DOING PHYSICS ONLINE

HSC PHYSICS MINDMAP SUMMARIES

To perform best in your HSC Physics Examination it is essential that you have **memorized** a great deal of information and understood the content covered by the syllabus.

A good way of learning for HSC Physics is to transfer information into your **long term memory** by spending a few minutes regularly going over each of the following mindmap summaries.

A mindmap summary contain critical information on what is essential for maximizing your HSC mark. Each mindmap contains a reference to a HSC Exam, e.g. 2012(34 e) – 2012 paper, question 34 , part e. Also there are links to more detailed notes.

When going over past papers or doing other questions you should always use the mindmaps and it may be necessary for you to add or modify a mindmap to improve it as you gain more insight into the physics content.

H.S.C. Physics examination papers

Four Fundamental Forces of Nature

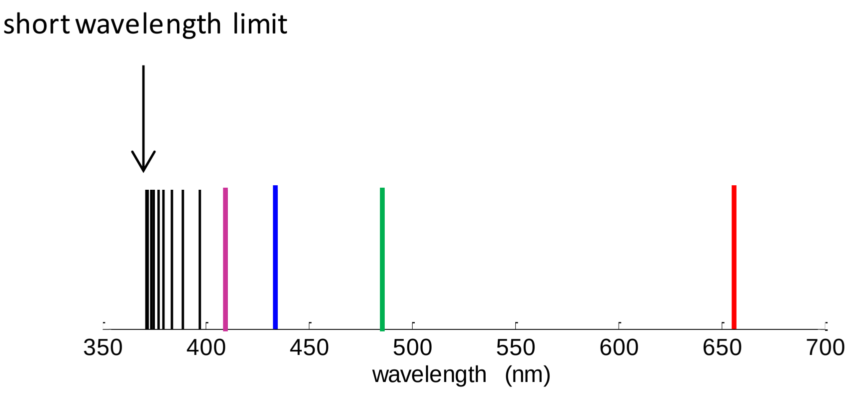
Force	Strength	Range	Direction	"Charge"	Boson
Strong nuclear	1	short ~ 10^{-15} m: between neighbouring nucleons	attractive	colour	gluon
Electromagnetic	10^{-2}	infinite: inverse square law dependent	attractive / repulsive	electric charge	photon
Weak	10^{-9}	short ~ 10^{-18} m	responsible for beta decay	weak	W^+ W^- Z^0
Gravitational	10^{-39}	infinite: inverse square law	attractive	mass	graviton

Hydrogen spectrum

Mathematical models (empirical) of the hydrogen atom spectrum were developed by **Balmer** and **Rydberg**

Rydberg equation $$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

λ wavelength of emitted electromagnetic radiation
R Rydberg constant $R = 1.097\times10^{7}$ m^{-1}
n_i quantum number for initial state (integer n_i = 3, 4, 5, …)
n_f quantum number for final state ($n_i > n_f$)
$n_f = 2 \rightarrow$ Balmer series



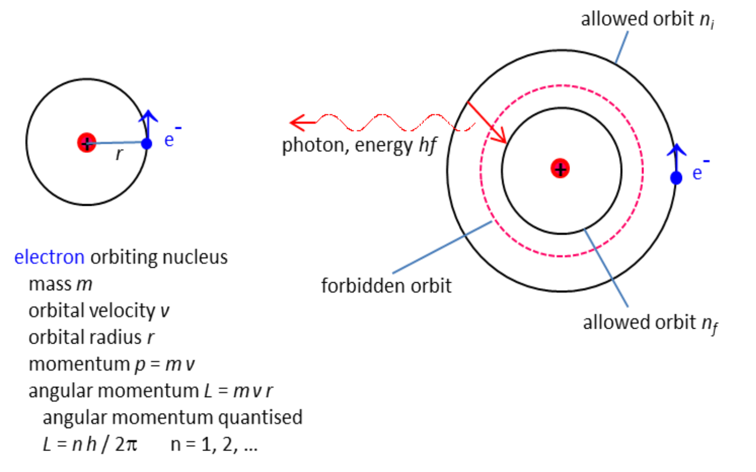
Bohr or **Bohr-Rutherford Model** of the hydrogen atom: mixture of classical physics & quantum physics ideas introduced by **Planck** (**quantization of energy**) & **Einstein** (**photon *E = h f***) . Electron exist in certain stable circular orbits around a positive nucleus. Quantum hypothesis: the angular momentum L of the electron is quantized

$$L = mvr = n\frac{h}{2\pi} \qquad \text{quantum number } n = 1, 2, 3, \ldots$$

$\rightarrow$ stable orbits for a discrete set of radii $r_n \propto n^2$
$\rightarrow$ total energy of electron in system quantised En $\propto -1/n^2$
$\rightarrow$ atom emits or absorbs energy only when electron moves from one stable orbit to another

