

7 Read the passage below and answer the questions that follow.

Beginning in 1934, the Italian physicist Enrico Fermi began bombarding elements with neutrons instead of protons, theorizing that Chadwick's uncharged particles could pass into the nucleus without resistance. Like other scientists at the time, Fermi paid little attention to the possibility that matter might disappear during bombardment and result in the release of huge amounts of energy in accordance with Einstein's formula, $E = mc^2$, which stated that mass and energy were equivalent. Fermi and his colleagues bombarded sixty-three stable elements and produced thirty-seven new radioactive ones. They also found that carbon and hydrogen proved useful as moderators in slowing the bombarding neutrons and that slow neutrons produced the best results since neutrons moving more slowly remained in the vicinity of the nucleus longer and were therefore more likely to be captured.

One element Fermi bombarded with slow neutrons was uranium, the heaviest of the known elements. Scientists disagreed over what Fermi had produced in this transmutation. Some thought that the resulting substances were new "transuranic" elements, while others noted that the chemical properties of the substances resembled those of lighter elements. Fermi was himself uncertain. For the next several years, attempts to identify these substances dominated the research agenda in the international scientific community, with the answer coming out of Nazi Germany just before Christmas 1938.

The radiochemists Otto Hahn and Fritz Strassmann were bombarding elements with neutrons in their Berlin laboratory when they made an unexpected discovery. They found that while the nuclei of most elements changed somewhat during neutron bombardment, uranium nuclei changed greatly and broke into two roughly equal pieces. They split and became not the new transuranic elements that some thought Fermi had discovered but radioactive barium isotopes (barium has the atomic number 56) and fragments of the uranium itself. The substances Fermi had created in his experiments, that is, did more than resemble lighter elements; they were lighter elements. Importantly, the products of the Hahn-Strassmann experiment weighed less than that of the original uranium nucleus, and herein lay the primary significance of their findings. For it followed from Einstein's equation that the loss of mass resulting from the splitting process must have been converted into energy in the form of kinetic energy that could in turn be converted into heat.

Calculations made by Hahn's former colleague, Lise Meitner, a refugee from Nazism then staying in Sweden, and her nephew, Otto Frisch, led to the conclusion that so much energy had been released that a previously undiscovered kind of process was at work. Frisch, borrowing the term for cell division in biology - binary fission - named the process fission. For his part, Fermi had produced fission in 1934 but had not recognized it.

The large amount of energy released in a nuclear fission reaction, together with the emission of more than one neutron, has made it possible for neutron-induced fission to be used as a source of useful energy. When a neutron is captured by a Uranium-235 nucleus, it causes the nucleus to fission. On average, 2.5 neutrons are emitted in these fission reactions. This is illustrated in Fig. 7.1.

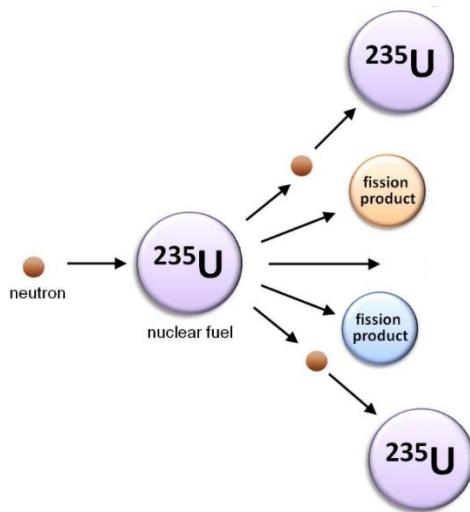


Fig. 7.1

When the conditions are suitable, a chain reaction can occur. If this chain reaction is not controlled, an explosion is likely to occur. However, if the chain reaction is controlled, as in a nuclear reactor, a source of continuous power may be created.

- (a) (i) Explain what is meant by neutron-induced fission.

.....

..... [1]

- (ii) Explain what is meant by chain reaction.

.....

..... [1]

- (iii) Suggest why, in an uncontrolled chain reaction where all neutrons are captured by Uranium-235 nuclei, the majority of the energy is released during the final stages of the fission of a sample of the uranium.

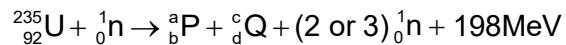
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..... [2]

[Turn over

- (b) The induced fission reaction of Uranium-235 may be represented by a nuclear equation of the form



The fission products P and Q have approximately equal masses. However, when any two nuclei are fissioned, the fission products may not be the same. If a large sample of Uranium- 235 is fissioned, many different fission products will be produced. The percentage amount of each fission product in the fissioned material is referred to as the percentage yield.

The variation with nucleon number of the percentage yield of different fission products is referred to as a 'fission yield curve' and is illustrated in Fig. 7.3.

