2

ATOMIC STRUCTURE

Content

2.1 The nucleus of the atom: neutrons and protons, isotopes, proton and nucleon numbers

2.2 Electrons: electronic energy levels, ionisation energies, atomic orbitals, extranuclear structure

Learning Outcomes

Candidates should be able to:

(a) identify and describe protons, neutrons and electrons in terms of their relative charges and relative masses

(b) deduce the behaviour of beams of protons, neutrons and electrons in an electric field

(c) describe the distribution of mass and charges within an atom

(d) deduce the numbers of protons, neutrons and electrons present in both atoms and ions given proton and nucleon numbers (and charge)

(e) (i) describe the contribution of protons and neutrons to atomic nuclei in terms of proton number and nucleon number

(ii) distinguish between isotopes on the basis of different numbers of neutrons present

(f) describe the number and relative energies of the s, p and d orbitals for the principal quantum numbers 1, 2 and 3 and also the 4s and 4p orbitals.

(g) describe the shapes of the s and p orbitals

(h) state the electronic configuration of atoms and ions given the proton number (and charge)

(i) (i) explain the factors influencing the ionization energies of elements (see the *Data Booklet*)

(ii) explain the trends in ionization energies across a period and down a group of the Periodic Table (see also Section 9)

(j) deduce the electronic configurations of elements from successive ionization energy data

(k) interpret successive ionization energy data of an element in terms of the position of that element within the Periodic Table

❷•❶ The nucleus of the atom

MCQs

02-1-M-01

07ZZ02-1-M-01

D Nucleon number = no. of protons + no. of neutrons

Proton number = no. of protons

Nucleon number = 58 or 60

Proton number = 28

Thus both have the same no. of protons but different no. of neutrons. (ans)

02-1-M-02

07ZZ02-1-M-02

A Relative atomic mass $= \dfrac{(20\times 9)+(22\times 1)}{10}$

$= 20.2$

Hence ratio = 1 : 9 (ans)

02-1-M-03

07ZZ02-1-M-03

D Deflection $\propto$ e/m

$$\frac{\text{Deflection (Ca)}}{\text{Deflection (Am)}} = \frac{\text{mass (Am)}}{\text{mass (Ca)}}$$

$$\text{Deflection (Ca)} = \left(\frac{241}{40}\right)\times 2$$

$= 12.1$ (ans)

02-1-M-04

07ZZ02-1-M-04

A No. of protons (Ge) = 32

Nucleon number = 68

No. of neutrons after transformation

= (68 – 32) + 1 = 37 (ans)

02-1-M-05

07ZZ02-1-M-05

D peak at 120 = $^{12}C^{19}F_2{}^{35}Cl^{35}Cl$

peak at 122 = $^{12}C^{19}F_2{}^{35}Cl^{37}Cl$

peak at 124 = $^{12}C^{19}F_2{}^{37}Cl^{37}Cl$

relative intensities = 9 : 6 : 1 (ans)

02-1-M-06

07ZZ02-1-M-06

A OH^- : no. of protons = 9

No. of neutrons = 17 – 9 = 8

No. of electrons = 9 + 1 = 10

No. of electrons > no. of protons > no. of neutrons (ans)

02-1-M-07

07ZZ02-1-M-07

B isoelectronic = same no. of electrons

CN^- : no. of protons = 13

No. of electrons = 13 + 1 = 14

N_2 : no. of protons = no. of electrons

= 14

Thus they are isoelectronic (ans)

Questions – 2.1

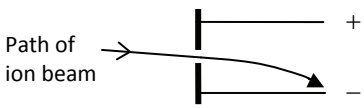
02-1-Q-01

07ZZ02-1-Q-01

(i) isotope : One of two or more atoms having the same atomic number but different mass numbers.

Isotope of iodine = A and D (same no. of protons i.e. 53)

(ii)



Angle of deflection is inversely proportional to mass of ion, proportional to charge of ion.

Charge to mass ratio of the ions of the two isotopes does not differ significantly. (ans)

❷•❷ Electrons: electronic energy levels, ionisation energies, atomic orbitals

MCQs

02-2-M-01

07ZZ02-2-M-01

C Fe^{2+} : no. of electrons = 24

predicted configuration = $3d^4\ 4s^2$

actual configuration = $3d^5\ 4s^1$

(higher stability with half-filled d-orbitals) (ans)

02-2-M-02

07ZZ02-2-M-02

D Proton no. = no. of electrons

no. of electrons = 26

electronic configuration = $3d^6\ 4s^2$

4 unpaired electrons in its ground state in 3d orbital (ans)

02-2-M-03

07ZZ02-2-M-03

D Deflection $\propto$ e/m

e/m ($^{6}_{3}Li^{+}$) = $\frac{1}{6}$

e/m ($^{12}_{6}C^{2+}$) = $\frac{2}{12} = \frac{1}{6}$ (ans)

