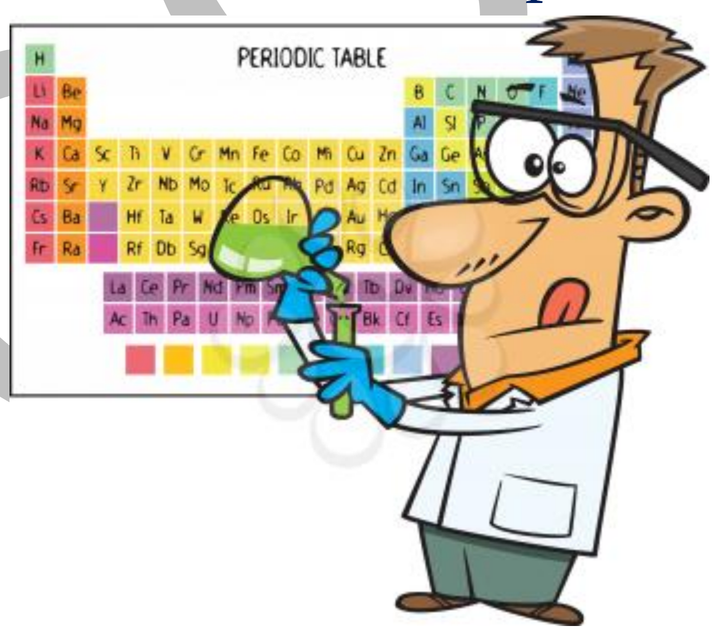
Edexcel AS Chemistry

(Code: WCH11)

Topic 01
Atomic structure and the periodic table



2A Atomic Structure

2A.1 Structure of the atom and isotopes

J.J. Thomson discovered the electron in 1897. Ernest Rutherford discovered the proton in 1917. James Chadwick discovered the neutron in 1932.

PARTICLE	SYMBOL	RELATIVE MASS	RELATIVE CHARGE	POSITION IN THE ATOM
proton	p	1	+1	nucleus
neutron	n	1	0	nucleus
electron	e^-	$\frac{1}{1840}$	−1	energy levels surrounding the nucleus

Carbon atoms

Mass number → 12, Atomic number → 6: $^{12}_{6}C$, $^{13}_{6}C$

Atomic number = number of protons (= number of electrons)

Mass number = number of protons + number of neutrons

SUBJECT VOCABULARY

atomic number (Z) the number of protons in the nucleus of an atom

mass number the sum of the number of protons and the number of neutrons in the nucleus of an atom

isotopes atoms of the same element that have the same atomic number but different mass number

ISOTOPE	SYMBOL FOR ISOTOPE	NUMBER OF PROTONS	NUMBER OF NEUTRONS	NUMBER OF ELECTRONS
chlorine-35	$^{35}_{17}Cl$	17	18	17
chlorine-37	$^{37}_{17}Cl$	17	20	17

DID YOU KNOW?

Isotopes of the same element have identical chemical properties because they have identical electronic configurations.

2A.2 Mass spectrometry and relative masses of atoms, Isotopes and molecules

Relative atomic mass

The ratio of the average mass per atom of the element to 1/12 of the mass of an atom of ^{12}C.

Lithium, in its naturally occurring compounds, has two isotopes of relative isotopic masses 6.015 and 7.016. The percentage abundance of each isotope is 7.59 and 92.41 respectively.

This is how you can calculate the relative atomic mass of lithium.

There are two stages.

