(c) Fig. 6.2 shows a film badge which is worn by people who work with ionising radiation, such as beta particles, X-rays and gamma rays. The film is wrapped in a light-tight paper wrapper. It is placed in a plastic holder which has a wide slot or 'window' cut through the plastic. The holder also contains a number of metallic and plastic filters. The amount of darkening in different regions of the film indicate the exposure to different types of radiation.

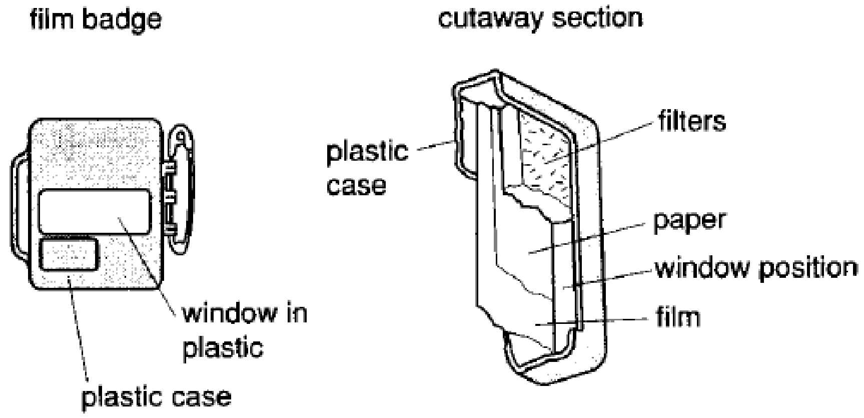

Fig. 6.2

Suggest why film badges are **not** suitable for monitoring alpha radiation, and why the window and the different types of filter are provided.

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.... [4]

[Total: 13]

31

The radius r of an atomic nucleus is related to the radius r_0 of a nucleon (proton or neutron) by the equation

$$r = r_0 A^{\frac{1}{3}}.$$ **equation 1**

(a) State the meaning of A.

....

....[1]

(b) On Fig. 1.1, sketch a graph to show the relation between r and A. Label the axes.

[2]

Fig. 1.1

(c) **(i)** Show that the equation

$$\left[\frac{4}{3}\pi r^3\right] = \left[\frac{4}{3}\pi r_0^{\,3}\right] A$$

can be derived directly from **equation 1**.

[2]

(d) Write an equation relating the mass m of a nucleus to the mass m_0 of a nucleon. Assume that both the proton and the neutron have the same mass m_0.

....

....[1]

(e) Using your answers to **(c)** and **(d)**, discuss whether the density of a nucleus depends on the value of A. State and explain what this implies about the spacing of the nucleons in nuclei of different sizes.

....

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....[3]

[Total: 11]

32

(a) Distinguish between a nuclear *decay* and a nuclear *fission*.

....

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....

....[2]

(b) Natural uranium is a mixture of uranium-235 ($^{235}_{92}U$) and uranium-238 ($^{238}_{92}U$). Write a nuclear equation to show how **one** of these nuclides can absorb a neutron, forming uranium-239.

....

....[1]

(c) Write nuclear equations to show how uranium-239 can undergo **two** beta decays, forming plutonium-239 ($^{239}_{94}Pu$).
The proton number for neptunium (Np) is 93.

....

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....[2]

(d) Plutonium-239 is fissile but it is also radioactive and decays with a half-life of 2.41×10^4 years.

(i) State the particle that is emitted when plutonium-239 decays.

....[1]

(ii) Show that the decay constant of plutonium-239 is about $9 \times 10^{-13}\,s^{-1}$.

[2]

(iii) A particular fuel rod contains 0.25 kg of plutonium-239.
Calculate the activity of this plutonium. Give an appropriate unit for your answer.

activity = ... unit .... [4]

[Total: 12]

33

This question is about nuclear fusion inside the Sun.

(a) Describe the conditions inside the Sun and explain how they favour nuclear fusion. Your account should explain why the material inside the Sun is in the plasma state and how the plasma is confined.

