TOPIC 28 Nuclear Physics

1 The number of nucleons in the nucleus of the atom $^{35}_{17}Cl$ is

A 17
B 18
C 35
D 52
E 53

J76/II/34

2 In a nuclear reaction, energy equivalent to 10^{-11} kg of matter is released. The energy released is approximately

A 4.5×10^{-6} J
B 9.0×10^{-6} J
C 3.0×10^{-3} J
D 4.5×10^{5} J
E 9.0×10^{5} J

J76/II/35

3 The binding energy per nucleon may be used as a measure of the stability of a nucleus. This quantity

A is directly proportional to the neutron/proton ratio of the nuclide.
B is a maximum for nuclides in the middle of the Periodic Table.
C increases uniformly throughout the Periodic Table.
D has maxima at values of atomic number corresponding to the noble (inert) gases.
E falls to zero for heavy radioactive nuclides. N78/II/37

4 The deviation of α-particles by thin metal foils through angles that range from 0° to 180° can be explained by

A scattering from free electrons.
B scattering from bound electrons.
C diffuse reflection from the metal surface.
D scattering from small but heavy regions of positive charge.
E diffraction from the crystal lattice. J79/II/33

5 When $^{238}_{92}U$ is bombarded with slow neutrons it is transformed, absorbing a single neutron and subsequently emitting two β-particles. The resulting nuclide is

A $^{240}_{93}Np$
B $^{240}_{91}Pa$
C $^{239}_{94}Pu$
D $^{239}_{90}Th$
E $^{235}_{88}Ra$

J79/II/34

6 The decay of $^{238}_{92}U$ to $^{239}_{93}Np$ by β-emission is not possible because

A β-decay only occurs in isotopes of low mass.
B $^{239}_{93}Np$ is not a stable isotope.
C mass number cannot increase in a decay process.
D atomic number cannot increase in a decay process.
E mass number and atomic number must both decrease in a decay process. J80/II/34

7 The isotope $^{226}_{88}Ra$ decays into $^{222}_{86}Rn$ with the emission of an α-particle and a γ-ray photon of frequency v.

The principle of conservation of energy is expressed in this decay the equation

A $88 = 86 + 2$
B $226 = 222 + 4$
C $[m_{Ra} - m_{Rn}]\, c^2 = hv$
D $\frac{1}{2} m_{Rn} u_{Rn}^2 = hv + \frac{1}{2} m_\alpha u_\alpha^2$
E $[m_{Ra} - (m_{Rn} + m_\alpha)]c^2 = hv + \frac{1}{2} m_\alpha u_\alpha^2 + \frac{1}{2} m_{Rn} u_{Rn}^2$

[Where appropriate, m represents the mass of a particle, u the speed of a particle and c the speed of electromagnetic radiation.] N80/II/39

8 The passage of γ-ray photons through materials sometimes results in pair production, i.e. the transformation of a γ-ray photon into a positron and an electron (each of mass m). What is the maximum wavelength of γ-ray photons for which pair production is possible?

A $\frac{1}{2\,mch}$
B $\frac{1}{2\,mc^2 h}$
C $\frac{h}{2\,mc}$
D $\frac{h}{2\,mc^2}$
E $\frac{h}{2\,mc^3}$

(c = the speed of light; h = the Planck constant) J82/II/37

9 The fission of a heavy nucleus gives, in general, two smaller nuclei, two or three neutrons, some β-particles and some γ-radiation. It is always true that the nuclei produced

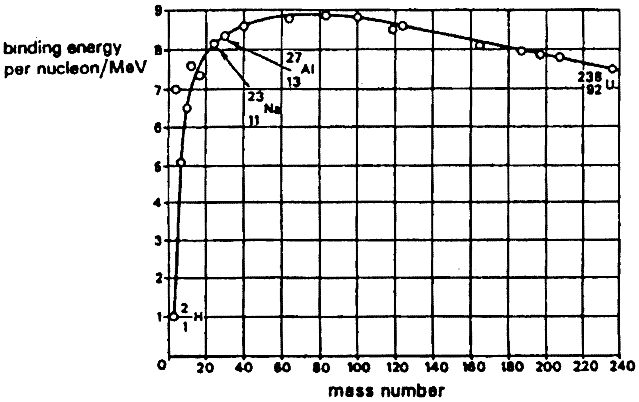
A have a total rest-mass that is greater than that of the original nucleus.
B have large kinetic energies that carry off the greater part of the energy released.
C travel in exactly opposite directions.
D have neutron-to-proton ratios that are too low for stability.
E have identical neutron-to-proton ratios. N82/II/35

10 The rest mass of the deuteron, $^{2}_{1}H$, is equivalent to an energy of 1876 MeV; the rest mass of a proton is equivalent to 939 MeV and that of a neutron to 940 MeV.

