Particles and Waves

Higher Physics

Higher Waves Revision Form

https://forms.office.com/r/UgSC4N4Q8s

Phase and Coherence

Phase

- *Two points on a wave that are vibrating in exactly the same way, at the same time, are said to be **in phase**, e.g. two crests, or two troughs.*
- ***IN PHASE ⇒ two sources with the same frequency and wavelength that have their maximum displacement at the same moment.***

Coherence

- Two sources that are oscillating with a constant phase relationship are said to be **coherent.** This means the two sources also have the same frequency. Interesting interference effects can be observed when waves with a similar amplitude and come from coherent sources meet.

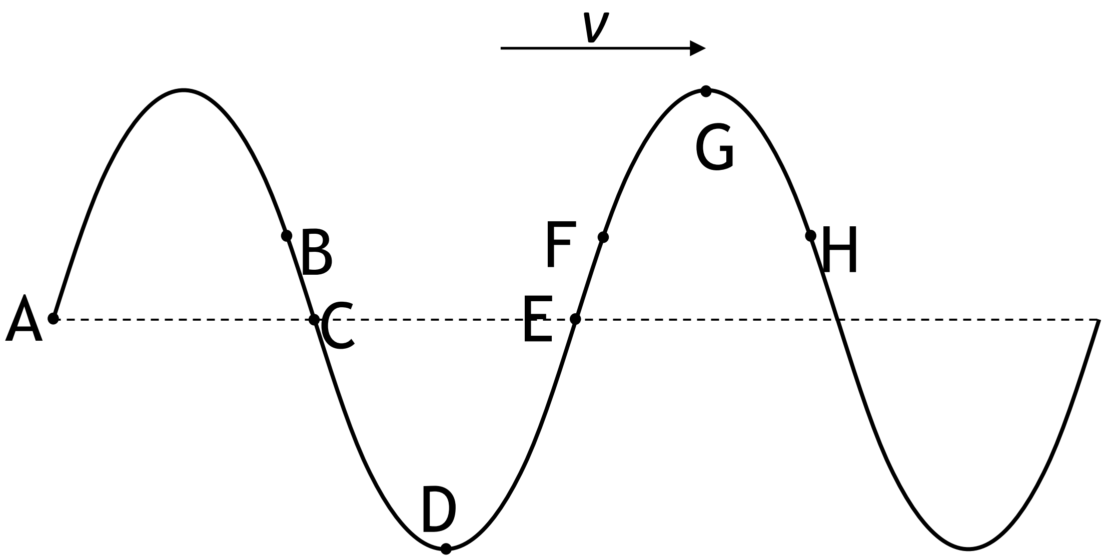
- *COHERENT ⇒ coherent sources have:*

i) the same frequency

ii) constant phase relationship

iii) similar amplitude.

Two points that are vibrating in exactly the opposite way, at the same time, are said to be **exactly out of phase**, or **180º out of phase**, e.g. a crest and a trough. **Out of phase** ⇒ *two sources with the same frequency and wavelength. One has a crest at a point where the other source has a trough (completely out of phase).*



Points ___ & ___ or ___ & ___ are in phase.
Points ___ & ___ or ___ & ___ or ___ & ___ are exactly out of phase.
Points ___ & ___ or ___ & ___ or ___ & ___ are 90° out of phase.
Points ___ and ___ are at present stationary.
Points ___, ___ and ___ are at present rising.
Points ___, ___ and ___ are at present dropping.

