- *__Candidates should be able to__ :*
  - *Describe qualitatively the **alpha-particle scattering experiment** and the evidence this provides for the **existence, charge and small size of the nucleus.***
  - *Describe the basic **atomic structure** of the atom and the **relative sizes** of the atom and the nucleus.*
  - *Select and use **Coulomb's law** to determine the force of repulsion, and **Newton's law of gravitation** to determine the force of attraction, between two protons at nuclear separations and hence the need for a short-range, attractive force between nucleons.*
  - *Describe how the **strong nuclear force** between nucleons is **attractive** and **very short-ranged.***
  - *Estimate the **density of nuclear matter.***
  - *Define **proton number** and **nucleon number.***
  - *State and use the notation $^{A}_{Z}X$ for the representation of nuclides.*
  - *Define and use the term **isotopes.***
  - *Use nuclear decay equations to represent **simple nuclear reactions.***
  - *State the **quantities conserved** in a nuclear decay.*

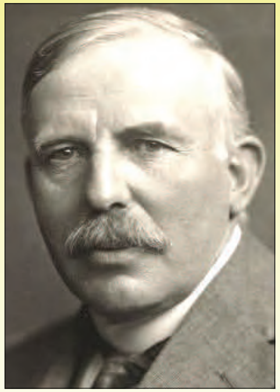
INTRODUCTION

- The idea that matter is composed of **very small particles** was first suggested by the Greek philosopher **Democritus** about **2000 years ago.** Our modern atomic theory was first postulated by **John Dalton** who thought of atoms as **tiny, indivisible** particles. Ideas about the **internal structure** of the atom did not start to emerge until the, mid 19th century.

- According to **J.J.Thomson,** every atom contains one or more negatively charged electrons. His model of the atom (known as the **PLUM PUDDING** model) visualised the atom as **a sphere having the positive charge uniformly distributed throughout its volume with the negatively charged electrons embedded in it** (Like the plums in a plum pudding).

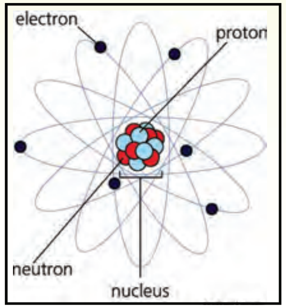
- **Ernest Rutherford** proposed the **NUCLEAR** model of the atom in 1914.

  In this model **the atom consists of a massive, positively charged nucleus at the centre, with much lighter, negatively charged electrons orbiting around it.**

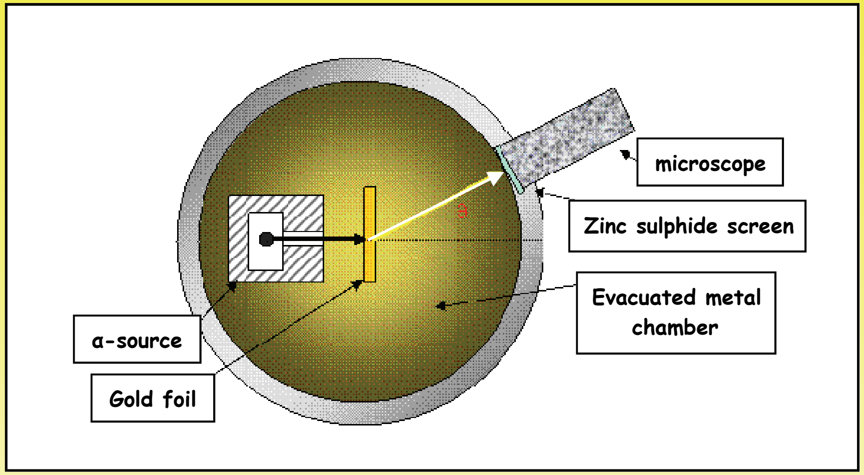


- He used **alpha (a) particles** (positively charged **helium nuclei** i.e. **2p +2n**) to probe the atom.

  He reckoned that if the positive charge was spread out throughout each atom (as Thomson had thought) , an a-particle beam directed at a thin metal foil would only be scattered slightly. He was astonished when some of the a-particles bounced back from the foil…… in his own words, **'as incredible as if you fired a 15-inch shell at tissue paper and it bounced back'.**



RUTHERFORD'S ALPHA SCATTERING EXPRIMENT



- A narrow, mono-energetic beam of α-particles was directed at a very thin gold foil in an evacuated container. A zinc sulphide screen was used to detect the scattered α-particles which produced a scintillation when they struck the screen. The pinpoints of light were then observed through a microscope which could be rotated at a constant distance from the foil.

  Rutherford and his students counted the number of α-particles reaching The detector over a fixed time interval for different angles of deflection from 0°to almost 180°.