$$\Delta E = \left|E_f - E_i\right| = h f$$

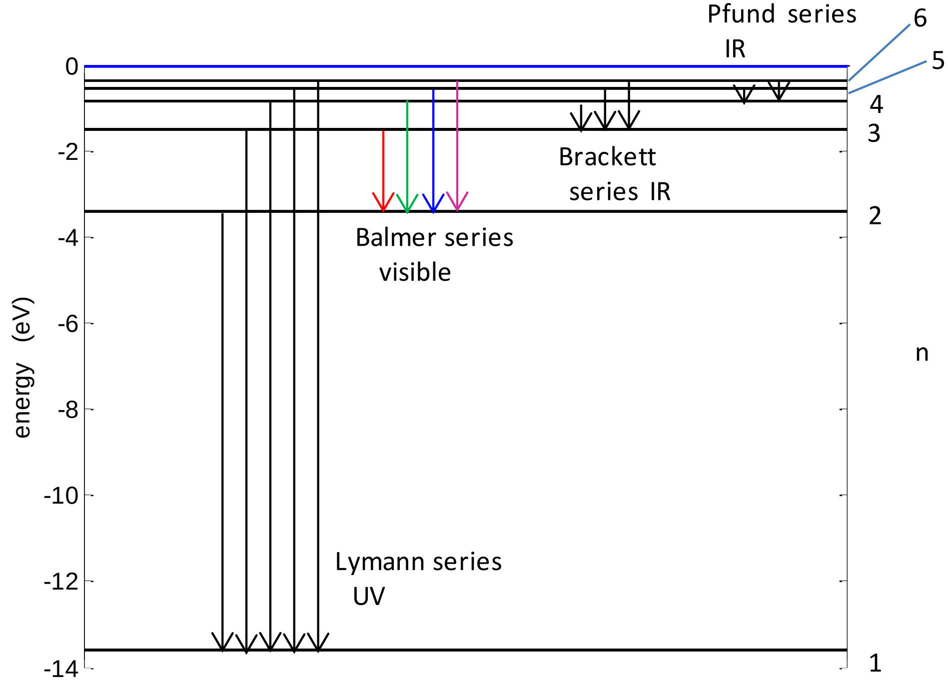
Bohr model $\rightarrow$ derivation of Rydberg equation, hence some theoretical justification of the equation.



Hydrogen spectrum

Rydberg equation

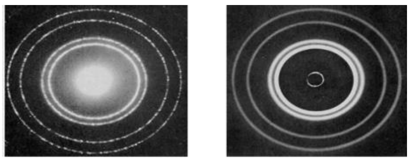
$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^{\,2}} - \frac{1}{n_i^{\,2}}\right)$$



Matter Waves: deBroglie's hypothesis: particles have wave-like properties

The momentum of a particle $p = m\,v$ is related to the wavelength λ of its associated matter wave.

deBroglie equation $$p = \frac{h}{\lambda} \qquad \lambda = \frac{h}{p}$$



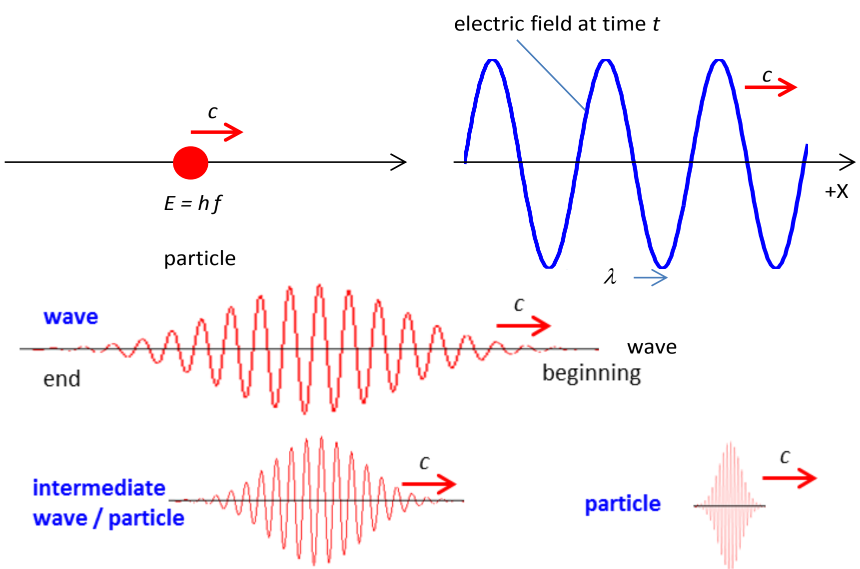
Electron beam   X-ray

Moving particles have a wavelength associated with them:

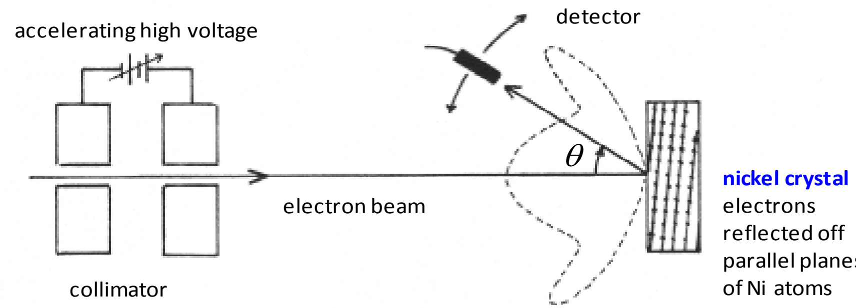
- larger speeds $\Rightarrow$ smaller wavelengths
- larger mass $\Rightarrow$ smaller wavelengths

Everyday objects $\rightarrow$ extremely small deBroglie wavelengths $\rightarrow$ **no** observable wave-like properties

Atomic sized objects $\rightarrow$ wave-like properties of particles are observable e.g. **diffraction of particles**