Points A & E, B & H are in phase

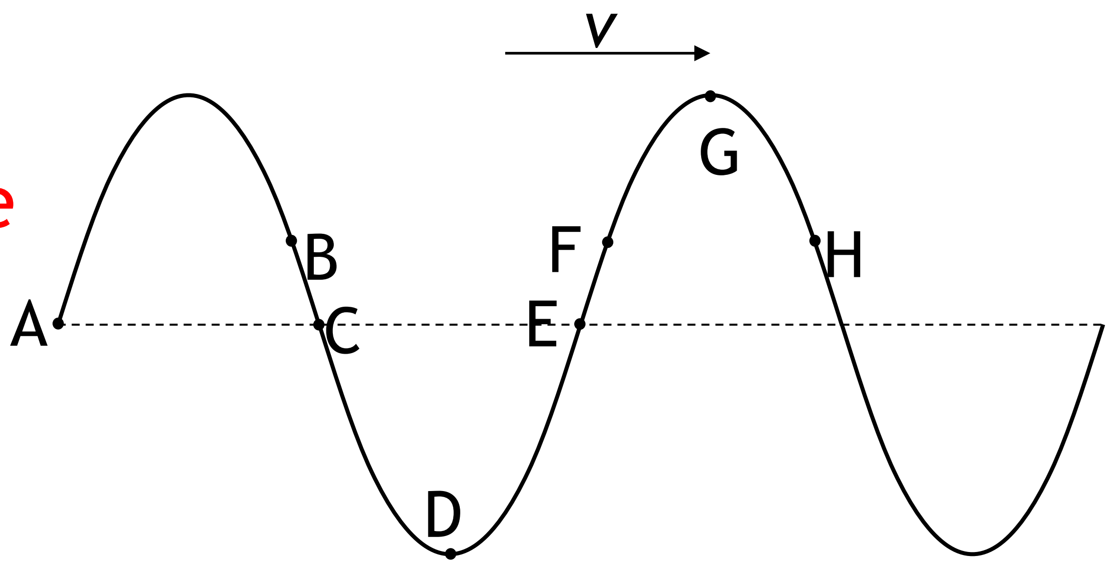
Points A& C, D & G, C&E are exactly out of phase

Points A& G, C & D, D & E, E & G are 90° out of phase

Points D & G are at present stationary

Points A, E and F are at present rising

Points B, C, & H are at present dropping

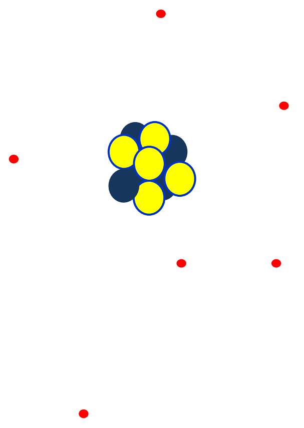


REVISION OF ATOMS

An atom consists of a positive nucleus and outer electrons
The **nucleus** contains **protons,** which have a positive charge and **neutrons,** which are neutral

- Electrons in outer shells, permanently moving
- Electrons = electrons, negative, distinct energy levels.

PROTON = Positive } *NUCLEUS*
NEUTRON = Neutral }



Electron has negative charge

Proton has positive charge

Neutron has zero charge

NOT TO SCALE
Remember -

Atoms

- Nucleus = protons and neutrons. Massive, neutrons no charge protons positive charge and hence positive nucleus. Protons and neutrons are made of quarks. Protons = uud, neutrons =ddu
- Most of the atom is empty space.
- In an atom the number of protons equals the number of electrons
- Most of the mass is concentrated in the nucleus (1 proton ≈ mass of 1 neutron ≈ mass of approximately 1850 electrons.
- Electrons stay in their orbits as they are bound by the positive nucleus (cf. us and the Earth).
- Energy must be added to remove an electron from the atom.
- We say that zero energy is taken as being when the electron is outside the “field” of the atom. Therefore, electrons in the atom have negative energy because they are bound.

THE STANDARD MODEL

Beware lots of new words coming up

I know that the Standard Model is a model of fundamental particles and interactions.

I can describe the Standard Model in terms of types of particles and groups

I can use orders of magnitude and am aware of the range of orders of magnitude of length from the very small (sub-nuclear) to the very large (distance to furthest known celestial objects).

I know that evidence for the existence of quarks comes from high-energy collisions between electrons and nucleons, carried out in particle accelerators.

I know that in the Standard Model, every particle has an antiparticle.

I know that the production of energy in the annihilation of particles is evidence for the existence of antimatter

I know that beta decay was the first evidence for the neutrino.

I know the equation for β- decay above (β+ decay not required) $^{1}_{1}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e + \overline{\nu_e}$

I know that fermions, the matter particles, consist of quarks (six types: up, down, strange, charm, top, bottom) and leptons (electron, muon and tau, together with their neutrinos).

I know that hadrons are composite particles made of quarks.

I know that baryons are made of three quarks.

I know that mesons are made of quark-antiquark pairs.

I know that the force-mediating particles are bosons: photons (electromagnetic force), W- and Z-bosons (weak force), and gluons (strong force).