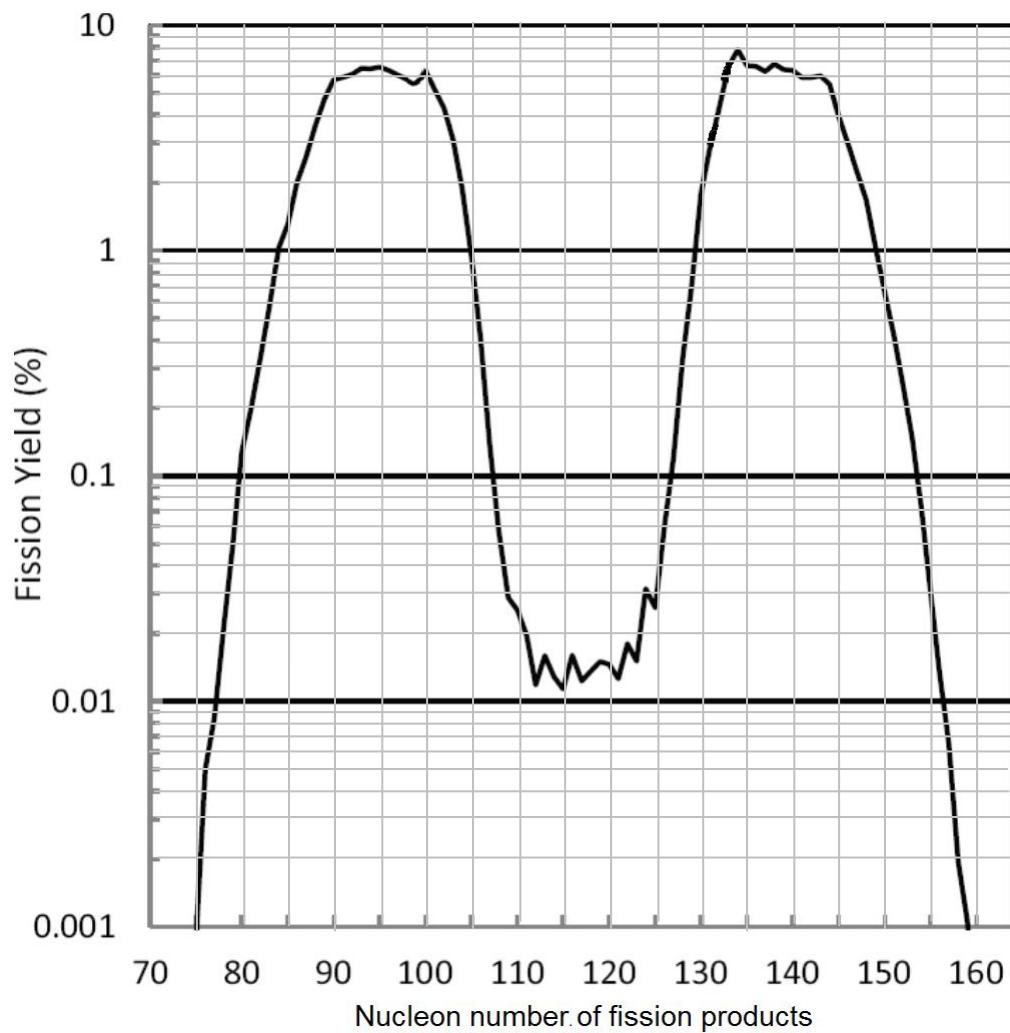


Fig. 7.3

- (i) State the proton number of the other fission product for the fission of one uranium if one of the products is $^{89}_{36}\text{Kr}$.

proton number = [1]

- (ii) Suggest why the percentage yield is shown on a logarithmic scale.

.....
..... [1]

- (iii) Show that the percentage yield of Molybdenum-99 ($^{99}_{42}\text{Mo}$) is about 400 times more than those fission products having approximately equal masses.

[2]

- (c) The energy released during one fission reaction of a uranium nuclei occurs partly as kinetic energy of the fission products (167 MeV) and of the neutrons (5 MeV).

- (i) Suggest one other mechanism by which energy is released in the fission reaction.

..... [1]

- (ii) In a nuclear power station, 25% of the energy of the fission products is converted into electrical energy.

Calculate, for the fission of a mass of 1.0 kg of Uranium-235,

1. the number of nuclei in 1.0 kg of Uranium-235,

number of nuclei = [2]

2. the electrical energy generated,

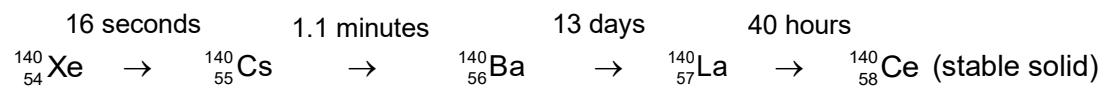
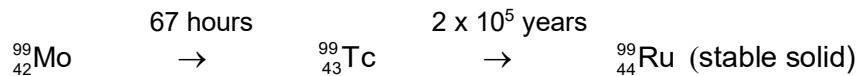
energy = J [3]

[Turn over

3. the average power output, in megawatts, of the power station if the uranium is fissioned in a time of 24 hours.

$$\text{power} = \dots \text{MW} [2]$$

- (d) The fission products are usually radioactive and give rise to a series of radioactive decay products. Each decay product has its own half-life. Two such fission products with their decay products and half-lives are shown below.



Consider equal amounts of these two products.

Suggest why there are very different problems for the storage of this nuclear waste.

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.....
.....

[3]

[Total: 19]