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....[5]

(b) One process by which hydrogen nuclei fuse is called the carbon cycle. The following equations represent the reactions which make up this cycle.

$${}^{12}_{6}C + {}^{1}_{1}H \longrightarrow {}^{13}_{7}N$$

$${}^{13}_{7}N \longrightarrow {}^{13}_{6}C + {}^{0}_{1}e$$

$${}^{13}_{6}C + {}^{1}_{1}H \longrightarrow {}^{14}_{7}N$$

$${}^{14}_{7}N + {}^{1}_{1}H \longrightarrow {}^{15}_{8}O$$

$${}^{15}_{8}O \longrightarrow {}^{15}_{7}N + {}^{0}_{1}e$$

$${}^{15}_{7}N + {}^{1}_{1}H \longrightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

(i) Why is this called the carbon cycle?

....

....[1]

(ii) Summarise the carbon cycle by reducing the six equations above to a single equation, in its simplest form.

[2]

(iii) The binding energy per nucleon of $^{4}_{2}He$ is 7.1 MeV.

Show that the energy released in joules when one $^{4}_{2}He$ nucleus is formed is about 4.5×10^{-12} J. By referring to your answer to **(b)(ii)**, give **one** reason why this is only an approximation.

....

....

....**[3]**

(c) It is estimated that 8×10^{37} helium nuclei are formed per second inside the Sun. Assuming that this is the only energy-generating process, calculate the total power emitted by the Sun.

power = ... W [2]

[Total: 13]

34

(a) State the names of **two** classes of particle, each of which includes both the proton and the neutron.

1. ....

2. .... [1]

(b) It is thought that, in certain circumstances, the proton has a slight probability of decaying into a neutron, a positron and a third particle.

Write an equation to represent this reaction.

State the name of the third particle.

....

....[2]

(c) A free neutron is known to decay with a half-life of about 10 minutes.

In what situation are both neutrons and protons stable?

....[1]

(d) **(i)** State the quark composition of

the proton ....

the neutron .... [2]

(ii) In the reaction

$$p^+ + p^+ \longrightarrow p^+ + n^0 + \pi^+$$

two quarks are created. These are a down quark (d) and an anti-down quark ($\bar{d}$).

Simplify this equation and using your answers to **(d)(i)**, write a quark equation.

[2]

(iii) Hence deduce the quark composition of the π^+ particle.

[2]

[Total: 10]

35

The radioactive nuclide $^{42}_{19}K$ decays by emission of a beta-particle. Fig. 5.1 shows the apparatus used to measure the half life of the nuclide. A Geiger-Muller (GM) tube connected to a counter is placed a short distance in front of the potassium source and the count per minute is recorded once every hour.

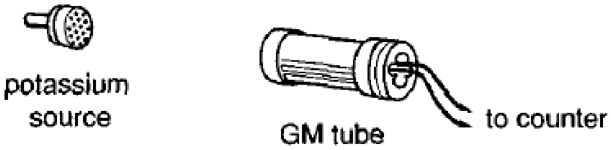

Fig. 5.1

(a) The activity of the potassium source is proportional to the count rate minus the background count rate, that is

activity = constant × (count rate – background count rate).

(i) Explain the meaning of the terms

activity ....

....[1]

background count rate ....

....[1]

(ii) Suggest, with a reason, **one** of the factors which affect the value of the **constant** in the equation above.

....

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....[2]

(b) (i) The radioactive decay law in terms of the count rate C corrected for background can be written in the form

$$C = C_0 e^{-\lambda t}$$

where λ is the decay constant.
Show how the law can be written in the linear form

$$\ln C = -\lambda t + \ln C_0$$

[2]

(ii) Fig. 5.2 shows the graph of ln C against time t for the beta-decay of potassium.