02-2-M-04

07ZZ02-2-M-04

B

	Difference in ionization energies ($kJ\ mol^{-1}$) W	Difference in ionization energies ($kJ\ mol^{-1}$) Z
1^{st} to 2^{nd}	1220	2090
2^{nd} to 3^{rd}	900	1900
3^{rd} to 4^{th}	8900	1800
4^{th} to 5^{th}	3200	3800
5^{th} to 6^{th}	3600	2000
6^{th} to 7^{th}	4900	7000

W belongs to Group III; Z belongs to Group VI

Formula of compound = W_2Z_3 (ans)

02-2-M-05

07ZZ02-2-M-05

A

	Difference in ionization energies ($kJ\ mol^{-1}$)
1^{st} to 2^{nd}	984
2^{nd} to 3^{rd}	780
3^{rd} to 4^{th}	2120
4^{th} to 5^{th}	1170
5^{th} to 6^{th}	6280
6^{th} to 7^{th}	3100
7^{th} to 8^{th}	3500

Highest jump in ionization energy between 5^{th} and 6^{th} electron, 6^{th} electron removed from an inner quantum shell.

Thus element belongs to Group V. It can form a chloride that is trigonal pyramidal in shape and has half-filled p-orbitals. (ans)

02-2-M-06

07ZZ02-2-M-06

D Sc: no. of electrons = 21

Electronic configuration

= $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1\ 4s^2$

Order are the electrons lost in forming the Sc^{4+} ion = 4s, 4s, 3d, 3p (ans)

02-2-M-07

07ZZ02-2-M-07

B No. of electrons = 16 (same as in Cl^+ and P^-)

no. of electrons in Cl^+ = 16

no. of electrons in P^- = 16

no. of electrons in Ar^{2-} = 20 (ans)

02-2-M-08

07ZZ02-2-M-08

D no. of electrons in Cr^{3+} = 21
electronic configuration of Cr^{3+} = $3d^3$

no. of electrons in Al^{3+} = 10
electronic configuration = $1s^2\ 2s^2\ 2p^6$

no. of electrons in Cu^{2+} = 27
electronic configuration = $3d^7\ 4s^2$

only Cr^{3+} has 3 unpaired electrons (ans)

02-2-M-09

07ZZ02-2-M-09

D no. of electrons = 24

electronic configuration
= $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$ (ans)

02-2-M-10

07ZZ02-2-M-10

A nucleon number = 89

Same nucleon no. and charge as $^{89}Y^{5+}$, so deflected to same extent and direction.

It has the configuration [Kr] $4d^{10}5s^2$ and the 3rd ionization energy is significantly larger than the 2nd ionization energy as the 3^{rd}

Electron is removed from an inner quantum shell. (ans)

02-2-M-11

07ZZ02-2-M-11

C No. of electrons (M^{2+}) = 23

electronic configuration = [Ne] $3s^2$ $3p^6$ $3d^3$ $4s^2$ (ans)

02-2-M-12

07ZZ02-2-M-12

A n = 2, orbitals = $2s^2$ $2p^6$

shape of s and p orbitals = spherical and dumb-bell

It is true that electrons occupy orbitals starting with those of lower energy first. (ans)

02-2-M-13

07ZZ02-2-M-13

C charge of Co = 3+

no. of electrons = 24

electronic configuration of ion = [Ar] $3d^6$ $4s^0$ (ans)

02-2-M-14

07ZZ02-2-M-14

D **Y** is able to remove the paired electrons in 3s easily due to inter-electronic repulsion, allowing for the expansion of the octet structure.

X is unable to do so as 2s is an inner quantum shell. (ans)

02-2-M-15

07ZZ02-2-M-15

D Negatively charged ions are smaller than their corresponding atoms due to the removal of electrons from the outer shell. (ans)

02-2-M-16

07ZZ02-2-M-16

D 2nd IE for sodium highest because 2nd electron removed is from an inner quantum shell (2p). (ans)

02-2-M-17

07ZZ02-2-M-17

D Ba is a Group II element; Cs is a Group I element; Xe is a Group 0 element.

Thus order from most endothermic is Xe > Ba > Cs (ans)

02-2-M-18

07ZZ02-2-M-18

C

	Difference in ionization energies (kJ mol^{-1})
1st to 2nd	810
2nd to 3rd	1600
3rd to 4th	1200
4th to 5th	11700
5th to 6th	3700
6th to 7th	4000

Big jump in IE indicates that the 5th electron is removed from an inner quantum shell.

Thus the element belongs to Group IV with the electronic configuration of ns^2np^2. (ans)

02-2-M-19

07ZZ02-2-M-19

D Only (1) is correct.

Group IV elements do not have a half-filled p orbital, p and s electrons do not occur in the same shell as they have different energy levels. (ans)

02-2-M-20

07ZZ02-2-M-20

D Cathodes attract negatively charged ions. A possible electronic configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$.

The 4s orbital accepts an electron easily due to its further distance from the nucleus. (ans)

02-2-M-21

07ZZ02-2-M-21

A To be isoelectronic, **Y** has to have a higher positive charge than **X**.

Thus **X** has a larger radius, which requires less energy than **Y** when a further electron is removed from or added to each particle. (ans)

02-2-M-22

07ZZ02-2-M-22

B Cr has 24 electrons and a predicted electronic configuration of $3d^4\ 4s^2$.

