Name: ………………………………………… Class: ………… Date: …………

1 Fig. 1.1 shows the main parts of a nuclear reactor.

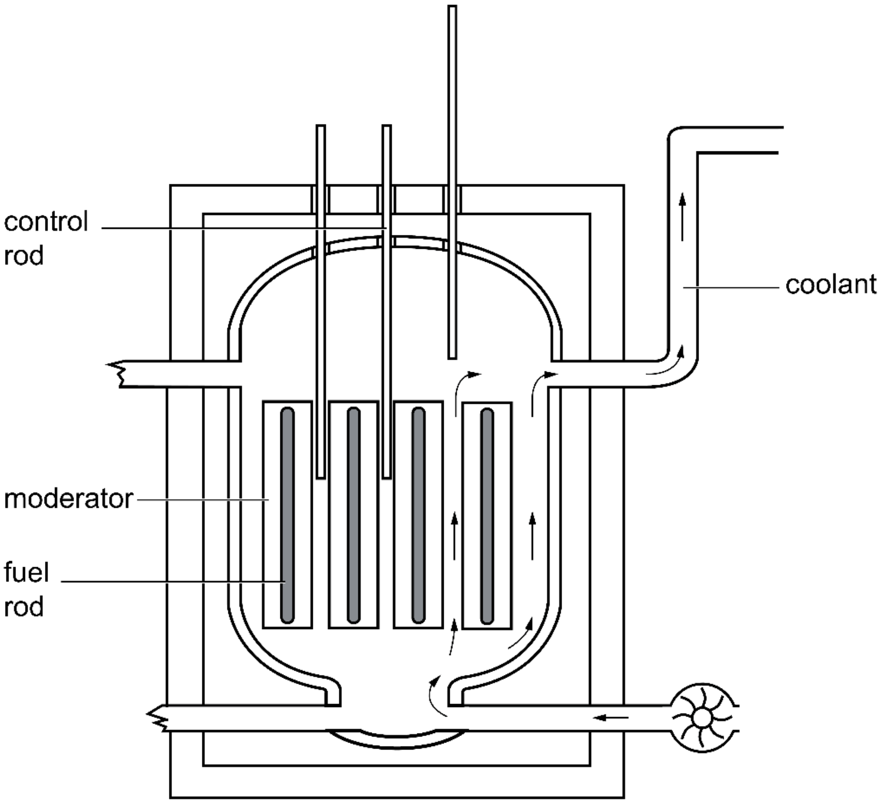

Fig. 1.1

(a) The fuel rod contains uranium-235, which can undergo nuclear fission.

Describe the process of nuclear fission that occurs in the fuel rod.

Your description should include the role of neutrons in the process.

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(b) Explain what happens as a control rod is moved out of the reactor core.

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(c) The nuclear reactor releases energy at a steady rate.

By referring to neutrons, describe what is happening to achieve this steady rate.

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(d) Explain the purpose of the moderator in the nuclear reactor.

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2 Protactiniu-234 ($^{234}_{91}Pa$) is a radioactive isotope of protactinium that decays to uranium-234 ($^{234}_{92}U$).

(a) Compare the nuclide notation $^{234}_{91}Pa$ with the nuclide $^{234}_{92}U$ and deduce what this shows about what is emitted from a nucleus of protactinium-234 as it decays to uranium-234.

Place a tick (✓) in the appropriate boxes of Table 2.1 to show what is deduced from comparing the nuclide notations.

Table 2.1

	yes	no	it is not possible to tell
An alpha-particle is emitted			
A beta-particle is emitted			
A gamma-ray is emitted			

(b) The most abundant isotope of protactinium is protactinium-231.

(i) Explain, by referring to their nuclear compositions, why protactinium-231 and protactinium-234 are both isotopes of the same element.

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(ii) Explain, by referring to their nuclear compositions, why protactinium-231 and protactinium-234 are different isotopes of that element.

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....

(c) A teacher places a radiation detector on a bench in a school laboratory and switches it on.

(i) The teacher measures and records the background radiation count rate.

Describe what is meant by 'background radiation' and state two significant sources of the count rate recorded by the teacher.

Background radiation ....

....

Source 1 ....

Source 2 ....

(ii) The teacher moves a sample of protactinium-234 so that it is next to the detector.

Suggest one precaution that ensures that the sample is moved in a safe way.

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(iii) The count rate is measured every 20 s with the sample present, and then corrected for background radiation.

Fig. 2.1 shows a graph of the corrected countrrate against time for the protactinium-234 sample.

