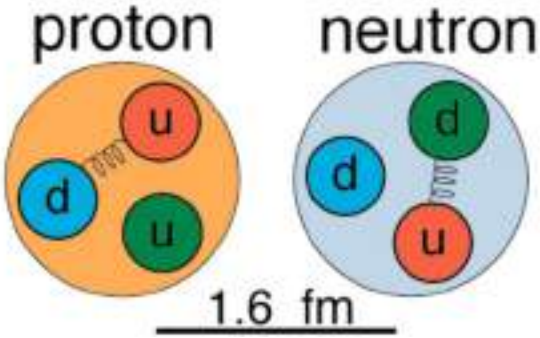
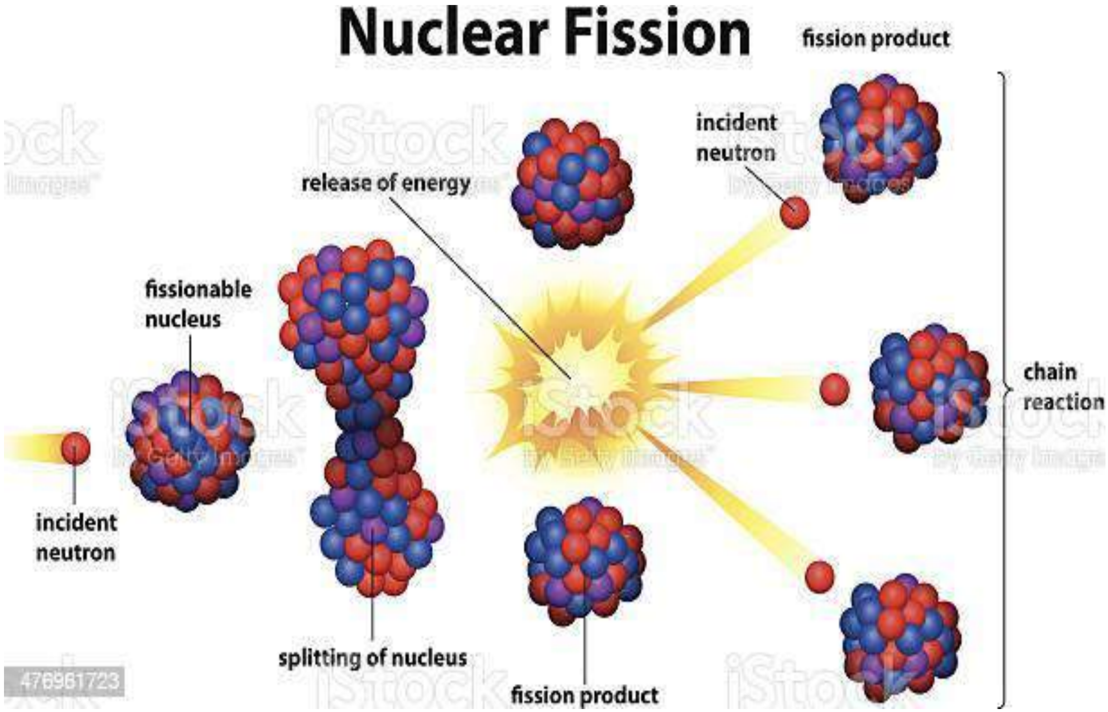
مقرر الكيمياء الفيزيائية (421 ك)

الجزء الخاص :

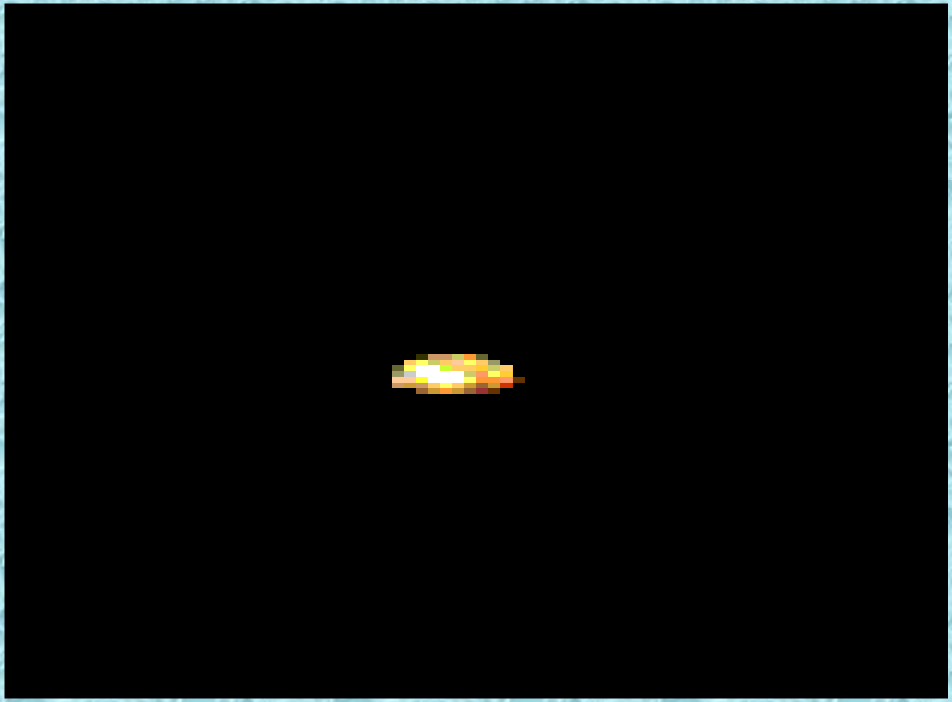
الكيمياء النووية و الاشعاعية

د/ صفاء النحاس عباس





NUCLEAR CHEMISTRY



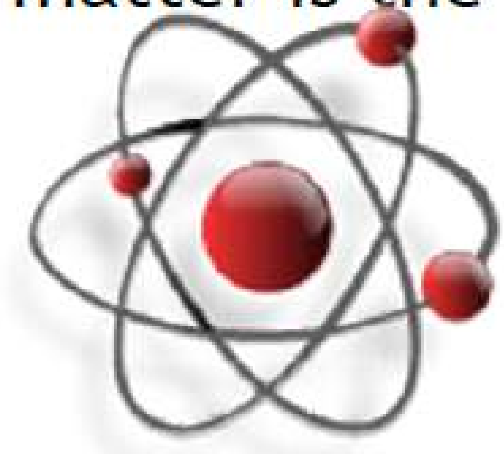
Dr. Safaa El Nahas

محتوى المقرر

- تركيب النواة ومكوناتها
- تفسير طبيعة النواة واستقرارها من عدمه والعوامل التى تحكم ذلك.
- النشاط الاشعاعى - طبيعة النشاط وأنواعه
- كيناتيكا التحلل والنمو الاشعاعى.
- - انواع الاشعة النووية وتفاعلاتها مع الوسط المحيط
- - النظائر النووية
- -قوانين الانحلالات النووية
- - أنواع التفاعلات النووية
- تفاعلات الانشطار النووى
- تفاعلات الاندماج النووى
- كيفية التحكم فى التفاعلات النووية وانتاج النظائر المشعة.
- معرفة استخدامات الكيمياء النووية لانتاج الطاقة
- المفاعلات النووية و انواعها
- تطبيقات الكيمياء النووية فى الكيمياء والطب والزراعة والصناعة والآثار

WHAT IS CHEMISTRY?

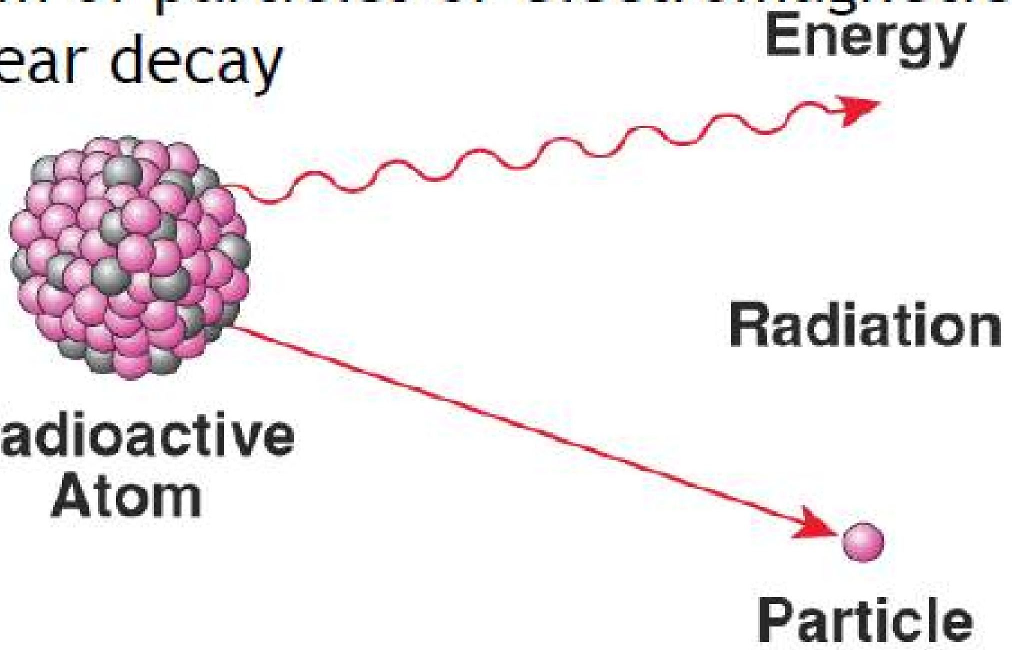
- Chemistry is the study of **matter** and the changes that it can undergo
- Matter is anything that has mass and takes up space
- Can be made up of pure or a mixture of pure substances in any state
- The smallest unit of matter is the **atom**



Lithium Atom

WHAT IS NUCLEAR CHEMISTRY?

- Nuclear Chemistry is the division dealing with the atomic nucleus, radioactivity, and nuclear reactions
- **Radioactivity** - the spontaneous emission of a stream of particles or electromagnetic rays in nuclear decay

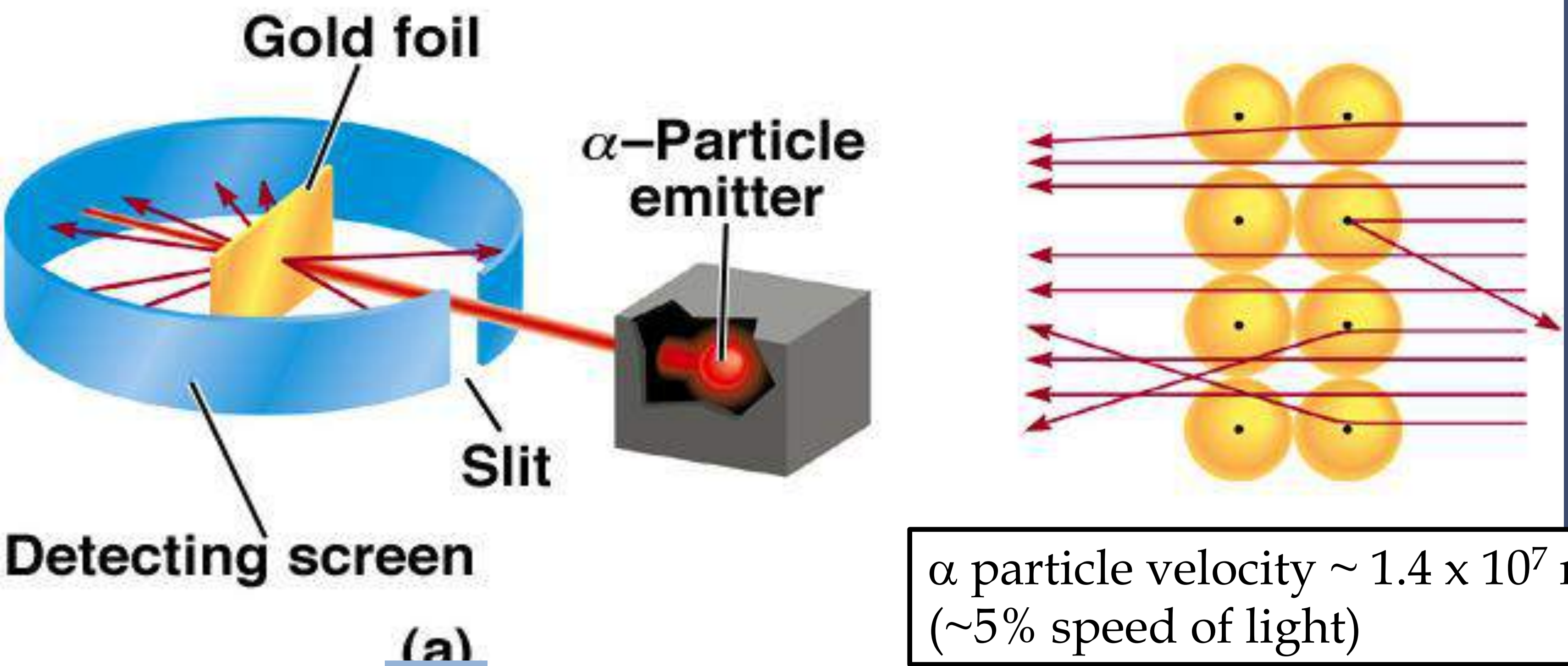


Any atom with 84 or more protons is radioactive

Area of Nuclear Chemistry

- **It is the chemistry of radioactive elements**
- **Nuclear chemistry associated with equipment (such as nuclear reactors)**
- **And For nuclear waste storage or disposal site.**
- **It includes the study of the chemical effects of the absorption of radiation within living animals, plants, and other materials.**
- **nuclear chemistry used in medical treatments (such as cancer radiotherapy).**
- **the use of radioactive tracers within industry, science and the environment; and the use of radiation to modify materials such as polymers.**
- Nuclear magnetic resonance (NMR) spectroscopy is commonly used in synthetic organic chemistry and physical chemistry and for structural analysis in macromolecular chemistry.

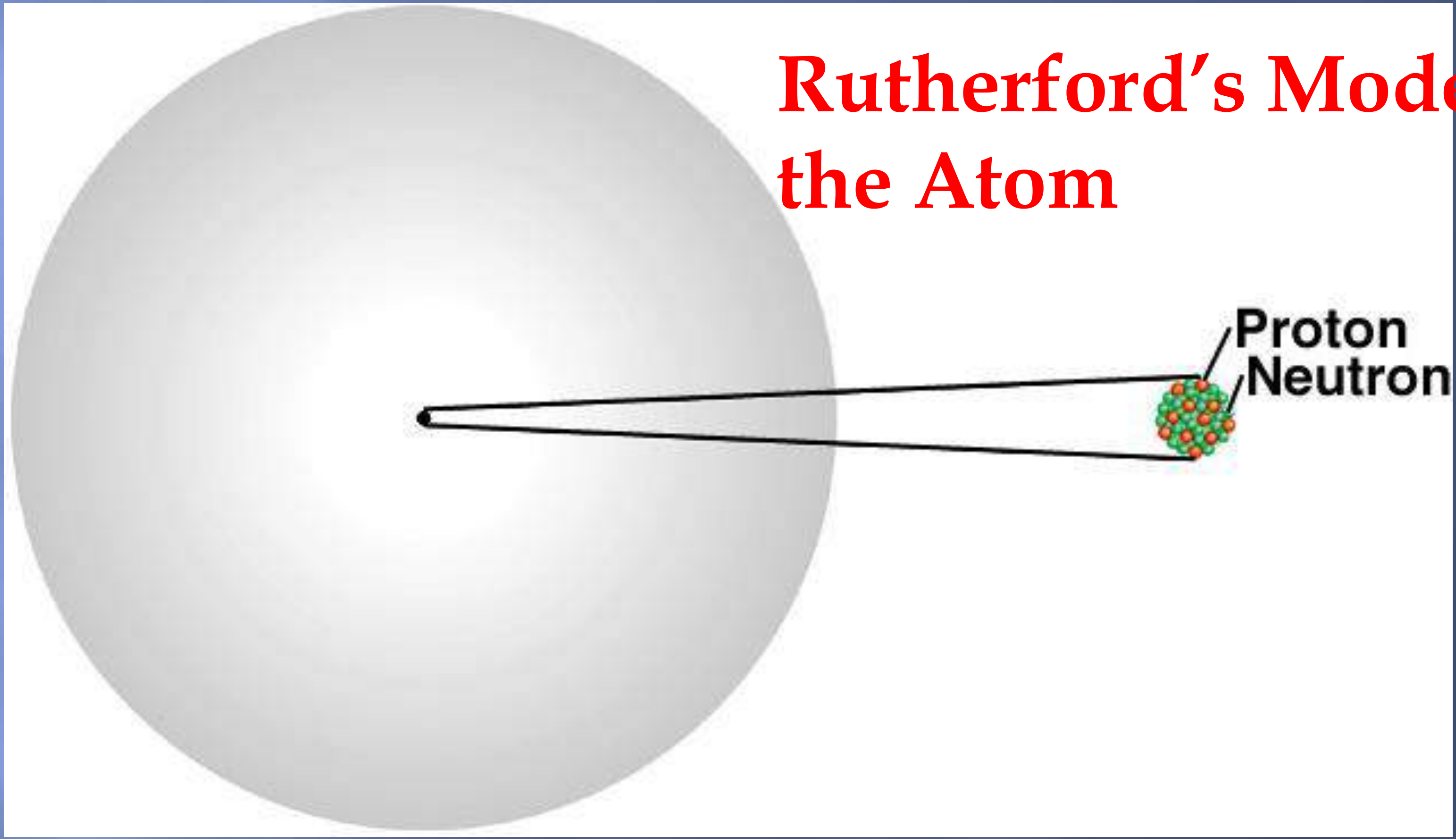
Rutherford's Experimental Design



α particle velocity ~ 1.4 x 10^7 m/s (~5% speed of light)

1. atoms positive charge is concentrated in the nucleus
2. proton (p) has opposite (+) charge of electron (-)
3. mass of p is 1840 x mass of e^- (1.67 x 10^{-24} g)

Rutherford’s Model of the Atom



atomic radius ~ 100 pm = 1 x 10^{-10} m

nuclear radius ~ 5 x 10^{-3} pm = 5 x 10^{-15} m

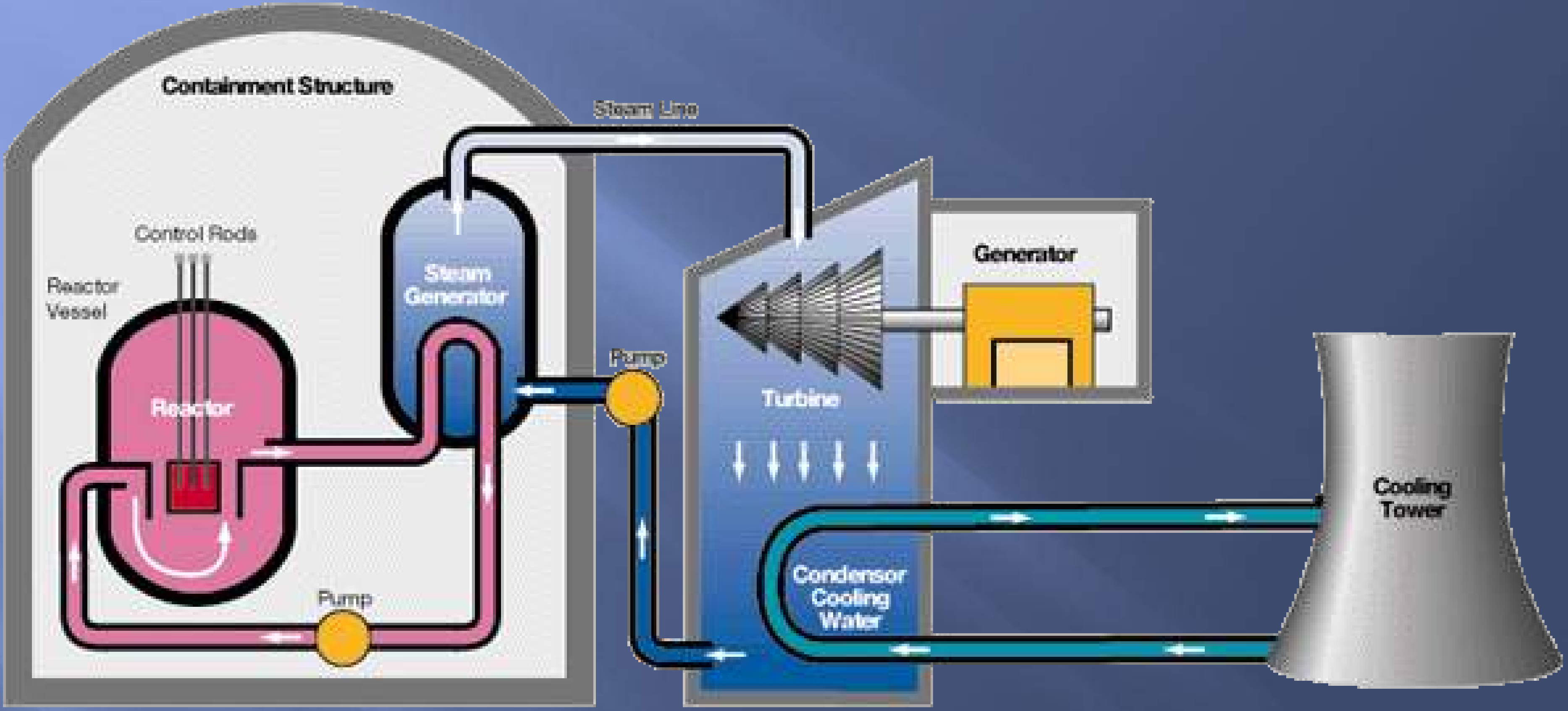
Nu-cl-ear

good ☺

Nu-cl-ear

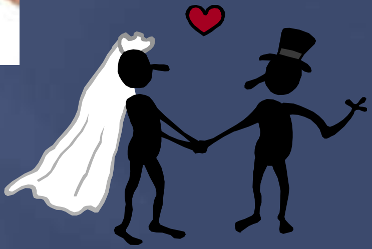
not so good ☹

Nuclear Reactor

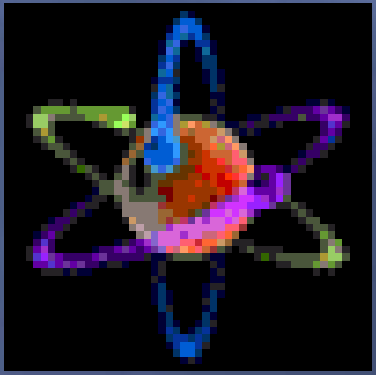


What can radiation do?

- Death
- Cancer
- Skin Burns
- Cataract
- Infertility
- Genetic effects



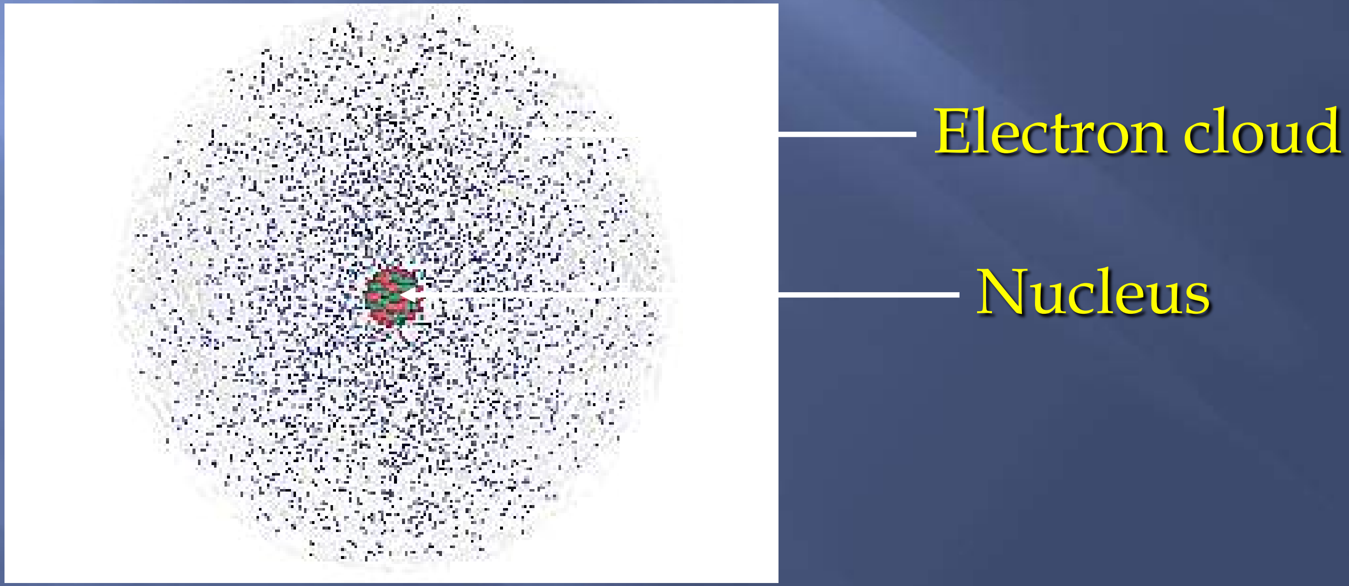
The Nucleus



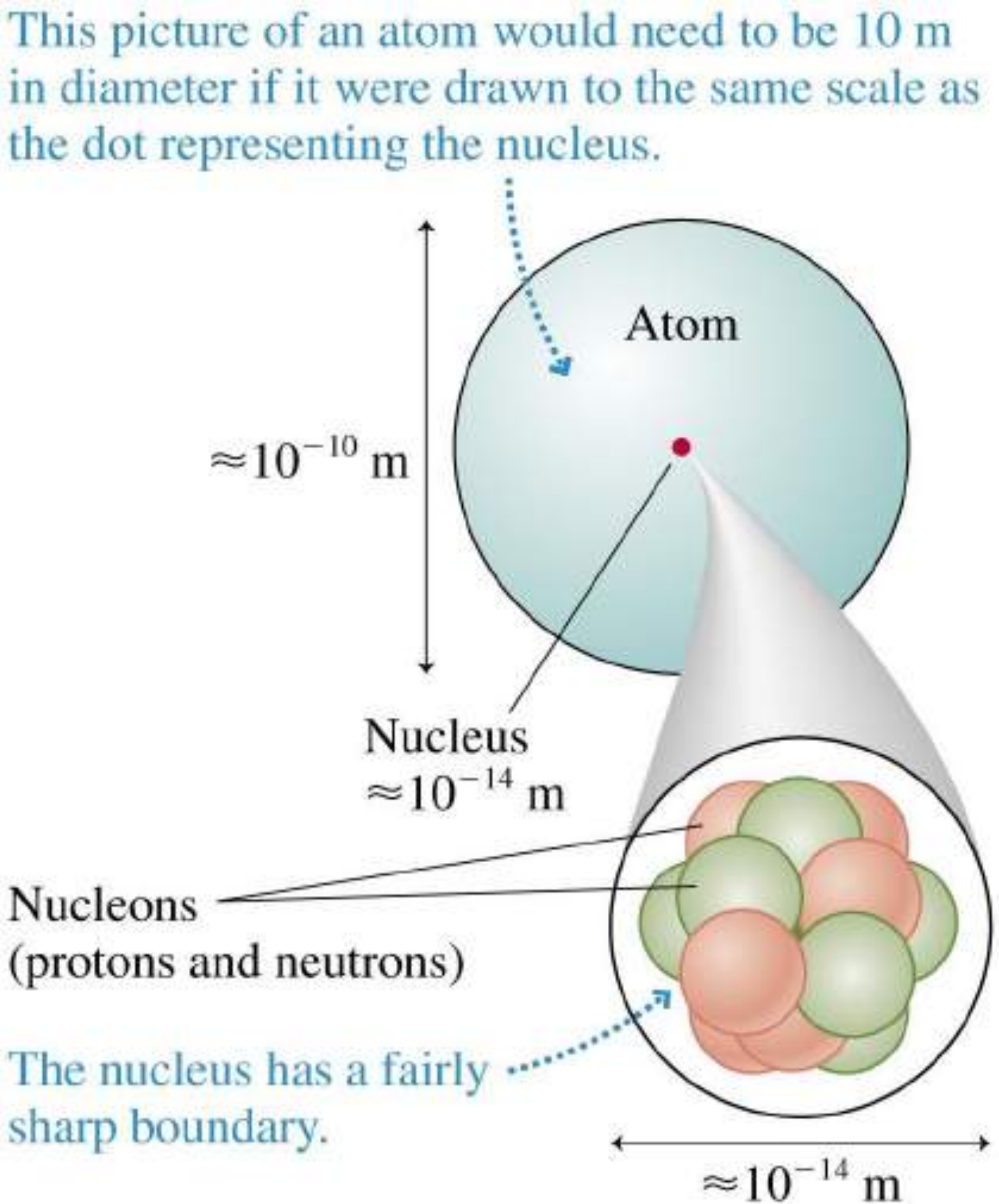
The Atom

An atom consists of a

- nucleus
  - (of protons and neutrons)
- electrons in space about the nucleus.



Nuclear Structure



This picture of an atom would need to be 10 m in diameter if it were drawn to the same scale as the dot representing the nucleus.

The nucleus has a fairly sharp boundary.

Structure and Properties of the Nucleus

The Nucleus is the (tiny) central part of an atom. The Nucleus is made of protons and neutrons

Proton has positive charge:

$$m_{\mathrm{p}} = 1.67262 \times 10^{-27}\,\mathrm{kg}$$

Neutron is electrically neutral:

$$m_{\mathrm{n}} = 1.67493 \times 10^{-27}\,\mathrm{kg}$$

Structure and Properties of the Nucleus

A and Z are sufficient to specify a nuclide.

(خاص بنواة الذرة دون اعتبار للغلاف الخارجى للذرة)

Nuclides are symbolized as follows:

$$^{A}_{Z}X$$

X is the chemical symbol for the element; it contains the same information as Z but in a more easily recognizable form.

Z : number of protons

A: mass number العدد الكتلى

Structure and Properties of the Nucleus

Neutrons and protons are collectively called nucleons.

The different nuclei are referred to as nuclides.

Number of protons: atomic number, Z

Number of nucleons: atomic mass number, A

Neutron number: $\boldsymbol{N = A - Z}$

العدد الكتلى A يمثل العدد الكلى للبروتونات و النيترونات فى النواة
و ليس الوزن الذرى atomic mass

حيث الوزن الذرى دائما كسر يصل الى 6 ارقام عشرية كونة عبارة عن
نسبة كتلة الذرة الى كتلة الكربون $_6C^{12}$

Atomic Mass الوزن الذرى

is the weighted average
mass of all the naturally occurring
isotopes of that element.

وحدة الكتلة الذرية (و. ك. ذ) Atomic mass unit

تستخدم وحدة خاصة لقياس كتل النوى والذرات تعرف باسم وحدة الكتلة الذرية . وقد اشتقت هذه الوحدة على أساس اعتبار أن كتلة نظير الكربون **12**($_6^{12}C$) مساوية **12** وحدة تماماً. أي أن وحدة الكتلة الذرية عبارة عن **12/1** من كتلة ذرة الكربون 12، أي ما يساوي **1.6555 × 10^{-24}** جرام.

وبالقياس على ذلك تكون كتلة نظير الهيدروجين $_1^1H$ هي **1.007825** و.ك.ذ، وكتلة البروتون هي **1.007277** و.ك.ذ، وكتلة النيوترون هي **1.008665** و.ك.ذ، وكتلة الإلكترون هي **0.000549** و.ك.ذ.

تحويل الكتلة إلى طاقة

$E= mc^2$ or $m = E/c^2$

(نظرية اينشتاين : تحويل الكتلة الى طاقة و العكس)

- **كمية الطاقة الناتجة عن تحويل المادة الى طاقة لا تتوقف على نوع المادة بل على كتلتها.**

$$E= mc^2$$

- الطاقة (جول) = الكتلة (كجم) × ($3*10^8$)^2 متر.ث ^{2}
- الطاقة (جول) = الكتلة (جم)× $9* 10^{13}$
- الطاقة (بالسعر) = الكتلة (جم)× $2.15 *10^{13}$
- **الطاقة (MeV) = الكتلة (amu)× 931.5**

الوحدات الذرية للطاقة (الإلكترون فولت) eV Units

$1\ \text{eV} = 1.6\times10^{-19}$ Joul

وتوجد لوحدة الإلكترون فولت عدة مضاعفات أهمها:

(1kev) كيلو إلكترون فولت ك.أ.ف = 10^{3} إلكترون فولت

$= 1.6\times10^{-16}$ جول.

(1Mev) ميغا إلكترون فولت م.أ.ف = 10^{6} إلكترون فولت

$= 1.6\times10^{-13}$ جول.

وحيث أن الطاقة والكتلة متكافئتان وفقاً لمبدأ أينشتين، فإنه يمكن التعبير عن وحدة الكتلة الذرية بوحدة الإلكترون فولت، حيث أن:

1 و.ك.ذ = **931** ميغا إلكترون فولت.

Structure and Properties of the Nucleus

Masses of atoms are measured with reference to the carbon-12 atom, which is assigned a mass of exactly 12u. A u is a unified atomic mass unit.

$$1\ \mathrm{u} = 1.6605 \times 10^{-27}\ \mathrm{kg} = 931.5\ \mathrm{MeV}/c^2.$$

Structure and Properties of the Nucleus

From the following table, you can see that the electron is considerably less massive than a nucleon.

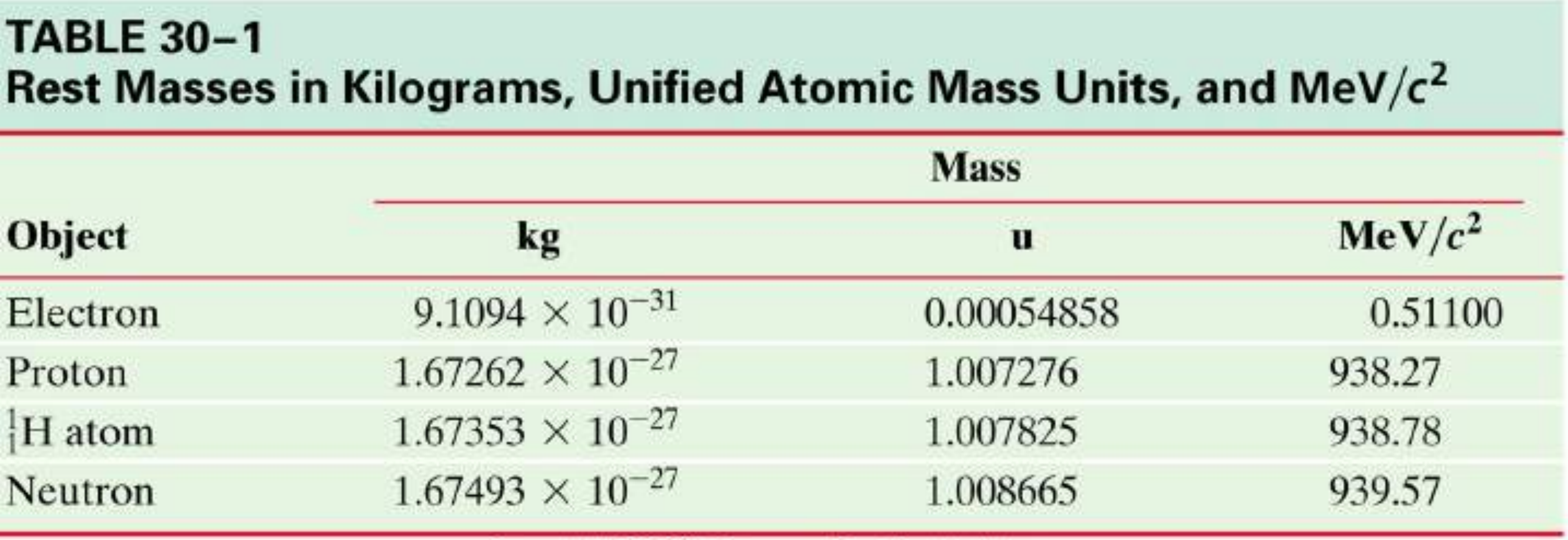


TABLE 30–1
Rest Masses in Kilograms, Unified Atomic Mass Units, and MeV/c^2

	Mass		
Object	**kg**	**u**	**MeV/c^2**
Electron	9.1094×10^{-31}	0.00054858	0.51100
Proton	1.67262×10^{-27}	1.007276	938.27
$^1_1$H atom	1.67353×10^{-27}	1.007825	938.78
Neutron	1.67493×10^{-27}	1.008665	939.57

$$E = mc^2 \quad \text{or} \quad m = E/c^2$$

(نظرية اينشتاين : تحويل الكتلة الى طاقة و العكس)

بعض التعريفات المهمة

ISOTOPES

- Atoms of the same element may have different neutron numbers, thus different mass numbers

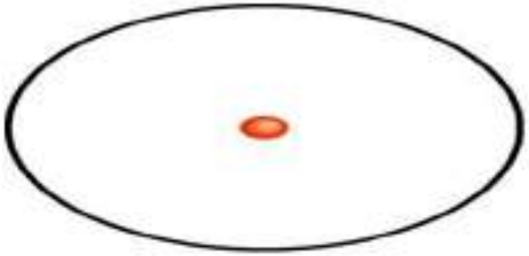
${}^{12}_{6}C$	Carbon-12	6 electrons, 6 protons, 6 neutrons
${}^{14}_{6}C$	Carbon-14	6 electrons, 6 protons, 8 neutrons

isotopes

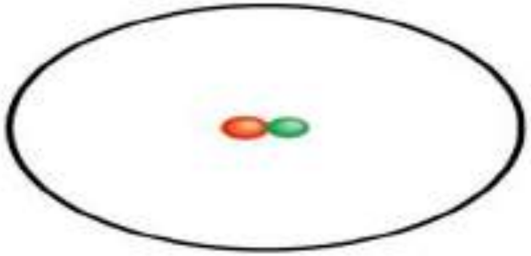
Nuclei with the same Z – so they are the same element – but different N are called isotopes.

For many elements, several different isotopes exist in nature.

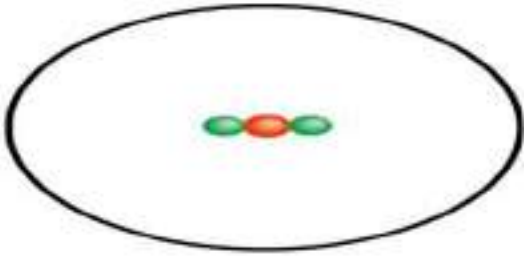
Different isotopes of the same element have the same atomic number but different mass numbers.



$^{1}_{1}\mathrm{H}$



$^{2}_{1}\mathrm{H}$



$^{3}_{1}\mathrm{H}$

بعض التعريفات

- <u>الآيزوبارات Isobars</u>:هى تلك النوى التى لها نفس عدد الكتلة لكنها تختلف فى عددها الذرى (Z) مثل($_7N^{14}$, $_6C^{14}$)

- <u>الآيزوتونات Isotons</u>:هى تلك النوى التى لها نفس النيوترونات وتختلف فى عدد الكتلة مثل ($_7N^{15}$, $_6C^{14}$)

- <u>النوى المتماثلة Mirror Nuclei</u>هى تلك النوى التى لها نفس عدد الكتلة A لكنها تتبادل فى عدديها الذرى(Z) وعدد النيوترونات N مثل($_9F^{17}$, $_8O^{17}$)

- <u>Nuclear isomers</u> هى تلك النوى التى لها نفس عدد الكتلة A ونفس عددها الذرى(Z) ولكنها تمتلك طاقات مختلفة ولكنها تختلف فى خواصها الانحلالية و مثال على ذلك النوى التى تكون فى حلالات متهيجة مثال Antimoine Sb^{124} الذى لة 3 أعمار نصف مختلفة و هم 60 يوم و21 دقيقة و1.3 دقيقة

The Nuclear Radius

Nucleus is very small

- single nucleon ~ $1x10^{-15}$ m or 1 fm
- **fm: femtometer, fermion, fermi**
- nucleus ~ 1 – 10 fm
- atom ~ 1 Å = 1 $x10^{-10}$ m = 100,000 fm

All experiments suggest that $R = R_0A^{1/3}$

R_0 = constant 1.1-1.6 fm; A-mass number

- 1 Fermi = 10^{-13} cm = 10^{-15} m

- Nuclear radius: that $R = R_0 A^{1/3}$
- Nuclear Size that $V = 4/3 \pi R^3$
- Nuclear Density that Density = mass/ volume

Density = A × (mass of nucleon)/ ($4/3 \pi R^3$)

$= A \times (1.7 \times 10^{-27}\ \mathrm{Kg}) / [4/3 \pi (1.4 \times 10^{-27}) A^{1/3})^3]$

Density = 1.5×10^{17} Kg/m^3

- و هذة النتيجة توضح ان كثافة المادة النووية عالية جدا جدا

لو اخذنا كتلة واحد inch^3 من المادة النووية فانة يحتوى على حوالى بليون طن

* (البوصة تساوي 2,54 سنتيمتر)

*(الطن = 1000كيلو جرام)

Nuclear density

- NUCLEONS (neutrons and protons) are very dense. They have similar mass so it follows that they have similar density. Their density is approximately $1.5*10^{17}kgm^{-3}$.
- Nuclear density is much bigger than atomic density. This suggests:

1. Most of an atoms mass is in its nucleus
2. The nucleus is small compared to the atom
3. An atom must contain a lot of empty space.

أحسب نصف قطر نواة $^{110}Ag_{47}$ و حجمها

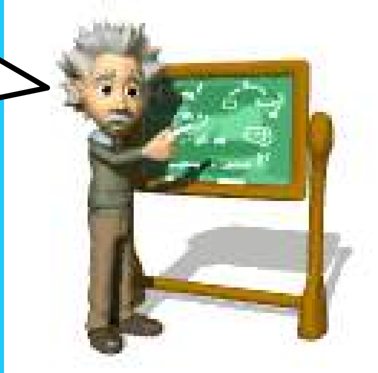
- that $R = R_0 A^{1/3}$
- $R= 1.2 \times 10^{-15} \times (110)^{1/3} = 5.75 \times 10^{-15} = 5.75$ Fermi
- $V= 4/3\ \pi\ R^3 = 4/3\ \pi\ R_0{}^3\ A= 798.4 \times 10^{-45}\ m^3$

Properties of Nucleons and nuclei
خصائص النيوكلونات والأنوية

- للبروتونات و النيوترونات و ايضا النواة ككل لها:
- تأثيرات مغناطسية- كهربية Magneto-Electrical effect-
- تأثيرات ميكانيكية Mechanical effects ناتجة من الحركة المسارية Orbiting Motion و حركة اللف أو الغزل Spinning Motion
- يمكن اعتبار جميع النيوكليدات فى حالتها المستقرة كروية الشكل
- الانحراف الحقيقى للنواة عن شكلها الكروى ينتج عن عزمها الكهربى رباعى القطبية

Nuclear Stability

It’s really not that difficult



Stable vs. Unstable

- A stable isotope does NOT undergo radioactive (or nuclear) decay.
- An unstable isotope undergoes radioactive (or nuclear) decay. Unstable isotopes are also known as radioisotopes or radionucleides

Nuclear Stability

- It depends on a variety of factors and no single rule allows us to predict
- whether a nucleus is radioactive and might decay unless we observe it.
- **The are some observations that have been made to help us make predictions**

1-Even –Odd Nature of the number of Protons& Neutrons

- Certain numbers of neutrons and protons are ***extra*** stable
- Nuclei with ***even*** numbers of both protons and neutrons are more stable than those with **odd** numbers of neutron and protons.

- All isotopes of the elements with atomic numbers higher than 83 are radioactive

1-Even –Odd Nature of the number of Protons& Neutrons

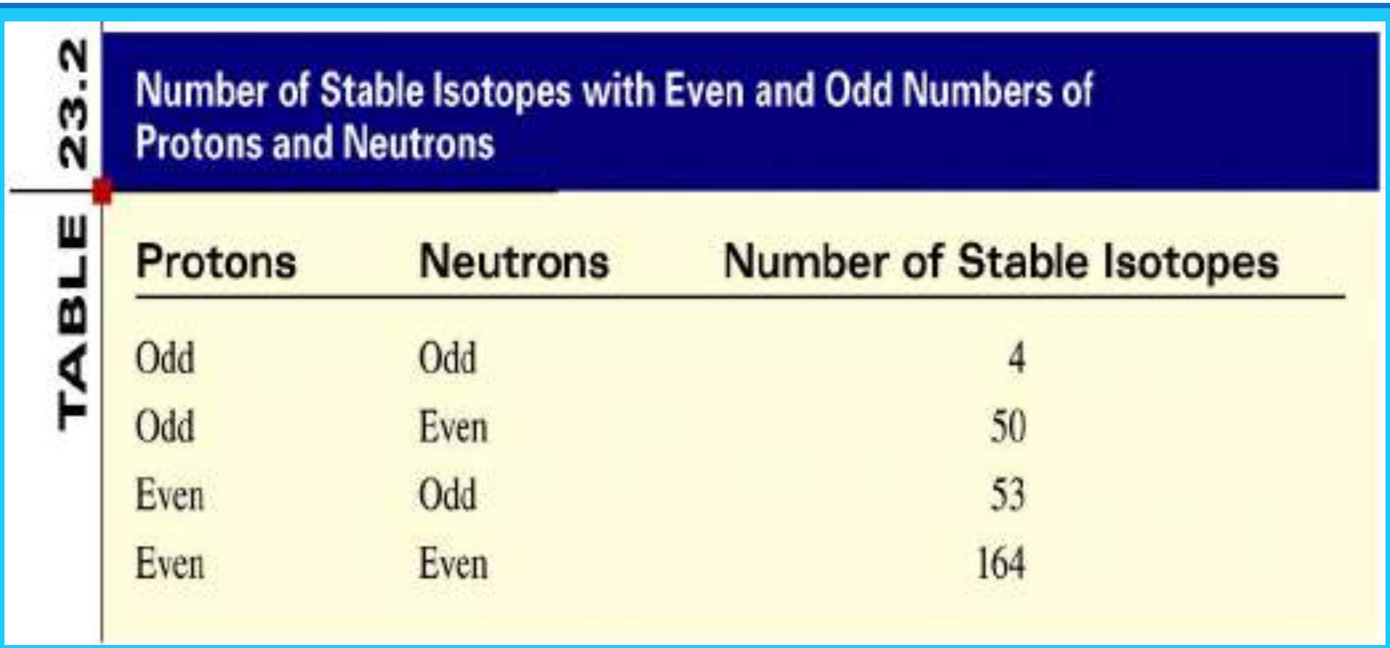
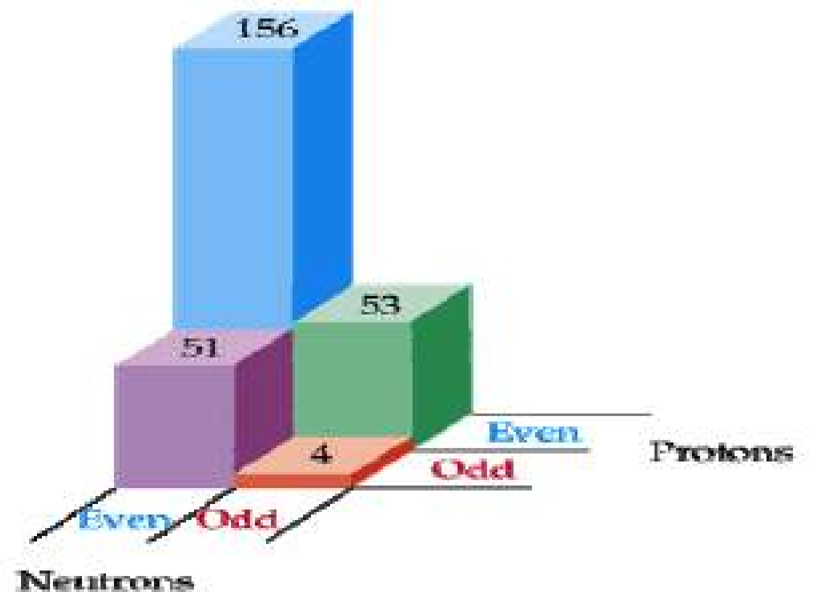


TABLE 23.2

Number of Stable Isotopes with Even and Odd Numbers of Protons and Neutrons

Protons	Neutrons	Number of Stable Isotopes
Odd	Odd	4
Odd	Even	50
Even	Odd	53
Even	Even	164



The Magic Numbers

For nuclei to be stable, there are some "magic numbers".

- **These are the numbers of neutrons and protons in a nucleus.**
- **If a nucleus has that much p or n, it is found to be more stable than the others.**
- **This numbers are usually even, for symmetry. (symmetry provides strength in bounds and thus stability.)**

These magic numbers are:

For protons: 2, 8, 20, 28, 50, 82.

For neutrons: 2, 8, 20, 28, 50, 82, 126.

Do you remember Noble Gases?

They contained the number of electrons that were completely filling an electron shell. Since the shell was completely filled, they were not active for reacting chemically, thus were called STABLE.

The magic numbers for the nucleus is just like that! Nucleons at that numbers are thought to fill a nuclear shell completely, thus, the nucleus with filled shells are more stable.

Slowly Slowly to nuclear belt stability

- A nucleus having very much protons compared to neutrons will never be stable,
- Yes, but this does not mean that a nucleus with many neutrons and little protons will be stable

2- Neutron to proton Ratio

- More massive nuclei require extra neutrons to overcome the Coulomb repulsion of the protons in order to be stable.
- The higher the binding energy per nucleon, the more stable the nucleus.

