Physics with Synno – Matter – Lesson 4

M.4 Structure of the Atom

Before we can discuss the processes involved in radioactivity we must look briefly at the structure of the atom and how it is involved radiation.

M.4.1 Models of the atom

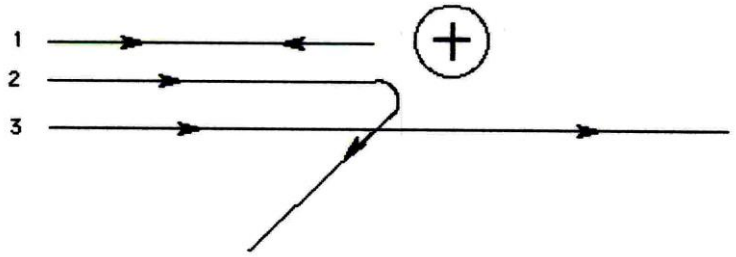
As we know all things are made up of "particles" and the smallest of these "particles" are called Atoms.

In around 1897 it was discovered by J. J. Thomson (Nobel 1906, Knighted 1908) that electrons were a part of the atom. Thompson suggested that positive and negative charges in the atom were mixed together as in a ' plum pudding', the pudding having the same volume as the atom.

Between 1909 and 1911 Sir Ernest Rutherford (Nobel 1908, Knighted 1914) together with his assistants Hans Geiger (of Geiger Counter fame) and Ernest Marsden, performed a series of experiments that cast doubts on the Thompson' plum pudding' model. They performed an experiment in which they bombarded a thin gold foil with α-particles. To their surprise most of the α-particles passed straight through , but some were deflected through large angles. This could not be explained by the Thompson model. They performed many more experiments and from their observations Rutherford concluded:

- most of the atoms mass is concentrated at the positively charged nucleus.
- surrounding the nucleus are a number of electrons.
- most of the atom is empty space.
- the total negative charge of the electrons balances the positive charge of the nucleus, thus the atom remains neutral.

The deflections observed by Geiger and Marsden can easily be explained as follows:

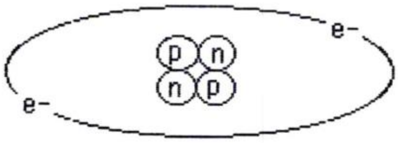


1. Direct hit bounces back
2. Near direct hit, greatly deflected
3. Miss, slight or no deflection. Since most of the atom is empty space, most of the α-particles behave like this.

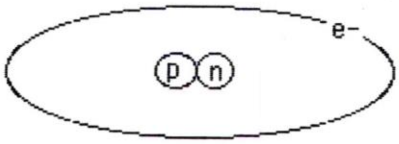
Video: Rutherford's Alpha Scattering Experiment2

This is the model that is accepted today, it has a nucleus which consists of particles which are of two kinds: Protons which have a positive charge and neutrons which have no charge. Orbiting this nucleus there are other particles called electrons which have negative charge. A neutral atom has the same number of electrons as it does protons.

Improvements on the model for the atom were made by each of these scientists and experiments to improve the model of the atom are still being made today, but the basic structure has remained unchanged. It looks like the following:



Eg. Helium

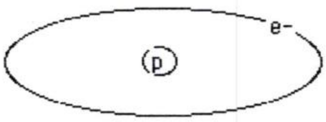


Eg. Hydrogen

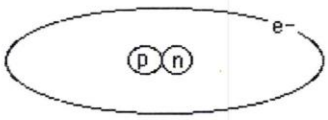
M.4.2 Isotopes

Chemical changes involve electrons either being shared between atoms or transferring between atoms. Nuclear reactions/changes involve changes in the nucleus. So isotopes are important when we are looking at nuclear reactions and changes, but what are isotopes?
It is known that atoms of the same element can have differing masses. This can happen if there is a differing number of neutrons in the nucleus of the atom.
Thus isotopes of an element are defined as having the same numbers of protons and electrons but differing numbers of neutrons.

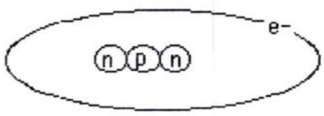
Eg. Hydrogen can have 3 different isotopes.



NO neutrons $^{1}_{1}H$



1 neutron $^{2}_{1}H$



2 neutrons $^{3}_{1}H$

It is this variation in neutrons that gives radioactive substances their properties.
Isotopes are also known as nuclides.

Video: Rare Isotope Rap

M.4.3 The Neutron

In 1920 Rutherford suggested that in a nucleus a proton and an electron may join to form another particle called a neutron.
In 1932 James Chadwick (Nobel 1935, Knighted 1945) suggested that penetrating radiation consisted of neutral particles of the same mass as a proton. He proposed these particles to be an electron and a proton in some combination.
The neutron is now considered a fundamental particle of the atom. Its charge is neutral and mass is that of a proton (close). A neutron by itself is unstable and will decay.

Atomic and Mass Numbers

Atoms are often symbolised as follows:-

Mass Number (A)
X (Symbol)
Atomic or Proton Number (z)

So the two Examples in section M.4.2 would be written as $^{4}_{2}He$ and $^{2}_{1}H$ respectively.

The protons and neutrons are known as nucleons. The number of neutrons in the nucleus of an atom is the difference between the mass and atomic numbers.

Example

Use the periodic table to determine:

a) the name of element $^{92}_{45}X$

Ruthenium

b) the number of protons, neutrons and nucleons in this isotope.

45 Protons, 47 Neutrons, 92 Nucleons

M.4.5 Naturally Occurring Radioactivity

Figure 4.4 This symbol is used to label and identify a radioactive source.

Atoms were once thought of as stable and unchangeable. But experiments performed by scientists such as Henri Becquerel, Rutherford, Marie and Pierre Curie (Both Nobel 1903, Marie Nobel 1911) showed that changes in radioactive decay are different to chemical changes.

Radioactivity can be defined as the spontaneous and uncontrollable decay of an atomic nucleus resulting in the emission of particles and rays. Some elements may have isotopes that are stable and others that are radioactive.

For example Carbon-14 and Carbon-12

Carbon-12 has 6 protons and 6 neutrons it is also very stable.
Carbon-14 has 6 protons and 8 neutrons it is unstable and decays radioactively.
An isotope such as carbon-14 is called a **radioisotope** since it decays radioactively.

	Group I	Group II											Group III	IV	V	VI	VII	VIII
Period 1					1 H 1.01													2 He 4.00
2	3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 NE 20.18
3	11 Na 22.99	12 Mg 24.31	Transition elements										13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.71	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.91	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.4	47 Ag 107.87	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
6	55 Cs 132.91	56 Ba 137.34	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (–)	108 Hs	109 Mt	110 ?	111 ?	112 ?						

Lanthanides

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97

Actinides

90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)

Every isotope of these elements is radioactive

M.4.5 Artificial Transmutation

Originally naturally occurring radioisotopes were used for research. Today most radioisotopes are artificially produced by a process called transmutation. This allows scientists and doctors access to many more radioisotopes, from which they can choose the one with the best characteristics to do the job.

One of the ways that artificial radioisotopes can be produced is through neutron absorption. In this method a stable sample of an element is bombarded with neutrons, a neutron can be captured by a nucleus, thus creating a radioactive substance. Cobalt-60 (used in cancer treatment) is produced in this way. Cobalt-59 is bombarded with neutrons.

The equation for this process is: ${}^{1}_{0}n + {}^{59}_{27}Co \rightarrow {}^{60}_{27}Co$

Problem Set # 4: Text Page 204 All Questions