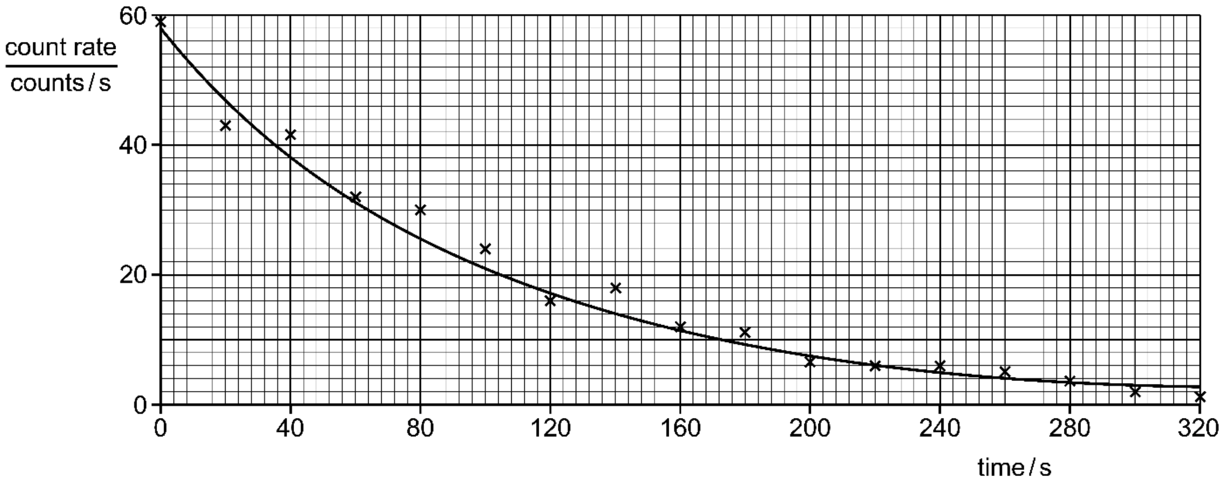

Fig. 2.1

The curve is the best-fit line.

Explain why many of the crosses do not lie on the curve.

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(iv) Using Fig. 2.1, determine the half-life of protactinium-234.

Show your working.

Half-life = ...

(v) The uranium-234 formed from the protactinium-234 is also radioactive. Its half-life is many thousands of years.

Explain why the radiation from uranium-234 does **not** affect the count rates measured in this experiment.

....

....

....

3 Isotope X is radioactive. IT decays by alpha-particle emission to a stable isotope.

(a) State how a nucleus of X changes when it emits an alpha-particle.

....

....

....

(b) There is a radiation detector in a laboratory where there are no radioactive samples.

The detector is switched on and shows an average count rate of 22 counts / minute.

(i) State why the radiation detector shows a count rate.

....

....

(ii) A sample of isotope C is placed 2 cm from the detector and the reading displayed is 8000 counts / minute.

The sample is moved a distance of 10 cm from the detector. The reading returns to an average value of 22 counts / minute.

Explain why the reading returns to the original value.

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(c) An alpha-particle passes into a region where here is a magnetic field. In the magnetic field, a force acts on the alpha-particle so that it follows a circular path. Fig. 3.1 shows that the particle passes through point J.

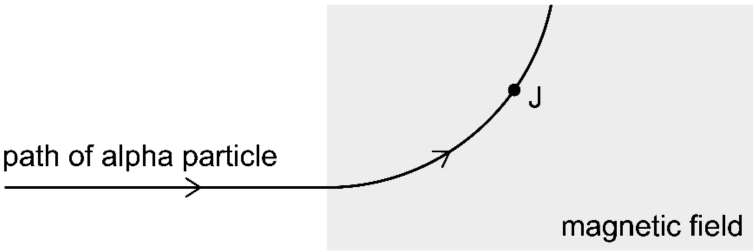

Fig. 3.1

(i) On Fig. 3.1, draw an arrow through point J to show the direction of the force on the alpha-particle at J.

(ii) Determine the direction of the magnetic field and mark a tick in the box (✓) that indicates this direction.

☐	To the left
☐	To the right
☐	Towards the top of the page
☐	Towards the bottom of the page
☐	Into the page
☐	Out of the page

(iii) Explain whether this force does work on the alpha-particle as the particle moves along the circular path.

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4 Phosphorous-32 ($^{32}_{15}P$) is an isotope of phosphorus that undergoes radioactive decay.

(a) The most common isotope of phosphorus is phosphorus-31.

(i) Describe the structure and composition of a neutral atom of phosphorus-31.