A deuteron may disintegrate to a proton and a neutron if it

A emits a γ-ray photon of energy 2 MeV.
B captures a γ-ray photon of energy 2 MeV.
C emits a γ-ray photon of energy 3 MeV.
D captures a γ-ray photon of energy 3 MeV.
E emits a γ-ray photon of energy 4 MeV. J83/II/37

11 The diagram shows a graph of the binding energy per nucleon for a number of naturally-occurring nuclides plotted against their mass number.



Which of the following statements is a correct deduction from the graph?

A Of the nuclides plotted, $^{2}_{1}$H is the most stable.

B Energy will be released if a nucleus with a mass number greater than about 80 undergoes fusion with any other nucleus.

C Energy will be released if a nucleus with a mass number less than about 80 undergoes fission as a result of particle bombardment.

D $^{27}_{13}Al$ will not spontaneously emit an alpha particle to become $^{23}_{11}$Na.

E $^{238}_{92}$U is the stable end-point of a number of radioactive series. J89/I/27

12 A stationary ^{238}U nucleus decays by α emission generating a total kinetic energy T.

$$^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + ^{4}_{2}\alpha$$

What is the kinetic energy of the α particle?

A slightly less than $T/2$
B $T/2$
C slightly less than T
D T
E slightly greater than T

N90/I/6

13 Helium nuclei may result from the bombardment of lithium nuclei with protons. The reaction can be represented by the following nuclear equation:

$$^{7}_{3}\text{Li} + ^{1}_{1}\text{p} \rightarrow 2[^{4}_{2}\text{He}] + \text{energy}$$

The speed of light is c, and the masses of the particles are:

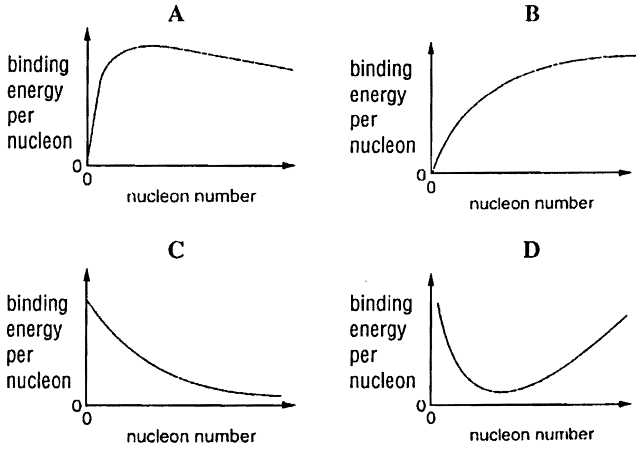
lithium m_L
helium m_H
proton m_P.

What is the net energy released during such a reaction?

A $[2m_H - (m_L + m_p)]\,c^2$
B $[(m_L + m_p) - 2m_H]\,c^2$
C $(2m_H + m_L + m_p)\,c^2$
D $\dfrac{(m_L + m_p) - 2m_H}{c^2}$
E $\dfrac{2m_H - (m_L + m_p)}{c^2}$

J93/I/29

14 Which sketch graph best represents the variation with nucleon number of binding energy per nucleon?



J94/I/29; J99/I/29

15 When the nucleus of an atom absorbs one of the atom's orbital electrons, the process is known as k-capture.

Which equation (in which X denotes the appropriate particle) represents this process?

A $^{55}_{26}\text{Fe} + ^{0}_{-1}\text{X} \rightarrow ^{55}_{25}\text{Mn}$

B $^{63}_{28}\text{Ni} \rightarrow ^{0}_{-1}\text{X} + ^{63}_{29}\text{Cu}$

C $^{10}_{5}\text{B} + ^{1}_{0}\text{X} \rightarrow ^{7}_{3}\text{Li} + ^{4}_{2}\text{He}$