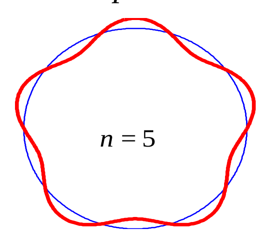


In 1927, **Davisson** and **Germer** confirmed de Broglie's momentum-wavelength mathematical model by observing electrons exhibiting **diffraction** effects when reflected from a nickel crystal. This was the first experimental confirmation of the wave nature of electrons.



deBroglie model of the atom: Bohr's allowed orbits corresponded to electrons in **standing wave** patterns around the nucleus – a whole number n of de Broglie wavelengths must fit around the circumference of an orbit of radius r - an electron behaves as if it is a standing wave, not a charged particle experiencing centripetal acceleration - the electron does not emit EM radiation.

$$n\lambda = n\frac{h}{p} = n\frac{h}{mv} = 2\pi r \quad \Rightarrow \quad mvr = L = \frac{h}{2\pi}n$$



mass m [kg]
velocity v [m.s^{-1}]
momentum $p = mv$ [kg.m.s^{-1}]
deBroglie wavelength λ [m]
Planck's constant h = 6.63x10^{-34} J.s

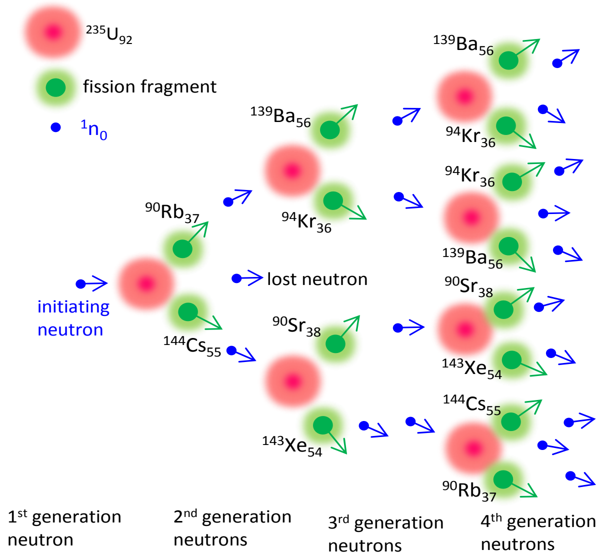
FISSION REACTOR

Component	Purpose
Fuel rods	Need enriched uranium **$^{235}U_{92}$** $^{235}U_{92}$ absorbs **slow moving neutron** – atom splits in a fission reaction releasing energy. Adding fuel rods increases reaction rate, removing fuel rods slows reaction rate.
Moderator	Probability that a $^{235}U_{92}$ nucleus absorbs a neutron increased if they moving slowly. Neutrons emitted during fission move very fast. Neutrons slowed down by a moderator – atoms similar mass to neutron. deuterium $^{2}H_{1}$ (heavy water), carbon (graphite), boron, beryllium.
Control rods	Movable control rods absorb neutrons to maintain the reactor at a critical level to maintain a self-sustaining chain reaction. Event of an accident can be dropped to be into reactor vessel to shut-down the fission process. Adding control rods reduces reaction rate and removing rods increases reaction rate.
Reflector	surrounding fuel rods and moderator $\rightarrow$ prevent the loss of neutrons $\rightarrow$ improves efficiency
Radiation shield	surrounds reactor vessel $\rightarrow$ reduced radiation leaks
Heat exchanger	transfer of the energy released by the fission reactions to produce steam
Electric generator	steam from the heat exchanger turns a turbine $\rightarrow$ electricity

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow {}^{236}U_{92}^{*} \rightarrow {}^{136}Xe_{56} + {}^{88}Sr_{36} + 12\,{}^{1}n_{0}$$

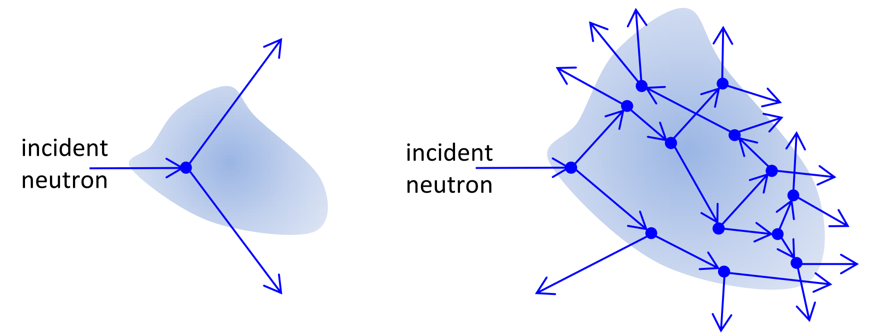
need extra neutrons to maintain fission reactions

UNCONTROLLED FISSION REACTIONS



Critical mass

minimum mass of uranium required for a sufficiently large self-sustaining chain reaction



Chain reaction → process in which neutrons released in fission produce an additional fission in at least one further nucleus → produces neutrons → process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons). If each neutron releases two more neutrons, then the number of fissions doubles each generation → enormous numbers of neutrons

RADIOISOTOPES

Radioisotope	Used in	Application
technetium 99 m (gamma)	medicine	scanning: brain, bone, liver, spleen, kidney, cancer detection, blood flow anomalies
cobalt 60 (gamma)	medicine	radiation therapy – irradiation and destruction of cancer cells
phosphorus 32 (beta)	agriculture	tracking a plant's uptake of fertilizer from the roots to the leaves
cobalt 60 (gamma)	engineering	control of thickness of materials in manufacture

NEUTRON SCATTERING

Neutron beams - nuclear reactor - scattering experiment $\rightarrow$ answers to fundamental questions on structure & composition of materials.