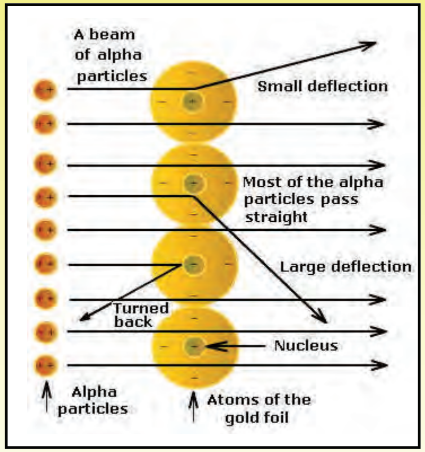
- Their measurements showed that :

  - **Most α's passed straight through the foil without deflection.**
  - **Some α's were deflected through small angles.**
  - **A small number of α's were deflected through angles > 90° And about 1 in 8000 suffered 'back scattering' (i.e. they were reflected back towards the source).**

- Rutherford concluded that :

  - **MOST OF THE ATOM'S MASS IS CONCENTRATED IN A VERY SMALL VOLUME, THE NUCLEUS, AT THE CENTRE OF THE ATOM.**
  - **THE NUCLEUS IS POSITIVELY CHARGED BECAUSE IT REPELS POSITIVELY CHARGED ALPHA-PARTICLES THAT APPROACH IT TOO CLOSELY.**

- The diagram shows the paths of some α-particles as they pass through the gold foil.



The electrostatic repulsion force between an α-particle and a nucleus is given by :

$$\boxed{F = Q_\alpha Q_N / 4\pi\varepsilon_0 r^2}$$

The **closer** an α-particle is moving to the nucleus (i.e. the **smaller r** is), the **larger F** is and so the **greater** the deflection will be.

Very few α-particles were scattered through large angles, so close approaches to the nuclei are rare and this indicates that :

- **THE NUCLEUS OCCUPIES ONLY A SMALL PROPORTION OF THE VOLUME OF THE ATOM.**

  (The nuclear radius is of the order of **10^{-15} m** and the radius of the atom is of the order of **10^{-10} m**).

PRACTICAL POINTS TO NOTE ABOUT THE ALPHA-SCATTERING EXPERIMENT

- **The a-particles all had the same energy**, otherwise slow a's would be deflected more than faster ones on the same initial path.
- **The apparatus was evacuated**, otherwise the a's would only travel 5 to 10 cm before being stopped by collisions with air molecules.
- **The a-particle source used had to have along half-life**, otherwise later readings would be lower than earlier ones due to radioactive decay.
- **The metal foil had to be very thin,** so as to minimise the chance that the a's might suffer more than one deflection.

PRACTICE QUESTIONS (1)

1 (a) In the Rutherford a-particle scattering experiment, most of the a-particles **passed straight through the metal foil without suffering any deflection.** What did Rutherford deduce about the atom from this observation ?

(b) A small fraction of the a-particles were **deflected through large angles.** What did Rutherford deduce about the atom from this observation ?

2 In Rutherford's a-particle scattering experiment, why was it essential that :

(a) The apparatus was in an **evacuated** chamber ?

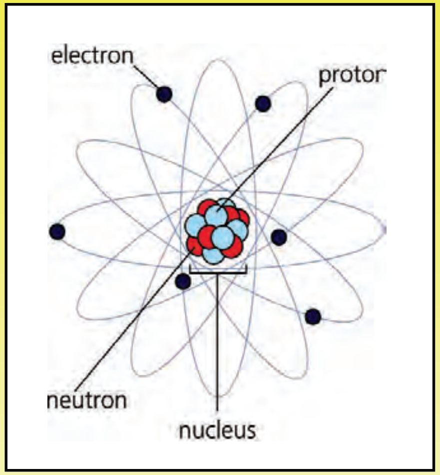
(b) The metal foil used was **very thin** ?

(c) The a-particles in the beam all had the **same energy** (and so the **same speed**) ?

(d) The a-particle beam was **collimated (i.e. narrow)** ?

THE STRUCTURE OF THE ATOM

- In the **NUCLEAR** model, the atom is envisaged as a central, positively-charged nucleus containing protons and neutrons with the negatively-charged electrons moving in circular orbits around the nucleus.



- The protons and neutrons are referred to as **NUCLEONS** because they are located in the nucleus.
- The properties of each of the particles found in the atom are shown in the table below :

PARTICLE	LOCATION	CHARGE	MASS/kg	MASS/u *
ELECTRON	Orbiting the nucleus	-1.6×10^{-19} C	9.11×10^{-31}	0.00055
PROTON	inside the nucleus	$+1.6 \times 10^{-19}$ C	1.673×10^{-27}	1.00728
NEUTRON	inside the nucleus	zero	1.675×10^{-27}	1.00867

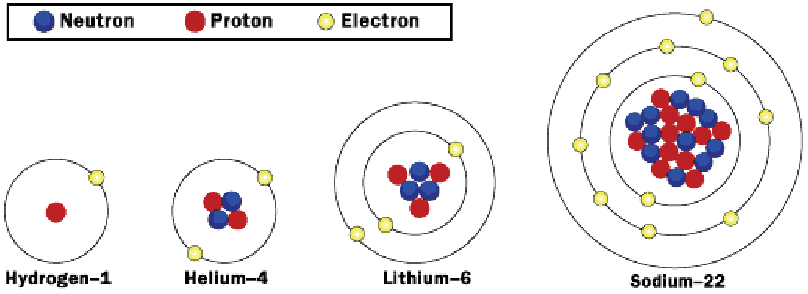
- Since the masses of these sub-atomic particles are so small, a very small unit, called the **ATOMIC MASS UNIT (u)** is used to measure them.

$$1 \text{ u} = 1.6605 \times 10^{-27} \text{ kg}$$

- **proton mass ≈ neutron mass = 1 u**

  electron mass ≈ 1/1800 u

- The diagrams below show some examples of atoms.



