Tutorial – Atomic Structure

Discussion Questions

Atomic Number and Mass Number

1. *Use of the Data Booklet is relevant to this question.*

Nuclear magnetic resonance (NMR) spectroscopy is an analytical technique that uses the magnetic properties of certain atomic nuclei in order to elucidate the structure of an organic molecule.

Atomic nuclei with an even number of protons and an odd number of neutrons (or vice versa) are most suitable for NMR spectroscopy.

Which of the following nuclei is **least** suitable for NMR spectroscopy?

A ^{28}Si **B** ^{31}P **C** ^{103}Rh **D** ^{19}F

A: no. of protons 14, no. of neutrons = 28 – 14 = 14 (even no. protons and neutrons) A
B: no. of protons 15, no. of neutrons = 31 – 15 = 16
C: no. of protons 45, no. of neutrons = 103 – 45 = 58
D: no. of protons 9, no. of neutrons = 19 – 9 = 10

2 *Use of the Data Booklet is relevant to this question.*

Tritium, $^{3}_{1}H$, a radioactive isotope of hydrogen, slowly turns into a helium isotope $^{3}_{2}He$.

Which statements about the two isotopes are **incorrect**?

1 Both isotopes have more neutrons than electrons.

2 Both isotopes have the same number of protons in their nuclei.

3 Both isotopes have the same number of charged sub–atomic particles.

A 2 only
B 1 and 3 only
C 2 and 3 only
D 1, 2 and 3

$^{3}_{1}H$ contains 1 proton, 1 electron and 2 (3 – 1) neutrons. D
$^{3}_{2}He$ contains 2 protons, 2 electrons and 1 (3 – 2) neutron.

1 ^{3}He has less neutrons than electrons.
2 ^{3}H has one proton while ^{3}He has two protons.
They are isotopes of different element, hence they CANNOT have the same number of protons.
3 ^{3}H has two charged sub–atomic particles while ^{3}He has four charged sub–atomic particles.

3 Some isotopes are unstable and undergo nuclear (radioactive) reactions. In one type of reaction, an unstable nucleus assimilates an electron from an inner orbital of its electron cloud. The net effect is the conversion of a proton and an electron into a neutron.

Which of the following describes this type of reaction?

A $^{11}C \rightarrow {}^{12}C$
B $^{111}I \rightarrow {}^{111}Te$
C $^{76}Br \rightarrow {}^{75}Br$
D $^{76}Kr \rightarrow {}^{75}Br$

The conversion results in the loss of a proton. So proton no decrease by 1. B
The reactant and the product cannot be the same element. Therefore options A and C are NOT the answers.
Since the proton is converted into a neutron, mass no (nucleon no do not change)

2015 P3 Q5

5 Lithium metal and its compounds have many uses, ranging from nuclear chemistry, rechargeable batteries, organic reagents and pharmaceuticals.

(a) *Naturally occurring* lithium contains isotopes ^{6}Li and ^{7}Li.

(i) What is meant by the terms

- proton number,
- nucleon number? [1]

proton number: **number of protons in the nucleus** of an atom
nucleon number: **total number of protons and neutrons in the nucleus** of an atom

(ii) The isotopes ^{6}Li and ^{7}Li have accurate isotopic mass of 6.015 and 7.016 respectively.
The A_r of lithium is 6.942.
Calculate the relative percentage abundances of the two isotopes, to **two** decimal places.

[2]

let relative percentage abundance of ^{7}Li = a

$$\frac{7.016 \times a + 6.015 \times (100-a)}{100} = 6.942$$

$$a = 92.61$$

∴ relative percentage abundance of ^{7}Li = **92.61%**,
relative percentage abundance of ^{6}Li = **7.39%** (2 dp)

(iii) A nuclear reaction is a reaction in which there is a change to an atomic nucleus.

An experimental nuclear reactor uses ^{6}Li and deuterium, ^{2}H, as fuel. Three nuclear reactions between these two atoms are described below (P^{+} is a proton; n is a neutron).

$$^{6}Li + {}^{2}_{1}H \rightarrow 2\,{}^{4}He$$

$$^{6}Li + {}^{2}_{1}H \rightarrow {}^{4}He + \mathbf{X} + n$$

$$^{6}Li + {}^{2}_{1}H \rightarrow \mathbf{Y} + P^{+}$$

Suggest the identities of **X** and **Y**.

