Chapter 30

The Atom

The Nucleus

Radioactivity

History Of Atomic Structure

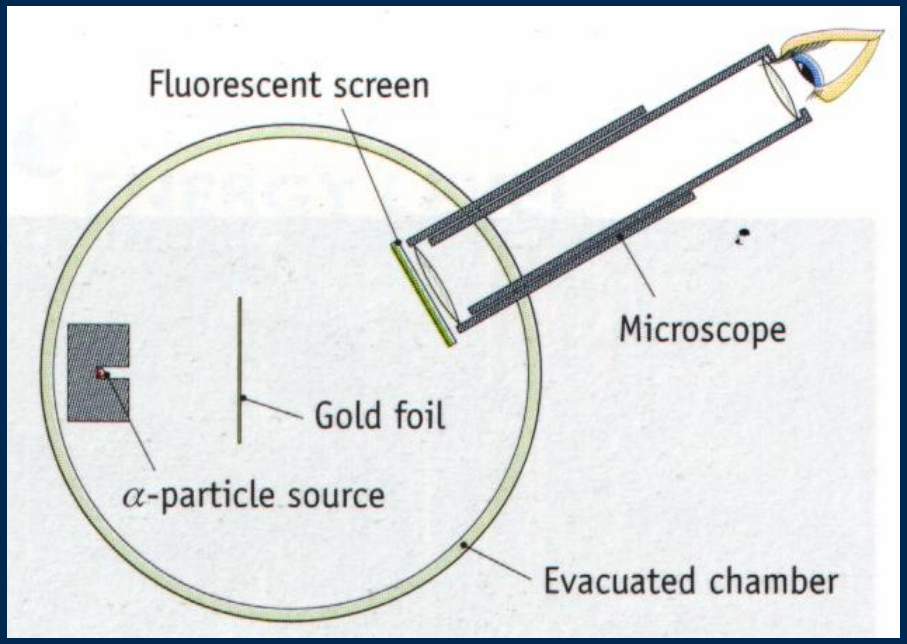
Greeks	**Air, water, fire and earth**	**(Thales of Miletus)**
	Matter composed of atoms	**(Democritus)**
1808	**Atomic theory of matter**	**(John Dalton)**
1869	**Periodic table**	**(Mendeleev)**
1800's	**Electricity in gases / vacuum - Cathode rays**	
1895	**Discovery of X-rays**	**(Rontgen)**
1896	**Discovery of radioactivity**	**(Becquerel)**
1897	**Discovery of the electron**	**(J. J. Thomson)**
1900	**Quantum theory**	**(Planck's)**
1904	**Plum-pudding model**	**(Thomson)**
1905	$E = mc^2$	**(Einstein)**

History Of Atomic Structure

1911	Discovery of the nucleus	(Rutherford)
1913	Bohr's theory of the atom - orbits	
1919	Discovery of the proton	(Rutherford)
	1st artificial transmutation (N → O)	
1926	Quantum mechanics / Uncertainty Principle	(Schrodinger & Heisenbergy)
1932	1st Accelerator	(Cockroft & Walton)
1932	Discovery of the neutron	(Chadwick)
1964	Quarks	(Gell-Mann & Zweig)

Rutherford's Expt.

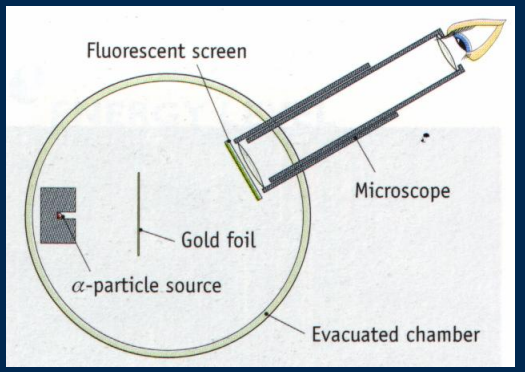
Discovery Of The Nucleus (1911)



- Gold foil – very thin
- Bombard
  with α-particles (+)
- Detection … flashes

Rutherford's Expt.

Discovery Of The Nucleus (1911)

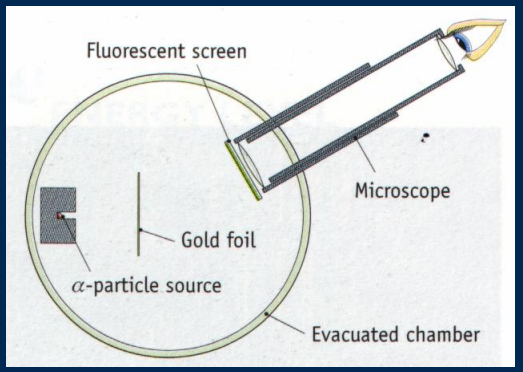


Result

- Most α-particles … undeflected
- Some α-particles …small angle deflection
- Very small number …**turned back**

Rutherford's Expt.

