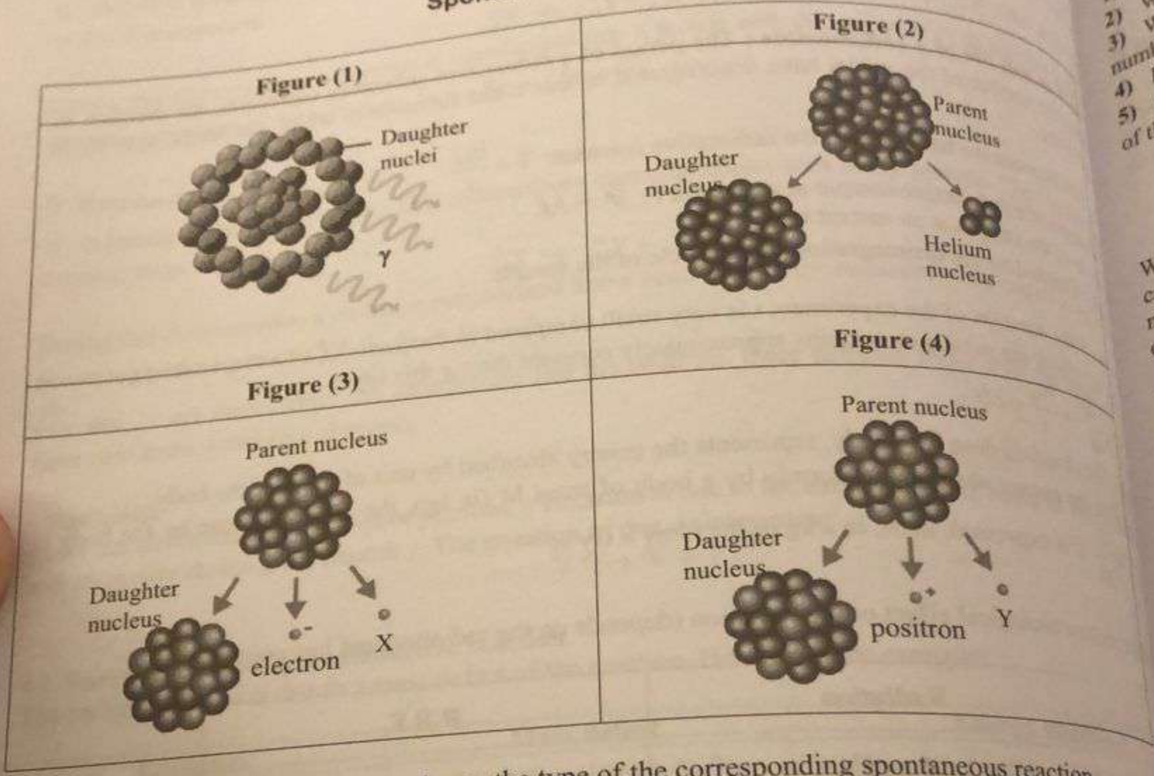
2 Exercises and problems

Given for all exercises, unless indicated otherwise :
Avogadro's number : $N_A = 6.022 \times 10^{23}$;
Planck's constant : $h = 6.62 \times 10^{-34}$ J.s ;
Speed of light in vacuum : $c = 3 \times 10^{8}$ m/s ;
Mass of the proton : $m_p = 1.00728$ u ;
$1\ u = 931.5\ MeV/c^2 = 1.66 \times 10^{-27}$ kg;
$1\ MeV = 1.6 \times 10^{-13}$ J;
mass of Helium : $m_{He} = 4.0026$ u ;
mass of a neutron : $m_n = 1.00866$ u

N⁰ 1
Spontaneous nuclear reactions



1) Identify, for each of the figures above, the type of the corresponding spontaneous reaction.
2) Identify the particles X and Y. Precise the speed of each.
3) What is the nature of the radiation emitted in figure (1) ?

N⁰ 2
Energetic study of the γ radiation

The mass of oxygen in the ground state is 15.994915 u, after the emission of a γ ray of energy 6.1 MeV.

1) Calculate the wavelength of the γ radiation.
2) Give the reason behind the emission of this radiation.
3) Write the equation of disintegration.
4) During the de-excitation, a mass is transformed into energy. Calculate, in u, this mass.
5) Calculate the mass of oxygen when it is in the excited state.

N° 3
Energetic study of an α radiation

Bismuth $^{212}_{83}Bi$ is α and γ radioactive. The daughter nucleus is an isotope of thallium Tl.

Given: $m_{Bi} = 211.991876$ u ; $m_{Tl} = 207.982013$ u and $m_{\alpha} = 4.0015$ u.

