Secondary Education

3rd year: Sections LH - SE

Physics

Chapter 5: Stimulated Nuclear Reactions: Fission and Fusion

تم الاعتماد على الكتاب المدرسي الوطني الصادر عن المركز التربوي للبحوث والانماء

إعداد مصطفى سكرية

Chapter 5: Stimulated Nuclear Reactions: Fission and Fusion

Objectives:

- Relate the energy produced to the mass defect;
- Understand what a nuclear fission reaction is;
- Understand what a nuclear fusion reaction is;
- Estimate the magnitude of the energy released in each reaction type;
- Give some examples on stimulated nuclear reactions.

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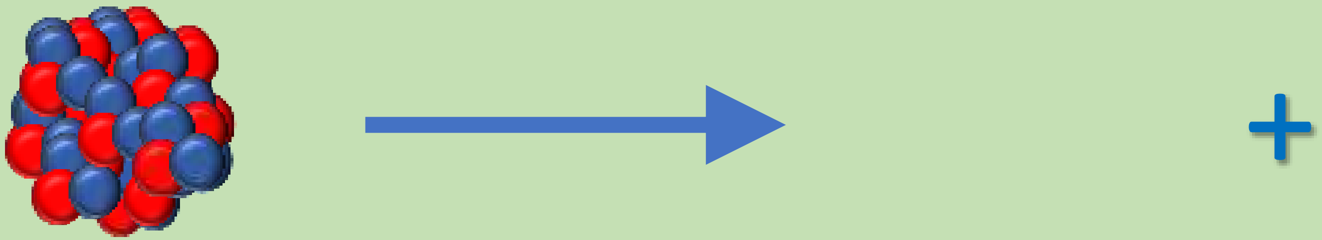
Chapter 5: Stimulated Nuclear Reactions: Fission and Fusion

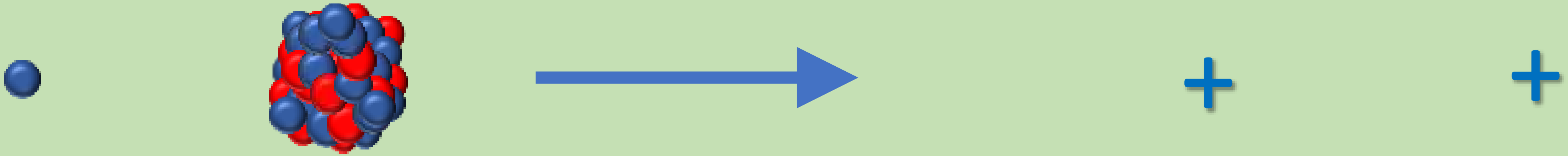
Introduction

The different forms of radioactivity (α, β and γ) seen in the previous chapter represent a type of nuclear reaction called spontaneous.

They don’t need any external intervention to take place.



Fission and fusion are nuclear reactions said to be provoked since they need an external intervention to be activated if they are to take place.



Chapter 5: Stimulated Nuclear Reactions: Fission and Fusion

Mass lost and energy

Most nuclear reactions liberate energy. This energy liberated is noticed with a loss in mass between the elements of the reaction before and after.

According to Einstein equivalence between the mass and energy, the mass is a measure of an amount of energy.

According to this, the energy liberated is: $E = (m_b - m_a)\times c^2$

With: m_b is the mass before the nuclear reaction;

m_a is the mass after the nuclear reaction;

c is the speed of light in vacuum, $c = 3\times10^8$ m/s.

In SI units, m is measured in kg , c in m/s and E in Joule (J)

In nuclear physics, the unit currently used is the electron-Volt (symbol eV) or its multiples, mainly the Mega-electron-Volt (symbol MeV)

$1\ eV = 1.6\times10^{-19}\ J$; $1\ MeV = 1.6\times10^{-13}\ J$

Application

In a nuclear power plant, uranium 235 nucleus undergoes under the impact of a slow neutron (thermal neutron) the following reaction:

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{94}_{39}Sr + ^{A}_{Z}Xe + 2\,^{1}_{0}n.$$

Given:
$m\left(^{235}_{92}U\right) = 235.0439\ u$;
$m\left(^{94}_{38}Sr\right) = 93.9145\ u$;
$m\left(^{A}_{Z}Xe\right) = 139.9252\ u$;
$m\left(^{1}_{0}n\right) = 1.0087\ u$;
$c = 3\times10^{8}\ m/s$;
$1\ u = 1.66 \times 10^{-27}\ kg.$

1) Determine Z and A indicating the used laws.