Discovery Of The Nucleus (1911)



- **Very small number …**

turned back

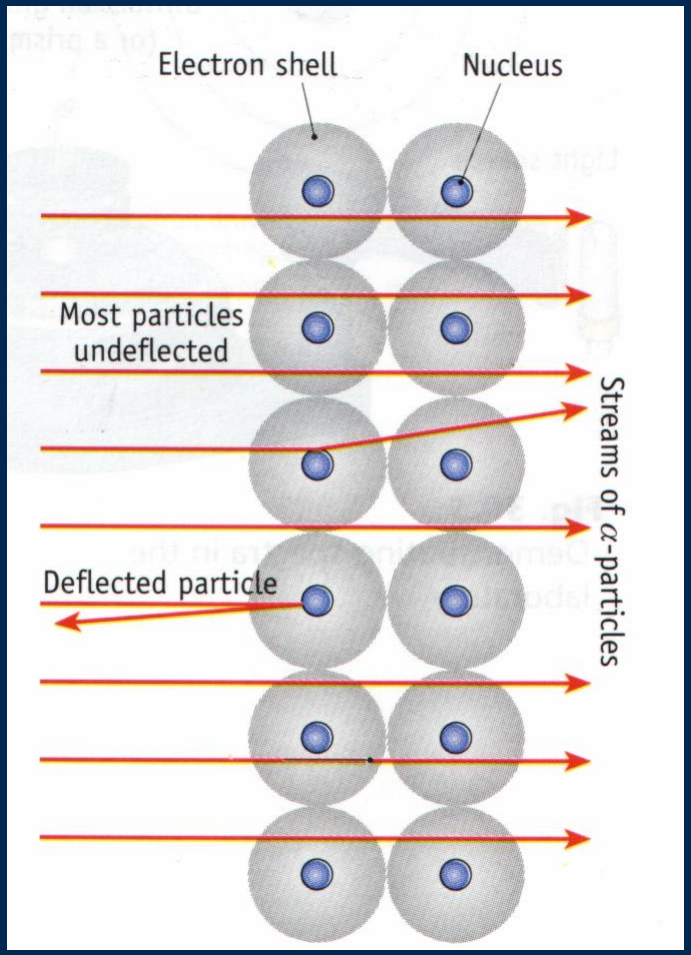
Rutherford wrote: ***"It was about as credible as if you had fired a 15" shell at a piece of tissue paper and it came back and hit you."***

Rutherford's Expt.

Conclusion

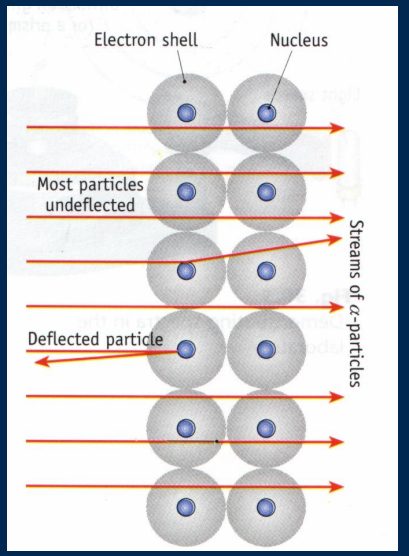
Nuclear model of the atom

- Tiny nucleus at centre
- that contains all the positive
- (and nearly all the mass)
- Electrons orbit this nucleus
- Atom is mostly empty space



Rutherford's Expt.

The Radius Of The Nucleus

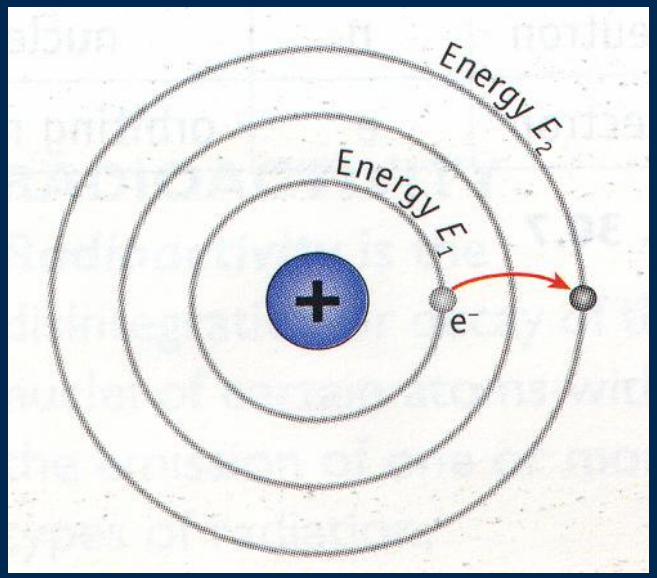


By counting the number of α-particles deflected at different angles …

Estimate = 10^{-15} m

Radius of atom = 10^{-10} m
(100,000 times bigger)