Neutrons - zero electrical charge $\rightarrow$ penetrate materials more effectively than X-rays. Moving neutrons have wave-like properties $\rightarrow$ deBroglie wavelength $\lambda = h/mv \sim \lambda_{Xrays} \sim$ spacing of atoms in solids $\rightarrow$ structure of materials. Crystalline solids – regular pattern for atoms – neutrons scattered off nuclei not electrons $\rightarrow$ distinctive diffraction pattern $\rightarrow$ can determine the position of atoms in the crystal.

Neutrons though electrically neutral, act as small magnets $\rightarrow$ atomic scale study of magnetism.

CONSERVATION LAWS: in an isolated system, particular measurable quantities do not change as the system evolves

- Conservation of mass/energy (equivalence of mass/energy $E = mc^2$)
- Conservation of linear momentum
- Conservation of angular momentum
- Conservation of electric charge
- Conservation of colour charge (quarks)

Conservation of mass-energy: nuclear reactions, radioactivity

mass/energy of reactants = mass/energy of products

mass of reactants m_R > mass of products m_P

mass defect $\Delta m = m_R - m_P$

kinetic energy of products $KE_P = \Delta m\, c^2$

Reactants $\rightarrow$ Products + KE_P

$$^{235}U_{92} + {}^{1}n_0 \rightarrow {}^{236}U_{92}^{*} \rightarrow {}^{136}Xe_{56} + {}^{88}Sr_{36} + 12\,{}^{1}n_0$$

$$^{232}Th_{90} \rightarrow {}^{228}Ra_{88} + {}^{4}He_2 \qquad {}^{4}He_2 \equiv \alpha$$

Chadwick: applied **conservation of mass/energy** and momentum to experimental results of alpha particle scattering from beryllium $\Rightarrow$ ejected particles neutral & mass like a proton $\Rightarrow$ **discovery of neutron**

Beta decay (Wolfgang Pauli):
Charge is conserved $\Rightarrow$ **beta particle** (β^+ or β^-) emitted from the nucleus.
Energy and momentum are conserved $\Rightarrow$ **neutrino** (ν_e or $\bar{\nu}_e$) must also be emitted from the nucleus (**Enrico Fermi** $\rightarrow$ neutrino).

$$^{19}Ne_{10} \rightarrow {}^{19}F_9 + e^+ + \nu_e \qquad e^+ \equiv \beta^+$$

Conservation of colour charge
Protons & neutrons (baryons) contain three quarks, each quark a different **colour**:
R + G + B gives W (white), i.e., zero colour charge.

Beta decay: conservation: charge, mass/energy, colour charge

Beta plus decay $p^+ \rightarrow n + e^+ + \nu_e$

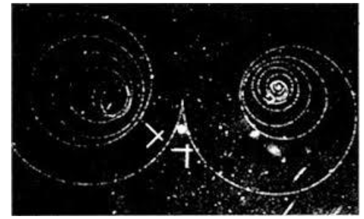
p[**d(-1/3)** **u(+2/3)** **u(+2/3)**]
$\rightarrow$ n[**d(-1/3)** **u(+2/3)** **d(-1/3)**]

ACCELERATORS: devices to accelerate charged particles to high energies - investigate structure of matter & to create radioisotopes

Types: cyclotron, Van de Graff, synchrotron, linear

Uses:

- Production of short half-life **radioisotopes** mainly used in medicine.
- Probing the **structure of matter** – higher the energy → larger momentum → smaller deBroglie wavelength → smaller the detail can be investigated by the beam.
- Creating **new particles**.
- Protons & neutrons internal structure → composed of three **quarks**



accelerator collisions analysed in Wilson cloud chamber: **+** & **-** particles deflected in opposite directions by magnetic field.

STANDARD MODEL: all matter composed of fermions (leptons & quarks) & gauge bosons

- MATTER
  - ATOMS
    - ELECTRONS (-) (lepton)
    - nucleus: PROTONS (+) NEUTRONS
      - QUARKS up u down d

proton
d (-1/2)
u (+2/3)
u (+2/3)
neutron
d (-1/3)
u (+2/3)
d (-2/3)
colour charge = white

$^{14}C_6$

6 protons $\rightarrow$ (6)(3) quarks = 18 quarks
$\rightarrow$ (6)(2) u quarks = 12 u quarks
$\rightarrow$ (6)(1) d quarks = 6 d quarks

8 neutrons $\rightarrow$ (8)(3) quarks = 24 quarks
$\rightarrow$ (8)(1) u quarks = 8 u quarks
$\rightarrow$ (8)(2) d quarks = 16 d quarks

$\rightarrow$ 42 quarks (20 u 22 d)

6 electrons $\rightarrow$ 6 leptons

High energy **accelerators**: collisions between particles
$\rightarrow$ protons & neutrons internal structure $\rightarrow$ **quarks model**
$\rightarrow$ 3 quarks determine **mass** and **charge** of proton & neutrons

Many **scientists** have made important contribution to atomic theory that has lead to significant advances in technology and significant impacts on society.