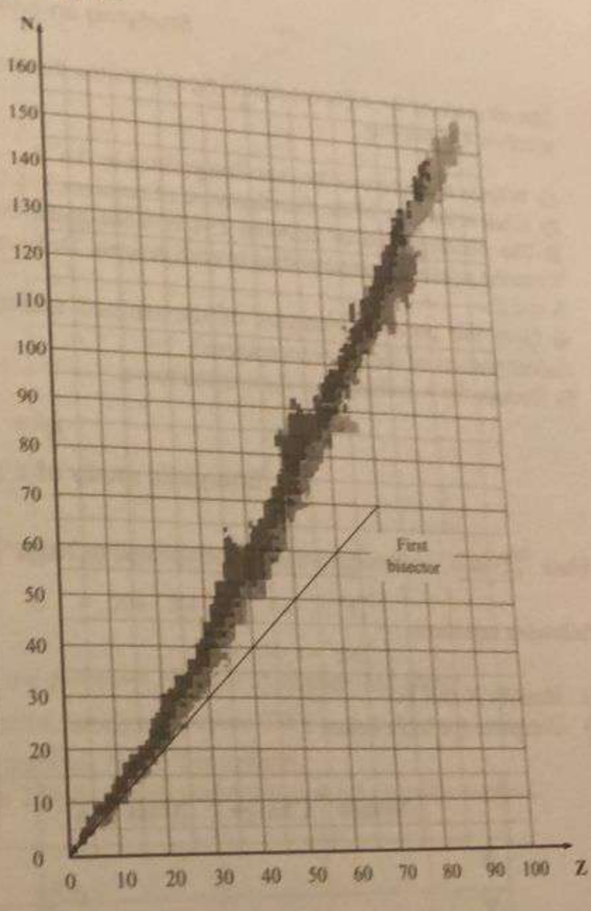
1) Give the cause of the emission of γ.
2) Write the equation (1) of the γ de-excitation.
3) Write the equation (2) of the disintegration of the bismuth nucleus and deduce the mass and charge numbers of the thallium nucleus.
4) Determine the energy liberated by the nuclear reaction (2).
5) Knowing that the wavelength of the γ radiation is 3.78 pm (1pm = 10^{-12} m). Determine the kinetic energy of the α radiation, and deduce its speed (we neglect the recoiling kinetic energy of the thallium nucleus).

N° 4
Segre's Diagram

We can classify all the known nuclei in a graph called Segre's diagram, which represents the number of neutrons N as a function of the number of protons Z.

We distinguish four difference zones :

- A central zone (1) called valley of stability and constituted of stable nuclei. (We note that for $Z < 30$ the stable nuclei are situated close to the first bisector, for which $N = Z$)
- A zone (2) where heavy nuclei are situated ($Z > 82$).
- A zone (3) where the present nuclei have excess in neutrons with respect to stable nuclei of the same mass number A.
- A zone (4) where we place nuclei which have an excess in protons with respect to stable nuclei of the same mass number A.



1) Name the forces of interaction which exist between the nucleons and indicate their types (attractive or repulsive).
2) Compare the magnitudes of the preceding forces. Indicate which insures the cohesion of the nucleus.
3) One of the preceding interactions can't have an effect except for short ranges. What is this interaction and give the order of magnitude of its range.
4) Precise, for each of the zones (2), (3) and (4), the type of the corresponding radioactivity.
5) Indicate, on the figure, the 4 zones of the hypothesis.

N° 5

Why do we neglect the recoiling kinetic energy of daughter nuclei ?

The radium (Rn) 226 nucleus, gives a radon (Ra) nucleus, in the ground state, by an α disintegration.

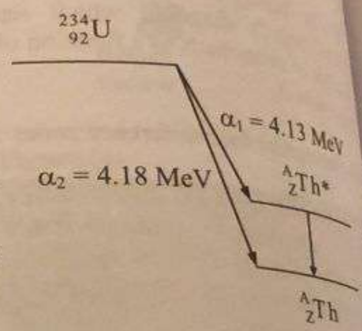
Given: $m_\alpha = 3726\ MeV/c^2$, $m_{Ra} = 206800\ MeV/c^2$ and $c = 3\times10^8\ m/s$.

1) Write the equation of disintegration of radium 226.
2) The experimental study shows that the kinetic energy of the α particle is: $E_{K\alpha} = 4.8\ MeV$.
a) Calculate the speed of the α particle.
b) Applying the conservation of the linear momentum to the disintegration of the radium nucleus, supposed at rest, calculate the speed of the produced nucleus.
c) Deduce, in MeV, the kinetic energy E_{KRn} of the radon nucleus.
d) Calculate the ratio $\frac{E_{KRn}}{E_{K\alpha}}$. Conclude.

N° 6

Studying an energy diagram

The diagram of the adjacent figure, represents the disintegration of the uranium 234 nucleus.



1) What is the nature of the radiation emitted by Th^* ?
2) What is the type of the disintegration of uranium 234 ?
3) The disintegration of uranium 234 is made under two processes. Write the equation corresponding to each process. Deduce the values of A and Z.
4) Give the possible energies of the emitted radiations by the disintegration of the uranium nucleus?
5) Deduce the wavelength of the emitted wave.

N° 7

Energetic study of a β^- radioactivity

Fluor $^{20}_{9}F$ is β^- radioactive and is transformed to Neon $^{A}_{Z}Ne$ in the ground state along the processes in the following equations :

$$\begin{cases} ^{20}_{9}F \rightarrow\ ^{A}_{Z}Ne^* + \beta^- + X \\ ^{A}_{Z}Ne^* \rightarrow Ne + Y \end{cases}$$

1) Identify X and Y.
2) Complete the table below :

	Nature	Charge	Mass in u	Speed in vacuum compared to the speed of light c
X				
Y				
β^-				

3) Summarize the system of equations in one equation.
4) In the presence of Y, of energy 1.6 MeV, the electron is emitted with a maximum kinetic 5.4 MeV . Given : mass of the electron : 5.50×10^{-4} u and the mass of the Neon nucleus : 19.99244

a) Using the relativistic formula of the kinetic energy of a particle of mass m moving with a speed V is : $E_k = \left(\frac{1}{\sqrt{1-\left(\frac{V}{c}\right)^2}} - 1\right)mc^2$. Calculate the speed of the electron.