Bohr's Model Of The Atom

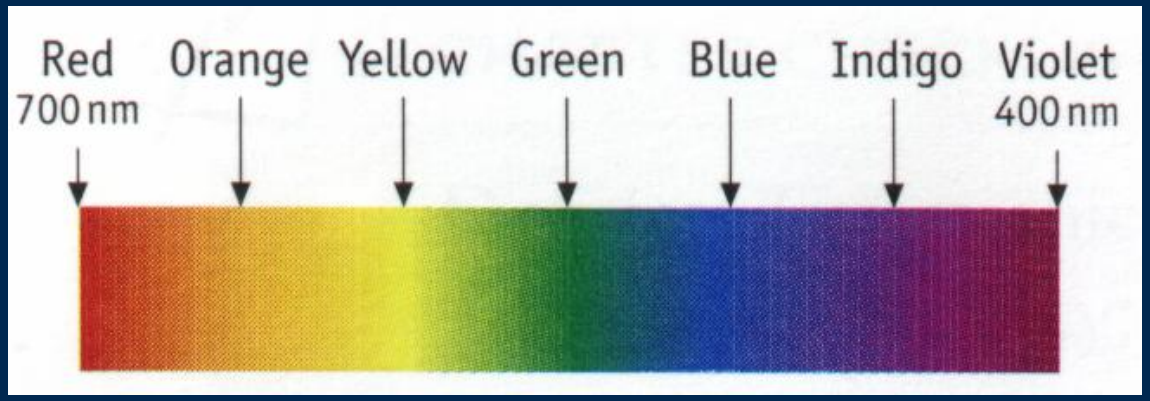


Orbits
(Energy Levels)

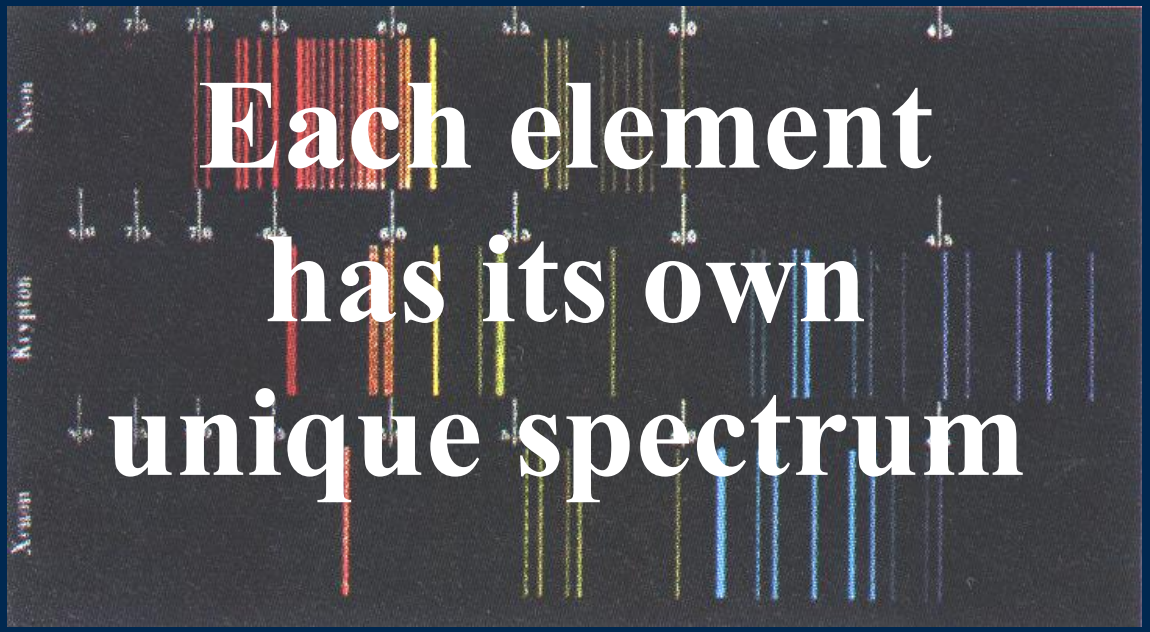
- Circular orbits
- Only certain orbits allowed
- Definite energy in each orbit (Energy levels)
- Energy put in .. electron to higher orbit
- Energy out .. when electron falls to a lower orbit
- Energy out as a photon of light
- $hf = E_2 - E_1$ … fixed frequency (colour)