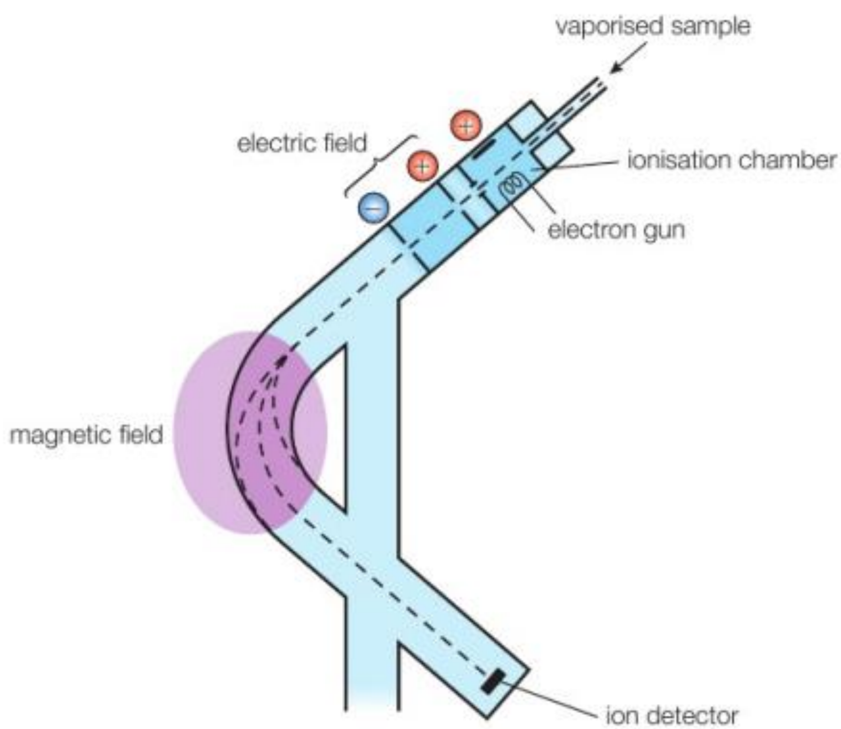
Stage 1: $(6.015 \times 7.59) + (7.016 \times 92.41) = 694.00241$

Stage 2: $\frac{694.00241}{100} = 6.9400241$

The relative atomic mass of lithium, to three significant figures, is 6.94.

Using data obtained from a mass spectrometer

A mass spectrometer measures the masses of atoms and molecules. It produces positive ions that are deflected by a magnetic field according to their mass-to-charge ratio (m/z). It also calculates the relative abundance of each positive ion and displays this as a percentage.



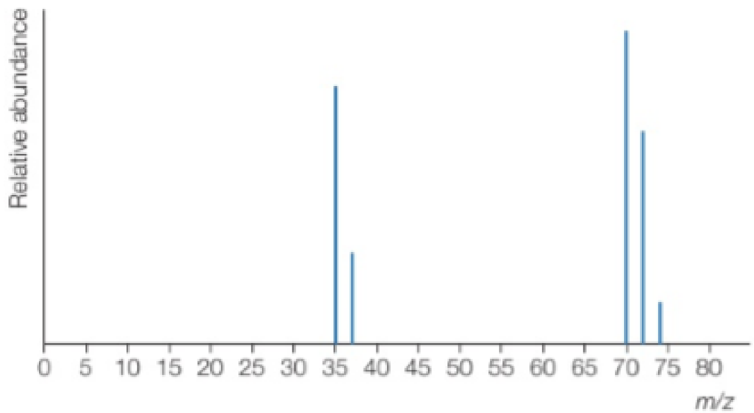
Determining relative molecular mass (M_r) of diatomic molecules

There are two peaks corresponding to isotopic masses of 35 and 37. The approximate relative peak heights for each isotope are 3:1 for chlorine-35: chlorine-37.

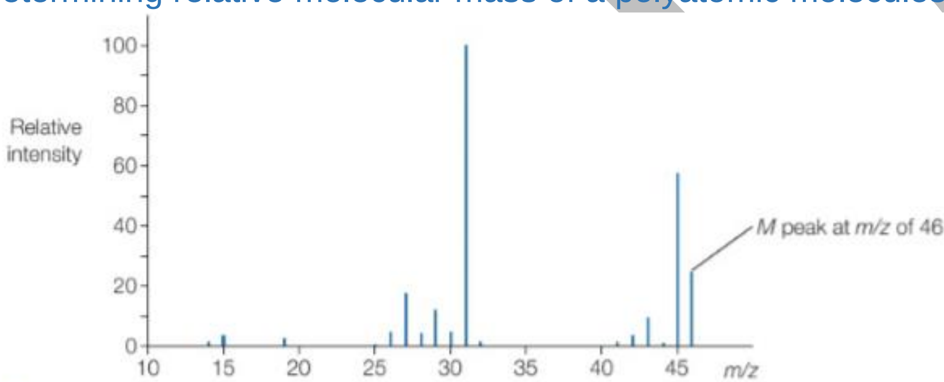
This gives an approximate relative atomic mass of this sample of chlorine of

