N° 1
Thermonuclear energy

The average kinetic energy of a particle at a temperature T is given by the expression: $E_K = \frac{3}{2}kT$

The temperature is expressed in Kelvin.

k is a constant called Boltzmann constant : $k = 8.62\times10^{-5}$ eV/K.

1) A fission reaction is produced by a thermal neutron at a temperature of 300 K. Calculate the average kinetic energy of the neutron. Deduce its speed.

Given the mass of a neutron : $m_n = 1.66\times10^{-27}$ kg.

2) A fission reaction is produced when the kinetic energy of each of the reacting nuclei is of the order of 0.1 MeV. Calculate the corresponding temperature to a fusion reaction.

N° 2
The two provoked nuclear reactions

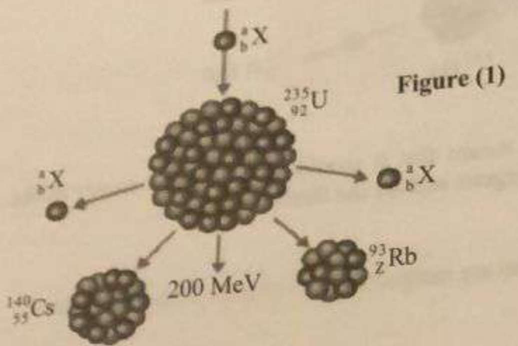

Figure (1)

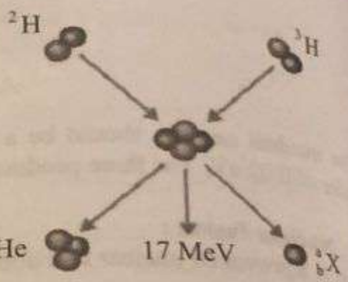

Figure (2)

1) Identify the particle $^{a}_{b}X$ and write the equations corresponding to figures (1) and (2).

2) Specify the type of each of the nuclear reaction schematized in the above figures.

3) What do the values 200 MeV and 17 MeV indicated in the figures (1) and (2) represent ?

4) a) Calculate the energy produced by 5 g of uranium in the reaction of figure (1) and that produced by 2 g of deuterium and 3 g of tritium in the reaction in figure (2). Given : Avogadro's number $N_A = 6.023\times10^{23}$.

b) Indicate which of the preceding reactions has more advantages.

N° 3
Energy liberated by nuclear fission

Given : the energy liberated by the fission of a uranium 235 nucleus is $\mathcal{E}_f = 200\text{MeV}$.

Avogadro's number : $N_A = 6.023\times10^{23}$.

1) A nuclear reactor of power 190 MW, consumes during three years, uranium 235. Calculate the mass of uranium 235 consumed in three years.

2) The fission of uranium 235 is produced by **ten moles** of the Uranium oxide UO_2. Uranium 235 in UO_2 is **enriched up to 3 %** with respect to the total uranium.

Calculate the duration of functioning of a lamp of 100 W by the fission of **ten moles** of UO_2.

N° 4

Reactions of chain fission reactions in a nuclear reactor

One of the fission reactions which produce a chain is the following:

$$\underset{(1)}{{}^{1}_{0}n} + {}^{235}_{Z}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + x\underset{(2)}{{}^{1}_{0}n}$$

Given:
Mass of uranium 235 : 235.0439 ; mass of baryum : 143.9229 u ; mass of krypton : 88.9176 u and masse of neutron : 1.00866 u.

1) Specify the numbers Z and x in the preceding fission reaction.
2) This fission reaction produces a chain reaction. Justify
3) Are the neutrons (1) and (2) energetically identical? Why ?
4) Calculate the energy liberated by this fission reaction.
5) Knowing that the kinetic energies of Ba and Kr are respectively 60 MeV and 107 MeV and that the emitted neutrons are monokinetic. We neglect the kinetic energy of the incident neutron and that of uranium.
a) Determine the kinetic energy of the produces neutron.
b) The kinetic energy of a thermal neutron is of the order of 0.02 eV. To make the preceding neutrons thermal in order to proceed with the chain, they are made to collide with free protons. After each collision the neutron loses half the amount of its kinetic energy. Find the number of collisions after which the neutron produced by the reaction becomes thermal.
6) A nuclear reactor, produces, by nuclear fission, an electric power of 190 MW, knowing that half of the nuclear energy liberated by the fission of uranium 235, using the preceding reaction, is transformed into electric energy.
Calculate the mass of uranium 235 consumed by the nuclear reactor during one year.

N° 5

Variation of the mass of the sun during its life

The sun, of actual mass of is $M_S = 2\times10^{30}$ kg, is a giant reactor of nuclear fission, it produces a radiant power of 3.9×10^{26} W supposed constant.

1) Calculate the mass lost by the sun knowing that its age is 4.5×10^{9} ans.
2) One of the nuclear fusion reactions, taking place in the core of the sun, transform hydrogen into helium:

$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}e + 2\nu + 25.7\ \text{MeV}$$

The mass of the core (where 35 % of it is hydrogen, 64 % is helium and 1 % is other elements) represents one eighth the mass of the sun.

a) Calculate the number of helium nuclei produced by the total fusion of hydrogen in the core.
b) Deduce the radiation energy produced by the transformation of hydrogen into helium.
3) When hydrogen is over, the sun formed of helium, and by fusion, helium is transformed into carbon under the reaction :

$$3.{}^{4}_{2}He \rightarrow {}^{12}_{6}C + \gamma + 7.27\text{MeV}$$

a) Calculate the total number of helium in the core.
b) Deduce the energy produced by the total fusion of helium and its formation into carbon.
4) The sun dies when its core has no more carbon.
a) Calculate the energy radiated by the sun before it dies.
b) After how much time will the sun die?