SUMMARY OF ORDERS OF MAGNITUDE

proton radius ≈ neutron radius	≈ 10^{-15} **m**
radius of nucleus	≈ 10^{-15} **m to** 10^{-14} **m.**
radius of atom	≈ 10^{-10} **m**
radius of molecule	≈ 10^{-10} **m to** 10^{-6} **m**

NUCLEAR TERMINOLOGY AND NOTATION

- Different atoms have nuclei which are distinguished by the different numbers of protons and neutrons they contain. The following terms are used to describe these differences.

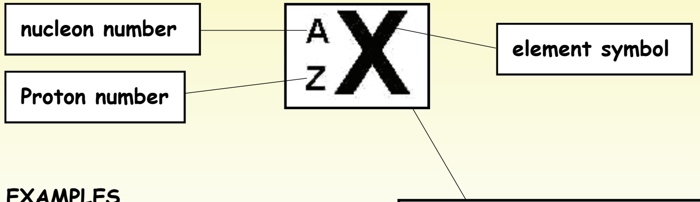
The PROTON (or ATOMIC) NUMBER (Z) is the number of **protons** contained in the nucleus of an atom.

The number of protons defines the element and dictates nearly all of its properties.

The NUCLEON (or MASS) NUMBER (A) is the total number of **Nucleons (i.e. protons + neutrons)** in the nucleus of an atom.

To obtain the number of neutrons in an atom, we simply **subtract the PROTON NUMBER (Z) from the NUCLEON NUMBER (A).**

- The standard notation for representing **nuclides** is as follows :



Each type of nucleus is referred To as a **NUCLIDE** and is characterised by its **proton number (Z)** and its **nucleon number (A).**

EXAMPLES

- HYDROGEN (1p + 0n) $^{1}_{1}\mathrm{H}$
- LITHIUM (3p + 4n) $^{7}_{3}\mathrm{Li}$
- CARBON (6p + 6n) $^{12}_{6}\mathrm{C}$
- CALCIUM (20p + 20n) $^{40}_{20}\mathrm{Ca}$

ISOTOPES

ISOTOPES are atoms of the **same element** having the **same proton number (Z)**, but a **different nucleon number (A)**.

The nuclei of the **ISOTOPES** of an element contain the **same number of protons but a different number of neutrons**.

- Because **ISOTOPES** have the **same number of protons**, they have the **same electron arrangement** and therefore, the **same chemical properties**, but they have **different physical properties** because their **atomic mass differs**.

- **EXAMPLES**

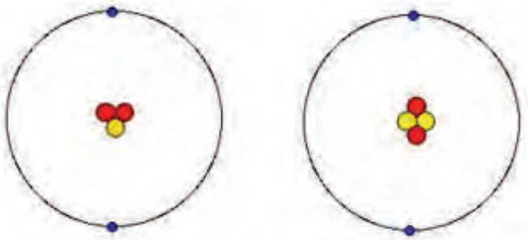
  - **HYDROGEN**

PROTIUM $^{1}_{1}H$ Has 1p, 1e, 0n

DEUTERIUM $^{2}_{1}H$ Has 1p, 1e, 1n

TRITIUM $^{3}_{1}H$ Has 1p, 1e, 2n

HELIUM



$^{3}_{2}He$ has 2p, 2e, 1n

$^{4}_{2}He$ has 2p, 2e, 1n

- All the elements have more than one isotope. Although there are only around **90** naturally-occurring elements, the number of known isotopes is about **1500**. Only about **300** occur in nature, and some of these are radioactive. The rest are man-made, and are all radioactive.

PRACTICE QUESTIONS (2)

1 A nucleus of strontium has a nucleon number of **90** and a proton number of **38**. Describe the structure of the strontium nucleus.

2 An element has several **isotopes**.

(a) In what way are the nuclei of these isotopes **the same** and how do they **differ** ?

(b) Explain why isotopes are **chemically identical**, but **physically different**.

3 State the number of **neutrons**, **protons** and **electrons** present in a neutral atom of each of the nuclides shown below :

$^{226}_{88}Ra$ $^{235}_{92}U$ $^{7}_{3}Li$ $^{63}_{29}Cu$ $^{137}_{55}Cs$

NUCLEAR REACTIONS AND EQUATIONS

- A nuclear reaction occurs when a nucleus changes its composition or releases energy. This can occur when :
  - An unstable nucleus emits an α, β or γ-radiation **(Radioactive decay)**.
  - A large nucleus splits into two smaller nuclei **(Fission)**.
  - A nucleus fuses with another nucleus **(Fusion)**.
  - A nucleus is struck by another particle **(Bombardment)**.

- When dealing with nuclear reactions, the following **conservation laws** apply :

CONSERVATION OF MASS/ENERGY

This means that the **number of protons** and the **number of neutrons** is **the same** on both sides of a nuclear reaction equation (i.e. **A** and **Z** are balanced across the equation).