D $^{7}_{3}\text{Li} + ^{1}_{1}\text{X} \rightarrow ^{8}_{4}\text{Be}$

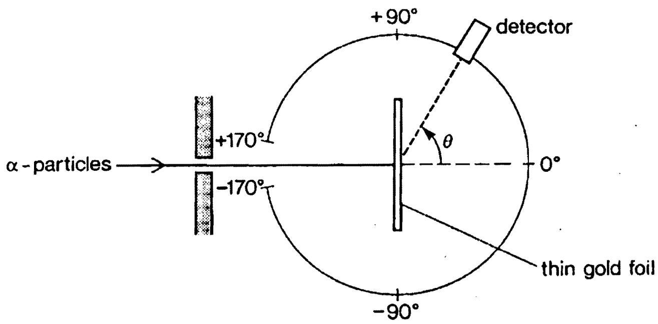
N94/I/29

16 Which statement correctly describes a nucleon?

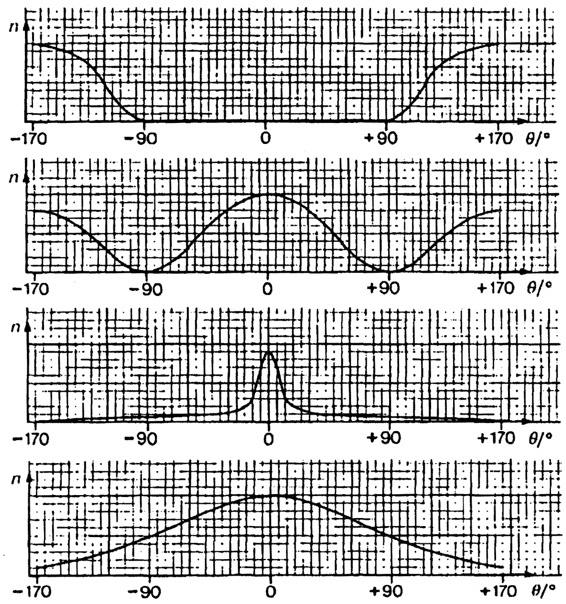
A a neutron or a proton
B a neutron, proton or an electron
C any atomic nucleus
D a radioactive atomic nucleus

J95/I/29

17 In repeating Rutherford's α-particle scattering experiment, a student used the apparatus shown, in a vacuum, to determine n the number of α-particles incident per unit time on a detector held at various angular positions θ.



Which graph best represents the variation of n with θ?



N95/I/28

18 One reaction which might be used for controlled nuclear fusion is shown.

$$^{7}_{3}Li + ^{2}_{1}H \rightarrow 2\,(^{4}_{2}He) + \mathbf{X}$$

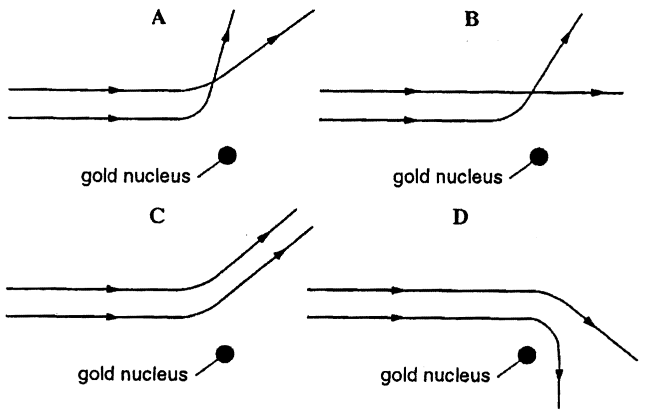
What is particle **X**?

A an α-particle
B an electron
C a neutron
D a proton

N95/I/30

19 Two α-particles with equal energies are fired towards the nucleus of a gold atom.

Which diagram could represent their paths?



N96/I/29; N2000/I/29

20 A nucleus has a nucleon number A, a proton number Z, and a binding energy B. The masses of the neutron and proton are m_n and m_p, respectively, and c is the speed of light.

The mass of the nucleus is given by the expression

A $(A - Z)m_n + Zm_p - B / c^2$
B $(A + Z)m_n + Zm_p + B / c^2$
C $Am_n + Zm_p - B / c^2$
D $Am_n + Zm_p + B / c^2$

N96/I/30

21 A high energy α–particle collides with a $^{14}_{7}N$ nucleus to produce a $^{17}_{8}O$ nucleus.

What could be the other products of this collision?

A a γ–photon alone
B a γ–photon and a β-particle
C a γ–photon and a neutron
D a γ–photon and a proton

J97/I/29

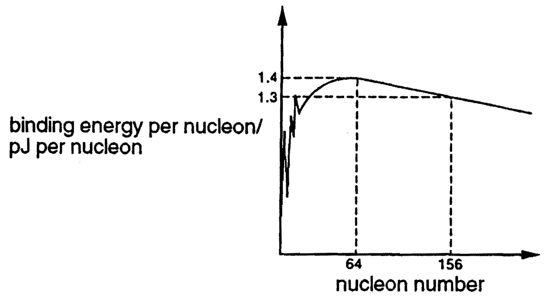
22 In an experiment to investigate the nature of the atom, a very thin gold film was bombarded with α-particles.

What pattern of deflection of the α-particles was observed?

A A few α-particles were deflected through angles greater than a right angle.
B All α-particles were deflected from their original path.
C Most α-particles were deflected through angles greater than a right angle.
D No α-particle was deflected through an angle greater than a right angle.

N97/I/29

23 The sketch graph shows how the binding energy per nucleon varies with the nucleon number for naturally occurring nuclides.



What is the total binding energy of the nuclide $^{156}_{64}Gd$?