The syllabus mentions a few of these scientists. Many examination questions ask you to give information about these contributions and significance of the role played by these scientists.

The following pages gives brief mindmap summaries about these scientists and the information given needs to be committed to **memory** so that you will be able to incorporate this knowledge in your HSC physics answers.

Contributions to Atomic Theory: Max Planck

His fame rests primarily on his role as originator of the quantum theory

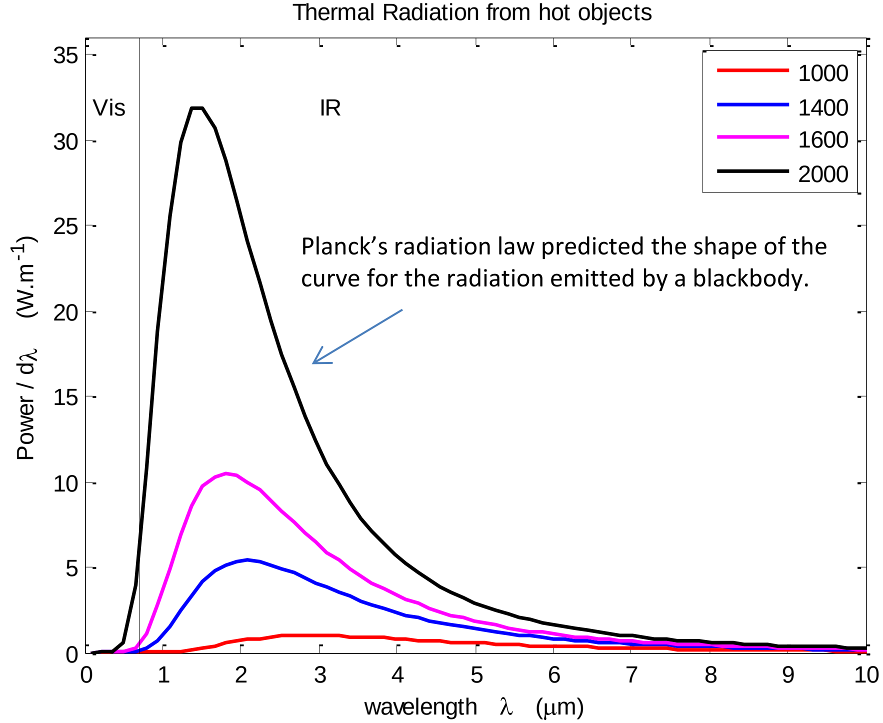
Hypothesis (1900) on radiation emitted & absorbed by walls of a blackbody cavity $\rightarrow$ radiation quantized: electromagnetic energy can only be emitted or absorbed in quantized form $\rightarrow$ energy can only be a multiple of an elementary unit ***hf***, where ***h*** is Planck's constant & ***f*** is frequency of oscillator.

His assumption of energy levels quantized enable him to obtain an equation to successfully describe the blackbody radiation curve (**Planck radiation law**) that agreed with experiment.

Each atom behaves as a small antenna (electromagnet oscillator):

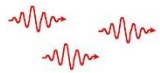
- Energy of an oscillator quantized $E = n\,h\,f$ (n = 1, 2, ….).
- Atomic oscillators do not radiate or absorb energy in continuously variable amounts
- Change in energy of oscillator (emission & absorption) quantized

$$\Delta E = |\,E_2 - E_1\,| = (n_2 - n_1)\,h\,f$$



Contributions to Atomic Theory: Albert Einstein

1905 Explanation of the **photoelectric effect** (light absorbed by a metallic surface may result in the emission of electrons from the surface) $\rightarrow$ electromagnetic waves have a **particle nature** $\rightarrow$ **photons** $\rightarrow$ using ideas of Planck $\rightarrow$ energy of a photon $\boldsymbol{E = h\,f}$



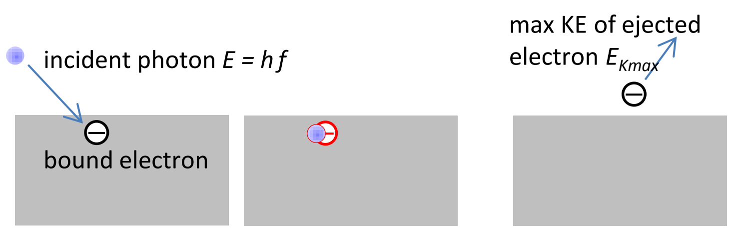
Conservation of energy:

energy of incident photon

= energy to remove electron from surface

+ kinetic energy released electron

$h\,f \;= W + E_K$



all photon energy acquired by electron: min energy required to remove electron from material W_{min} (work function)

Conservation of energy:

$$h\,f = W_{\min} + \tfrac{1}{2} m_e\, v_{\max}^{\;2}$$

Electron ejected from surface without delay ("kicked-out")

Theory of Special Relativity (1905) $\rightarrow$ **equivalence of mass and energy** $\rightarrow$

$\boldsymbol{E = m\,c^2}$

$\rightarrow$ energy released ΔE in nuclear transformations:

mass defect Δm = (mass reactants – mass of products)