Evidence For Energy Levels

Spectra



Emission continuous spectrum



Each element has its own unique spectrum

Emission line spectrum

Why Each Element Has Its Own Characteristic Spectrum …

Each element has its own set of energy levels

The energy levels in neon are different to the energy levels in helium

→ The sets of colours emitted (spectrum) for neon are different
to the set of colours (spectrum) for helium

Emission Continuous Spectrum

Consists of an unbroken spread of colours from red to violet

(All wavelengths are emitted)

Sources

Incandescent solid or liquid

Example: Tungsten filament

Emission Line Spectrum

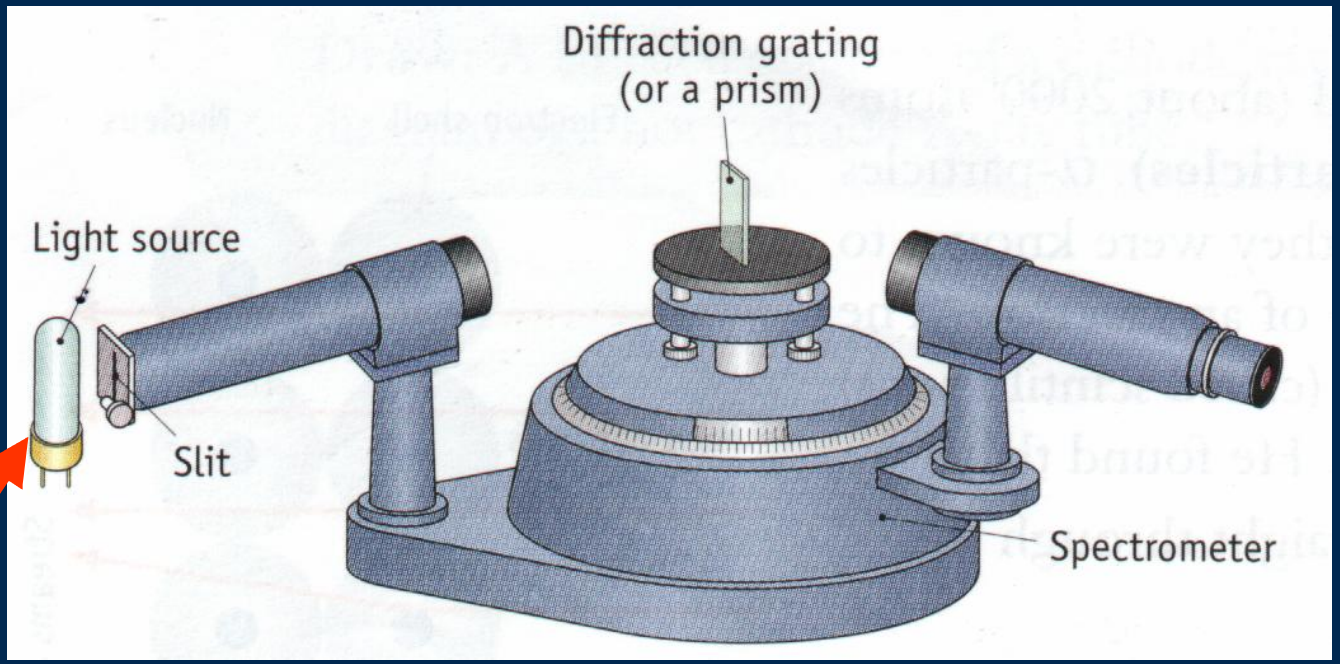
Consists of bright lines
of different colours
(of different wavelengths)