....

....

....

(ii) State how an atom of phosphorus-32 differs from an atom of phosphorus-31.

....

....

(b) Phosphorus-32 decays by beta-particle emission to a stable isotope of sulfur. The half-life for this decay is 2.0 weeks.

(i) State how a nucleus of this isotope of sulfur is different to a nucleus of phosphorus-32.

....

....

(ii) At time t = 0, a radioactive sample contains 3.2×10^{11} atoms of phosphorus-32.

At the same moment, the sample contains no atoms of sulfur. This is shown by the cross on Fig. 4.1.

On Fig. 4.1, plot a graph, to show how the total number of sulfur atoms in the sample changes with t and draw a suitable curve.

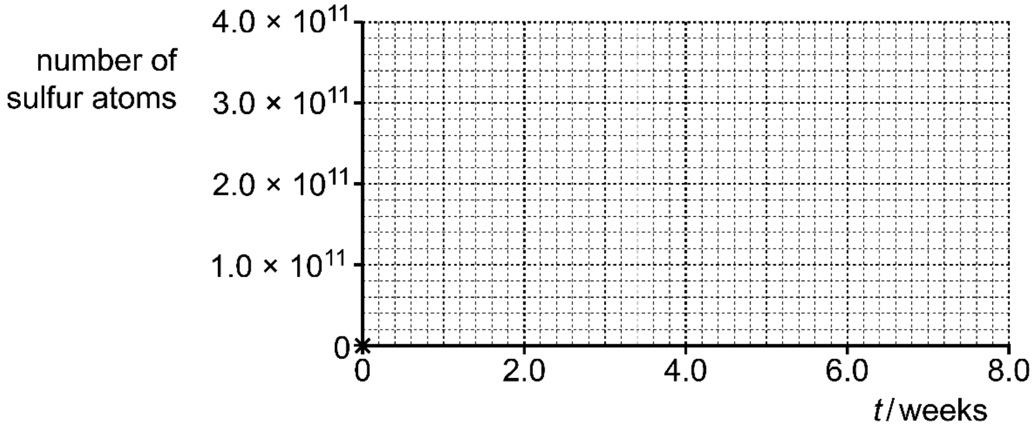

Fig. 4.1

(c) State two precautions taken when storing or moving radioactive materials.

1. ....

....

2. ....

....

5 All the isotopes of the gas radon are radioactive.

(a) State one similarity and one difference between the nuclei of two different isotopes of radon.

similarity ....

....

difference ....

....

(b) The isotope radon-222 decays by alpha-particle emission to an isotope of polonium (Po). The proton number (atomic number) of polonium is 84.

(i) Determine the number of neutrons in an atom of the polonium isotope.

number of neutrons = ...

(ii) Determine the number of protons in an atom of radon-222.

number of protons = ...

(iii) Describe how a neutral atom of helium ($^{4}_{2}He$) differs from an alpha-particle.

....

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(c) In an experiment to collect a small quantity of helium, a sample of radon-222 is enclosed in an inner glass tube which has a very thin wall. Fig. 5.1 shows that this tube is placed inside a container that is initially evacuated.

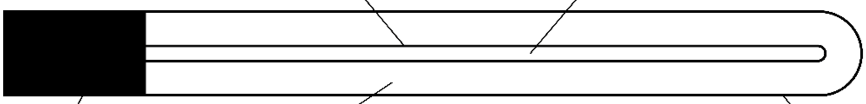

Fig. 5.1

Both the container and the inner glass tube are sealed.

As the radon-222 decays, alpha-particles pass through the thin wall of the inner glass tube.

Fig. 5.2 shows how the total number of alpha-particles produced by the radioactive decay of the radon-222 changes as time passes.