A 83 pJ
B 90 pJ
C 203 pJ
D 218 pJ

J98/I/29

24 The nucleus of the nuclide $^{A}_{Z}X$ has mass M.

In terms of the rest mass of the proton m_p and the rest mass of the neutron m_n, what is the binding energy per nucleon of this nucleus?

A $\left(\frac{Am_p + Zm_n - M}{Z}\right)c^2$

B $\left(\frac{M - Zm_p - Am_p}{A}\right)c^2$

C $\left(\frac{M - Zm_p - (A - Z)m_n}{Z}\right)c^2$

D $\left(\frac{Zm_p + (A - Z)\,m_n - M}{A}\right)c^2$

N98/I/29

25 Two deuterium nuclei fuse together to form a Helium-3 nucleus, with the release of a neutron. The reaction is represented by

$$^{2}_{1}H + ^{2}_{1}He \rightarrow ^{3}_{2}He + ^{1}_{0}n + \text{energy}.$$

The binding energies **per nucleon** are:

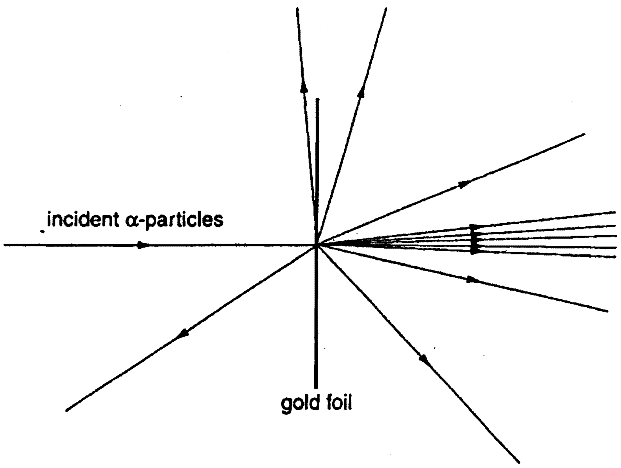
for $^{2}_{1}H$ 1.09 MeV,

for $^{3}_{2}He$ 2.54 MeV.

How much energy is released in this reaction?

A 0.36 MeV **C** 3.26 MeV
B 1.45 MeV **D** 5.44 MeV N99/I/29

26 A thin gold foil is bombarded with α-particles as shown.



The results of this experiment provide information about the

A binding energy of a gold nucleus.
B energy levels of electrons in gold atoms.
C size of a gold nucleus.
D structure of a gold nucleus. J2000/I/29

27 Find the mass equivalent to 934 MeV of energy.

[Electron charge = -1.6×10^{-19} C; speed of light = 3.0×10^{8} m s^{-1}.]
N76/I/9

28 The relative atomic masses, A_r, of a number of nuclides are listed below:

nuclide	A_r
$^{4}_{2}He$	4.0026
$^{23}_{11}Na$	22.9898
$^{27}_{13}Al$	26.9815

Discuss whether it is possible for $^{27}_{13}Al$ spontaneously to emit an alpha particle. J77/I/10

29 An electron and a positron (a particle of equal mass to an electron but with positive charge) may annihilate one another, producing two γ-ray photons of equal energy. What is the minimum energy of each of these photons?

[Mass of electron, $m_e = 9.1 \times 10^{-31}$ kg; speed of light, $c = 3.0 \times 10^{8}$ m s^{-1}.] J78/I/1

30 A stationary $^{214}_{84}Po$ nucleus spontaneously emits an alpha particle, forming a nuclide of lead (Pb). Write down the atomic number and mass number of this nuclide. Explain in general terms how energy is conserved during the process. J80/I/11

31 An approximate relationship between the radius R of a nucleus and its mass number A is

$$R/\text{m} \approx 1.2 \times 10^{-15} A^{1/3}.$$

Estimate *(a)* the number density of nucleons within a nucleus (i.e. the number of nucleons in unit volume of nuclear matter), *(b)* the density of a nucleus.

[Take the proton mass m_p and the neutron mass m_n as 1.7×10^{-27} kg.] J81/I/10

32 Find the mass of one joule. J81/I/12

33 A nitrogen nucleus $^{14}_{7}N$, bombarded with an alpha particle of a certain energy, transmutes to an oxygen nucleus $^{17}_{8}O$ and a proton.

(a) Write an equation for this nuclear reaction, showing the mass numbers and the atomic numbers of the particles involved.

(b) Find the minimum energy of the alpha particle to make this reaction occur.

[Mass $^{14}_{7}N = 2.32530 \times 10^{-26}$ kg; mass of $^{17}_{8}O = 2.82282 \times 10^{-26}$ kg; proton mass, $m_p = 0.16735 \times 10^{-26}$ kg; mass of alpha particle $= 0.66466 \times 10^{-26}$ kg.] N82/I/11

34 By definition, the mass of an atom of $^{12}_{6}C$ is exactly 12 m_u. Find the sum of the rest masses of the constituent electrons, protons and neutrons of a ^{12}C atom, expressing your answer in m_u. Why is your answer not exactly 12 m_u?

