1 Electrical power generated by nuclear fission makes an important contribution to world energy needs. However Rutherford, who is credited with the discovery and first splitting of the nuclear atom, later said:

"The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."

Rutherford carried out experiments that involved firing alpha particles at nitrogen atoms.

(a) (i) Complete the equation for the interaction between nitrogen and alpha particles.

(1)

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\alpha \rightarrow \ldots\ldots\mathrm{O} + \ldots\ldots{}^{1}\mathrm{p}$$

(ii) This interaction requires a small energy input. Other similar nuclear reactions may give an energy output of no more than 20 MeV, giving some justification to Rutherford's statement. Suggest why Rutherford's statement eventually turned out to be very inaccurate.

(1)

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(b) Uranium-235 is able to undergo fission when it absorbs a neutron to become uranium-236. The equation below shows a possible fission reaction.

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3 \times {}^{1}_{0}\mathrm{n}$$

Use the data in the table to show that the energy released by the fission of one uranium nucleus is about 170 MeV.

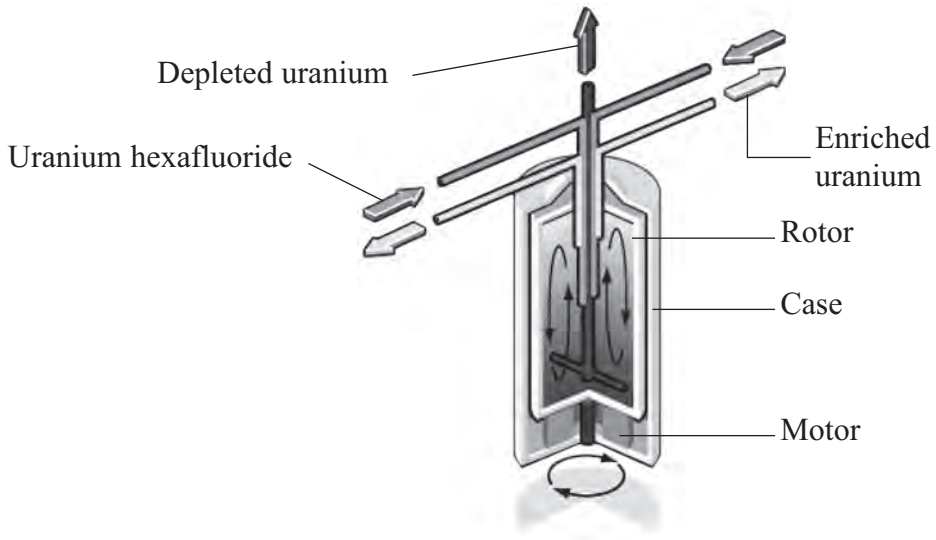
Isotope	Mass / 10^{-27} kg
^{235}U	390.29989
^{141}Ba	233.99404
^{92}Kr	152.64708
^{1}n	1.67493

(4)

(c) Naturally occurring uranium is more than 99% uranium-238. Fuel for a fission reactor requires at least 3% of the uranium to be uranium-235.

Uranium hexafluoride gas is used during the uranium enrichment process. It is fed into a centrifuge, and a rotating cylinder (rotor) sends the uranium-238 to the outside of the cylinder, where it can be drawn off, while the uranium-235 diffuses to the centre of the cylinder.

Gas centrifuge



(i) Give **one** similarity and **one** difference between the nuclei of uranium-238 and uranium-235.

(2)

Similarity .....

Difference .....

(ii) The rotor has a diameter of 30 cm and spins at a rate of 60,000 revolutions per minute.

Calculate the centripetal acceleration at the rim of the rotor.

(2)

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Centripetal acceleration .....

(iii) The rotor is subjected to huge forces because of the high spin rate.

Give **two** mechanical properties essential for the material from which the rotor is made.

(2)

Property 1 .....

Property 2 .....

(d) The waste heat from some power stations is transferred to water.

The San Onofre Nuclear Generating Station in California has reactors with a total output power of 2200 MW. These reactors circulate sea water at an average mass flow rate of 7.0×10^4 kg s^{1}. The water is heated to approximately 11 K above the input temperature as it flows through condensers, before being discharged back into the ocean.

Show that the rate at which energy is removed from the reactors is about 3000 MW, and hence estimate a value for the efficiency of the electrical power generation process.

specific heat capacity of the sea water 3990 J kg ^{1} K ^{1}

(4)

Efficiency .....

(Total for Question 16 marks)

2 In September 1987, two youngsters in Brazil removed a stainless steel cylinder from a machine in an abandoned clinic. Five days later they sold the cylinder to a scrap dealer who prised open a platinum capsule inside to reveal a glowing blue powder. The powder was found to contain caesium-137 and had an activity of 5.2×10^{13} Bq.

Caesium-137 is a β -emitter with a half-life of 30 years.

*(a) Discuss the dangers to the youngsters of possessing this cylinder for 5 days.

(3)

(b) Complete the equation to represent the decay of caesium-137 into barium.

(2)

$$^{137}_{55}\text{Cs} \rightarrow \text{\_\_\_\_}\text{Ba} + \text{\_\_\_\_}\beta^-$$

(c) (i) The decay of caesium into barium is a random process. Why is the decay process described as random?

(1)

(ii) Show that the decay constant for the caesium-137 is about 7×10^{-10} s^{-1}.

(2)

(d) In September 2007, 20 years after the cylinder was removed from the machine, the substance was still highly radioactive. Calculate the number of caesium-137 atoms remaining in the powder.

(4)

Number .....

(e) Caesium-137 is one of the products from the nuclear fission of uranium-235 in a nuclear reactor.

(i) Complete the equation for this reaction and show the number of neutrons released.

(1)

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{137}_{55}\mathrm{Cs} + {}^{95}\mathrm{Rb} + \ldots\ldots {}^{1}_{0}\mathrm{n}$$

(ii) Explain the significance to the operation of the reactor of the number of neutrons emitted in each fission.

(2)

(Total for Question 15 marks)

3 In 2012, building commenced on the International Thermonuclear Experimental Reactor (ITER) in France. The aim is for this fusion reactor to be working by 2020.

(a) (i) Describe the process of nuclear fusion.

(2)

(ii) Explain why it is difficult to maintain the conditions needed for nuclear fusion in a reactor.

(2)

(b) Explain why the fusion of hydrogen nuclei should release energy.

(2)

(Total for Question = 6 marks)