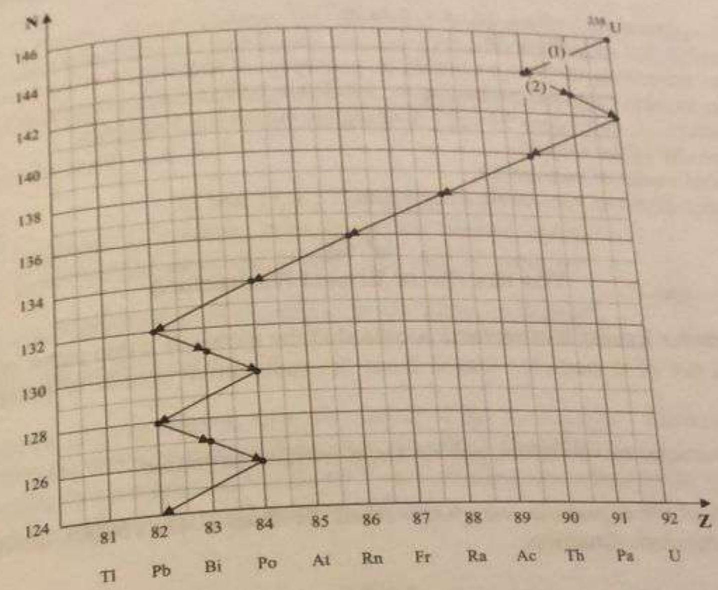
b) Neglecting the recoil energy of Neon and supposing that fluor is at rest. Calculate the energy liberated by the reaction of disintegration of fluor.

c) Deduce, in u, the mass of fluor 20.

N° 8
Radioactive family

A radioactive family is composed of a system of unstable nuclei all originating from the same unstable nucleus which, by disintegration, will finally give a stable one.

In the figure below, we consider the family of the radioactive uranium 238.



1) Specify the type of the radioactivity of each of the processes (1) and (2) schematized above.
2) Can you note a β^+ disintegration in the radioactive family of uranium 238 ?
3) Uranium is naturally transformed into a stable nucleus. Name this nucleus.
4) Write the equation of disintegration of uranium 238 during its transformation into a stable nucleus.

N° 9
Applications of the law of radioactive decay

A - The radioactive constant of the isotope of mercury 197 is $0.0108\ h^{-1}$.
1) Calculate the period of mercury 197.
2) Find the ratio of the rest number of nuclei to the initial number of mercury nuclei after 3 periods. Sa
question for after 10 days.

B – The half life of a radioactive isotope is 6.5 h. Knowing that the sample contains initially $48\times10^{...}$ ... this isotope.
1) Calculate the initial activity of this sample.
2) Find the activity of the sample after 28 h. Deduce the remaining number of nuclei and the ... number of nuclei.

C – The half life of radon 222 is 3.9 days. A sample containing radon 222 produces, during 5 s, ... particle. Calculate :
1) The radioactive constant of radon 222.
2) The activity of the sample.
3) The mass of radon in the sample.

D – Gallium $^{67}_{31}Ga$ is a radioactive, with a period of 78.25 h. A sample initially contains a mass of 3.4... gallium.
1) Calculate the initial activity and that after 48 h.
2) Find the volume of helium produced after 48 h. Given: Molar volume at N.T.P: 22.4 L.

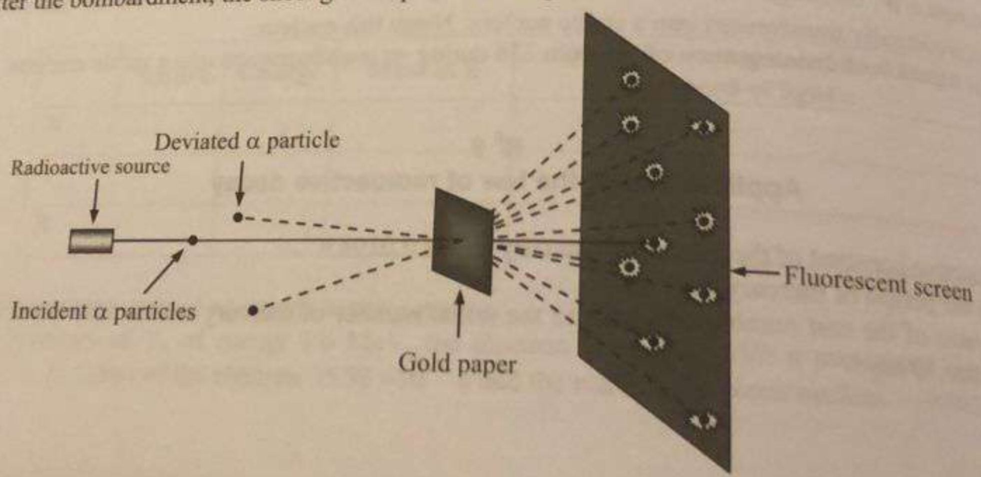
E – The radioactive constant of sodium 24 : $\lambda = 1.3\times10^{-5}\ s^{-1}$.
1) Calculate the half life T of sodium 24.
2) Let N(t) be the remaining number of nuclei in a sample of sodium 24 at an instant t. Determine, ... function of N(t), the number of nuclei remaining at : t + T; t + 1,5T; t + 2T.
3) A sample of sodium 24, undergoes 54×10^{17} disintegrations during 5 minutes.
a) Calculate the activity of the sample.
b) Find the number of nuclei of sodium 24.
c) Deduce the number of nuclei remaining after a time T ; 1.5T and 2T.