$((3 \times 35) + (1 \times 37)) +4=35.5.$

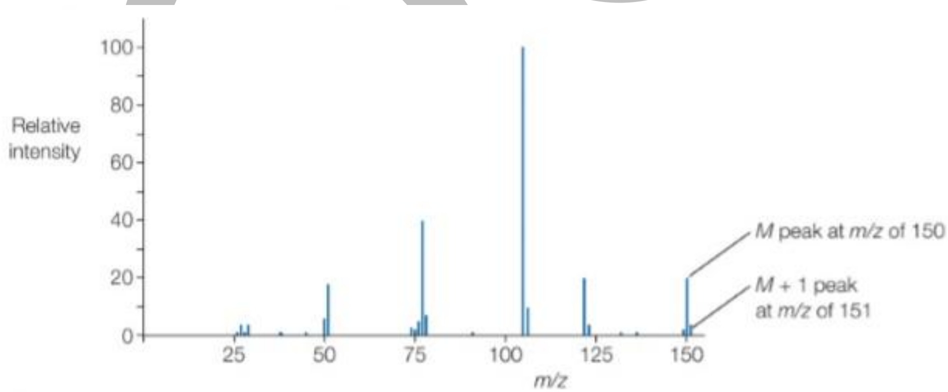
You will notice in the diagram that there are three peaks, which correspond to molecular masses of 70, 72 and 74.



Determining relative molecular mass of a polyatomic molecules



Mass spectrum of ethanol (M_r = 46).



Mass spectrum of ethyl benzoate (M_r = 150).

2A.3 Atomic orbitals and electronic configurations

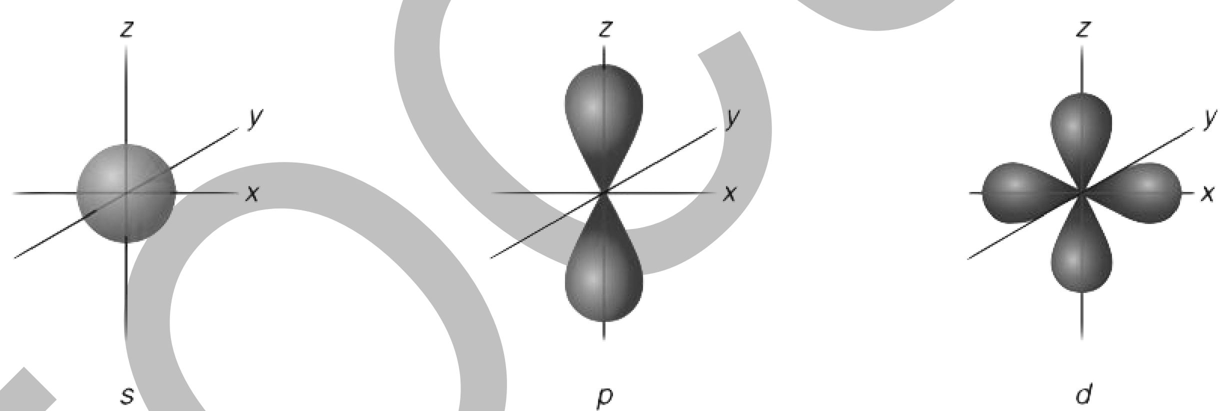
Quantum shells

Electrons can only exist in certain well- defined energy levels called quantum shells. All electrons in a quantum shell have similar, but not identical, energies.