Sources

Elements (made of atoms)
in gas state

Examples: Discharge tubes / Street lamps

Viewing A Spectrum



Tungsten filament lamp

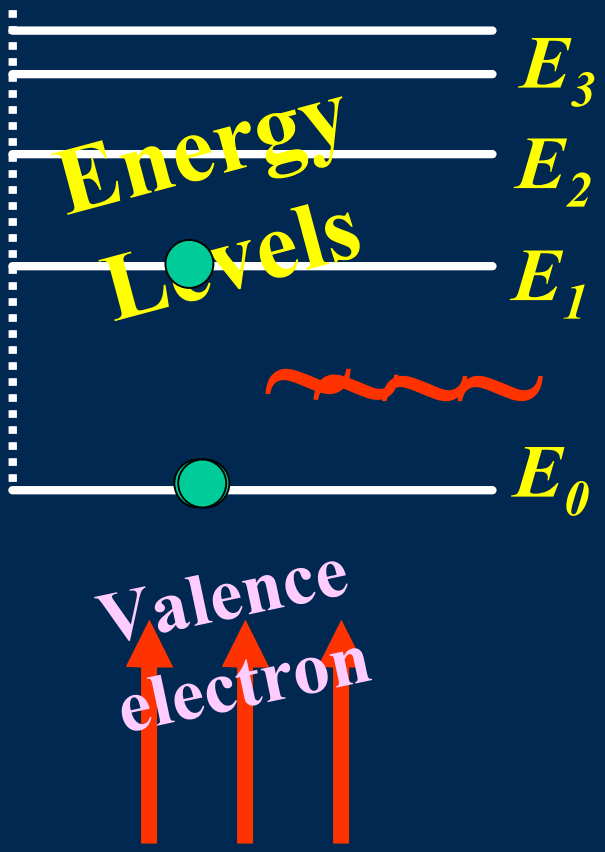
or

Discharge tube

Uses Of Spectra

- **To identify an element**
  (Each element has its own unique spectrum)
- **To check the purity of an element**
- ***** To give information about the energy levels in the atom**
- **In astronomy – Doppler shift for speed of stars / rotation of Sun**

Emission Line Spectra & Energy Levels



- Energy levels
- Valence electron
- Energy in … e^- to higher level
- e^- returns to lower level … emitting energy as a photon
- $hf = E_1 - E_o$
- .. definite frequency (colour)
- Different jumps → different colours
- Fixed set of energy levels → fixed set of colours

Bohr's Model

explained the hydrogen spectrum

but …

Energy Levels **Yes**

Quantum Theory
Uncertainty Principle
Orbitals *s, p, d, f*

Lasers

Light Amplification by the Stimulated Emission of Radiation

A laser produces

- **A very intense beam**
- **of monochromatic**
- **coherent light**

Lasers

Electrons are "pumped" to a higher energy level
(population inversion)

Stuck in higher level

Photons "stimulate" their return to the ground state

Avalance of photons emitted …

Lasers

Light Amplification by the Stimulated Emission of Radiation

A laser produces

- **A very intense beam (all photons in phase)**
- **of monochromatic (same photons / levels)**
- **coherent light (in phase)**

Lasers - Uses

- Repair retina
- Cure short-sightedness
- Cut tissue
- Cut metal
- Welding
- Reading a CD
- Supermarket chechout to read bar-codes
- Send information through optic fibres
- etc.

Structure Of The Nucleus

By 1932 …

protons & neutrons

Structure Of The Nucleus

Properties Of Protons & Neutrons

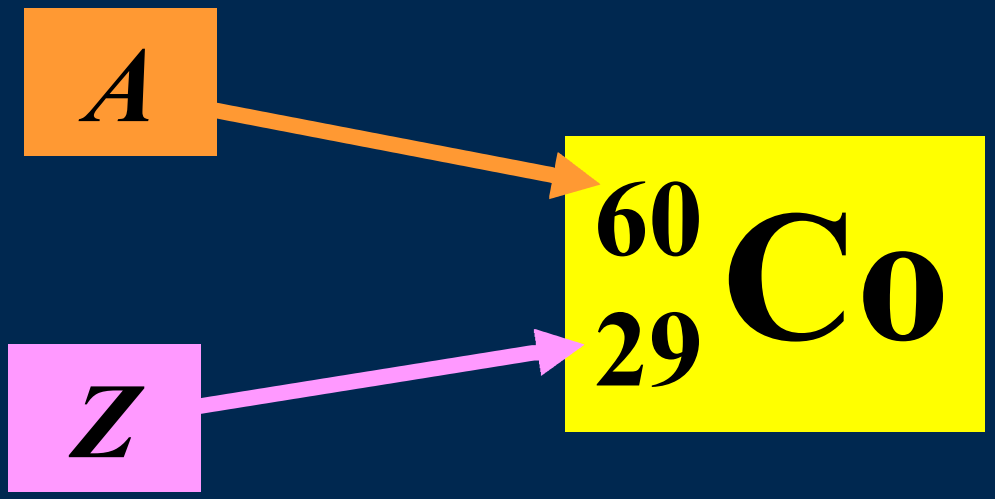
Particle	Symbol	Location	Charge	Mass
Proton	p	nucleus	+1	1
Neutron	n	nucleus	0	1
Electron	e^-	orbits …	-1	1/2000

Atomic Number (Z)

Mass Number (A)

Number of protons

Number of protons and neutrons



How many protons?
How many neutrons?