Actual configuration is $3d^5\ 4s^1$ due to the higher stability achieved with the latter configuration. (ans)

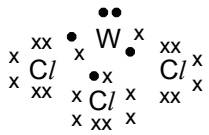
Questions – 2.2

02-2-Q-01

07ZZ02-2-Q-01

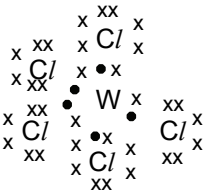
(a) (i) Group V. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

(ii)



WCl_3

Trigonal pyrimidal



WCl_5

Trigonal bipyrimidal

(iii) Pair I: P and X, Group VI
Pair II: Q and Y, Group VII

(iv) $S^+ : 1s^2\ 2s^2\ 2p^6$
$T^+ : 1s^2\ 2s^2\ 2p^6\ 3s^1$

3s electron in T^+ is higher in energy than 2p electron in S^+, and also experiences greater shielding by the pair of electrons in the inner 2p orbital.

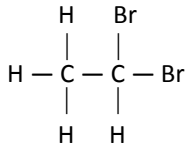
Hence, it requires less energy to remove, resulting in a lower 2nd IE of T than that of S.

(b) (i)

m/e	Species	Relative Abundance	Abundance Ratio
171	$[CH^{79}Br_2]^+$	¼	1
173	$[CH^{79}Br^{81}Br]^+$, $[CH^{81}Br^{79}Br]^+$	½	2
175	$[CH^{81}Br_2]^+$	¼	1

(ii) m/e 15

(iii)



(ans)

02-2-Q-02

07ZZ02-2-Q-02

(a) Tc^{6+}

No. of protons = 43
No. of neutrons = 56
No. of electrons = 37

(b)

Grp	m/e	Ion	Rel. abundance	Abundance ratio
A	115	$^{99}Tc^{16}O^{+}$		
	116	$^{99}Tc^{17}O^{+}$		
B	131	$^{99}Tc^{16}O_2^{+}$		
	132	$^{99}Tc^{16}O^{17}O^{+}$, $^{99}Tc^{17}O^{16}O^{+}$		
	133	$^{99}Tc^{17}O_2^{+}$		
C	147	$^{99}Tc^{16}O_3^{+}$	8/27	8
	148	$^{99}Tc^{16}O_2{}^{17}O^{+}$, $^{99}Tc^{16}O^{17}O^{16}O^{+}$, $^{99}Tc^{17}O^{16}O_2^{+}$	12/27	12
	149	$^{99}Tc^{16}O^{17}O_2^{+}$, $^{99}Tc^{17}O^{16}O^{17}O^{+}$, $^{99}Tc^{17}O_2{}^{16}O^{+}$	6/27	6
	150	$^{99}Tc^{17}O_3^{+}$	1/27	1

(ans)

02-2-Q-03

07ZZ02-2-Q-03

(a)

Particle	Electric charge	Mass number	Number of		
			p	e	n
X	0	**32**	16	**16**	16
Y	–1	81	**35**	36	**46**
Z	**+3**	70	31	28	**39**

(b) (i) electronic configuration of particle **Y**
$= 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$

(ii) Ionic size of **Y** is larger than that of Rb^+;
Both are isoelectronic but the nuclear charge of **Y** is smaller than that of Rb^+ as **Y** has fewer no. of protons.

(c) (i) First IE of **X** is lower than P due to mutual repulsion of paired electrons in a 3p orbital of **X**.

(ii) First IE of **X** is higher than that of Se; Se has an additional principal quantum shell, therefore greater shielding effect by inner shells' electrons and larger atomic radius than **X**.

(d) **X** forms covalent bonds with F_2. $\mathbf{X}F_4$ can readily form as **X** has energetically accessible empty 3d orbitals to expand its octet in $\mathbf{X}F_4$.

Mg forms an ionic compound with F_2.

Large amount of energy is needed to remove 4 electrons from Mg to form Mg^{4+} as the 3rd and 4th IE are particularly high. Hence, its enthalpy change of reaction is highly endothermic. (ans)

02-2-Q-04

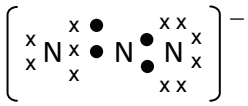
07ZZ02-2-Q-04

(a) (i) More energy is required to remove electrons from an increasingly positive ion. There is a stronger electrostatic force of attraction between the ion and the remaining electrons.

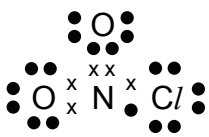
(ii) A large amount of energy is required to remove the 6th electron, which is from the inner quantum shell, thus experiencing a greater electrostatic force of attraction with the positive ion.

Hence **E** belongs to Group V. The electron arrangement in the outer shell of **E** is ns^2np^3.

(b) (i)



N_3^-
Linear



$NCl O_2$
Trigonal planar

(ii) NaN_3 is soluble in water since the lone pair of electrons can form ion-dipole interactions with water molecules.

$NaClO_2$ is soluble in water due to the formation of hydrogen bonds between its molecules and that of water.