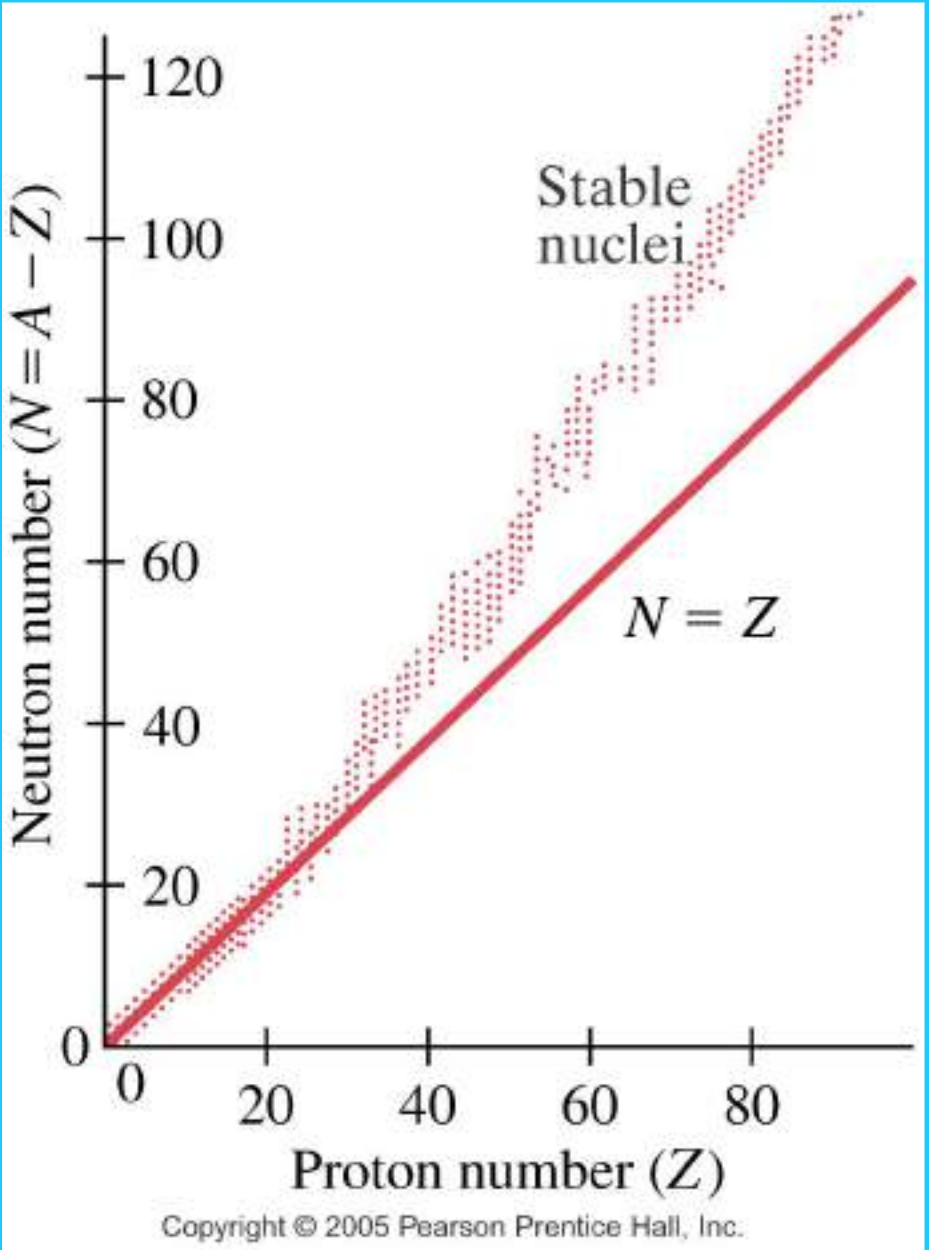


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CHART OF THE NUCLIDES

- We organize all the known isotopes of the elements into another chart, called the **Chart of the Nuclides**

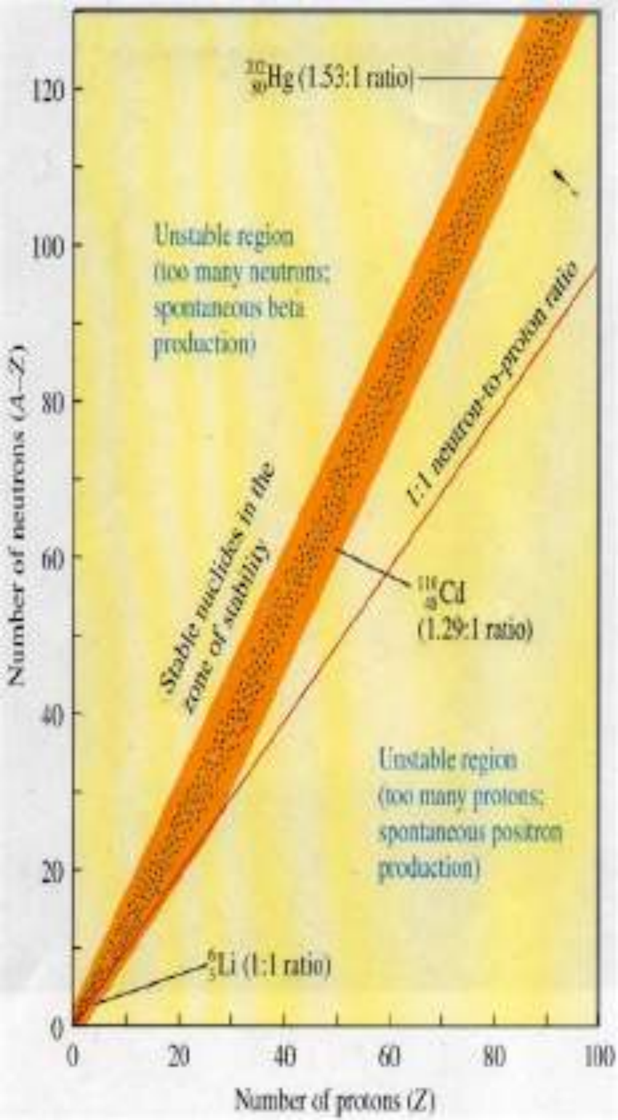
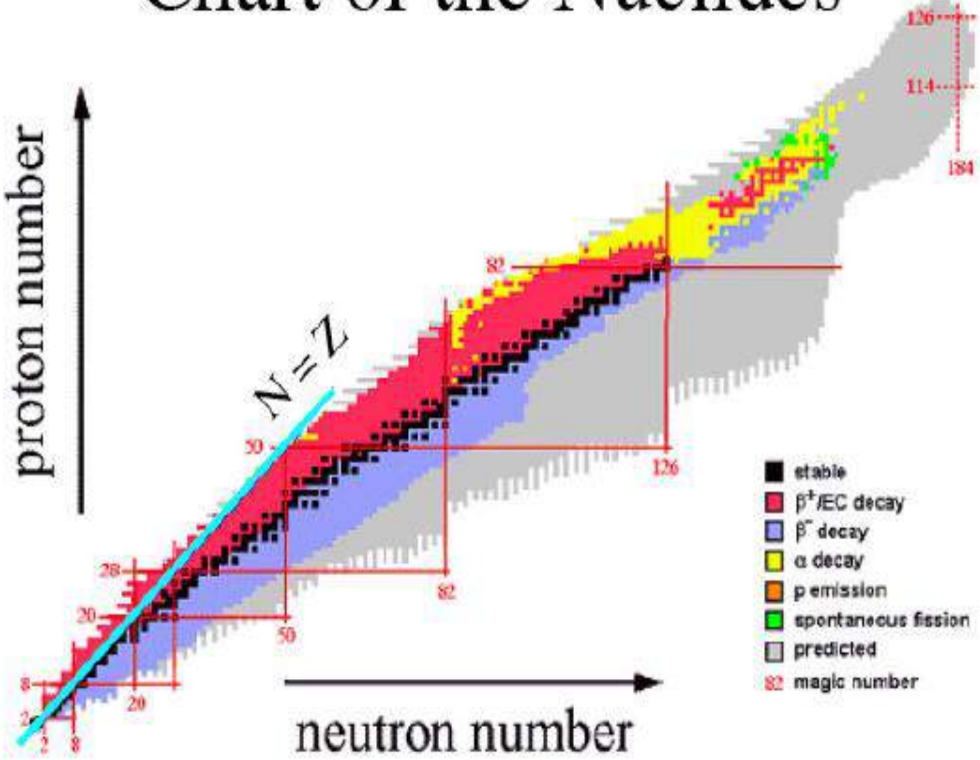


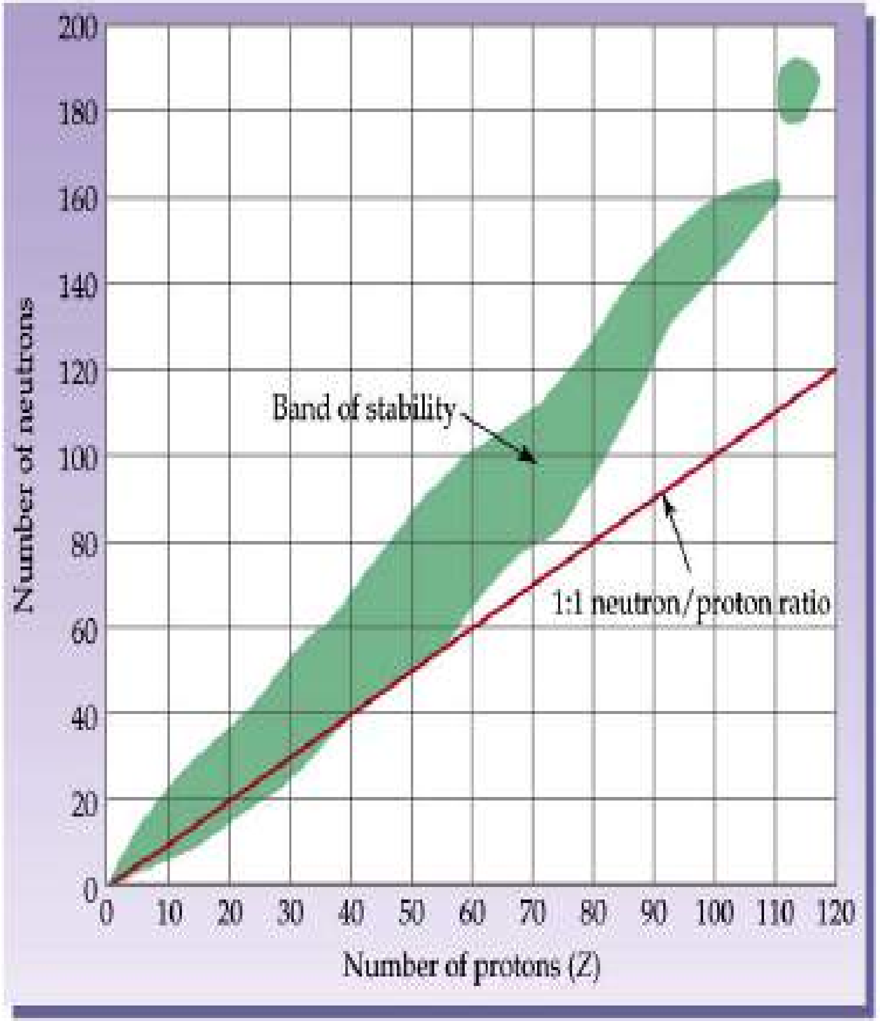
Chart of the Nuclides



Symmetric: Equal numbers of protons and neutrons
Asymmetric: Unequal numbers of protons and neutrons

- **The band of nuclear stability** indicates neutron and proton combinations giving rise to observable nuclei with measured half-lives.

- The island of stability corresponds to predicted super heavy nuclei first observed in 1999.



Neutron to proton ratio
and the belt of Stability

- The more protons packed together the more neutrons are needed to bind the nucleus together.

- Nucleus with an atomic number up to twenty has almost equal number of protons and neutrons.

- Nuclei with higher atomic numbers have more neutrons to protons.

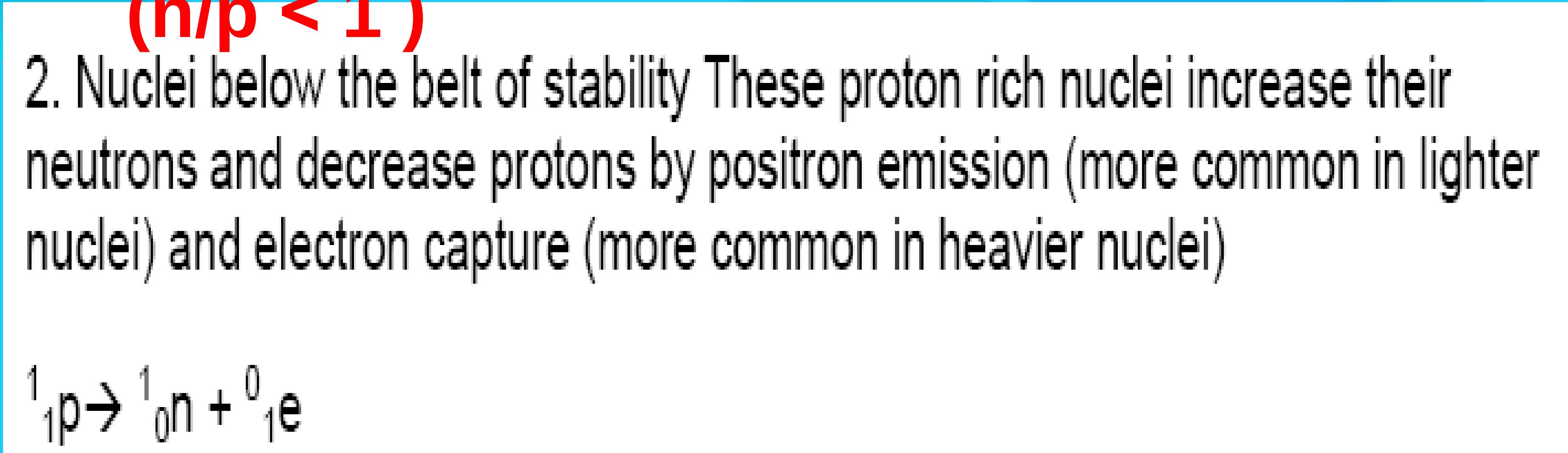
- The number of neutrons needed to create a stable nucleus increase more than the number of proton

Belt of stability

- 1. Nuclei above the belt of stability (n/p > 1)
- These neutron rich isotopes can lower their ratio and move to the belt of stability by emitting a beta particle.
- This increases number of protons and decreases neutrons

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e $$

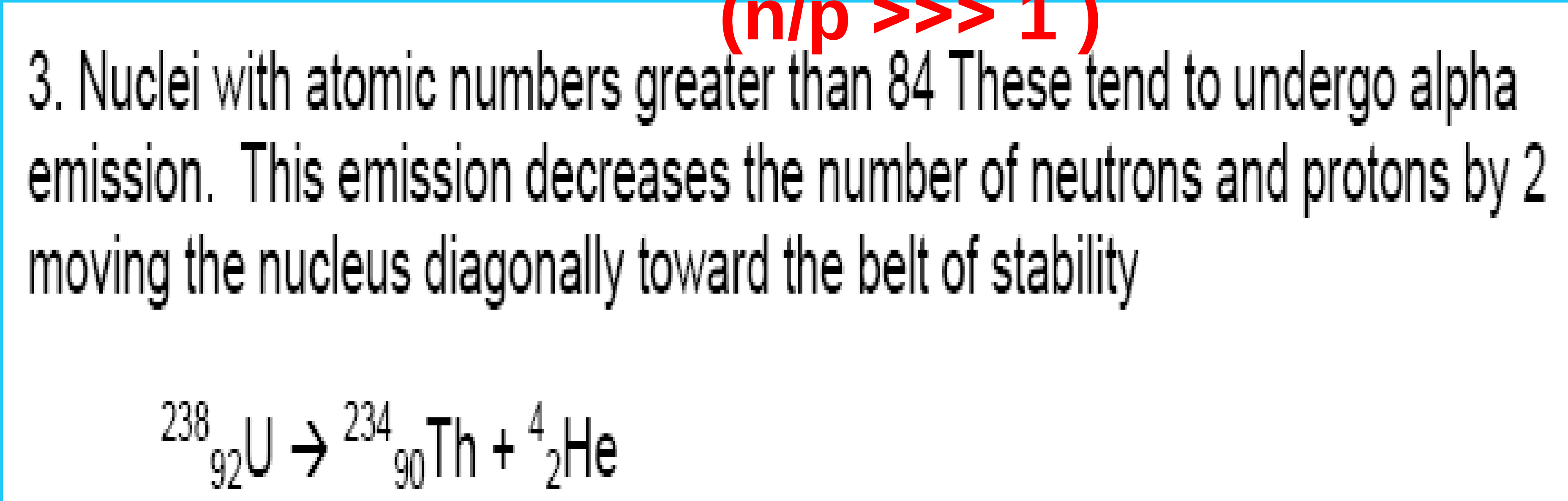
(n/p < 1)



2. Nuclei below the belt of stability These proton rich nuclei increase their neutrons and decrease protons by positron emission (more common in lighter nuclei) and electron capture (more common in heavier nuclei)

$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e$

(n/p >>> 1)

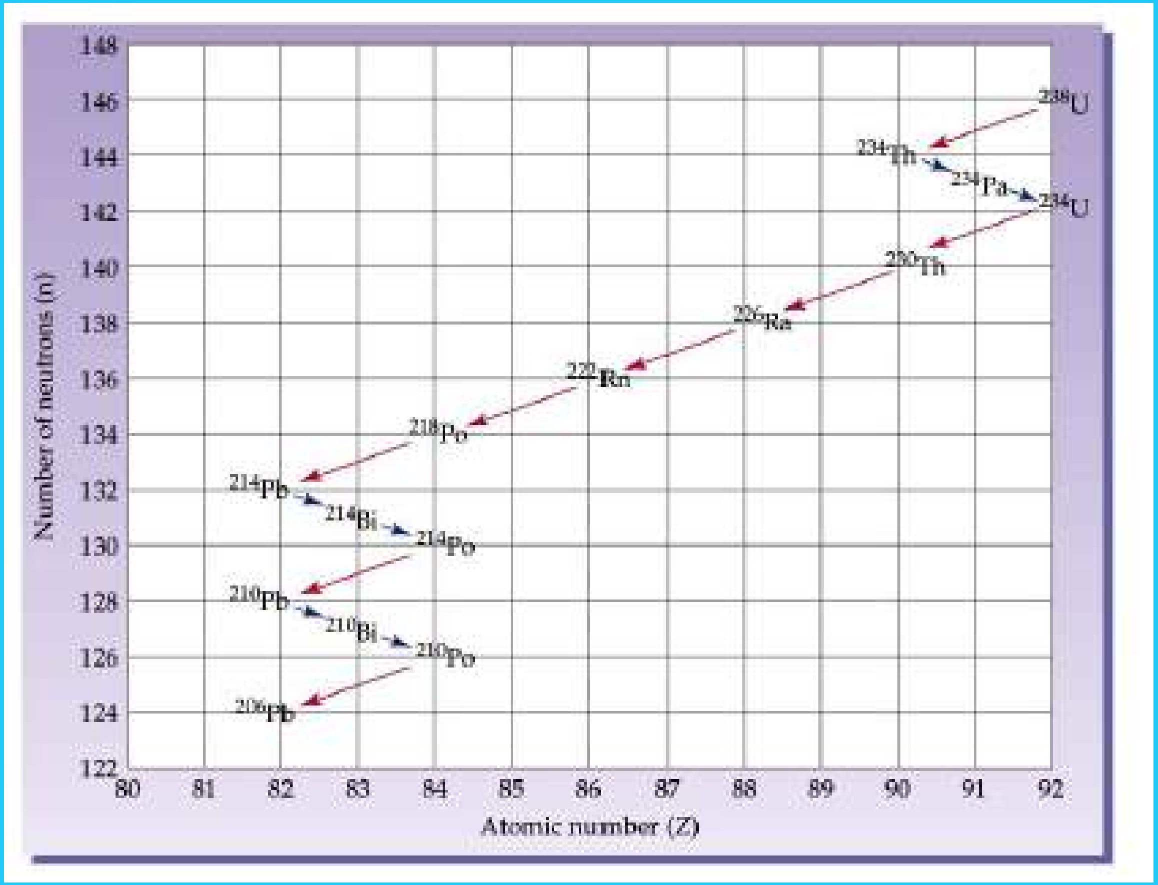


3. Nuclei with atomic numbers greater than 84 These tend to undergo alpha emission. This emission decreases the number of neutrons and protons by 2 moving the nucleus diagonally toward the belt of stability

$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

Decay Series

- Some nuclei undergo a whole series of disintegrations called a *decay series*, leading to nonradioactive species.



What holds the nucleus together?

❑ Inside the nucleus, the **attractive strong force** is stronger than the **repulsive electromagnetic force**.

❑ Protons and neutrons both “experience” the strong force.

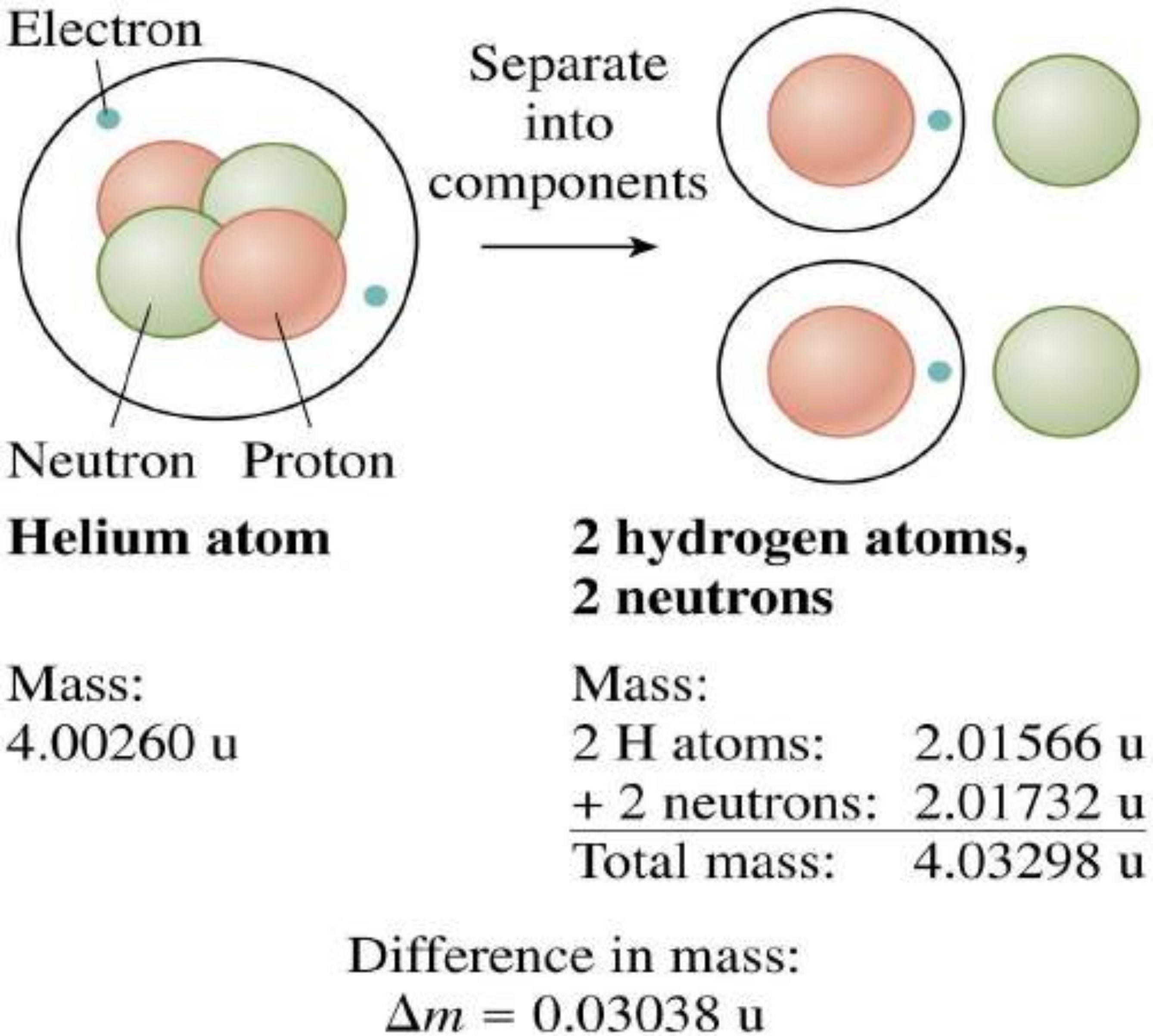
❑ The actual binding that occurs between ***proton-proton*** and ***proton-neutron and neutron-neutron*** is the residual of the strong interaction between the constituent quarks.

Mass Defect

The total mass of a stable nucleus is always less than the sum of the masses of its separate protons and neutrons.

Where has the mass gone?

Binding Energy of a Helium Nucleus



Helium atom

Mass:
4.00260 u

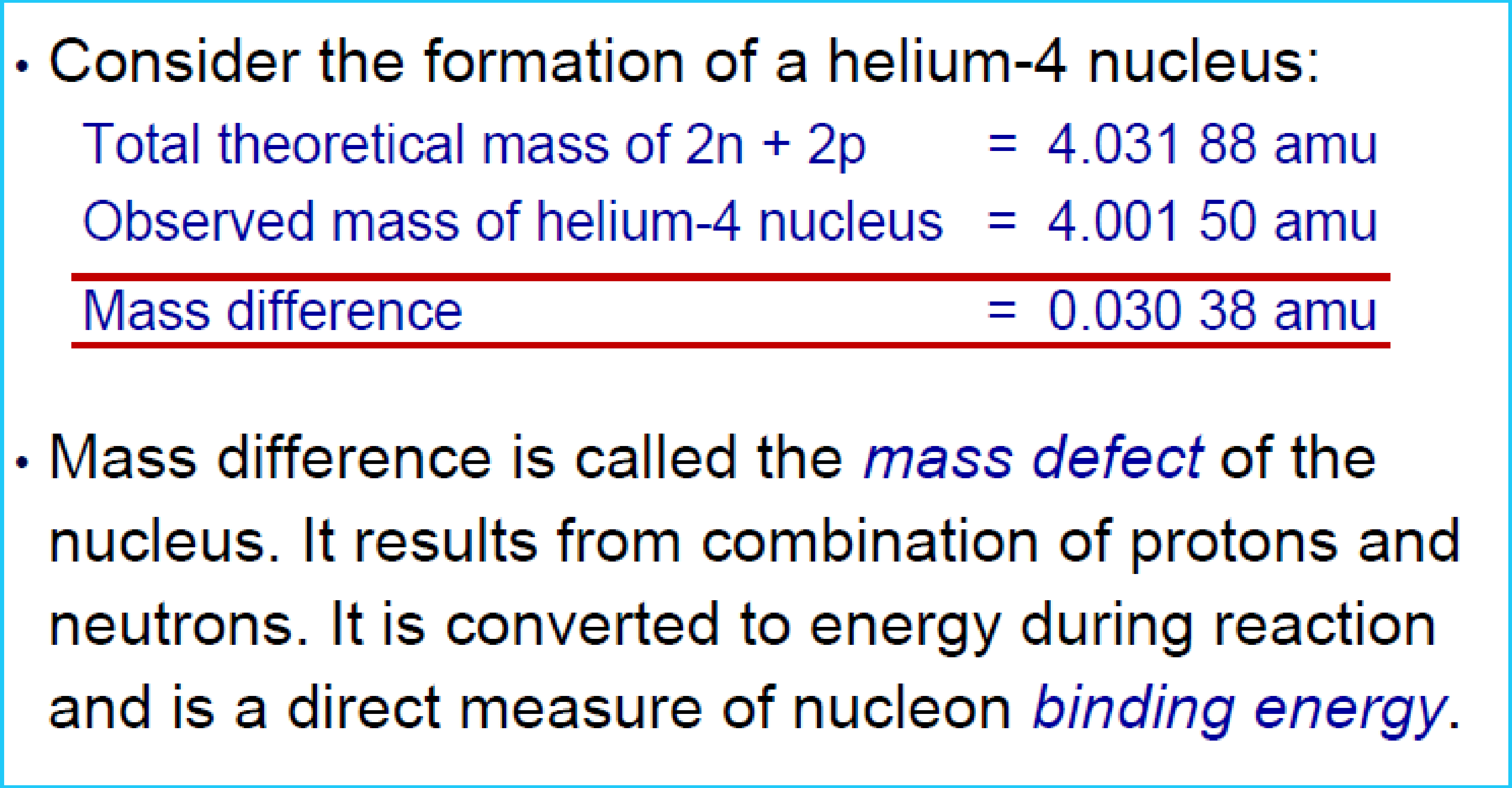
2 hydrogen atoms, 2 neutrons

Mass:

2 H atoms:	2.01566 u
+ 2 neutrons:	2.01732 u
Total mass:	4.03298 u

Difference in mass:
$\Delta m = 0.03038$ u

Mass Defect



- Consider the formation of a helium-4 nucleus:

Total theoretical mass of 2n + 2p = 4.031 88 amu

Observed mass of helium-4 nucleus = 4.001 50 amu

Mass difference = 0.030 38 amu

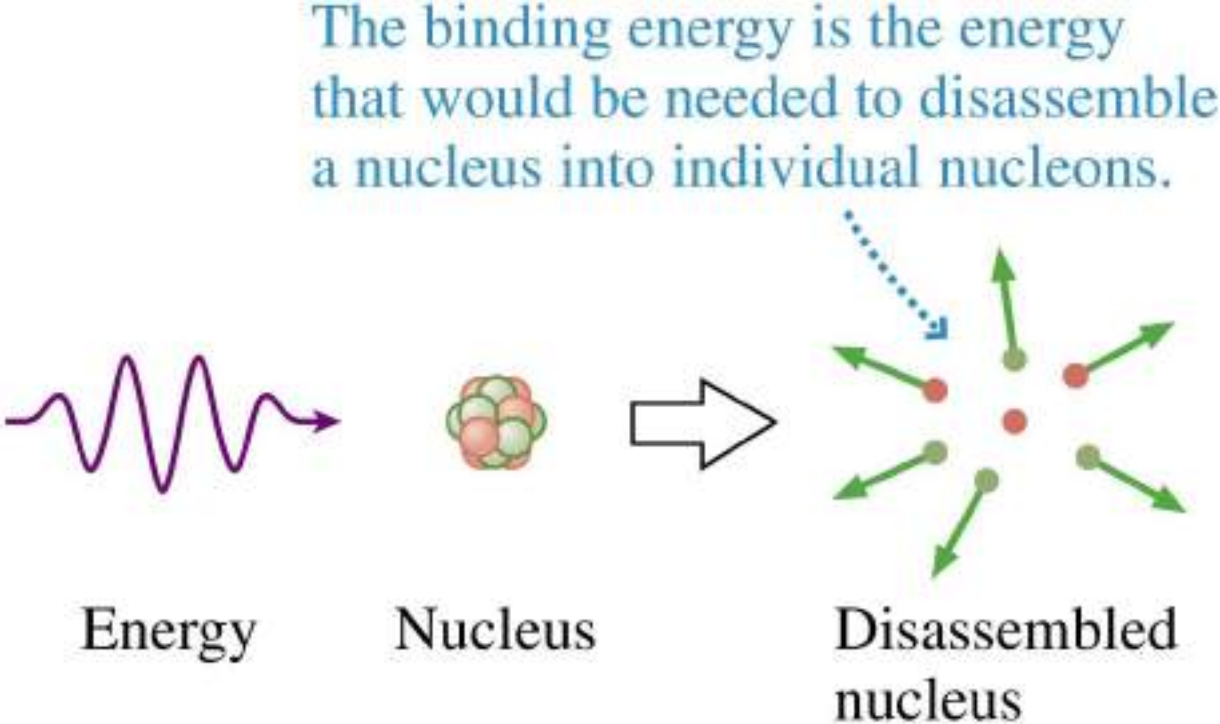
- Mass difference is called the *mass defect* of the nucleus. It results from combination of protons and neutrons. It is converted to energy during reaction and is a direct measure of nucleon *binding energy*.

3-Binding Energy

Mass defect has become energy, such as radiation or kinetic energy, released during the formation of the nucleus.

This difference between the total mass of the constituents and the mass of the nucleus is called the total binding energy of the nucleus.

Binding Energy : the energy that holds nucleons together



The binding energy is the energy that would be needed to disassemble a nucleus into individual nucleons.

V/u)

s

Binding Energy

$$BE=[(M_{(Z\ protons)} + M_{(N\ neutrons)}) - M_{(Nucleus)}] \times 931.49$$

Atomic Number: $A = Z + N$

BE is the energy required to separate the full nucleus into its individual protons and neutrons

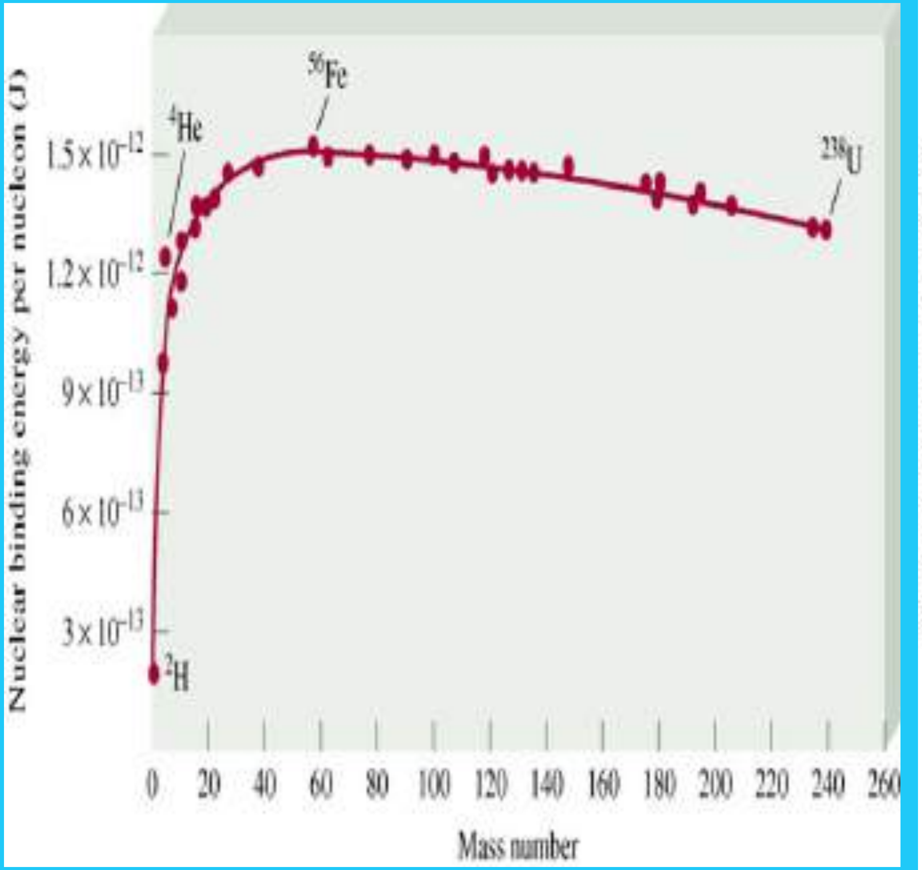
$$E = mc^2$$

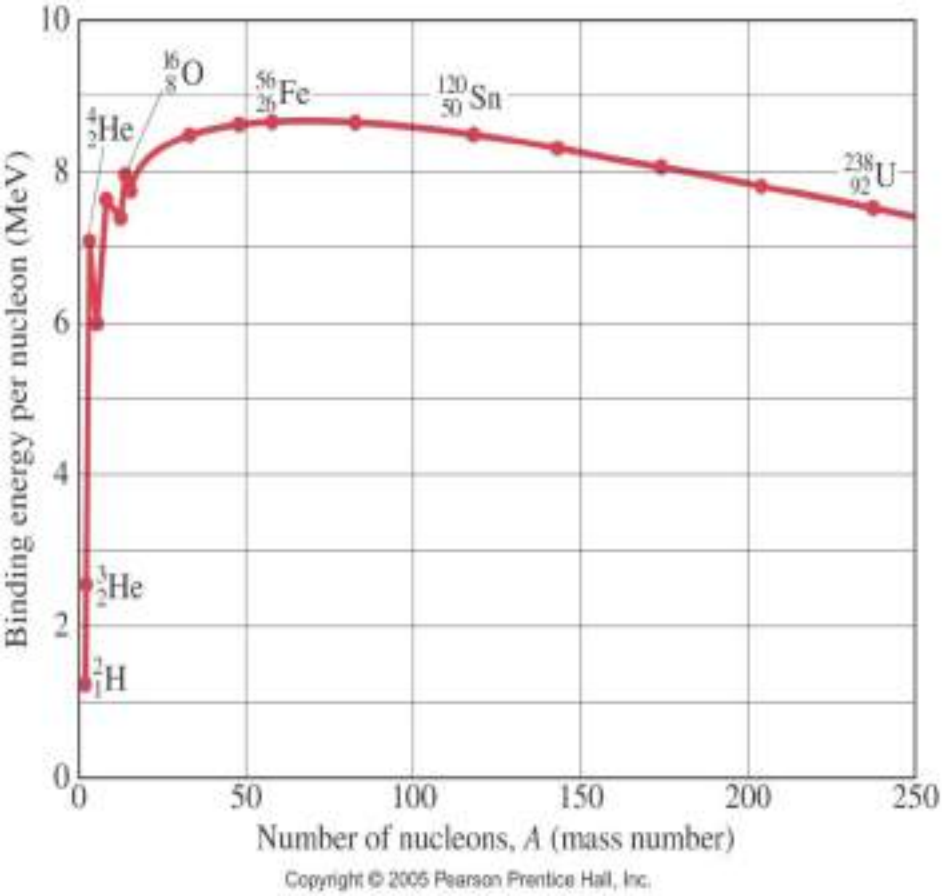
Binding energy per nucleon.

- Binding Energy is related to nuclear stability
- Binding Energy is increased as A is increased
- **To compare how tightly bound different nuclei are, we divide the binding energy by A to get the binding energy per nucleon.**
- **binding energy per nucleon =**

Total binding energy / A

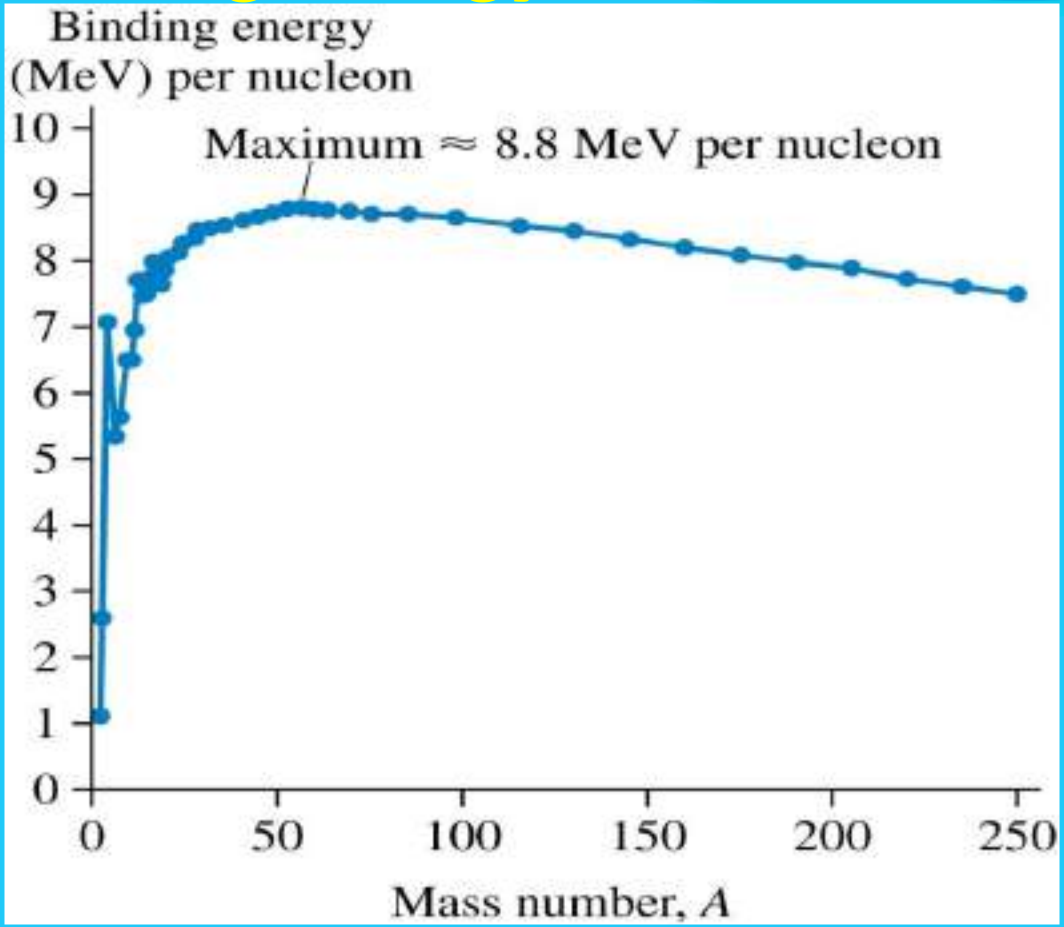
Nuclear binding energy per nucleon vs Mass number



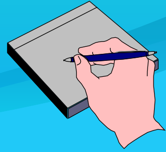


$$\frac{\text{nuclear binding energy}}{\text{Nucleon(A)}} \uparrow \qquad \text{nuclear stability} \uparrow$$

Curve of Binding Energy

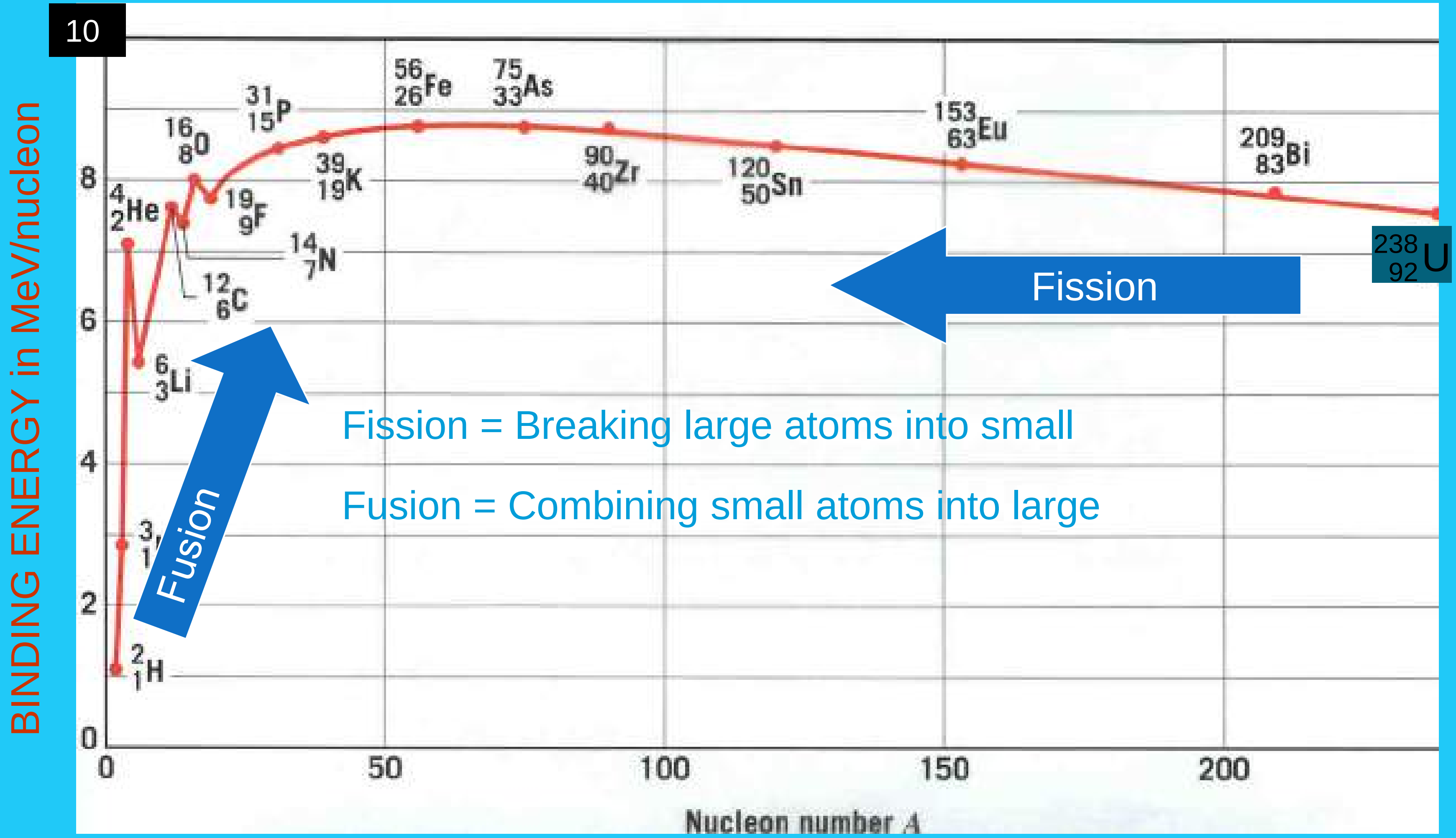


- Light nuclei can become more stable through fusion.
- Heavy nuclei can become more stable through fission.
- All nuclei larger than a certain size spontaneously fission.



Binding Energy Plot

Iron (Fe) has most binding energy/nucleon. Lighter have too few nucleons, heavier have too many.



Fission = Breaking large atoms into small

Fusion = Combining small atoms into large

تفسير المنحنى

- ويوضح الشكل السابق العلاقة بين طاقة الربط لكل نيوكلون والعدد الوزني للعناصر المختلفة.
- حيث يوضح المنحنى أن طاقة الربط للنواة الخفيفة ^2H صغيرة جدا و هذا يدل على عدم إستقرار هذه الأنوية.
- وتزداد قيمة $\Delta E/A$ إلى أن تصل قيمة عالية حوالي 8.8 مليون إلكترون فولت عند النويدات ذات وزن ذري 50
- وبعدها تقل قيمة طاقة الربط كلما زاد الوزن الذري لتصل إلى 7.6 لليورانيوم (نواة غير مستقرة).

تفسير المنحنى

- من الشكل :منحنى طاقة الربط لكل نيوكليون للأنوية المستقرة كدالة لعدد الكتلة A.
- **ومن المنحنى نجد أيضا أن طاقة الربط للأنوية التالية: ^{16}O, ^{4}He, ^{12}C أعلى من العناصر التي تجاورها وذلك لأنها أنوية مستقرة. وعلى ذلك فإن طاقة الربط لكل نيوكلون تعطي معلومات عن درجة ثبات النواة.**
- ويستنتج من ذلك أنه لو دمجت نواتا ذرتين خفيفتين فإن النواة الناتجة تكون أكثر إستقرارا إلا أنه يفقد مقدار من الكتلة (نتيجة لعملية الدمج هذه) رغم أن
- لنواة الجديدة تشمل مجموع محتويات النواتين، ويتحول المقدار المفقود من الكتلة إلى طاقة منتشرة وهذا ما يحدث في عملية الإندماج النووي Nuclear Fusion

Example

Calculate the binding energy per nucleon for $_{90}Th^{232}$ by (MeV) if you know that the actual weight for Th is 232.0381 amu?

BE= { Zm H + NmN – ZMA } × 931.5 =

BE = { 90 × 1.007825 + 142 ×1.008665 -232.03812} ×931.5

BE = 1766.57 MeV

BE/A = 1766.57/232 = 7.61 MeV

Why do protons & protons, protons & neutrons, and neutrons & neutrons all bind together in the nucleus of an atom?

The Strong Force

Electromagnetic? No, this would cannot cause protons to bind to one another.

Gravity ? NO, way too feeble (even weaker than EM force)

Need a force which:

A) Can overcome the electrical repulsion between protons.

B) Is 'blind' to electric charge (*i.e.*, neutrons bind to other neutrons!)

Quantum theory of EM Interactions is incredibly precise. That is, the theoretical calculations agree with experimental observations to incredible accuracy.

➔ Build a similar theory of the strong interaction, based on force carriers

4 -The strong nuclear force

If you consider that the nucleus of all atoms except H contain more than one proton in them, and each proton carries a postive charge,

why do the nuclei of these atoms stay together? The protons must feel a repulsive force from the other neighboring protons.

This is where the strong nuclear force comes in.

But where does the energy that creates this force come from?