N⁰ 10

The results of Ernest Rutherford

In 1911, the British scholar **Ernest Rutherford** bombarded the atoms of a thin paper of gold (of thickness of the order 1 μm) by a ray of α particles issued from the radioactive source of polonium, he reached the following results :

1. The majority of α particles traversed the golden sheet without deviation.
2. A very small number of the α particle, which traversed the sheet (1 for 10000), deviated by more than ... with respect to their incident direction.
3. Among the deviated particles. A larger number of the α particles has undergone an important deviation and some has recoiled towards the source along the incident direction.
4. After the bombardment, the sheet gains a positive charge.



3- **Interpretation of the results :**
1) Identify the α particle (name ; symbol; charge number ; mass number).
2) The gold nucleus is characterized by : $^{197}_{79}Au$.

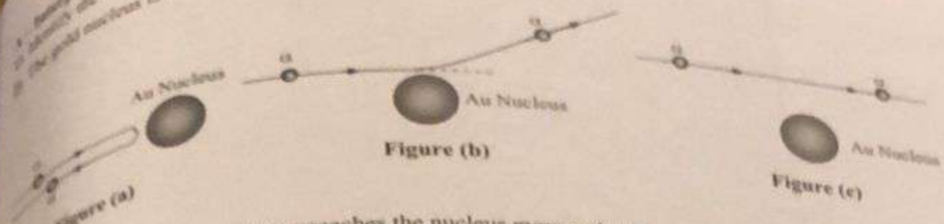
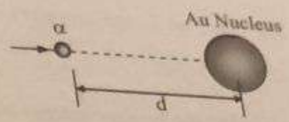


Figure (a)
Figure (b)
Figure (c)

a) In the figure (a), the α particle approaches the nucleus more and rebounds back.
In figure (b), the α particles almost reach the gold nucleus and deviates away from the incident direction.
The deviations in the figures (a) and (b) are interpreted by a force. Name this force and give its expression.
b) In the figure (c), the α particle doesn't undergo any deviation. Interpret this observation.
c) Associate to each of the figures (a), (b) and (c) the number of the result corresponding to the experiment of **Rutherford**.
d) One of the results of **Rutherford** shows the existence of free space in the gold atom. Precise the number of the result.
e) How do you interpret the result in n° **4.** ?

B- **Theoretical study**

The polonium source produces α particle with an initial kinetic energy $E_{c0} = 5.28\,MeV$. The potential energy of the system [α ; Au] is given by : $E_P = \frac{2.2752}{d}\times10^{-13}$ (E_P is expressed in MeV and d is the distance between the centers of the nuclei expressed in m).



1) The particle α rebounds, at a distance d_0 from the center of the Au nucleus , when its initial kinetic energy is transformed totally into potential energy of the system [α ; Au]. Calculate d_0.
2) Knowing that the radius of a nucleon: $r_0 = 1.2\times10^{-15}$ m. Calculate the radius of the gold nucleus.
3) The α particle could never reach the gold nucleus. Why ?

N° 11

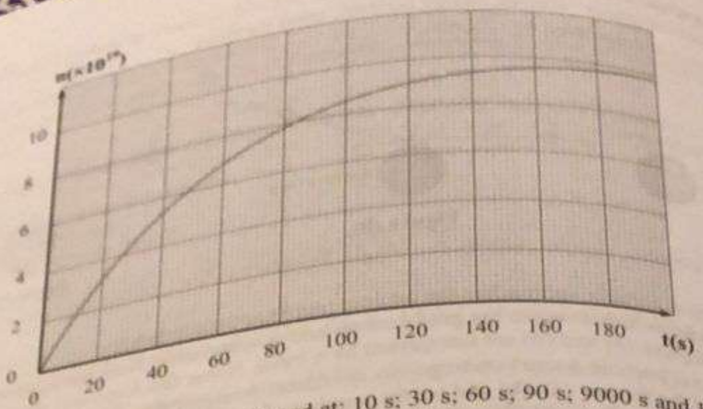
Studying the disintegration of Neon 23 sample

Indications: Neon 23, is β^- radioactive, and is transformed to sodium.

The number of protons in the Neon nucleus is : 10.

The respective masses of the neon and sodium nuclei : 22.994465 u and 22.989768 u.

1) Determine, with justification, the mass number and the charge number of the produced sodium nucleus.
2) Calculate the radii of the neon and sodium nuclei supposed spherical.
3) Calculate the binding energy per nucleon for each of the preceding nuclei.
4) Compare the stabilities of the preceding nuclei. Was this conclusion expected? Why?
5) We study the number of nuclei « n » of sodium produced by a sample of neon with time, it allows us to represent the graph in the following paper :



a) Extract the number of sodium nuclei produced at: 10 s; 30 s; 60 s; 90 s; 9000 s and 10000 s.
b) Deduce the number of neon present in the sample at $t_0 = 0$ s.
c) Find, using the graph, the half life of the radioactive neon 23.

N° 12
Aston curve

The curve of Aston represents the binding energy per nucleon $\left(E_a = \frac{E_B}{A}\right)$ of a nucleus as a function of mass number A.

1) Define the binding energy of a nucleus.
2) Give the expression of the binding energy per nucleon of a nuclide $^{A}_{Z}X$.
3) In the table below we give a nuclide and its corresponding binding energy per nucleon.