[Unified atomic mass constant, $m_u = 1.6606 \times 10^{-27}$ kg;
rest mass of electron, $m_e = 9 \times 10^{-31}$ kg;
rest mass of proton, $m_p = 1.6726 \times 10^{-27}$ kg;
rest mass of neutron, $m_n = 1.6750 \times 10^{-27}$ kg.]
J83/I/12

35 Deuterium is represented by the symbol $^{2}_{1}H$. What nucleons make up its nucleus? Use the data below to calculate the binding energy of the deuteron (the deuterium nucleus):

atomic masses: deuterium, 2.01410 m_u,
hydrogen, 1.00783 m_u;
rest mass of neutron, m_n: 1.00867 m_u. J84/I/12

36 The rest masses of the neutron, proton and electron are 1.0087 m_u, 1.0073 m_u and 0.0005 m_u respectively. Explain why it is energetically possible for a neutron spontaneously to emit a beta-particle. Using conventional symbols, write down an equation for this decay. J87/II/6

37 *(a)* Write down the numbers of electrons, protons and neutrons in a neutral atom of $^{12}_{6}C$.

(b) The masses of the electron, proton and neutron are 0.00055 m_u, 1.00728 m_u and 1.00867 m_u respectively. Find the sum of the masses of the constituents of the $^{12}_{6}C$ atom. (Give your answer in m_u.)

(c) By definition, the mass of the $^{12}_{6}C$ atom is 12 m_u exactly. Why is your answer to *(b)* not 12 m_u exactly?
[3] N87/II/5

38 A country at a particular time is using 40 000 MW of electrical power. Given that 1 kg of coal can produce 20 MJ of electrical energy, find

(a) the mass of coal burnt per second if all the electrical energy is produced by burning coal,

(b) the mass equivalence of the energy being supplied per second. [4] J88/II/7

39 The first nuclear reaction induced in a laboratory (performed by Rutherford in 1919) can be represented by:

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H.$$

(a) What information can be obtained from the symbol $^{17}_{8}O$?

(b) The total rest masses are as follows:

$$^{14}_{7}N + ^{4}_{2}He = 18.00568\ m_u,$$
$$^{17}_{8}O + ^{1}_{1}H = 18.00696\ m_u.$$

Use these values to explain how it is possible for the reaction to proceed. [4] N88/II/6

40 *(a)* Explain what is meant when two nuclides are said to be *isotopes*.

(b) (i) State the number of neutrons and the number of protons contained in a single nucleus of the nuclide $^{14}_{6}C$.

(ii) Write down the symbol for another possible isotope of carbon. [4] N89/II/6

41 *(a)* Fig. 1 represents a short part of the track of an α-particle as it approaches a stationary nucleus **N**. Complete the diagram to show the path of the α-particle as it passes by, and moves away from, N. [2]

Fig. 1

(b) Classic experiments on α-particle scattering were performed by Rutherford, Geiger and Marsden. State the experimental observation obtained from such experiments which suggested that

(i) the nucleus is small,

(ii) the nucleus is massive and charged. [2]

(c) One isotope of thallium (T*l*), atomic number 81, has nuclei of mass number 205.

(i) What is meant by the term *isotope*?

(ii) Write down the notation for the representation of this thallium nucleus.

(iii) For this thallium nucleus, write down

(1) the number of protons,

(2) the number of neutrons. [5]
N92/II/7

42 *(b)* The mass equivalence of the energy emitted per second by the Sun is 4.4×10^9 kg. Calculate

(i) the energy emitted in one day by the Sun,
N94/II/7 (part)

43 Uranium nuclei when bombarded by neutrons may undergo nuclear reactions. One such reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{56}Ba + ^{90}_{36}Kr +$$

(a) (i) Complete the equation for this nuclear reaction.

(ii) Name this type of nuclear reaction. [2]

(b) The binding energy per nucleon of Uranium-235 is approximately 7.5 MeV and that of Barium-144 and Krypton-90 is approximately 8.5 MeV.

(i) Estimate the energy change in this nuclear reaction.

energy change = ... MeV

(ii) Suggest two forms of energy into which the energy in (i) is transformed during a reaction of this type. [5]
J97/II/7

44 A collision takes place between an α-particle travelling at 3.0×10^7 m s^{-1} and a stationary nitrogen nucleus. It results in the following nuclear reaction.

$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

The masses of the nuclei involved are listed below.

$^{14}_{7}N$	13.9993 *u*
$^{4}_{2}He$ (α-particle)	4.0015 *u*
$^{17}_{8}O$	16.9947 *u*
$^{1}_{1}H$ (proton)	1.0073 *u*

The particles move in a straight line, as shown in Fig. 2. The speed of the proton after the collision is 6.0×10^7 m s^{-1}.