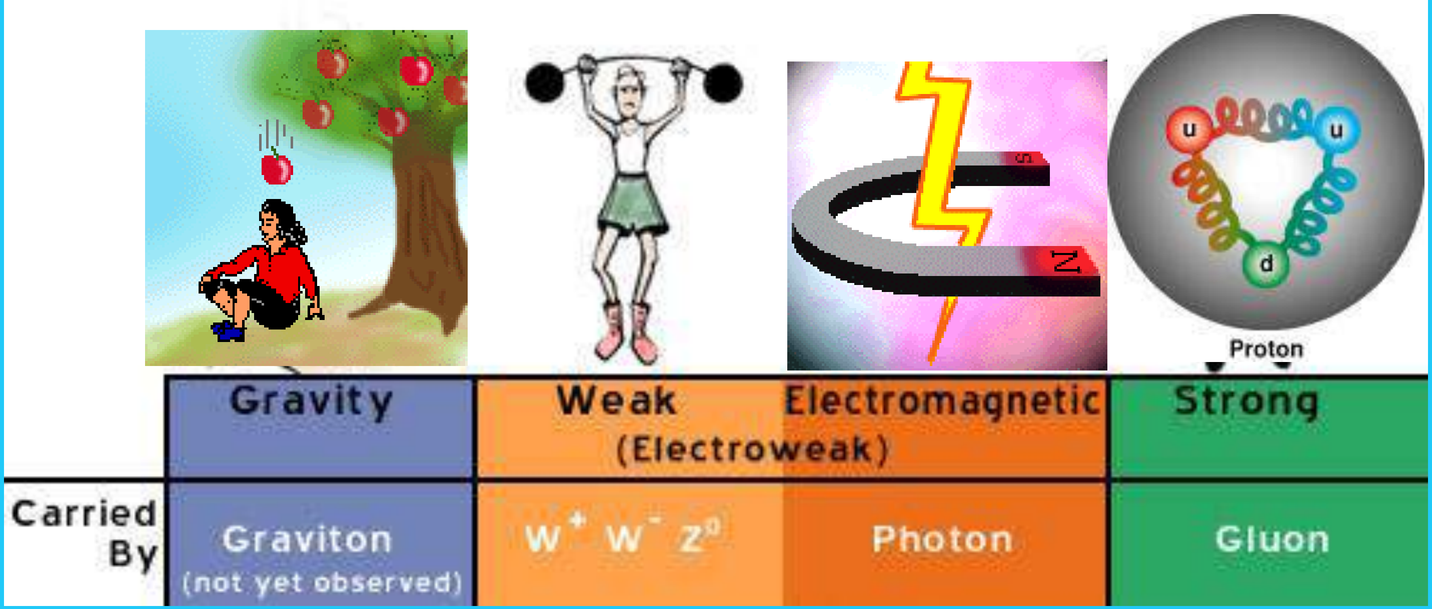
From mass defect which arise from the actual mass of a nucleus and the mass of seperated nucleons of that nucleus.

4- Nuclear Forces

The force that binds the nucleons together is called the strong nuclear force. It is a very strong, but short-range, force.

The Coulomb force is long-range; this is why extra neutrons are needed for stability in high-Z nuclei.

The four forces of Nature



	Gravity	Weak	Electromagnetic	Strong
		(Electroweak)		
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon

There are four fundamental forces, or interactions in nature.

- Strong nuclear
- Electromagnetic
- Weak nuclear
- Gravitational

Strongest

Weakest

1- Strong nuclear force

- Holds the nuclei of atoms together
- Very strong, but only over very, very, very short distances (within the nucleus of the atom)

2- Electromagnetic force

- Causes electric and magnetic effects
  - Like charges repel each other
  - Opposite charges attract each other
  - Interactions between magnets

❑ Weaker than the strong nuclear force

❑ Acts over a much longer distance range than the strong nuclear force

3- Weak nuclear force

- Responsible for nuclear decay
- Weak and has a very short distance range
- لاتتحول نكهة كوارك الى نكهة اخرى إلا عن طريق القوة النووية الضعيفة

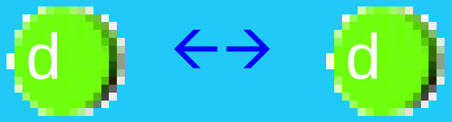
4- Gravitational force

- Weakest of all fundamental forces, but acts over very long distances
- Always attractive
- Acts between any two pieces of matter in the universe
- Very important in explaining the structure of the universe

The strong nuclear force

- The strong nuclear force (= strong force) is one of the four basic forces in nature
- As its name shows us, it is the strongest of the four. But,
- it also has the shortest range, meaning that particles must be extremely close before it performs its effects.

How strong is strong?



- 100 times stronger than the electromagnetic repulsion

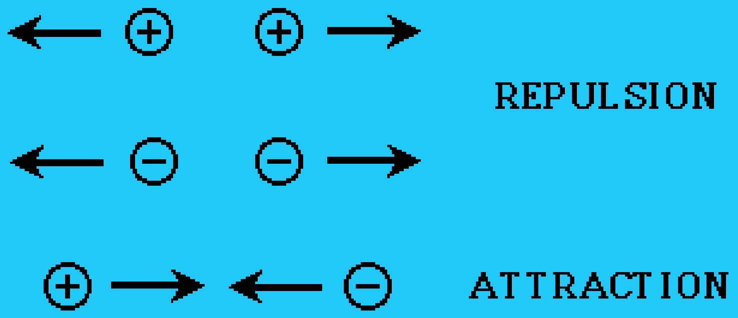
- 100,000 times stronger than the weak force

- 100 trillion trillion trillion times stronger than the Gravitational attraction

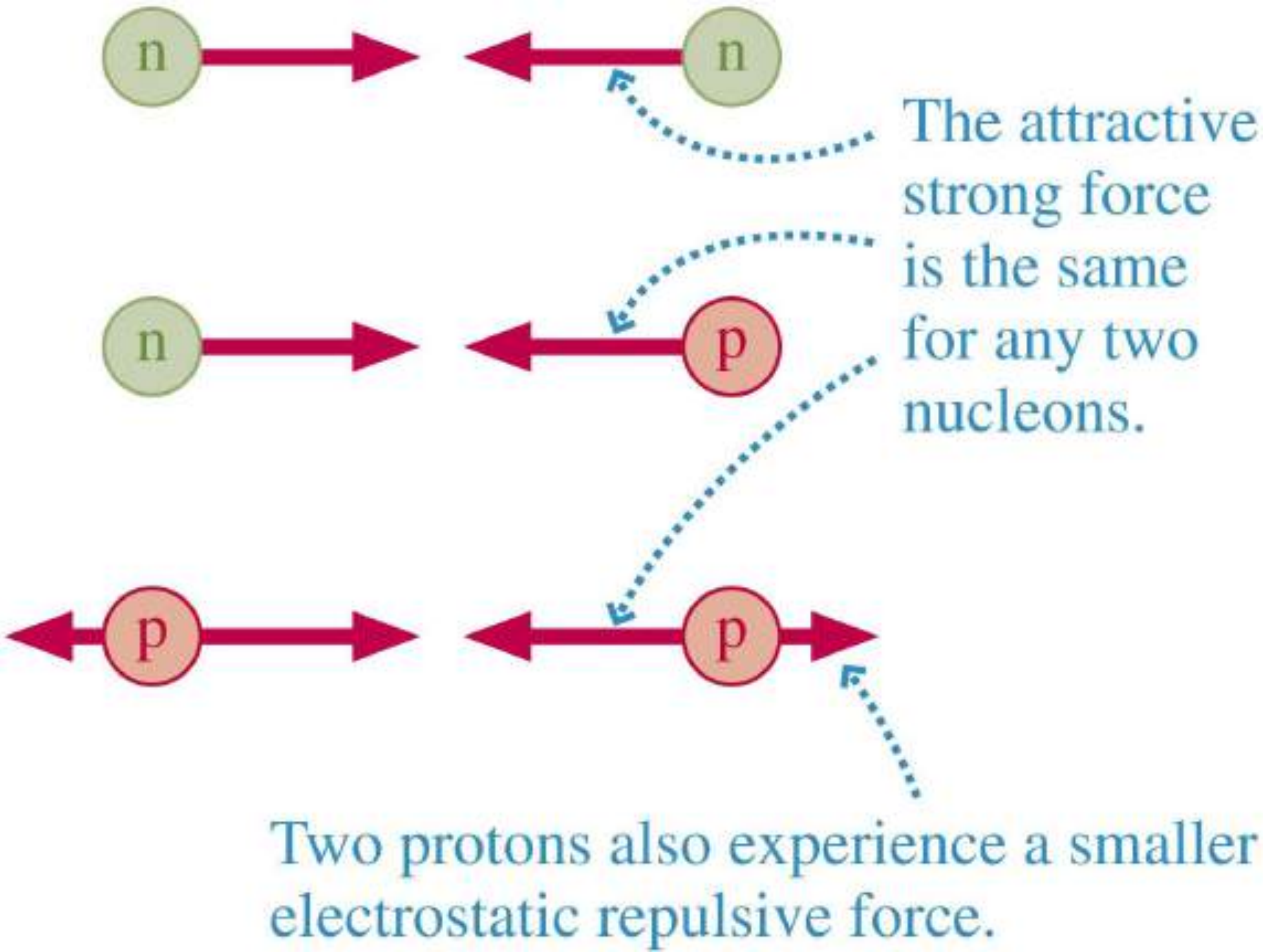
The strong nuclear force

Its main job is to hold together the the subatomic particles of the nucleus = the protons + neutrons = the nucleons.

We have learned, previously, that like charges repel, and unlike charges attract.



Nuclear Forces



The attractive strong force is the same for any two nucleons.

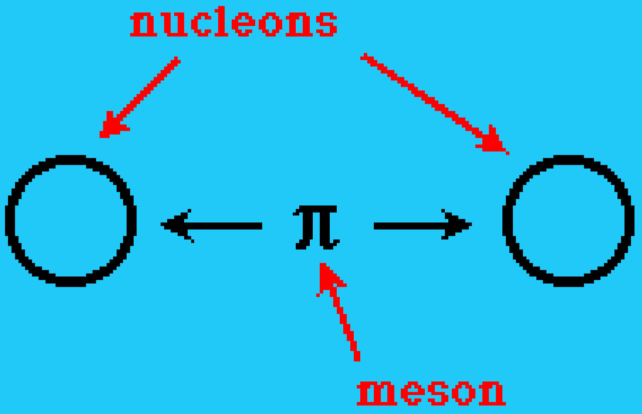
Two protons also experience a smaller electrostatic repulsive force.

The strong nuclear force

- The strong nuclear force is created between nucleons by the exchange of particles called **mesons** (chargeless hadrons made up of 1 quark and 1 antiquark).

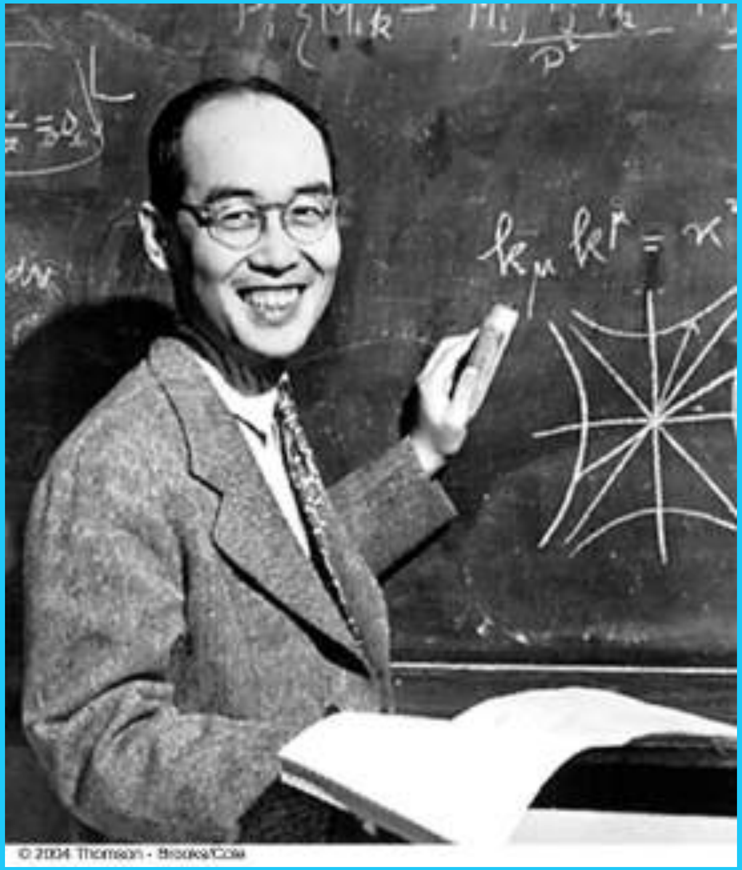
- This exchange is like constantly hitting a ping-pong ball back and forth between two people.

- As long as this meson exchange can happen, the strong force is able to hold the participating nucleons together.



Hideki Yukawa

- 1907 – 1981
- Nobel Prize in 1949 for predicting the existence of mesons
- Developed the first theory to explain the nature of the nuclear force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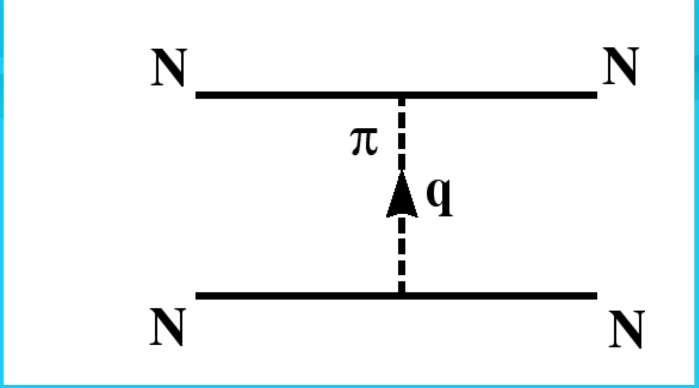
Mesons



- Developed from a theory to explain the nuclear force
- Yukawa used the idea of forces being mediated by particles to explain the nuclear force
- A new particle was introduced whose exchange between nucleons causes the nuclear force
  - It was called a *meson*
  - The proposed particle would have a mass about 200 times that of the electron

الميزونات:

- هى جسيمات ذات كتلة واقعة بين كتلة الالكترونات و البروتونات نظريا.
- كتلة هذة الجسيمات تقدر 200-300 قدر كتلة الالكترون

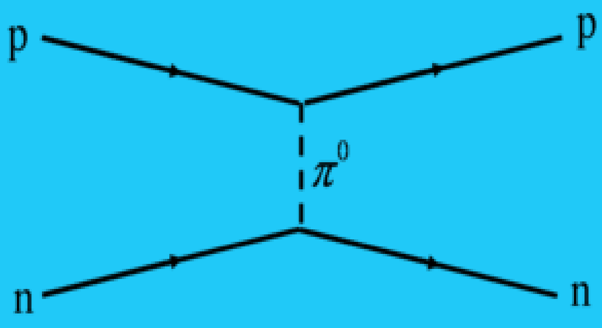
البايميزونات:

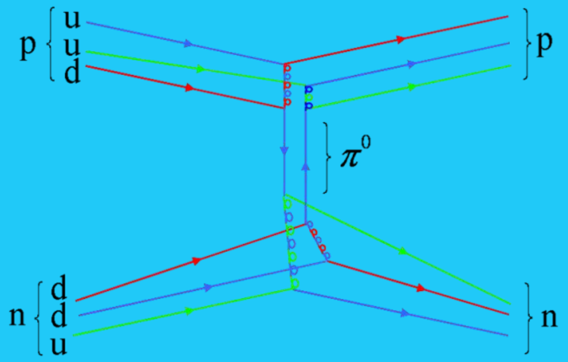
هى حاملات التاثيرات المتبادلة النووية وهى ثلاثة أنواع ميزونات ذات شحنة موجبة و ميزونات ذات شحنة سالبة و ميزونات ذات شحنة متعادلة

نظرية الميزونات فى تفسير القوى النووية

- ماهى التفاعلات الداخلية بين النيوكليونات التى تؤدى الى نقص االطاقة؟
- اقترح يوكاوا ان القوى النووية تنشأ من تبادل جسيمات تسمى الباى(π) ميزونات بين النيوكليونات المتجاورة بسرعة الضوء
- اذا تمتلك النيوكليونات (البروتونات أو النيوترونات) أجزاء مركزية متماثلة تحاط بسحابة من عدد من الميزونات يمكن ان تكون متعادلة, سالبة أو موجبة الشحنة

- الانتقال التبادلى بين(n – n)أو (p – p) يتم بواسطة ميزون متعادل الشحنة
- الانتقال التبادلى بين (n – p)يتم بواسطة ميزون مشحون بشحنة سالبة او موجبة



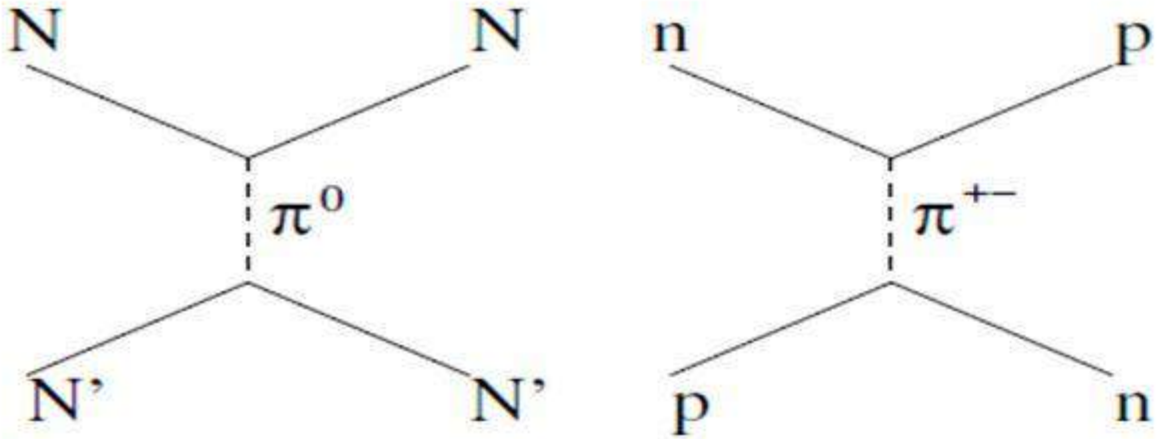


The nature of nuclear forces:

Intermediate particles with similar masses were discovered and named as π mesons. In quantum field theory, forces between particles are described by the exchange of virtual particles:

$$p \rightarrow p + \pi^0 \rightarrow p \,, \qquad n \rightarrow n + \pi^0 \rightarrow n$$

$$n \rightarrow p + \pi - \rightarrow n, \qquad p \rightarrow n + \pi + \rightarrow p,$$



Protons and neutrons emit and absorb mesons(pions).

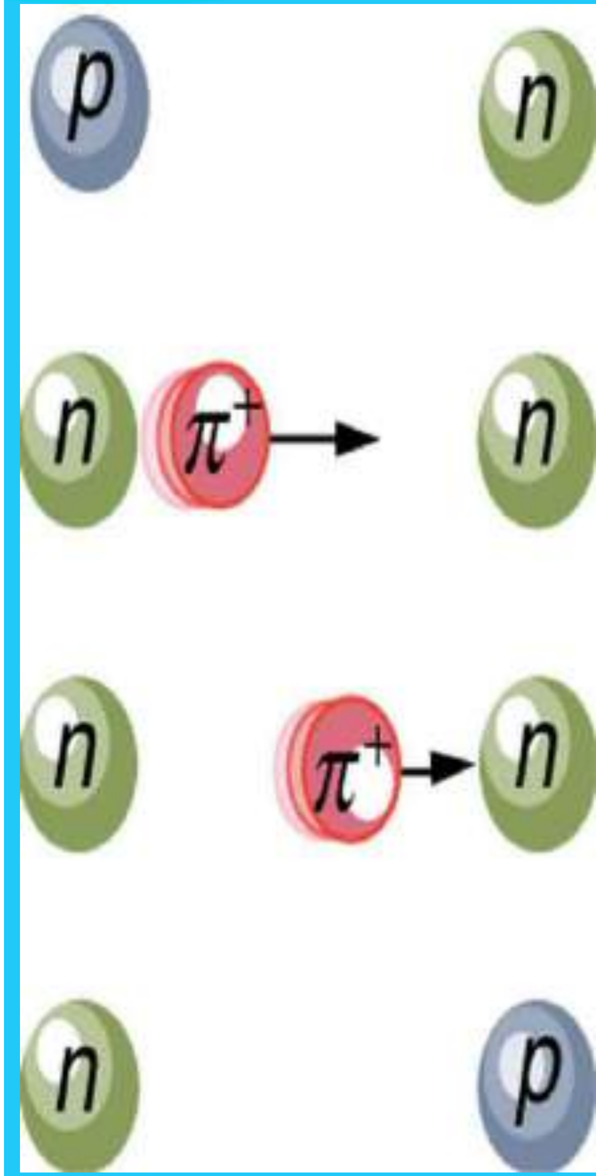
Meson theory of Nuclear Forces by Yukawa (1935)

- A **meson** may be π^+, π^- or π^0

A neutron, by **accepting** a π^+ meson converted in to a proton.

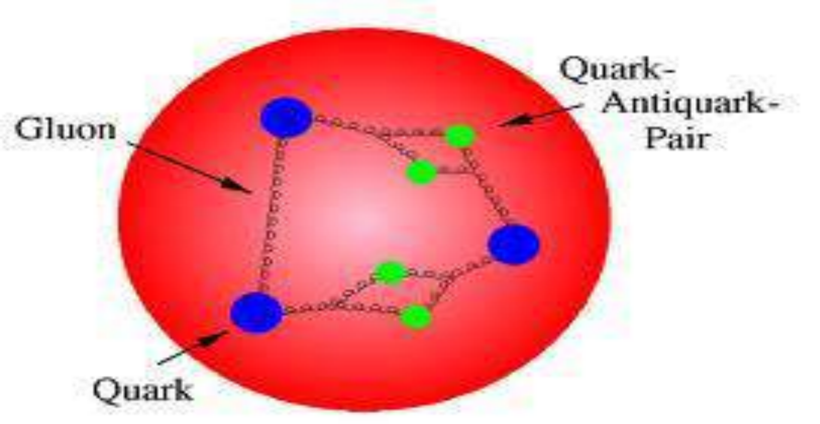
A proton, by **ejecting** a π^+ meson converted in to a neutron.

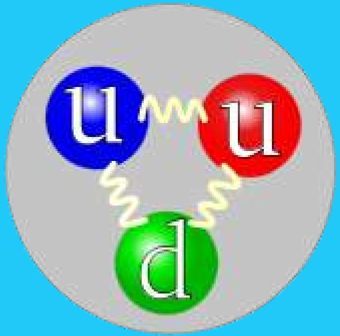
- A neutron, by **ejecting** a π^- meson converted in to a proton.
- A proton, by **accepting** a π^- meson converted in to a neutron.



الجسيمات الأولية

- تجتمع الكواركات معا لتتشكل جسيمات مركبة تسمى هادرونات، الأكثر استقرارا التي هي البروتونات والنيوترونات، وهي مكونات نواة الذرة.
- لا يمكن أن تظهر الكواركات بشكل مفرد حر فهي دائما محتجزة ضمن هادرونات ثنائية (ميزونات) أو ثلاثية (باريونات) مثل البروتونات والنيوترونات،.

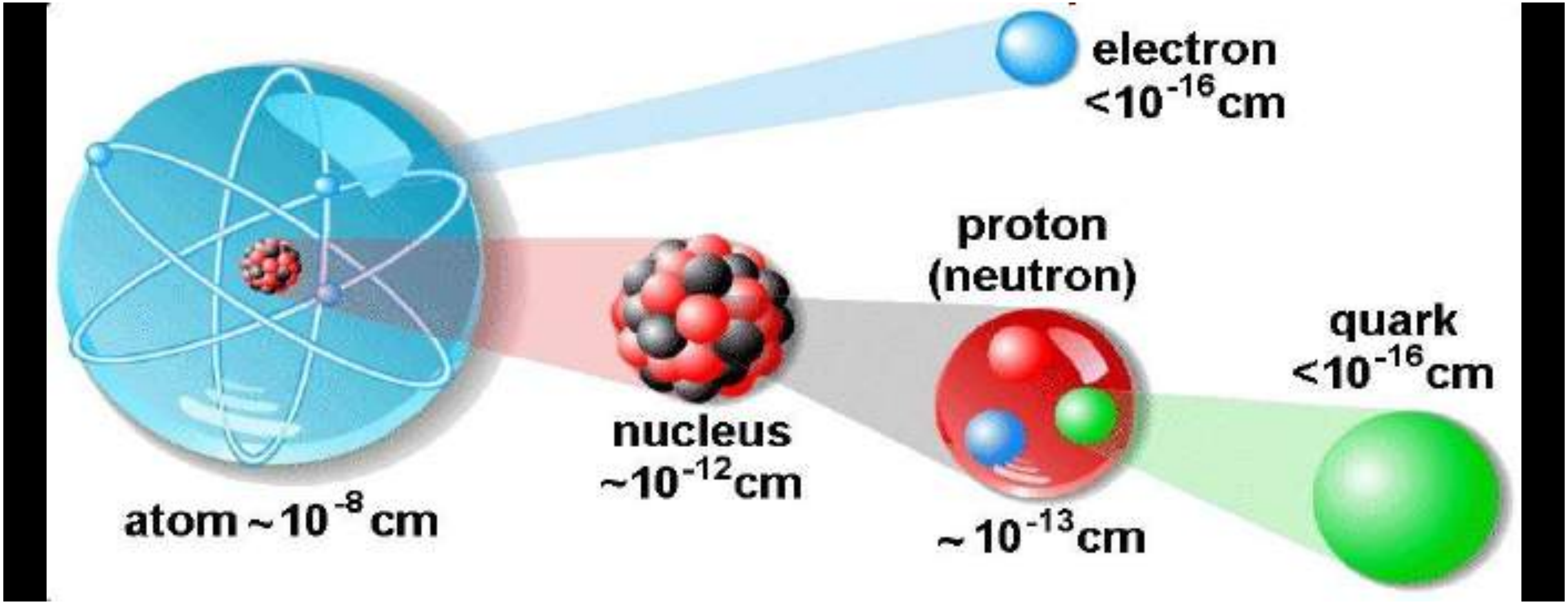




الجسيمات الاولية The Elementary Particles

Families of Quarks

What do we know about matter?



The Elementary Particles الجسيمات الاولية

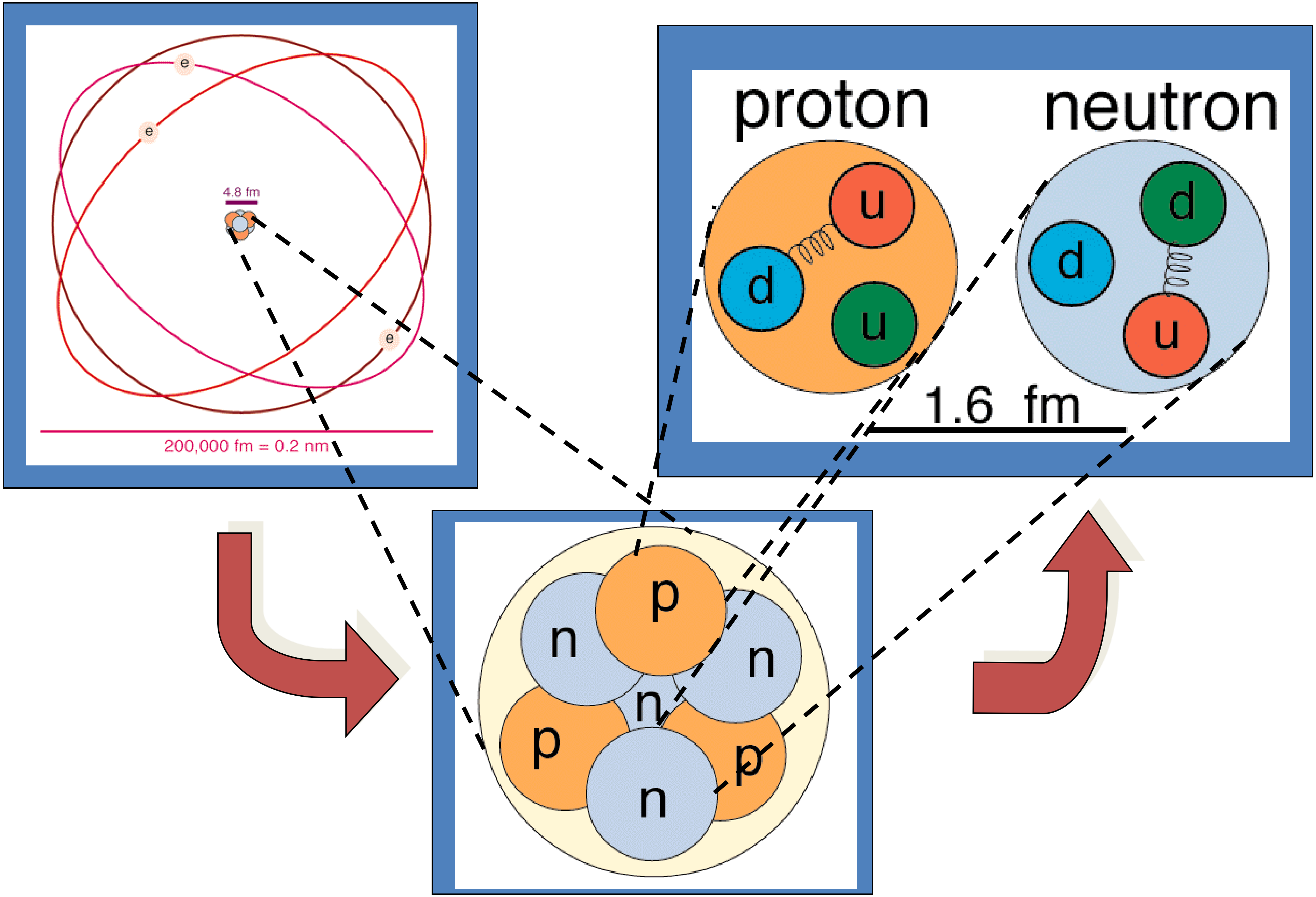
-لم تعد البروتونات والنيوترنات جسيمات أولية غير قابلة للتجزئة

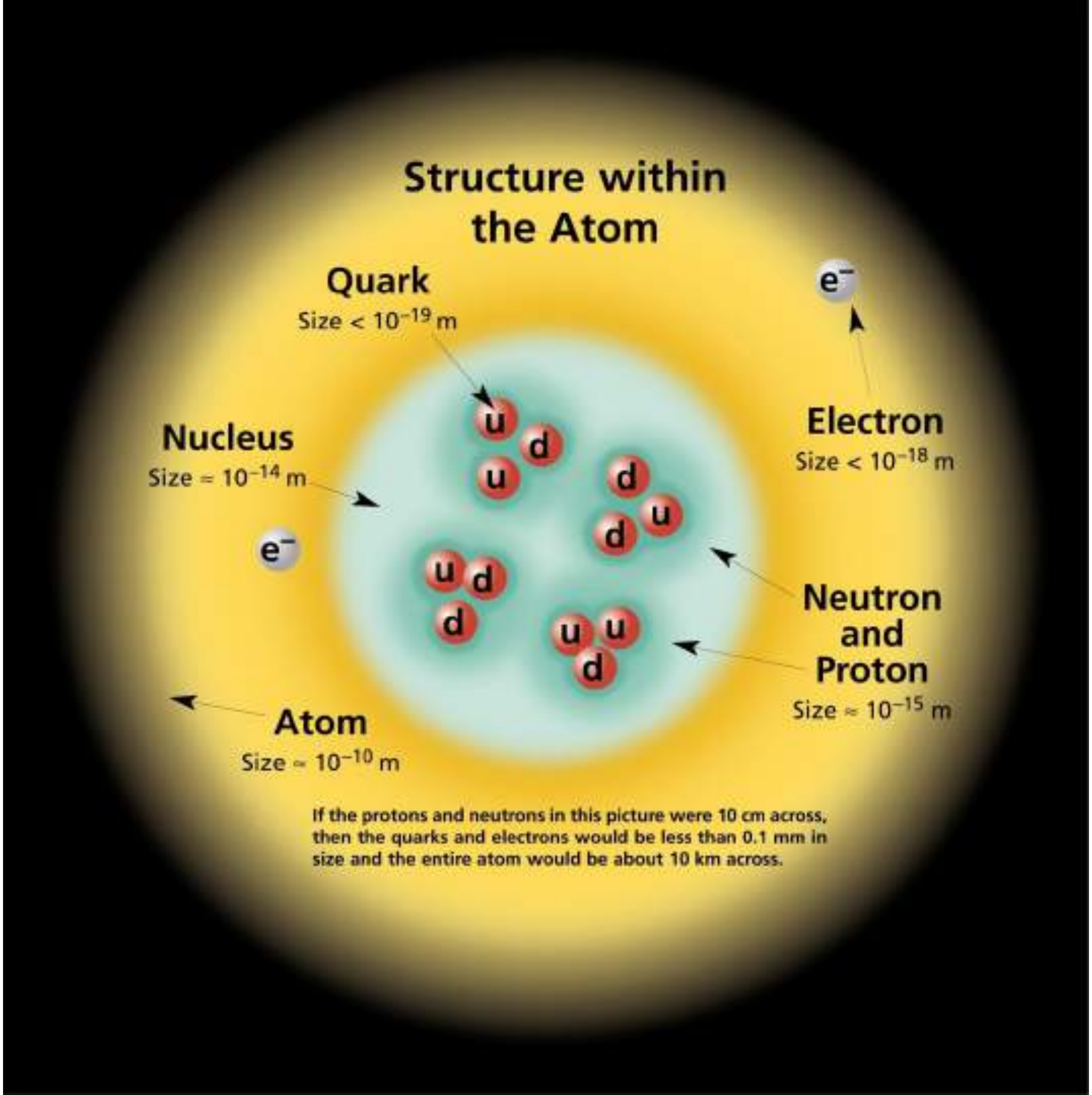
-يعتقد الان ان الكوارك هو أصغر الجسيمات أولية غير قابلة للتجزئة

- فهى اما وسائط بأعمار قصيرة للغاية كالميزونات

- أو جسيمات مستقرة لكنها تتحرر فقط خلال التحولات النووية

Back to matter & quarks…



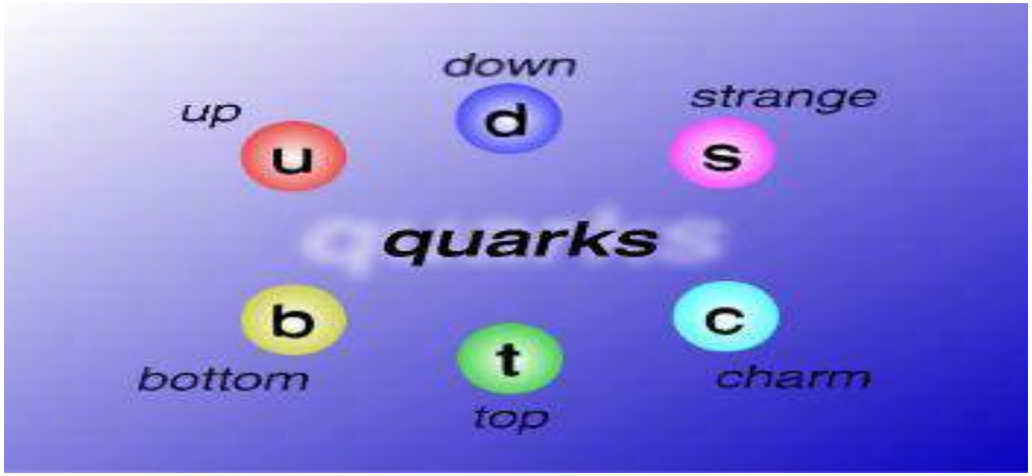


Structure within the Atom

If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

الكوركات

- **الكوارك** هو جسيم أولي لها كتلة تتم مشاهدتها عند حدوث تصادم شديد بين البروتون والإلكترون. وقد أطلق موري جيلمان هذا الاسم على الكوارك. منها ستة أنواع.
- للكوارك ست أنواع وتسمى بالنكهات وهي: العلوي، السفلي، الساحر، الغريب، القمي، والقعري.
- كل من الكوارك العلوي والسفلي له أقل من كتلة من باقي الكواركات الأخرى. فالكواركات الأثقل تتحول إلى علوية وسفلية بسرعة خلال عملية تسمى اضمحلال الجسيم: حيث تتحول حالة الكتلة الأثقل إلى حالة كتلة أخف. لهذا فالكوارك العلوي والسفلي هما الأكثر استقرارا ووجودا في



- **لدى الكوارك خصائص أساسية مثل** الشحنة الكهربائية والشحنة اللونية والدوران المغزلي والكتلة. فالكواركات هي الجسيمات الأولية الوحيدة في النموذج القياسي لفيزياء الجسيمات التي تُظهِر جميع القوى الأساسية الأربع المسماة بالتفاعلات الأساسية وهي الكهرومغناطيسية والجاذبية والتآثر القوي والضعيف، بالإضافة إلى أنها الجسيمات الوحيدة التي لا تعد شحنتها الكهربائية مضاعفات صحيحة للشحنة الأولية.

ولكل كوارك جسيم مضاد، وهو نظير مطابق له، لديه نفس قدر شحنة الكوارك ولكن بشحنة معاكسة.
سمّى جيل مان الكوارك بهذا الاسم بعيد سماعه لصوت البط. وقد استغرق بعض الوقت لصياغة التهجئة الصحيحة للمصطلح الجديد، حتى وجد كلمة كوارك "*Quark*" في كتاب جيمز جويس

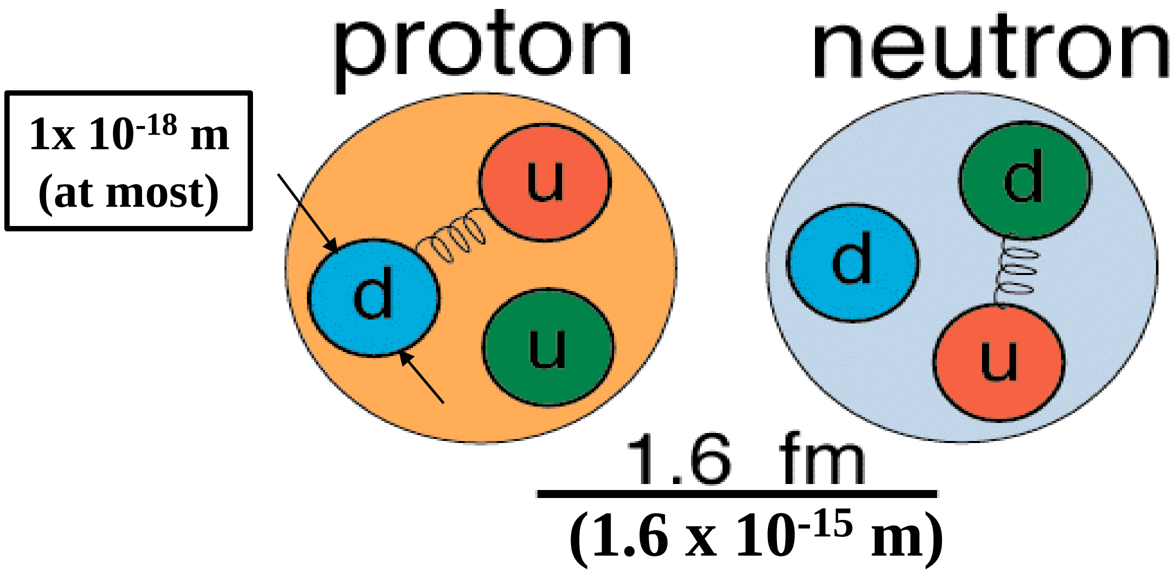
Quarks

Since 1969, many other experiments have been conducted to determine the underlying structure of protons/neutrons.

All the experiments come to the same conclusion.

➔ Protons and neutrons are composed of smaller constituents.

These quarks are the same ones predicted by Gell-Mann & Zweig in 1964.



- Protons
  - 2 **“up”** quarks
  - 1 **“down”** quark
- Neutrons
  - 1 **“up”** quark
  - 2 **“down”** quarks

Are there any other quarks other than UP and DOWN ?

Three Families of Quarks

Woohhh, fractionally charged particles?

	Generations		
	Increasing mass		
	I	**II**	**III**
Charge = **-1/3**	**d** **(down)**	**s** **(strange)**	**b** **(bottom)**
Charge = **+2/3**	**u** **(up)**	**c** **(charm)**	**t** **(top)**

Also, each quark has a corresponding antiquark.
The **antiquarks** have **opposite charge** to the quarks

Anti-particles too !

- We also know that every particle has a corresponding **antiparticle**!

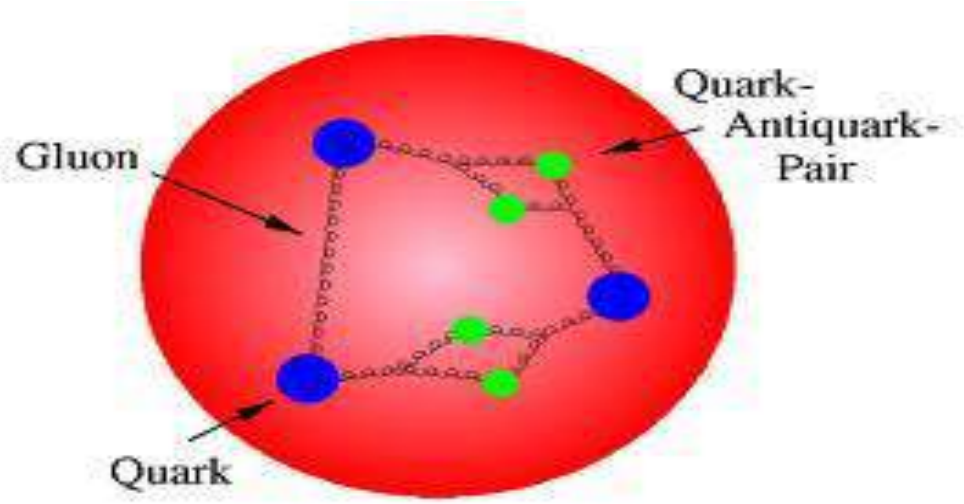
- That is, there are also **6 anti-quarks, they have opposite charge to the quarks.**

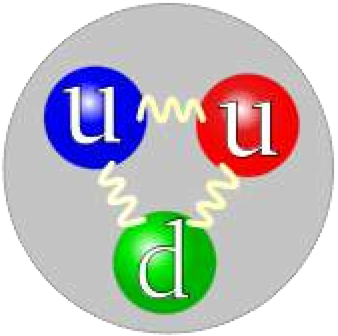
- So, the full slate of quarks are:

Particle	**Q= +2/3**	u, c, t	**Quarks**
	Q= -1/3	d, s, b	
Anti-Particle	**Q= -2/3**	$\bar{u}, \bar{c}, \bar{t}$	**Anti-Quarks**
	Q= +1/3	$\bar{d}, \bar{s}, \bar{b}$	

-تجتمع الكواركات معا لتشكل جسيمات مركبة تسمى هادرونات، الأكثر استقرارا التي هي البروتونات والنيوترونات، وهي مكونات نواة الذرة.

- لا يمكن أن تظهر الكواركات بشكل مفرد حر فهي دائما محتجزة ضمن هادرونات ثنائية (ميزونات) أو ثلاثية (باريونات) مثل البروتونات والنيوترونات، وتسمى هذه الظاهرة بالحبس اللوني (Color confinement)، لهذا السبب فمعظم المعلومات عن الكواركات تم استخلاصها من ملاحظات الهادرونات نفسها.

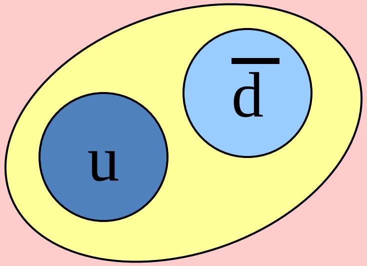




Mesons

- **Mesons** are also in the **hadron family**.

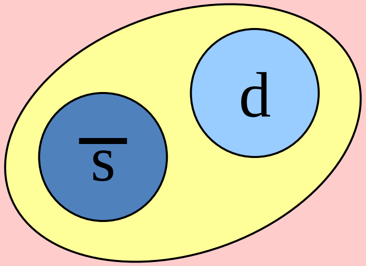
- They are formed when a **quark** and an **anti-quark** "bind" together. (We'll talk more later about what we mean by "bind").



What's the charge of this particle?

Q=+1, and it's called a π^+

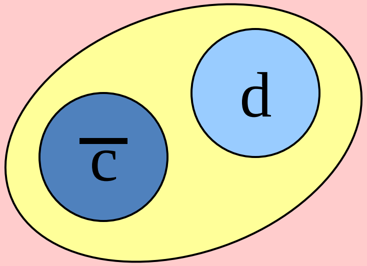
M~140 [MeV/c^2]
Lifetime~2.6x10^{-8} [s]



What's the charge of this particle?

Q= 0, this strange meson is called a K^0

M~500 [MeV/c^2]
Lifetime~0.8x10^{-10} [s]



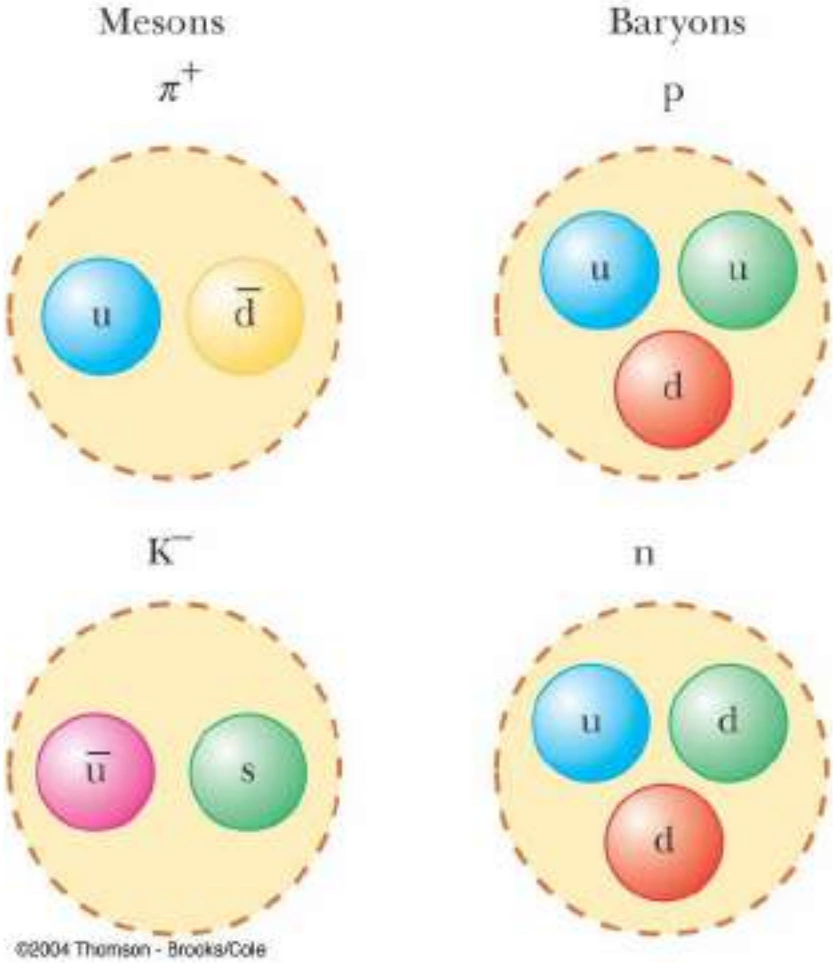
What's the charge of this particle?

Q= -1, and this charm meson is called a D^-

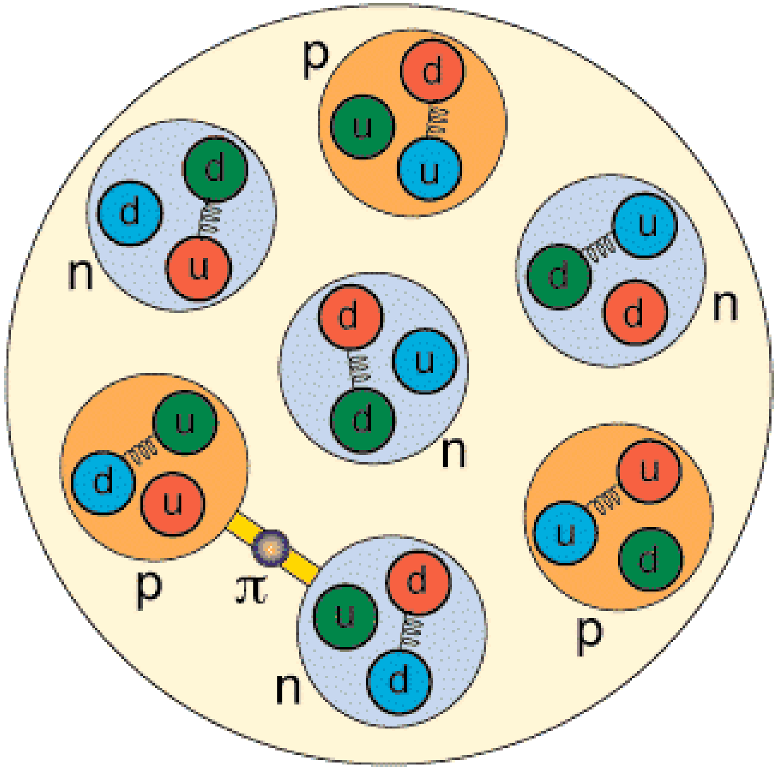
M~1870 [MeV/c^2]
Lifetime~1x10^{-12} [s]

Quark Composition of Particles – Examples

- Mesons are quark-antiquark pairs
- Baryons are quark triplets



Protons & Neutrons



To make a proton:
We bind **2 up quarks** of **Q = +2/3**
and **1 down quark** of **Q = -1/3**.
The total charge is

2/3 + 2/3 + (-1/3) = +1 !

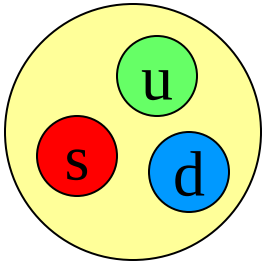
To make a neutron:
We bind **2 down quarks of Q= -1/3**
with **1 up quark of Q = +2/3** to get:

(-1/3) + (-1/3) + (2/3) = 0 !

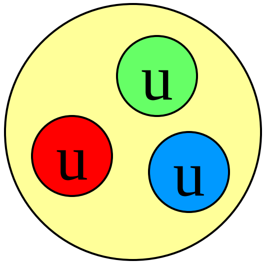
So, it all works out ! But, yes, we have
FRACTIONALLY CHARGED PARTICLES!

Are there baryons other than protons and neutrons?

