is applied, the layers of positive ions can slide past one another into new positions; because the delocalised electrons are not tied to any particular ion, they simply move along too and continue to hold the ions together in their new arrangement. This is why metals can be hammered into sheets or drawn into wires without breaking, unlike ionic compounds, where sliding layers brings ions of the same charge together, causing them to repel and the structure to shatter.