**Nuclear and Particle Physics – 2021/20 GCE Physics A Component 02**

**1.** Nov/2021/Paper_H556_02/No.13

The medical tracer fluorine-18 is used in positron emission tomography (PET).
Fluorine-18 is a beta-plus emitter with a short half-life.

Describe how the fluorine-18 nuclei are located in a patient using a PET scanner.

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**2.** Nov/2021/Paper_H556_02/No.15

A radiation detector is placed in front of a beta-emitting source.
The count-rate is measured and recorded every 10 minutes.
The results are shown below.

$311\,s^{-1}$ $309\,s^{-1}$ $299\,s^{-1}$ $307\,s^{-1}$ $321\,s^{-1}$

What term can be used to describe the data shown?

**A** exponential

**B** linear

**C** random

**D** spontaneous

Your answer [ ] **[1]**

**3.** Nov/2021/Paper_H556_02/No.23

**(a)** Explain the function of the control rods and the moderator in a nuclear fission reactor.

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**(b)*** Some nuclear fission reactors use uranium-235 as fuel. In the future, there is possibility of using hydrogen-2 as fuel in fusion reactors.

Here is some information and data on fission and fusion reactions.

| | Fission reactor | Fusion reactor |
|---|---|---|
| **Typical reaction** | ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n$ | ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$ |
| **Approximate energy produced in each reaction** | 200 MeV | 4 MeV |
| **Molar mass of fuel material** | uranium-235: 0.235 kg mol$^{-1}$ | hydrogen-2: 0.002 kg mol$^{-1}$ |

- Describe the similarities and the differences between fission and fusion reactions.
- Explain with the help of calculations, which fuel produces more energy per kilogram.

**[6]**

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**4.** Nov/2021/Paper_H556_02/No.25

**(a)** A researcher is doing an experiment on a radioactive solution in a thin **glass** tube.
The solution has two radioactive materials **X** and **Y**.
The table below shows some data on these two materials.

| | **Material X** | **Material Y** |
|---|---|---|
| Half-life | 10 minutes | 10 hours |
| Particles emitted | Alpha | Beta-minus |
| Daughter nuclei | Stable | Stable |

The solution has the same number of nuclei of **X** and **Y** at the start.

**(i)** State and explain which material has the greatest activity at the start.

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**(ii)** State why it is dangerous for the researcher to handle the test tube with bare hands.

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**(b)** Carbon-14 ($^{14}_{6}C$) is produced in the upper atmosphere of the Earth by collisions between nitrogen nuclei and fast-moving neutrons.
The nuclear transformation equation below shows the formation of a single carbon-14 nucleus.

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + X$$

**(i)** State the proton number of particle X.

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

**(ii)** Use the data below to determine the binding energy per nucleon of the $^{14}_{6}C$ nucleus. Write your answer to **3** significant figures.

- mass of neutron = $1.675 \times 10^{-27}$ kg
- mass of proton = $1.673 \times 10^{-27}$ kg
- mass of $^{14}_{6}C$ nucleus = 14.000 u
- 1 u = $1.66 \times 10^{-27}$ kg

binding energy per nucleon = .................................. J per nucleon **[4]**

**5.** Nov/2020/Paper_H556_02/No.9

A student is modelling the decay of a radioactive source using the equation $\Delta N/\Delta t = -0.5N$.
The student decides to use $\Delta t = 0.10$ s.
The number $N$ of radioactive nuclei is 2000 at $t = 0$.

Part of the modelling spreadsheet from the student is shown below.

| ***t*/s** | **Number *N* of radioactive nuclei remaining at time *t*** | **Number of nuclei decaying in the next 0.10 s** |
|---|---|---|
| 0 | 2000 | 100 |
| 0.10 | 1900 | |
| 0.20 | | |
| 0.30 | | |
| | | |

What is the value of $N$ at $t = 0.30$ s?

**A** 1700

**B** 1710

**C** 1715

**D** 1805

Your answer ☐ **[1]**

**6.** Nov/2020/Paper_H556_02/No.10

The total energy released in a single fusion reaction is 4.0 MeV.

What is the change in mass in this fusion reaction?

**A** $7.1 \times 10^{-36}$ kg

**B** $7.1 \times 10^{-30}$ kg

**C** $2.1 \times 10^{-21}$ kg

**D** $4.4 \times 10^{-17}$ kg

Your answer ☐ **[1]**

**7.** Nov/2020/Paper_H556_02/No.12

The table below shows the quark compositions of four particles **A**, **B**, **C** and **D**.

| A | B | C | D |
|---|---|---|---|
| u u d | u d d | u d s | s s s |

Which particle has a positive charge?

Your answer ☐ **[1]**

**8.** Nov/2020/Paper_H556_02/No.21

**(a)** In the 1800s, the atom was considered to be a fundamental particle. It was an indivisible particle of matter. Modern physics shows that this idea is not correct.