[2]

$${}^{6}_{3}Li + {}^{2}_{1}H \rightarrow 2\,{}^{4}_{2}He$$

$${}^{6}_{3}Li + {}^{2}_{1}H \rightarrow {}^{4}_{2}He + {}^{3}_{2}He + {}^{1}_{0}n$$

$${}^{6}_{3}Li + {}^{2}_{1}H \rightarrow {}^{7}_{3}Li^{-} + {}^{1}_{1}p^{+}$$

X: ${}^{3}_{2}He$ **Y**: ${}^{7}_{3}Li^{-}$

6 Beams of charged particles are deflected by an electric field. When a beam of protons passes through an electric field of constant strength, the angle of deflection is +12 °.

In another experiment under identical conditions, particle Y is deflected by an angle of – 4 °.

What could be the composition of particle Y?

	protons	neutrons	electrons
1	1	2	2
2	3	3	5
3	4	5	1

A 1, 2 and 3 **B** 1 and 2 **C** 1 only **D** 3 only

Answer: **B**

Magnitude of angle deflected $\propto$ charge/mass
charge/mass for $^{1}H^{+}$ = 1 $\Rightarrow$ deflected by 12 ^{o} for 1 unit of charge/mass

To be deflected through angle of – 4 ^{o} (i.e. opposite side of protons),
particle Y should be negatively-charged, with charge/mass = – 1/3

Option 1: charge/mass = – 1/3 ✓
Option 2: charge/mass = – 2/6 = – 1/3 ✓
Option 3: charge/mass = + 3/9 = + 1/3 ✗

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7 Which statement about relative molecular mass are correct?

1 It is the sum of the relative atomic masses of all the atoms within the molecule.

2 It is the ratio of the average mass of a molecule to the mass of a ^{12}C atom.

3 It is the ratio of the mass of 1 mol of molecules to the mass of 1 mol of ^{1}H atoms.

A 1, 2 and 3 **B** 1 and 2 only **C** 2 and 3 only **D** 1 only

[Only option 1 is correct] so answer is option **D**

Option 2: It is the ratio of the average mass of a molecule as compared to $\frac{1}{12}$ of the mass of a ^{12}C atom, NOT the mass of a ^{12}C atom.

Option 3 is wrong as the mass of atoms or compounds (1 mole/ 1 particle) must be compared against $\frac{1}{12}$ of (1 mole/ 1 particle) of ^{12}C, NOT ^{1}H.

^{12}C is used as the reference because of its abundance as well as stability.

Electronic Configuration

8 Gallium has the electronic configuration [Ar] $3d^{10}4s^{2}4p^{1}$, where [Ar] represents the electronic configuration of argon. In which order are the electrons lost in forming the Ga^{4+} ion?

A 3d, 4p, 4s, 4s **B** 4s, 4s, 4p, 3d **C** 4p, 3d, 3d, 3d **D** 4p, 4s, 4s, 3d

Ga is a group 13 element.

The sequence of electrons removed should start from electron of highest energy to electron of lower energy.

The energy of electron

1) increases with the quantum number n.
2) Within a quantum shell, energy of subshell decreases in the following order:

f > d > p > s

highest lowest

Hence the sequence is from 4p subshell first where there is only 1 e, followed by 2 e in the 4s subshell. The 4th one from the 3d subshell.

9 An isolated gaseous species has paired electrons in at least one of its 3d orbitals and a fully filled 4s subshell.

What could be the identity of the species?

A Cu **B** Fe^{3+} **C** Ni^{2+} **D** Sr^{2+}

Cu: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}4s^1$ D

Fe^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

Ni^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^8$

Sr^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2 4p^6$

10 Which ion has the most number of unpaired electrons?

A Cr^{3+} **B** Ni^{2+} **C** Ca^{2+} **D** Co^{3+}

Cr^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3$ (3 unpaired e^- in 3d orbitals)
Ni^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^8$ (2 unpaired e^- in 3d orbitals)
Ca^{2+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ (0 unpaired e^-)
Co^{3+}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ (4 unpaired e^- in 3d orbitals)

11 *Use of the Data Booklet is relevant to this question.*

What do the ions $^{23}Na^+$ and $^{24}Mg^{2+}$ have in common?

A Both ions have more electrons than neutrons.
B Both ions have 12 neutrons in their nuclei.
C Both ions contain the same number of nucleons in their nuclei.
D Both ions have an outer electronic configuration of $3s^2\ 3p^6$.

Option A is wrong as they are cations, not anions.
Option C is wrong as their nucleon number (mass number) are 23 and 24 respectively.
Option D is wrong because they assume Ne noble gas configuration where the outer electronic configuration is $2s^2 2p^6$.