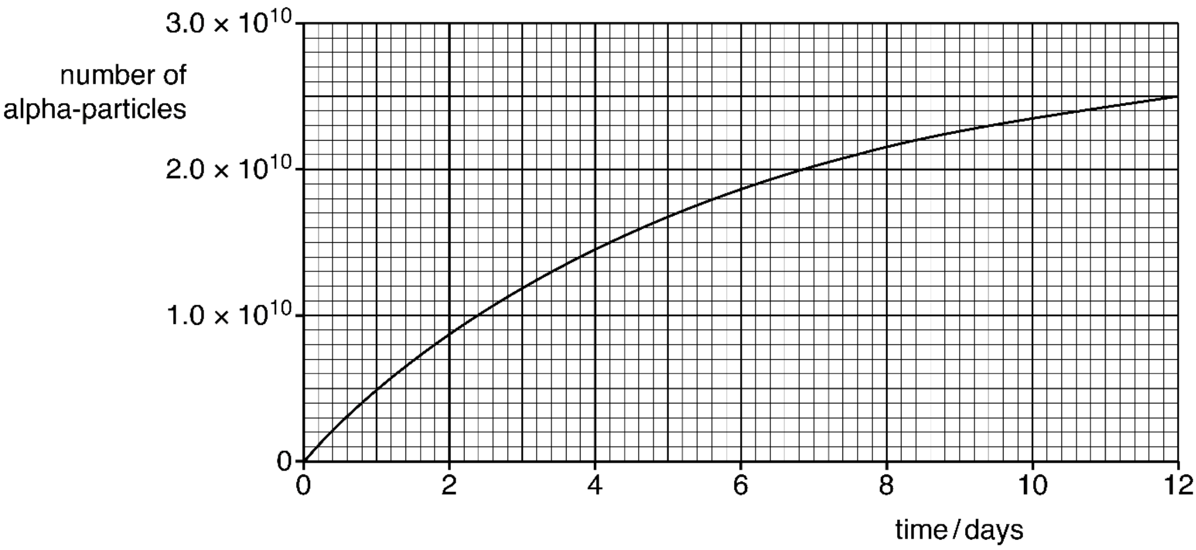

Fig. 5.2

(i) Use Fig. 5.2 to determine the number of alpha-particles produced in 7.6 days.

....

(ii) Initially, there are 2.8×10^{10} atoms of radon-222 in the inner glass tube. As each radon- 222 atom decays, it produces an alpha-particle.

Calculate the number of radon-222 atoms that remain after 7.6 days.

Number of atoms remaining = ...

(iii) Using the number of radon-222 atoms present initially and the number present after 7.6 days, calculate the half-life of radon-222.

Half-life = ...

(d) The alpha-particles become helium atoms which are collected in the vacuum shown in Fig. 5.1.

Explain, in terms of the properties of alpha-particles, why the wall of the inner glass tube must be extremely thin.

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(e) In some parts of the world, radon-222 accumulates in the air in buildings and is breathed in by people.

Explain why the presence of an alpha-emitter in the lungs is particularly hazardous.

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6 Fig. 6.1 shows a radiation detector placed on a laboratory bench.

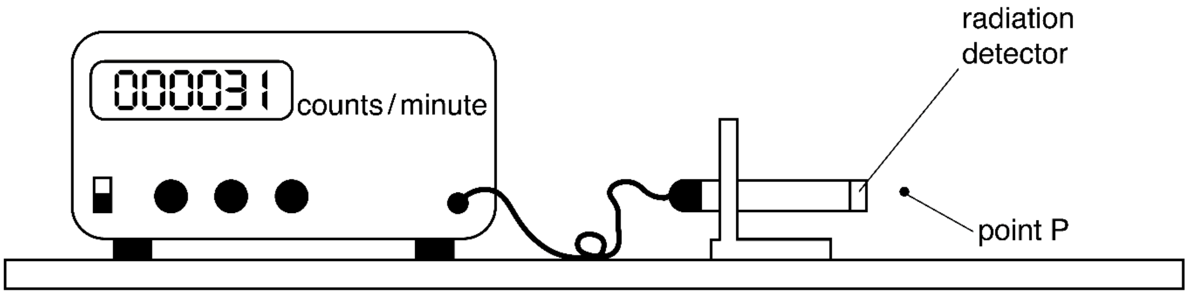

Fig. 6.1

The detector is switched on and six readings of the count rate are recorded.

The table in Fig. 6.2 shows the readings obtained.

Reading number	1	2	3	4	5	6
Count rate / Counts / minute	31	36	29	32	31	33

Fig. 6.2

(a) Using all the readings obtained, determine an average value for the background count rate.

background count rate = ...

(b) Fig. 6.1 shows a point P which is a very short distance from the end of the radiation detector.

A sample of the radioactive isotope cobalt-60 is placed at P. The average value of the count rate obtained is now 975 counts / minute.

The average count rate is determined with different objects between the radiation detector and the sample. The table in Fig. 6.3 shows the results obtained.

Object	Average count rate / Counts / minute
No object	975
Four sheets of paper	976
0.50 mm thickness sheet of aluminium	117
2.0 cm thickness sheet of lead	52

Fig. 6.3

(i) Indicate, by placing ticks (✓) in the appropriate boxes, the radiation emitted by cobalt-60.