Orders of Magnitude

Size	Powers of 10	
	10^{-18} m	
1 fm (femto)	10^{-15} m	
	10^{-14} m	
1 pm (pico)	10^{-12} m	
1Å (Angstrom)	10^{-10} m	
1 nm (nano)	10^{-9} m	
	10^{-8} m	
	10^{-7} m	
1 µm (micro)	10^{-6} m	
	10^{-5} m	
	10^{-4} m	
1 mm (milli)	10^{-3} m	
1 cm (centi)	10^{-2} m	
	10^{-1} m	
1 m	10^{0} m	
	10^{1} m	

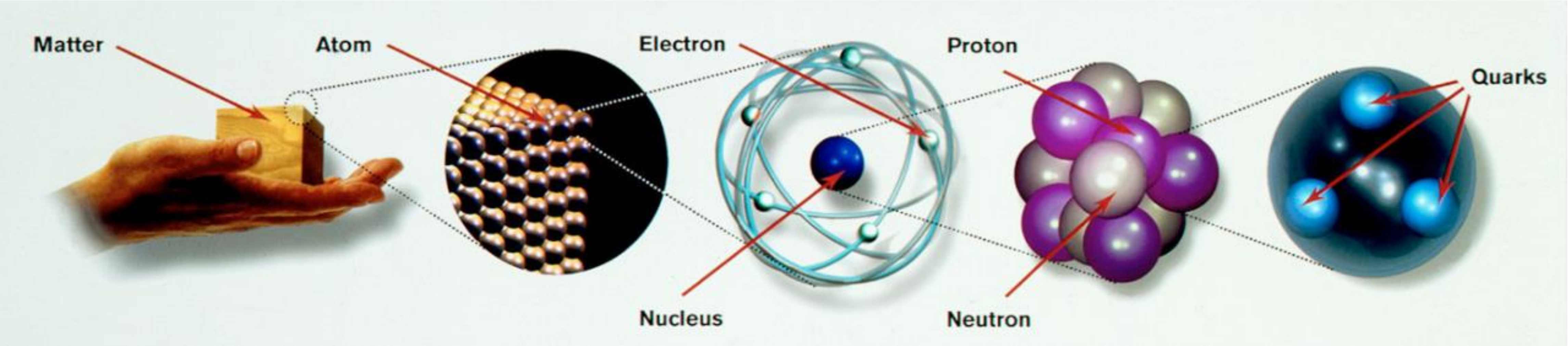
In your groups try to fill in the table A3 version

ORDERS OF MAGNITUDE

- The very famous 1977 video!
- https://www.youtube.com/watch?v=0fKBhvDjuy0
- The latest version
- https://www.youtube.com/watch?v=FglEbPXxka4
- But this is better
- https://www.youtube.com/watch?v=bhofN1xX6u0
- And this has commentary by Morgan Freeman and is most like the original https://www.youtube.com/watch?v=44cv416bKP4
- Or finally https://www.youtube.com/watch?v=50tpm2fAf-Y

….. And before we start someone needs to apologise.

Particle Cosmology



Courtesy CERN ***CERN-DI-9501005***

Thomson (1897): Discovers electron

Rutherford (1909): Nuclear Atom (proton)

Chadwick (1932): Discovers neutron

SLAC (1968): Quarks in neutrons and protons

THE STANDARD MODEL OF PARTICLE PHYSICS

- The ancient Greeks believed the world was made of 4 **elements** (fire, air, earth and water). Democritus used the term ‘atom’, which means “indivisible” (cannot be divided) to describe the basic building blocks of life, so he got that wrong then! Other cultures including the Chinese and the Indians had similar concepts.

Figure 1 Lavoisier

In 1789 the French chemist Lavoisier discovered through very precise measurement that the total mass in a chemical reaction stays the same. He defined an element as a material that could not be broken down further by chemical means, and classified many new elements and compounds. His work was so admired that at the age of 50 he was guillotined during the French Revolution for his aristocratic background.

THE PERIODIC TABLE – ORDER OUT OF CHAOS

In 1803 Dalton measured very precisely the proportion of elements in various materials and reactions. He discovered that they always occurred in small integer multiples. This is considered the start of modern atomic theory.

In 1869 Mendeleev noticed that certain properties of chemical elements repeat themselves periodically and he organised them into the first periodic table.

Figure 1: Photograph courtesy of the Cavendish Laboratory, Cambridge.