Electrons in the first four quantum shells

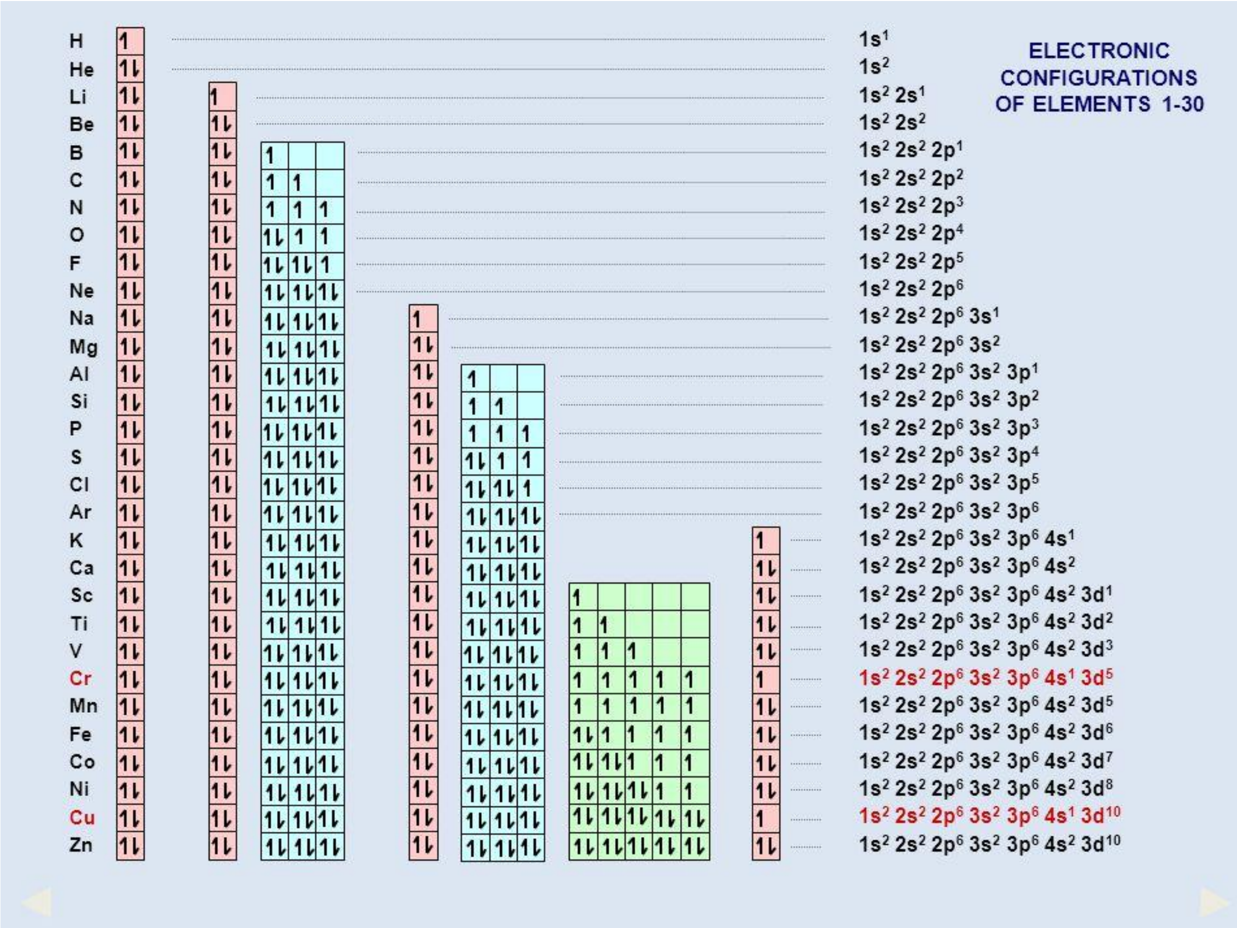
Each quantum shell, apart from the first, is further divided into sub-shells of slightly different energy levels.

- There is only one sub-shell in the first quantum shell. This is labelled the 1s sub-shell.
- The second quantum shell has two sub-shells, labelled 2s and 2p. Electrons in the 2p sub-shell have a slightly higher energy level than those in the 2s sub-shell.
- The third quantum shell is divided into three sub-shells, labelled 3s, 3p and 3d. Electrons in the 3p sub-shell have slightly higher energy than those in 3s, and those in the 3d sub- shell have slightly higher energy than those in 3p.
- The fourth quantum shell is divided into four sub-shells, labelled 4s, 4p, 4d and 4f. Again, the electron energies increase in the order 4s < 4p < 4d <4f.



	NUMBER OF ELECTRONS
first quantum shell	2
second quantum shell	8
third quantum shell	18
fourth quantum shell	32

Electronic configurations



Spin-spin pairing and electronic configurations

Hund's rule and the Pauli Exclusion Principle

Hund’s rule states: Every orbital in a subshell is singly occupied with one electron before any one orbital is doubly occupied, and all electrons in singly occupied orbitals have the same spin.

Pauli's Exclusion Principle states that no two electrons in the same atom can have identical values for all four of their quantum numbers.

2A.4 ionization energies

Ionization energy is a measure of the energy required to completely remove an electron from an atom of an element.