Describe the fundamental particles within an atom of carbon-14 ($^{14}_{6}C$).
In your answer state the composition of the hadrons.

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**(b)** The half-life of the isotope carbon-14 is 5700 years (y).

**(i)** Show that the decay constant $\lambda$ for this isotope is about $1.2 \times 10^{-4}\,y^{-1}$.

**[1]**

**(ii)** Carbon-dating is a technique used to date an ancient wooden axe.
The ratio of carbon-14 to carbon-12 in the axe material is 78% of the current ratio of carbon-14 to carbon-12 in a living tree.

Calculate the age in years of the wooden axe.

age = ........................................................ y **[3]**

**(iii)** State **one** assumption made in the calculation in **(ii)**.

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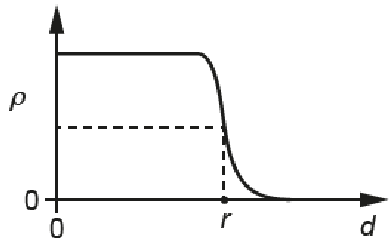
**(c)*** A graph of the density $\rho$ of a nucleus against distance $d$ from the centre of the nucleus is shown below.




The radius of the nucleus $r$ is taken as the distance $d$ where the density is half the maximum density.

**Fig. 21.1** shows the density $\rho$ variation for three different nuclei and **Table 21.1** shows the nucleon number $A$ of each nucleus.

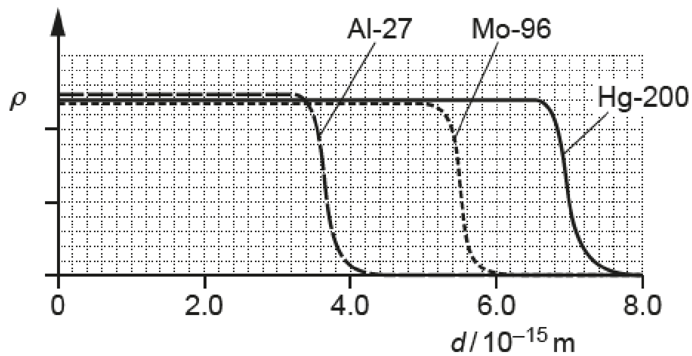



**Fig. 21.1**

| **Nucleus** | **Nucleon number *A*** |
|---|---|
| Al-27 | 27 |
| Mo-96 | 96 |
| Hg-200 | 200 |

**Table 21.1**

Use the information provided opposite to

- describe how the density of a nucleus depends on its nucleon number $A$
- show numerically that $r \propto A^{1/3}$
- estimate the mean density of the nuclei. **[6]**

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**9.** Nov/2021/Paper_H556_03/No.3(c)

**(c)** The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α-particle emission with a half-life of 88 years.
The kinetic energy of each α-particle is $8.8 \times 10^{-13}$ J.

**(i)** Calculate the number *N* of plutonium-238 nuclei needed to provide the power of 470 W.

*N* = ........................................................ **[3]**

**(ii)** Calculate the power *P* still available from the plutonium-238 source 100 years later.

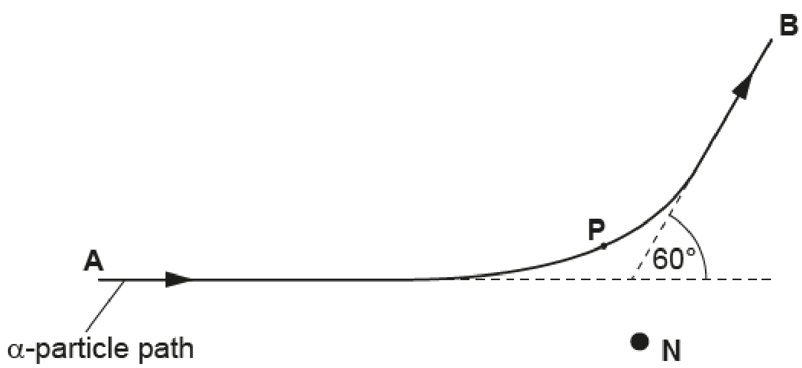
*P* = .................................................... W **[3]**

**10.** Nov/2020/Paper_H556_03/No.6(a, b)

A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

**P** marks its position of closest approach to the gold nucleus.




**(a)** Another α-particle in the beam is deflected by the same gold nucleus **N** through an angle of 30°.

Sketch its path onto the diagram above. **[2]**

**(b)** The distance between **P** and **N** is $6.8 \times 10^{-14}$ m.

Calculate the magnitude of the electrostatic force $F$ between the α-particle ($^{4}_{2}He$) and the gold nucleus ($^{197}_{79}Au$) when the α-particle is at **P**.

$F$ = ........................................................ N **[4]**