Isotopes

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

Atoms of an element that have

the same number of protons

but different numbers of neutrons

$^{235}_{92}U$ $^{238}_{92}U$

Radioactivity

Discovery 1896 Becq

- Uranium
- ...kened
- ...ed with dark paper

Uranium is radioactive

Conclusion Uranium was emitting a penetrating radiation

Radioactivity

Definition

- The spontaneous
- disintegration (or decay)
- of a nucleus
- with the emission of one or more types of radiation

Three Kinds Of Nuclear Radiation

Alpha-radiation	(alpha-particles)	α-particles
Beta-radiation	(beta-particles)	β-particles
Gamma-radiation	(gamma-rays)	γ-radiation

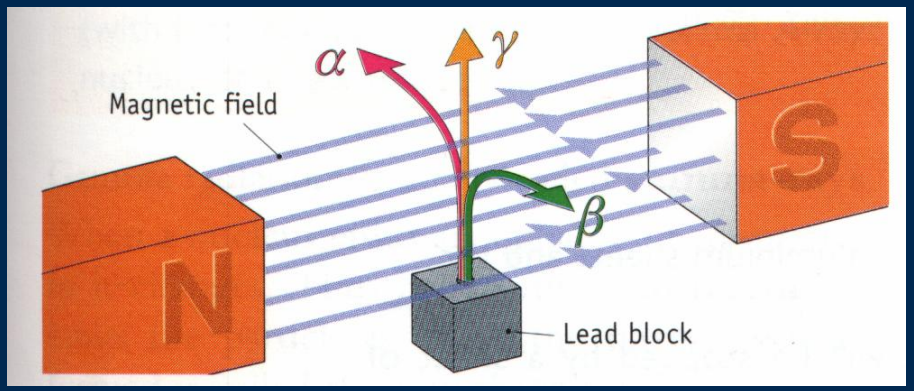
Three Kinds Of Nuclear Radiation

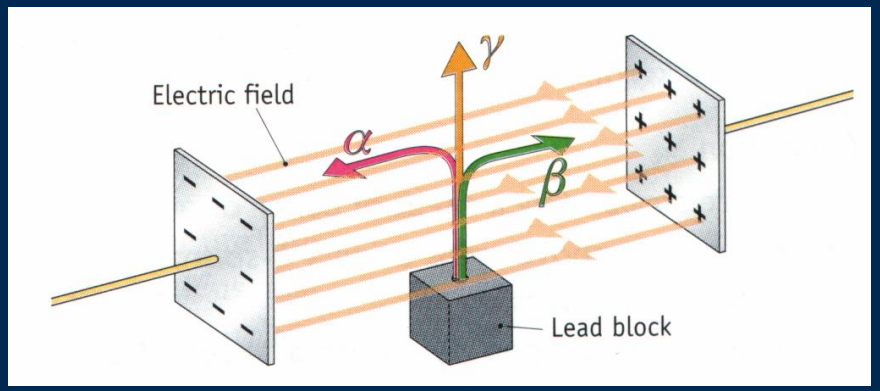
Evidence for …

- Deflection in electric & magnetic fields
- Ionisation
- Penetration

Three Kinds Of Nuclear Radiation

Deflection in Electric/Magnetic Fields



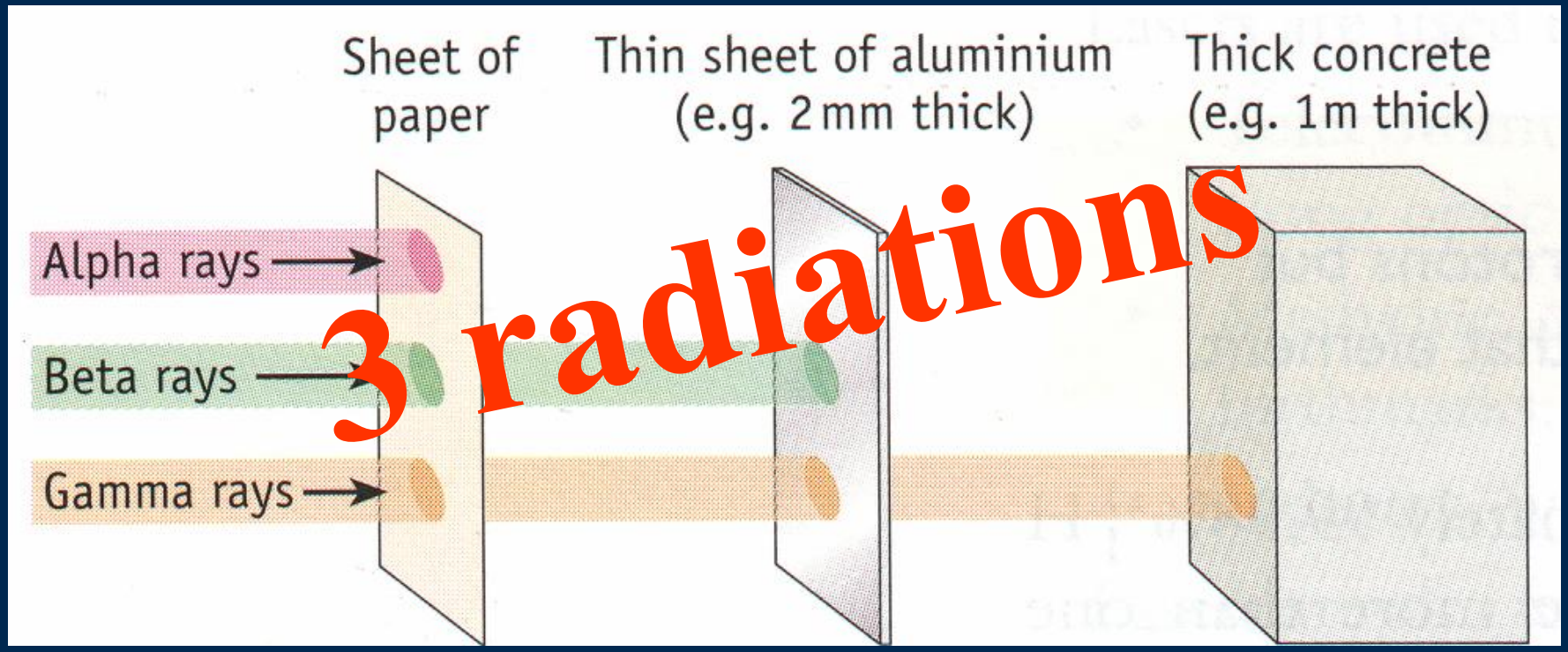


Photographic film

3 spots ➔ 3 radiations

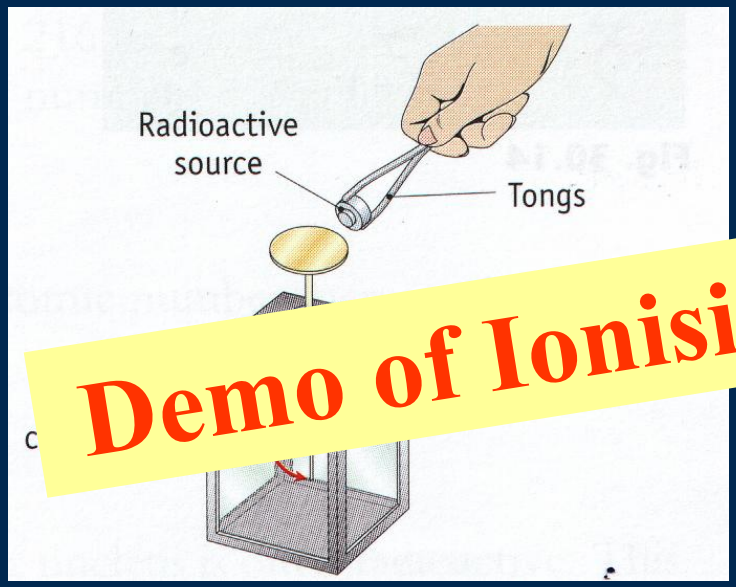
Three Kinds Of Nuclear Radiation

Penetrationg Power



Three Kinds Of Nuclear Radiation

Ionising Ability



Demo of Ionising Effect of Radiation

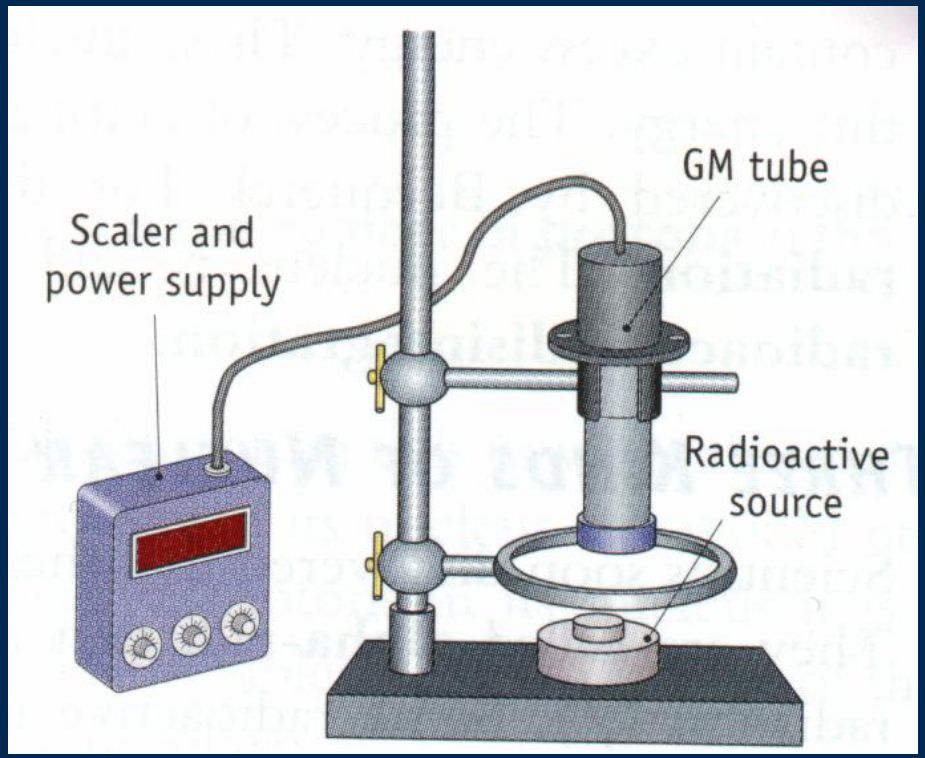
α Leaves fall rapidl…

…more slowly

γ Little effect …

Demo Penetrating Power of the Radiations

Measure background radiation



Alpha Source

Measure count-rate

Paper → background

Air → background

Beta Source