- Good question, my dear …
- The answer is a resounding **YES !**
- Other quarks can combine to form other baryons. For example:



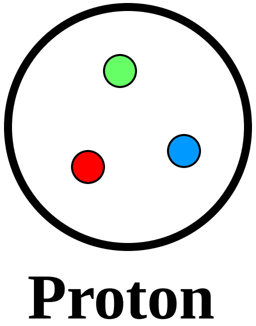
This combination is called a
Lambda baryon, or Λ^0 for short
What is the charge of this object?)



This combination is called a
Delta baryon, or Δ^{++} for short
What's this one's charge?

Flavor	Q/e
u	+2/3
d	-1/3
s	-1/3

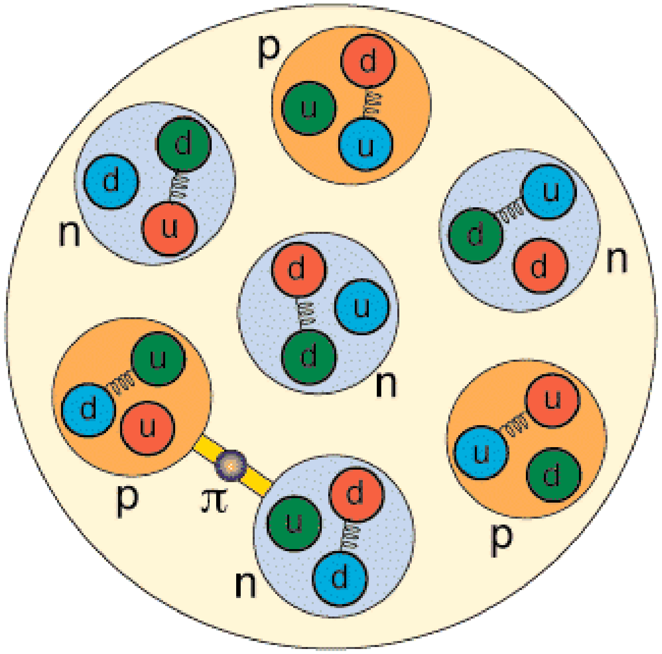
Quark Confinement



☐ **Quarks are "confined" inside objects known as "hadrons".**

☐ **This is a result of the "strong force" which we will discuss later…**

Why does the nucleus stay together ?



So far, the only "fundamental" forces we know about are:

(a) Gravity
(b) EM force (Electricity + Magnetism)

Which one of these is responsible for binding protons to protons and protons to neutrons ???

☐ Since like sign charges repel, it can't be EM force?
☐ Gravity is way, way, way too weak…

Then what is it???

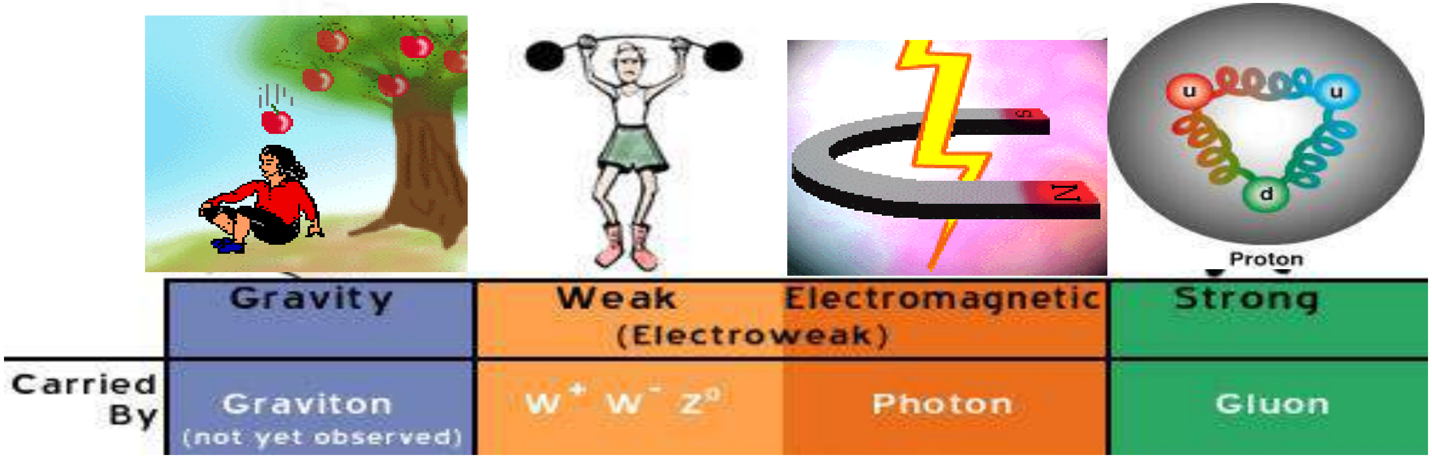
Strong Force

This is the third **fundamental force** in nature and is by far the strongest of the four forces. More on forces later…

So why does matter appear to be so rigid ?

Forces, forces, forces !!!!

It is primarily the strong and electromagnetic forces which give matter its solid structure.



	Gravity	Weak	Electromagnetic	Strong
		(Electroweak)		
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon

The four forces of Nature

-تجتمع الكواركات معا لتشكل جسيمات مركبة تسمى هادرونات، الأكثر استقرارا التي هي البروتونات والنيوترونات، وهي مكونات نواة الذرة.

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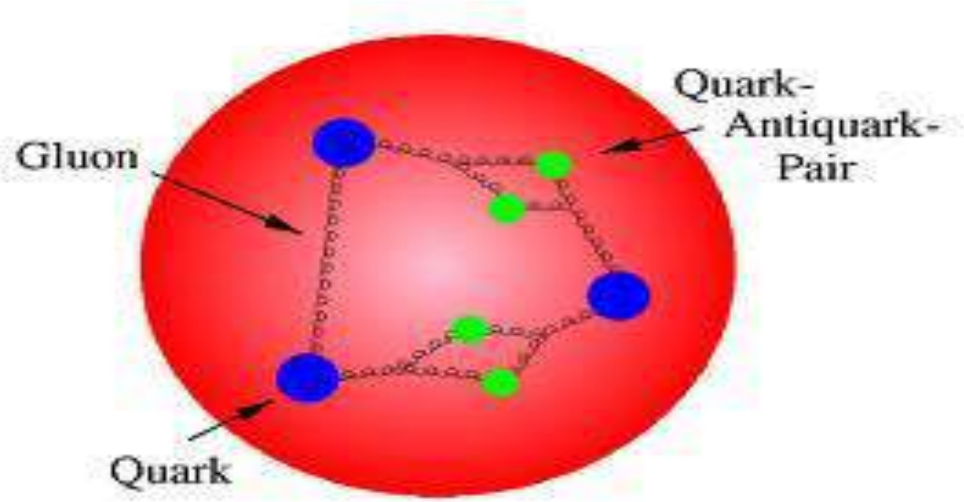
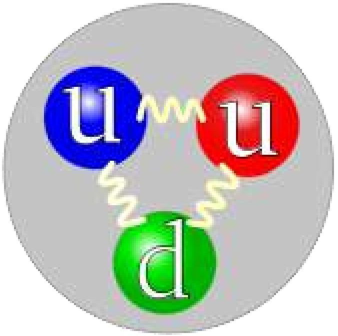




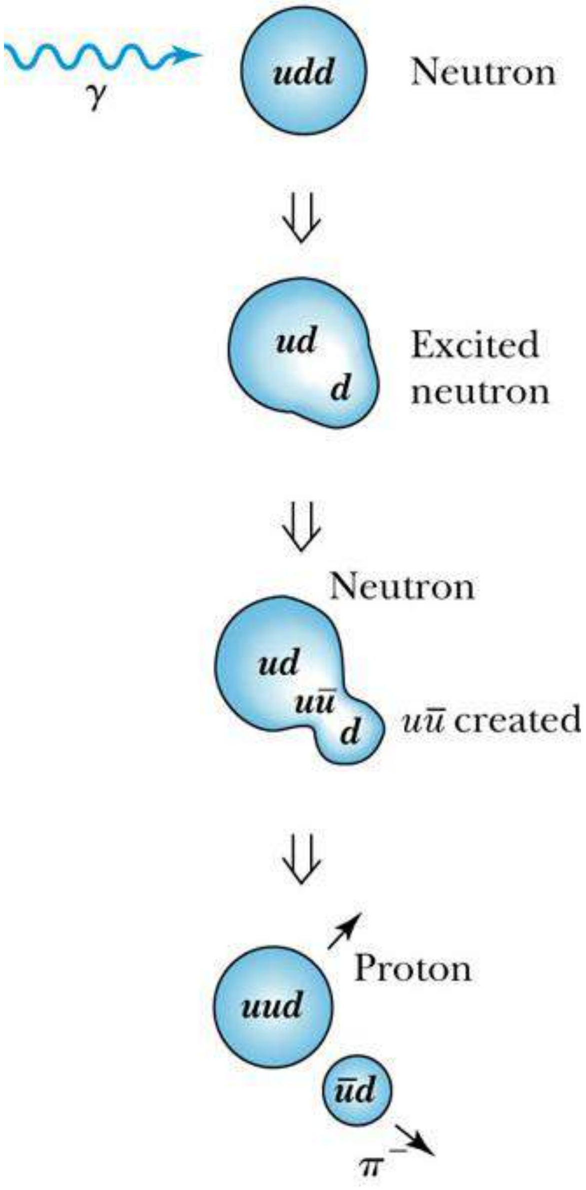
الشحنة اللونية

- يمتلك الكوارك خاصية تسمى **الشحنة اللونية**. وتتكون تلك الشحنة من ثلاث أنواع، سميت عشوائيا بالأزرق والأخضر والأحمر.[1]
- لكل نوع من تلك الأنواع مكمل من ضديد اللون - ضديد الأزرق، ضديد الأخضر، وضديد الأحمر. فإذا كان الكوارك يحمل لونا ما، فإن ضديد الكوارك يحمل ضديد اللون.
- التفاعل القوى وهو يتوسط قوة تحمل الجسيمات وتسمى بالغالونات

Confinement

- Physicists now believe that free quarks cannot be observed; they can only exist within hadrons.

$$\gamma + n \rightarrow p + \pi^-$$



•**When a high-energy gamma ray is scattered from a neutron, a free quark cannot escape because of confinement.**

• **For high enough energies, an antiquark-quark pair is created (for example, $u\bar{u}$), and a pion and proton are the final particles.**

How do we know any of this?

❑Recall that high energy particles provide a way to probe, or “see” matter at the very smallest sizes. (Recall Electron microscope example).

❑ Today, high energy accelerators produce energetic beams which allow us to probe matter at its most fundamental level.

"Particles, particles, particles."

❑ As we go to higher energy particle collisions:

1) Wavelength probe is smaller ➔ **see finer detail**

2) Can produce more **massive objects**, via **$E=mc^2$**

مصادم الهادرونات الكبير

Large Hadron Collider "LHC"

- **مصادم الهدرونات الكبير** (بالإنجليزية:) (Large Hadron Collider) اختصاراً **LHC)** هو أضخم مُعجِّل جسيمات وأعلاها طاقة وسرعة، يستخدم هذا السينكروترون لمصادمة جسيمات دون ذرية وهي البروتونات بطاقة تصل إلى 7 تيراإلكترون فولت (1.12 ميكروجول). يعجّل فيض من البروتونات في دائرة المعجل إلى سرعة قريبة من سرعة الضوء تصل طاقة حركتها 3.5 تيرا (1 تيرا =10^{12}) إلكترون فولت TeV، وفي نفس الوقت يقوم المعجل بتسريع فيض آخر من البروتونات في الاتجاه العكسي (في أنبوب دائري آخر موازي للأول) إلى سرعة قريبة من سرعة الضوء أيضا بحيث تصل طاقة حركته 3.5 تيرا إلكترون فولط. تحافظ على بقاء البروتونات المعجلة في أنبوب كل فيض منها الدائري البالغ طوله 27 كيلومتر مغناطيسات قوية جدا تستهلك طاقة كهربائية عالية تستلزم التبريد بالهيليوم السائل ذو درجة حرارة نحو 4 كلفن أي نحو 270 درجة تحت الصفر المئوي.[2][1]
- بعد تسريع فيضي البروتونات إلى طاقة 3.5 تيرا إلكترون فولط في اتجاهين متضادين، يسلط فيضي البروتونات عند نقاط معينة للالتقاء والتصادم ببعضهما البعض، وتصبح طاقة التصادم بين كل بروتونين 7 تيرا إلكترون فولط. خصصت 4 نقاط لتصادم البروتونات على دائرة المعجل الكبرى البالغ محيطها 27 كيلومتر. وأنشئت عند تلك النقاط مكشافات (عدادات) لتسجيل نواتج التصادمات، ومن المتوقع أن تحتوي نواتج الاصطدام على جميع الجسيمات دون الذرية المعروفة لنا منها إلكترونات ومضاد الإلكترون وبروتونات ونقائض البروتونات وكواركات وغيرها، ويأمل العلماء اكتشاف جسيمات أولية جديدة لا نعرفها.
- مصطلح هادرون يشير إلى الجسيمات التي تحتوي على الكواركات ومن تلك الجسيمات البروتون والنيوترون. بينما يمتلك البروتون شحنة كهربائية موجبة لا يمتلك النيوترون شحنة كهربائية. لهذا السبب يمكن تعجيل البروتونات في المعجل أو المصادم بواسطة تسليط مجال كهربائي عليها ومتواصلا عبر دائرة المعجل، ولا يمكن تعجيل النيوترونات. هذا يعني أن مصادم الهدرونات الكبير ما هو إلا معجل للبروتونات، ويسمى الكبير حيث أن دائرته يصل قطرها 27 كيلومتر على الحدود بين سويسرا وفرنسا بالقرب من مدينة جينيف وهو مبني 100 متر تحت الأرض بحيث لا تصل إليه أشعة كونية تشوش على قياساته.

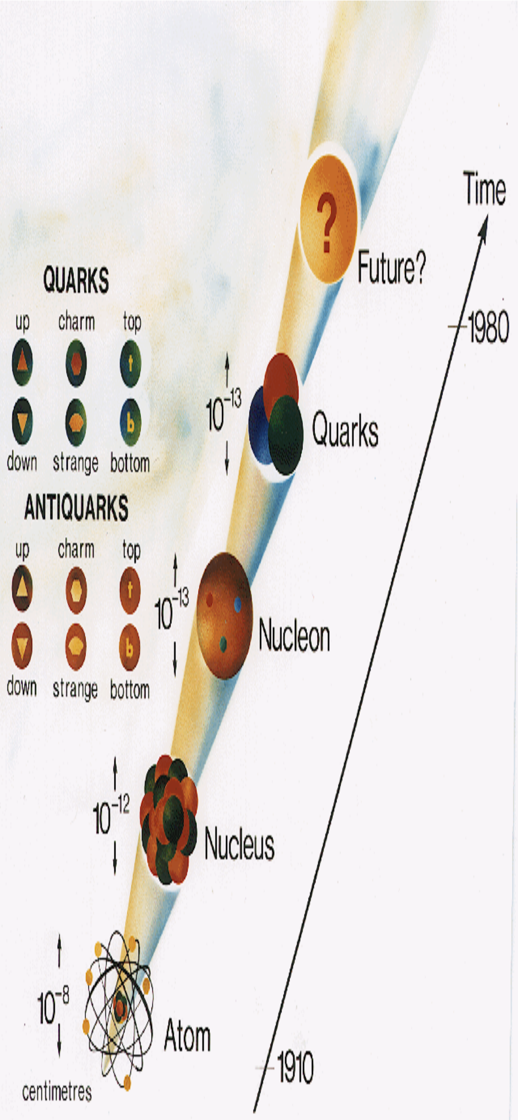
Who Is ATLAS?

- ATLAS is one of four large experiments at LHC
- تبنت المنظمة الأوروبية للبحث النووي (CERN)بناء مجمع مصادم الهادرونات الكبير، أو " Large Hadron Collider"ويرمز له بالرمز " LHC"
- وتقوم تلك الأجهزة برصد طاقة وسرعة واتجاه حركة الجسيمات الناتجة عن التصادم وذلك باستخدام تقنيات معقدة، وذلك لمحاولة تحديد الجسيمات الناتجة عن التصادم واكتشاف جسيمات جديدة. ونذكر من تلك المجسات أهمهم وهم " ATLAS"و " CMS"و " ALICE"و " LHCb".
  - The ATLAS collaboration consists of
    - ~2500 physicists including
    - ~700 graduate students from
    - 169 different institutions in
    - 37 different countries

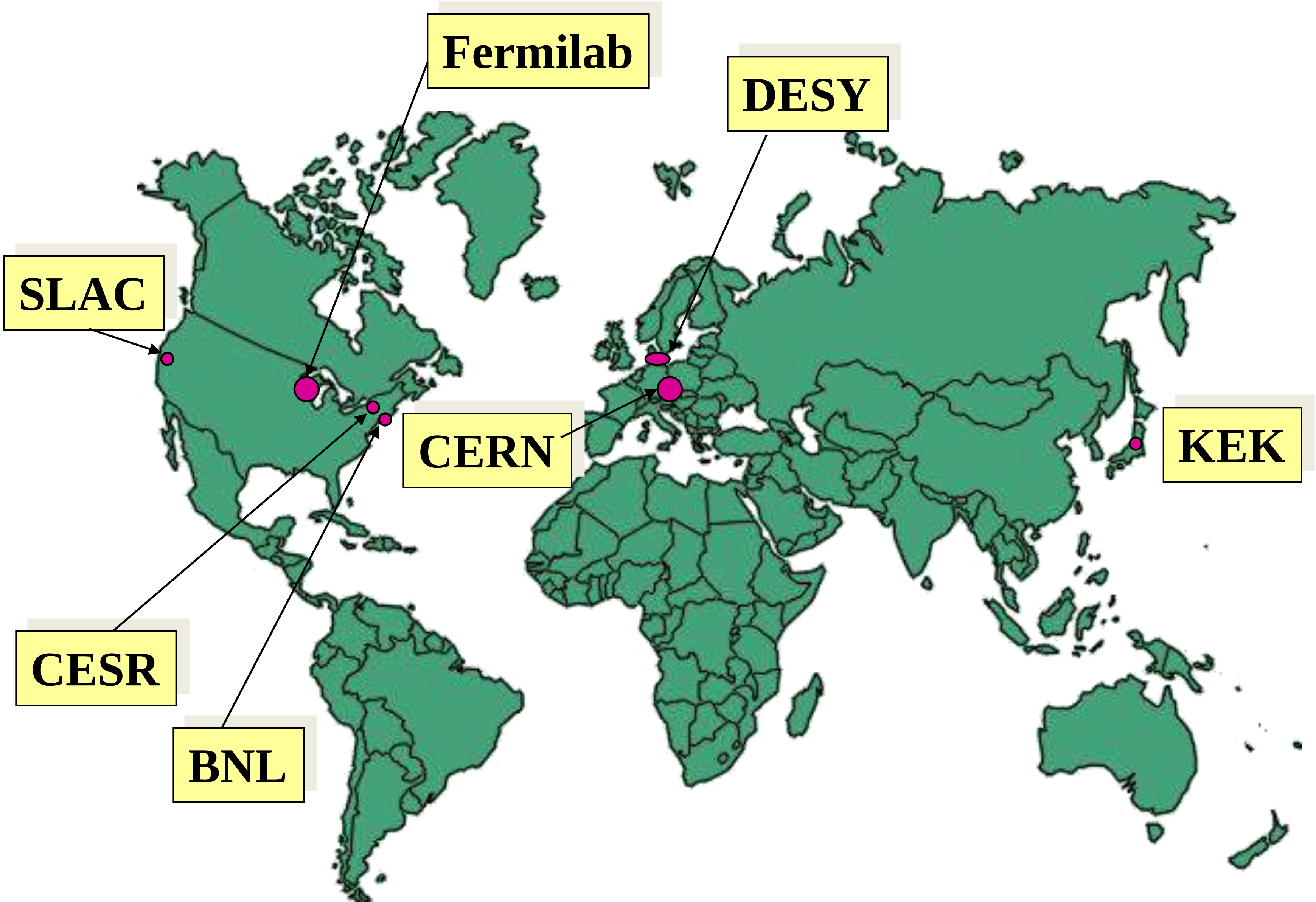
ATLAS is a United Nations of particle physics.

Final Words

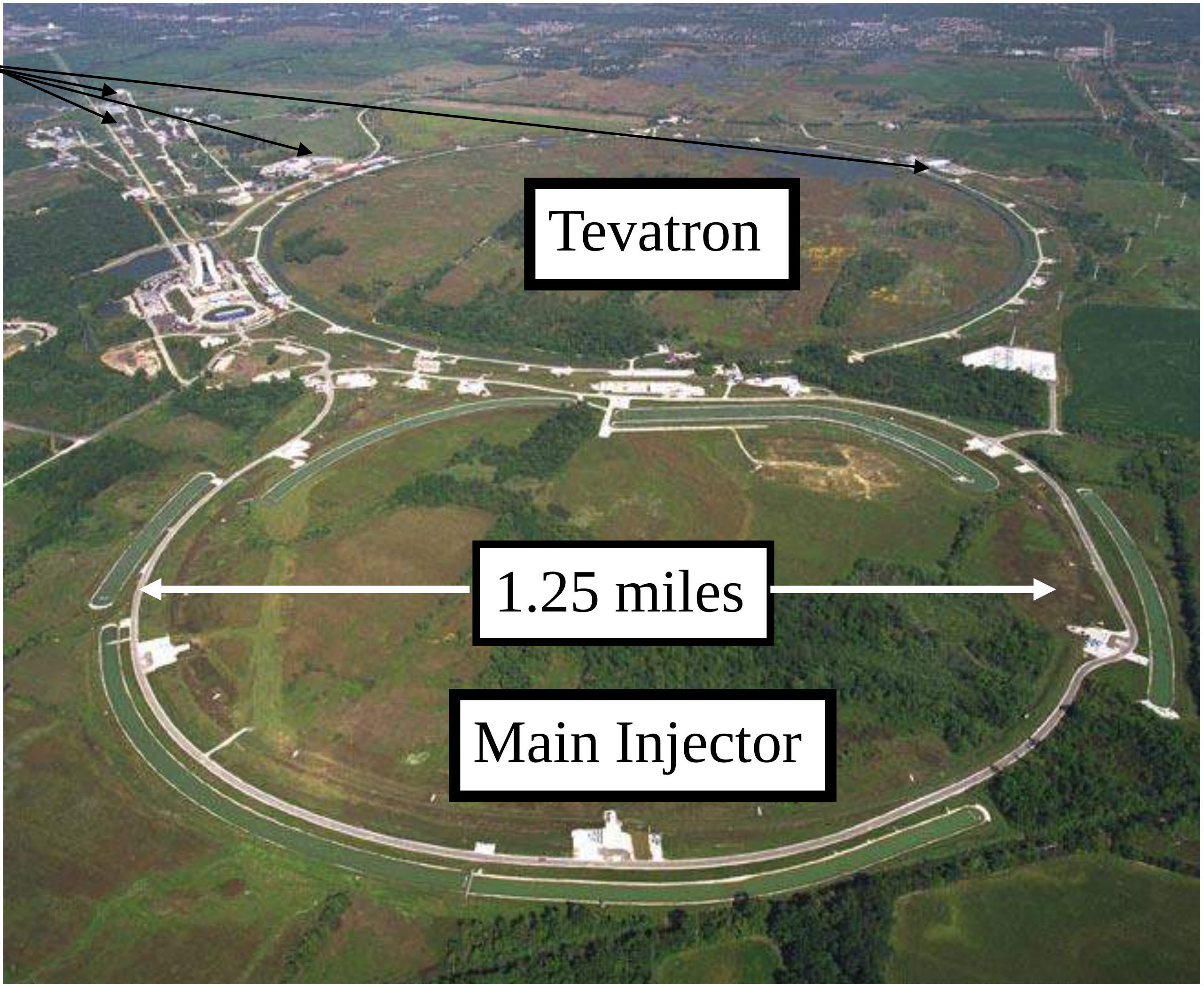
- After 25 years of planning and 15 years of design and construction, the LHC is finally about to turn on.
- This is the chance of a lifetime.
- Our understanding of the way the Universe works is about to be revolutionized.
  - We just don’t know exactly how…
  - https://www.youtube.com/ مصادم
    الهادرونات الكبير (مترجم)



Major High Energy Physics Labs (accelerators + detectors)



Fermilab Accelerator
(30 miles from Chicago)



Experimental areas

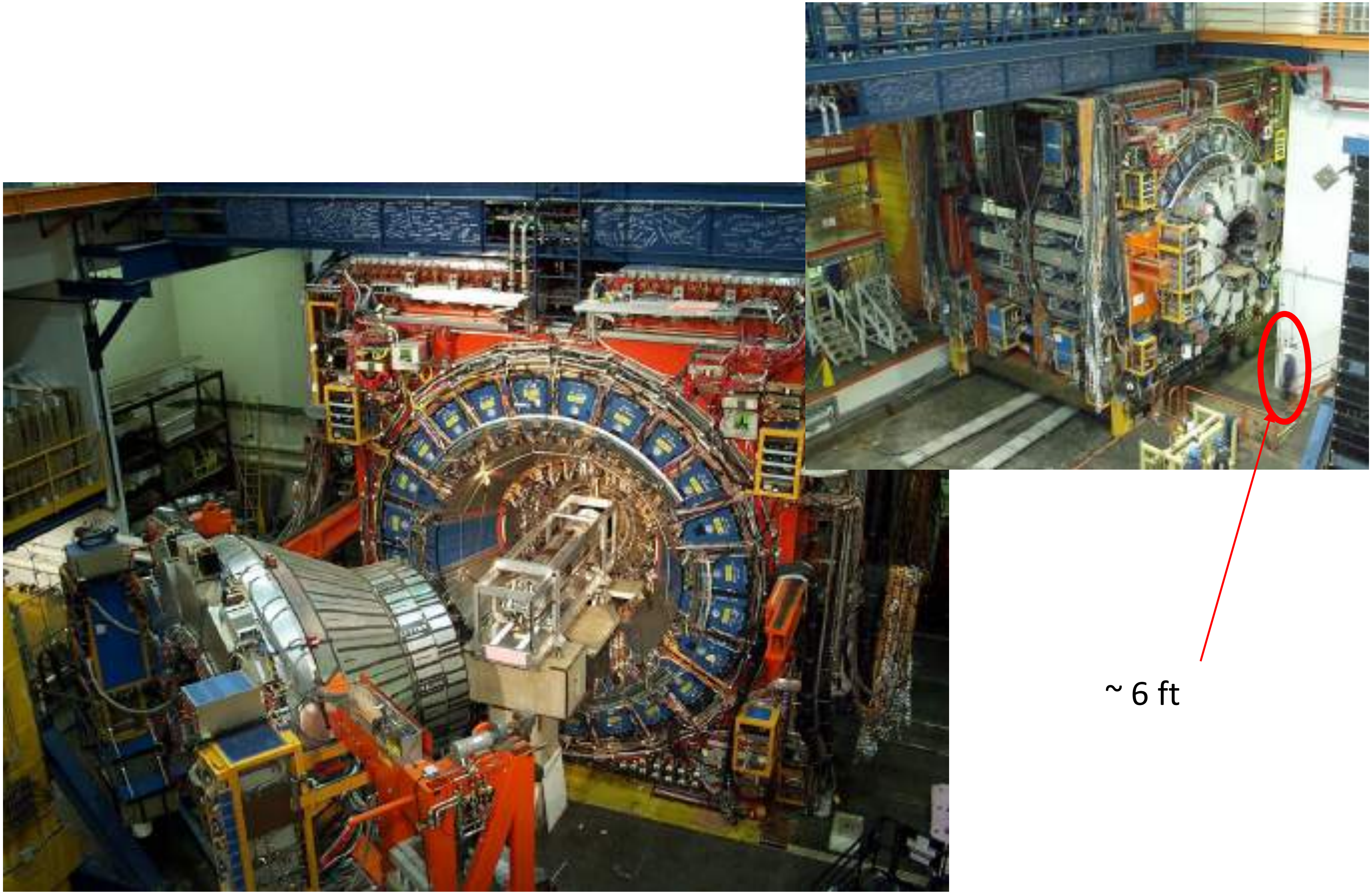
Tevatron

1.25 miles

Main Injector

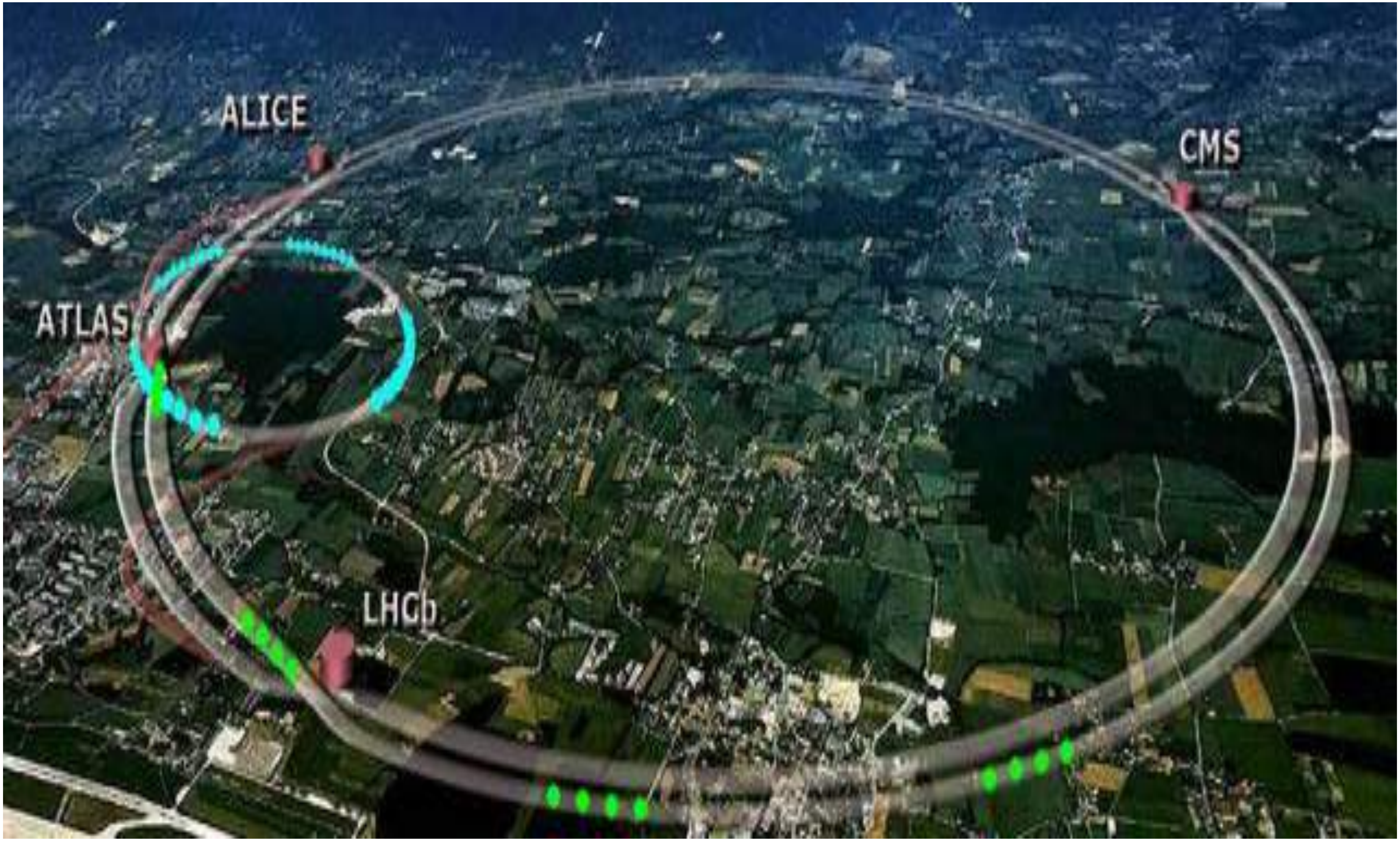
Top Quark discovered here at FNAL in 1995.

“Typical” Particle Detector

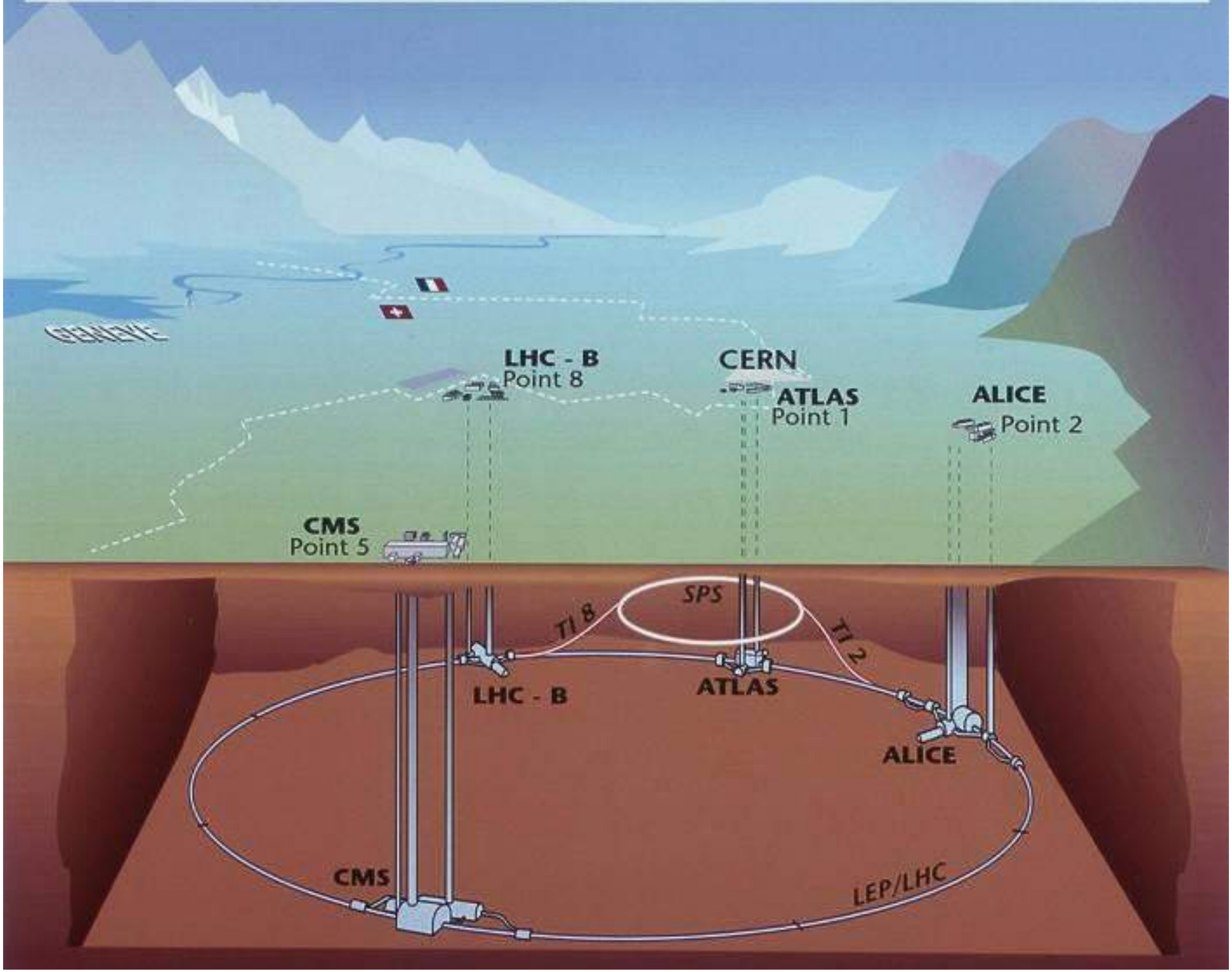


~ 6 ft

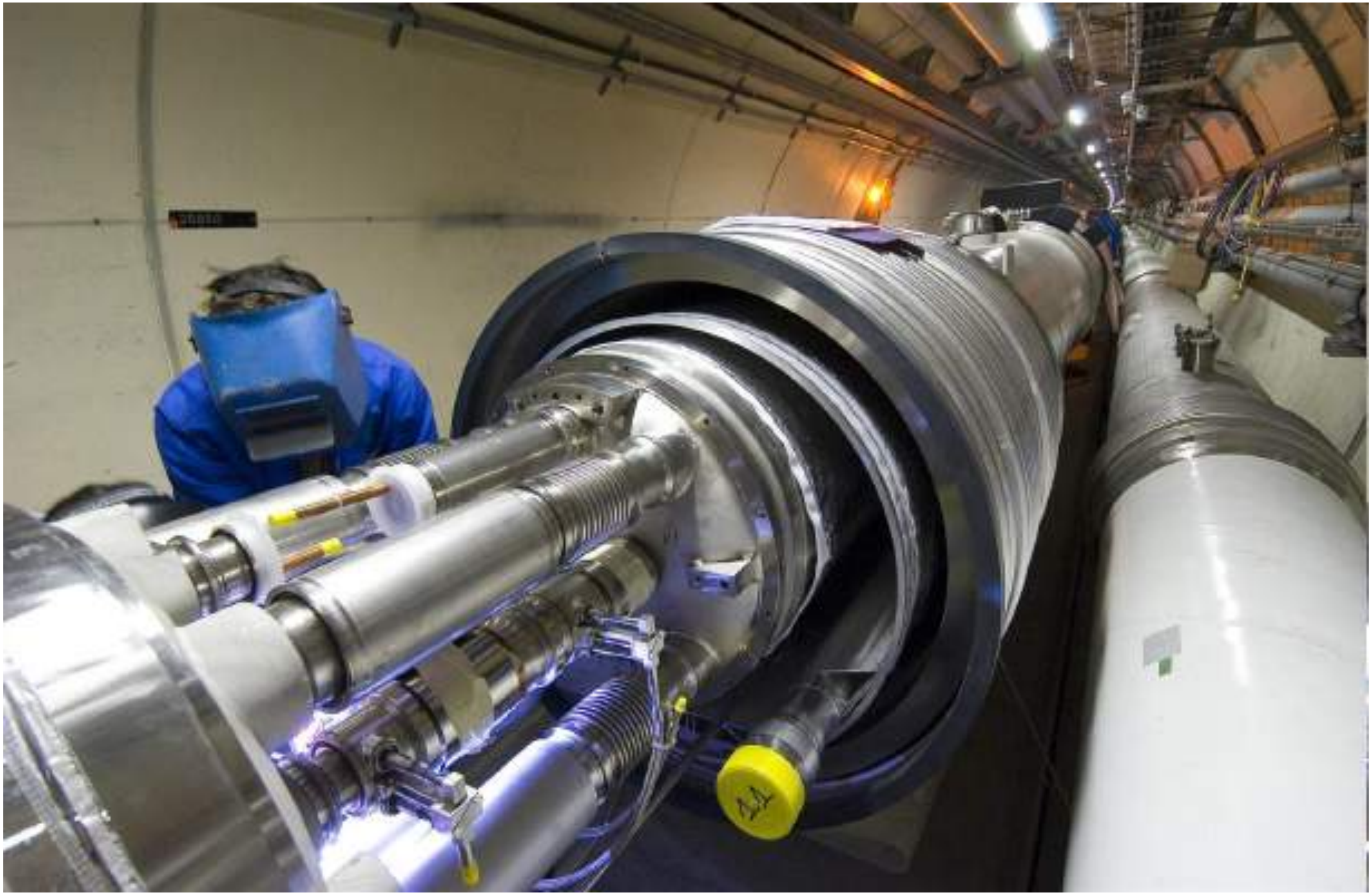
ويوجد هذا المصادم في أنبوب محيط دائرة طوله 27 كيلومترعلى عمق 175 متر تحت الحدود الفرنسية السويسرية بالقرب من مدينة جنيف.

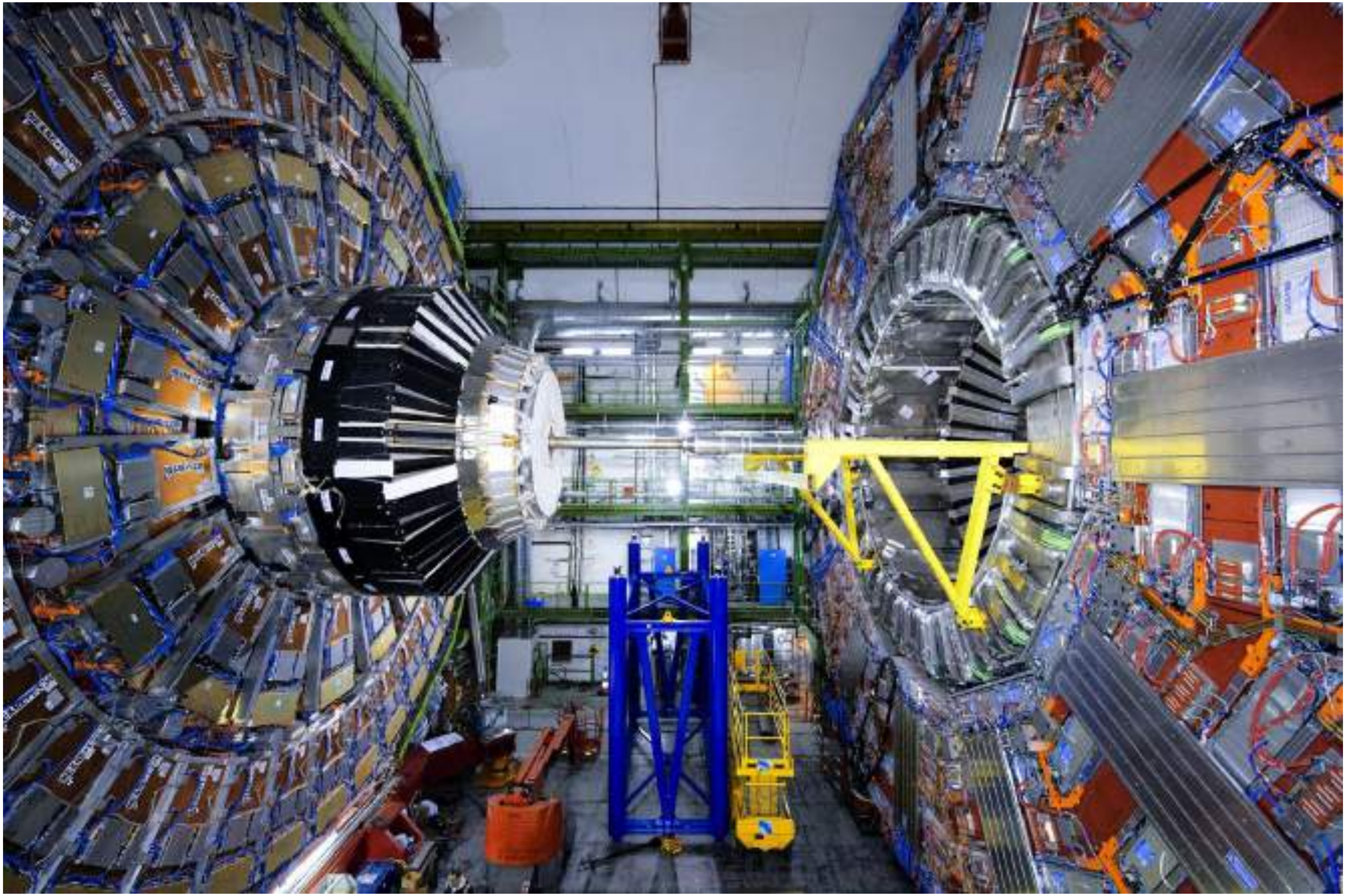

ALICE
CMS
ATLAS
LHCb

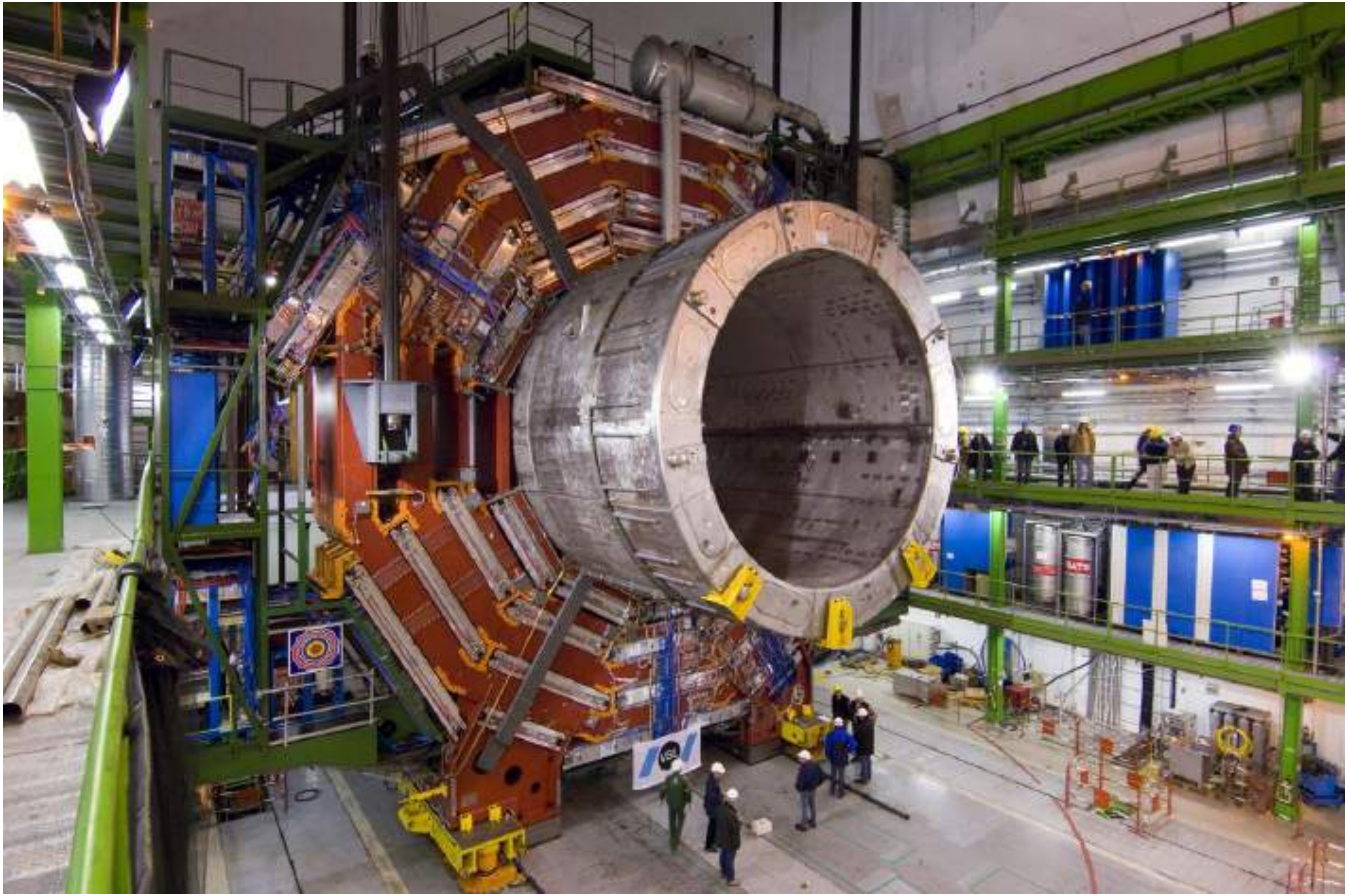
Overall view of the LHC experiments.