Option B is correct as shown in the working below:

	$^{23}Na^+$	$^{24}Mg^{2+}$
No. of protons	11	12
No. of neutrons	23 – 11 = 12	24 – 12 = 12
No. of nucleons (protons + neutrons)	23	24

12 A stable ion of **Q** has the following properties:

- has a noble gas configuration
- was obtained by removing electrons from the same orbital

Which could be **Q**?

A Al **B** Ca **C** Cu **D** S

S being a non-metal is NOT able to form a stable cation, it should form an anion instead.
Except Sc, the remaining d block metals in period 4 do not form noble gas configuration upon forming a stable cation.
Hence, option C and D are incorrect.

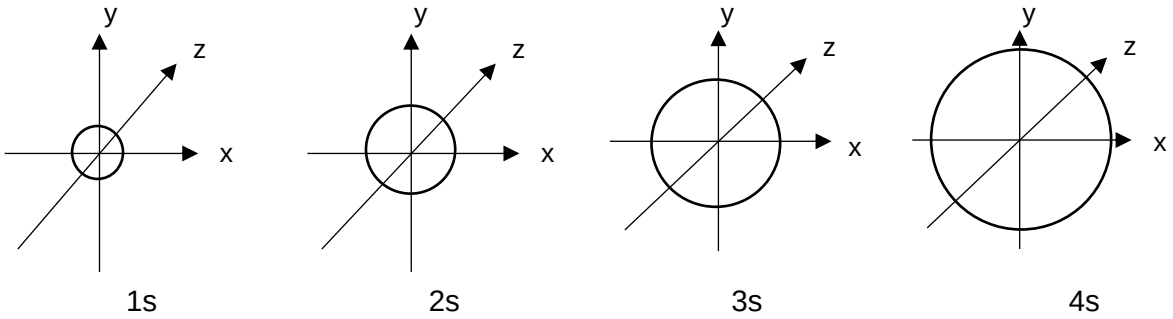
Since **Q** was obtained by removing electrons from the same orbital, **Q** has to be either a metal in Group 1 or 2.

13 Write the *ground state* electronic configuration of

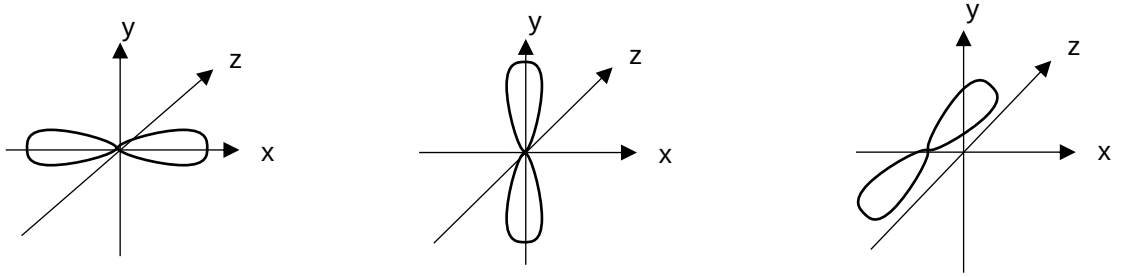
(a) S atom
(b) O^+ ion
(c) Cl^- ion
(d) Cu atom
(e) Fe^{3+} ion
(f) Ge atom

(a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$
(b) $1s^2\ 2s^2\ 2p^3$
(c) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$
(d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$
(e) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$
(f) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$

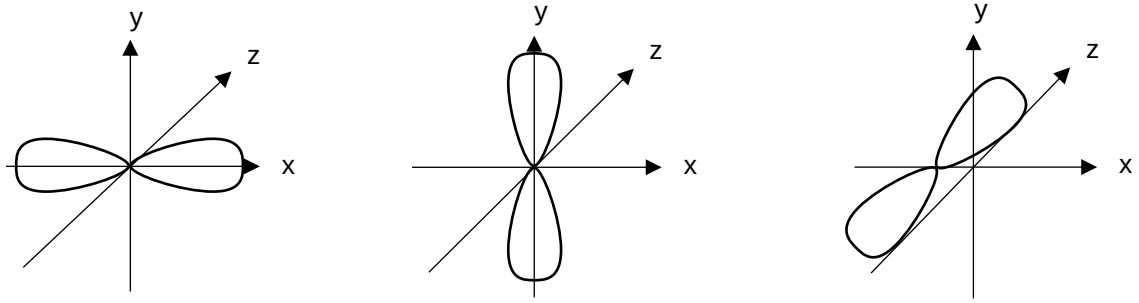
14 Describe the shapes of all the orbitals occupied by electrons in Manganese atom, $_{25}Mn$.
Electronic configuration of Mn is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$