$^{A}_{Z}X$	$^{2}_{1}H$	$^{3}_{1}H$	$^{4}_{2}He$	$^{6}_{3}Li$	$^{12}_{5}B$	$^{12}_{7}N$	$^{12}_{6}C$	$^{20}_{10}Ne$	$^{31}_{15}P$	$^{40}_{20}Ca$
$\frac{E_B}{A}$ (MeV)	1.12	2.83	7.1	4.7	6.7	6.2	7.68	8.0	8.48	8.55

$^{A}_{Z}X$	$^{56}_{26}Fe$	$^{88}_{Z}Rb$	$^{98}_{42}Mo$	$^{120}_{50}Sn$	$^{137}_{55}Cs$	$^{157}_{64}Gd$	$^{197}_{79}Au$	$^{206}_{82}Pb$	$^{235}_{92}U$	$^{239}_{94}Pu$
$\frac{E_B}{A}$ (MeV)	8.7	8.68	8.64	8.5	8.45	8.2	7.92	7.86	7.6	7.56

a) Represent the Aston curve.
Scale: 1 cm ↔ 20 unit of mass (on the abscissa axis) and 1 cm ↔ 1 MeV (on the ordinate axis).
b) Specify the most stable nucleus.
c) The more stable nuclei have a binding energy larger than or equal to 8 MeV. Extract the interval of mass number corresponding to these nuclei.
d) Find, graphically, the binding energy per nucleon of $^{190}_{76}Os$ (Osmium). Deduce its mass.
e) Knowing that the mass of $^{88}_{Z}Rb$ (rubidium) is: 87.911326 u. Calculate the atomic number Z of Rb.

N° 13
Half-life of Vanadium 52

We study the disintegration of a sample containing vanadium 52 nuclei. Using a counter, we determine the number of disintegrations in a constant duration of $\tau = 5$ s. The measurements are taken in minutes.

t (min)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
n	[illegible]	1257	1075	873	741	584	471	428	355	296	235	195	155	132

1) Define the activity of a sample at a given instant.
2) Calculate, in Bq, the activities detected which correspond to the instants in the above table.
3) Represent, on a figure, the activity as a function of time.
4) Extract the half life of vanadium 52.

N° 14
Using detectors

The radioactive phosphorous isotope $^{32}_{15}P$ is used, in the biochemical studies of the organs, by the emission of β^- particles.

We plant in an organ 10^{-6} g of phosphorous 32, of half life 14.3 days.

1) Write the equation of the disintegration of phosphorous 32.
2) Calculate the radioactive constant of phosphorous.
3) Deduce the initial activity of phosphorous.
4) Calculate the percentage of the activity after 57 days with respect to the initial activity.
5) Find the time when the activity of phosphorous become 1/100 of its initial value ?

N° 15
Age of a volcanic rock

The radioactive decay and the ratio of the masses of $^{87}Sr/^{87}Rb$ are used to date back volcanic rocks.

A – Studying the radioactivity of the $^{87}_{37}Rb$ nucleus

The rubidium nucleus is radioactive and is transformed into strontium. Write the equation of disintegration of rubidium. Specify the type of this disintegration.

B – Age of the rock

A cold volcanic rock has a mass ratio $^{87}Sr/^{87}Rb$ equal to 0.004. Knowing that this rock doesn't contain, at the instant we find it, any rubidium of radioactive period 4.8×10^{10} years.

1) We designate by N_d the number of disintegrations by the rock and by N_{Rb} the actual number of rubidium.

show that : $\dfrac{N_d}{N_{Rb}} = 0.04$.

2) By the aid of the decay law of radioactivity. Find the age of the rock.

N° 16
Age of rocks by potassium 40

The potassium nucleus $^{40}_{19}K$, is β^{+} radioactive, it is transformed into argon Ar.
The half life of potassium 40: $T = 1.5\times10^{9}$ years.

A – Studying the nucleus $^{40}_{19}K$
1) Write the equation of the transformation of a proton into a neutron.
2) Write the equation of disintegration of potassium 40.
3) Define the half life of a radioactive nuclide.
4) Calculate, in $year^{-1}$ and in s^{-1}, the radioactive constant λ of potassium 40.

B – Dating back volcanic rocks
An ancient volcanic rock, contains 25 g of potassium 40 and 0.66×10^{-2} g of argon. Knowing that this ro[ck] doesn't contain any potassium 40 when it was formed.
1) Calculate the ratio of the number of disintegrated nuclei N_d to the number of remaining nuclei o[f] potassium in the rock.
2) What can we say about the age of the rock compared to T ? Deduce that $N_d = \lambda N t$.
3) Deduce the age of the rock.

N° 17
Dangers of radioactivity

We consider an iodine 131 sample (β^{-} radioactive) and another cesium 137 (β^{-} radioactive) each carrying th[e] same number of nuclei $N_0 = 10^{20}$ at the instant $t_0 = 0$.
The period of iodine 131: $T_I = 8$ days and that of cesium 137: $T_{Cs} = 30$ years.

1) Define a radioactive period.
2) Why is the radioactive sample dangerous ?
3) We denote by N the remaining number of nuclei in a sample at an instant t. Complete the table below.

	t	0	8 days	1 year	30 years	300 years
For iodine	$\frac{N}{N_0}$					
	Activity: A_I (Bq)					
	Power of the sample (Watt)					
For cesium	$\frac{N}{N_0}$					
	Activity: A_{Cs} (Bq)					
	Power of the sample (Watt)					

[G]iven: The energy liberated by the disintegration of an iodine 131 nucleus and by a cesium 137 nucleus ar[e] [re]spectively 0.9780 MeV and 1.07 MeV.

Specify, referring to the table, the sample which is more dangerous for man.