<u>First ionization energy</u>
$A(g) \rightarrow A^{+}(g) + e^{-}$

<u>Second ionization energy</u>
$A^{+}(g) \rightarrow A^{2+}(g) + e^{-}$

<u>Third ionization energy</u>
$A^{2+}(g) \rightarrow A^{3+}(g) + e^{-}$

Successive ionization energies

1st	2nd	3rd	4th	5th	6th
496	4563	6913	9544	13352	16611

7th	8th	9th	10th	11th
20115	25491	28934	141367	159079

Successive ionisation energies, in kJ mol^{-1}, of sodium.

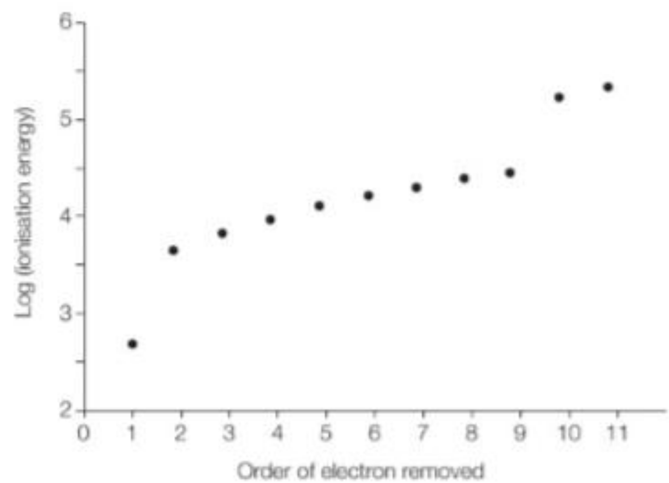


fig A Graph showing the trend in successive ionisation energies for sodium.

The difference in energy between the electron when it has been removed and the energy it has when it is in its original orbital in the quantum shell is known as the ionisation energy. We can represent this by the equation:

Ionisation energy (IE) = energy of electron when removed - energy of electron when in the orbital

The ionisation energy for a particular electron in a given atom depends solely on the energy it has when it is in its orbital within the atom.

Energy of an electron

The factors that affect the energy of an electron are:

- The orbital in which the electron exists
- The nuclear charge of the atom (i.e. the number of protons in the nucleus)
- The repulsion (shielding) experienced by the electron from all the other electrons present.

Trends in ionization energy

There are two major trends:

1. Across a period
   First ionization energy generally increases as you move left to right across a period.
2. Down a group
   First ionization energy generally decreases as you move down a group

2B The periodic table

2B.1 The periodic table

Groups, period and blocks

s-block								d-block						p-block			
1	2											3	4	5	6	7	8
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe

2B.2 Periodic properties

1. Atomic radii
   Radius of the atom decreases across each period.

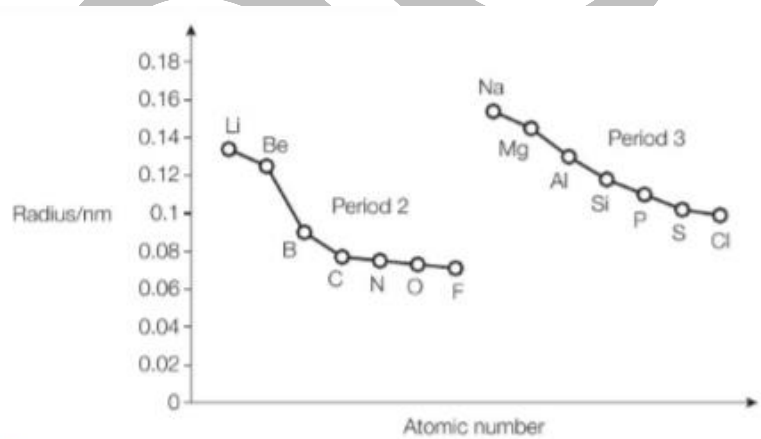


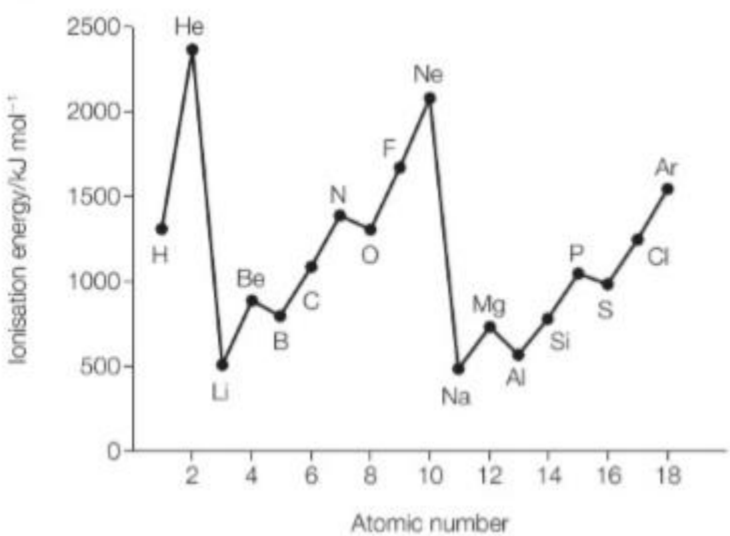
fig B Trend in covalent radii across the second and third periods.

2. Melting and boiling temperatures
Elements with giant lattice structures have high melting and boiling temperatures, and those with simple molecular structures have low melting and boiling temperatures.

PERIOD 2	Li	Be	B	C (DIAMOND)	N	O	F
melting temperature / °C	181	1278	2300	3550	−210	−218	−220
boiling temperature / °C	1342	2970	3927	4827	−196	−183	−188
type of bonding	metallic	metallic	covalent	covalent	covalent	covalent	covalent
structure	giant lattice	giant lattice	giant lattice	giant lattice	simple molecular	simple molecular	simple molecular

PERIOD 3	Na	Mg	Al	Si	P	S	Cl
melting temperature / °C	98	649	660	1440	44	113	−101
boiling temperature / °C	883	1107	2467	2355	280	445	−35
type of bonding	metallic	metallic	metallic	covalent	covalent	covalent	covalent
structure	giant lattice	giant lattice	giant lattice	giant lattice	simple molecular	simple molecular	simple molecular

3. First ionization energies



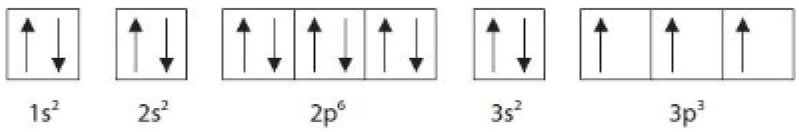
Exercise

1. Ionisation energies provide information about the number of electrons and the arrangement of the electrons in an atom of an element. A student's definition of first ionisation energy is shown.

   > First ionisation energy is the energy released when one mole of gaseous atoms loses one mole of electrons to form one mole of gaseous 1+ ions.

   There is one incorrect word in the student's definition. Identify the word, giving the reason why this word is incorrect.

2. This question is about the electronic structure of some Group 5 elements.
   The electronic configuration of a phosphorus atom can be written
   $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$
   An alternative way to express the electronic configuration is

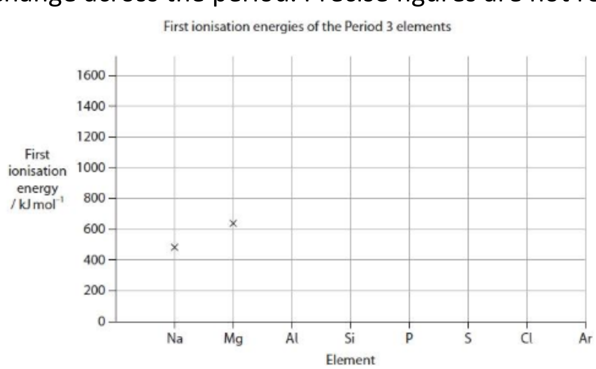
   

   i. State what is meant by the two arrows in the first box.
   ii. State why the arrows are all pointing in the same direction in the 3p boxes.