Figure 1 Photograph courtesy of the Cavendish Laboratory, Cambridge

THE DISCOVERY OF THE ELECTRON

- In 1897 J.J. Thomson discovered the electron and the concept of the atom as a single unit ended. This marked the birth of particle physics.
- Although we cannot see atoms using light which has too large a wavelength, we can use an electron microscope. This fires a beam of electrons at the target and measures how they interact. By measuring the reflections and shadows, an image of individual atoms can be formed. We cannot actually see an atom using light, but we can create an image of one. The image shows a false-colour scanning tunnelling image of silicon.

The Structure of Atoms

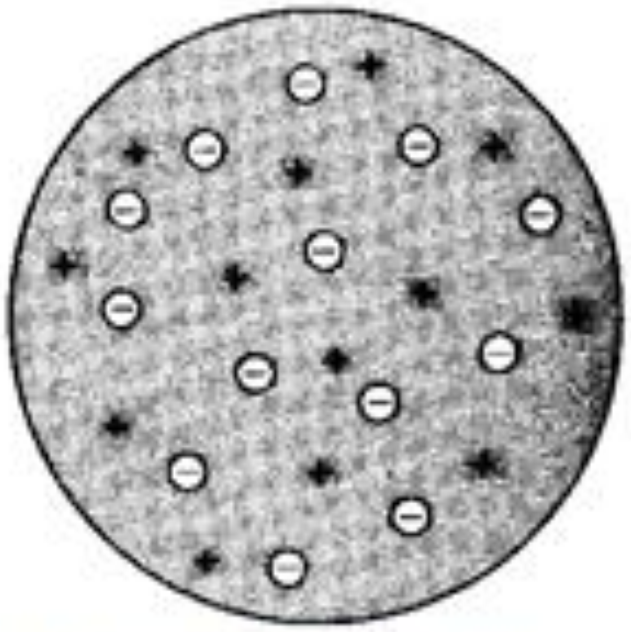


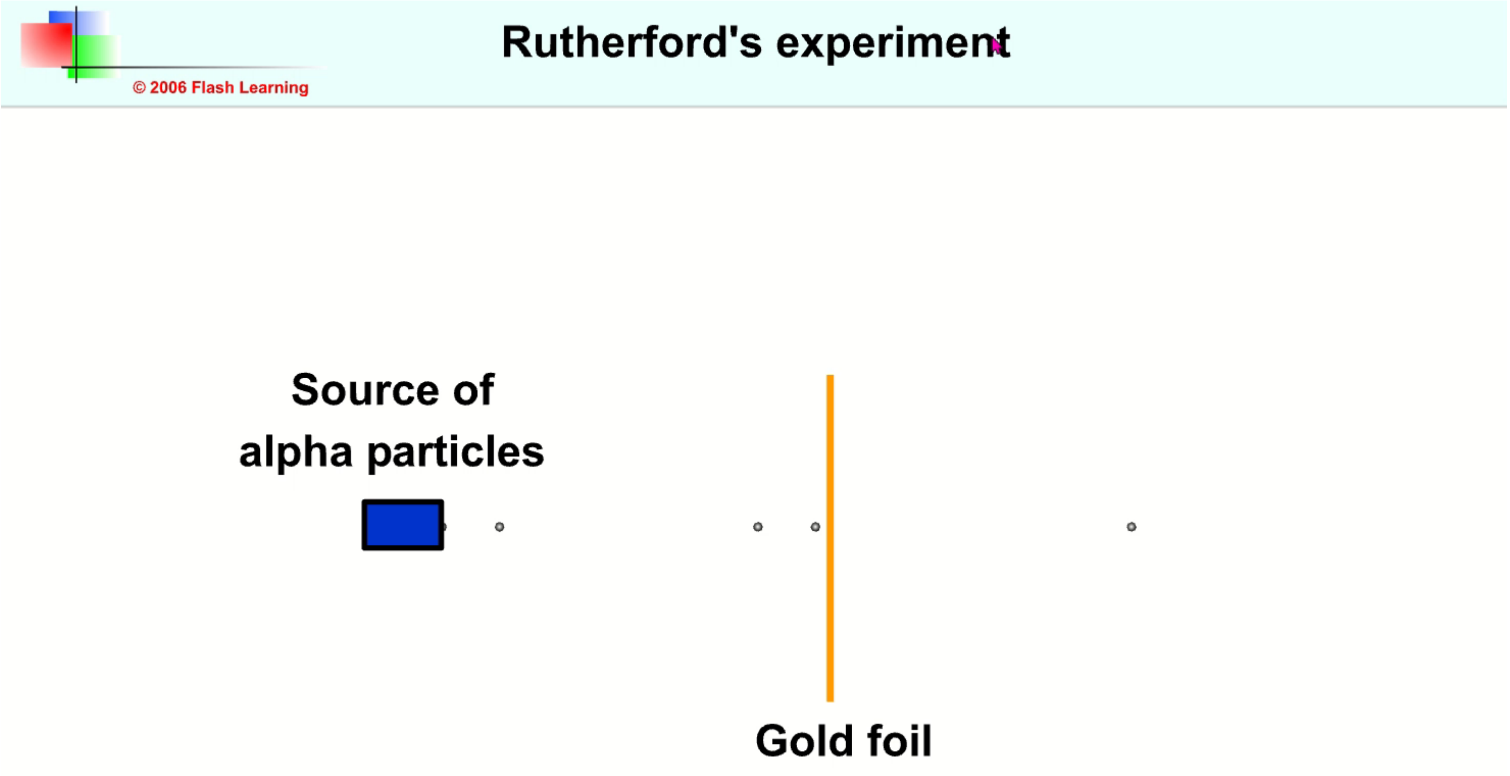
Figure 1 JJ Thompson's Plum Pudding Model of the Atom