*The exceptions to this are **beta-decay** (in which a β^--particle is emitted when a neutron in the nucleus changes into a proton) and **high-energy collisions**.*

CONSERVATION OF MOMENTUM

CONSERVATION OF ELECTRIC CHARGE

This means that the **total charge** of all the **nuclei** and **particles** is **the same** on each side of a nuclear reaction equation.

RADIOACTIVE DECAY

1. ALPHA (α)-DECAY

When an unstable nucleus decays by emitting an **α-particle** (i.e. a helium nucleus), it loses **2 protons + 2 neutrons** and so it's **A decreases by 4** and its **Z decreases by 2**.

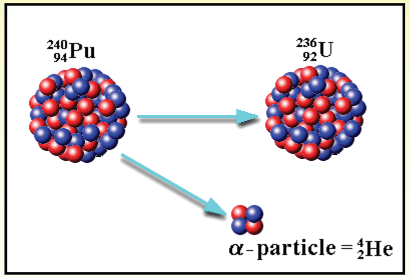
The nuclear equation which describes the decay of a parent nuclide into a daughter nuclide by **α-particle** emission is :

$$\underset{\text{parent nuclide}}{{}^{A}_{Z}X} \longrightarrow \underset{\text{daughter nuclide}}{{}^{A-4}_{Z-2}Y} + \underset{\alpha\text{-particle}}{{}^{4}_{2}He} + \underset{\text{appears as k.e. of daughter and }\alpha\text{-particle}}{(ENERGY)}$$

- **A** and **Z** are balanced across the equation (i.e. there is **mass** and **charge** conservation).

- **Plutonium-**240 is a typical α-emitter which decays to **uranium-236**.

  Write down the equation for this α-decay and check to see if there is mass and charge conservation.



EQUATION :

A-number :
Z-number :

BETA MINUS (β^-)-DECAY

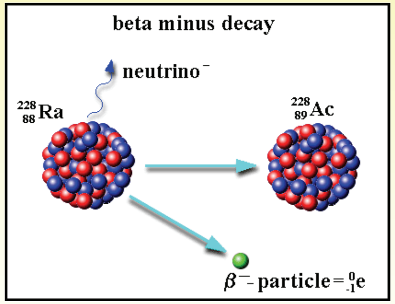
When an unstable atom decays by emitting a **β^--particle** (i.e. a high-speed electron) what happens is that one of the **neutrons** in the nucleus changes into a **proton** (which stays in the nucleus) plus an **electron** (which is emitted as a **β^--particle**) plus another particle, called an **antineutrino.**

The nuclear equation which describes the decay of a parent nuclide into a daughter nuclide by **β^--particle** emission is :

$$\underbrace{{}^{A}_{Z}X}_{\text{parent nuclide}} \longrightarrow \underbrace{{}^{A}_{Z+1}Y}_{\text{daughter nuclide}} + \underbrace{{}^{0}_{-1}e}_{\beta^-\text{-particle}} + \underbrace{{}^{0}_{0}v}_{\text{antineutrino}} + \text{(ENERGY)}$$

- **A** and **Z** are balanced across the equation (i.e. there is **mass** and **charge** conservation).
- **Radium-228** is a typical β-emitter which decays to **actinium-228.**

  Write down the equation for this β-decay and check to see if there is mass and charge conservation.



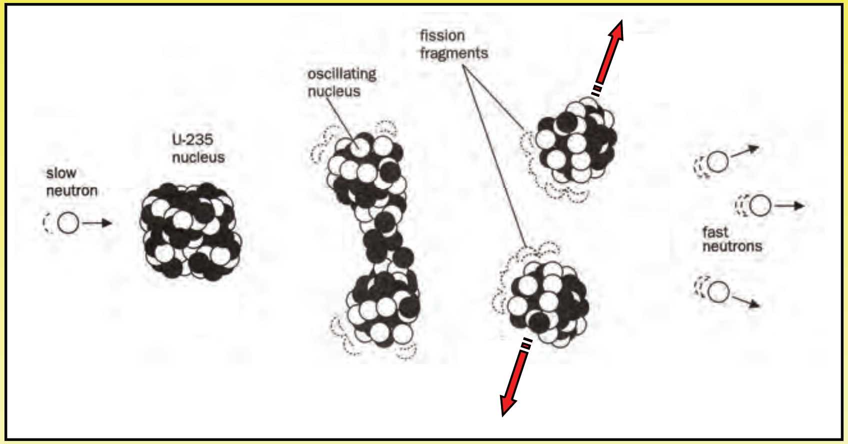
EQUATION :

A-number :

Z-number :

NUCLEAR FISSION

- Massive, unstable nuclei, such as those of uranium-235, can split apart into two more stable nuclei.



- Fission occurs when a slow-moving neutron collides with a **U-235** nucleus. The neutron is **absorbed** and this produces a very unstable nucleus **(U-236),** which splits into two smaller, more stable nuclei. Several neutrons are also released and these may go on to cause further fissions. Energy is released from each fission event.
- Write down the equation for this **fission** reaction and check to see if there is **mass** and **charge** conservation.