N° 18
Using the Geiger counter

A Geiger counter, an α and a β detector, is placed just in front of a source of radioactive polonium 210 emitting α and γ.
We make 10 measurements, each corresponding to a duration of $\tau = 60$ s. The results are summarized in the table below:

N° of the measurement	1	2	3	4	5	6	7	8	9	10
n: detected number in each measurement	70	77	93	81	66	57	89	68	72	83

1) The detected number by the counter does not follow any law. What does it signify ?
2) Calculate the average value $\bar{n}_0$ of the numbers obtained in the above table.
3) Calculate the average value of $\bar{a}_0$ representing the average value of the numbers detected per second of the values in the table.
4) Why doesn't the number $\bar{a}_0$ have the same unit as the activity ?
5) We repeat the previous measurement and we introduce between the radioactive source and the counter an aluminum paper and we note that the detected numbers are very small compared to the absence of the paper. Interpret this observation.
6) After 60 day of the first measurement, we repeat the preceding experiment, in the absence of the aluminum paper, we find an average value $\bar{a} = 0.9195$. Calculate the half life T of the polonium 210 radionuclide.
7) The source is placed at a distance L = 2 cm from the opening of the Geiger counter; this opening is circular rand of radius r = 0.5 mm.
a) Why should we approach the radioactive source from the counter?
b) Deduce the activity of the source in the first experiment. **Given :** The area of a sphere of radius R is $4\pi R^2$.

N° 19
Studying Bismuth 212

I - Study of the nucleus $^{212}_{83}Bi$

1) Find the numbers of protons and neutrons in the nucleus $^{212}_{83}Bi$.
2) Knowing that the nucleus is spherical an that the average radius of a nucleon is $r_o = 1.2 \times 10^{-15}$ m. Calculate the average radius of the nucleus $^{212}_{83}Bi$.
3) Calculate the binding energy per nucleon of $^{212}_{83}Bi$. Mass of the ^{212}Bi nucleus: $m_{Bi} = 211{,}991876$ u ;

II - Effect of the disintegration of a sample of $^{212}_{83}Bi$

The magnetic analysis of a sample containing the radioelement bismuth $^{212}_{83}Bi$ α emitter, shows that the α particles emitted, form five monokinetic groups α_0, α_1, α_2, α_3 and α_4 called α rays. This explains the emission of four groups of gamma radiations called gamma rays γ.

α Rays	Relative abundance (%)	Kinetic energy of α particle in MeV	γ ray energy in MeV
α_0	27.2	....	0
α_1	69.9	6.036	0.048
α_2	1.6	5.762	....
α_3	0.18	5.611	0.473
α_4	1.1	5.591	0.493

1) Write, with justification, the equation of disintegration of the particle ^{212}Bi . The daughter nuclei emit an isotope of thallium Tl.
2) What is the origin behind the emission of a γ ray ? What is its nature?

3) Under what form does the energy liberated by the integration of one particle of ^{212}Bi appear (the daughter nuclei are nearly immobile)?

4) In the adjacent table we summarize the abundance of α rays and the corresponding kinetic energy of emission of a radioactive sample of ^{212}Bi.

a) Using some of the given in the table, calculate the energy liberated by the disintegration of a Bi nucleus.

b) Complete the table.

c) Calculate the maximum wavelength of the emitted photon.

5) A sample of 1 mg of pure ^{212}Bi, is used to dissolve an aluminum paper placed at a certain distance from the sample.

Knowing that the paper interacts with 20 % of the α particles (the average kinetic energy $E_{K\alpha} = 6.0...$) emitted by the sample.

The total fusion of the paper needs an energy of 45 000 J. The period of ^{212}Bi is T = 1 hours.

a) Calculate the radioactive constant λ of the sample.

b) Determine the number of particles N_0 of ^{212}Bi which are found initially in the sample of 1 mg.

c) Find the number n_i of α particles necessary to melt the aluminum paper.

d) Show that the duration of the exposition of the paper of the sample is : $t = -\frac{1}{\lambda}\ln\left(1-\frac{5n}{N_0}\right)$. Calculate

N° 20
Studying Radon 219

A – The period of Radon 219

We measure, at different separated instant by a different time constants of 8 second, the activities of a sample of Radon 219, we find the results in the table below (**Given :** $1Ci = 3{,}7.10^{10}$ Bq):

t : time (s)	0	8	16	24	32
A : activity (Ci)	10000	2500	625	156.25	39.0625
Ln(A)	9.2	7.8	6.4	5	3.7

1) Define the activity of a sample and the half life T of a radioelement.
2) Trace in a system of orthogonal axes, the representative curve of Ln(A) as a function of time t.
3) Deduce, graphically, that the value of the period of radon 219 is T = 4s and calculate the time constant of the disintegration λ.
4) Deduce the number of the nuclei N_0, Radon 219, which exists in the sample at t = 0.

B – The disintegration of Radon 219

The Radon nucleus $^{219}_{86}Rn$ is an α emitter and transforms into polonium Po. The measurement of the maximum distance covered by an α particle in a chamber of bubbles permitting to calculate its kinetic energy.

1) Write, listing the laws used, the equation of disintegration of the Radon nucleus 219.
2) The daughter nucleus can be found in an excited state or in the ground state.

a) Indicate the nature of the radiation emitted by the daughter nucleus during its de-excitation ?

b) In what forms of energy does the energy liberated by the disintegration of the Radon 219 nucleus appear in each of the following cases: **i)** the daughter nucleus is in the fundamental state.
ii) the daughter nucleus is in an excited state.

c) During the disintegration of a sample of Radon 219, the kinetic energies of the emitted α particles are 6.82 MeV ; 6.55 MeV and 6.43 MeV.

i. Deduce the energy liberated by the disintegration of the Radon 219 nucleus and calculate the energies of the emitted γ rays.

ii. Calculate at t = 8 s, the power of the sample.