Measure count-rate

Aluminium → background

Air → little effect

Gamma Source

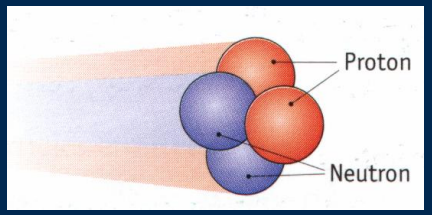
Measure count-rate

Lead needed to …

Nature of α, β, and γ Radiation

Alpha Radiation (Alpha-particles)

- High speed
- helium nuclei
- ejected from the nucleus
- of a radioactive atom



$^{4}_{2}He$

Beta Radiation (Beta-particles)

- High speed
- electrons
- ejected from the nucleus
- of a radioactive atom

$^{0}_{-1}e$

Nature of α, β, and γ Radiation

Gamma Radiation (Gamma-Rays)

- High frequency (*or* short wavelength)
- electromagnetic radiation
- emitted from the nucleus
- of a radioactive atom

Change To The Nucleus When α Is Emitted

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

$$^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$$

Parent nucleus

Daughter nucleus

Change To The Nucleus When β Is Emitted

$$^{228}_{88}\mathrm{Ra} \rightarrow {}^{228}_{89}\mathrm{Ac} + {}^{0}_{-1}\mathrm{e}$$

$$^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}\mathrm{Y} + {}^{0}_{-1}\mathrm{e}$$

$$^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e}$$

Change To The Nucleus When γ Is Emitted

$${}^{A}_{Z}X$$

No change

but … less energy

Properties of α, β, γ

	Nature	Ionising Ability	Penetrating Power	Range
α-particle				
β-particle				
γ-rays				

Properties of α, β, γ

	Nature	Ionising Ability	Penetrating Power	Range
α-particle	Helium nucleus	Greatest	Least	Paper
β-particle	Electron	Less than ..	More than ..	Al