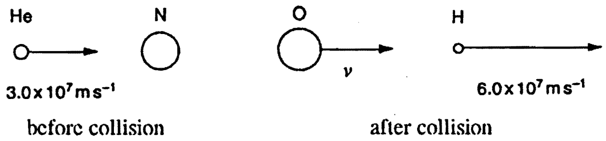


Fig. 2

(a) State the number and type of particles which form an α-particle. [2]

(b) Calculate the small change in mass, in kilograms, which takes place in this nuclear reaction.

change in mass = ... kg [3]

(c) Use your answer to *(b)* to calculate the minimum kinetic energy needed by the α-particle to cause the nuclear reaction.

kinetic energy = ... J [2]

(d) Use the principle of conservation of momentum to calculate *v*, the velocity of the oxygen nucleus after the collision.

v = ... m s^{-1}

in direction .... [4]

J98/II/7

Long Questions

45 Explain the terms *mass excess* and *nuclear binding energy.* [4]

Give a short account of how nuclear binding energies are measured in practice. [6]

In a proposed fusion reactor, one possible reaction is ${}^2_1H + {}^3_1H = {}^4_2He + {}^1_0n$. How much energy might 150 kg of the appropriate mixture of isotopes of hydrogen produce? For how long, to the nearest month, would this supply a city with an average demand of 1.5×10^9 W, if the process were 8.0% efficient? [8]

[Speed of light, $c = 3.0 \times 10^8$ m s^{-1}; 1 month = 2.6×10^6 s.

Nuclide	Relative atomic mass, A_r
^{2}H	2.014102
^{3}H	3.016050
^{4}He	4.002603
^{1}n	1.0086651]

N77/III/6

46 Yellow light from a small distant source enters a telescope and falls on a strip of blackened platinum placed in the focal plane of the objective lens. The resistance of the platinum changes. In order to produce the same change in resistance when the telescope is turned away from the source, a current of 2.0×10^{-3} A at a p.d. of 4.0×10^{-3} V must be passed through the strip. Calculate

(a) the number of photons from the source failing on the strip each second.

(b) the mass associated with these photons.

It is said that 'the Sun loses about four million tonnes a second'. Comment on this in the light of the principle of conservation of mass.

[Wavelength of yellow light = 5.9×10^{-7} m; speed of light = 3.0×10^8 ms^{-1}; the Planck constant = 6.6×10^{-34} J s.]

N79/III/1 (part)

47 What do you understand by

(a) relative atomic mass,

(b) isotopes of an element,

(c) nuclear binding energy?

Calculate the binding energy of the deuteron ${}^2_1H$, given the following data:

mass of proton = 1.672648×10^{-27} kg;
mass of neutron = 1.674954×10^{-27} kg,
mass of deuteron = 3.344275×10^{-27} kg;
speed of light = 2.997925×10^8 m s^{-1}.

Quote your answer to the level of accuracy justified by these values, explaining why you claim this precision.

Outline one method for measuring the mass of the proton and give an elementary mathematical treatment of the theory of the experiment. N81/III/6

48 Define *relative atomic mass* and explain the term *nuclear binding energy.*

Identify the numbers and symbols represented by the letters, q, r, s, t, u, and v in the nuclear equation

$${}^3_1q + {}^2_rH = {}^4_sHe + {}^t_vu + 17.5\text{ MeV}$$

Express 17.5 MeV in joules.

The product particles each have a greater mass than when at rest. Account for this and calculate the overall difference.

If 200 kg of mixed material (denoted by 'q' and H) were used each year to fuel a fusion power station with an overall conversion efficiency of 10%, estimate the electrical power output and the waste heat produced. J82/III/6

49 *(d)* A stationary radon nucleus may decay spontaneously into a polonium nucleus and an α-particle as shown below.

$${}^{222}_{86}Rn \longrightarrow {}^{218}_{84}Po + {}^4_2He$$

The rest masses of these nuclei are ^{222}Rn, 222.0176 u; ^{218}Po, 218.0090 u; ^{4}He, 4.0026 u, and it may be assumed that no γ-ray is emitted.

(i) Calculate the total kinetic energy of the decay products.

(ii) Explain how the principle of conservation of momentum applies to this decay and calculate the speed of the α-particle. [7]

N83/I/13 (part); N91/III/2 (part)

50 *(c)* Evidence for the existence of the nucleus came from observations of the way in which alpha-particles were scattered by thin metal foils.

(i) Give a labelled sketch of an apparatus suitable for studying this scattering.

(ii) What aspects of the results of such experiments indicated that atoms contains small, massive, positively-charged nuclei? N84/I/14 (part)

51 A $^{238}_{92}U$ nucleus, originally at rest, spontaneously decays to form a thorium (Th) nucleus and an alpha particle. A gamma ray is not emitted.