   Soddy's Laws:

   Conservation of mass number: 236 = A + 96; then A = 140;

   Conservation of charge number: 92= Z + 38; then Z = 54.

2) Calculate, in u and in kg, the mass lost «Δm» of the above reaction.

   Δm = m (U) + m (n) – m (Xe) – m (Sr) – 2 m (n) = 0.1955 u = 3.245×10^{-28} kg.

3) Calculate, in joules, the energy liberated by the above reaction.

   $E = \Delta m \times c^2$.

   $E = 3.245\times10^{-28} \times 9\times10^{16} = 2.92\times10^{-11}$ J

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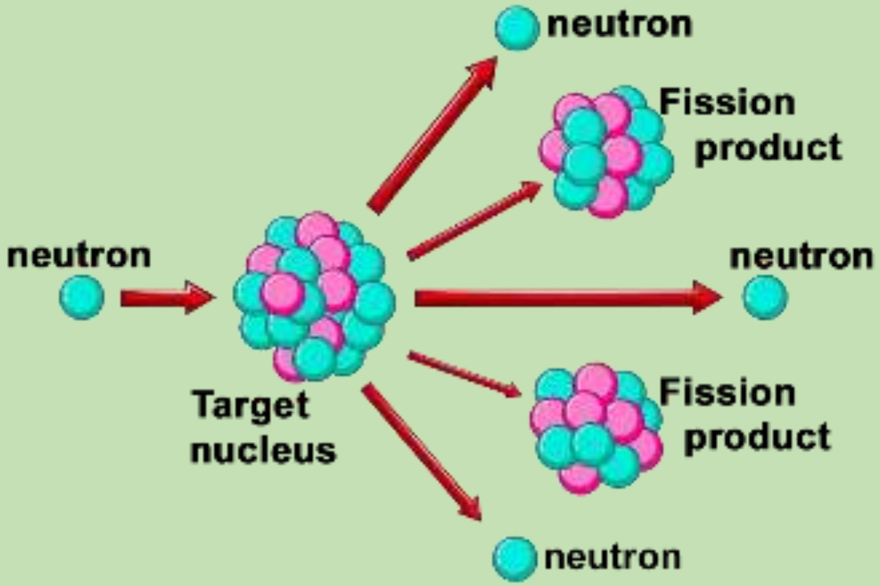
Nuclear fission

Fission is a stimulated nuclear reaction during which a heavy nucleus is divided into two lighter nuclei under the impact of a neutron.



Since neutrons lack electric charge, they are used as projectiles to bombard a nucleus targets in order to obtain other nuclei. The most commonly used nuclide in nuclear fission reactions is the uranium 235.

The fission of each U-235 nucleus produces approximately 200 MeV of energy.

Note that, all these reactions confirm Soddy's laws.

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{85}_{35}Br + {}^{148}_{57}La + 3\,{}^{1}_{0}n $$

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{91}_{36}Sr + {}^{142}_{56}Xe + 3\,{}^{1}_{0}n $$

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{94}_{39}Sr + {}^{140}_{54}Xe + 2\,{}^{1}_{0}n $$