γ-rays	em radiation	Least	Greatest	Pb

Properties of α, β, γ

	Charge	Relative Mass	Electric & Magnetic Fields	
α-particle				
β-particle				
γ-rays				

Properties of α, β, γ

	Charge	Relative Mass	Electric & Magnetic Fields
α-particle	+2	4	As + charge
β-particle	-1	1/2000	As – charge
γ-rays	0	0	Undeflected

P1 How many protons, neutrons, electrons in $^{23}Na_{11}$?

Protons	11
Neutrons	12
Electrons	11

P2 What is X and what is Y in each of the following nuclear reactions?

$$^{220}_{86}Rn \rightarrow X + {}^{4}_{2}He$$

$$^{228}_{88}Ra \rightarrow Y + {}^{0}_{-1}e$$

$$^{216}_{84}X$$

$$^{228}_{89}Y$$

Po

$$^{216}_{84}Po$$

Ac

$$^{228}_{89}Ac$$

P3 When an isotope undergoes radioactive decay the daughter nucleus is often radioactive. This in turn decays and the process continues until a stable isotope is formed. The series of isotopes formed is called a radioactive decay series.

Construct a radioactive decay series beginning with $^{226}Ra_{88}$ and ending with $^{214}Bi_{83}$.

(Consider only elements with atomic numbers 82, 84 and 86.)

P3

$^{226}Ra_{88} \rightarrow {}^{214}Bi_{83}$

$^{4}_{2}He$ $^{0}_{-1}e$

226 → 214 = - 12 ∴ 3 α emitted

88 should drop by (3x2) → 82

82 → 83 ∴ 1 β emitted

P3 Radioactive Decay Series

$$^{226}_{88}\mathrm{Ra} \xrightarrow{\alpha} {}^{222}_{86}\mathrm{Rn} \xrightarrow{\alpha} {}^{218}_{84}\mathrm{Po} \xrightarrow{\alpha} {}^{214}_{82}\mathrm{Pb} \xrightarrow{\beta} {}^{214}_{83}\mathrm{Bi}$$