- At the start of modern physics at the beginning of the 20th century, atoms were treated as semi-solid spheres with charge spread throughout them. J.J. Thompson's model of the atom (1904) suggested that the positive charge was distributed evenly throughout the atom and the negative charges were fixed throughout; like fruit through a Christmas pudding, hence the model was known as the Plum Pudding Model.

- This model fitted in well with experiments that had been done by then, but a new experiment by Ernest Rutherford in 1909 would soon change this. This was the first scattering experiment – an experiment to probe the structure of objects smaller than we can actually see by firing something at them and seeing how they deflect or reflect. According to the Plum Pudding Model, if charged particles were fired at the atoms you would only expect the charges to deflect slightly

Watch carefully

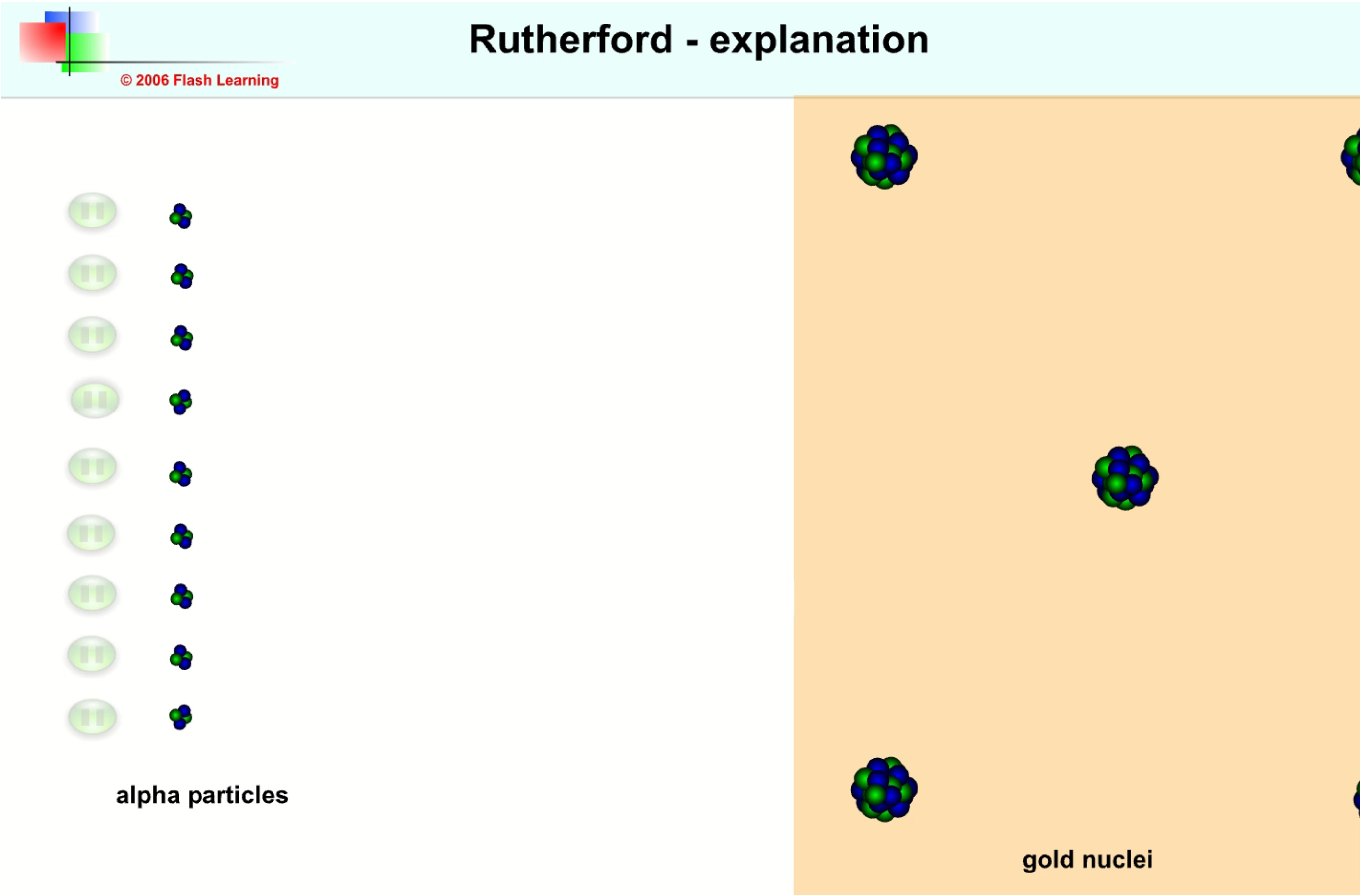
- You might miss it!
- Record what happens to the particles!



