Atomic Structure

An atom is the smallest electrically neutral particle that takes part in a chemical reaction.
An atom is composed of electrons, protons and neutrons the properties of which are given in the table below:

components	symbol	charge	mass
Proton	p	+1	1
Neutron	n	0	1
Electron	e	-1	$\frac{1}{1840}$

The proton and neutron are situated in the nucleus whereas the electrons rotate around the nucleus in definite shells.

Definitions

Atomic number is the number of protons present in the nucleus of an atom. All atoms of the same element have the same number of protons and thus the same atomic number.

Atomic mass is the sum of protons and neutron in an atom.

Isotopes are atoms of the same element having the same atomic number but different number of neutron and thus different atomic mass.

Relative atomic mass is the number of time atoms of an element are heavier than a 12^{th} of carbon-12 isotope. Relative atomic mass is obtained as an average of atomic mass of isotopes of an element in the ratio of their existence or relative abundance.

Example 2.1

Natural chlorine has Isotopes ^{35}Cl and ^{37}Cl the percentage of the abundance of these isotopes is 75%and 25%respectively. Calculate the atomic mass of Cl-atom.

Solution

The question implies that for every 100 atoms of chlorine, 75 of them each weigh 35units and 25 of them each weigh 25units.

Thus mass of 100 atoms of chlorine = 75 x 35 + 25 x 37

Relative atomic mass of chlorine = average mass of 100 atoms = $\frac{35\ x\ 75+37\ x\ 25}{100}$ = 35.50

Trial 2.1

The relative atomic mass of copper is 63.5. Calculate the percentage of the isotopes $^{63}Cu$and ^{65}Cu in it.

Trial 2.2

Naturally occurring born consist of two isotopes whose atomic weights are 10.01 and 11.01. the atomic weight of born is 10.181. Calculate the % of each isotope in naturally occurring boron

Trial 2.3

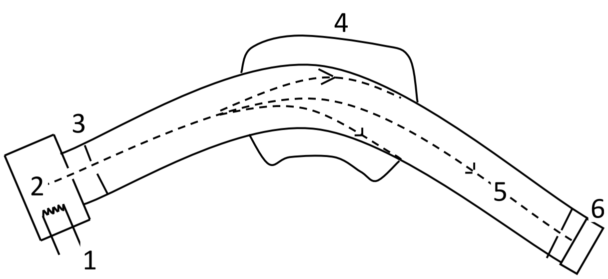
Naturally occurring carbon consist of two isotopes namely ^{12}C and ^{13}C. What is the % abundance of the isotopes in a sample of carbon whose atomic weight is 12.01112? Assume that the nucleic masses of $^{12}C$and ^{13}C are 12.0 and 13.00339 respectively

Trial 2.4

A sample of ordinary neon is found to consist of 20Ne, 21Ne and 22Ne isotopes in percentage of 90.92%, 0.26% and 8-82% respectively. Calculate the actual atomic weight of neon.

Determination of Relative atomic masses

Mass spectrometer



Functions at each numbered step

1. Heated filament gives electrons. They pass into the ionization chamber.
2. The sample to be analyzed is injected as a gas into the ionization chamber. Electrons collide with and ionize the molecules of the sample.

3. To this plate a negative potential is applied (about 800V). The electric field accelerates the positive ions while repelling the negative ions.
4. An electromagnet produces a magnetic field. The field deflects the beam of ions into circular paths. Ions with a high ratio of charge to mass are deflected more than those with low ratio of charge/mass.
5. By varying the magnetic field ions that have a correct charge/mass ratio are directed through the slit to the collector.
6. Amplifier. Here the charge received by the collector is turned into a sizable electric current, interpreted and recorded.
7. If the magnetic field is kept constant while the accelerating voltage is continuously varied, one species after another is deflected into the ion collector.

Uses of mass spectrophotometer

1. Determination of the relative molecular mass of a compound.
2. Identification of compounds
3. In forensic science it is useful because a small sample gives results.

Trial 2.5

(a) Define the terms; mass number, isotope, relative atomic mass

(b) Chlorine has two isotopes of relative atomic masses 34.97 and 36.96 and relative abundance 75.77% and 24.23% respectively.
Calculate the mean relative atomic mass of naturally occurring chlorine

Trial 2.6(1984/1/5)

Element X with atomic number 84 and mass number 216 decays by loss of an α-particle gives element Y. Y further decays by loss of β-particle to give Z.