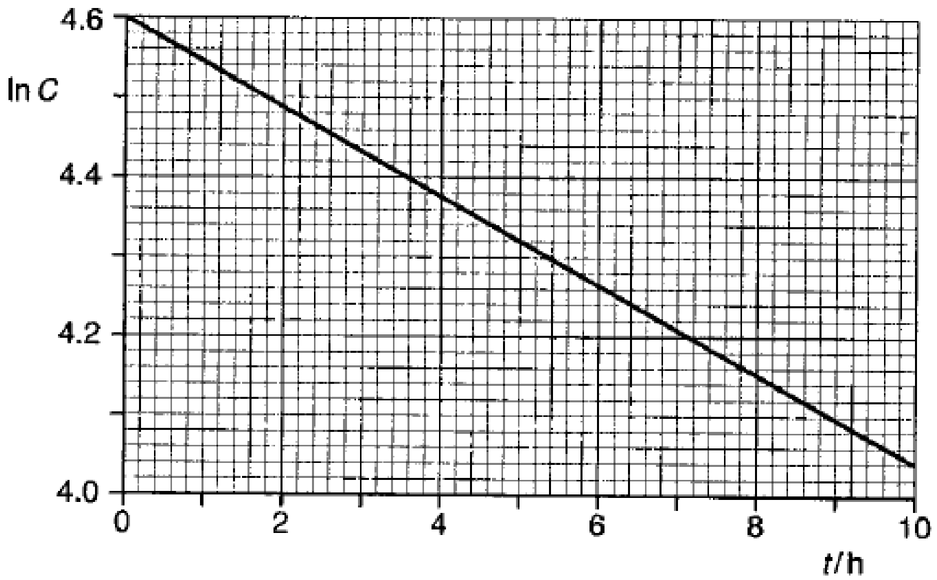

Fig. 5.2

Use data from the graph to estimate the half-life of the potassium nuclide.

half-life = ...h [3]

(c) State **three** ways in which decay by emission of an α-particle differs from decay by emission of a β-particle.

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....[3]

[Total: 12]

36

In this question, four marks are available for the quality of written communication.

(a) Describe what conclusions can be drawn about the structure of the atom from Rutherford's experiment in which α-particles are scattered by gold nuclei. Explain how and why the experiment differs when high-speed electrons are fired at nuclei.

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.... [7]

37

(a) The radius of a nucleon (proton or neutron) is r_0.

(i) Write an expression for the volume of a nucleon.

....[1]

(ii) A particular nucleus consists of A nucleons.
Using your answer to **(i)**, write an expression for the volume of this nucleus.

....[1]

(iii) The radius of this nucleus is r. Using your answer to **(ii)**, show that

$$r^3 = A r_0^{\,3}$$

[2]

(iv) On Fig. 1.1, draw a line to represent the variation of r^3 with A.

Fig. 1.1

State the gradient of this line.

....

[3]

(b) **(i)** Use your answer to **(a)(ii)** to estimate the density of a gold nucleus ($^{197}_{79}Au$). Assume that the radius r_0 of a nucleon is 1.4×10^{-15} m.

density = ... kg m^{-3} [3]

(ii) Metallic gold has a density of 1.9×10^4 kg m^{-3}. Estimate the percentage of the volume of the gold atom that is occupied by the nucleus. Explain your working.

percentage = ... % [2]

[Total: 12]

38

(a) (i) State what is meant by *nuclear binding energy*.

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....[1]

(ii) Fig. 2.1 shows the binding energy per nucleon for five nuclides, plotted against nucleon number.