Age of a rock

Nucleus	$^{238}_{92}U$	$^{210}_{84}Po$	$^{206}_{82}Pb$	$^{4}_{2}He$
Mass in u	238048	209.982	205.974	4.002063
Half-life	4.51×10^{9} yrs			

I- Studying the nuclei $^{238}_{92}U$ and $^{206}_{82}Pb$

1) Calculate the ratio of the volumes of the Uranium 238 with respect to that of Lead 206.

2) Find the binding energy per nucleon of the nucleus $^{238}_{92}U$.

3) Knowing that the binding energy per nucleon of the nucleus $^{206}_{82}Pb$ is 7.67 MeV/nucleon. Deduce the stability of Uranium 238 with respect to that of Lead 206.

II- Disintegrations and energy liberated

Uranium 238 after a series of disintegrations of α and β^- is transformed into Lead 206.

1) Write the equation of the disintegration, and precise the number x of the α nuclei and the number y of the emitted β particles. Indicate the laws used.

2) Knowing that the Lead 206 nucleus is the daughter nucleus of Polonium 210.

a) Complete the equation of the following disintegration: $^{210}_{84}Po \rightarrow {}^{A}_{Z}X + {}^{206}_{82}Pb$. Deduce the type of disintegration of the Polonium nucleus.

b) Calculate the energy liberated E_L during the disintegration of the Polonium nucleus.

c) We suppose that the kinetic energies of polonium and Lead are nearly zero and that of the nucleus X is $E_{CX} = 5.3$ MeV.

Show the existence of a γ ray of a determined wavelength.

III- Age of the rock

In an ancient rock we find 42 g of Uranium $^{238}_{92}U$ and 2 mg of Lead $^{206}_{82}Pb$. We suppose that the Lead 206 is not radioactive and the rock doesn't initially contain Lead 206.

1) Calculate the radioactive constant λ of the Uranium 238 radioelement.

2) Let N_0 be the number of nuclei of uranium in the rock at $t_0 = 0$ just before the presence of Lead. We designate by t the time if which the rock has been under the ground.

a) Calculate, as a function of N_0, λ and the number of Uranium nuclei N_U and of Lead N_{Pb} which are present in the rock at a time t.

b) Verify that: $\frac{N_{Pb}}{N_U} \cong \lambda t$. We can use the approximation $e^{\varepsilon} \cong 1+\varepsilon$ for $\varepsilon << 1$.

c) Deduce the age of the rock.

N° 22

The radioactivity of Cobalt 60

Cobalt $^{60}_{27}Co$ is β^- radioactive. Its radioactive constant is $\lambda = 4.17\times10^{-9}\ s^{-1}$.

The daughter nucleus of $^{60}_{27}Co$ is an isotope of Ni (nickel) which de-excites and gives two radiations.

1) Identify the β^- particle.

2) What is the type of the emitted radiation by the nickel ? Write the equation of the of this emission.

3) Determine the number of protons and that of neutrons in the daughter nucleus of cobalt 60.

4) Calculate, in years, the half life of the cobalt 60.

5) The β^- particle is emitted with a kinetic energy 5×10^{-14} J. These particles are absorbed by human tiss

of mass 32 kg.

a) Determine the power transferred to the tissues by a source of cobalt 60 whose activity is of $6 \times 10^{1?}$ Bq
b) This power is practically constant during one day. Justify.
c) Calculate the absorbed dose by the tissue during one second.
d) This radiation is deadly when the absorbed dose is larger than 10 J/kg. Starting from what exposure duration is the radiation deadly?

N° 23
Age of a carbon sample

Plants contain radioactive carbon 14 and non radioactive carbon 12. The proportion of these two isotopes, in plants, is practically constant and given by the ratio: $r = \frac{N(^{14}C)}{N(^{12}C)} = 1.3 \times 10^{-12}$.

At death, the plants don't assimilate the carbon, the preceding ratio is no more constant since carbon 14 is no more compensated.

The radioactive period of carbon 14 is T = 5730 years.

1) After death, does r increase or decrease ? Explain.
2) Calculate the radioactive constant of carbon 14.
3) A sample, of carbon of mass 25 g, is found in a prehistoric plant. The activity of the sample is 25 disintegrations per minute.
a) Calculate the number of the carbon 14 and 12 nuclei which is actually present in the sample (we neglect the mass of carbon 14)
b) Deduce the number of carbon 14 nuclei which is found in the sample at death.
c) Calculate the duration of death of the sample.

N° 24
Biological consequences of a radiation

A person, of mass m = 87 kg, is under α radiations, of mass m' = 0.25 g, of plutonium 239 of half life 24100 years. The energy of an α particle emitted is 5.2 MeV. The biological efficiency relative to the α radiation is 13. Knowing that the person is disposed in front of the sample for 12 h and its body receives 95 % of the α radiations.

Calculate:
1) The initial number of the plutonium nuclei in the sample.
2) The number of plutonium nuclei disintegrating in 12 h.
3) The energy absorbed by the person during 12 h.
4) The dose and the physiological equivalent of the absorbed does by the person.
5) Using the table below, deduce the consequences of this radiation on the person.