(a) Using conventional notation for mass numbers and atomic numbers, write down the equation which describes this disintegration.

(b) The alpha particle produced in this disintegration travelled 25 mm in a cloud chamber. Given that, on average, an alpha particle creates 5.0×10^3 ion pairs per mm of track in the cloud chamber and that the energy require to produce an ion pair is 5.2×10^{-18} J, find the kinetic energy with which the alpha particle was emitted.

(c) Hence deduce the initial velocities of the alpha particle and the thorium nucleus.

(d) Calculate the difference between the rest mass of the original uranium nucleus and the sum of the rest masses of the products of the disintegration.

J85/II/11 (part)

52 The conventional notation for a certain nuclide is $^{81}_{35}Br$.

(a) Write down (i) the number of protons, (ii) the number of neutrons, in its nucleus.

(b) The mass of the nucleus is 80.8971 m_u. Taking the proton and neutron masses to be 1.0073 m_u and 1.0087 m_u respectively, deduce the binding energy per nucleon.

(c) Sketch a labelled graph showing how the binding energy per nucleon varies with mass number, indicating the approximate position of $^{81}_{35}Br$ on the curve.

(d) Explain the implications for the stability of a given nuclide of a *low* value of the binding energy per nucleon.

Because the neutron is uncharged, its mass cannot be determined directly using a conventional mass spectrometer. Explain how a nuclear reaction such as

$$^1_1H + ^1_0n \rightarrow ^2_1H + \gamma$$

might be used to measure the neutron mass, provided that certain quantities are known or can be measured. What are these quantities? N85/II/11

53 Draw a labelled diagram of the type of apparatus used by Rutherford, Geiger and Marsden to investigate the scattering of alpha-particles by metal foils.

Describe how the distribution of scattered alpha-particles can be determined.

Describe qualitatively this distribution.

How was this distribution interpreted in terms of the nuclear model of the atom?

An alpha-particle travels from a great distance directly towards a gold ($^{197}_{79}Au$) nucleus, which can be assumed to remain stationary throughout the interaction. The alpha-particle returns along the same path without penetrating the nucleus. If x is the separation of the alpha-particle and the nucleus, draw on the same x-axis labelled graphs showing for the alpha-particle *(a)* the electrostatic potential energy V, *(b)* the kinetic energy T. Mark on the x-axis the distance x_0 of closest approach of the particles. State the relation between the two graphs.

When the alpha-particle is a great distance from the nucleus its kinetic energy is 8.0×10^{-13} J; find x_0. N86/II/12

54 Explain what is meant by the terms *nucleon, atomic number* and *mass number*.

Briefly describe an experiment which led to an appreciation of the size of the nucleus relative to that of the atom. Explain qualitatively how the results were interpreted.

Experiments indicate that the radius R of a nucleus (which is assumed to be spherical) is given by the approximate relation.

$$R/m \approx 1.2 \times 10^{-15} A^{1/3}$$

where A is the mass number of the nucleus.

(a) Use this relation to estimate the volume occupied by each nucleon in a nucleus.

(b) Hence show that the average distance between nucleons is about 2×10^{-15} m.

(c) Estimate the electrostatic repulsion between neighbouring protons in a nucleus. Comment on your answer. J87/II/12

55 *(a)* Outline an experiment which gives evidence for the existence and small size of the atomic nucleus. [4]

(b) An atom of magnesium consists of:

12 electrons each of mass 0.00055 u
12 protons each of mass 1.00728 u
13 neutrons each of mass 1.00866 u

(i) Which particles are in the nucleus and what is the nucleon number (mass number) of this nucleus?

(ii) Which number determines that the atom is an atom of magnesium rather than of any other element?

(iii) The mass of this magnesium atom is 24.98584 u. Calculate the total mass of the constituent particles. Explain the difference.

(iv) Calculate in joules the binding energy of the atom. [9] N90/III/6 (part)

56 *(a)* (i) Explain what is meant by the *nucleon number* and the *nuclear binding energy* of a nucleus.

(ii) Sketch a fully labelled graph to show the variation with nucleon number of the binding energy per nucleon.

Hence explain why fusion of nuclei having high nucleon numbers is not associated with a release of energy. [9] J92/III/6 (part)

57 *(c)* When beryllium is bombarded with α-particles of energy 8.0×10^{-13} J, carbon atoms are produced, together with a very penetrating radiation. The nuclear reaction might be

EITHER (i) $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{13}_{6}C + \gamma$

OR (ii) $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$.

(1) Explain what is meant by $^{13}_{6}C$.

(2) The energy of the penetrating radiation is found to be at least 8.8×10^{-12} J for each γ or $^{1}_{0}n$ produced. Show that equation *(c)* (i) cannot be valid. Explain your reasoning carefully.