$\boldsymbol{\Delta E = \Delta m\,c^2}$

e.g. radioactivity, nuclear reactions, fission, fusion

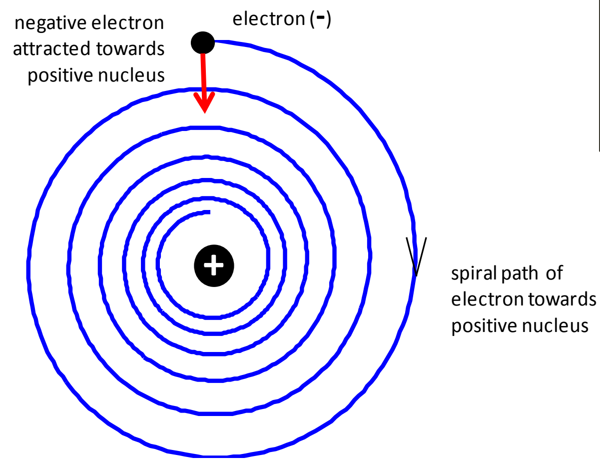
Consequences: nuclear weapons (clash between countries, possible destruction of man-kind), nuclear power (huge potential for supplying world's energy needs), radioisotopes (medicine, agriculture, industry)

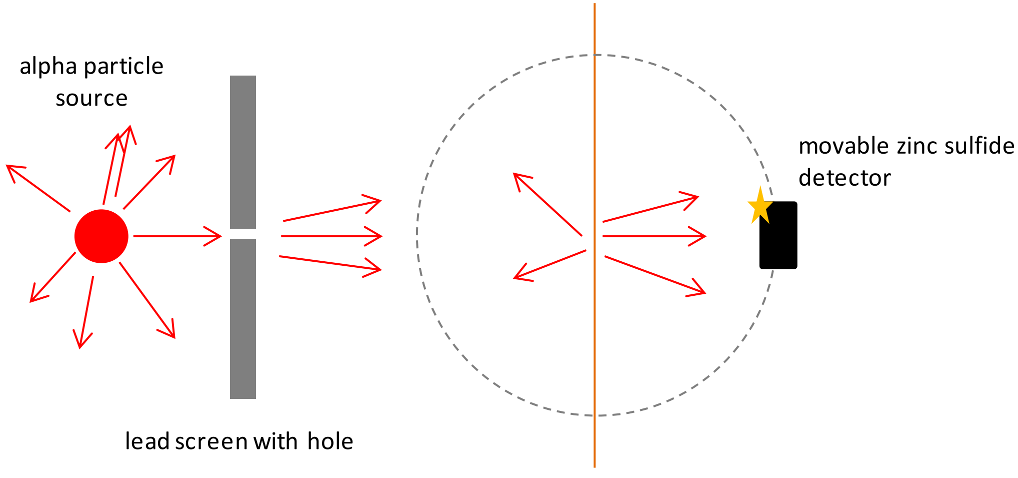
Contributions to Atomic Theory: Ernest Rutherford (father of nuclear physics)

1911 **Rutherford's scattering experiment** → **discovery of the nucleus** → **planetary model of the atom**:
atom mainly empty space with electrons in circular orbits about a small positive massive nucleus.

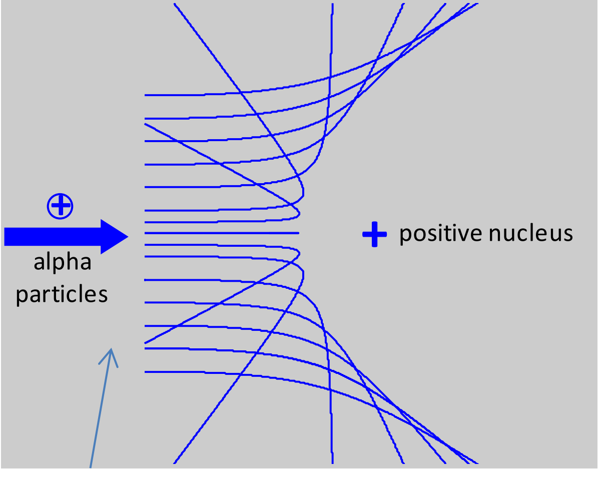
1917 Rutherford → transmutation of nitrogen into oxygen $^{14}N + \alpha \rightarrow {}^{17}O + p$ was the first observation of an induced nuclear reaction
1932 Rutherford's team (John Cockcroft & Ernest Walton) → accelerated protons against lithium-7, to split the nucleus into two alpha particles. The feat was popularly known as "splitting the atom"
1932 under Rutherford's leadership James Chadwick discovered the neutron.

Problem: electrons in circular orbits → accelerate (classical theory) → should emit electromagnetic radiation → electrons should spiral into nucleus





Rutherford's scattering experiment



large angle scattering from massive positive nucleus

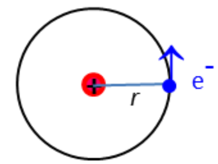
Bohr (Bohr-Rutherford) model of the atom → atomic nucleus at the centre and electrons in circular orbits around it (like planets orbiting the Sun). He helped develop quantum mechanics → electrons move from one energy level to another in discrete steps, instead of continuously. Bohr model explains the Rydberg formula for the spectral emission lines of atomic hydrogen.
Bohr model limited to hydrogen-like atoms only.