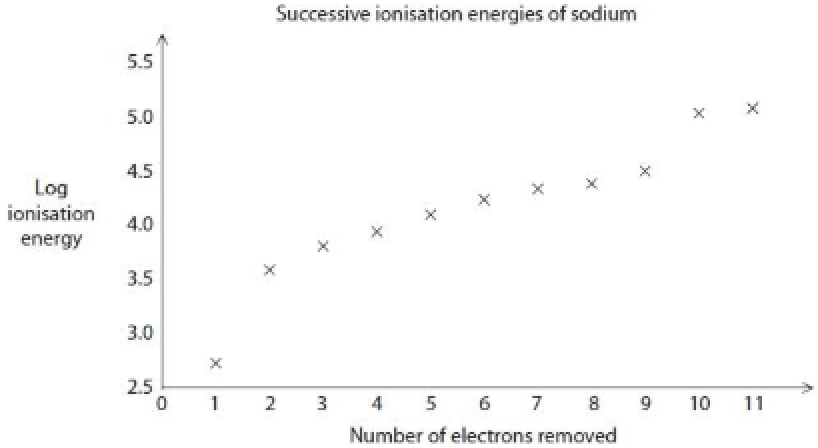
3. Chlorine and iodine are in the same group in the Periodic Table.
   i. Complete the electronic configuration of chlorine using the s, p, d notation.
   $1s^2$
   ii. Explain why iodine and chlorine have many similar chemical reactions.

4. Magnesium bromide, MgBr2, is an ionic compound.
   i. The first ionisation energy of sodium is 496 kJ mol^{-1}. Explain why the first ionisation energy of magnesium is higher than that of sodium.
   ii. Write the equation, including state symbols, to show the third ionisation energy of magnesium.

5. This question is about ionisation energies.
   i. Complete the graph to show how the first ionisation energies of the Period 3 elements change across the period. Precise figures are not required.

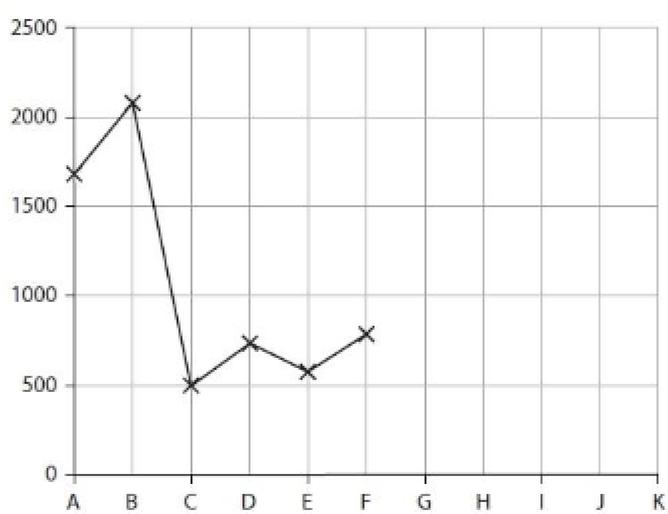
ii. The successive ionisation energies of sodium are shown on the graph.



State what deductions can be made from this graph.

6. This question is about hydrogen, the element with atomic number Z = 1.
   i. Write an equation to represent the first ionisation energy of hydrogen. Include state symbols.
   ii. The sequence of the first three elements in the Periodic Table is hydrogen, helium and then lithium. Explain why the first ionisation energy of hydrogen is less than that of helium, but greater than that of lithium.

7. Electrons in atoms occupy orbitals.
   i. The graph shows the first ionisation energies for a series of six consecutive elements A–F. The letters are not their chemical symbols. Complete the graph of the first ionisation energies for the next five elements.



   ii. Explain why the value of the first ionisation energy for D is greater than for C
   iii. Explain why the value of the first ionisation energy of E is less than for D.

8. Ionisation energies provide information about the number of electrons and the arrangement of the electrons in an atom of an element. Write an equation for the second ionisation energy of oxygen. Include state symbols.

9. Ionisation energies provide information about the number of electrons and the arrangement of the electrons in an atom of an element. The successive ionisation energies for magnesium are given in the table.

Electron number removed	1	2	3	4	5	6	7	8	9	10	11	12
Ionisation energy / $kJ\,mol^{-1}$	738	1451	7733	10541	13629	17995	21704	25657	31644	35463	169996	189371
Log (ionisation energy)	2.87	3.16	3.89	4.02	4.13		4.34	4.41	4.50	4.55	5.23	

i. Complete the table
ii. Give a reason why the logarithm of the ionisation energy, rather than just the ionisation energy, is used to plot a graph.
iii. Give a reason why the successive ionisation energies increase.
iv. Plot the graph of log(ionisation energy) against electron number removed. Join the individual points using straight lines.
v. Identify on the graph, using a circle, the points that represent the removal of the electrons in the outermost energy level of magnesium.