☐ alpha-particles ☐ beta-particles ☐ gamma rays

(ii) This radiation is produced when a nucleus of cobalt-60 ($^{60}_{27}Co$) decays into a nucleus of the daughter product X. Product X is not radioactive.

Determine

1. the number of protons in a nucleus of X,

number of protons = ...

2. the number of neutrons in a nucleus of X.

number of neutrons = ...

(c) The half-life of cobalt-60 is 5.3 years.

(i) State what is meant by *half-life*.

....

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(ii) When there is a lead sheet between the detector and the sample, the average count rate is obtained from six readings taken at one-minute intervals. The six readings are given in the table in Fig. 6.4.

Reading number	1	2	3	4	5	6
Count rate Counts / minute	31	36	29	32	31	33

Fig. 6.4

There are reasons for suggesting that the variation in these readings is random and not because the number of cobalt-60 atoms in the sample is decreasing.

State two of these reasons.

1 ....

....

2 ....

....

7 Thorium-229 is a radioactive isotope used in several medical applications that involve alpha-particles and beta-particles.

(a) During ionisation, a helium atom becomes a helium ion.

Fig. 7.1 shows a diagram of a helium (He^+) ion.

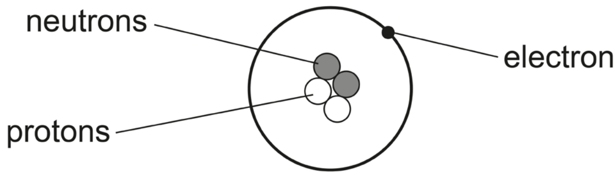

Fig. 7.1

(i) State how the structure of a helium atom differs from the structure of the helium ion.

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....

(ii) State how the structure of an alpha-particle differs from the structure of the helium ion.

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(iii) A nucleus of thorium-229 ($^{229}_{90}Th$) decays by alpha (α) emission to a nucleus of element X.

$$^{229}_{90}Th \rightarrow X + {}^{4}_{2}\alpha$$

The nucleus of X then decays to a nucleus of Y by beta (β) emission.

$$X \rightarrow Y + {}^{0}_{-1}\beta$$

Complete Fig. 7.1 to show the number of protons and neutrons in a nucleus of X and in a nucleus of Y.

Table 7.1

Nucleus	Number of protons	Number of neutrons
X		
Y		

(b) Experiments can show that a sample of a material is radioactive.

Describe the apparatus and the procedure used to show that a sample emits both alpha-particles and beta-particles.

You may draw a diagram of the apparatus, if you wish.

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(c) **(i)** State what is meant by the half-life of thorium-229.

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(ii) A sample of pure thorium-229 contains 4.0×10^{14} atoms. After 22 000 years, the number of atoms of theorium-229 in the sample is 5.0×10^{13}.

Determine the half-life of thorium-229.

Show your working.

Half-life = ...

8 A highly radioactive source that emits beta-particles is placed a few centimetres away from a detector as shown in Fig. 8.1.

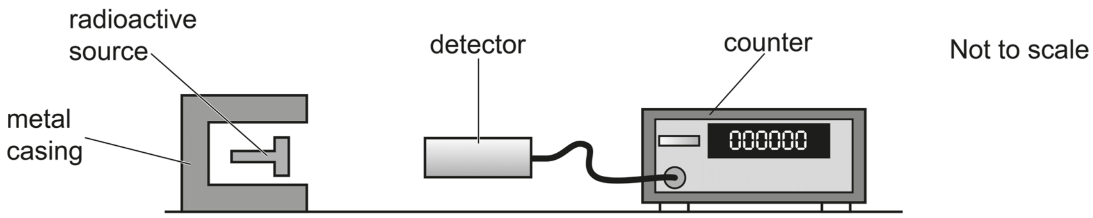

Fig. 8.1

(a) State the name of the particle which has the same mass and charge as a beta-particle.

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(b) State and explain why the metal casing in Fig. 8.1 is used.

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(c) State and explain what happens to the number of particles detected in a minute as the radioactive source is moved:

(i) a few centimeters further away from the source

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(ii) more than a metre away from the source.

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(d) A nucleus of strontium-90 (Sr-90) decays by beta emission to a nucleus of yttrium (Y).

Complete the decay equation for this decay.

$${}^{90}_{38}Sr \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}Y + {}^{\cdots\cdots}_{-1}\beta$$

(e) Nuclear fusion and nuclear fission both release large amounts of energy.

(i) Describe how the process of nuclear fusion differs from the process of nuclear fission.

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(ii) Describe the conditions needed for nuclear fusion to take place.

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