N° 6
Plutonium 239 as a fuel

A nuclear reactor produced electricity using natural uranium. Natural uranium is composed of 99.3 % uranium 238 (non fissile) and of 0.7 % of uranium 235 (fissile).

The starting of the reactor requires increasing the percentage of fissile nuclei, for this we enter the ... increasing uranium 235 with respect to uranium 238 by gaseous diffusion.

The fission, by slow neutrons, of uranium 235, produces fast neutrons which are captured by uranium 238 to form uranium 239. Uranium 239 β^- radioactive and is transformed into fissile plutonium 239.

Given : $m_{\bar{\nu}} = 5.5\times10^{-4}$ u; mass of neutron $m_n = 1.00866$ u ; 1 u = 931.5 MeV/c^2.

1) Define « fissile nucleus ».
2) Give the other name for «slow neutron».
3) What are the characteristics (mass; charge; speed and penetration ability) of an antineutrino ?
4) In the third paragraph we talk about three nuclear reactions two of which are the following:

$$ {}_0^1n + {}_{92}^{235}U \rightarrow {}_{84}^{140}Xe + {}_{38}^{95}Sr + x\,{}_0^1n \quad (1)$$

$$ {}_{92}^{A'}U \rightarrow {}_{Z''}^{A''}Pu + 2.{}_{-1}^{0}e + 2.\bar{\nu} \quad (2)$$

a) Determine x, A', A" and Z" in the equations (1) and (2).
b) Indicate the type of each of the reactions (1) and (2) (spontaneous or provoked).
c) Write the third equation.

5) The kinetic energy of a rapid neutron, produced by the reaction (1), is $E_{Kn} = 2$ MeV. The neutron is not relativist.

a) Calculate the speed V_n of the neutron.
b) Determine, applying the conservation of linear momentum on equation (3), the kinetic energy of uranium 239 nucleus. Knowing that the uranium 238 nucleus is supposed to be at rest.
c) Specify if the equation (3) liberates or consumes energy.

6) One of the fission reactions of plutonium 239 is the following:

$$ {}_0^1n + {}_{94}^{239}Pu \rightarrow {}_{58}^{146}Ce + {}_{38}^{94}Sr + 2.{}_{-1}^{0}e + 2.\bar{\nu}$$

	Pu	Ce	Sr
Nucleus			
Mass in u	239.0522	145.9187	93.9154

a) Calculate the energy produced by the fission reaction of plutonium 239.
b) An electric plant, using a nuclear reactor, produces an electric power of 1300 MW. This power is obtained by the fission of uranium 235 and of plutonium 239. The energy liberated by plutonium 239 represents 27 % of the produced electric energy.

Calculate the yearly mass of plutonium 239 which produces the 27 % of the electric energy.

N° 7
Production of nuclei by nuclear collisions

Given: 1 u = 931 MeV/c²

Nucleus	$^{7}_{3}Li$	$^{1}_{1}H$	$^{1}_{0}n$	$^{4}_{2}He$	$^{14}_{7}N$	$^{17}_{8}O$
Mass in u	7.0158	1.0073	1.0087	4.0015	14.0031	16.9991

1) Consider the lithium nucleus : $^{7}_{3}Li$.
Define the binding energy of a nucleus, then determine its value is MeV.

2) The lithium $^{7}_{3}Li$ nuclei are bombarded by protons. We obtain on α particles.
a) Write the equation of the nuclear reaction listing the laws used.
b) We detect, in addition to α particles, γ radiation. Explain the origin of this radiation.
c) Determine the energy liberated by the nuclear reaction, and indicate under what form this energy appears.

3) The preceding α particles are used to transform immobile nitrogen $^{14}_{7}N$ nuclei, to oxygen $^{17}_{8}O$.
a) Write the equation of this reaction, precising what other nuclei appear.
b) Calculate the mass defect in this reaction. Interpret the result.
c) Find the minimal kinetic energy of a helium nucleus necessary to realize this reaction.

N° 8
*Formation of a nucleus X

An α particle, of kinetic energy 5.30 MeV, is captured by $^{9}_{4}Be$ nucleus, initially at rest. A nucleus X is produced with the emission of γ rays of wavelength 8.5×10^{-14} m.

1) Write the equation of disintegration and identify the nucleus X.
2) Calculate the energy liberated by this reaction.
3) Calculate the energy of the γ radiation.
4) Applying the conservation of total energy, calculate the kinetic energy of X.

Given:
$1u = 931.5\ MeV/c^2 = 1.66\times10^{-27}\ kg$; $1\ MeV = 1.6\times10^{-13}\ J$;
Planck's constant : $h = 6.62\times10^{-34}\ J.s$; $m_{\alpha} = 4.0026\ u$; $m_{Be} = 9.0121\ u$; $m_X = 13.0033\ u$.