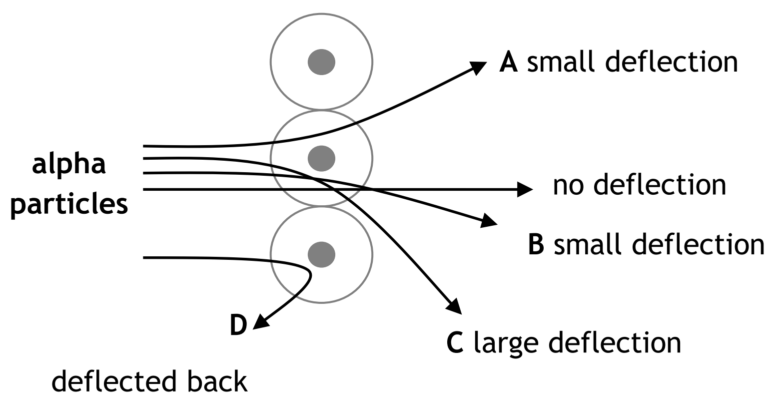
Explanation of the famous experiment

- Most alpha particles pass straight through
- Some are deflected
- Very few rebound

- Explain these findings



Conclusion



Results

most alpha particles went straight through the foil with little or no deflection detected between positions A and B.

a small fraction of the particles were scattered through very large angles e.g. to position C, and a very small number were even deflected backwards, e.g. to position D.

Conclusion

The atoms contain more open space than explained by the plum-pudding model and was mainly open space. The foil, which was at least 100 atoms thick, suggesting the atom must be mostly empty space!