(a) write down
  (i) the mass number of element Y
  (ii) the atomic number of element Z

(b) In which group of the Periodic Table would you expect Z?

(c) The table shows the mass numbers and the percentage abundance of an element.

Mass number	% abundance
54	5.84
56	91.68
57	2.17
58	0.31

Calculate the relative atomic mass of Q

Trial 2.7 (2007/1/)

(a)(i) Define the term isotope
  (ii) Describe the main steps involved in the operation of a mass spectrometer (diagram not required)

(b) The table below shows the information from a mass spectrum of a lead sample.

Isotope	Detector/mA
204	0.16
206	2.72
207	2.50
208	5.92

Calculate

(i) The relative abundance of the different isotopes of lead in the sample used

(ii) The relative atomic mass of lead

(iii) State two advantages of Using a mass spectrometer over depression of freezing point method of determining relative atomic mass.

(c) The initial count of a radioactive nucleus was $680s^{-1}$, after 350s, the count rate was $125s^{-1}$. Calculate

(i) decay constant

(ii) half life of the nucleus

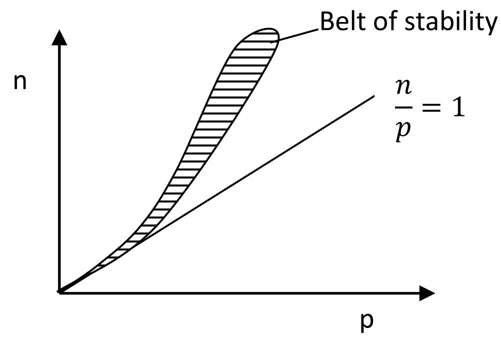
Nuclear stability

A stable nucleus is one that does not undergo spontaneous disintegration

Factors affecting nuclear stability

1. *Even and odd number of protons (p) and neutrons (n):* nuclides with even proton and even neutrons tend to be more stable than those with even protons and odd neutrons or odd protons-even neutrons than those with odd proton and odd neutrons.
2. *Neutrons to proton ratio ($^n/_p$ ratio)*

   A plot of the graph of neutrons versus proton indicating the zone of stability is given below



The belt of stability is the region of $\frac{n}{p}$ where we find most stable nuclei, i.e. non-radioactive nuclei. The belt goes on widening as the number of protons (or atomic number of the element s) increases. The nuclei whose $\frac{n}{p}$ value lies above or below this belt are radioactive and hence spontaneously disintegrate to give stable nuclei.

(i) the nuclei above the belt of stability are rich in neutrons and hence disintegrate in such a way that one of the neutron is converted to a proton

i.e. [${}_0^1n \rightarrow {}_1^1H$ or ${}_1^1p$ + ${}_{-1}^{0}e$] or such nuclei emit a β-particle.

Example

(a) ${}_{11}^{24}Na \rightarrow {}_{12}^{24}Mg + {}_{-1}^{0}e$

(b) ${}_{6}^{14}C \rightarrow {}_{7}^{14}N + {}_{-1}^{0}e$

(ii) The nuclei lying below the belt of stability are deficient in neutrons and hence disintegrate in such a way that one of their proton is converted into a neutron. The conversion can be done by any of the following two ways

(a) emission of positron: ${}_1^1H \rightarrow {}_0^1n + {}_{+1}^{0}e$

(b) electron capture process

${}_1^1H + {}_{-1}^{0}e(electron) \rightarrow {}_0^1n$

(iii) ${}_{82}^{208}Pb$ and ${}_{83}^{209}Bi$ are the heaviest stable nuclei. Nuclei having higher number of protons or neutrons disintegrate by loss of α(${}_2^4He$), ${}_{+1}^{0}e$, ${}_{-1}^{0}e$ or by fission process.

3. Packing fraction (f)

Packing fraction (f) $= \frac{Isotopic\ mass - mass\ number}{mass\ number} \times 10^4$

If the packing fraction is negative or low positive value, the nuclide is stable. The nuclei having very high positive value are unstable

4. *mass defect*

This is the difference in [masses of all protons, + all neutrons + mass of all electrons) – actual atomic mass of all atoms. The bigger the mass defect the more stable the nuclide.