EQUATION :

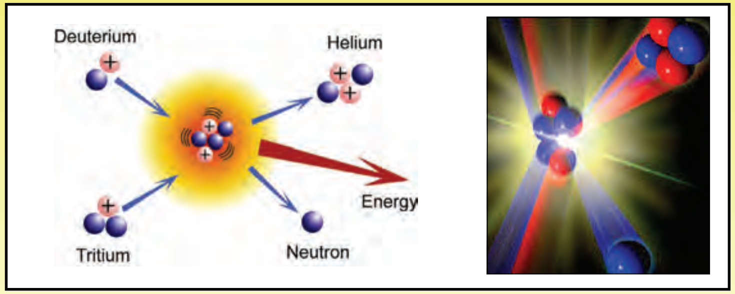
A-number :

Z-number :

NUCLEAR FUSION

- Nuclear fusion takes place when two light nuclei combine to form a larger, more stable nucleus.

  Nuclear fusion can only take place if the two nuclei that are to be combined collide at high speed, thus overcoming the electrostatic repulsion and coming close enough to interact through the strong nuclear force.



The diagram above shows a deuterium nucleus fusing with a tritium nucleus to form a helium nucleus and a neutron, with the release of energy.

- Write down the equation for this **fusion** reaction and check to see if there is **mass** and **charge** conservation.

EQUATION :

A-number :
Z-number :

1 Identify the missing numbers, **x** and **y**, in each of the following nuclear reactions :

(a) $^{4}_{2}\mathrm{He} + {}^{x}_{4}\mathrm{Be} \longrightarrow {}^{1}_{0}\mathrm{n} + {}^{12}_{y}\mathrm{C}$

(b) $^{6}_{3}\mathrm{Li} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{x}_{2}\mathrm{He} + {}^{3}_{y}\mathrm{H}$

2 You are given the following **proton numbers** :

Lead (Pb) = 82 **fluorine (F) = 9** **iron (Fe) = 26**

Write nuclear equations for the following decays :

(a) The emission of a **β⁻-particle** (electron) from **oxygen-19** $\boxed{^{19}_{8}\mathrm{O}}$

(b) The emission of an **α-particle** (helium nucleus) from **polonium-212** $\boxed{^{212}_{84}\mathrm{Po}}$

(c) The emission of a **β⁺-particle** (positron) from **cobalt-56** $\boxed{^{56}_{27}\mathrm{Co}}$

3 In one of the **nuclear fusion** reactions that occur in the Sun, the carbon isotope, **carbon-12** (containing **6 protons + 6 neutrons**) is formed from the fusion of a **proton** with a nucleus of the nitrogen isotope, **nitrogen-15** (containing **7 protons + 8 neutrons**).

Write a balanced equation for this nuclear reaction and state the new element which is formed.

THE STRONG NUCLEAR FORCE (STRONG INTERACTION)

- With the exception of **HYDROGEN,** which only contains a single proton, all nuclei contain positively charged protons and uncharged neutrons.

  The protons **repel** each other with an **electrostatic force** which is **directly proportional to the product of their charges and inversely proportional to the square of their distance apart.**

  We know that matter stays together, nuclei do not blow apart. So there must be an attraction force between nucleons which balances the repulsion force. Could this be the gravitational attraction force which exists between all massive particles? We can find out if this is true by calculating the magnitudes of the **ELECTROSTATIC REPULSION FORCE (F_E)** and the **GRAVITATIONAL ATTRACTION FORCE (Fg)** between two protons at their typical separation distance in a nucleus.

  The two equations which we need to use are :

$$\underset{(N)}{F_E} = \frac{\overset{(C)}{Q_1}\overset{(C)}{Q_2}}{\underset{(F\ m^{-1})}{4\pi\varepsilon_o}\underset{(m)}{r^2}}$$

$$\underset{(N)}{F_g} = \frac{\overset{(N\ m^2\ kg^{-2})}{G}\ \overset{(kg)}{m_1}\ \overset{(kg)}{m_2}}{\underset{(m)}{r^2}}$$

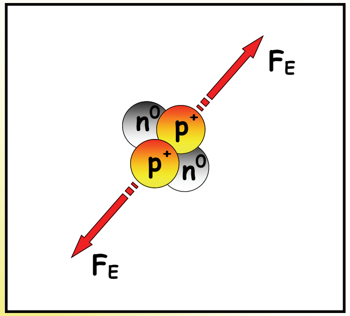
COULD THE GRAVITATIONAL FORCE BE HOLDING NUCLEI TOGETHER?

Consider the two protons in a helium nucleus. Using the data provided below, calculate :

(a) The **electrostatic repulsion force (F_E).**

(b) The **gravitational attraction force (F_g).**

which acts between the two protons which are 1.0×10^{-15} m apart.



- **Charge on proton, e** = **$+1.6 \times 10^{-19}$ C.**
- **Mass of proton, m_p** = **1.67×10^{-27} kg.**
- **$1/4\pi\varepsilon_o$** = **9.0×10^9 m F^{-1}**
- **G** = **6.67×10^{-11} N m ^{2} kg^{-2}.**

The calculation of the electrostatic repulsion and gravitational forces between two adjacent protons has shown that the gravitational force is far too small to be the force which holds nucleons together.