Postulate 1: angular momentum L quantized plus principle of conservation of energy → **stable orbits** (no emission of electromagnetic radiation) with discrete total energy

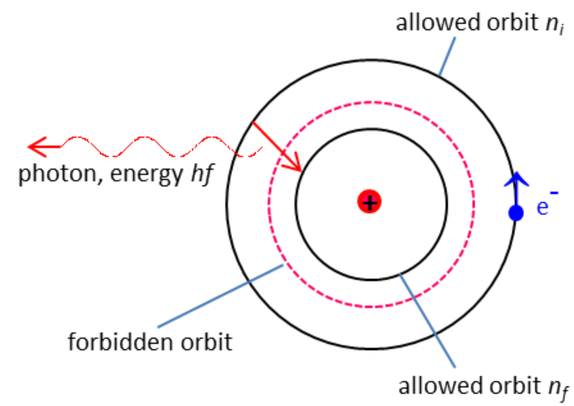
$$L = m v r = n \frac{h}{2\pi} \qquad r_n = \frac{\varepsilon_0 h^2}{\pi q_e^2 m_e} n^2 \qquad r_n \propto n^2$$

$n = 1, 2, 3, \ldots$

$$E_n = -\frac{m_e q_e^4}{8 \varepsilon_0 h^2} \frac{1}{n^2} \qquad E_n \propto \frac{-1}{n^2}$$



electron orbiting nucleus
mass m
orbital velocity v
orbital radius r
momentum $p = m v$
angular momentum $L = m v r$
angular momentum quantised
$L = n h / 2\pi$ n = 1, 2, …



Postulate 2: Atom emits or absorbs energy only when an electron moves from one stable state to another. In a transition from its initial state to its final state, a photon is either emitted or absorbed and the energy of the photon is equal to the difference in the energy of the two states.

$$\Delta E = \left| E_f - E_i \right| = h f$$

Problems: * Discrepancies between predicted & measured wavelengths for line spectra other than hydrogen,& makes poor predictions regarding the spectra of larger atoms. * Quantisation rule for angular momentum was completely arbitrary. * Conceptual difficulty with how the electromagnetic waves emitted by an atom were produced & what was the oscillation that determined the frequency of the emitted radiation. * Violates the Heisenberg Uncertainty Principle because it considers electrons to have both a known position & momentum. * Theory gives an incorrect value for the ground state orbital angular momentum. * It does not predict the relative intensities of spectral lines. * Does not explain fine structure & hyperfine structure in spectral lines. * Does not explain the Zeeman Effect.

Contributions to Atomic Theory: Werner Heisenberg

One of the key creators of **quantum mechanics**. He published his work in 1925 in a breakthrough paper on using a **matrix formulation** (matrix – two dimensional array of numbers) to describe the state of an electron in an atomic system.

Heisenberg Uncertainty Principle (1927) $\rightarrow$ a mathematical inequality asserting a **fundamental limit to the precision** with which certain pairs of physical properties of a particle known as complementary variables, such as position x and momentum p, can be known simultaneously $\rightarrow$ the more precisely the position *x* of some particle is determined, the less precisely its momentum *p* can be known, and vice versa

$$\Delta p \, \Delta x \geq \frac{h}{4\pi}$$

Contributions to Atomic Theory: Wolfgang Pauli

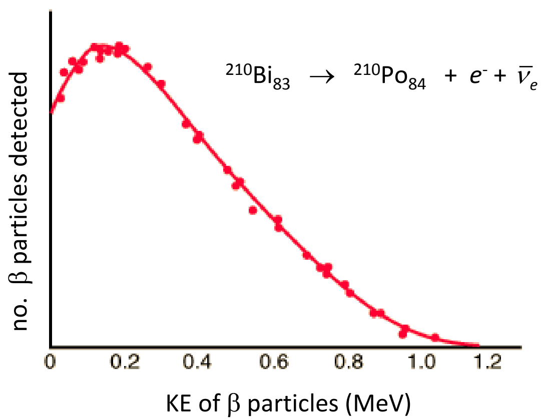
Pauli Exclusion Principle (quantum mechanical principle 1925) → that no two identical **fermions** (particles with half-integer spin) may occupy the same quantum state simultaneously → no two electrons in a single atom can have the same four quantum numbers → if n, ℓ, and m_ℓ are the same, m_s must be different such that the electrons have opposite spins. Integer spin particles, **bosons**, are not subject to the Pauli exclusion principle: any number of identical bosons can occupy the same quantum state, as with, for instance, photons produced by a laser.

In **beta decay** an electron or positron is emitted from an unstable nucleus.

$$n \rightarrow p^+ + e^- \qquad p^+ \rightarrow n + e^+$$

At beta particle can have a continuous range of energies when emitted and this fact could not be explained as it appeared that energy and momentum were **not** conserved. Pauli solved the problem by suggesting a third particle called a **neutrino** was also emitted hence energy and momentum could be conserved.