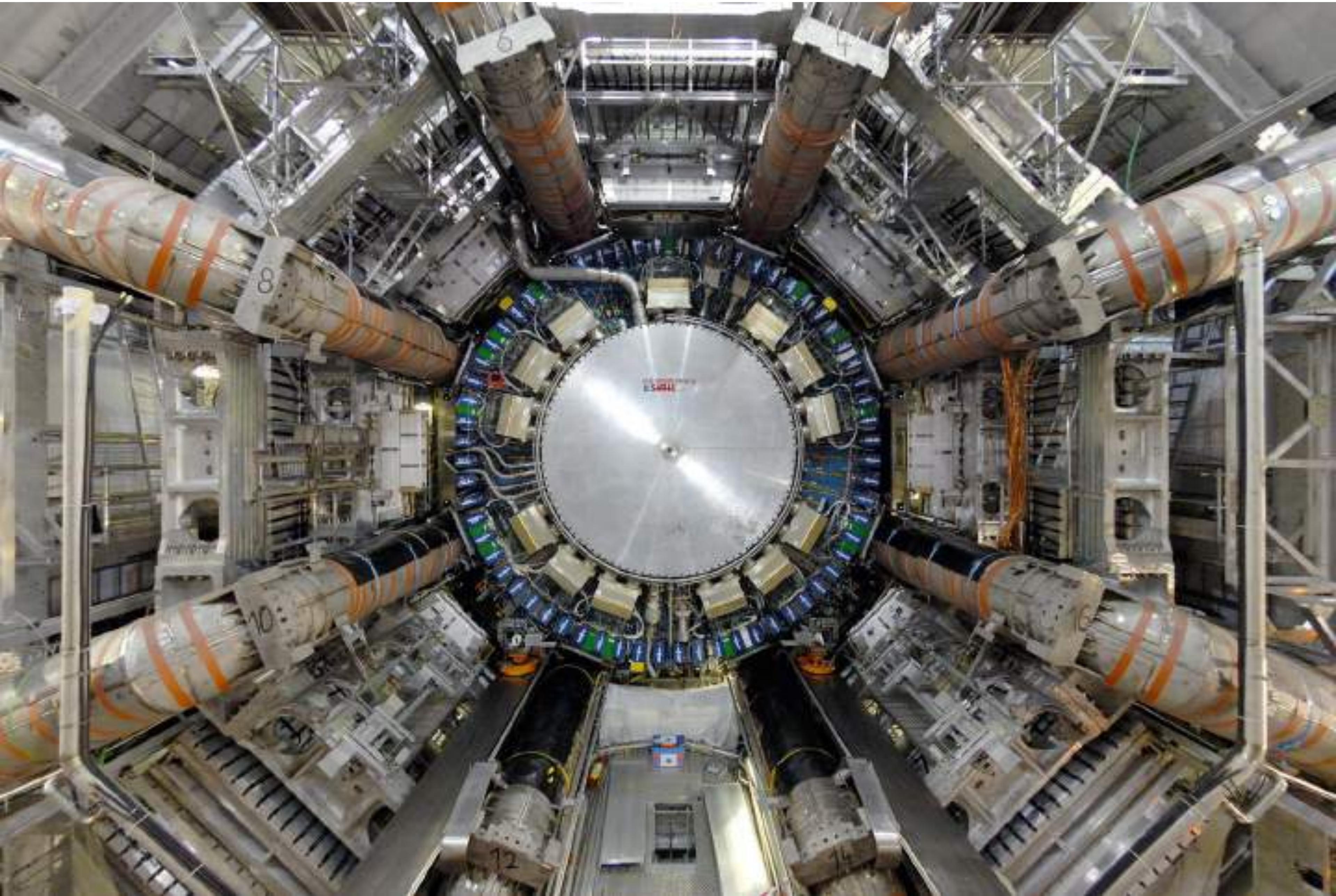
Inside the Tunnel







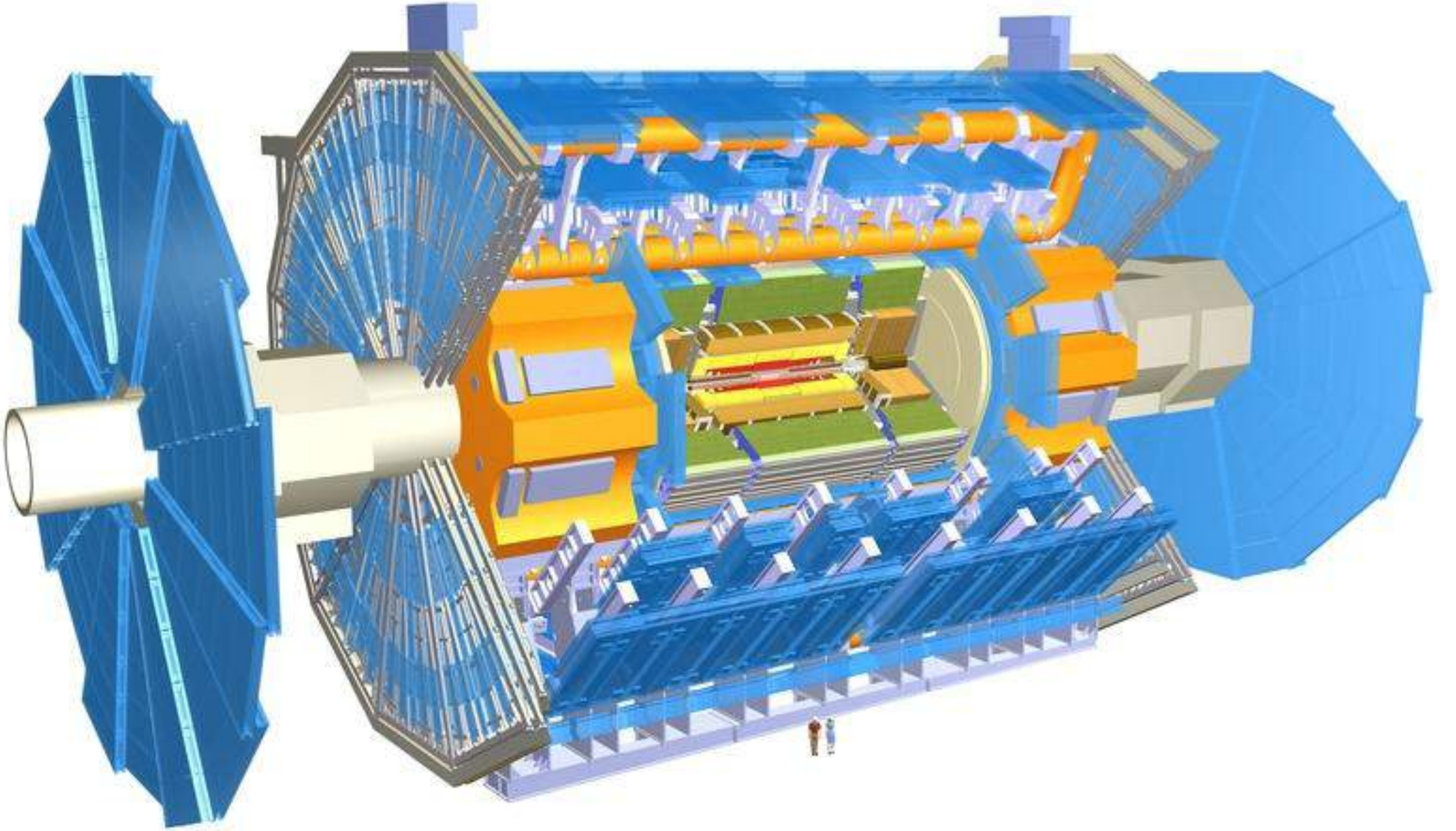
ATLAS Detector at CERN



ATLAS Collaboration

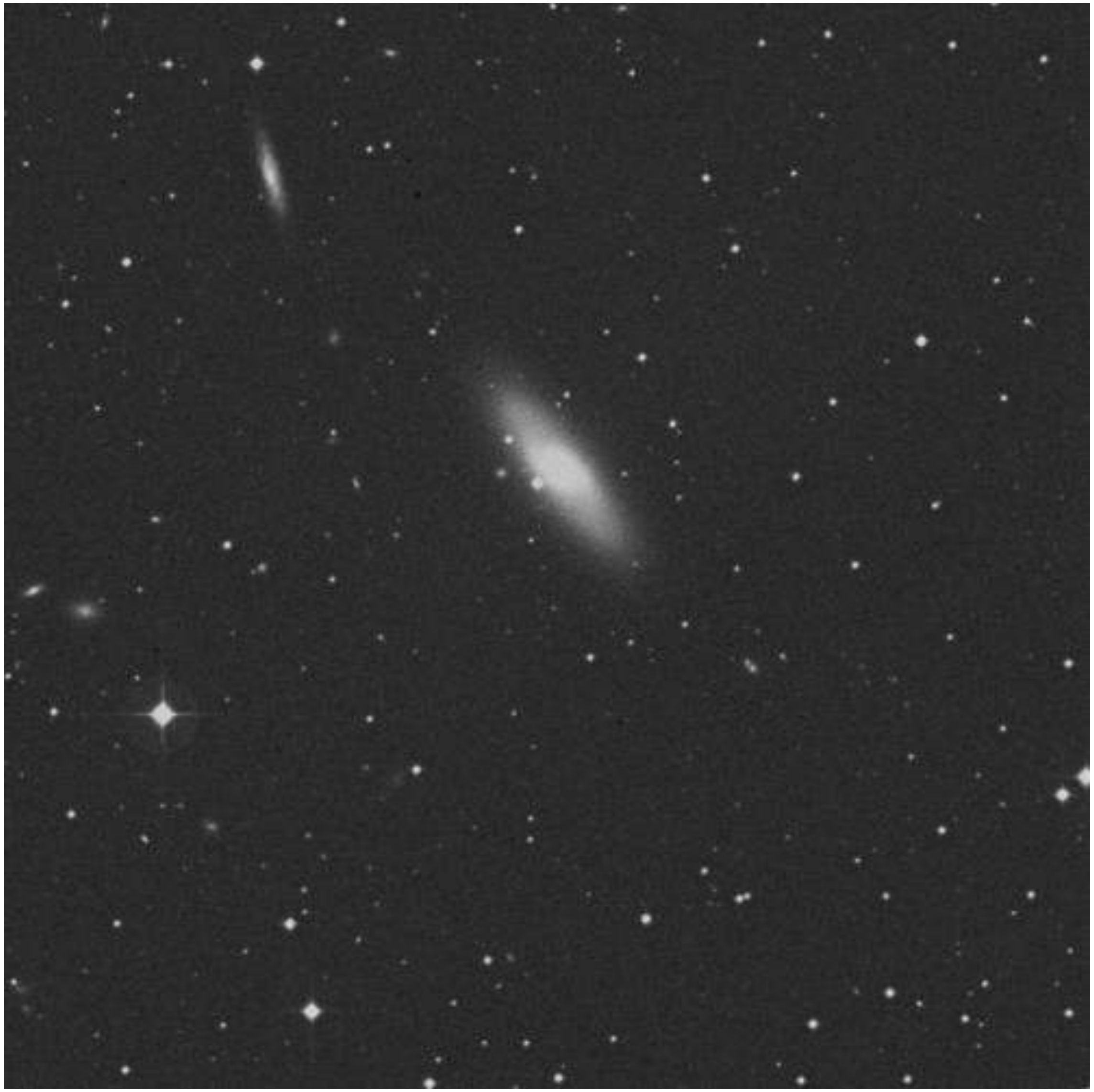
- Armenia
- Australia
- Austria
- Azerbaijan
- Belarus
- Brazil
- Canada
- China
- Czech Republic
- Denmark
- France
- Georgia
- Germany
- Greece
- Israel
- Italy
- Japan
- Morocco
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Russia
- Serbia
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Taiwan
- Turkey
- UK
- USA
- CERN
- JINR

ATLAS

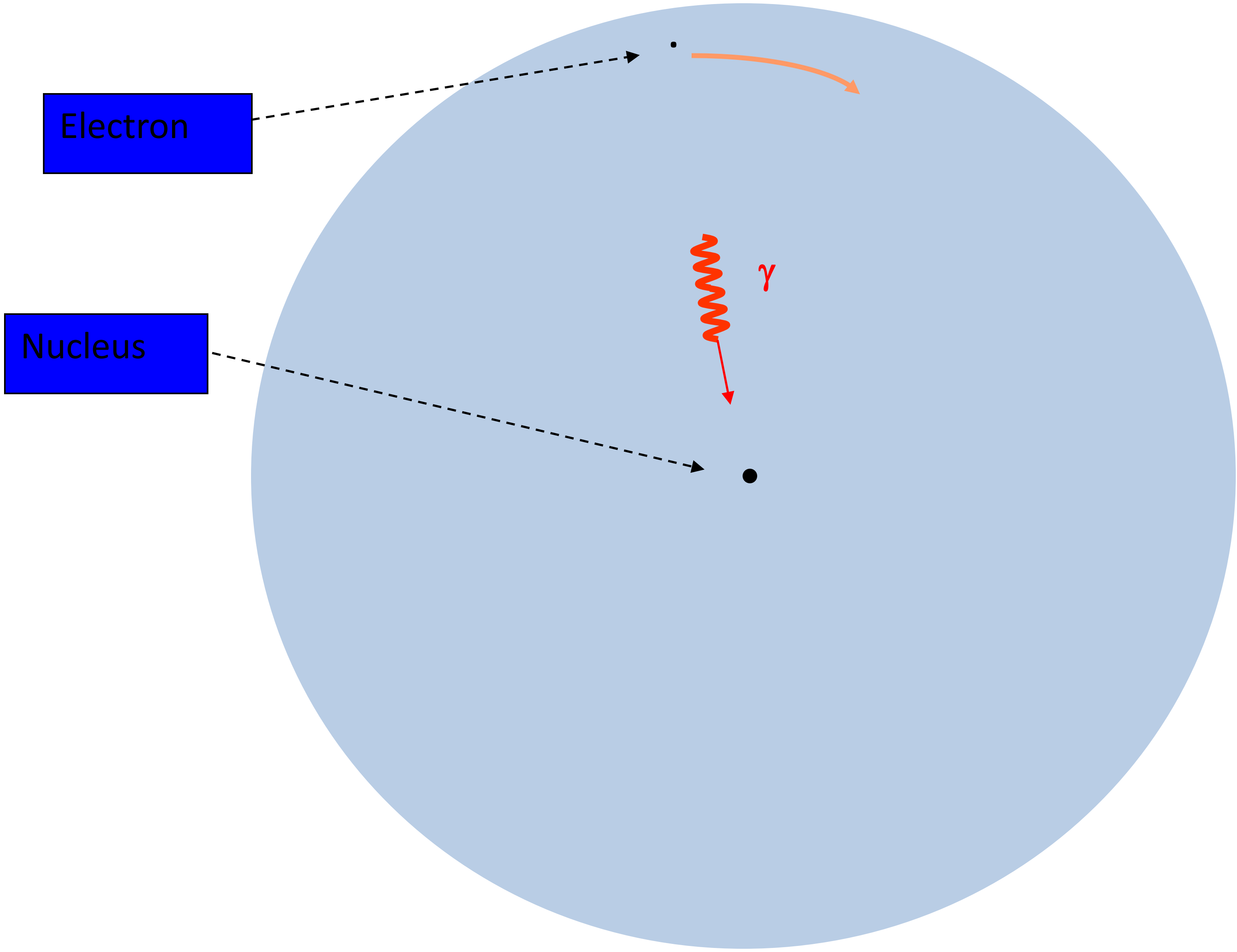


ATLAS is VERY BIG

Space is mostly “empty space”



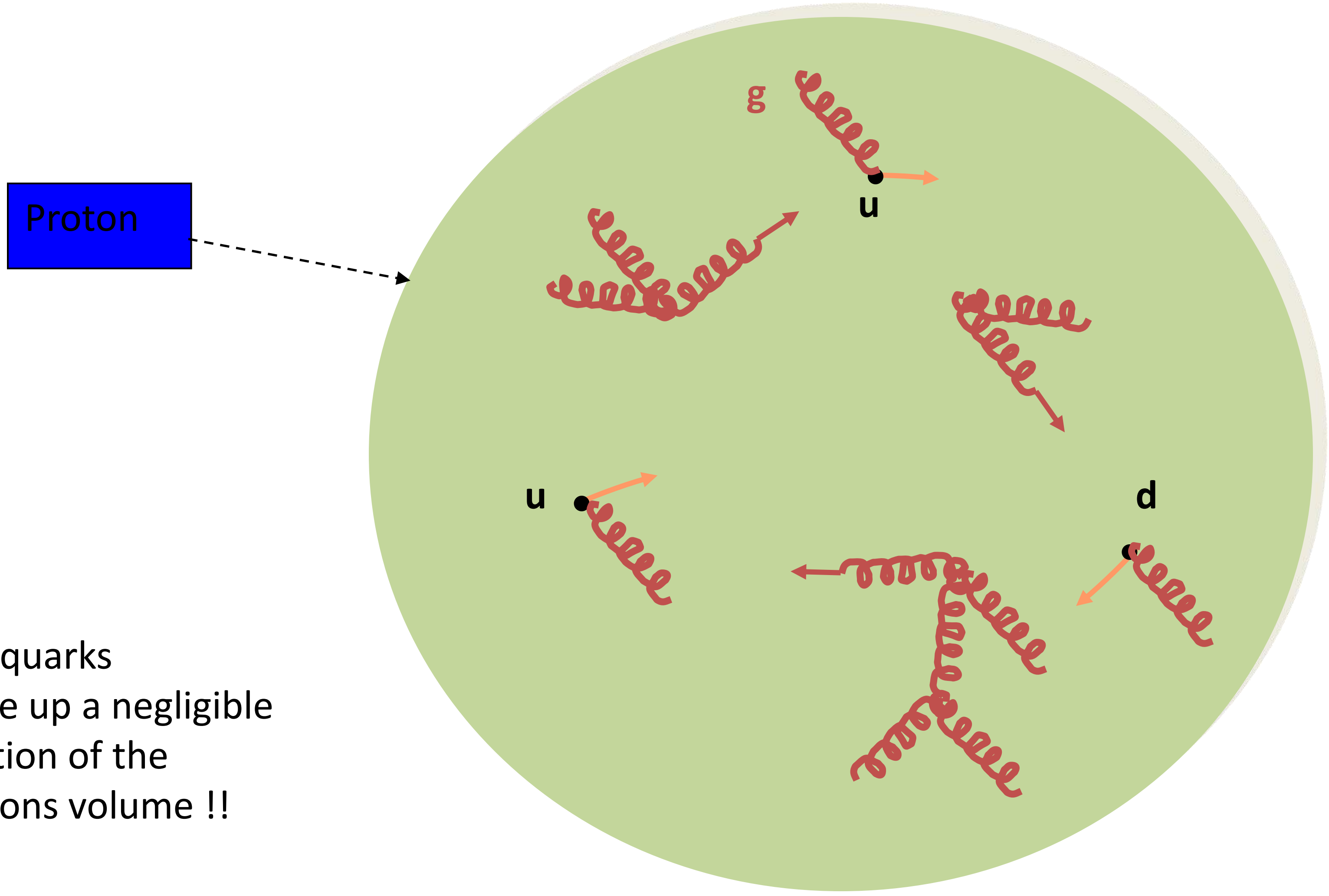
Atoms are > 99.999% empty space



Electron

Nucleus

Protons & Neutrons are > 99.999% empty space



The quarks
make up a negligible
fraction of the
protons volume !!

The Universe

The entire universe is almost all empty space !

(YIKES)

Forces are a huge part of our existence !

TOPICS OF INTEREST
Higgs Particle

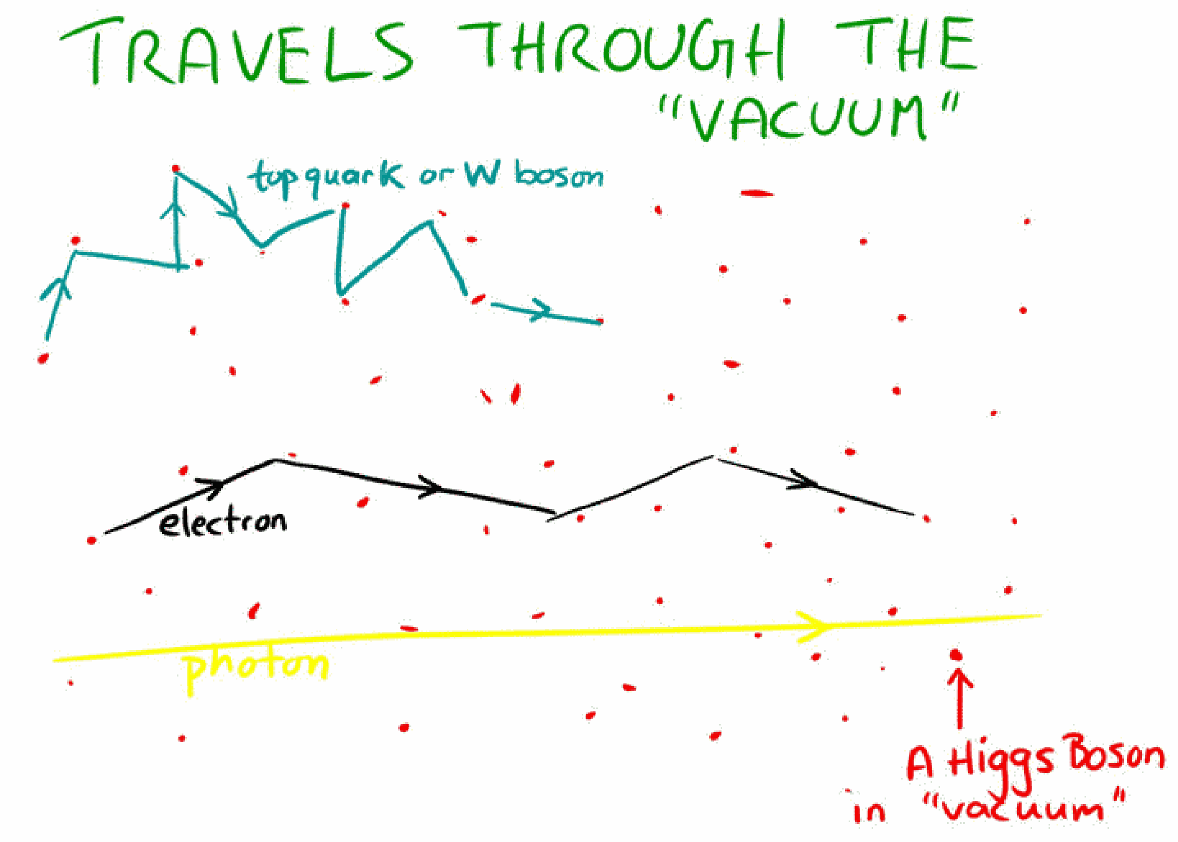
HIGGS SEEN AT LHC!

Peter Higgs, the man for whom the Higgs boson particle was named tours the LHC

www.fnal.gov/pub/presspass/press_releases/cdms-result-2008.html
Alan Walker/AFP/Getty Images

TOPICS OF INTEREST
Higgs Particle

What role does the Higgs Particle Play?



Higgs particle interacts with particles, thus slowing them down. This results in energy converted into mass.

Raman Sundrum (Johns Hopkins Univ,KITP Teachers Conference, 5/31/2008

بوزون هيغز
Higgs boson

- جسيم أولي يُظن أنه المسؤول عن اكتساب المادة لكتلتها. وقد تم رصد إشارات لجسيم هيغز عملياً في عام 2011 في مايعرف بـ مصادم الهادرونات الكبير، وأعلن مختبر سيرن في 4 يوليو 2012 أنه متأكد بنسبة 99.999% من وجود بوزون هيغز فعلياً
- . وكان قد تنبأ الفيزيائي الإسكتلندي "بيتر هيغز" عام 1964 بوجوده في إطار النموذج الفيزيائي القياسي الذي يفترض أن القوى الأساسية قد انفصلت عند الانفجار العظيم ، وكانت قوة الجاذبية هي أول ما انفصل ثم تبعتها بقية القوى.
- ويُعتقد طبقا لهذه النظرية أن البوزون - وهو جسيم أولي افتراضي ثقيل ، تبلغ كتلته نحو 200 مرة كتلة البروتون حسب نظرية هيغز - هو المسؤول عن طريق ما ينتجه من **مجال هيجز** على حصول الجسيمات الأولية لكتلتها ، مثل الإلكترون والبروتون والنيوترون وغيرها
- فالتصور هو انه عندما يتحرك فهو يعاني مقاومة من مجال هيغز ، تلك المقاومة تظهر على اللاإلكترون في هيئة كتلة. كل جسيم أولى يكتسب كتلته عندما يتحرك في مجال هيغز "الأساسي" ويتأثر بهذا المجال .
- فالبروتون مثلا يعاني في مجال هيغز أكثر مما يعاني الإلكترون ، وهذا هو تفسير هيغز بأن البروتون أكبر كتلة نحو 1840 مرة من كتلة الإلكترون . وطبقا لنظرية هيغز كل جسيم أولى يكتسب كتلته بقدر تأثره وتفاعله مع مجال هيغز . صاغ هيغز نظريته هذه خلال الستينيات من القرن الماضي.

So why is this study interesting/important?

☐ **All matter, including us, takes on its shape and structure because of the way that quarks, leptons and force carriers behave.**

☐ **Our bodies, and the whole universe is almost all empty space !**

☐ **By studying these particles and forces, we're trying to get at the question which has plagued humans for millenia …**

How did the universe start ?

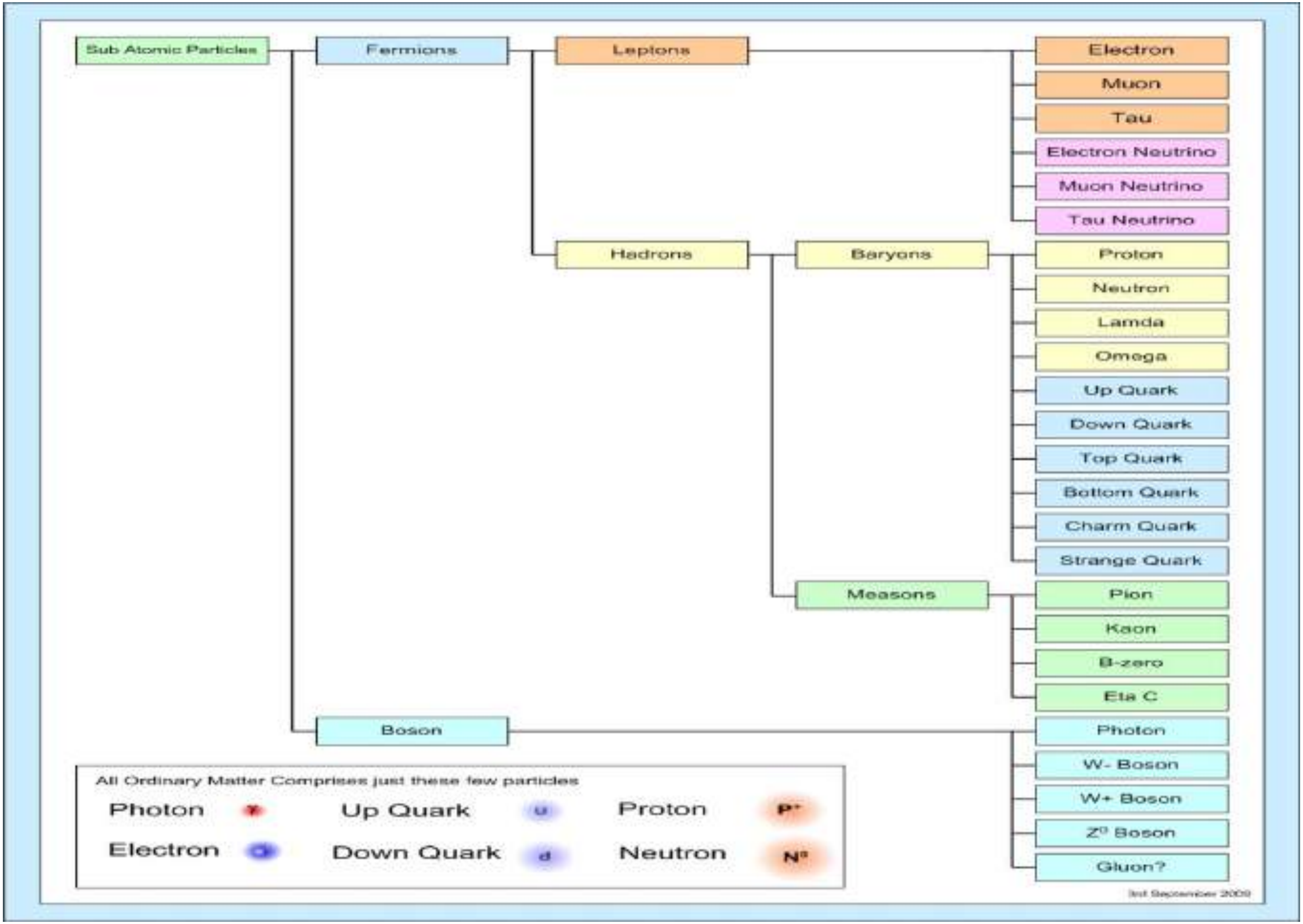
And how did we emerge from it all ?

Where's has all the antimatter gone ?

Finally

- Understanding this special state of matter can provide insight into the evolution of the universe,
- which is believed to have passed through a similar high density/high temperature state nanoseconds after the Big Bang.

- . دراسة تلك الجسيمات الناتجة تساعدنا على فهم نشأة المادة ونشأة الكون .
- من ناحية أخرى فلا يتضمن النموذج العياري للجسيمات تفسيرا واضحا لوجود الجاذبية وهي قوة أساسية في الكون .
- وكذلك لا يقول النموذج شيئا عن الطاقة المظلمة ولا عن المادة المظلمة واللتان تشكلان نحو 80 % من الكون ، ويأمل الفزيائيون أن يتوصلوا عن طريق مصادم الهادرونات الكبير إلى اكتشافات تفسر لنا تلك الألغاز.



3rd September 2009


Questions??

Types of Radioactive Decays

Radioactivity

- When the strong force can hold a nucleus together forever, the nucleus is **stable**.
- If not, the nucleus becomes **unstable** and can break apart or decay by emitting particles and energy.
- Large nuclei are more unstable; all with more than 83 protons are radioactive.

The stabilization (decrease in energy) of unstable nucleus may occur in a number of ways with emission of radiation:

Types of Radiation

- **Alpha (ά) – a positively charged (+2) helium isotope -**

$$^{4}_{2}He$$

- **Beta (β) – an electron**

$$^{0}_{-1}e$$

- **Gamma (γ) – pure energy; called a ray rather than a particle**

$$^{0}_{0}\gamma$$

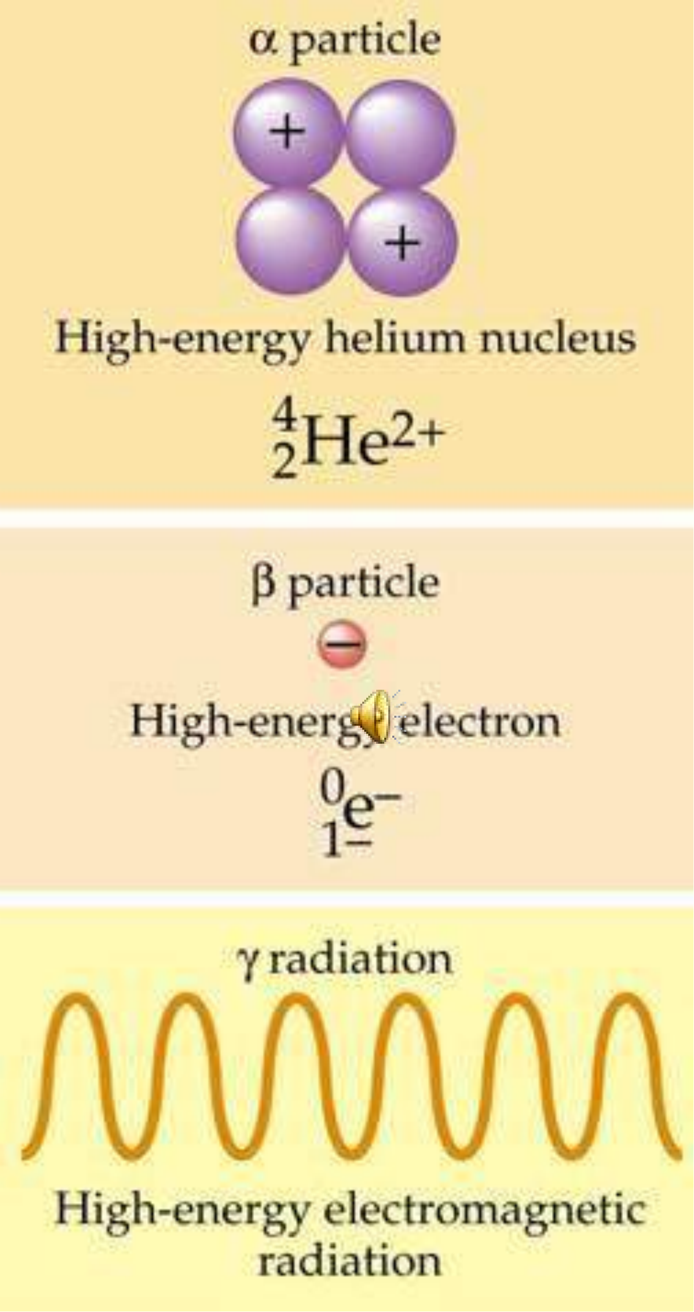


Figure 4.4: The components of α rays, β rays, and γ rays.

History of discovery

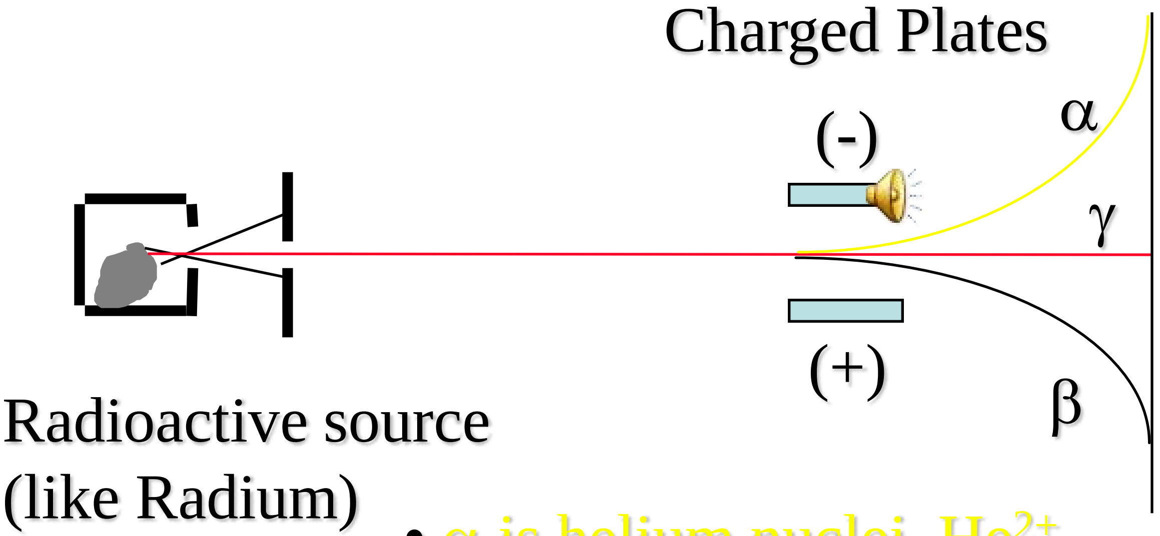
- **In the years 1899 and 1900 physicists Ernest Rutherford and Paul Villard separated radiation into three types: alpha, beta, and gamma, based on penetration of objects and ability to cause ionization.**

- **Alpha rays were defined by Rutherford by their lowest penetration of ordinary objects.**

- **An alpha particle is deflected by a magnetic field**

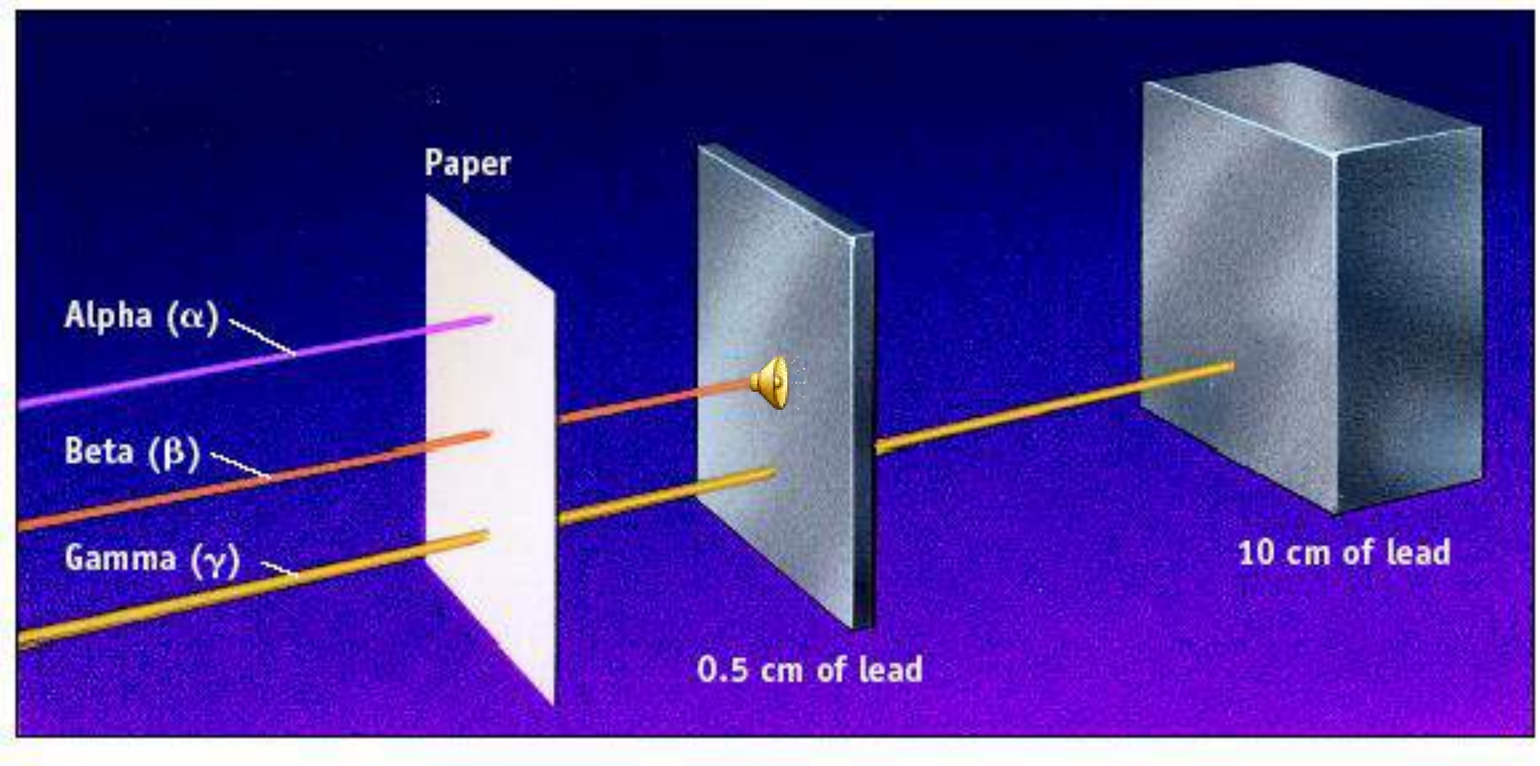
- **In 1907, Ernest Rutherford and Thomas Royds finally proved that alpha particles were indeed helium nuclei.**

Types of Radiation from Radioactive Decay



- α is helium nuclei, He^{2+}
- **β is electron beam, e^-**
- **γ is electromagnetic radiation (high-energy light)**

Penetrating Ability



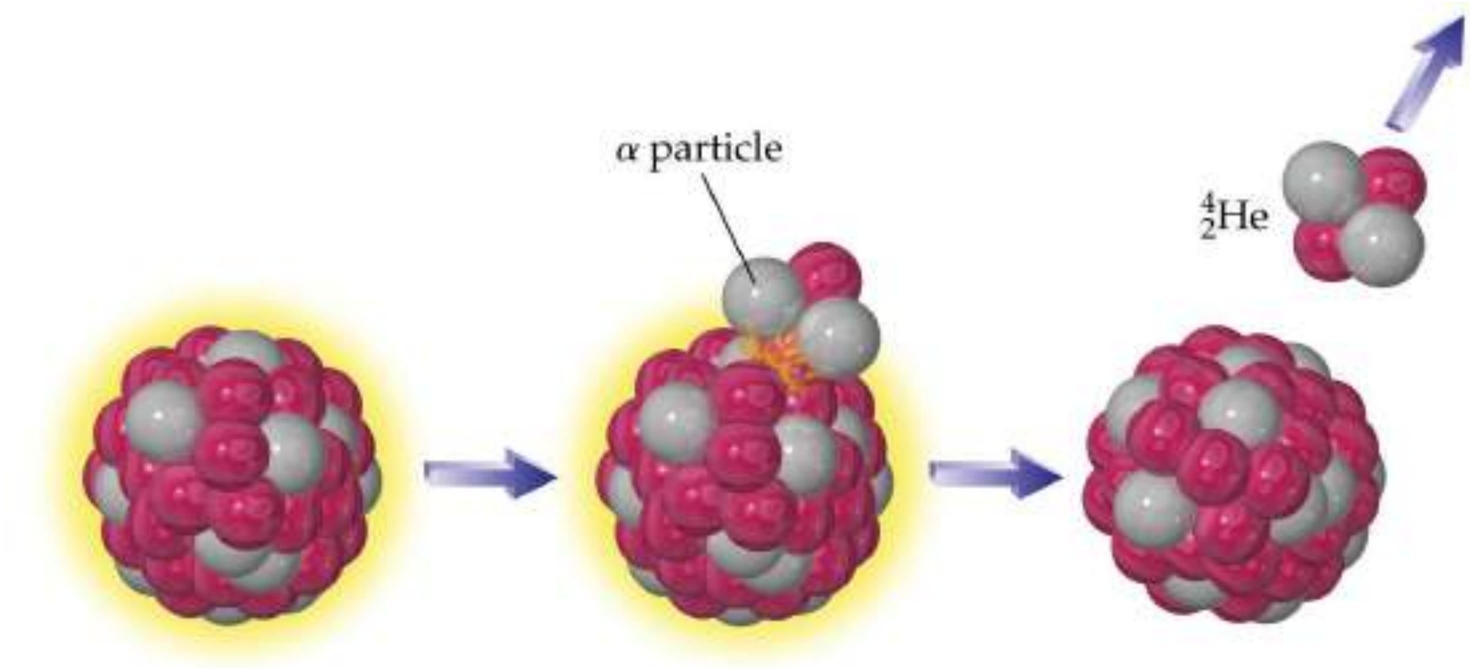
Alpha Decay

- Alpha decay is when a radioactive isotope spits out an alpha particle.
- An alpha particle is two protons and two neutron that form a small nucleus.
- Alpha decay may be thought some times as nuclear fission where the parent nucleus splits into two daughter nuclei.

<u>This is not always right.</u>

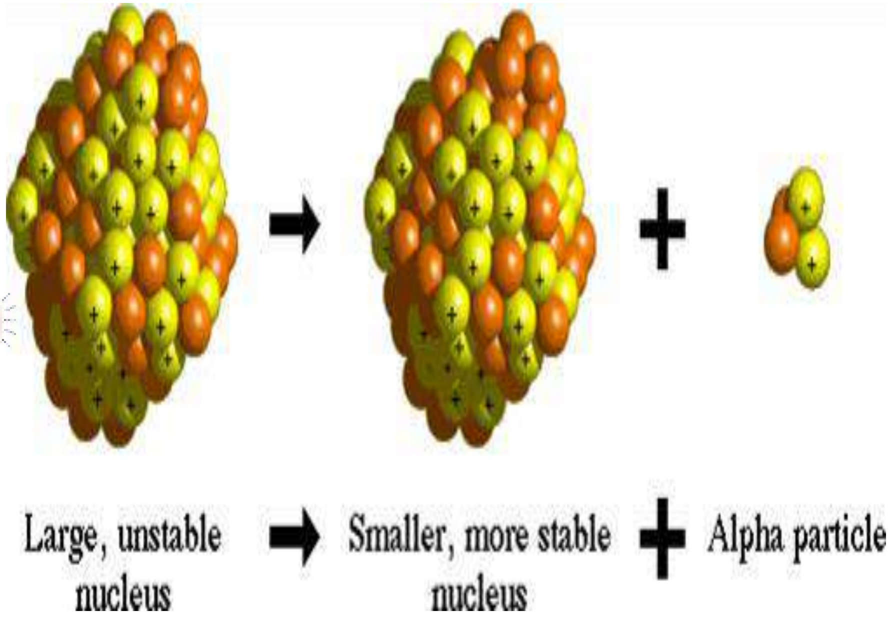
- alpha particle emission
  - loss of a helium nucleus.

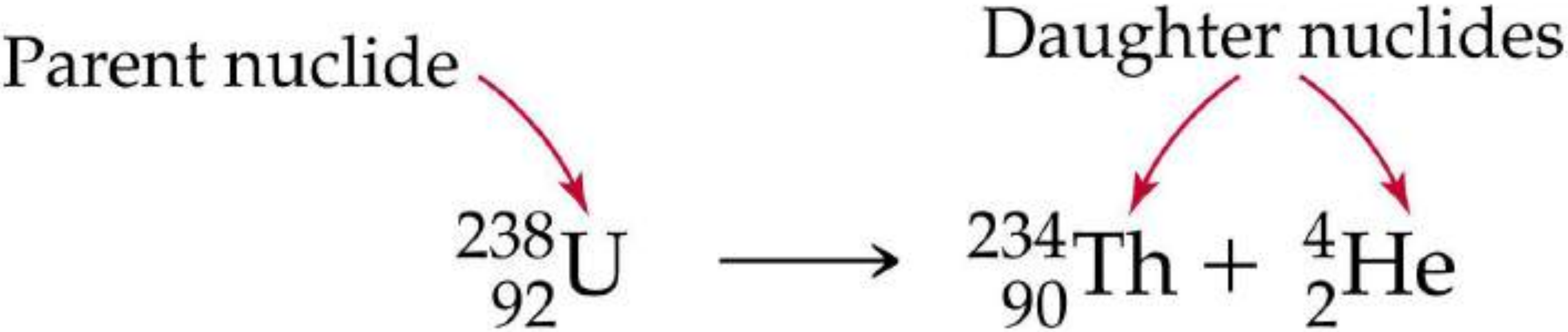
An α particle



Alpha Decay

- Since an atom loses two protons during alpha decay**, it changes from one element to another**.
- For example, after undergoing alpha decay, an atom of uranium (with 92 protons) becomes an atom of thorium (with 90 protons).





$$^{A}X_{Z} \rightarrow {}^{A-4}Y_{Z-2} + \alpha$$

- **كتلة جسيم الفا =الكتلة الذرية لذرة الهليوم مطروحا منها كتلة الكترونين و قيمتها (**
(M_{α} = 4.0026O3 amu

- **ام شحنة جسيم الفا = ضعف شحنة البروتون (q_{α} = 2e) و قيمتها (q_{α} = $3.1*10^{-19}$ coul)**

Decay Rules

1) Nucleon Number (A) is conserved.
2) Atomic Number (Z) is conserved.
3) Energy is conserved.
4) momentum is conserved

α: example $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + \alpha$ recall $^{4}_{2}\mathrm{He} = \alpha$

1) 238 = 234 + 4 Nucleon number conserved

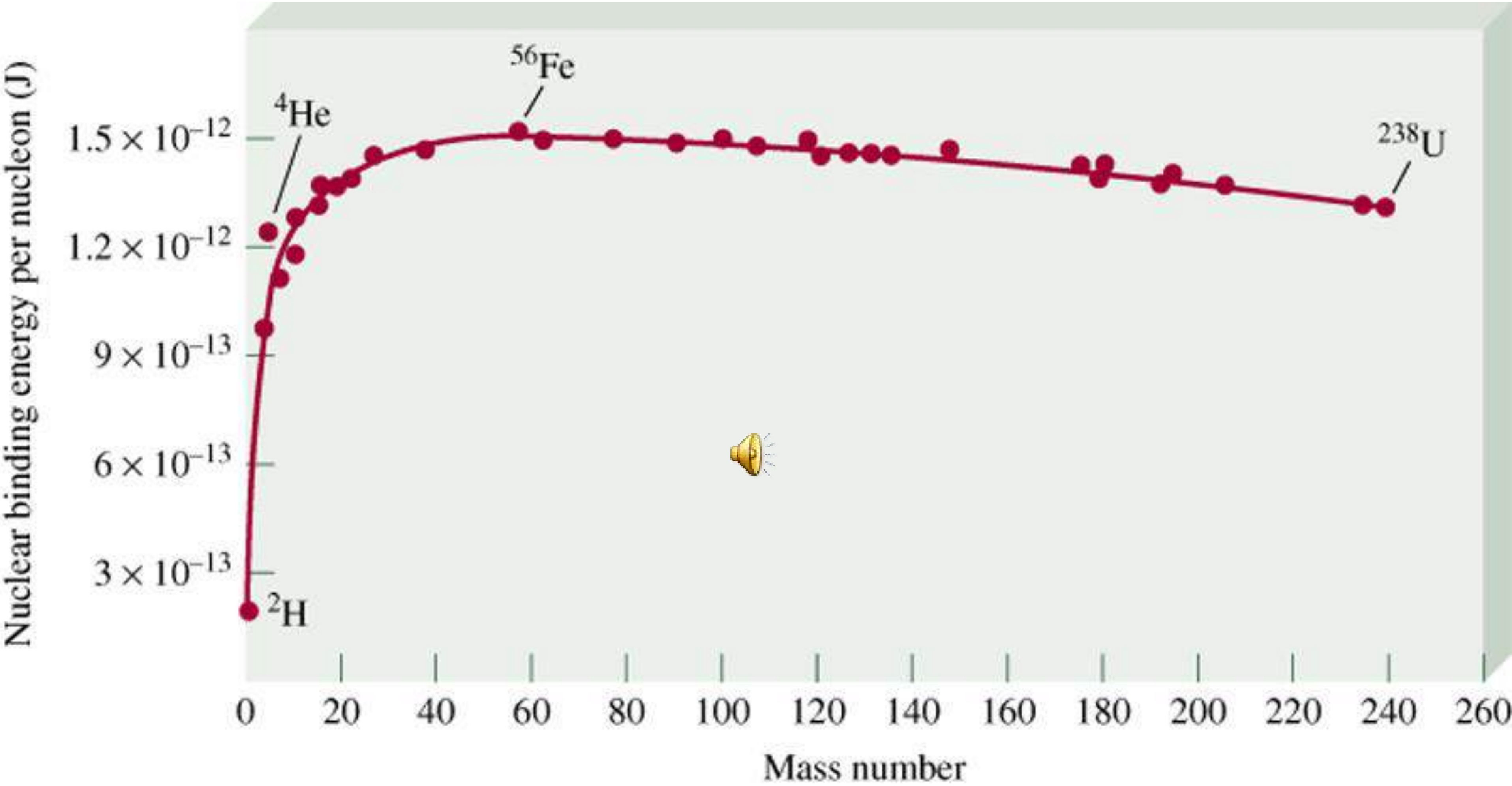
2) 92 = 90 + 2 Charge conserved

β: example $^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}e^{-} + \boxed{{}^{0}_{0}\bar{\nu}}$

Needed to conserve momentum.