So there must be some other force which acts between nucleons to keep them together. This force is called the **STRONG NUCLEAR FORCE** or the **STRONG INTERACTION (F_S)** and has the following properties :

- It has a **VERY SHORT RANGE**

  It does not extend much beyond adjacent nucleons and so has no effect outside the nucleus (i.e. $F_S \approx 0$ at separations **(r)** > **about 5.0 x 10^{-15} m**).

- It is **INDEPENDENT OF CHARGE**

  So it acts between **ALL NUCLEONS** (i.e. proton-proton, proton-neutron and neutron-neutron).

- It is **ATTRACTIVE**

  Until the separation (r) becomes < **about 2.0 x 10^{-15} m.**

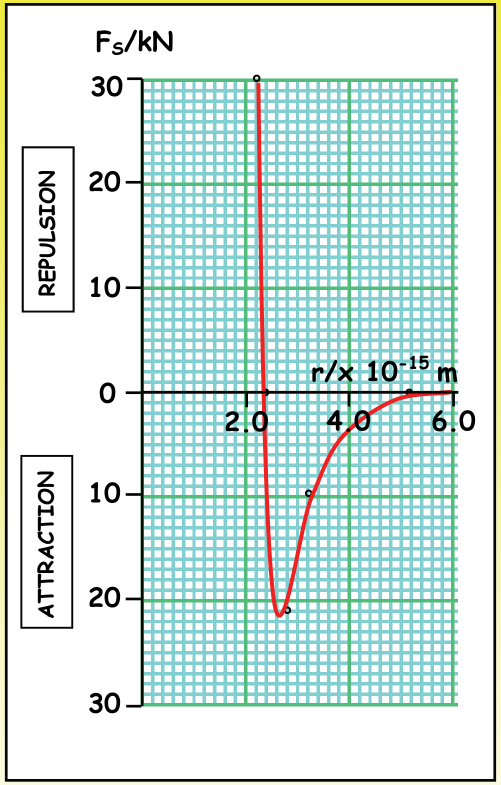
  And then it becomes increasingly **REPULSIVE**

  Otherwise the nucleons would collapse in on themselves.

The graph opposite shows how the **strong force (F_S)** varies with **nucleon separation (r).**

NOTE

- F_S is **REPULSIVE** for **r** less than **2.4 x 10^{-15} m.**
- F_S is **ATTRACTIVE** for **r** between **2.4 x 10^{-15} m** and **5.0 x 10^{-15} m.**
- F_S = **zero** for **r** greater than **5.0 x 10^{-15} m.**
- F_S can be as large as a few hundred times greater than the electrostatic force.



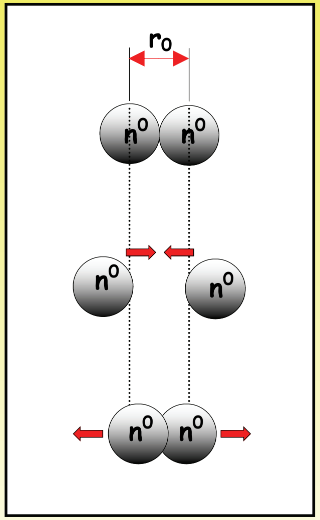
- With the exception of the hydrogen nucleus, which consists of a single proton, all other nuclei contain both protons and neutrons in order to be stable.
- The resultant force on any nucleon is the vector sum of the strong nuclear force and the repulsive electrostatic force. In the case of a neutron, which has no charge, it is simply the strong force.

The **EQUILIBRIUM SEPARATION (r_0)** is the distance between two nucleons at which the resultant force between them is **zero**, so that they are then in equilibrium.

- In the case of two adjacent neutrons, the resultant force is simply the strong force, since there is no electrostatic repulsion.

  If the neutrons are moved further apart than their equilibrium separation **(r_0)**, there is a large attraction force which pulls them back together.

  If the neutrons are moved closer than **r_0**, a large repulsive force will push them back to their equilibrium separation.



- In the case of two adjacent protons, the resultant force is the vector sum of the strong nuclear force attraction and the electrostatic repulsion.

  Since the strong nuclear force is very much greater than the electrostatic repulsion force, it dominates and this means that the equilibrium separation of the protons is virtually the same as that for a neutron-neutron pair.

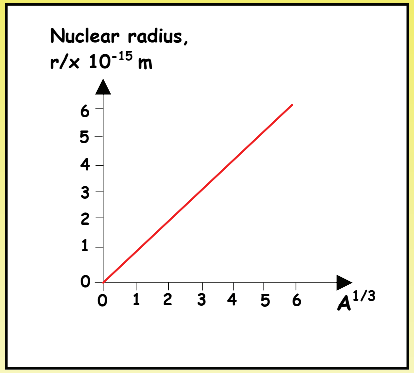
NUCLEAR DENSITY

- Analysis of experimentally obtained data shows that the **radii (r)** of nuclei is related to their **nucleon number (A)** by the following equation :

$$\boxed{r = r_0 A^{1/3}}$$

Where **r_0 is the radius of a single nucleon.**
So the radius of a nucleus is directly proportional to the **cube root of the number of nucleons** contained in the nucleus.

Thus plotting a graph of **r** against **$A^{1/3}$** for a number of different nuclei yields a straight line through the origin as shown opposite.