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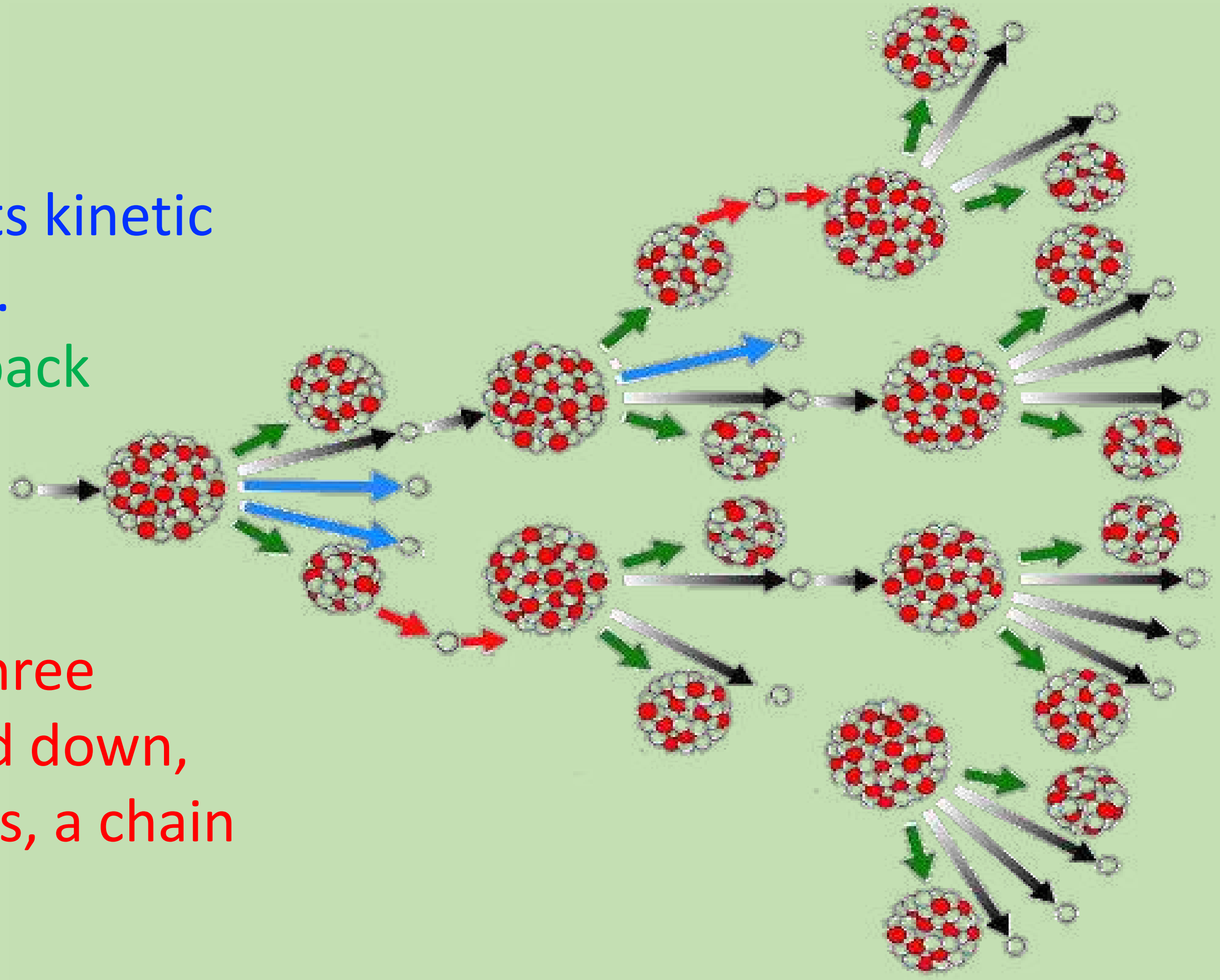
Nuclear fission

The chain reaction

The neutron can cause fission only if its kinetic energy is around 0.02 eV; ($V \approx 2$ km/s).

If the neutron is too slow, it bounces back on the nucleus. If it is too fast, it goes through without being captured.

The fission reaction liberates two or three neutrons. If these neutrons are slowed down, they can generate another fission, thus, a chain reaction is produced.



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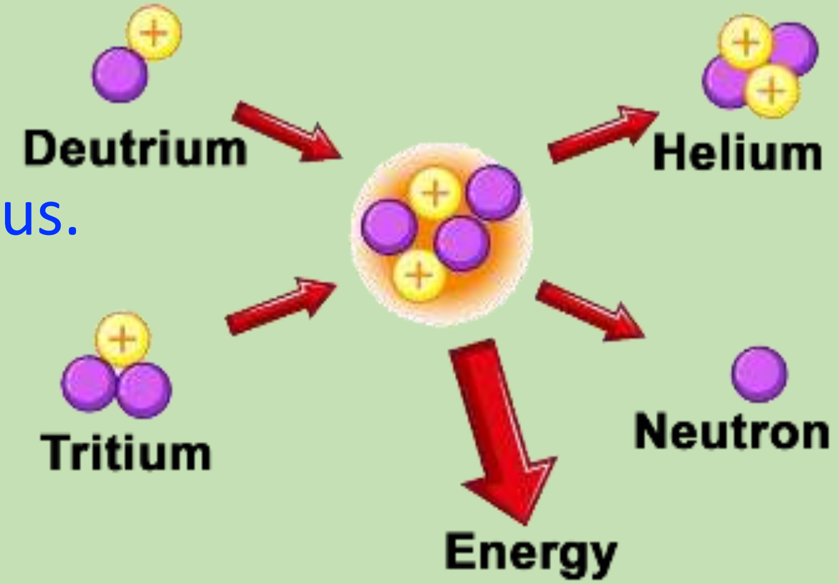
Nuclear fusion



Fusion is a stimulated nuclear reaction that consists in the binding of two light nuclei to form one heavier nucleus.

