1)

(a) State, with a reason, whether or not protons and neutrons are fundamental particles.

....

.... **[1]**

(b) State **two** fundamental particles that can be classified as leptons.

.... **[1]**

(c) Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 ($^{40}_{19}K$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for $^{40}_{19}K$.

$$^{40}_{19}K \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}Ca + \cdots\cdots\cdots + \cdots\cdots\cdots$$ **[2]**

(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

....

....

....

....

.... **[2]**

(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012% of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is 0.040 kg mol^{-1}.

Calculate the activity from this banana.

activity = ... Bq **[3]**

2)

(a) Explain how the experiments on the scattering of alpha-particles by a metal foil provided evidence for the nuclear model of the atom.

In your answer, you should make clear how your conclusions link with the observations.

....

....

....

....

....

.... **[3]**

(b) Fig. 5.1 shows an alpha-particle ($^{4}_{2}He$) of kinetic energy 8.0 MeV moving directly towards a nucleus of aluminium-27 ($^{27}_{13}Al$), initially at rest.

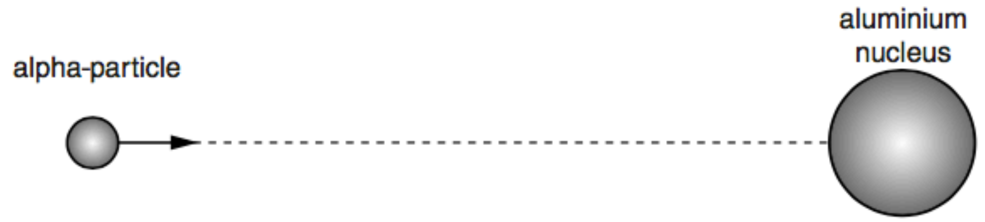

Fig. 5.1

(i) The alpha-particle comes to rest instantaneously a short distance away from the aluminium nucleus. It then reverses its direction of travel. Describe and explain the motion of the aluminium nucleus at the instant the alpha-particle is at rest.

....

....

....

....

.... **[2]**

(ii) Calculate the initial speed of the alpha-particle.

mass of alpha-particle = 6.6×10^{-27} kg

speed = ... $m\,s^{-1}$ **[2]**

(iii) The electric force experienced by the alpha-particle when it is close to the aluminium nucleus is 270 N. Calculate the separation *r* between the alpha-particle and the aluminium nucleus when the alpha-particle experiences this force.

r = ... m **[3]**

(iv) Consider the situation where the alpha-particle travels much closer to the aluminium nucleus than in **(b)(iii)**.

Discuss how the strong nuclear force may affect the resultant force on the alpha-particle.

....

....

....

.... **[2]**

3)

(a) The diameter of a nucleus is about 10^{-14} m.

(i) Complete the sentence below.

The diameter of a nucleus is .... times smaller than the diameter of an atom. **[1]**

(ii) Very high-energy electrons are diffracted by the nucleus when they have a wavelength similar to the nuclear diameter.

1 Estimate the momentum of an electron with a de Broglie wavelength equal to the diameter of a nucleus.

momentum = ... kg m s^{-1} **[2]**

2 Suggest why the speed of these electrons cannot be calculated by dividing the answer to **(ii)1** by the mass 9.11×10^{-31} kg.

....

....

....

.... **[1]**

(b) The table of Fig. 5.1 shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}P$	$^{30}_{15}P$	$^{31}_{15}P$	$^{32}_{15}P$	$^{33}_{15}P$
Type of decay	β^+	β^+	stable	β^-	β^-

Fig. 5.1

(i) State the difference between each of the isotopes shown in the table.

....

.... **[1]**

(ii) Describe the structure of the proton in terms of up (u) and down (d) quarks.

.... **[1]**

(iii) Describe what happens in a beta-plus (β^+) decay using a quark model.

....

....

.... **[2]**

(iv) State **two** quantities conserved in a beta decay.

....

.... **[1]**

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits β^+ or β^-.

....

....

.... **[1]**

[Total: 10]

4)

Technetium-99m is a common medical tracer injected into patients before they have a scan with a gamma camera. Technetium-99m is a gamma emitter with a half-life of about 6 hours. Each gamma ray photon has energy 2.2×10^{-14} J.

A patient is given a dose with an initial activity of 500 MBq.

(a) Explain what is meant by *activity*.

....

.... **[1]**

(b) Calculate the initial rate of energy emission from the dose of technetium-99m.

rate of energy emission = ... $J s^{-1}$ **[2]**

(c) Name and describe the function of the main components of a gamma camera.

In your answer you should make clear how a good quality image can be achieved with these components.