$$n \rightarrow p^+ + e^- + \bar{\nu}_e \qquad p^+ \rightarrow n + e^+ + \nu_e$$



Contributions to Atomic Theory: James Chadwick

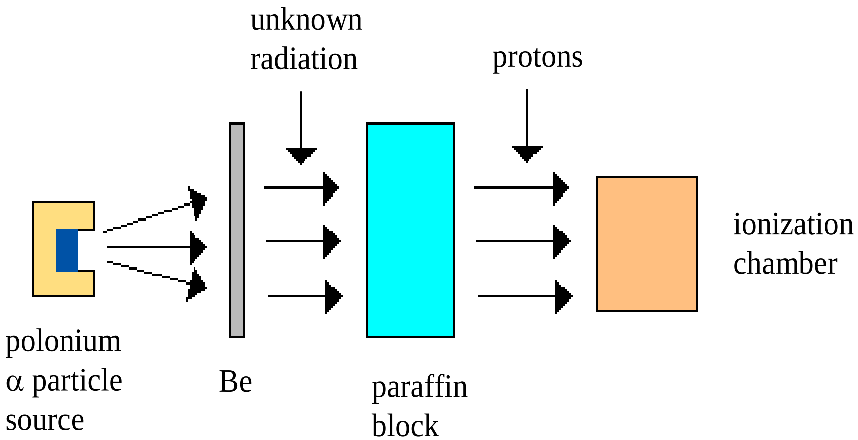
The Neutron

Rutherford (1920) - a proton and an electron within the nucleus might combine together to produce a neutral particle. He named this particle the **neutron**. Experimental difficulties associated with the detection of a neutral particle greatly hindered the research. In 12 years of searching, no such particle was found.

1930 Bothe & Becker, bombarded the element beryllium Be with alpha particles and found a very penetrating form of radiation that was much more energetic than gamma-rays was emitted from Be.

1932 Frederic & Irene Joliot – the unknown radiation could pass through thick sheets of lead but it was stopped by water or paraffin wax. They found that large numbers of very energetic protons were emitted from the paraffin when it absorbed the radiation. The Joliots assumed that the radiation must be an extremely energetic form of gamma radiation.

1932 **James Chadwick -** gamma rays produced by alpha particle bombardment of Be would not have sufficient energy to knock protons out of paraffin → momentum could not be conserved in such a collision between a gamma ray and a proton. He proposed that the radiation emitted from the Be was a new type of neutral particle – the neutron, as originally proposed by Rutherford. He then applied the **conservation of energy** and **momentum laws** to his experimental results and showed that the particles emitted from the Be had to be neutral with about the same mass as the proton. **Chadwick had indeed discovered the neutron**. He explained that when the neutrons emitted from the Be collided with the light hydrogen nuclei in the paraffin, the neutron came to a sudden stop and the hydrogen nucleus (proton) moved off with the same momentum as the neutron had before the collision.



Joliot's Experiment

$$^{4}He_{2} + {}^{9}Be_{4} \rightarrow {}^{12}C_{6} + ???$$

Chadwick→

$$^{4}He_{2} + {}^{9}Be_{4} \rightarrow {}^{12}C_{6} + {}^{1}n_{0}$$

Contributions to Atomic Theory: Enrico Fermi

Best known for his work on the **first nuclear reactor** (Manhattan Project: 1942 Chicago - Fermi and Robert Oppenheimer are referred to as the "father of the atomic bomb"). Fermi led the team that designed and built the Chicago Pile-1, and initiated the first artificial self-sustaining nuclear chain reaction that went critical on 2 December 1942.

Contributions to the development of: quantum theory, nuclear physics (nuclear power, induced radioactivity, discovery of transuranic elements, discovered that **slow neutrons** were more easily captured than fast ones to produce fission reactions), particle physics (developed a model for **beta decay** that incorporated the emission of an invisible & neutral particle which he called the **neutrino**), statistical mechanics (Fermi-Dirac statistics: particles that obey the Pauli Exclusion Principle are called **fermions**).

He held several patents related to the use of nuclear power, and was awarded the 1938 Nobel Prize in Physics for his work on induced radioactivity and the discovery of transuranic elements. Fermi was widely regarded as one of the very few physicists to excel both theoretically and experimentally.

Described one of the four fundamental forces of nature – the **weak interaction** involved in beta decay.

Worked on thermonuclear hydrogen (super) bomb immediately after WWII. In 1949 he strongly opposed the development of a hydrogen bomb on both moral and technical grounds.

Science Technology Society

We now live in a technological world that has only come about by an understanding how nature works through science.

Scientific Theories: physics of the atom $\rightarrow$ Quantum Mechanics $\rightarrow$ wave / particle description of nature

$\Uparrow\Downarrow$

Technological developments:

$\rightarrow$ **LASERS** $\rightarrow$ printed circuit boards, flat panel displays, hard disks, optical fibres, semiconductors wafers used to create components of our smartphones, tablets, laptops, TVs

$\rightarrow$ **SEMICONDUCTORS** $\rightarrow$ transistors $\rightarrow$ integrated circuits $\rightarrow$ microprocessors used to create computers, phones, medical instrumentation, consumer products, …

$\Downarrow$

Society: functioning of our global world depends upon electricity, communication and computer processing, … $\rightarrow$ information from around the world in "the palm of your hand" $\rightarrow$ internet (world wide web) $\rightarrow$ transfer of information, communication, education, banking, social networking, …

Scientific Theories: physics of the atom $\rightarrow$ $E = mc^2$ & Quantum Mechanics $\rightarrow$ nuclear physics

$\Uparrow\Downarrow$

Technological developments:

$\rightarrow$ **NUCLEAR POWER** $\rightarrow$ fission reactors

$\rightarrow$ **NUCLEAR WEAPONS** $\rightarrow$ thermonuclear weapons - uses the energy generated by a fission bomb to compress and ignite a nuclear fusion stage $\rightarrow$ incredible amounts of energy released.

$\Downarrow$

Society: Good: possible clean and abundant energy for the world.

Bad: nuclear contamination (Fukushima Japan), possible destruction of man-kind, global clashes – cold war, USA & Iran.