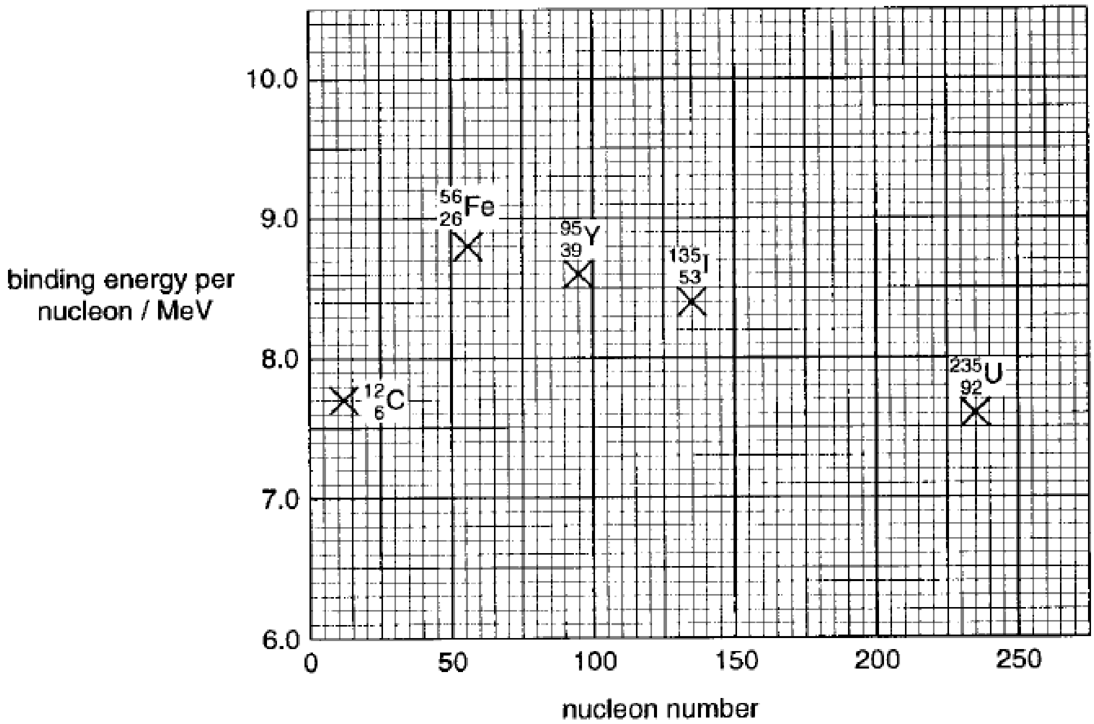

Fig. 2.1

$^{56}_{26}Fe$ has the highest binding energy per nucleon. $^{12}_{6}C$ and $^{235}_{92}U$ have less binding energy per nucleon.
Explain how these values relate to the possibility of fission or fusion of the nuclides $^{56}_{26}Fe$, $^{12}_{6}C$ and $^{235}_{92}U$.

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....[4]

(b) (i) A $^{235}_{92}U$ nucleus inside a nuclear reactor can absorb a thermal neutron.
State what is meant by a *thermal neutron*.

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....[1]

(ii) Write a nuclear equation for this reaction.

[1]

(iii) The resulting nucleus undergoes fission. Iodine-135 ($^{135}_{53}I$) and yttrium-95 ($^{95}_{39}Y$) are produced.
Write a nuclear equation for this reaction.

[1]

(iv) Use data from Fig. 2.1 to deduce how much energy in MeV is released when one nucleus of $^{235}_{92}U$ undergoes these reactions.

energy = ... MeV [4]

[Total: 12]

39

This question is about the properties of **baryons** and **leptons**.

(a) Choose **two** examples of **baryons**

For each example discuss

- their composition
- their stability.

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(b) Choose **two** examples of **leptons**

For each example discuss

- their composition
- the forces which affect them
- where they may be found.

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[Total: 12]

40

In nuclear fission, energy is released.

(a) Explain what is meant by *nuclear fission*.

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....[1]

(b) In a possible fission reaction $^{235}_{92}U$ captures a neutron to become a compound nucleus before splitting into $^{141}_{56}Ba$ and $^{92}_{36}Kr$ releasing three neutrons.

Write down the nuclear reaction equation for this event.

....[2]

(c) The total mass of the compound nucleus $^{236}_{92}U$ before fission is 236.053 u. The total mass of the fission products is 235.867 u. Use these data to calculate the energy released in the fission process.

energy = ...J [3]

(d) Most of the energy released arises from the electrostatic repulsion of the two nuclei as they move apart. Use the information in **(b)** to show that the force *F* between the two nuclei at the instant after fission occurs is about 3000 N.
Assume the nuclei act as point charges a distance *r* apart of 1.3×10^{-14} m.

[4]

[Total: 10]

41

In this question, four marks are available for the quality of written communication.

(a) State and compare the nature and properties of the three types of ionising radiations emitted by naturally occurring radioactive substances.