.... **[5]**

[Total: 8]

5)

(a) **(i)** Complete Fig. 9.1 to show the quark composition and charge for neutrons and protons.

	quark composition	charge
neutron		
proton		

Fig. 9.1

[2]

(ii) Complete Fig. 9.2 to show the composition of quarks.

quark	charge	baryon number	strangeness
up		+ 1/3	
down			0

Fig. 9.2

[2]

(b) When a neutron decays it can produce particles that include an electron.

(i) Complete the decay equation below for a neutron.

$^{1}_{0}n \rightarrow$

[2]

(ii) Name the interaction responsible for the decay of the neutron.

.... **[1]**

(iii) Electrons and neutrons belong to different groups of particles. Name the group of particles to which each belongs.

electrons ....

neutrons .... **[1]**

[Total: 8]

6)

(a) Describe what is meant by the **spontaneous** and **random** nature of radioactive decay of unstable nuclei.

....

....

....

.... **[2]**

(b) Define the *decay constant*.

....

.... **[2]**

(c) Explain the technique of radioactive carbon-dating.

....

....

....

....

....

.... **[4]**

(d) The activity of a sample of living wood was measured over a period of time and averaged to give 0.249 Bq. The same mass of a sample of dead wood was measured in the same way and the activity was 0.194 Bq. The half-life of carbon-14 is 5570 years.

(i) Calculate

1 the decay constant in y^{-1} for the carbon-14 isotope

decay constant = ... y^{-1} **[1]**

2 the age of the sample of dead wood in years.

age = ... y **[2]**

(ii) Suggest why the activity was measured over a long time period and then averaged.

....

.... **[1]**

(iii) Explain why the method of carbon-dating is not appropriate for samples that are greater than 10^5 years old.

....

.... **[1]**

[Total: 13]

7)

The isotopes of carbon-14 ($^{14}_{6}C$) and carbon-15 ($^{15}_{6}C$) are beta-minus emitters. The table in Fig. 5.1 shows the maximum kinetic energy of each electron emitted and the half-life of the isotope.

isotope	maximum kinetic energy / MeV	half-life
$^{14}_{6}C$	0.16	5560 years
$^{15}_{6}C$	9.8	2.3 s

Fig. 5.1

(a) State one property common to all isotopes of an element.

....

.... **[1]**

(b) The neutrons and protons inside each isotope experience fundamental forces. Name the two fundamental forces experienced by both neutrons and protons.

1. ....

2. .... **[2]**

(c) An isotope of carbon-15 decays into an isotope of nitrogen (N).

(i) Complete the nuclear reaction below.

$$^{15}_{6}C \rightarrow {}^{\dots\dots}_{\dots\dots}N + {}^{0}_{-1}e + \overline{\nu}$$

[1]

(ii) Use the quark model to state the changes taking place within the nucleus of the carbon-15 atom.

....

.... **[1]**

(d) **(i)** Estimate the maximum speed of an electron from the nucleus of carbon-14.

speed = ... $m s^{-1}$ **[2]**

(ii) Suggest why the actual speed of the electron is much less than your answer in **(i)**.

....

.... **[1]**

(e) **(i)** Calculate the decay constant λ in s^{-1} of carbon-14.

λ = ... s^{-1} **[2]**

(ii) The molar mass of carbon-14 is $14\,g\,mol^{-1}$. Show that 1.0 mg of carbon-14 has 4.3×10^{19} nuclei.

[1]

(iii) Calculate the activity of the 1.0 mg mass of carbon-14.

activity = ... Bq **[2]**

(f) The isotope of carbon-14 is very useful in determining the age of a relic (e.g. ancient wooden axe) using a technique known as carbon-dating.
Describe carbon-dating and explain one of its major limitations.

....

....

....

....

....

....

....

....

....

....

.... **[4]**

[Total: 17]

8)

The radioactive nucleus of plutonium ($^{238}_{94}$Pu) decays by emitting an alpha particle ($^{4}_{2}$He) of kinetic energy 5.6MeV with a half-life of 88 years. The plutonium nucleus decays into an isotope of uranium.

(a) State the number of neutrons in the **uranium** isotope.

.... **[1]**

(b) The mass of an alpha particle is 6.65×10^{-27} kg.

(i) Show that the kinetic energy of the alpha particle is about 9×10^{-13} J.

[1]

(ii) Calculate the speed of the alpha particle.

speed = ... m s^{-1} **[2]**

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate 62W for the onboard electronics.

(i) Use your answer to **(b)(i)** to show that the initial activity of the sample of plutonium-238 is about 7×10^{13} Bq.

[1]

(ii) Calculate the decay constant of the plutonium-238 nucleus.

1 year = 3.16×10^7 s

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

(iii) The molar mass of plutonium-238 is 0.24 kg. Calculate

1 the number of plutonium-238 nuclei in the source

number of nuclei = ... **[2]**

2 the mass of plutonium in the source.

mass = ... kg **[1]**

[Total: 10]

9)

The nuclear reaction represented by the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{39}Y + ^{139}_{53}I + 3\,^{1}_{0}n$$

takes place in the core of a nuclear reactor at a power station.