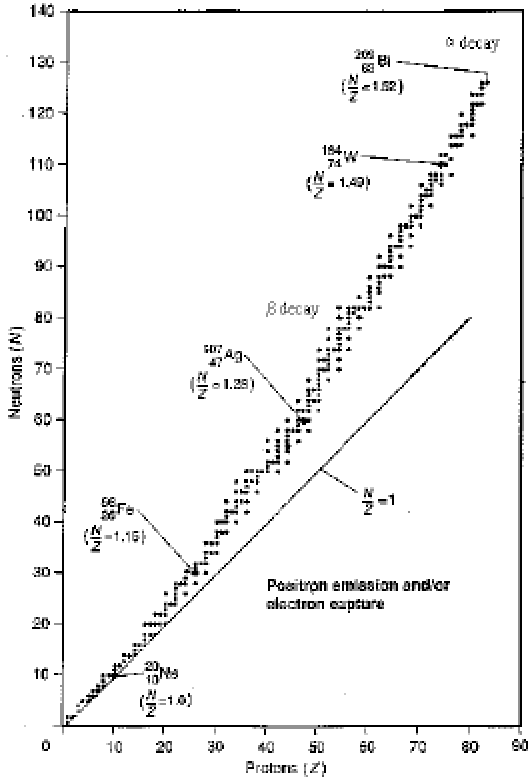
γ: example ${}^{A}_{Z}P^{*} \rightarrow {}^{A}_{Z}P + {}^{0}_{0}\gamma$

Nuclear binding energy per nucleon vs Mass number



$$\frac{\text{nuclear binding energy}}{\text{nucleon}} \uparrow \qquad \text{nuclear stability} \uparrow$$

Belt of stability



$^{238}_{92}\mathrm{U} \rightarrow \alpha$

$\downarrow$ 4.51 x 10^9 yr

$^{234}_{90}\mathrm{Th} \rightarrow \beta$

$\downarrow$ 24.1 days

$^{234}_{91}\mathrm{Pa} \rightarrow \beta$

$\downarrow$ 1.17 min

$^{234}_{92}\mathrm{U} \rightarrow \alpha$

$\downarrow$ 2.47 x 10^5 yr

$^{230}_{90}\mathrm{Th} \rightarrow \alpha$

$\downarrow$ 7.5 x 10^4 yr

etc...

$\downarrow$

$^{206}_{82}\mathrm{P}$

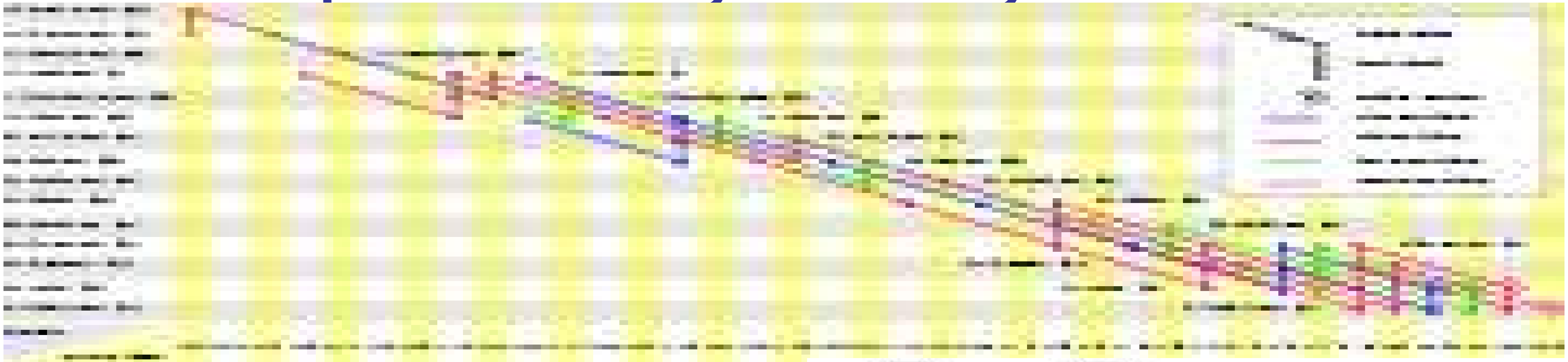
3. Nuclei with atomic numbers greater than 84 These tend to undergo alpha emission. This emission decreases the number of neutrons and protons by 2 moving the nucleus diagonally toward the belt of stability

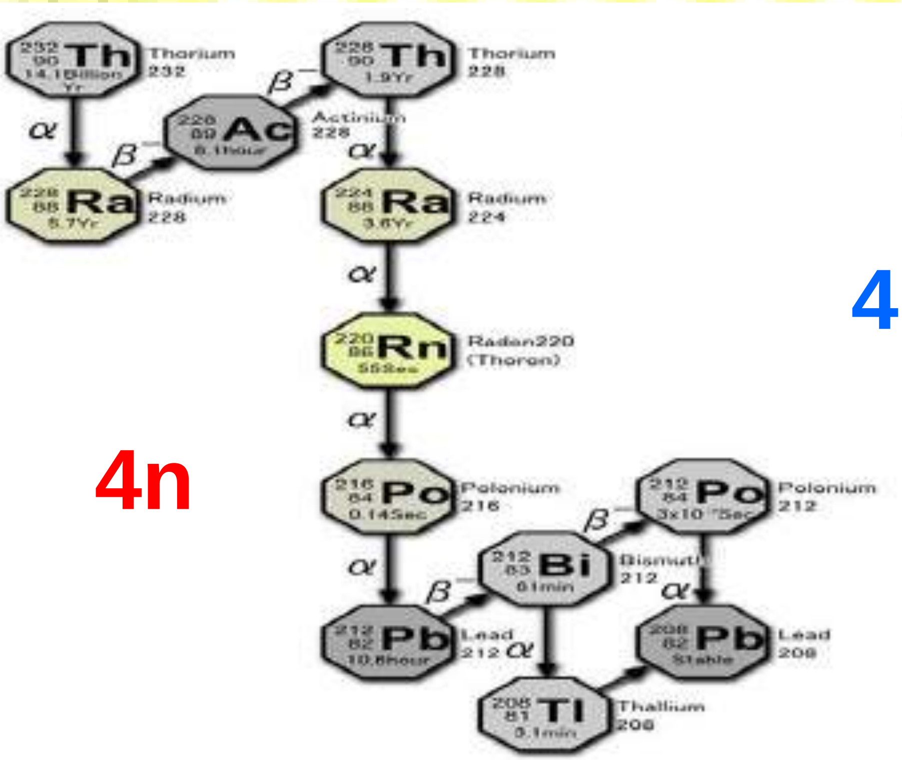
$^{238}{}_{92}\mathrm{U} \rightarrow {}^{234}{}_{90}\mathrm{Th} + {}^{4}{}_{2}\mathrm{He}$

السلاسل الاشعاعية الطبيعية

مجموعة الثوريوم	$A=4n$
مجموعة اليورانيوم	$A=4n+2$
مجموعة الاكتينيوم	$A= 4n+3$
مجموعة النبتونيوم	$A= 4n+1$

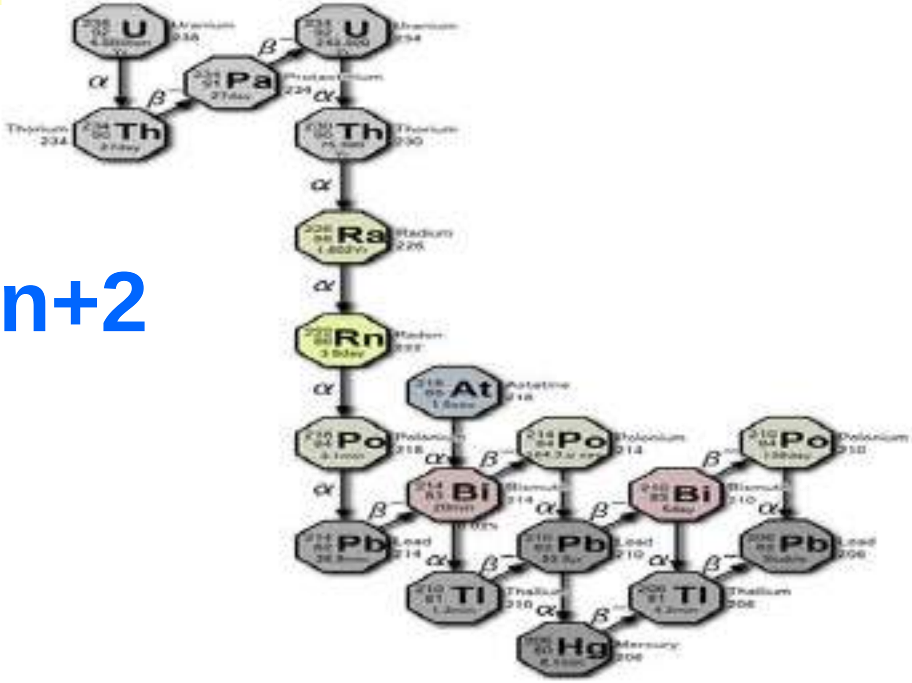
Alpha decay-Decay chains





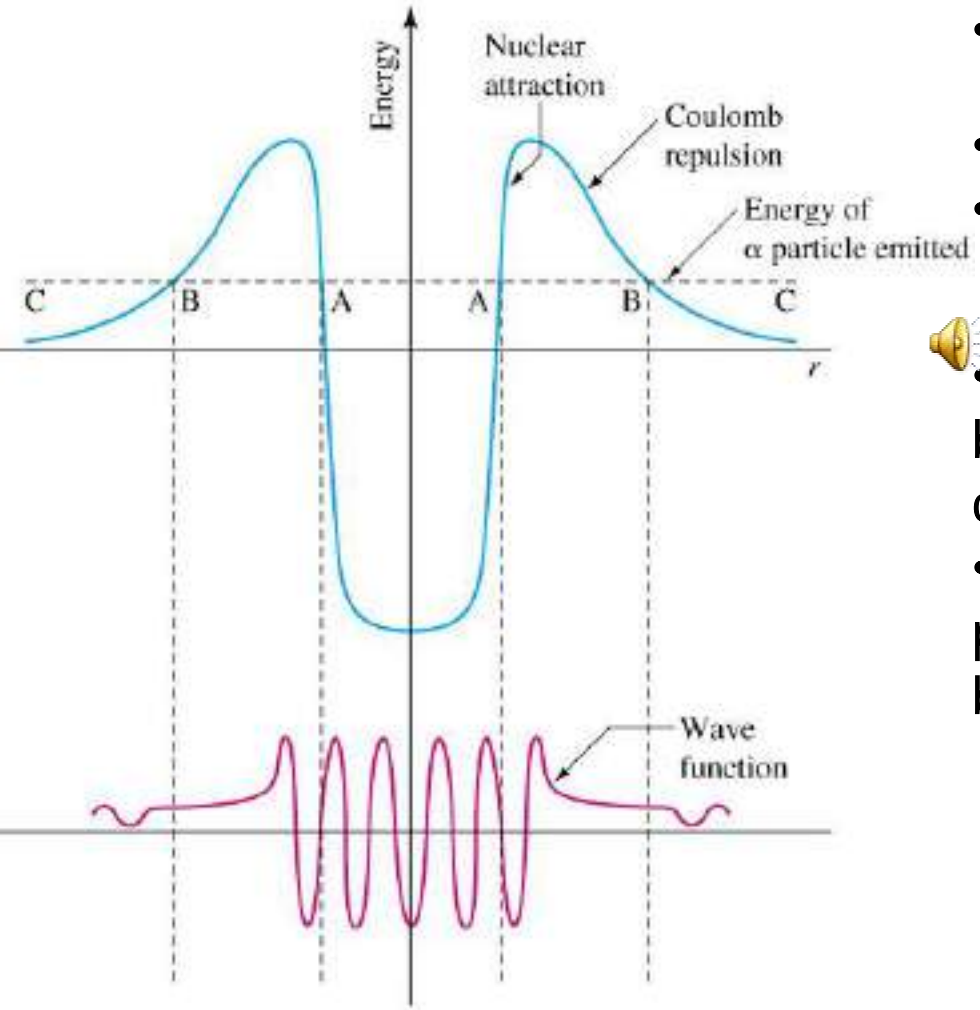
4n

4n+2



So how does the alpha particle ever leave?

Tunneling Out of the Nucleus



- How can alpha particle emerge from nucleus?
- There is potential barrier so high
- The height of potential barrier for a typically heavy nucleus is 20 Mev to emit 6 Mev alpha particles .

•The alpha-particle suppose to oscillate back and forth Inside the barrier making collisions with barrier.

•By classical physics, there is no possibility for alpha particle to climb barrier

Mechanism of production

- Alpha decay results from the Coulomb repulsion between the alpha particle and the rest of the nucleus, which both have a positive electric charge, but which is kept in check by the nuclear force.

- However, the quantum tunneling effect allows alphas to escape even though they do not have enough energy to overcome the nuclear force.

- This is allowed by the wave nature of matter, which allows the alpha particle to spend some of its time in a region so far from the nuclus

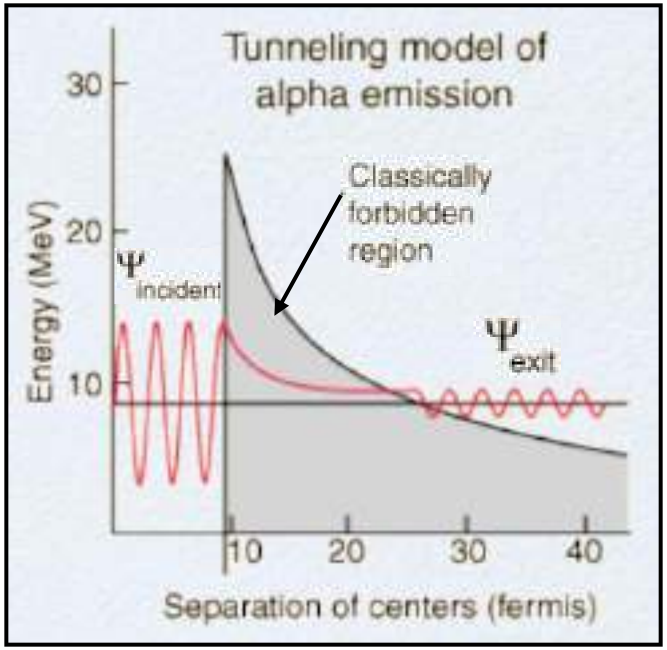
- **By 1928, George Gamow had solved the theory of the alpha decay via tunneling.**
- **The alpha particle is trapped in a potential well by the nucleus.**
- **Classically, it is forbidden to escape, but according to the then newly discovered principles of quantum mechanics, it has a tiny (but non-zero) probability of "tunneling" through the barrier and appearing on the other side to escape the nucleus.**

So how does the alpha particle ever leave?

By classical physics, there is no possibility for alpha particle to climb barrier

Schrodinger wave equation

QM tunnelling through barrier:



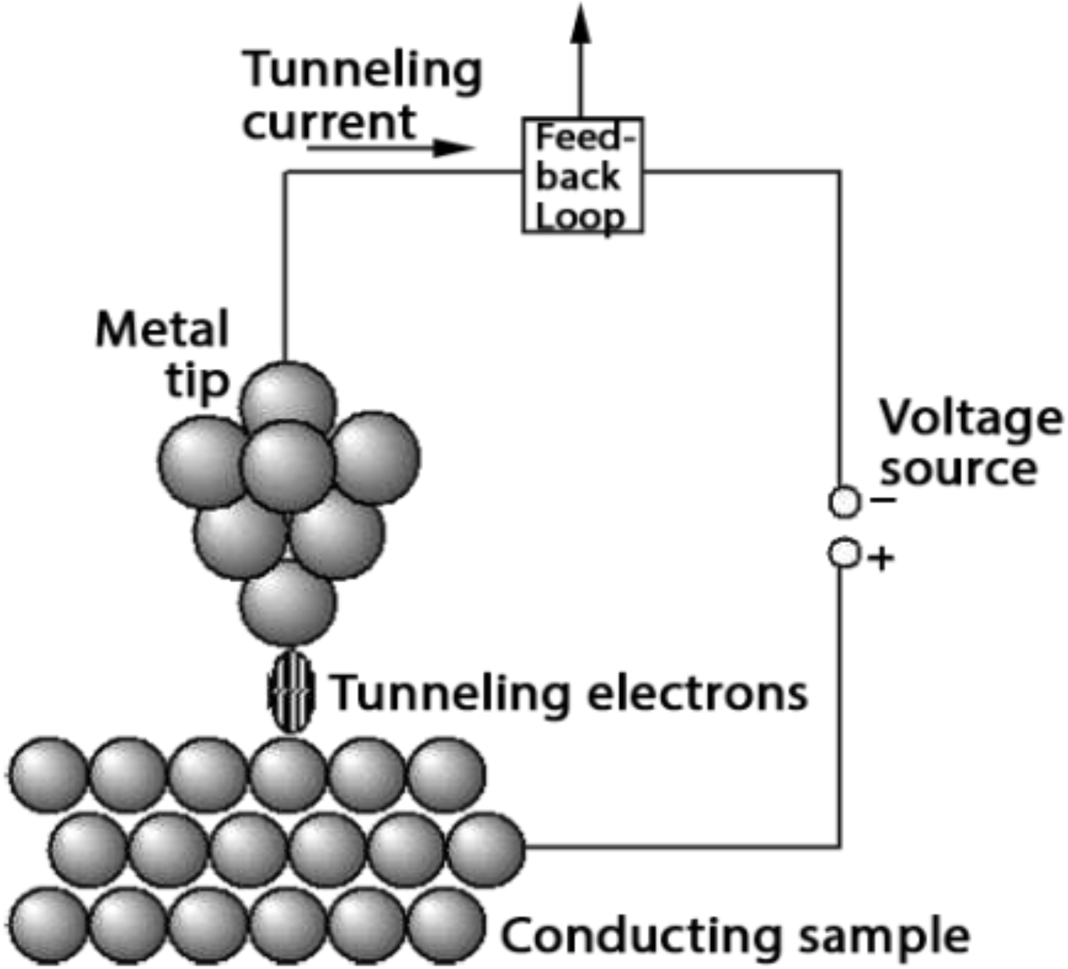
Probability of tunnelling out =
Square of ratio of wavefunctions (Ψ)
inside and outside barrier

(إبساى) دالة الموجة →(Ψ)

Quantum_tunnel_effect_and_its_application_to_the_scanning_tunneling_microscope.ogv.720p.webm

- ان تصور الفيزيائيين في البدء لتفسير ظاهرة استطاعة الشحنات الصغيرة مثل جسيم ألفا الفرار من جهد النواة أنها تتخلل الحاجز الجهدي إلى الخارج
- ، حيث أن طاقتها أقل من "ارتفاع " الجهد. (مثال من الميكانيكا الكلاسيكية ، نفترض حجرا تحت جبل ، ولكي يصل إلى الناحية الأخرى من الجبل لا بد و ان يحصل الحجر على طاقة (أو سرعة) تمكنه من صعود الجبل و الهبوط من الناحية الاخري.)
- **والتفسير الحديث يقول أنه نظرا لمبدأ عدم التأكد $(\Delta E\Delta t \geq \hbar)$ فإن جسيم ألفا رغم أن طاقته لا تكفي لتعدية جهد النواة حيث يوجد له احتمال صغير أن يحصل على طاقة ΔE أعلى من جهد النواة لمدة زمنية صغيرة Δt، وأثناء تلك الفترة " يقفز" ويتعدى جهد النواة ويخرج منها.**

Electron tunneling for scanning tunneling microscopy (STM)



Decay Constant for Alpha particles

ثابت الانحلال = حاصل ضرب عدد المحاولات انفلات جسيم الفا فى وحدة الزمن فى احتمال عبور حاجز الجهد بتصادم واحد مع الجدار

Gamow express the decay constant for alpha emission as:

$$\lambda_\alpha = f\,T$$

$$f = \frac{v}{2R} = \frac{\sqrt{(2V_\circ + Q)\,u}}{2R}$$

$$T = e^{-2G}$$

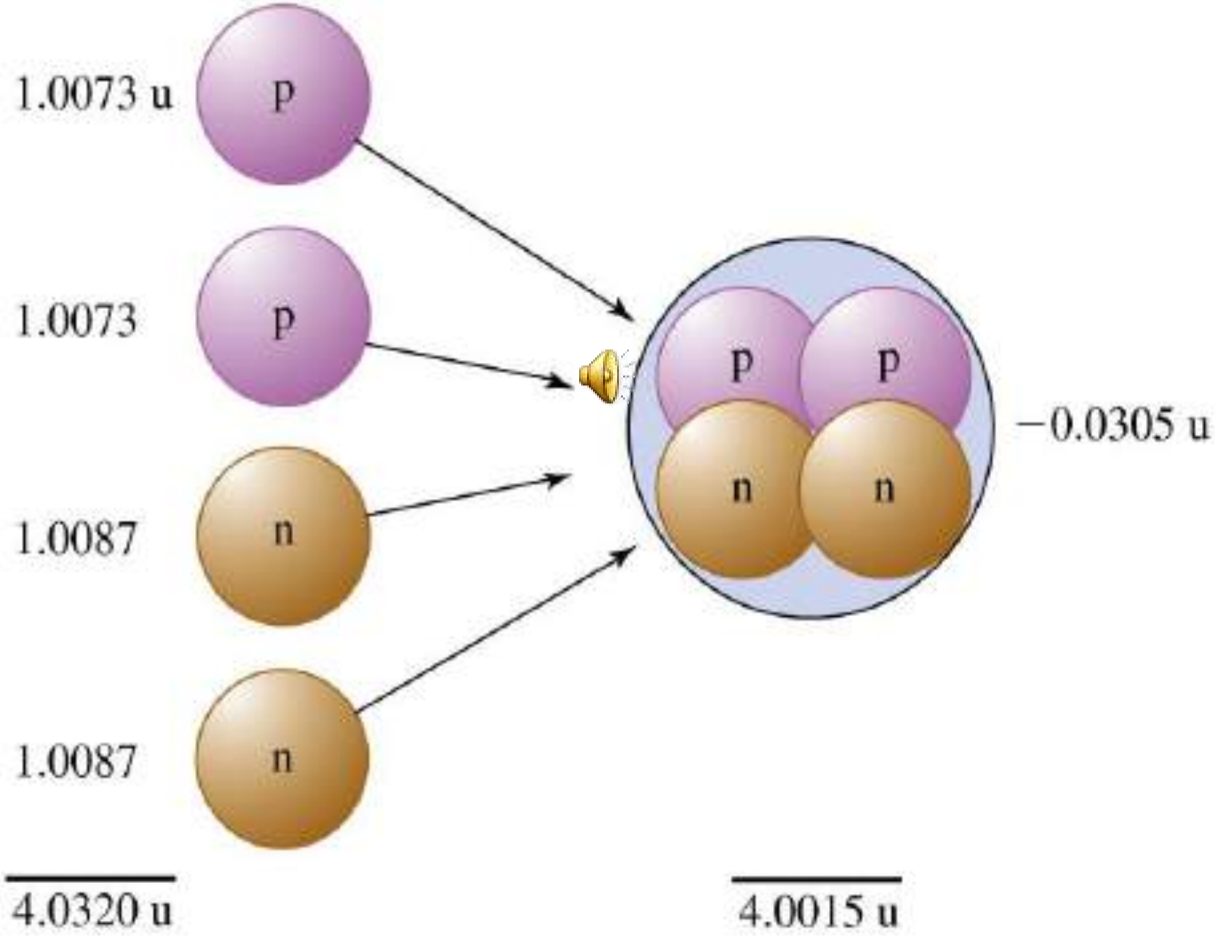
$$\lambda = \frac{2^{\frac{1}{2}}\pi^2 h^2}{M^{\frac{3}{2}} R^3 \left(E_B - E\right)^{1/2}} e^{\left[-\frac{R}{h}(2ME_B)^{\frac{1}{2}}\pi(\frac{E_B}{E})^{1/2}-4\right]}$$

f = frequency factor
T = transmission coefficient through the barrier
v = velocity
V_0 = well depth
u = reduced mass
R = radius of daughter
G = Gamow factor
E_B = height of coulomb
M = reduced mass for α
Z = atomic number of daughter
E= Q = decay energy
l= angular momentum

لابد ان يعدل ارتفاع الحاجز بحيث ان يشمل حاجز الطرد المركزى

$$\longrightarrow Barrier\ Height = \frac{l(l+1)}{2MR^2}h^2$$

Nuclear Binding Energy For alpha partical



احسب طاقة انحلال الفا من التفاعل الاتى:

$$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}He$$

الحل

$$Q=\left[M_{p}-(M_{d}+M_{\alpha})\right]C^{2}$$

$$Q=\left[M_{Rn}-M_{Po}-M_{\alpha})\right]C^{2}$$

$$Q=\left[222.017-218.008-4.002\right]u\times931.5$$

$$Q=5.587MeV$$

Who carry the total energy?

$$E(Q)=\Delta m\left[M_p-(M_d+M_\alpha)\right]C^2$$

$$E=E_\alpha+E_d$$

$$E=E_\alpha+\frac{1}{2}m_2V_2^2$$

$$m_\alpha v_\alpha+m_2v_2=0$$

$$v_2=\frac{m_\alpha}{m_2}v_\alpha$$

$$E=\left(\frac{m_\alpha+m_2}{m_2}\right)E_\alpha$$

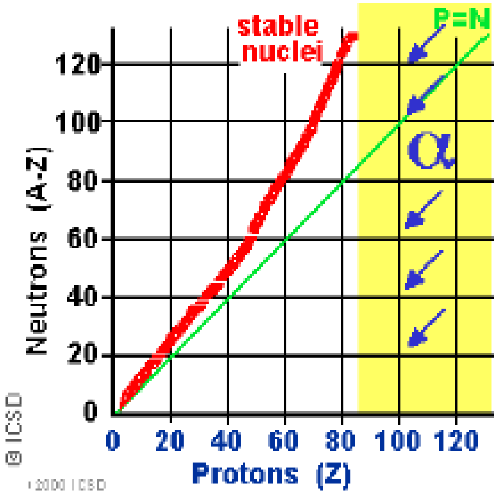
$$E_\alpha=\left(\frac{m_2}{m_\alpha+m_2}\right)E$$

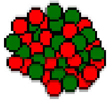
$$E_\alpha\cong E$$

و يتطلب قانون حفظ angular momentum

كمية الحركة الفا = كمية الحركة لنواة الوليدة

- Resulting nucleus has -2p and -2n
- Gamma-rays can also be emitted





$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + 2\,{}^{0}_{0}\gamma$$

$$Q = \Delta m \left[M_p - (M_d + M_\alpha) \right] C^2$$

$$Q = E_\alpha + E_\gamma$$

$$E_\alpha = Q - E_\gamma$$

$$E_\gamma = Q - E_\alpha$$

Energy

- The energy of alpha particles emitted varies, with higher energy alpha particles being emitted from larger nuclei,
- Most alpha particles have energies of between 3 and 8 MeV (mega-electron-volts), corresponding to extremely long to extremely short half-lives of alpha-emitting nuclides, respectively.
- The energy of the alpha emitted is mildly dependent on the half-life for the emission process .

Energy is divided between the decay products:

Q = 5.4 MeV

5.3 MeV to alpha particle

+ 0.1 MeV to recoil nucleus

Total 5.4 MeV (no gamma rays in this case)

Alpha particles are usually monoenergetic but sometimes have two or more energies very close together. In those cases, a small portion of the energy is lost by some other method such as gamma ray emission.

Conversion of Mass to Energy

After the emission of an alpha particle, the resulting products have less mass than the starting materials, the difference is converted to energy (Q) that mostly goes into the kinetic energy of the alpha particle:

$$M_{Po} = M_{Pb} + M_{He} + Q$$

$$Q = M_{Po} - M_{Pb} - M_{He}$$

$$Q = 210.04850 - 206.033883 - 4.00387 \text{ amu}$$

$$Q = (0.0058 \text{ amu})(931.5 \text{ Mev/amu})$$

$$Q = 5.4 \text{ MeV}$$

Alpha RECOIL REACTIONS

α-Decay

$$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + \alpha$$

A Rn^{222} nucleus has decayed into a Po^{218} nucleus and an α-particle. The Po^{218} nucleus recoils when α- particle is ejected.

ALPHA RECOIL REACTIONS

$$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + \alpha$$

- **ENERGY BALANCE**
- Although the total energy change for the decay of Rn-222 to Po-218 is 5.58 MeV, the energy of the alpha particle is only 5.48 MeV.
- The difference of 0.10 MeV is the recoil energy imparted to the newly formed Po^{218} nucleus.
- Assuming the validity of nonrelativistic mechanics, this recoil energy can be calculated:
- **$\text{Mass}_{\text{alpha}}$ x $\text{Energy}_{\text{alpha}}$ = $\text{Mass}_{\text{daughter}}$x $\text{Energy}_{\text{daughter}}$**
- **for Po^{218}, E_{recoil} = (4) (5.48) / 218 = 0.101 MeV**

Relationship between Decay Energy (Q) and mass number (A)

$$Q = \Delta m\left[M_p - (M_d + M_\alpha)\right]$$

$$Q = \frac{1}{2}M_\alpha v_\alpha^2 + \frac{1}{2}M_d v_d^2$$

$$v_d = \frac{M_\alpha}{M_d}v_\alpha$$

$$Q = \frac{1}{2}M_\alpha v_\alpha^2 + \frac{1}{2}M_d\left(\frac{M_\alpha}{M_d}\right)^2 v_\alpha{}^2$$

$$\frac{E_d}{E_\alpha} = \frac{M_\alpha}{M_d} = \frac{4}{(A-4)}$$

$$Q = E_\alpha\left[\frac{A}{A-4}\right]$$

احسب طاقة انحلال الفا من التفاعل الاتى:

$$^{222}_{86}Rn \rightarrow ^{218}_{84}Po + ^{4}_{2}He$$

الحل

$$Q=\left[M_p-(M_d+M_\alpha)\right]C^2$$

$$Q=\left[M_{Rn}-M_{Po}-M_\alpha)\right]C^2$$

$$Q=\left[222.017-218.008-4.002\right]u\times 931.5$$

$$Q=5.587MeV$$

احسب طاقة الحركة لجسيم الفا فى التفاعل السابق؟

$${}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

- لحل

$$Q = E_{\alpha}\left[\frac{A}{A-4}\right]$$

$$E_{\alpha} = Q\left[\frac{A-4}{A}\right]$$

$$E_{\alpha} = 5.587\left[\frac{222-4}{222}\right]$$

$$E_{\alpha} = 5.486MeV$$

Velocity & kinetic Energy of Alpha particles

$$E_\alpha = \frac{1}{2} M_\alpha v^2$$

$$E_\alpha = \frac{1}{2}\left[4.0038 \times 1.66 \times 10^{-24}\right] \times v^2$$

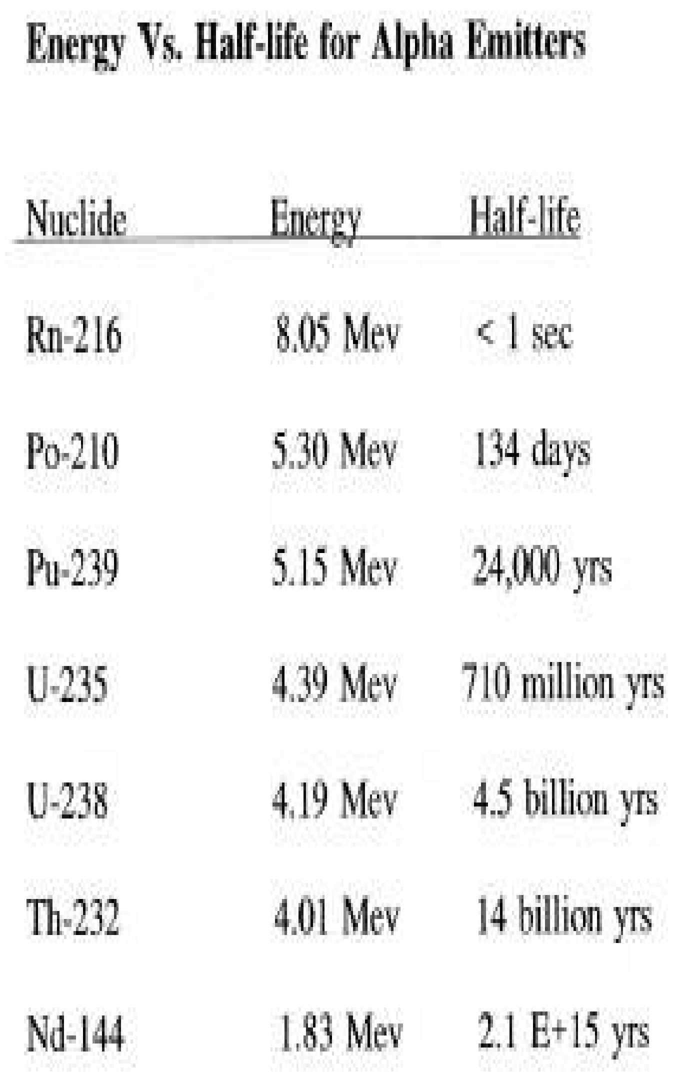
$$E_\alpha = 2.074 \times 10^{-18} \times v^2$$

$$E_\alpha = \frac{1}{2} M_\alpha v^2$$

$$v = \sqrt{\frac{2E_\alpha}{m}}$$

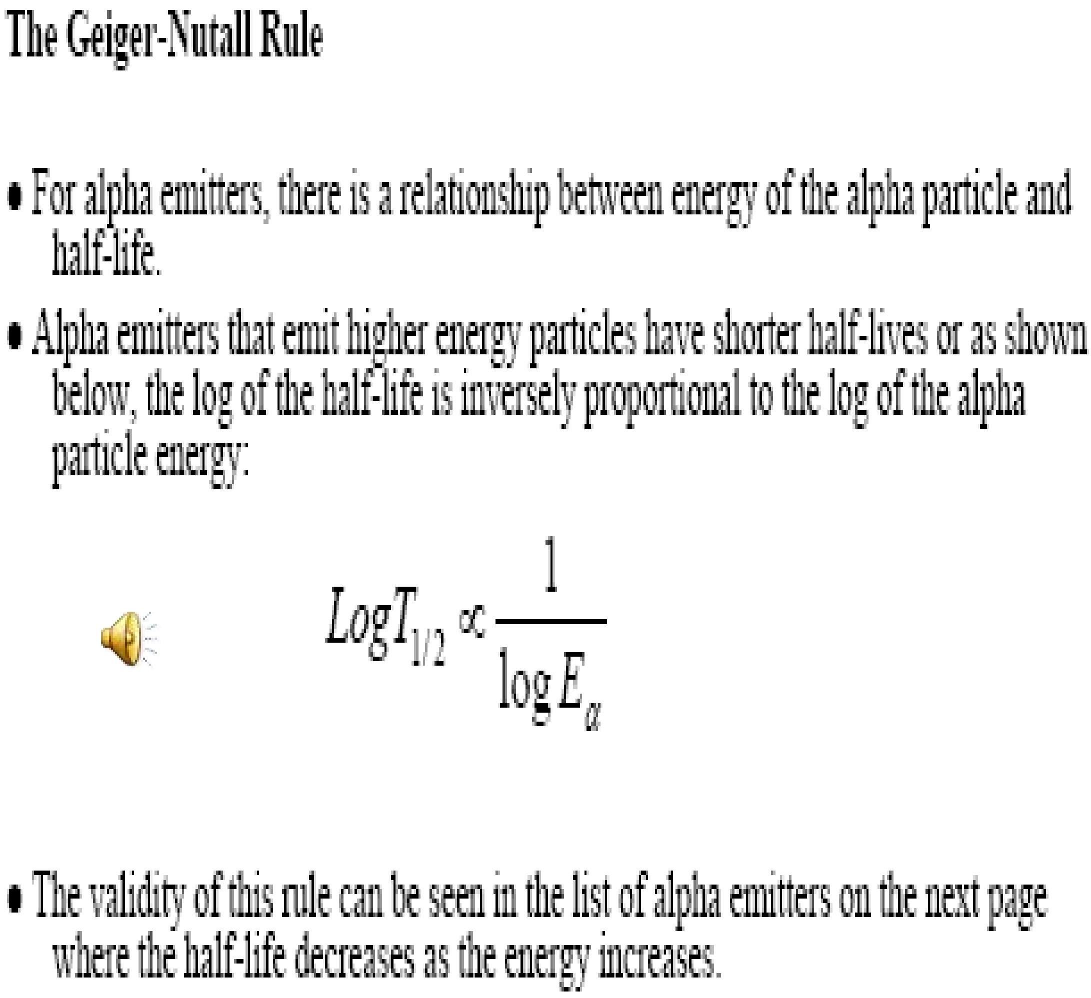
The Relationship between $t_{1/2}$ and Eα

- Gamow solved a model potential for the nucleus and derived from first principles a relationship between the half-life of the decay for parent nuclei, and the energy of the emission,
- which had been previously discovered empirically, and was known as the Geiger–Nuttall law.



Energy Vs. Half-life for Alpha Emitters

Nuclide	Energy	Half-life
Rn-216	8.05 Mev	< 1 sec
Po-210	5.30 Mev	134 days
Pu-239	5.15 Mev	24,000 yrs
U-235	4.39 Mev	710 million yrs
U-238	4.19 Mev	4.5 billion yrs
Th-232	4.01 Mev	14 billion yrs
Nd-144	1.83 Mev	2.1 E+15 yrs



The Geiger-Nutall Rule

- For alpha emitters, there is a relationship between energy of the alpha particle and half-life.
- Alpha emitters that emit higher energy particles have shorter half-lives or as shown below, the log of the half-life is inversely proportional to the log of the alpha particle energy:

$$LogT_{1/2} \propto \frac{1}{\log E_{\alpha}}$$

- The validity of this rule can be seen in the list of alpha emitters on the next page where the half-life decreases as the energy increases.

The greater the excess energy of an alpha emitter the greater the decay energy and shorter its half-life

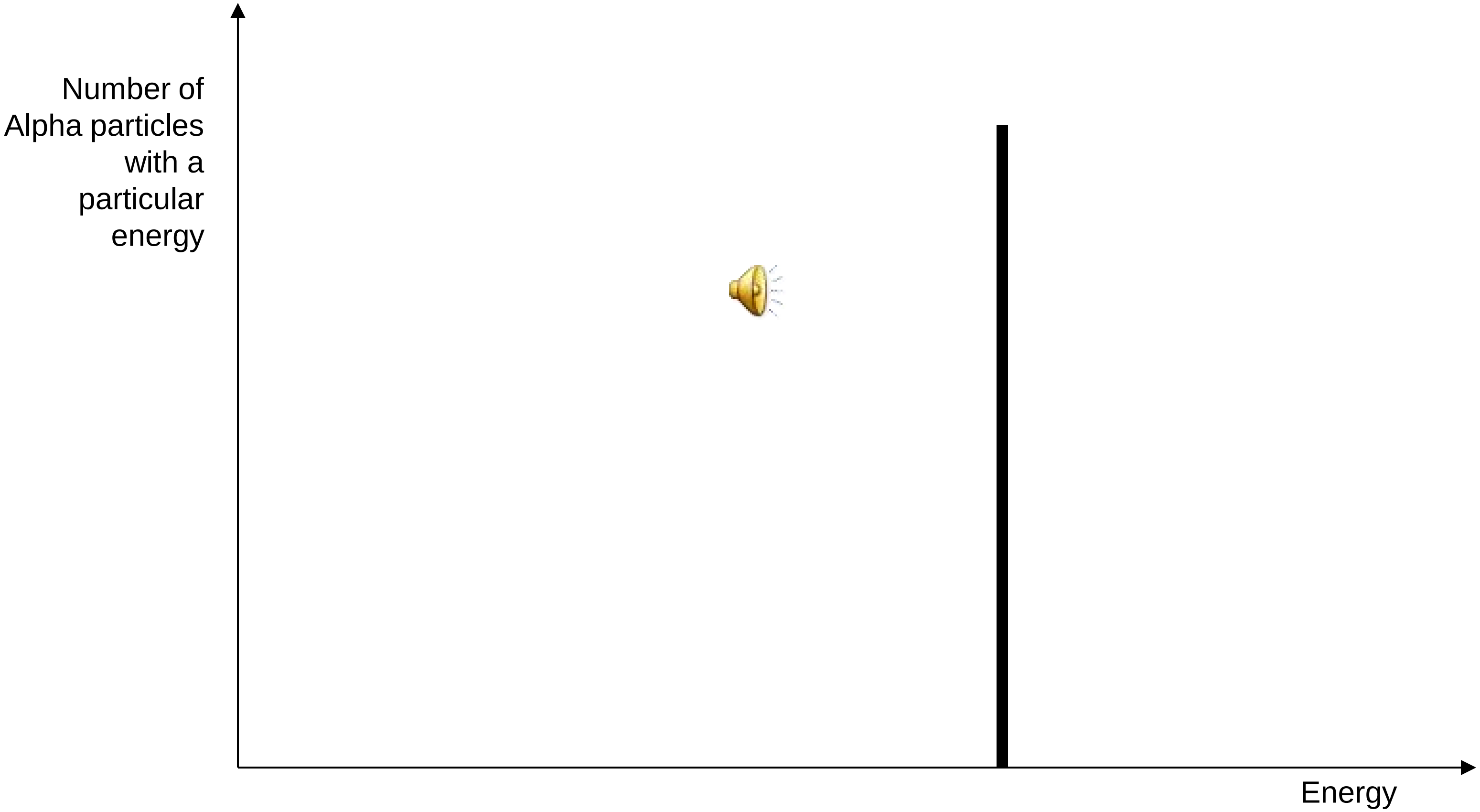
$$\log t_{\frac{1}{2}} = 37.6 - 4.00 E_{\alpha}$$

اطياف جسيمات الفا
alpha particles specrta◌ِ◌

- وجد ان نواة (^{232}Th) تمتلك مجموعتين من جسيمات الفا بطاقات (3.994, 3.936 MeV)
- وجد ان نواة (^{239}Th) تمتلك اربع مجموعات من جسيمات الفا بطاقات (4.436, 4.471, 4.615, 4.682 MeV)

- وجد ان نواة (^{226}Ra) تمتلك ثلاث مجاميع من جسيمات الفا بطاقات (4.34, 4.59, 4.77 MeV)
-

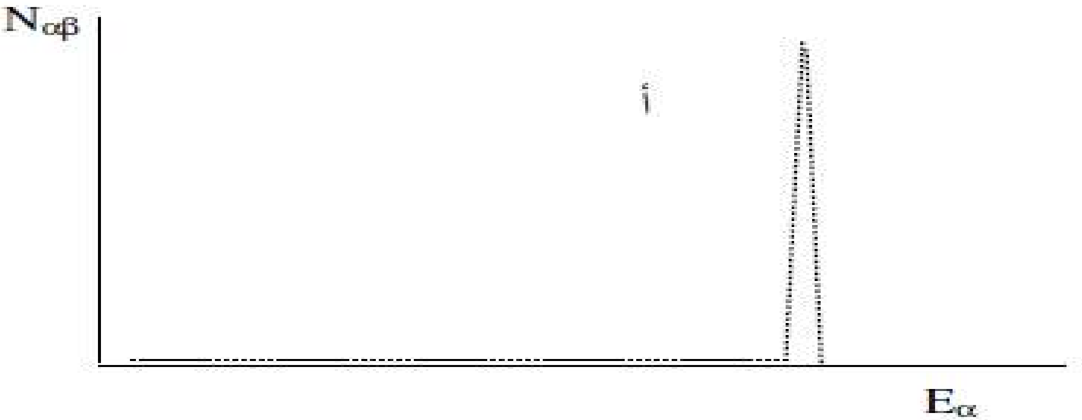
The Alpha Energy Spectrum



Alpha spectrum

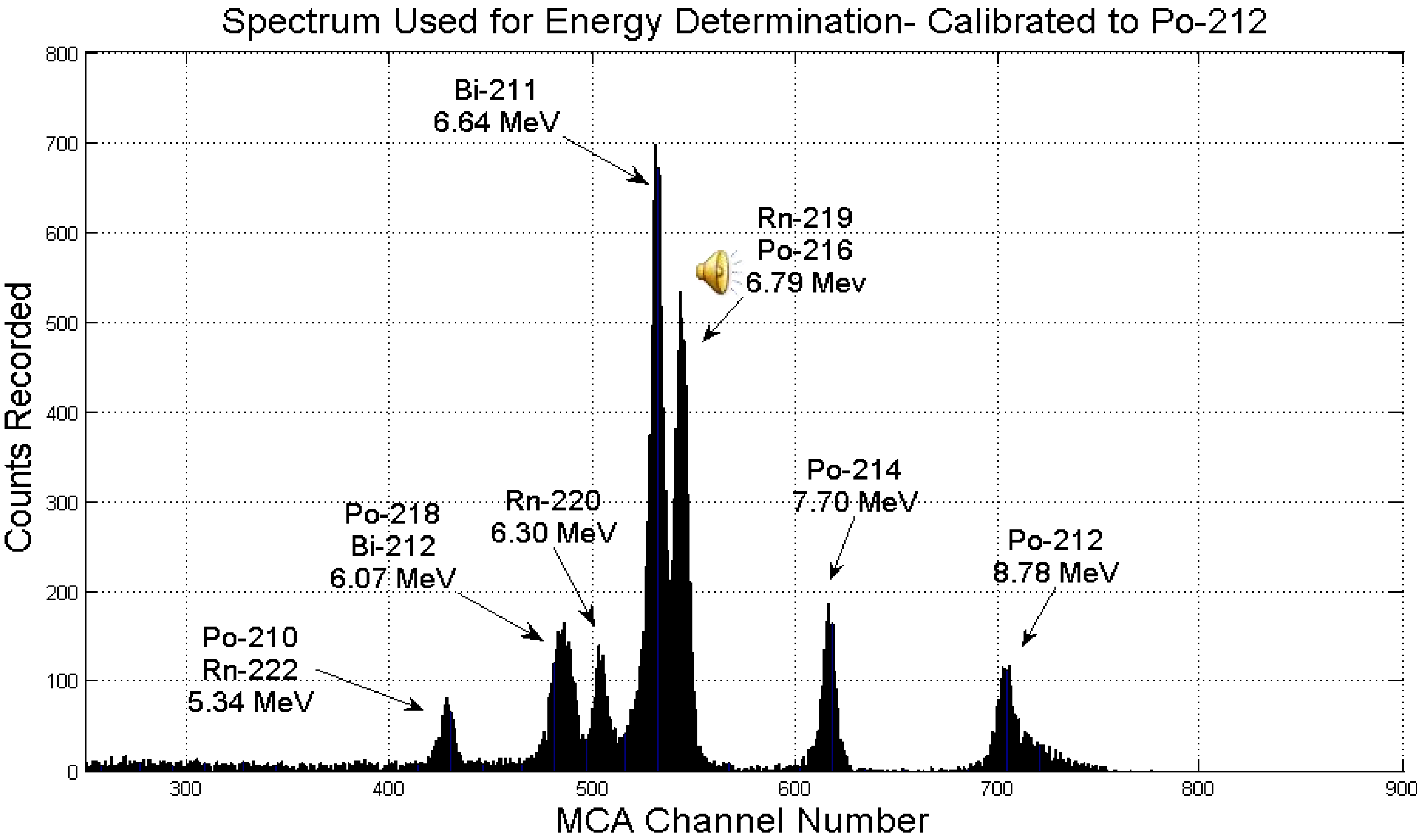
وتجدر الإشارة إلى أن طاقة جسيمات ألفا الصادرة عن نظير معين تتخذ قيمة واحدة. ولكن إذا تكونت النواة الوليدة في حالات مختلفة الإثارة فعندئذ تكون طاقات جسيمات ألفا مختلفة ولكنها ذات قيم محددة. فمثلا نجد أن طاقة جسيمات ألفا الصادرة عن نظير البولونيوم 210 تتخذ قيمة واحدة هي 5.305 ميغا إلكترون فولت. أما جسيمات ألفا الصادرة عن اليورانيوم 238 فتتخذ قيمتين هما 4.198 ميغا إلكترون فولت، 4.149 ميغا إلكترون فولت. ويعود السبب في ذلك إلى أن نواة الثوريوم 234 الوليدة قد تتكون في الحالة الأرضية فتتخذ جسيمات ألفا القيمة الأكبر للطاقة، وقد تتكون هذه النواة الوليدة في حالة مثارة فتتخذ جسيمات ألفا القيمة الأصغر للطاقة. ويمكن حساب طاقة جسيمات ألفا الصادرة من نظير معين وذلك باستخدام علاقة أينشتين لتكافؤ الكتلة والطاقة، حيث أن الطاقة E الناتجة عن التفكك هي:

$$E = \{ (M_p - (M_d + M_\alpha) \} C^2 \qquad (2-2)$$

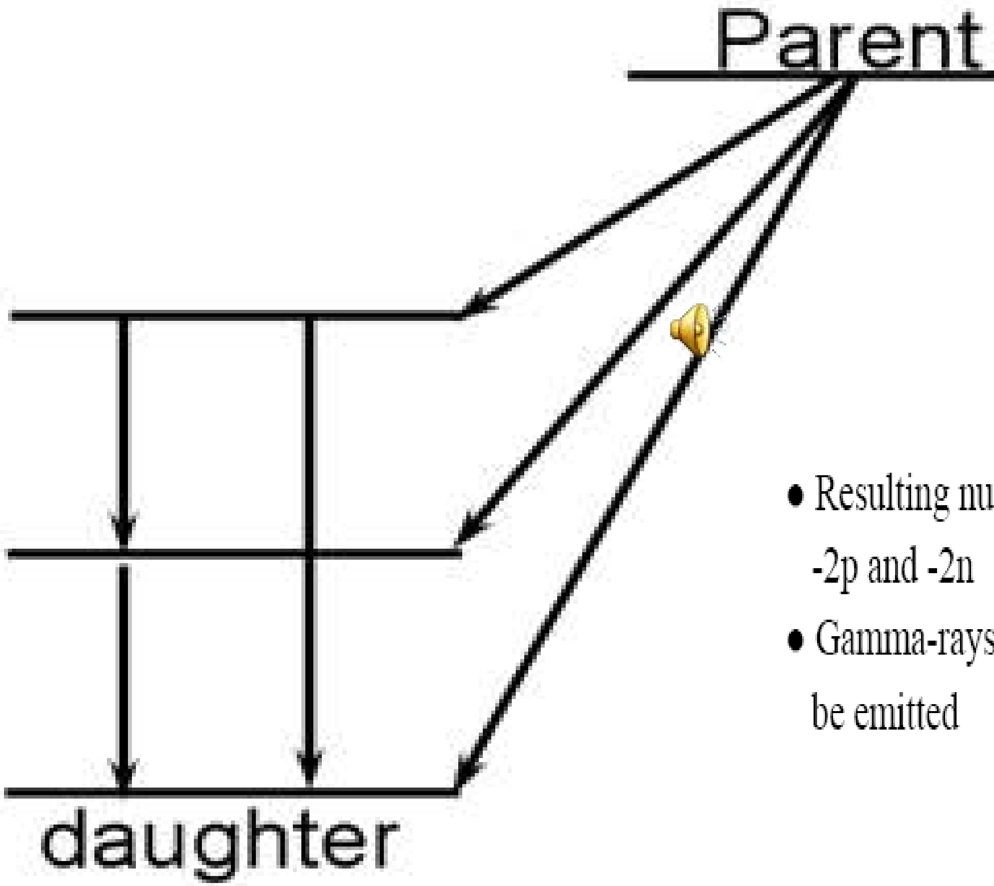


Energy Spectrum from Can Detector

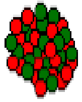
Calibrated to Po-212 alpha energy of 8.78 MeV



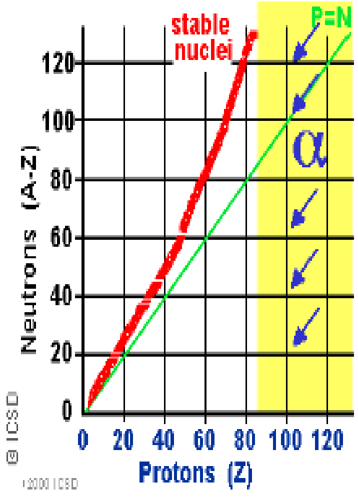
Alpha Decay Scheme



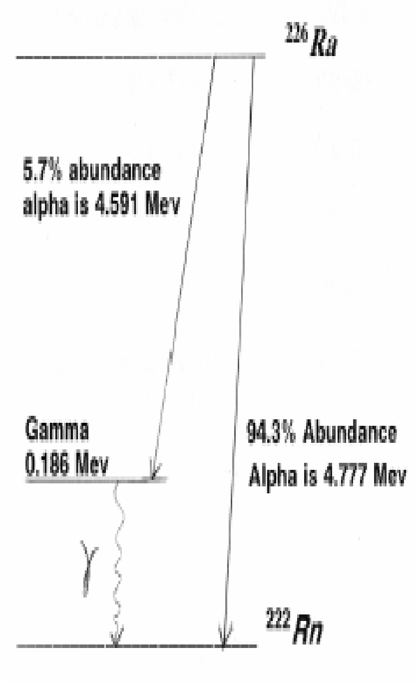
- Resulting nucleus has -2p and -2n
- Gamma-rays can also be emitted



$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He \; + 2 \, ^{0}_{0}\gamma$$



Example of decay with two alpha energies:



Lowest energy alpha leaves Rn-222 in excited state which decays by gamma emission.