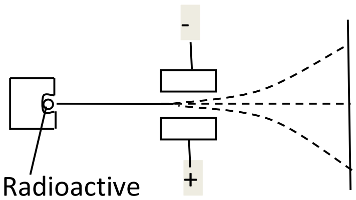
5. Magic number: A nucleus containing protons or neutron or both equal to the magic number (i.e. 2, 8, 20, 28, 50, 82or 126) are very stable.

Nuclear reaction

This is a reaction where rearrangement of protons and neutrons in the nucleus of an atom take place and new element is formed.

Types of radiations

There are three types of radiations given by radioactive substances. They all cause certain substances, such as zinc sulphide, to luminesce, and all ionize gases through which they pass. They differ in their response to an electric field in the manner shown in figure below:



γ-rays

These uncharged rays are similar to X-rays

- they have high penetrating power; being able to pass through 0.1m of metal.
- have negligible weight
- are un deflected by electric field
- ionize gases they pass through

α-rays

- positively charged helium ions
- ionize gases they pass through
- deflected towards negative electric field
- have low penetrating power

β-rays

- negatively charged
- deflected toward positive electric field
- have medium penetrating power
- ionize gases they pass through

Balancing nuclear equations

The sum of protons and the mass number on the either side of the equation should be equal. Deficits are balanced with either α-particle ($^{4}_{2}He$), β-particle ($^{0}_{-1}e$, or $^{0}_{-1}\beta$) or positron($^{0}_{+1}e$) or neutron ($^{1}_{0}n$).

Example 2.2(1985/1/6c)

The nucleus of element X reacts with an alpha particle according to the following equation

$^{m}_{n}X + ^{4}_{2}He \rightarrow ^{45}_{21}Sn + ^{1}_{0}n$

Determine the values of m and n.

Solution

m+4 = 45 +1; m = 42

n + 2 = 21 + 0

n = 19

∴ X is potassium, i.e., the number of protons in an atom is characteristic of an element.

Trial 2.8(1986/1/2)

Polonium $^{216}_{84}Po$ undergoes radioactive to give element Y according to the following equation

$^{216}_{84}Po \rightarrow$ Y +α

(a) Calculate

(i) atomic number of Y (½ mk)

(ii) the mass number of Y (½ mk)

(b) Y decays further to form Z as shown by the equation below

Y → Z + β

Calculate

(i) the atomic number of Z (½ mk)

(ii) the mass number of Z (½ mk)

Trial 2.9(1991/1/3)

(a) The following equation shows part off the radioactive decay of Thorium.

$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa$ + ___ → X +α

(i) Name the particle emitted in the first stage of the reaction (1mk)

(ii) State the atomic number and the atomic mass of X (1mk)

Trial 2.10

(a) State three properties of beta particles

(b) complete the following nuclear transformations

(i) $^{239}_{94}Pu + {}^{1}_{0}n \rightarrow {}^{86}_{34}Se + {}^{150}_{60}Nd$ + _____

(ii) $^{235}_{96}Cm + {}^{4}_{2}He \rightarrow$ ______

(iii) $^{235}_{92}U + {}^{1}_{0}\text{n} \rightarrow {}^{148}_{57}La$ + _____ + $3{}^{1}_{0}n$

(c) Francium isotope ($^{223}_{87}Fr$) emits beta particles. the rate of emission reduces from 14.0 to 7.5 counter in 80 second. Calculate the half life of isotopes.

Trial 2.11 (1994/1/1)

(a) $^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U}$ + --------

(b) $^{6}_{3}\text{Li} + {}^{1}_{0}\text{n} \rightarrow {}^{3}_{1}\text{H}$ +---------

(c) $^{107}_{47}\text{Ag} + {}^{1}_{0}\text{n} \rightarrow$.................

Trial 2.12 (2000/1/2)

(a) Complete the following equations for the decay of bismuth.

$^{214}_{83}\text{Bi} \rightarrow {}^{0}_{-1}\text{e}$ + --------

(b) The half-life of bismuth is 19.7minutes. Determine the time taken for 43% by mass of bismuth to decay.