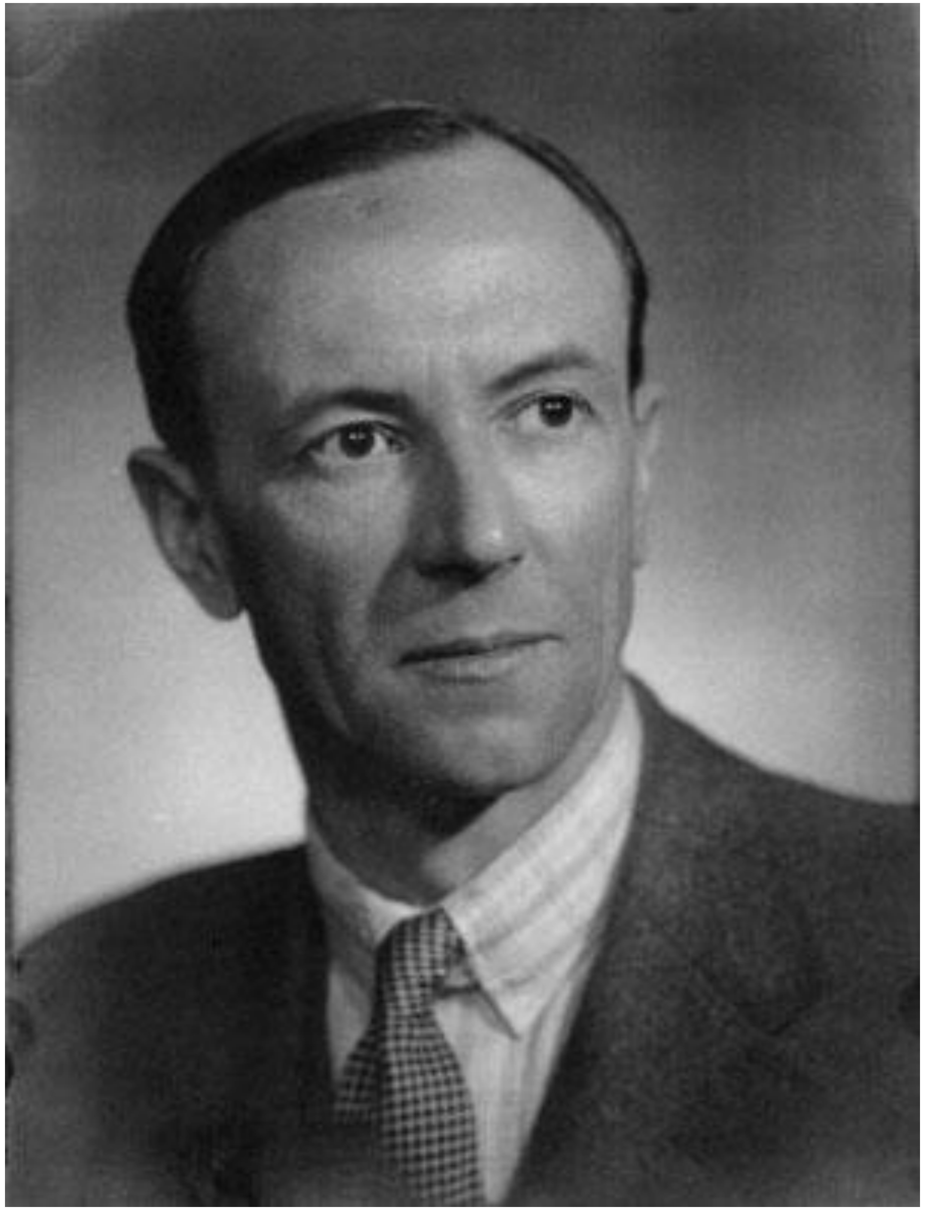
Strong forces are needed to achieve this (alpha particles were travelling at about 10^6 m s^{-1}). This suggested a concentration of atomic charge. The alpha particles must be encountering something of very large mass and a positive charge.

1 : 8000

Relative sizes: a nucleus the size of a pea would result in the atom being the size of a football pitch (if drawn to the same scale).

The discovery of the Neutron

- Physicists realised that there must be another particle in the nucleus to stop the positive protons exploding apart, and to account for the additional mass scientists had determined was in atoms. This is the neutron which was discovered by Chadwick in 1932. This explained isotopes – elements with the same number of protons but different numbers of neutrons.



A bit of Chemistry

Each element, and hence the way it behaves, has a set number of protons, e.g. Hydrogen always has just 1 proton, and Carbon has 6 protons. In all atoms the number of protons in the nucleus is equal to the number of electrons surrounding the nucleus, (if not then the particle is an ion and not an atom).
The number of neutrons in the nucleus of any element can vary. We call these isotopes, e.g. carbon usually has 6 neutrons but can have 8. Larger atoms usually have many more isotopes.
We can represent each type of atom in the following way
where

A = mass number (no. of protons +neutrons) ie nucleons

Z = atomic number (no.of protons)

X = symbol to represent the atom, either 1 capital letter or one capital followed by 1 lower case letter.