Each of the nuclei involved in a nuclear fusion reaction has a positive electric charge. In order for them to merge, they need a great speed.

The kinetic energy of the two nuclei should be around 0.1 MeV. Therefore a temperature of approximately 100 million degrees is needed so that the nuclei reach this value.

The fusion reaction is as follows:

$$^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{4}_{2}\mathrm{He} + ^{1}_{0}\mathrm{n}$$

This basic reaction produces 17 MeV of energy, which is a lot considering how small the masses are.

Application

Efficiency of a nuclear power plant (session 2019-2)

A nuclear power plant uses uranium ${}^{235}_{92}\mathrm{U}$ to produce electric energy. The aim of this exercise is to determine the efficiency of this nuclear power plant. One of the possible nuclear reactions of the uranium ${}^{235}_{92}\mathrm{U}$ is given by the following equation:

$${}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{94}_{39}\mathrm{Sr} + {}^{140}_{Z}\mathrm{Xe} + x\,{}^{1}_{0}\mathrm{n}$$

Take: m (${}^{1}_{0}\mathrm{n}$) = 1.0087 u; c = 3×10^{3} m/s ; 1 u = 1.66×10^{-27} kg.
m (${}^{235}_{92}\mathrm{U}$) = 234.9942 u; m (${}^{94}_{39}\mathrm{Sr}$) = 93.8945 u; m (${}^{140}_{Z}\mathrm{Xe}$) = 138.8892 u

1) The above nuclear reaction is fission. Justify.

   This reaction is fission. The heavy nucleus of uranium is divided into lighter nuclei (Sr and Xe) under the impact of a neutron ${}^{1}_{0}\mathrm{n}$.

2) Indicate the approximate value of the kinetic energy of a neutron that produces a nuclear fission.

   The kinetic energy of the neutron is around 0.02 eV.

Application

c = 3×10³ m/s ; 1 u = 1.66×10⁻²⁷ kg.
m ($^{235}_{92}U$) = 234.9942 u; m ($^{94}_{39}Sr$) = 93.8945 u;
m ($^{140}_{Z}Xe$) = 138.8892 u; m ($^{1}_{0}n$) = 1.0087 u;

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{94}_{39}Sr + ^{140}_{Z}Xe + x\,^{1}_{0}n$$

3) Determine Z and x, indicating the laws used.

Soddy's Laws: Conservation of mass number A : 1 + 235 = 94 + 139 + x then x = 3

Conservation of charge number Z : 92 = 38 + Z then Z = 54

4) Calculate, in u and then in kg, the loss of mass Δm that occurs in this reaction.

The mass lost $\Delta m = m_{before} - m_{after}$

$\Delta m = (234.9942 + 1.0087) - (93.8945 + 138.8892 + 3\times1.0087)$

$= 0.1931\ u = 0.1931\times1.66\times10^{-27} = 3.20546\times10^{-28}$ kg

5) Calculate, in J, the energy liberated by the fission of one nucleus of uranium $^{235}_{92}U$.

$E_{lib} = \Delta m\times c^2 = 3.20546\times10^{-28} \times (3\times10^8)^2 = 2.884914\times10^{-11}$ J

Application

$m\left({}^{235}_{92}U\right) = 234.9942\ u$; $1\ u = 1.66\times10^{-27}$ kg.

$E_{lib} = 2,884914\times10^{-11}$ J

6) The nuclear power plant consumes 1 kg of uranium ${}^{235}_{92}U$ in one day.
Assume that all the nuclei of uranium undergo fission according to the above equation.

6-1) Show that the energy liberated by the fission of 1 kg of uranium is $E = 7.3955\times10^{13}$ J.

$234.9942\times1.66\times10^{-27}$ kg → 2.884914×10^{-11} J

1 kg → E Then : $E = \frac{2.884914\times10^{-11}}{3.9009\times10^{-25}} = 7.3955\times10^{13}$ J

6-2) Deduce the energy E_1 liberated by the fission of the uranium in one second.

The liberated energy per 1 s : $E_1 = \frac{7.39550\times10^{13}}{24\times3600} = 8.5596\times10^{8}$ J

6-3) The efficiency of this power plant is given by:

$r = \frac{E_{electric}}{E_1}$ where $E_{electric}$ is the electric energy produced in one second.

Calculate the efficiency of this power plant knowing that $E_{electric} = 2.575\times10^{8}$ J.

Efficiency $r = \frac{2.575\times10^{8}}{8.5596\times10^{8}} = 0.30 = 30\ \%$

youtube.com/watch?v=3wxWNAM8Cso&t=162s