- The **density (ρ)** of a nucleus may be calculated by assuming it to be a sphere, **radius (r)**, **mass (M)**, consisting of **(A) nucleons** each of **mass (m)**.

Mass = volume x density

$$M = 4/3\ \pi r^3 \times \rho \qquad \text{(but } r = r_0A^{1/3} \text{ and } M = Am\text{)}$$

$$Am = 4/3\ \pi r_0^{\ 3} A \times \rho$$

From which :

(kg m^{-3}) (kg)

$$\rho = \frac{3m}{4\pi r_0^{\ 3}}$$

(m)

- The equation on page 11 shows that the density of a nucleus does not depend on the number of nucleons it contains, so **all nuclei have the same density.**

NUCLEAR DENSITY CALCULATION

Given that :

- Nucleon radius **(r_0)** = **1.2×10^{-15} m** and
- Nucleon mass **(m)** = **1.67×10^{-27} kg.**

Nuclear density (ρ) is given by :

$$\rho = \frac{3 \times 1.67 \times 10^{-27}}{4 \times \pi \times (1.2 \times 10^{-15})^3} = \boxed{1.8 \times 10^{17}\ \text{kg m}^{-3}}$$

This is around 10 million million times the density of the densest metal. Such a high figure is accounted for by the fact that atoms are almost entirely empty space.

In a uranium atom, about **99.8%** of the mass is contained in the nucleus, which occupies the tiniest proportion of the volume of the atom, the rest being **empty space,** sparsely populated by **92** electrons.

If all the matter which constitutes planet Earth **(6.0×10^{24} kg)** were compressed into a cube of nuclear matter (i.e. if all the atoms were stripped of their electrons), its sides would only be **300 m** long!

PRACTICE QUESTIONS (4)

1 Calculate the **mass, radius, volume and density** of :

(a) A **carbon-12** nucleus containing 6 protons and 6 neutrons.

(b) A **uranium-238** nucleus containing 92 protons and 146 neutrons.

Given that :

- Both nuclei are **spherical.**
- The radius of a nucleon (p or n), **(r_0)** = **1.2×10^{-15} m.**
- The mass of a nucleon (p or n), **(m)** = **1.67×10^{-27} kg.**

HOMEWORK QUESTIONS

1 **(a)** Using diagrams to illustrate your answer, describe **Rutherford's alpha-particle scattering experiment.**

(b) What were the **results** obtained from this experiment?

(c) What did these results indicate about the **existence, charge and size of the atomic nucleus.**

2 **(a)** Using a diagram to illustrate your answer, describe the basic **structure of the nuclear atom.**

(b) What are the relative sizes of the **atom** and the **nucleus?**

(c) Define **nucleon number (A)** and **proton number (Z).**

(d) Explain what is meant by the term **isotope,** giving an example to illustrate your answer. Why are the isotopes of the atoms of a given element **chemically identical?**

3 With the exception of hydrogen, all other nuclei contain more than one proton and since these are **positively charged**, they **repel** each other. So, there has to be an **attractive force** between nucleons in order for matter to hold together.

(a) Explain why the **gravitational force** cannot be the attractive force which holds nucleons together.

(b) Using a **strong nuclear force** against **nucleon separation** graph, state the **properties** of the strong nuclear force.

(c) (i) What is meant by **equilibrium separation (r_0)** for nucleons in a nucleus?

(ii) Explain what happens when nucleons are pushed **further apart** or **closer together** than r_0.

4 This question is about nuclear density.

(a) Fig 1. shows the relationship between the **cube of the radius (r)** of atomic nuclei and **nucleon number (A).**

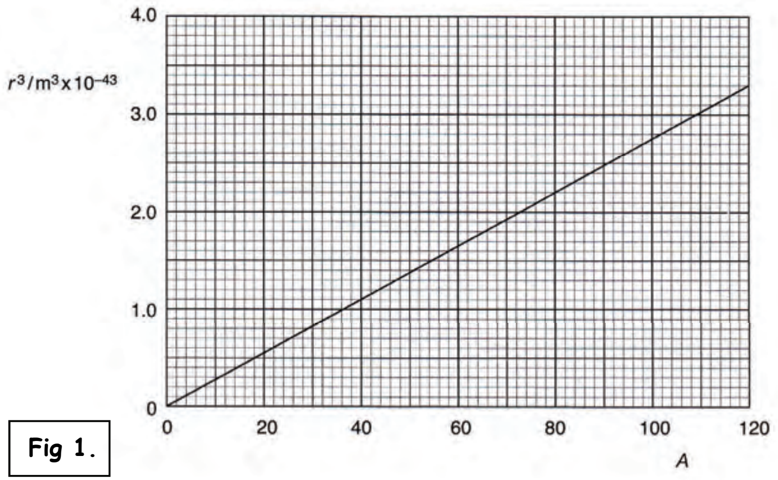


Fig 1.

(i) Deduce the **gradient** of this graph.

(ii) Use your answer to **(i)** to calculate the **radius r_0** of a single nucleon.

(b) Calculate the **density** of a carbon-12 nucleus $\boxed{^{12}_{6}C}$

(c) Diamond is formed from carbon-12 atoms. The density of diamond is **3530 kg m^{-3}**.