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....**[6]**

(b) Describe experiments which would enable you to determine the **nature** and **energy** of the emissions from a sample of rock containing several radioactive nuclides. A space has been left for you to draw suitable diagram(s), if you wish to illustrate your answer.

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....[6]

Quality of Written Communication [4]

[Total: 16]

42

Fig. 1.1 shows two protons **A** and **B** in contact and at equilibrium inside a nucleus.

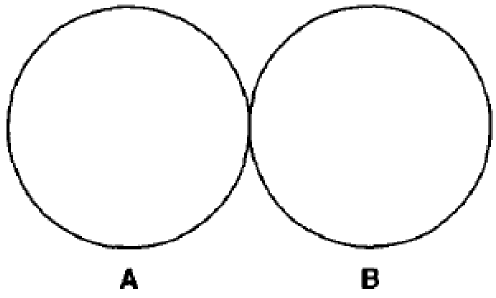

Fig. 1.1

Proton **A** exerts three forces on proton **B**. These are an electrostatic force F_E, a gravitational force F_G and a strong force F_S.

(a) On Fig. 1.1, mark and label the three forces acting on proton **B**. Assume that every force acts at the centre of the proton. [2]

(b) Write an equation relating F_E, F_G and F_S.

[1]

(c) The radius of a proton is 1.40×10^{-15} m.
Calculate the values of

(i) F_E

F_E = ... N [2]

(ii) F_G

F_G = ... N [2]

(iii) F_S.

F_S = ... N [1]

(d) Comment on the relative magnitudes of F_E and F_G.

....

....[1]

(e) Fig. 1.2 shows two **neutrons** in contact and at equilibrium inside a nucleus.

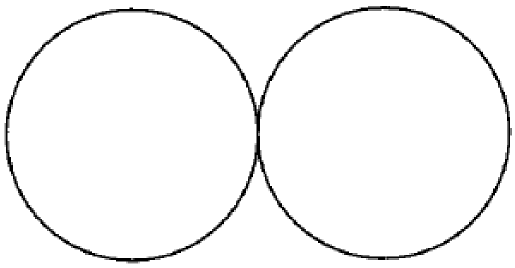

Fig. 1.2

Without further calculation, state the values of F_E, F_G and F_S for these neutrons.

(i) F_E = ... N [1]

(ii) F_G = ... N [1]

(iii) F_S = ... N [1]

[Total: 12]

43

This question is about the production and use of plutonium-239 ($^{239}_{94}Pu$).
In a uranium fission reactor, uranium-238 ($^{238}_{92}U$) is bombarded with neutrons.
A nucleus of $^{238}_{92}U$ can absorb a neutron.
The product of this reaction then undergoes two decay reactions to produce $^{239}_{94}Pu$.

(a) Write nuclear equations for these three reactions.
Use X to represent any intermediate nuclide.

(a) Write nuclear equations for these three reactions.
Use X to represent any intermediate nuclide.

(i) absorption of a neutron

[1]

(ii) first decay reaction

[2]

(iii) second decay reaction

[1]

(b) **(i)** State the half-life of plutonium-239.

half-life = ... y [1]

(ii) Calculate the decay constant λ of plutonium-239.

decay constant = ... s^{-1} [2]

(c) Plutonium-239 can be used (with uranium-235) in a different kind of reactor. A particular fuel rod for such a reactor has a mass of 4.4 kg, of which 5.0 % is plutonium-239.

(i) Show that the number of atoms of plutonium in this fuel rod is 5.5×10^{23}.

[2]

(ii) Calculate the activity of the plutonium in this fuel rod.
State the unit of your answer.

activity = ... unit........ [3]

[Total: 12]

44

The Sun's energy is generated by fusion reactions.
Fusion is most likely to occur when reacting nuclei approach each other along the same straight line. Fig. 3.1 shows two protons which have the same initial speed.

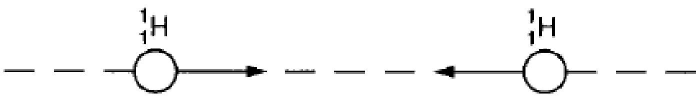

Fig. 3.1

(a) Describe the energy changes in this system as the protons approach each other and come to rest.

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....[3]