Equivalent physiological dose in Sv	Consequences
> 10	100 % death
5	50 % of deaths, cancers, blood troubles, …
2	10 % death ; cancers, diarrhea ; vomiting, …
1	Digestive troubles, sterility, risking cancer,…
0.05	Modification of the blood group formula
< 0.05	No effect

N° 25

Characteristics of the α particle — Avogadro's number

Radium 226 is a radioactive and of half life: T = 1600 years.

A- Determination of the charge of α

We place a mass m = 10^{-2} mg of radium 226 at he centre of a glass sphere, of internal radius R = 8 cm. On internal part of the sphere, we glue a small zinc sulfide screen and we observe it using a microscope. And we have vacuum inside the sphere. The radium emits particles in all directions and each time an α particle hits the screen we get scintillation.

For each element of screen area 0.01 mm², we note 19 scintillations in 100 s.

1- Calculate, in Bq, the activity of a sample of 10^{-2} mg of radium.

2- Verify that the activity of 1mg of radium is : A = 15.3×10^{7} Bq.

3- The α particle carries a positive electric charge. We receive on the armature of a capacitor, of capacitance C = 10 pF, half of the α particles emitted by a mass of 1 mg of radium, the other armature is grounded. During 1 minute, the potential difference between the armatures, is U = 147 V. Calculate the charge of an α particle.

B- Determination of Avogadro's number and the mass of α

We determine the total volume of helium released in one year, by 1 mg of radium, we find 0.172 mm³ (under normal conditions).

1) Determine Avogadro's number i.e the number of atoms in one mole of helium of mass M = 4g and of molar volume V_m = 22400 cm³ (under normal conditions).

2) Calculate the mass of the α particle.

C- Determination of the speed of α

A milligram of radium, placed in a calorimeter, release 5.85 J during 10 hours. We admit that 90 % of this energy is taken as kinetic energies for α. Calculate the speed of the α just born.

N° 26

Dating of the Trojan War

The collisions of the cosmic rays, composed particularly of very fast protons, with the nuclei found in the atmosphere, liberates fast neutrons. If the neutrons become thermal, it will interact in the atmosphere with the nuclide of Nitrogen-14 producing carbon-14 according to the reaction below :

$$ {}_{0}^{1}n + {}_{7}^{14}N \rightarrow {}_{6}^{14}C + {}_{b}^{a}X $$

Carbon-14 is radioactive, β^- emitter, **<u>of half life 5730 years</u>**, and is absorbed by the plants and the other living organisms as the ordinary carbon. **<u>In each gram of the living organism, the atoms of carbon are of large majority of stable carbon-12, but there is also 5.9×10¹⁰ atoms of radioactive carbon-14</u>**.

At the moment of death of the organism, it stops absorbing carbon, so the radioactive isotope is no more absorbed and its proportion decreases with time.

Given :
$1\ u = 931.5\ MeV/c^2$; $1\ MeV = 1.6\times10^{-13}\ J$; $c = 3\times10^{8}\ m/s$; Planck's constant : $h = 6.62\times10^{-34}\ J.s$

Masses of particles

$^{1}_{0}n$	$^{1}_{1}p$ (proton) :	e :	$^{14}_{7}N$:	$^{14}_{6}C$:	$^{12}_{6}C$
1.00866 u	1.00727 u	5.5×10^{-4} u	13.99924 u	14.003242 u	12.000000 u

A – Preliminary study.

1) a) Define thermal neutron.

b) The temperature T of such neutron is of the order of 500 K. Calculate the average kinetic energy of thermal neutron using the formula $E_K = kT$ where $k = 86\ \mu eV/K$ is Boltzmann constant.

c) Identify the particle $^{a}_{b}X$.

2) a) Determine the balanced equation of the disintegration of carbon-14.

b) i – Calculate the binding energy per nucleon of the nuclide of carbon-14.

ii – The binding energy per nucleon of carbon-14 is smaller than or greater than that of Nitrogen-14 ? Justify without calculations, your response.

c) i – Calculate the energy liberated by the disintegration of a nuclide of carbon-14.

ii – Knowing that carbon-14 is at rest and the kinetic energy of the daughter nucleus is negligible, and that of β is 156 keV, calculate the energy of the emitted photon in the absence of neutrino or of antineutrino.

iii – Justify the emission of this photon.

B – Dating

The archaeological site of **Trojan** is among the most common known archaeological sites in the world. It is situated under the hill of **Hissarlik** in **Turkish**.

During his digging in 2009, the archaeologist Ernst **Pernicka** discovered in **Trojan VII** *(city destroyed by fire during the* **Trojan** *war)*, a lot of skeletons of men and horses carrying the marks of a violent death, as well as many weapons and signs of fighting such as arrows stuck in the wall and traces of fire.

He decides then to make carbon-14 dating of a sample of 5 g of charcoal discovered in the fireplace by digging. The measurements reveal an activity of 0.7778 Bq.

1) Calculate, in s^{-1} and in $years^{-1}$, the radioactive constant of carbon-14.

2) Find the number of nuclides of carbon-14 found in the sample of charcoal discovered by Ernst.

3) Determine the theoretical date of the war of **Trojan VII**.

4) The preceding calculated date is not accurate, taken into consideration the evolution during time of solar activity and of the terrestrial magnetic field which both influence on the quantity of ^{14}C initially formed. The correct date is determined with the help of the document of the above figure.

According to historians, the war of **Trojan** happened between the years 1344 and 1150 B.C.

Ernst Pernicka confirms the wartime given by historians. Justify.