(i) Calculate the ratio : $\dfrac{\textbf{density of a carbon-12 nucleus}}{\textbf{density of diamond}}$

(ii) Explain why this ratio is so large.

(OCR A2 Physics - Module 2825/04 - June 2007)

5 The radius **(r)** of a nucleus is related to the nucleon number (A) of the nucleus by the equation : $\boxed{r = r_0 A^{1/3}}$

(a) Fig 2. shows this relationship as a graph.

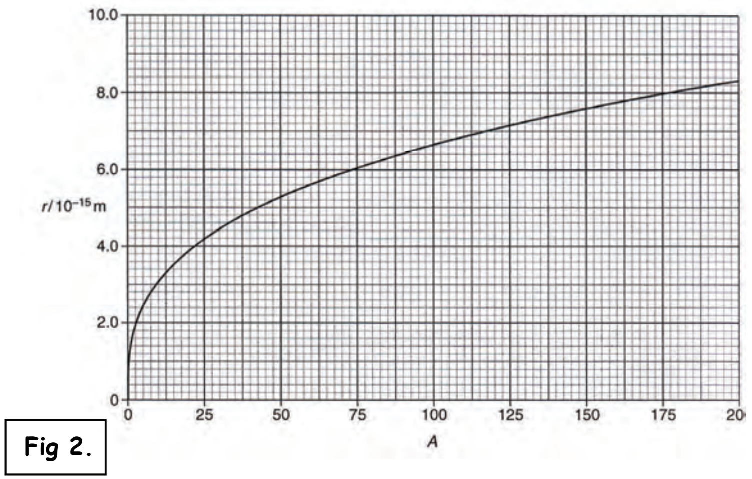


Fig 2.

Use information from **Fig 2.** to calculate the value of r_0.

(b) **(i)** Show that the radius of a **uranium-235** $^{235}_{92}U$ nucleus is about **9×10^{-15} m**.

(ii) Show that the mass of a **uranium-235** nucleus is about **4×10^{-25} kg**. Assume that proton mass = neutron mass = **1.67×10^{-27} kg**.

(iii) Calculate the density of a **uranium-235** nucleus.

(iv) A **uranium-235** nucleus can absorb a neutron and undergo fission. The products of a particular fission reaction are **selenium-83** and a **cerium** nuclide. A **single neutron** is emitted during this fission.

$^{83}_{34}Se$ $\qquad$ $^{X}_{Y}Ce$

State the values of **X** and **Y**.

(v) Calculate the ratio : $\dfrac{\textbf{radius of cerium nucleus}}{\textbf{radius of selenium nucleus}}$

(vi) Explain in words why both the **selenium** and the **cerium** nuclei have the same density as the **uranium-235** nucleus.

(OCR A2 Physics - Module 2825/04 - January 2009)

6 Two adjacent protons, situated inside a certain nucleus, are acted upon by three forces. These are **electrostatic, gravitational** and **strong interaction (i.e. strong force).**

(a) State whether each of these is **attractive** or **repulsive**.

(b) The average separation of the nucleons is **0.80×10^{-15} m**. Calculate, giving an appropriate unit in each case, the magnitude of :

(i) The **electrostatic force**.

(ii) The **gravitational force**.

(c) Use your answers to **(b)** to comment on the relative importance of **electrostatic** and **gravitational** forces inside the nucleus.

(d) Fig 3. shows the variation with nucleon-nucleon separation of the strong interaction between two nucleons.

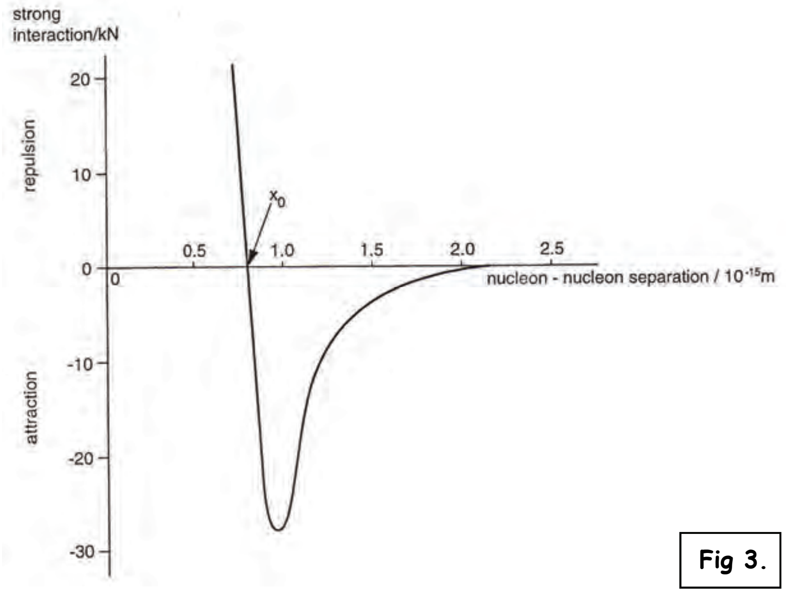


Fig 3.

When both nucleons are **neutrons,** the equilibrium separation is **x_0**. Explain whether the equilibrium separation between two **protons** will be **greater, less than** or **equal to x_0**.

(OCR A2 Physics - Module 2825/04 - June 2004)