(a) Describe how this reaction can lead to a chain reaction.

....

....

.... **[1]**

(b) Explain the role of fuel rods, control rods and a moderator in a nuclear reactor.

In your answer you should make clear how chain reactions are controlled in the reactor.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... **[5]**

(c) In the nuclear reactor of a power station, each fission reaction of uranium produces 3.2×10^{-11} J of energy. The electrical power output of the power station is 3.0 GW. The efficiency of the system that transforms nuclear energy into electrical energy is 22%. Calculate

(i) the total power output of the reactor core

power output = ... W **[1]**

(ii) the total energy output of the reactor core in one day

1 day = 8.64×10^4 s

energy output = ... J **[1]**

(iii) the mass of uranium-235 converted in one day. The mass of a uranium-235 nucleus is 3.9×10^{-25} kg.

mass = ... kg **[2]**

(d) Discuss the physical properties of nuclear waste that makes it dangerous.

....

....

....

.... **[2]**

[Total: 12]

10)

(a) In experiments carried out to determine the nature of atoms, alpha particles were fired at thin metal foils. Describe how the alpha-particle scattering experiments provide evidence for the existence, charge and size of the nucleus.

In your answer, you should make clear how your conclusions link with your observations.

....

....

....

....

....

....

....

....

....

....

....

.... **[5]**

(b) Describe the nature and range of the **three** forces acting on the protons and neutrons in the nucleus.

....

....

....

....

....

....

....

....

....

....

....

....

.... **[5]**

(c) The radius of a $^{235}_{92}U$ nucleus is 8.8×10^{-15} m. The average mass of a nucleon is 1.7×10^{-27} kg.

(i) Estimate the average density of this nucleus.

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

(ii) State one assumption made in your calculation.

....

.... **[1]**

[Total: 14]

11)

(a) A sample of a radioactive isotope contains 4.5×10^{23} active undecayed nuclei. The half-life of the isotope is 12 hours. Calculate

(i) the initial activity of the sample

activity = ... s^{-1} **[2]**

(ii) the number of active nuclei of the isotope remaining after 36 hours

number = ... **[1]**

(iii) the number of active nuclei of the isotope remaining after 50 hours.

number = ... **[2]**

(b) Explain why the activity of a radioactive material is a major factor when considering the safety precautions in the disposal of nuclear waste.

....

....

....

.... **[2]**

[Total: 7]

12)

There are two types of beta decay, beta-plus and beta-minus. An isotope of carbon ${}^{15}_{6}C$ decays by beta emission into an isotope of nitrogen ${}^{15}_{7}N$. An isotope of phosphorus ${}^{30}_{15}P$ decays by beta emission into an isotope of silicon ${}^{30}_{14}Si$.

(a) Complete the following decay equations for the carbon and phosphorus isotopes.

(i) carbon decay

$${}^{15}_{6}C \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}N + \ldots\ldots$$

(ii) phosphorus decay

$${}^{30}_{15}P \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}Si + \ldots\ldots$$

[3]

(b) State the two beta decays in terms of a quark model of the nucleons.

(i) beta-plus decay

(ii) beta-minus decay

[2]

(c) Name the force responsible for beta decay.

.... **[1]**

[Total: 6]

13)

A proton travelling at a high velocity is fired at a stationary proton. It stops momentarily at a distance of 2.0×10^{-15} m from the stationary proton.

(a) Calculate the electrostatic force acting on each proton when separated by 2.0×10^{-15} m.

force = ... N **[2]**

(b) The two protons fuse together. Explain how the protons are able to remain together.

....

.... **[1]**

(c) Explain why the proton must have a very large velocity for the fusion to occur and the protons to remain together.

....

....

....

.... **[2]**

[Total: 5]

14)

Fluorodeoxyglucose (FDG) is a radiopharmaceutical used for PET scans. It contains radioactive fluorine-18, which is a positron-emitter with a half-life of 6.6×10^3 s.
A patient is injected with FDG which has an initial activity of 250 MBq.

(a) Calculate the decay constant of fluorine-18.

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

(b) Show that the initial number of fluorine-18 nuclei in the FDG is about 2×10^{12}.

[1]

(c) About 9.9% of the mass of FDG is fluorine-18. Use your answer in **(b)** to determine the initial mass of FDG given to the patient. The molar mass of fluorine-18 is 0.018 kg mol^{-1}.

mass = ... kg **[3]**

(d) A typical PET scan takes 20 minutes. Determine the activity of FDG in the patient after this time.

activity = ... MBq **[2]**

(e) Positron emission tomography (PET) can be used to locate an area of increased activity within the brain. Describe the principles of PET.

In your answer you should make clear how the position of increased activity is located.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... **[4]**

[Total: 12]