Nuclide	mass/u
$^{9}_{4}Be$	9.0150
$^{4}_{2}He$	4.0040
$^{13}_{6}C$	13.0075

[7] N93/III/6 (part)

58 *(a)* Describe, using a sketch, a simple model for the nuclear atom. [3]

(b) In the α-particle scattering experiment, α-particles, travelling in a vacuum, are incident on a gold foil. Draw sketch diagrams to illustrate the path of an α-particle, the original path of which

(i) is directly towards the nucleus of a gold atom,

(ii) passes close to the nucleus of a gold atom,

(iii) passes some distance from the nucleus. [3]

(c) Describe and explain how the α-particle scattering experiment which you have illustrated in part *(b)* gives evidence for the existence and small size of the nucleus. [4]

(d) The structure of the nucleus was clarified further by the experiment illustrated in Fig. 3.

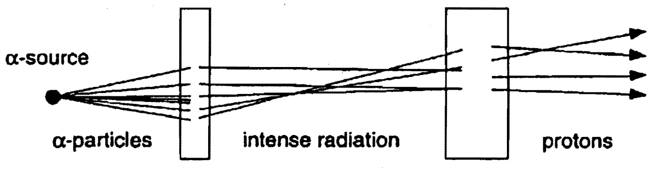


Fig. 3

α-particles were fired at a piece of beryllium and an intense radiation was found to be emitted from the beryllium. When this radiation entered a solid containing many hydrogen atoms, many protons were knocked forward from the solid. The initial reaction in the beryllium is now known to be

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{1}_{0}n + ^{12}_{6}C.$$

(i) In the equation what symbol is used to represent the α-particle?

(ii) What information does the symbol give about the α-particle?

(iii) Suggest, with a reason, which particle is responsible for knocking a proton out of the solid containing the hydrogen atoms.

(iv) The intense radiation was originally thought to be γ-rays. Why does the existence of the knocked-forward protons make this impossible? [6]

(e) The masses of the particles referred to in part *(d)* are as follows.

$^{4}_{2}He$	+ $^{9}_{4}Be$	$\longrightarrow$ $^{1}_{0}n$	+ $^{12}_{6}C$
4.00260u	9.01212u	1.00867u	12.00000u

(i) Calculate the loss of mass which appears to take place in the reaction.

(ii) Hence find the energy equivalence of this mass. [4] J95/III/6

59 *(a)* State the meaning of each of the following terms:

(i) nucleon number (mass number),

(ii) proton number (atomic number),

(iii) isotopes,

(iv) binding energy,

(v) conservation of mass. [7]

(b) Describe the principle of the mass spectrometer and explain how the spectrometer can be used to indicate the relative abundance of isotopes in a sample of an element. [7]

(c) The binding energy per nucleon varies with nucleon number in the way shown in Fig. 4.

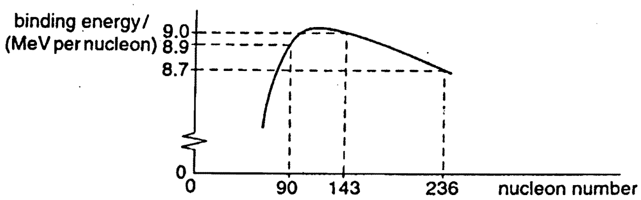


Fig. 4

During one particular fission process, a Uranium –236 nucleus gives, among its fission products, a Strontium –90 nucleus and a Xenon –143 nucleus.

(i) Use the values on Fig. 4 to calculate the energy released during this fission process.

(ii) What other fission particles are produced by this process? Why do these particles not have to be taken into account in the calculation in (i)?

(iii) Why does a release of energy occur when there is an *increase* in the binding energy? [6]

N96/III/6

60 *(c)* When Uranium–235 nuclei are fissioned by slow-moving neutrons, two possible reactions are

reaction 1: ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{139}_{54}Xe + {}^{95}_{38}Sr + 2{}^{1}_{0}n$ + energy,

reaction 2: ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{116}_{46}Pd + xc$ + energy,

(i) For reaction 2, identify the particle c and state the number x of such particles produced in the reaction. [2]

(ii) The binding energy per nucleon E for a number of nuclides is given in Fig. 5.

nuclide	E /MeV
${}^{95}_{38}Sr$	8.74
${}^{139}_{54}Xe$	8.39
${}^{235}_{92}U$	7.60

Fig. 5

1. State what is meant by the *binding energy per nucleon* of a nucleus.
2. Show that the energy released in reaction 1 is 210 MeV.
3. The energy released in reaction 2 is 163 MeV. Suggest, with a reason, which one of the two reactions is more likely to occur. [7]

N97/III/6 (part)

61 *(a)* Distinguish between a *nucleon*, a *nucleus* and a *nuclide.* [5]

J2000/III/6 (part)