Some typical alpha emitters

Nuclide	Alpha Energy(Mev)
Ra-226	4.77, 4.59
Th-232	4.01, 3.95
Pu-239	5.15, 5.13
U-238	4.19

Note that these nuclides are all heavy elements as is typical for alpha emitters

Alpha Decays

- **In the alpha decay scheme, there are three possible routes of decay from parent to ground state of the daughter; the only mode of decay is alpha.**

- **In Route 1, the decay is directly to the ground state. There is no excited or metastable state formed and no gamma rays are released.**

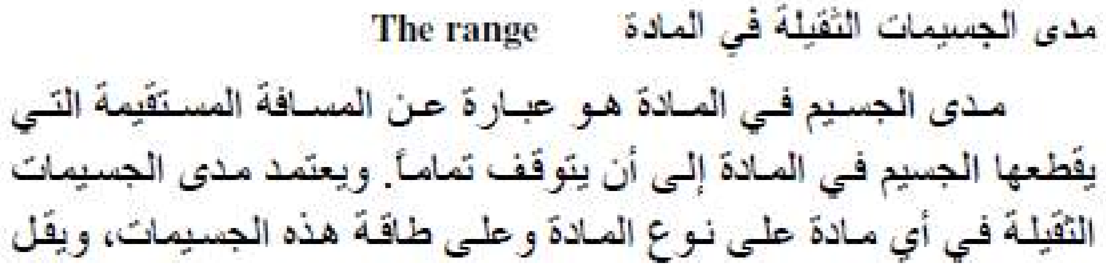
- **In Route 2, there is decay by alpha to a metastable state of the daughter, followed by emission of a gamma ray and transition to the ground state.**

- **In Route 3, there is alpha decay to a highly excited state of the daughter, followed by gamma ray emission either directly to the ground state or indirectly to the ground state through sequential emission of two separate gamma rays .**
- **Regardless of the route taken, the energy expended in transition from parent to daughter is a fixed amount.**

Reaction of α with matter

- **This energy is a substantial amount of energy for a single particle, but their high mass means alpha particles have a lower speed (with a typical kinetic energy of 5 MeV, the speed is 15,000 km/s which is 5% of the speed of light) than any other common type of radiation (β particles, neutrons, etc.).**
- **γ rays, being an electromagnetic radiation, move at the speed of light.**
- **Because of their charge and large mass, alpha particles are easily absorbed by materials, and they can travel only a few centimeters in air.**
- **They can be absorbed by tissue paper or the outer layers of human skin (about 40 micrometers, equivalent to a few cells deep).**

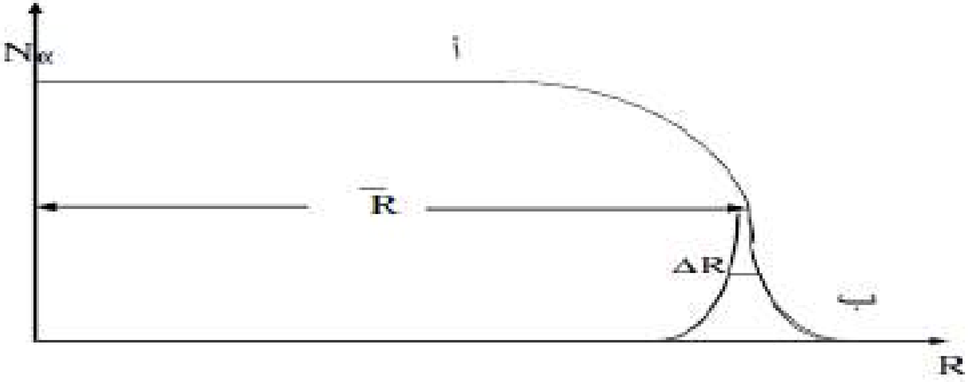
The Reaction of Alpha particle with matter



مدى الجسيمات الثقيلة في المادة The range

مدى الجسيم في المادة هو عبارة عن المسافة المستقيمة التي يقطعها الجسيم في المادة إلى أن يتوقف تماماً. ويعتمد مدى الجسيمات الثقيلة في أي مادة على نوع المادة وعلى طاقة هذه الجسيمات، ويقل

المدى كلما زادت كثافة المادة، ويزيد كلما زادت طاقة الجسيمات. وعموماً، فإن مدى الجسيمات الثقيلة صغير، حيث يبلغ مدى جسيمات ألفا بطاقة 5 ميغا إلكترون فولت في الهواء حوالي 3.5 – 4سم، في حين لا يزيد مدى هذه الجسيمات في النسيج البشري على حوالي 40 ميكرون، أي أقل من سماكة طبقة الجلد السطحية الميتة، أي أن قدرة الجسيمات الثقيلة على الاختراق تعتبر صغيرة. لذا، فإن هذه الجسيمات لا تحتاج إلى حواجز سميكة للوقاية منها.

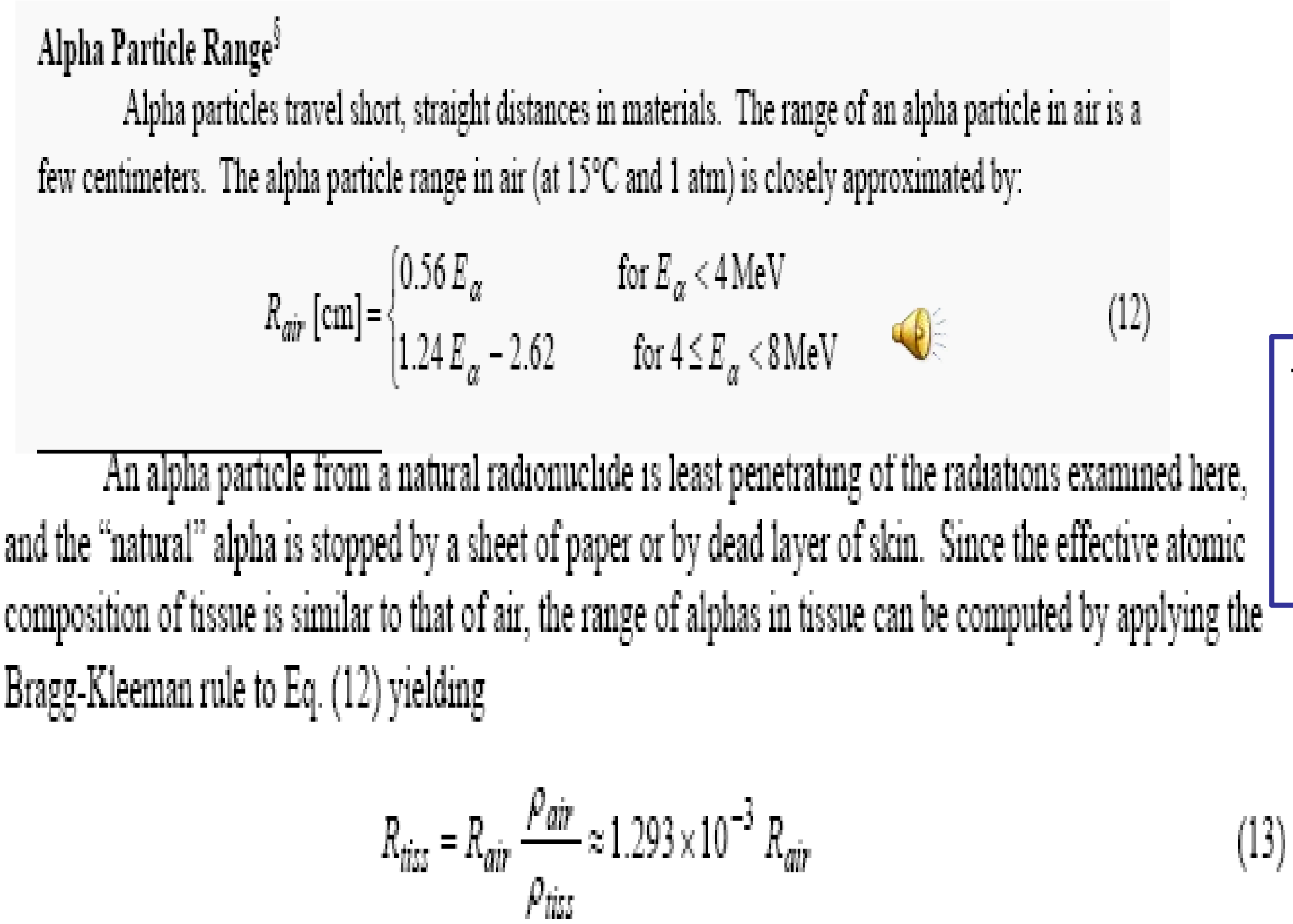


شكل(1−3)

أ− مدى جسيمات α في الهواء

ب− المنحنى التفاضلي للتبعثر

Determination of the range of alpha particle in air



Alpha Particle Range[§]

Alpha particles travel short, straight distances in materials. The range of an alpha particle in air is a few centimeters. The alpha particle range in air (at 15°C and 1 atm) is closely approximated by:

$$R_{air}\,[\text{cm}] = \begin{cases} 0.56\,E_\alpha & \text{for } E_\alpha < 4\,\text{MeV} \\ 1.24\,E_\alpha - 2.62 & \text{for } 4 \le E_\alpha < 8\,\text{MeV} \end{cases} \qquad (12)$$

An alpha particle from a natural radionuclide is least penetrating of the radiations examined here, and the "natural" alpha is stopped by a sheet of paper or by dead layer of skin. Since the effective atomic composition of tissue is similar to that of air, the range of alphas in tissue can be computed by applying the Bragg-Kleeman rule to Eq. (12) yielding

$$R_{tiss} = R_{air}\frac{\rho_{air}}{\rho_{tiss}} \approx 1.293 \times 10^{-3}\,R_{air} \qquad (13)$$

the range of α particle in air is roughly given by relationship:

$E_\alpha \approx R$

$$\frac{R_1}{R_2} = \frac{\rho_2}{\rho_1}\sqrt{\frac{M_1}{M_2}}$$

Uses

- **Spacecraft Power**
- **Radioisotope thermoelectric generators are used to power a wide array of satellites and spacecraft. These devices function like a battery, with the benefit of a long life span. Plutonium-238 serves as the fuel source, producing alpha radiation resulting in heat, which is converted to electricity.**

- **artificial heart pacemakers Alpha radiation is used as an energy source to power heart pacemakers. Plutonium-238 is used as the fuel source for such batteries; with a half-life of 88 years, this source of power provides a long lifespan for pacemakers.**

- **Static eliminators Alpha radiation from polonium-210 is used to eliminate static electricity in industrial applications. The positive charge of the alpha particles attracts free electrons, thus reducing the potential for local static electricity. This process is common in paper mills.**

- Remote Sensing Stations
- The Unites States Air Force uses alpha radiation to power remote sensing stations in Alaska. Strontium-90 is typically used as the fuel source. These alpha-powered systems enable unmanned operations for long periods of time without the need for servicing.

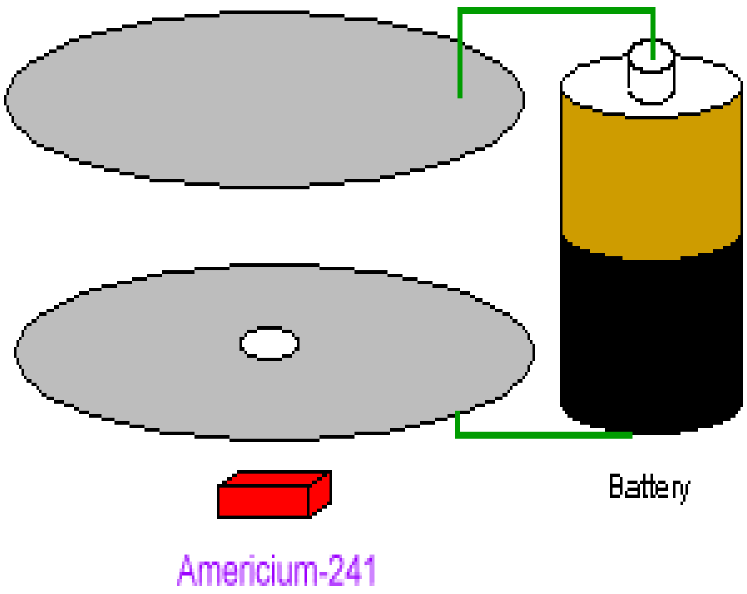
- cancer therapy:
- Researchers are currently trying to use the damaging nature of alpha emitting radionuclide inside the body by directing small amounts towards a tumor. The alphas damage the tumor and stop its growth while their small penetration depth prevents radiation damage of the surrounding healthy tissue. This type of cancer therapy is called unsealed source radiotherapy.

- Smoke Detector
- Alpha radiation is used in some smoke detectors. The alpha particles from americium-241 bombard air molecules, knocking electrons free. These electrons are then used to create an electrical current. Smoke particles disrupt this current, triggering an alarm.

SMOKE DETECTORS

...an interesting use of alpha radiation

One interesting use of alpha decay can be found in smoke detectors, which seems like an unlikely place. Smoke detectors contain the radioactive isotope americium-241 which was obtained from the decay of plutonium. Alpha particles from the americium collide with oxygen and nitrogen particles in the air creating charged ions. An electrical current is applied across the chamber in order to collect these ions. When there is smoke in this chamber the alpha particles are absorbed by the smoke. This lowered the number of ions in the air and thus the electrical current is reduced setting of the alarm. Americium-241 is quite safe because the alpha particles usually travel only a few centimeters in air.



What is transmutation

- After an alpha particle is emitted, the nucleus has 2 fewer protons & neutrons than it had.
- ***Transmutation*** is the process of changing one element to a different element by the decaying process.
- $^{210}_{84}\text{Po} – {}^{4}_{2}\text{He} = {}^{206}_{82}\text{Pb}$
- The polonium atom has become a lead atom.

Another useful application of alpha particle

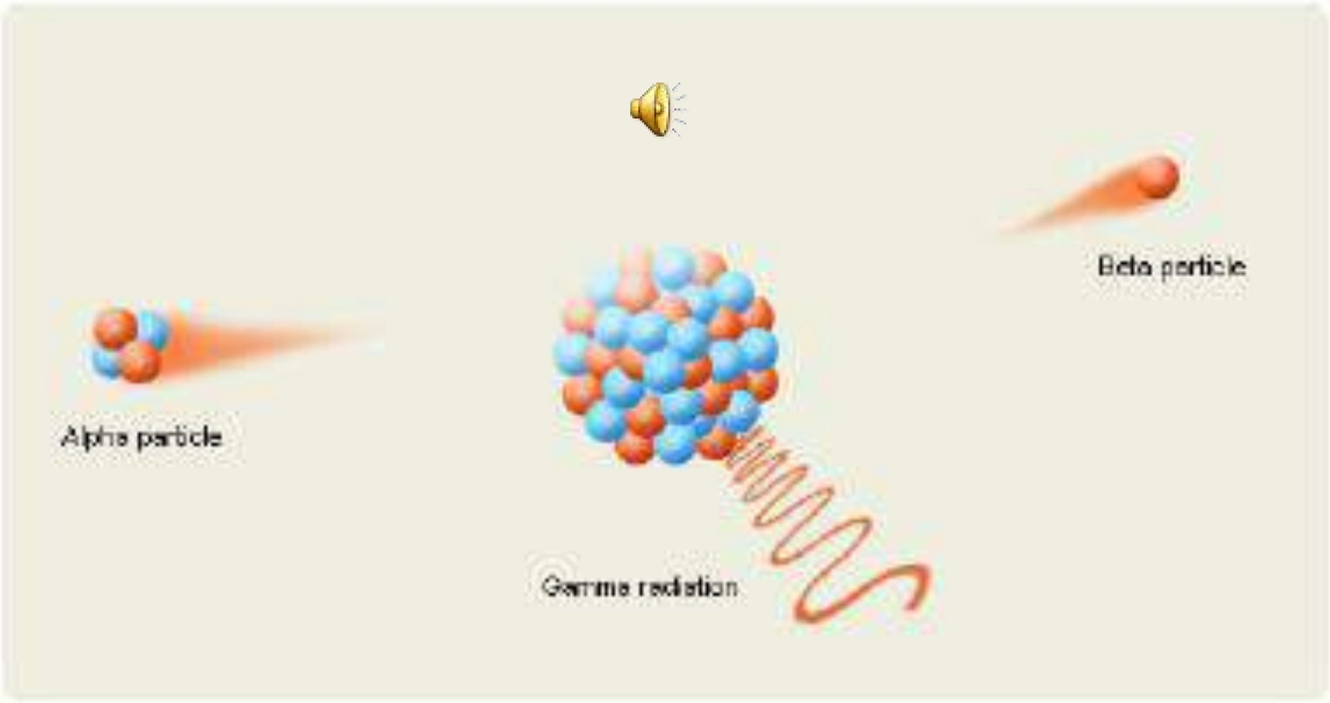
Rutherford – the first successful alchemist

- Transformed N to O
  - $^{14}N + \alpha \rightarrow {}^{17}O + 1H$
- **Why wouldn't it be practical to convert Pb into Au?**
- The conversion of platinum into gold has been achieved by bombarding platinum-198 with neutrons to produce platinum-199. This isotope, in turn, decays to gold-199 with the loss of a subatomic particle.

CHACTERISTICS OF ALPHA PARTICLES

- Consist of 2 protons and 2 neutrons
- Mass of an alpha particle is ~8000 m_e or 4 amu
- Charge = +2
- Are highly ionizing
- Have low penetrating abilities (only cm in air and mm in water)
- Easily shielded; common types of shielding are paper, cardboard, air, clothing; will not penetrate skin
- Health hazard when taken internally
- Some used in medicine, and industry
- Common sources = smoke detectors (Am-241) and lantern mantles (thorium nitrate

Gamma Decay

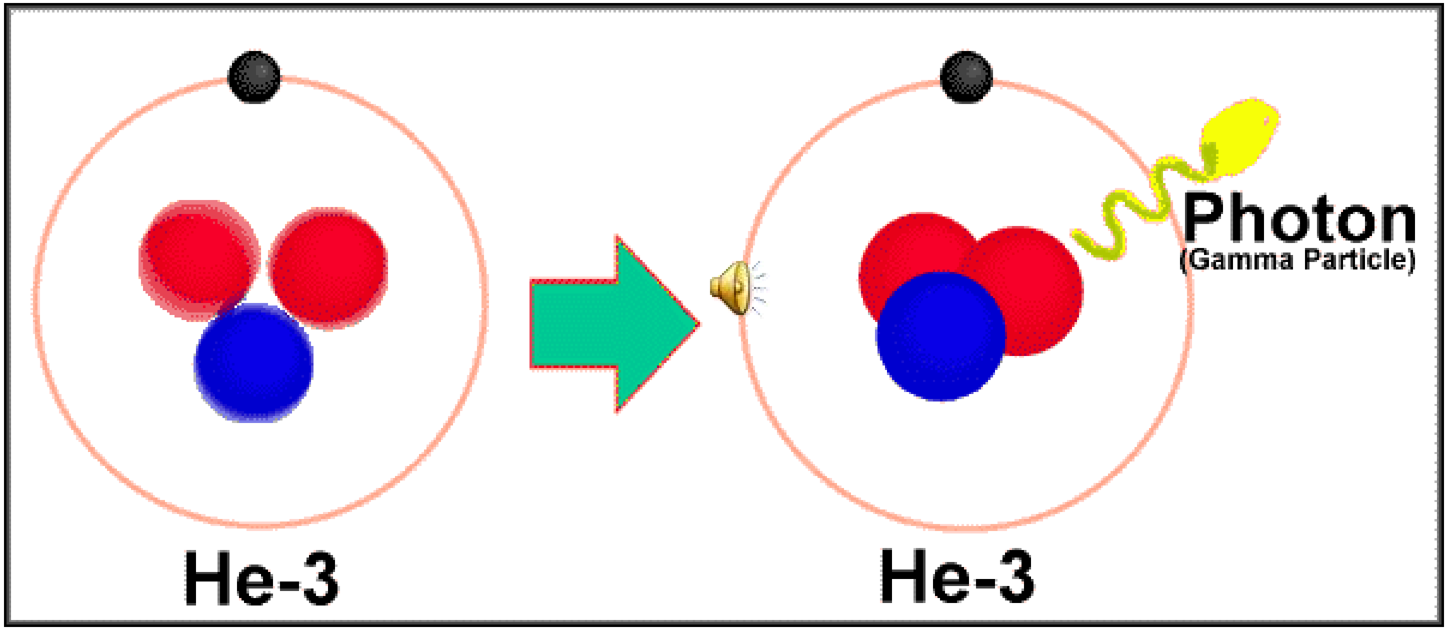


Gamma Decay

- Definition
- Properties
- **Different GAMMMA RAYS AND X- RAYS**
- **Internal Conversion**
- Auger electrons
- **Interaction of Gamma rays with matter**
- Intensity of Gamma &Half Value Layer (HVL)
- ***Application of Gamma Rays***

Gamma Emission

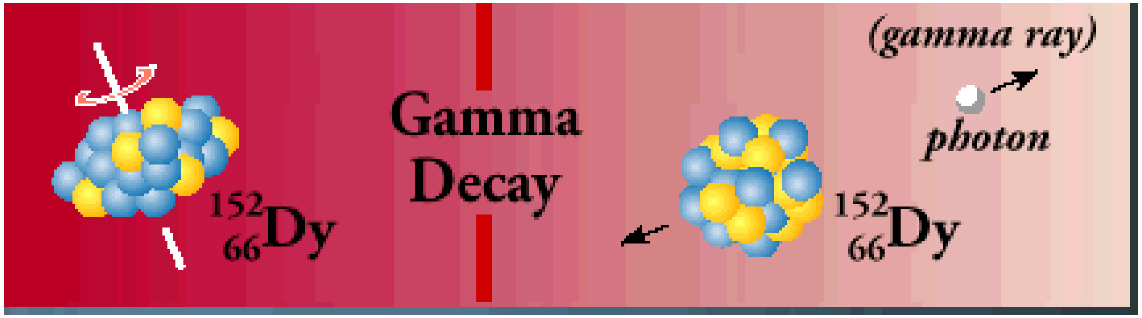
High energy wave emitted from the nucleus of an unstable atom.



Emission of high energy changed the nucleus from an excited state to a ground state.

Gamma Decay

- A gamma ray is a photon.
- A photon is an amount of electromagnetic energy
- that has a mass of zero, no charge, and a long lifespan.
- A nucleus changes from a higher energy state to a lower energy state through production of photons.
- **Through the process of Gamma Decay, the number of protons and neutrons** **DO NOT Change**.



GAMMMA RAYS

- Photons emitted from unstable nuclei to rid themselves of excess energy.

- Gamma photons are subatomic packets of pure energy.

- They are higher in energy and more penetrating than the photons that make up visible light.

Gamma Emission

Ex. Polonium-210 undergoes gamma decay to produce this daughter nuclide

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{A}_{Z}\mathrm{X} + {}^{0}_{0}\gamma$$

Atomic Mass: $210 = A + 0$

$A = 210$

Atomic #: $84 = Z + 0$

$Z = 84$

$$^{A}_{Z}\mathrm{X} = {}^{210}_{84}\mathrm{Po}$$

Balancing a nuclear equation:

$$^{234}_{90}\mathrm{Th} \longrightarrow\ ^{234}_{91}\mathrm{Pa} +\ ^{0}_{-1}\beta +\ ^{0}_{0}\gamma$$

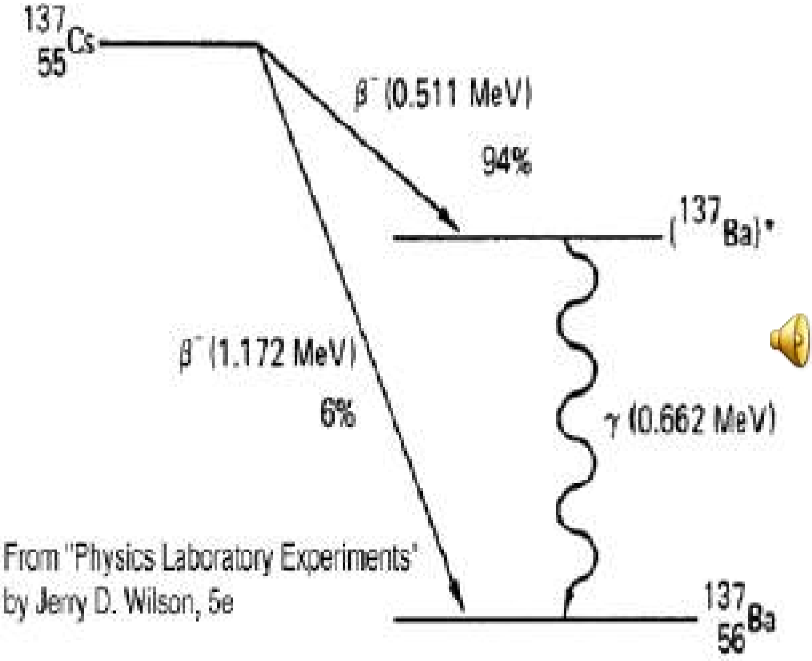
Protactinium

1) Total Nucleon Number (TOP VALUES) =Total number of protons and neutrons
2) Total electric charge (BOTTOM VALUES)

Are kept the same.

$$^{14}_{6}\mathrm{C} \longrightarrow\ ^{14}_{7}\mathrm{N} +\ ^{0}_{-1}\beta +\ ^{0}_{0}\gamma$$

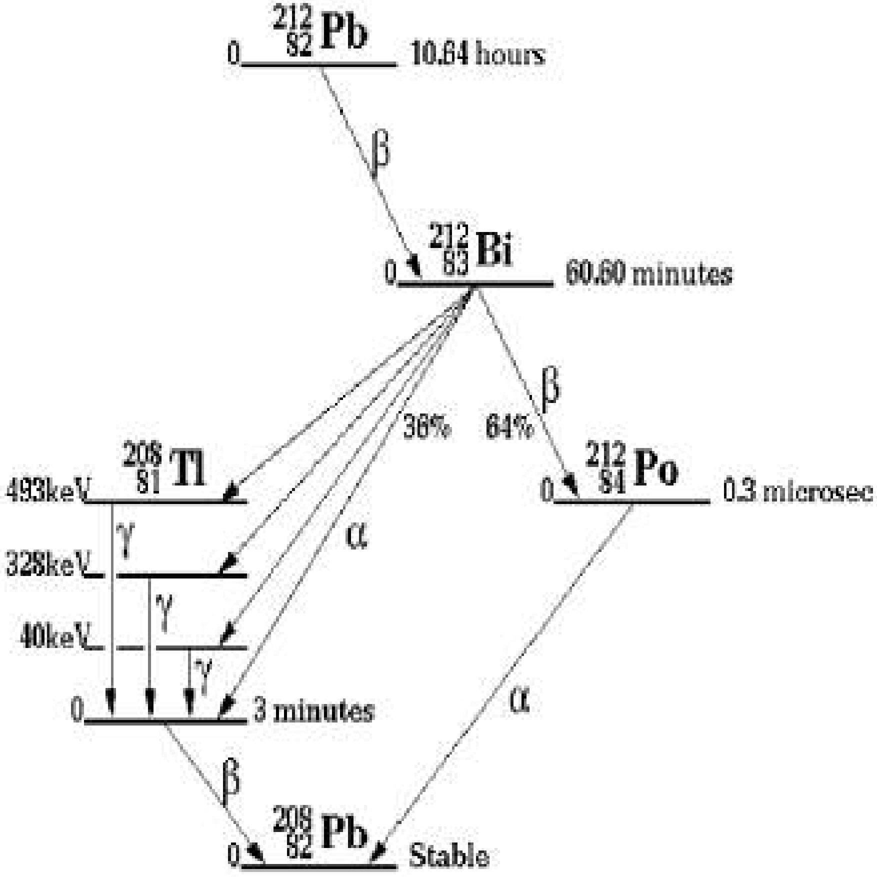
DECAY SCHEMES



From "Physics Laboratory Experiments"
by Jerry D. Wilson, 5e

Figure 49.2 Decay scheme of Cs-137. Most of the cesium-137 (Cs-137) nuclei (94%) decay to an excited state of barium-137 ($^{137}Ba^*$), which then gamma decays to a stable state.

DECAY SCHEMES



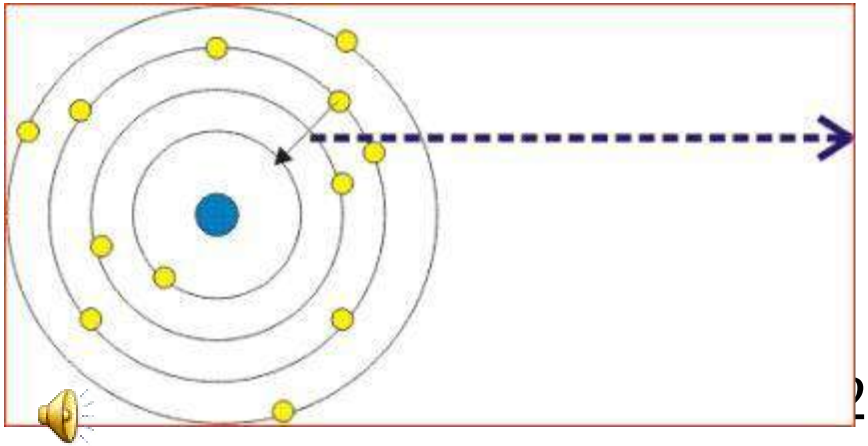
GAMMMA RAYS AND X- RAYS

- Have the same properties except for their origin.
- Gammas come from within the nuclei of atoms
- X-rays come from outside the nuclei
- The difference lies in the way of production:
    - Gamma in nucleus
    - X Ray in atomic shell

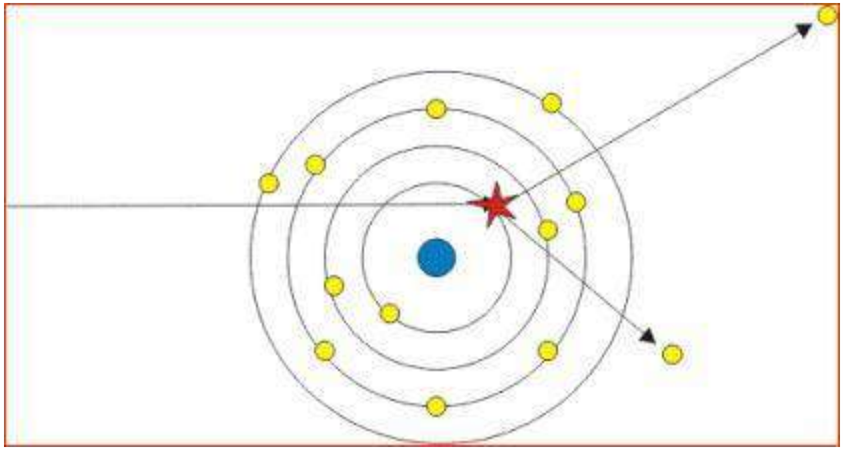
- Both are electromagnetic energy in the form of emitted photons
- Gamma-rays: monoenergetic (one or more lines)
- X Rays: a spectrum

Types of X Ray production

- **Characteristic X Rays:**



1-The incoming electron knocks out an inner shell atomic electron



2- An electron from a higher shell fills the vacancy and the energy difference is emitted as an X Ray of an energy characteristic for the transition

1-5-2 الأشعةالسينية المميزة للعنصر

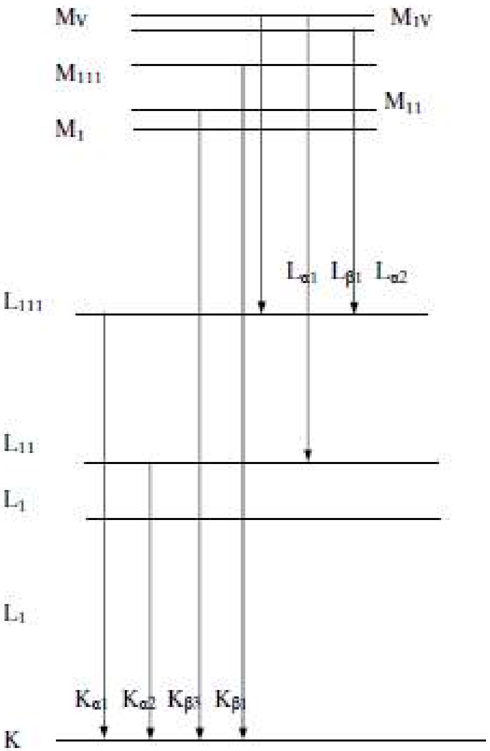
يصدر هذا النوع من الأشعة السينية عند انتقال الإلكترونات الذرية من مدارات (قشرات) ذات طاقة أعلى إلى مدارات ذات طاقة أقل في الذرة نفسها. فعند وجود فجوة إلكترونية في مدار ذي طاقة أقل ينتقل أحد الإلكترونات من مدار ذي طاقة أعلى ليشغل هذه الفجوة، وينطلق في اللحظة نفسها فوتون أشعة سينية (موجة كهرومغناطيسية) حاملاًفرق طاقتي الإلكترون في المداين. ولما كانت قيم طاقات الإلكترونات في المدارات الذرية محددة وثابتة للعنصر الواحد وتختلف من عنصر لآخر، فإنه تتخذ فوتونات الأشعة السينية المنطلقة نتيجة لانتقال الإلكترونات بين المدارات قيما محددة وثابتة للطاقة بالنسبة للعنصر الواحد، وتختلف هذه القيم باختلاف العنصر. وهذا يعني أنه عند إثارة الإلكترونات في مدارات ذرات العنصر الواحد بأي أسلوب من أساليب الإثارة تصدر ذرات هذا العنصر (لحظة التخلص من الإثارة) فوتونات سينية ذات طاقات محددة ومعلومة ومميزة للعنصر. ويطلق عليهذه الأشعة اسم الأشعة السينية المميزة للعنصر وتعد بصمة من بصماته، وتستخدم عادة في عمليات التحليل الكمي والكيفي للعناصر.

$K_{\alpha 1}$ (L_3 -> K) = 88.005 – 13.035 = 74.97 KeV

$K_{\alpha 2}$ (L_2 -> K) = 88.005 – 15.200 = 72.805 KeV

$K_{\beta 1}$ = (M_3 -> K) = 88.005 – 3.066 = 84.939 KeV

$K_{\beta 2}$ = (M_2 -> K) = 88.005 – 3.554 = 84.451 KeV



شكل (4-2)

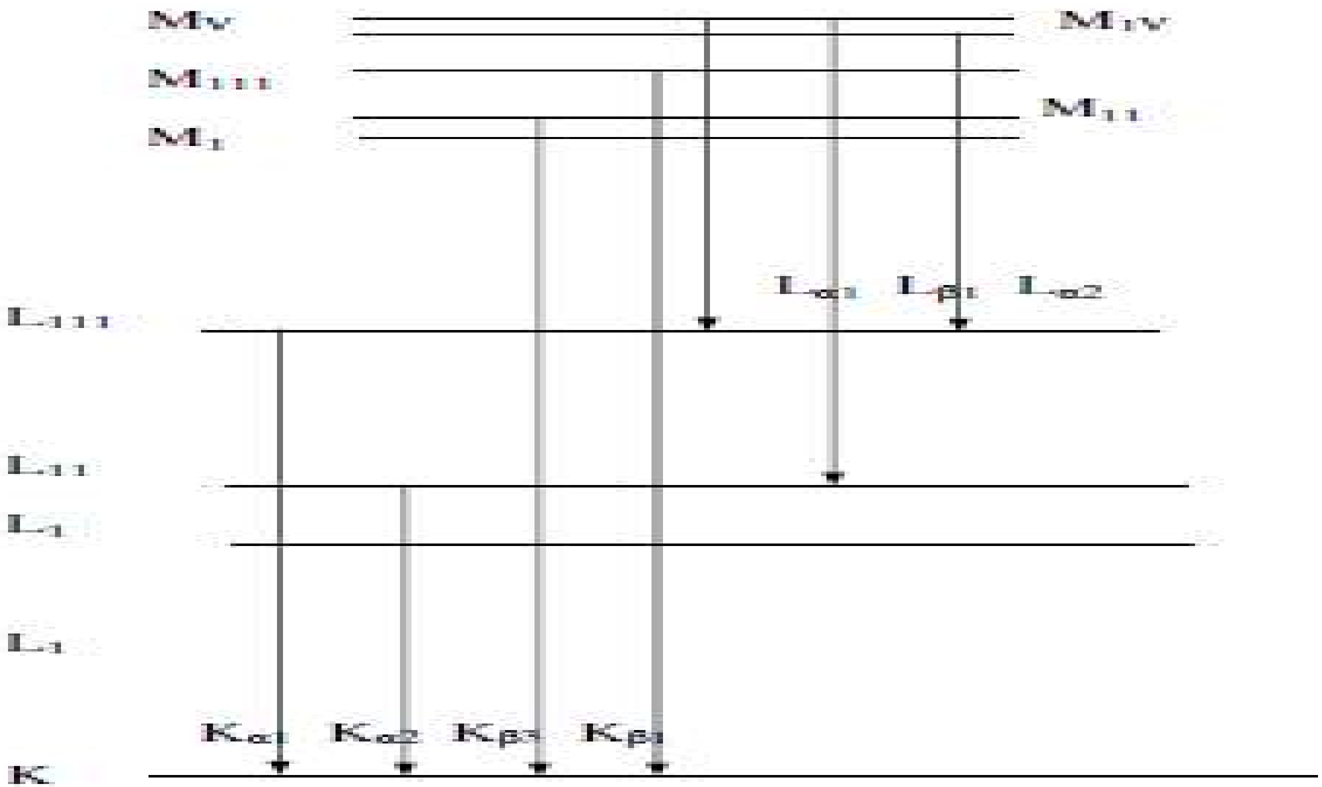
القشرات و القشرات الفرعية للإلكترونات في الذرة وخطوط الأشعة السينية المنبعثة عند انتقال الإلكترونات من القشرات الأعلى للأدنى

$K_{\alpha 1}$ (L_3 -> K) = 88.005 – 13.035 = 74.97 KeV

$K_{\alpha 2}$ (L_2 -> K) = 88.005 – 15.200 = 72.805 KeV

$K_{\beta 1}$ = (M_3 -> K) = 88.005 – 3.066 = 84.939 KeV

$K_{\beta 2}$ = (M_2 -> K) = 88.005 – 3.554 = 84.451 KeV

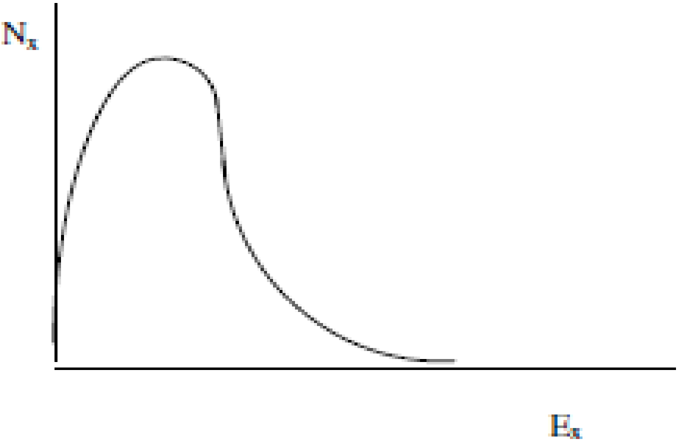


Types of X Ray production

- **Bremsstrahlung:**
- The incoming electron is deflected in the atomic shell and decelerated. The energy difference is emitted as an X Ray

2-5-2 الأشعة السينية الانكباحية

عند حدوث انكباح شديد (أي تناقص شديد في السرعة) للإلكترون، أو لأي جسيم مشحون سريع بصفة عامة، بسبب تفاعل هذا الإلكترون أو الجسيم المشحون مع المجال الكهربائي الشديد للذرة أو للنواة تنطلق الطاقة التي يفقدها الإلكترون (أو الجسيم المشحون) بسبب تناقص سرعته في صورة فوتون أشعة سينية يحمل فرق طاقة الإلكترون أو الجسيم قبل وبعد التفاعل. وتسمى الأشعة المتولدة بهذا الأسلوب بالأشعة السينية الانكباحية. ويتميز طيف الأشعة الانكباحية شكل (2-5) بأنه طيف مستمر، أي تتخذ طاقة الفوتونات قيما مختلفة تبدأ من الصفر وتنتهي عند أقصى قيمة لطاقة الإلكترون أو الجسيم المنكبح. ومن أمثلة الأشعة السينية الانكباحية تلك الأشعة [illegible]ي يتم توليدها في أنابيب الأشعة السينية المستخدمة في التشخص الطبي وفي التطبيقات الصناعية المختلفة، حيث يتم تعجيل الإلكترونات باستخدام فرق جهد كبير ثم تكبح الإلكترونات المعجلة علىمادة المصعد (الأنود) فتنطلق الأشعة الانكباحية.



PROPERTIES OF GAMMMA (γ) AND X RAYS

- Charge is 0 (no charge)

- Mass is 0 (no mass)

- Low ionization

- High Penetration abilities
  - penetrating power is dependent upon the energy of the emitted photons

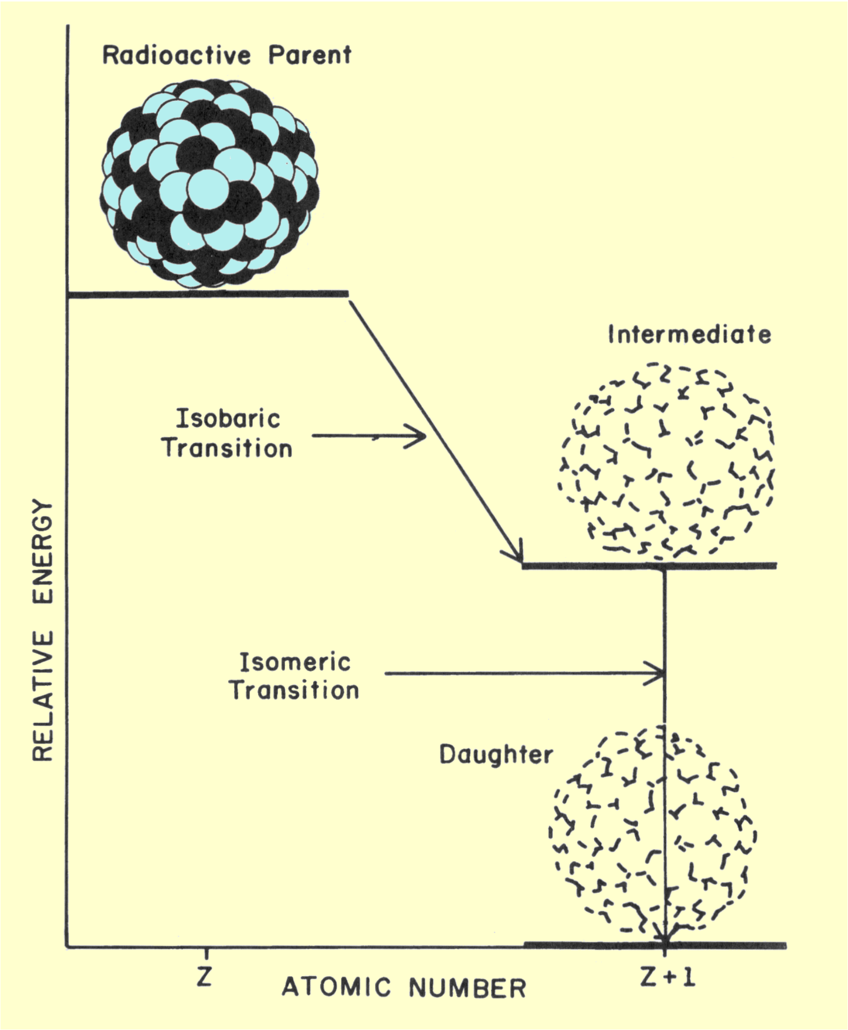
Energy of photon

- **Photons are used to describe the wave-particle duality of light**.
- **The energy of a photon depends upon its frequency**.
- This helps to explain the photoelectric effect; only photons having a sufficiently high energy are capable of dislodging an electron from the illuminated surface.

$$E = h\upsilon$$

- where *E* is the photon energy in J, v is the photon frequency in Hz, and h is Planck's constant, 6.626 x 10^{-34} J/Hz.