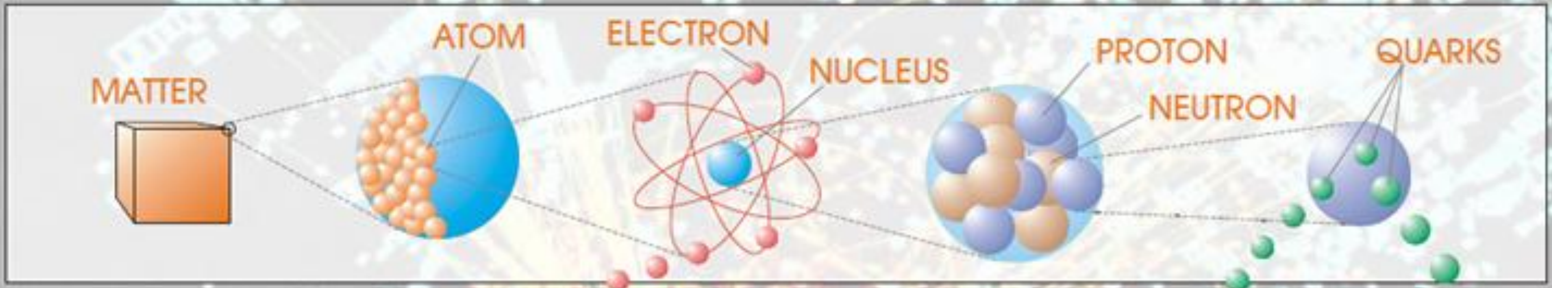
$$^{A}_{Z}X$$

Symbol	Name	Protons	Neutrons	Electrons	Is there an isotope of the element in this table?
$^{1}_{1}H$		1	0	1	
$^{14}_{6}C$		6	8	6	
$^{12}_{6}C$		6	6	6	
$^{197}_{79}Au$		79	118	79	
$^{238}_{92}U$		92	143	92	
$^{235}_{92}U$		92	146	92	
$^{220}_{88}Ra$		88	132	88	
$^{222}_{86}Rn$		86	136	86	

Matter and Antimatter

Royal Holloway University of London

The Structure of Matter



LEPTONS — These particles exist on their own

QUARKS — These particles only exist bound together

		Leptons: Charge = -1	Leptons: Charge = 0	Quarks: Charge = +2/3	Quarks: Charge = -1/3
Constituents of ordinary matter.	1st Family	ELECTRON (e^-) Responsible for electricity and chemical reactions. Mass = 0.51 MeV/c^2	ELECTRON NEUTRINO (ν_e) Rarely interacts with other matter. Observed 1956.	UP (u) Mass ~ 3 MeV/c^2	DOWN (d) Mass ~ 6 MeV/c^2
				Protons are made up of two up quarks and one down quark. Neutrons are made up of one up quark and two down quarks.	
These particles existed in the early moments after the Big Bang. Now they are found only in cosmic rays and at particle accelerators.	2nd Family	MUON (μ^-) A heavier relative of the electron. Discovered 1937. Mass = 0.106 GeV/c^2	MUON NEUTRINO (ν_μ) A relative of ν_e. Discovered 1962.	CHARM (c) A heavier relative of the up quark. Discovered 1973. Mass ~ 1.2 GeV/c^2	STRANGE (s) A heavier relative of the down quark. Evidence 1947. Mass ~ 0.1 GeV/c^2
	3rd Family	TAU (τ^-) A heavier relative of the electron and muon. Discovered 1975. Mass = 1.78 GeV/c^2	TAU NEUTRINO (ν_τ) Indirect evidence 1975. Directly observed 2000.	TOP (t) The heaviest quark. Discovered 1994. Mass ~ 175 GeV/c^2	BOTTOM (b) A heavier relative of the down and strange quarks. Discovered 1977. Mass ~ 4.2 GeV/c^2

Until recently it was generally thought that the neutrinos have zero mass. Several recent experiments suggest that the mass of the neutrinos is not zero.

ALL OF THE ABOVE PARTICLES HAVE AN ANTIPARTICLE COUNTERPART.

A particle and its antiparticle can annihilate to produce the bosons that carry forces, e.g. $e^+e^- \rightarrow \gamma\gamma$.

A particle - antiparticle pair can be produced from a force-carrying boson, e.g. $Z \rightarrow b\bar{b}$, $\gamma \rightarrow e^+e^-$.

Background: Simulation of a Higgs decay to two hadronic jets