10. This question is about ions and ionic compounds. The first three ionisation energies of calcium are shown in the table.

	First ionisation	Second ionisation	Third ionisation
Ionisation energy / $kJ\,mol^{-1}$	590	1145	4912
Orbital			

i. Complete the table by identifying the specific orbital from which each electron is removed.
ii. Write the equation for the third ionisation energy of calcium. Include state symbols.
iii. Explain why the difference between the second and third ionisation energies of calcium is much larger than the difference between the first and second ionisation energies.

11. Bromine exists as two stable isotopes. The two isotopes are represented by the symbols $^{79}_{35}Br$ and $^{81}_{35}Br$. Give one similarity and one difference between these two isotopes by referring to the number of particles in the nuclei of the two isotopes.

12. This is a question about atoms, isotopes and ions. The percentage composition of the two bromine isotopes in a sample is given in the table.

Isotope	Relative isotopic mass	Percentage abundance
bromine-79	78.918	50.52
bromine-81	80.916	49.48

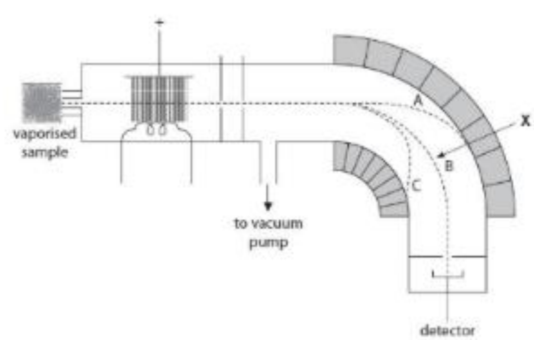
Calculate the relative atomic mass of bromine in this sample. Give your answer to two decimal places.

13.
   a. State what is meant by the term relative atomic mass
   b. A 5.000 g sample of lithium, containing the two isotopes lithium-6 and lithium-7, was found to contain 0.460 g of the isotope lithium-6. Calculate the relative atomic mass of lithium for this sample. Give your answer to an appropriate number of significant figures

Isotope	Relative isotopic mass
Lithium-6	6.015
Lithium-7	7.016

14. A phosphorus atom has mass number 31. Phosphorus has one naturally occurring isotope with mass number 31. Chlorine exists as two isotopes with mass numbers 35 and 37. Give the formulae and mass/charge ratio of the ions responsible for the molecular ion peaks in the mass spectrum of phosphorus (III) chloride, PCl_3.

15. This question is about isotopes. The relative isotopic abundances of an element can be measured using a mass spectrometer. A simplified and incompletely labelled diagram of a mass spectrometer is shown.
   a. Name the feature of the mass spectrometer responsible for the behavior of the ions in the region indicated by the arrow X.
   b. Explain the three ion pathways, A, B and C, shown in the region indicated by the arrow X.
   c. Give a reason why the mass spectrometer must be operated under vacuum.



16. Give the meaning of the term 'periodicity'. Illustrate your answer by referring to the atomic radii of the Period 2 and Period 3 elements. Specific values of atomic radii are not required.

17. This question is about trends within Group 2 of the Periodic Table. Describe, with the aid of a labelled diagram, how you would compare the thermal stability of two different Group 2 nitrates using simple laboratory equipment. Your answer must include one safety precaution (excluding the use of gloves, laboratory coat and eye protection).

18. A student stated that 'the elements scandium and zinc are d-block elements but are not transition metals'. Discuss this statement, using appropriate electronic configurations to support your answer.

19. This question is about the chemistry of elements in the d-block of the Periodic Table. * Many of the d-block elements are also classified as transition metals. Explain why two of the d-block elements within Period 4 (scandium to zinc) are not classified as transition metals. You should include full electronic configurations where relevant.

20. This question is about hydrogen, the element with atomic number Z = 1.
    a. Write an equation to represent the first ionisation energy of hydrogen. Include state symbols.
    b. The sequence of the first three elements in the Periodic Table is hydrogen, helium and then lithium. Explain why the first ionisation energy of hydrogen is less than that of helium, but greater than that of lithium