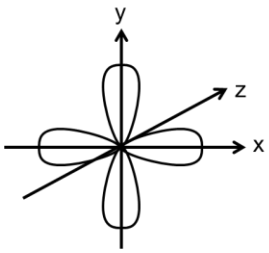
1s 2s 3s 4s



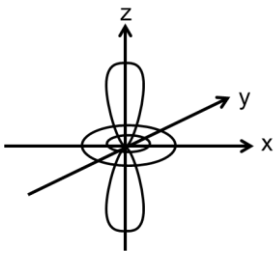
$2p_x$ $2p_y$ $2p_z$



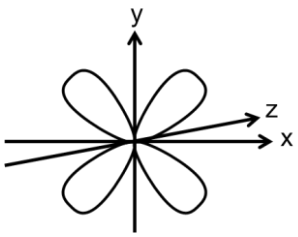
$3p_x$ $3p_y$ $3p_z$



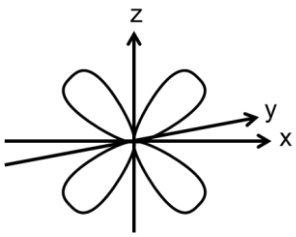
$3d_{x^2-y^2}$ orbital



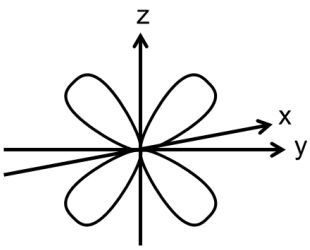
$3d_{z^2}$ orbital



$3d_{xy}$ orbital



$3d_{xz}$ orbital



$3d_{yz}$ orbital

Successive Ionisation Energy

15 *Use of the Data Booklet is relevant to this question.*

The electronic configuration of four elements are given.

Which element will most easily form an isolated gaseous ion with the charge of 3+?

A $1s^2\,2s^2\,2p^3$ **B** $1s^2\,2s^2\,2p^6\,3s^2\,3p^3$

C $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^1\,4s^2$ **D** $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^5\,4s^2$

To form a gaseous ion with charge +3, total energy required = 1^{st} + 2^{nd} + 3^{rd} I.E.

		element	Sum of 1^{st} + 2^{nd} + 3^{rd} I.E.
A	**$1s^2\,2s^2\,2p^3$**	**N**	**8850**
B	$1s^2\,2s^2\,2p^6\,3s^2\,3p^3$	**P**	**5880**
C	$1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^1\,4s^2$	**Sc**	**4262**
D	$1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^5\,4s^2$	**Mn**	**5476**

16 The successive ionisation energies of two elements, **M** and **N**, are given.

Ionisation energy / kJ mol^{-1}	1st	2nd	3rd	4th	5th	6th	7th	8th
M	1090	2350	4610	6220	37800	47000	-	-
N	1251	2298	3822	5158	6542	9362	11018	33604

What is the formula of the compound that **M** and **N** are likely to form?

A **MN** **B** **M_2N_2** **C** **MN_4** **D** **M_4N**

For element **M**: biggest increase between 4th and 5th ionisation energy.
(Largest difference in IE between 4th and 5th I.E.)
5th electron is removed from the inner principal quantum shell which is closer to the nucleus.
Thus the element has 4 valence electrons.
Element **M** belongs to Group 14.

For element **N**: biggest increase between 7th and 8th ionisation energy.
(Largest difference in IE between 7th and 8th I.E.)
8th electron is removed from the inner principal quantum shell which is closer to the nucleus.
Thus the element has 7 valence electrons.
Element **N** belongs to Group 17.

So the likely formula of the compound formed is **M**N_4.

17 The successive ionisation energies (I.E.) of two elements, **Q** and **R**, are shown below:

IE / kJ mol^{-1}	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
Q	1000	2252	3357	4556	7004	8496	27107	31719
R	578	1817	2745	11577	14842	18379	23326	27465

What is the likely formula of the compound formed when **Q** and **R** reacts together?

A **Q_3R_2** **B** **Q_2R_3** **C** **QR_3** **D** **Q_3R**

For element **Q**: biggest increase between 6th and 7th ionisation energy.
(Largest difference in IE between 6th and 7th I.E.)
7th electron is removed from the inner principal quantum shell which is closer to the nucleus.
Thus the element has 6 valence electrons. Element **Q** belongs to Group 16.

For element **R**: biggest increase between 3rd and 4th ionisation energy.
(Largest difference in IE between 3rd and 4th I.E.)
4th electron is removed from the inner principal quantum shell which is closer to the nucleus.
Thus the element has 3 valence electrons. Element **R** belongs to Group 13.

So the likely formula of the compound formed is **Q_3R_2**.