Solutions to trials of chapter 2

Trial 2.1

^{63}Cu = 72.5% and ^{65}Cu = 27.5%

Trial 2.3

$^{10.1}B$ = 91.9 and $^{11.1}B$ = 8.1

Trial 2.3

^{12}C = 98.892 and ^{13}C = 1.108

Trial 2.4

Atomic mass of neon = 20.179

Trial 2.5

Relative atomic mass = 35.429446

Trial 2.6(1984/1/5)

(a)(i) 212 (ii) 83

(b) Group 5

(c) 55.9111

Trial 2.7 (2007/1/)

(a) Isotopes are atoms of the same element having the same number of protons but different number of neutrons.

(ii) Main steps involved in operation of mass spectrophotometer

- A vaporized sample of a substance whose mass is to be determined is introduced into the ionization chamber
- Electrons from heated filament collide with the gaseous molecules of the substance producing positive ions.
- The positive ions are accelerated by the electric field into the magnetic field where they are deflected into circular path according to charge/mass ratios. Ions with high charge mass ratio are deflected more strongly than those with low values of charge/mass.
- By varying the magnetic and/or electric field, ions of a particular mass charge ration is selected and directed to the detector. This amplifies and records the relative abundance of various ions and hence isotopes in a sample.

(b)(i) Total current = 0.16 + 2.72 + 2.50 + 5.92

= 11.3

% $^{204}_{82}Pb$ isotope = $\frac{0.16}{11.3} x\ 100 = 1.42$

% $^{206}_{82}Pb$ isotope = $\frac{2.72}{11.3} x\ 100 = 24.07$

% $^{207}_{82}Pb$ isotope = $\frac{2.50}{11.3} x\ 100 = 22.12$

% $^{208}_{82}Pb$ isotope = $\frac{5.92}{11.3} x\, 100 = 52.39$

(ii) Relative atomic mass

$\{\frac{1.42\, x\, 204}{100} + \frac{24.07\, x\, 206}{100} + \frac{22.12\, x\, 207}{100} + \frac{52.39\, x\, 208}{100}\}$

= 207.2

(iii) – require small sample

- it is very accurate
- less tedious.

(e) from In$\frac{N_0}{N}$ = Kt

In$\frac{680}{125}$ = 350k

⇨ K= 4.83 x $10^{-3}s^{-1}$

(ii) from $t_{1/2}$ = $\frac{In\, 2}{K}\frac{In\, 2}{4.83\, x\, 10^{-3}}$ = $143s^{-1}$

Trial 2.8(1986/1/2)

(a)(i) atomic mass of Y = 82

(ii) mass number of Y = 212

(b)(i) atomic mass of Z = 83

(ii) mass number of Z = 212

Trial 2.9(1991/1/3)

(i) particle emitted = beta ($^{0}_{-1}\beta$)

(ii) atomic number of X = 89

Mass number of X = 230

Trial 2.10

(b)(i) $^{239}_{94}Pu + ^{1}_{0}n \longrightarrow ^{86}_{34}Se + ^{150}_{60}Nd + \mathbf{4^{1}_{0}n}$

(ii) $^{235}_{96}Cm + ^{4}_{2}He \longrightarrow \mathbf{^{239}_{98}Cf}$

(iii) $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{148}_{57}La + \mathbf{^{85}_{35}Br} + 3^{1}_{0}n$

(c) From In $\frac{N_0}{N}$ = Kt

K = In $\frac{14}{7.5}$ ÷ 80 = $0.0078s^{-1}$

t ½ =$\frac{In2}{K}$ = $\frac{In2}{0.0078}$ = 88.865s

Trial 2.11 (1994/1/1)

(a) $^{234}_{91}Pa \longrightarrow ^{234}_{92}U + \mathbf{^{0}_{-1}\beta}$

(b) ${}^{6}_{3}\text{Li} + {}^{1}_{0}\text{n} \rightarrow {}^{3}_{1}\text{H} + {}^{\mathbf{4}}_{\mathbf{2}}\boldsymbol{He}$

(c) ${}^{107}_{47}\text{Ag} + {}^{1}_{0}\text{n} \rightarrow {}^{108}_{47}Ag$

Trial 2.12 (2000/1/2)

(a) ${}^{214}_{83}\text{Bi} \rightarrow {}_{-1}^{0}\text{e} + {}^{\mathbf{214}}_{\mathbf{84}}\mathbf{po}$

END