ISOMARIC TRANSITIONS

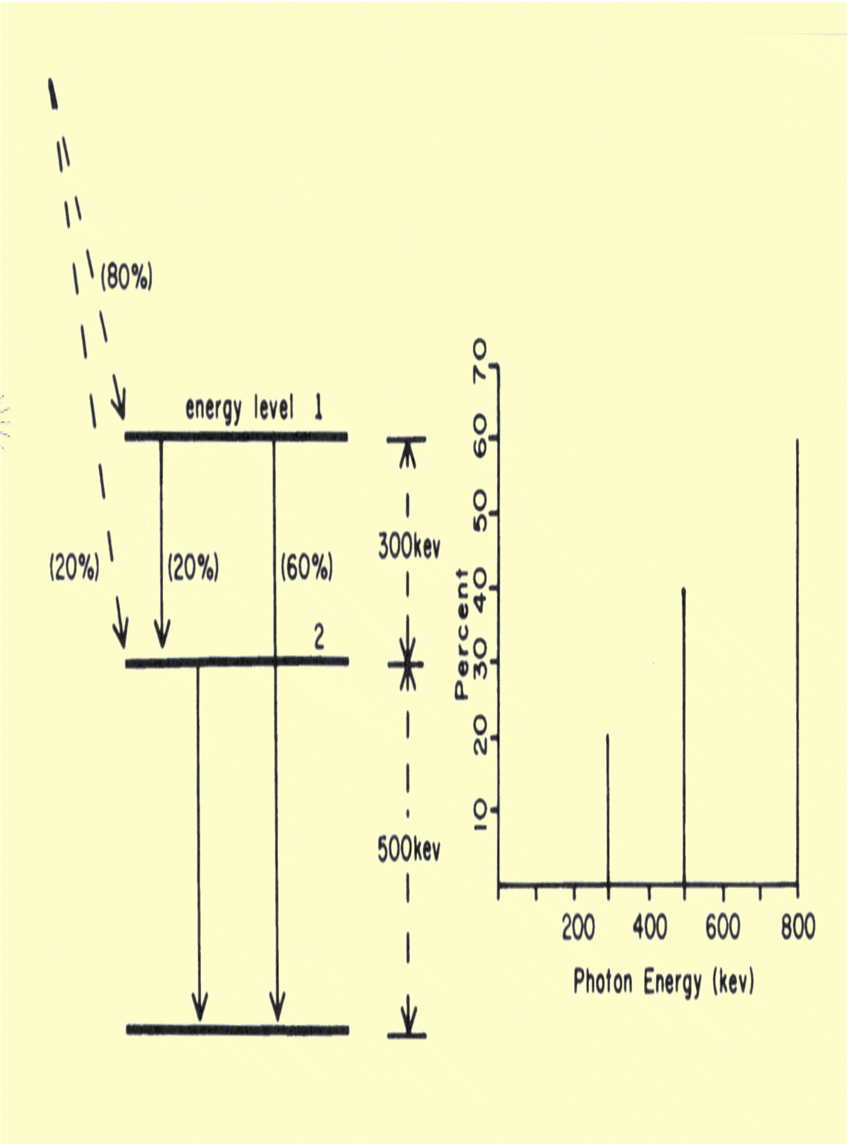


Most radioactive transitions have several steps. For most radionuclides,

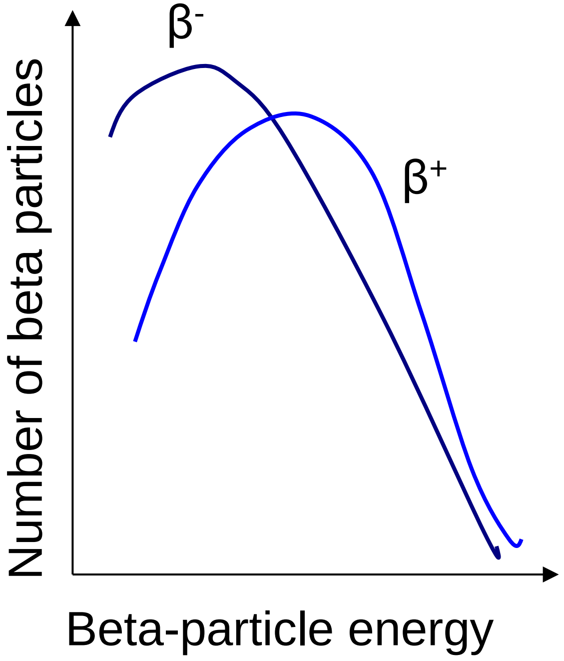
- The first step is an *isobaric* transition usually followed by an *isomeric* transition and interactions with orbiting electrons.
- The three types of isobaric transitions of interest to us are :
- (1) beta emission,
- (2) positron emission,
- (3) electron capture.

Energy of gamma photon

- The energy of a gamma photon is determined by the difference in energy between the intermediate and final states of the nucleus undergoing <u>**isomeric transition**</u>.
- This difference is the same for all nuclei of a specific nuclide.
- However, many nuclides have more than one intermediate state or energy level.
- When this is the case, a radionuclide might emit gamma photons with several different energies.



Gamma Spectrum



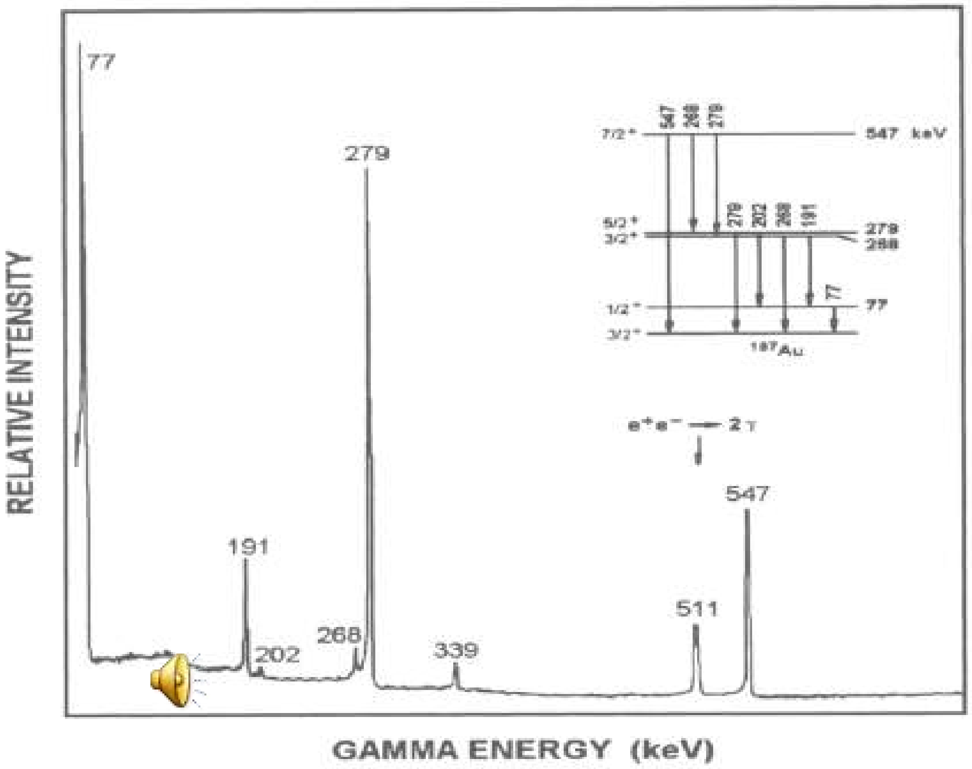


FIG. 4.4. Gamma spectrum and decays scheme for ^{197}Au, produced through Coulomb excitation of gold by a 12 MeV ^{4}He beam. (According to M. G. Bowler.)

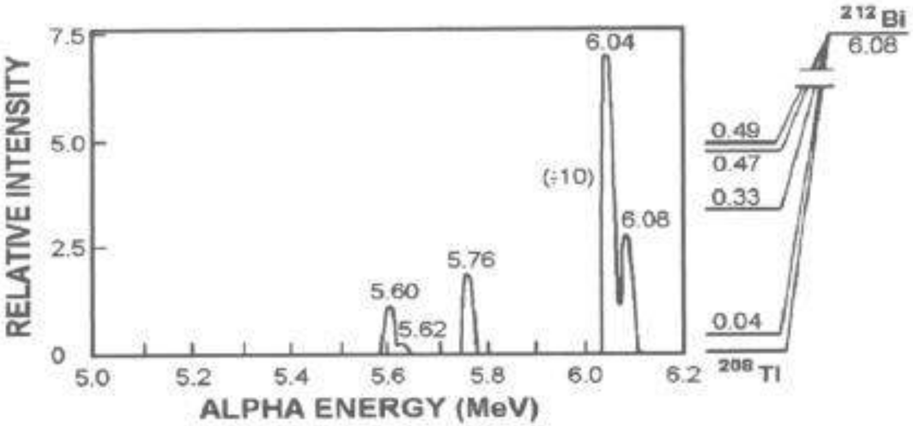


FIG. 4.3. Alpha energy spectrum from ^{212}Bi → ^{208}Tl. (According to E. B. Paul.)

Energy of emission photon

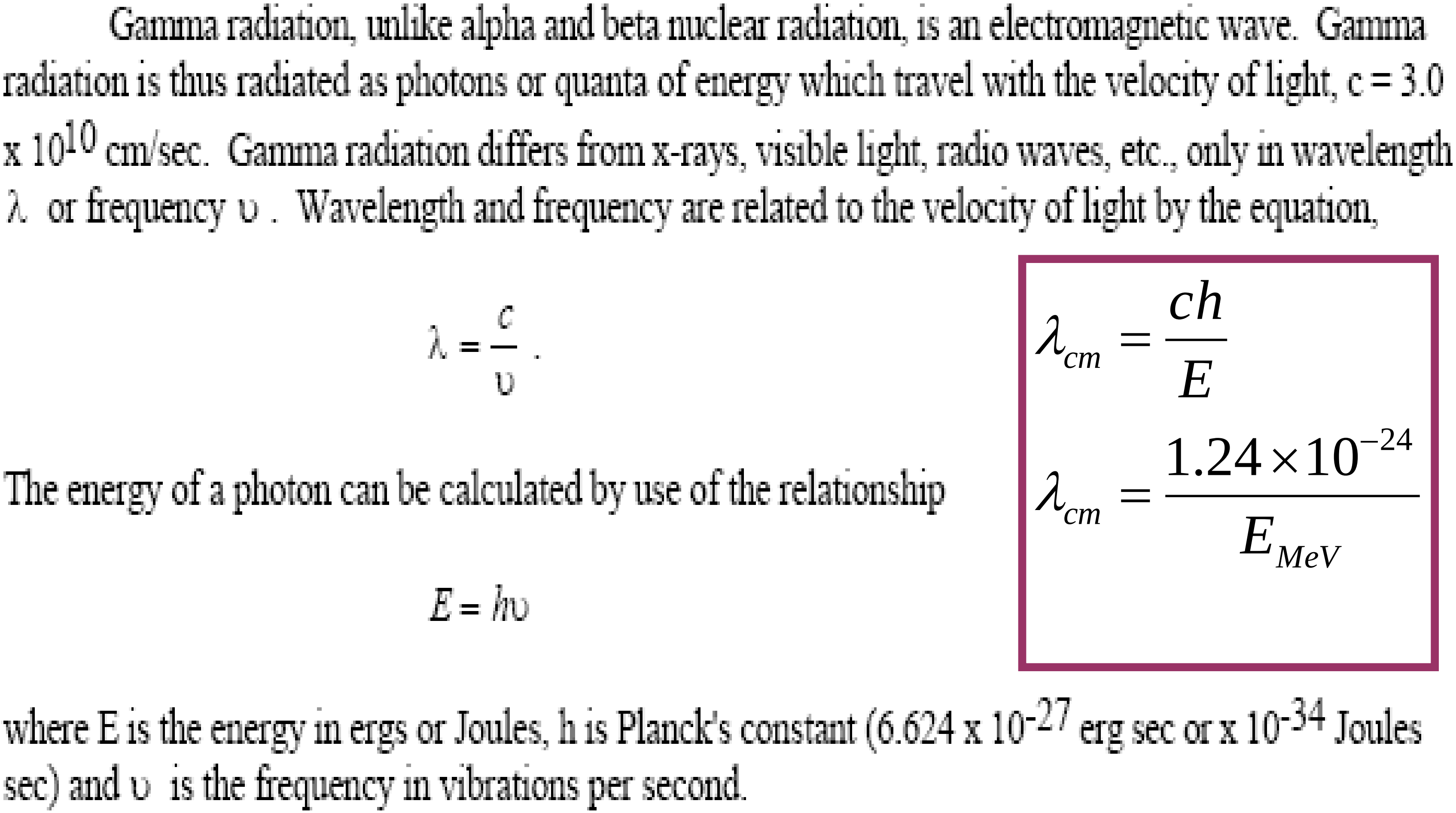
$$E_{photon} = \Delta E = E_{high} - E_{low}$$

$$\Delta E = h\nu = hc/\lambda$$

$$\nu = \Delta E/h$$

ν and λ giving rise to single frequencies and wavelengths

Gamma wavelength



Gamma radiation, unlike alpha and beta nuclear radiation, is an electromagnetic wave. Gamma radiation is thus radiated as photons or quanta of energy which travel with the velocity of light, c = 3.0 x 10^{10} cm/sec. Gamma radiation differs from x-rays, visible light, radio waves, etc., only in wavelength λ or frequency υ. Wavelength and frequency are related to the velocity of light by the equation,

$$\lambda = \frac{c}{\upsilon}\ .$$

The energy of a photon can be calculated by use of the relationship

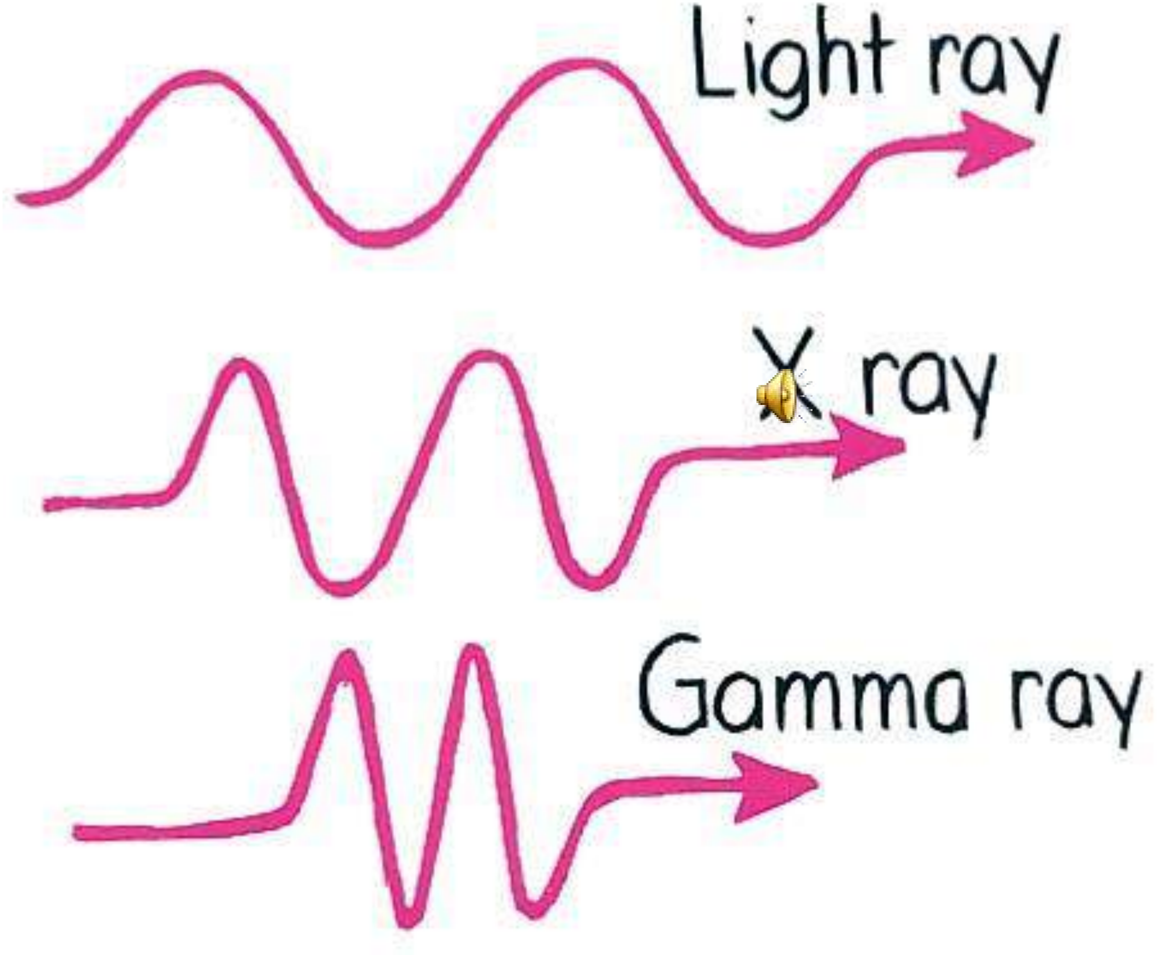
$$E = h\upsilon$$

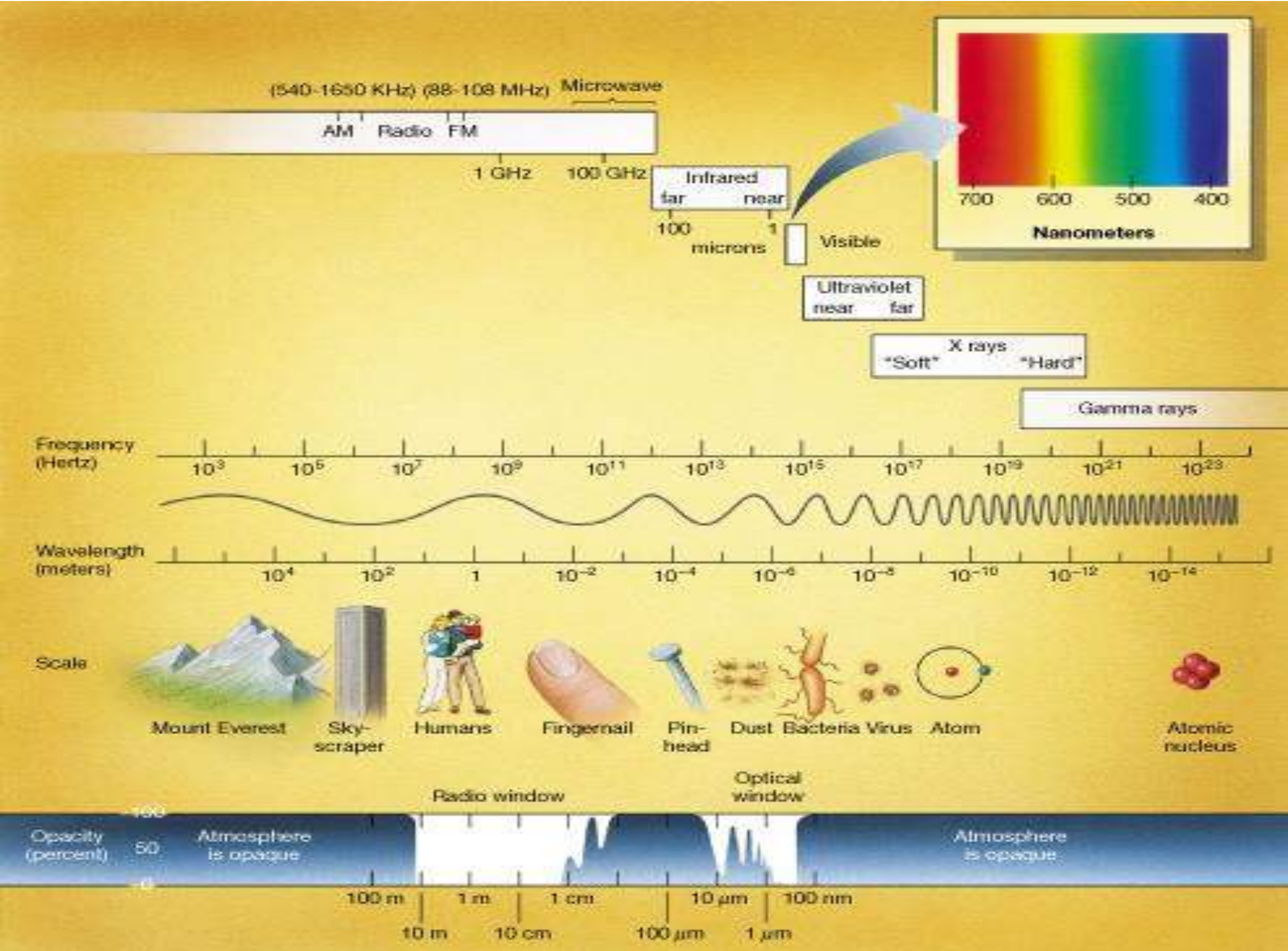
where E is the energy in ergs or Joules, h is Planck's constant (6.624 x 10^{-27} erg sec or x 10^{-34} Joules sec) and υ is the frequency in vibrations per second.

$$\lambda_{cm} = \frac{ch}{E}$$

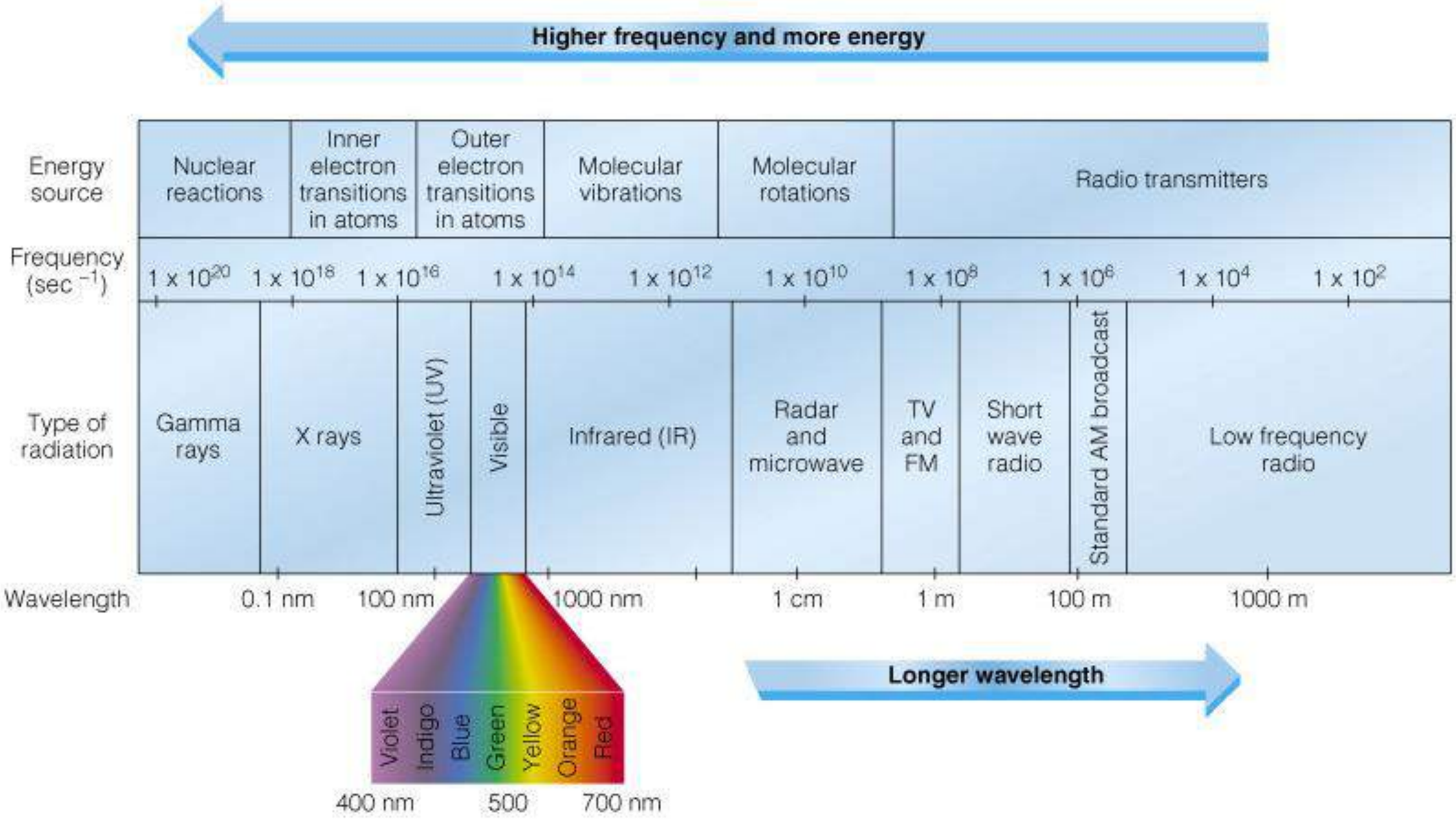
$$\lambda_{cm} = \frac{1.24\times10^{-24}}{E_{MeV}}$$

Which is more penetrating? Why?



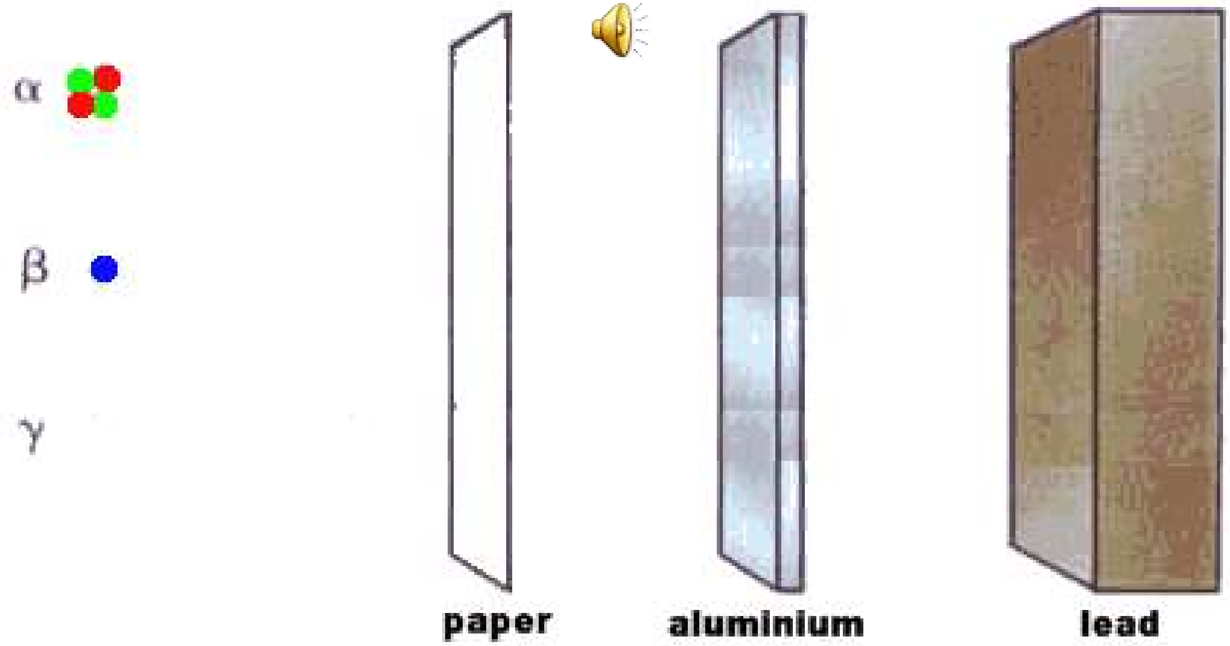

(540-1650 KHz) (88-108 MHz)
Microwave
AM
Radio
FM
1 GHz
100 GHz
Infrared
far
near
100
1
microns
Visible
700
600
500
400
Nanometers
Ultraviolet
near
far
X rays
"Soft"
"Hard"
Gamma rays
Frequency (Hertz)
10^3
10^5
10^7
10^9
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}
10^{21}
10^{23}
Wavelength (meters)
10^4
10^2
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
Scale
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus
Radio window
Optical window
Opacity (percent)
100
50
0
Atmosphere is opaque
Atmosphere is opaque
100 m
10 m
1 m
10 cm
1 cm
100 µm
10 µm
1 µm
100 nm

The Electromagnetic Spectrum



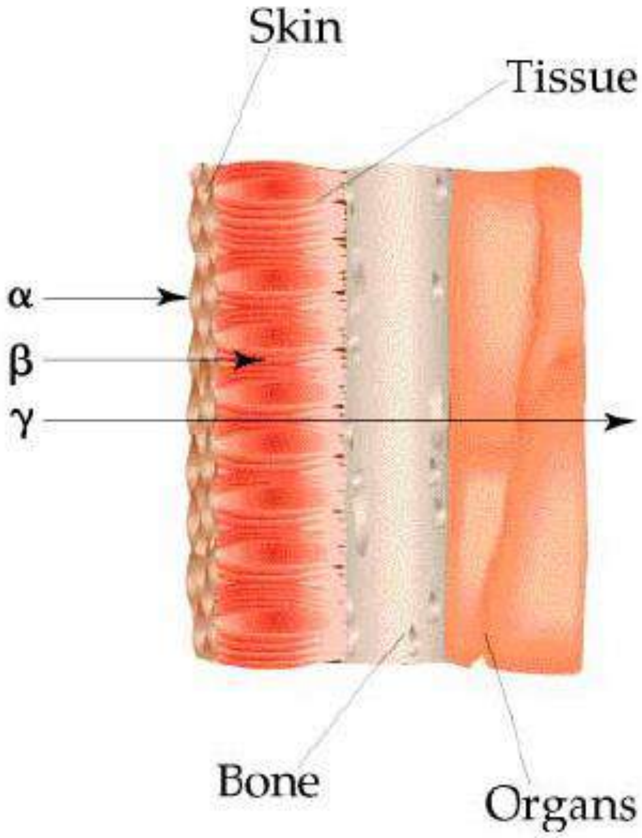
Properties of Gamma Radiation

- Needs a lead block or a thick concrete block to be stopped. (Lead has a high density and it is not radioactive.)



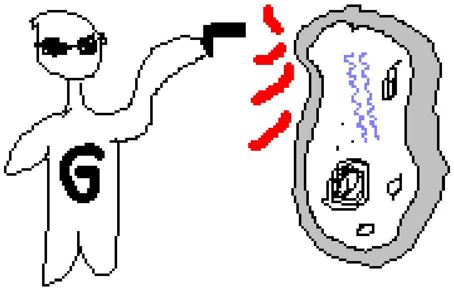
Biological Effects of Radiation 02

- γ*-rays* are particularly harmful because they penetrate in the same way as X rays.
- α*-particles* interact with the skin and β*-particles* interact up to 1 cm into the tissue
- α*-particles* are particularly dangerous when ingested or inhaled.



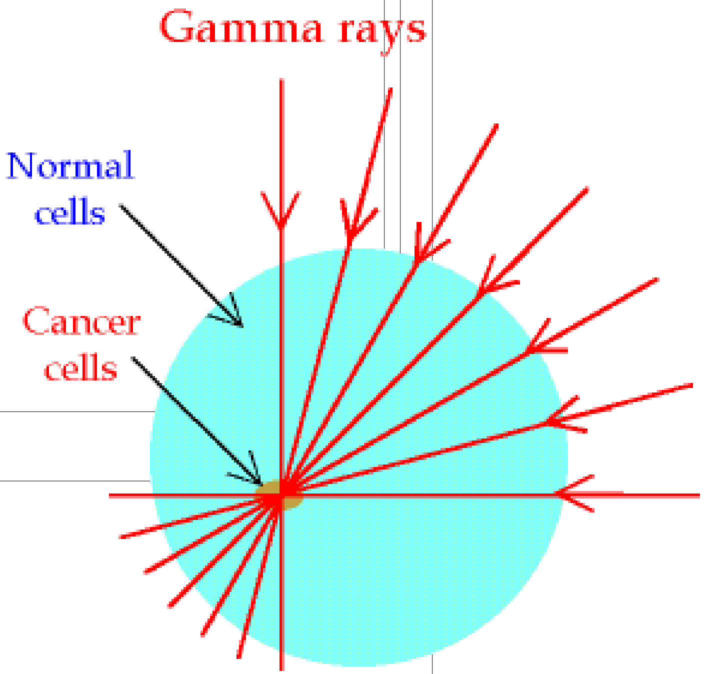
Properties of Gamma Radiation

- Highly concentrated gamma-rays can kill living cells



High-energy radiation kills cells by damaging their DNA, thus blocking their ability to grow and increase in number.

- In cancer treatments, focused gamma rays can be used to eliminate malignant cells, known as radiotherapy



Internal Conversion process

Internal Conversion process

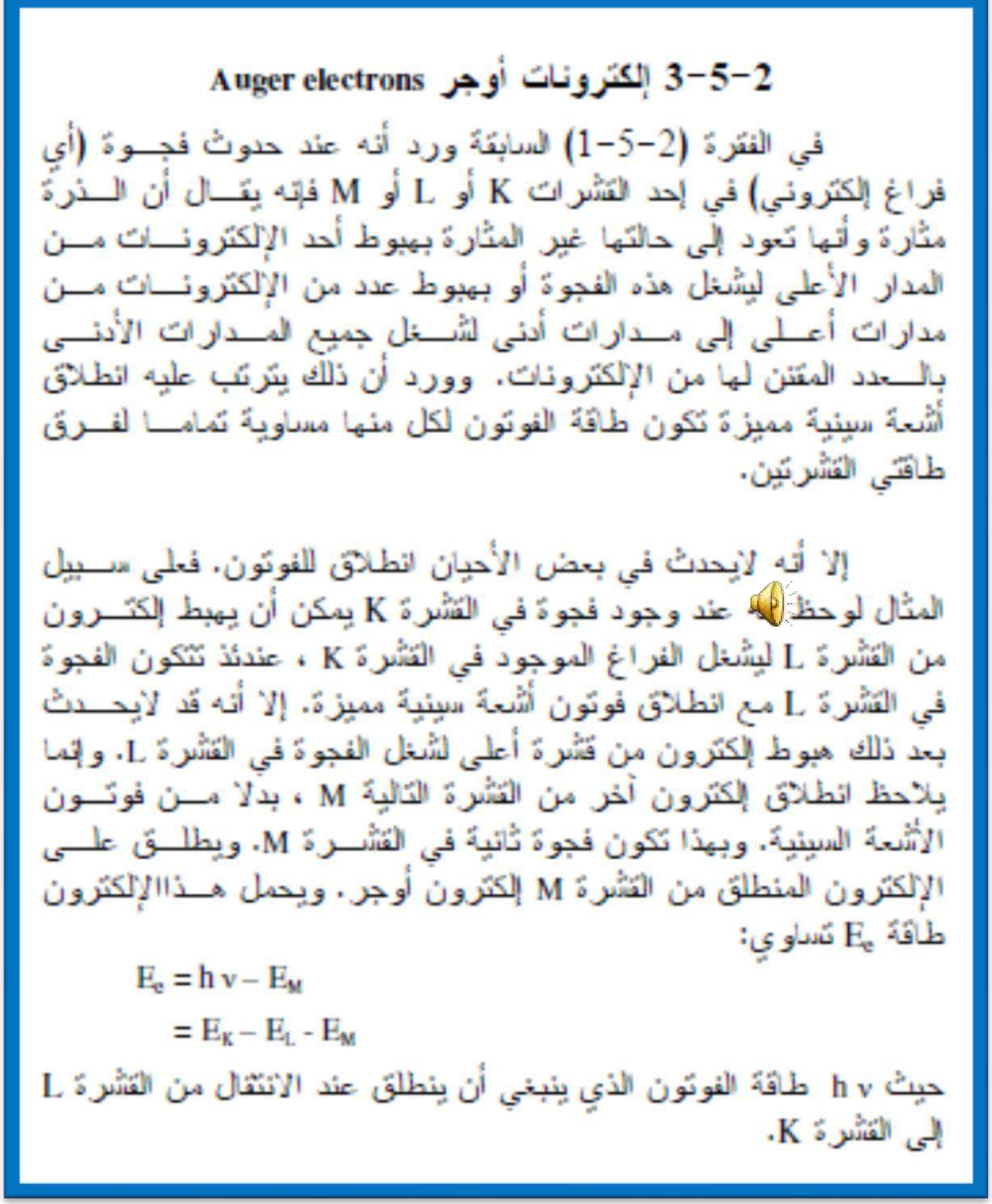
- Under some conditions, the energy from an isomeric transition can be transferred to an electron within the atom.
- This energy supplies the binding energy and expels the electron from the atom. This process is known as internal conversion (IC) and is an alternative to gamma emission.
- In many nuclides, isomeric transitions produce gamma photons and IC electrons.
- When an electron is removed from the atom by internal conversion, a vacancy is created.
- When the vacancy is filled by an electron from a higher energy level, energy must be emitted from the atom as a characteristic x-ray photon or an Auger electron.

Energy of emitted electron: $E_e = E_\gamma - B_e$

where E_γ is excitation energy of nucleus, B_e is binding energy of electron

التحول الداخلي

- في عملية التحول الداخلي تستطيع النواة ان تعطي طاقتها مباشرة الى الكترون مداري ، حيث يتفاعل المجال المغناطيسي للنواة مع الالكترونات الذرية مما ينتج عنه انتقال الطاقة من هذا المجال الى الالكترون المداري .
- وبالتالي تفقد النواة طاقتها التي تعطى الى الالكترون وينتج عن ذلك انطلاق الالكترون (K,L,..) الى الخارج بطاقة حركة T تساوي
- $T_e = E_{exctid} – E_{B.E}$
- حيث
- E_{exc} طاقة اثارة النواة (طاقة اشعاع γ)
- $E_{B.E}$ طاقة ترابط الالكترون في مداره



2-5-3 إلكترونات أوجر Auger electrons

في الفقرة (2-5-1) السابقة ورد أنه عند حدوث فجوة (أي فراغ إلكتروني) في إحد القشرات K أو L أو M فإنه يقال أن الذرة مثارة وأنها تعود إلى حالتها غير المثارة بهبوط أحد الإلكترونات من المدار الأعلى ليشغل هذه الفجوة أو بهبوط عدد من الإلكترونات من مدارات أعلى إلى مدارات أدنى لشغل جميع المدارات الأدنى بالعدد المقتن لها من الإلكترونات. وورد أن ذلك يترتب عليه انطلاق أشعة سينية مميزة تكون طاقة الفوتون لكل منها مساوية تماما لفرق طاقتي القشرتين.

إلا أنه لايحدث في بعض الأحيان انطلاق للفوتون. فعلى سبيل المثال لوحظ عند وجود فجوة في القشرة K يمكن أن يهبط إلكترون من القشرة L ليشغل الفراغ الموجود في القشرة K ، عندئذ تتكون الفجوة في القشرة L مع انطلاق فوتون أشعة سينية مميزة. إلا أنه قد لايحدث بعد ذلك هبوط إلكترون من قشرة أعلى لشغل الفجوة في القشرة L. وإنما يلاحظ انطلاق إلكترون آخر من القشرة التالية M ، بدلا من فوتون الأشعة السينية. وبهذا تكون فجوة ثانية في القشرة M. ويطلق على الإلكترون المنطلق من القشرة M إلكترون أوجر. ويحمل هذاالإلكترون طاقة E_e تساوي:

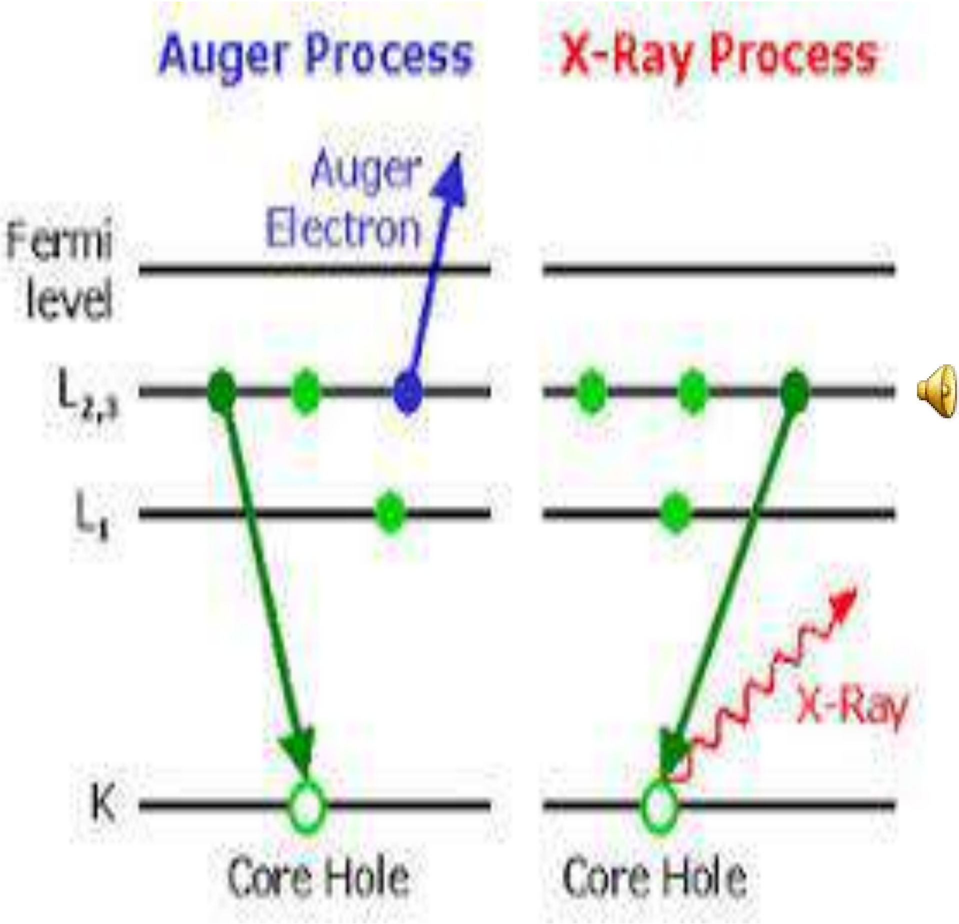
$$E_e = h\nu - E_M$$

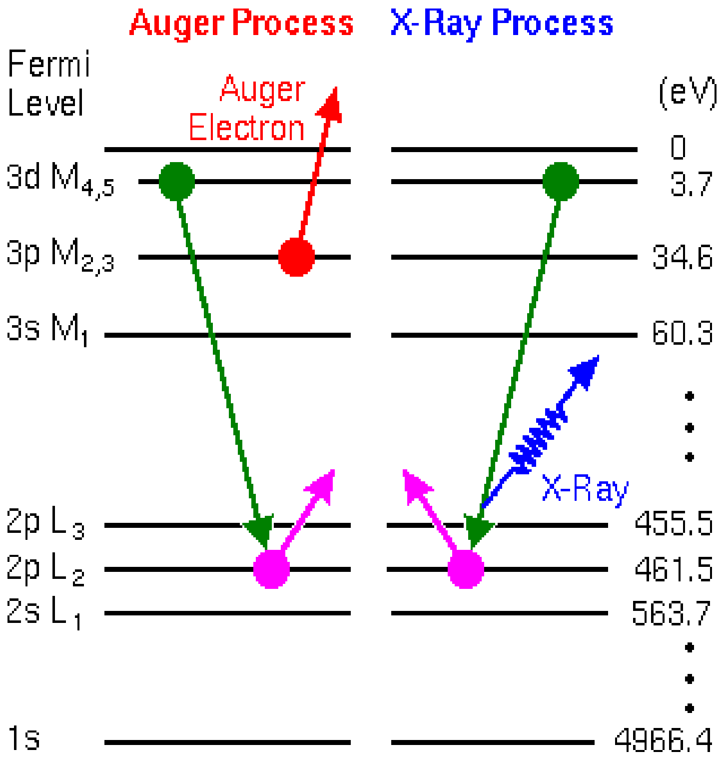
$$= E_K - E_L - E_M$$

حيث $h\nu$ طاقة الفوتون الذي ينبغي أن ينطلق عند الانتقال من القشرة L إلى القشرة K.

- **Auger electrons**, which may also be produced after an internal conversion, arise from

a mechanism that is different from that of internal conversion, but is analogous to it.


Auger Process
X-Ray Process
Auger
Electron
Fermi
level
$L_{2,3}$
L_1
K
X-Ray
Core Hole
Core Hole


Auger Process
X-Ray Process
Fermi
Level
Auger
Electron
(eV)
0
3d $M_{4,5}$
3.7
3p $M_{2,3}$
34.6
3s M_1
60.3
X-Ray
2p L_3
455.5
2p L_2
461.5
2s L_1
563.7
1s
4966.4

The Auger Effect

- The **Auger effect** is a physical phenomenon in which the filling of an inner-shell vacancy of an atom is accompanied by the emission of an electron from the same atom.
- When a core electron is removed, leaving a vacancy, an electron from a higher energy level may fall into the vacancy, resulting in a release of energy.
- Although most often this energy is released in the form of an emitted photon, **the energy can also be transferred to another electron, which is ejected from the atom**; this second ejected electron is called an **Auger electron**

Internal Conversion

- **Internal conversion** is a radioactive decay process where an excited nucleus interacts with an electron in one of the lower atomic orbitals, causing the electron to be emitted (ejected) from the atom.

- Thus, in an internal conversion process, a high-energy electron is emitted from the radioactive atom, **but not from a nucleon in the nucleus.**
- The electron is ejected as a result of an interaction between the entire nucleus and an outside electron that interacts with it.

Comparison between Internal Conversion and Beta Decay

- the high-speed electrons from internal conversion are not beta particles,
- Since no beta decay takes place during internal conversion where, the element atomic number (Z) does not change and no transmutation of one element to another is seen as is the case with gamma decay
- Since an electron is lost, The neutral atom becomes ionized.
- Also, no neutrino is emitted during internal conversion.
- internal converted electrons do not have the characteristic energetically spread spectrum of beta particles but have a well-specified discrete energy and the spectrum of internally converted electrons has a sharp peak.

Internal Conversion

- Internal conversion is favored when the energy gap between nuclear levels is small.

- In the internal conversion process occur when the wavefunction of an inner shell electron penetrates the nucleus.
- Most internal conversion (IC) electrons come from the K shell.
- The internal conversion process competes with gamma decay. This competition is quantified in the form of the **internal conversion coefficient.**

معامل التحول الداخلي

- معامل التحول هو النسبة بين ثابت انحلال التحول الداخلي وثابت انحلال γ

$$\alpha = \frac{\lambda_e}{\lambda}$$

- اي انه النسبة بين معدل انطلاق الكترونات التحول الداخلي (او عددها N_e) ومعدل انطلاق اشعة γ (او عدد الفوتونات N_γ)

-

$$\alpha = \frac{N_e}{N_\gamma}$$

$$\alpha_K = \frac{\lambda_{eK}}{\lambda} = \frac{N_{eK}}{N_\gamma} \qquad \alpha_l = \frac{N_{el}}{N_\gamma} \qquad \alpha_M = \frac{N_{eM}}{N_\gamma}$$

- $\alpha = \alpha_k + \alpha_L + \alpha_M + \ldots\ldots$

- (طاقة اشعة x الصادرة) $h\upsilon_k = I_k - I_L$

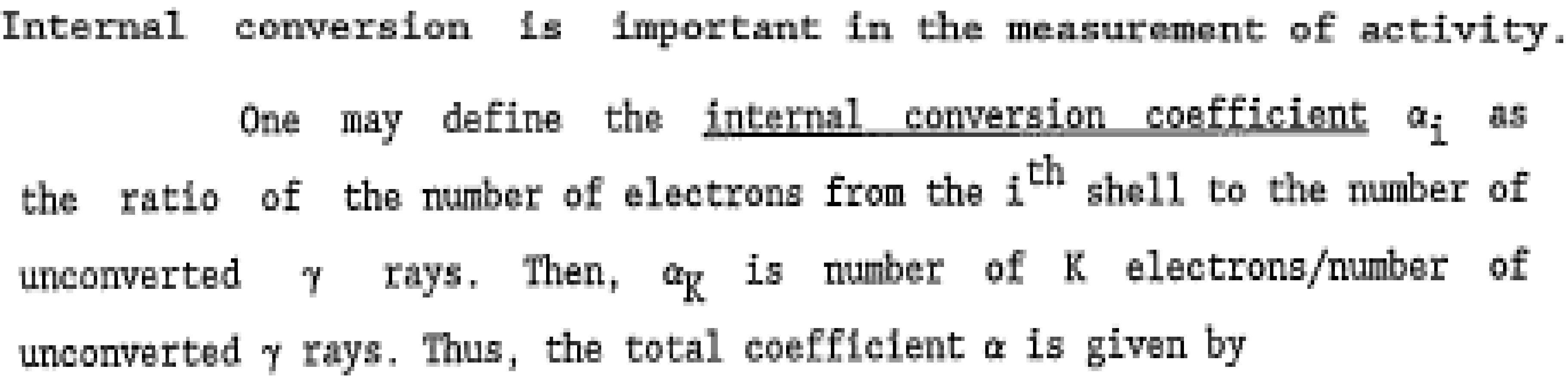
Internal Conversion Coefficient

ويعرف الاحتمال النسبي لحدوث التحول الداخلي من القشرة K على أنه نسبة عدد الإلكترونات المنطلقة من القشرة K إلى عدد فوتونات جاما المنبعثة من نفس العينة من هذه النوى. وعموما، تتغير قيمة معامل التحول الداخلي α_k بين صفر ، 1 وتزيد قيمته عموما بزيادة العدد الذري Z للنواة. وتحدد معاملات التحول الداخلي بالنسبة للقشرات L ، M بنفس الأسلوب إلا أن هذه المعاملات تقل كثيرا بالنسبة لمعاملات القشرة K .

$$\alpha = \frac{\lambda_e}{\lambda} \qquad \alpha = \frac{N_e}{N_\gamma}$$

$$\alpha = \alpha_K + \alpha_L + \alpha_M + \alpha_N + \ldots$$

Internal Conversion Coefficient

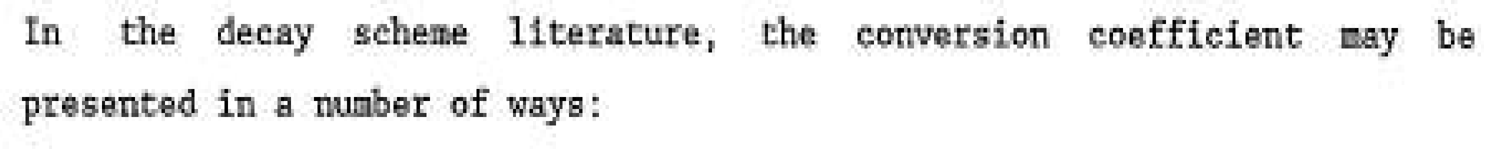


Internal conversion is important in the measurement of activity.

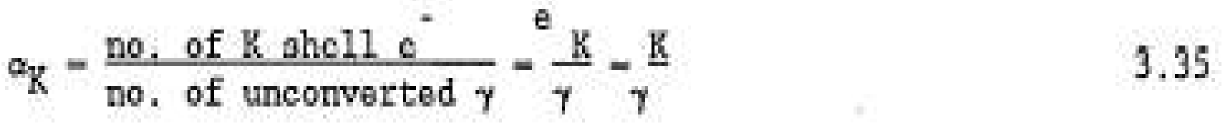
One may define the internal conversion coefficient α_i as the ratio of the number of electrons from the i^{th} shell to the number of unconverted γ rays. Then, α_K is number of K electrons/number of unconverted γ rays. Thus, the total coefficient α is given by

The conversion coefficients α are introduced: $\alpha = N_e/N_\gamma$

$\alpha = \alpha_K + \alpha_L + \alpha_M + \alpha_N + \ldots$



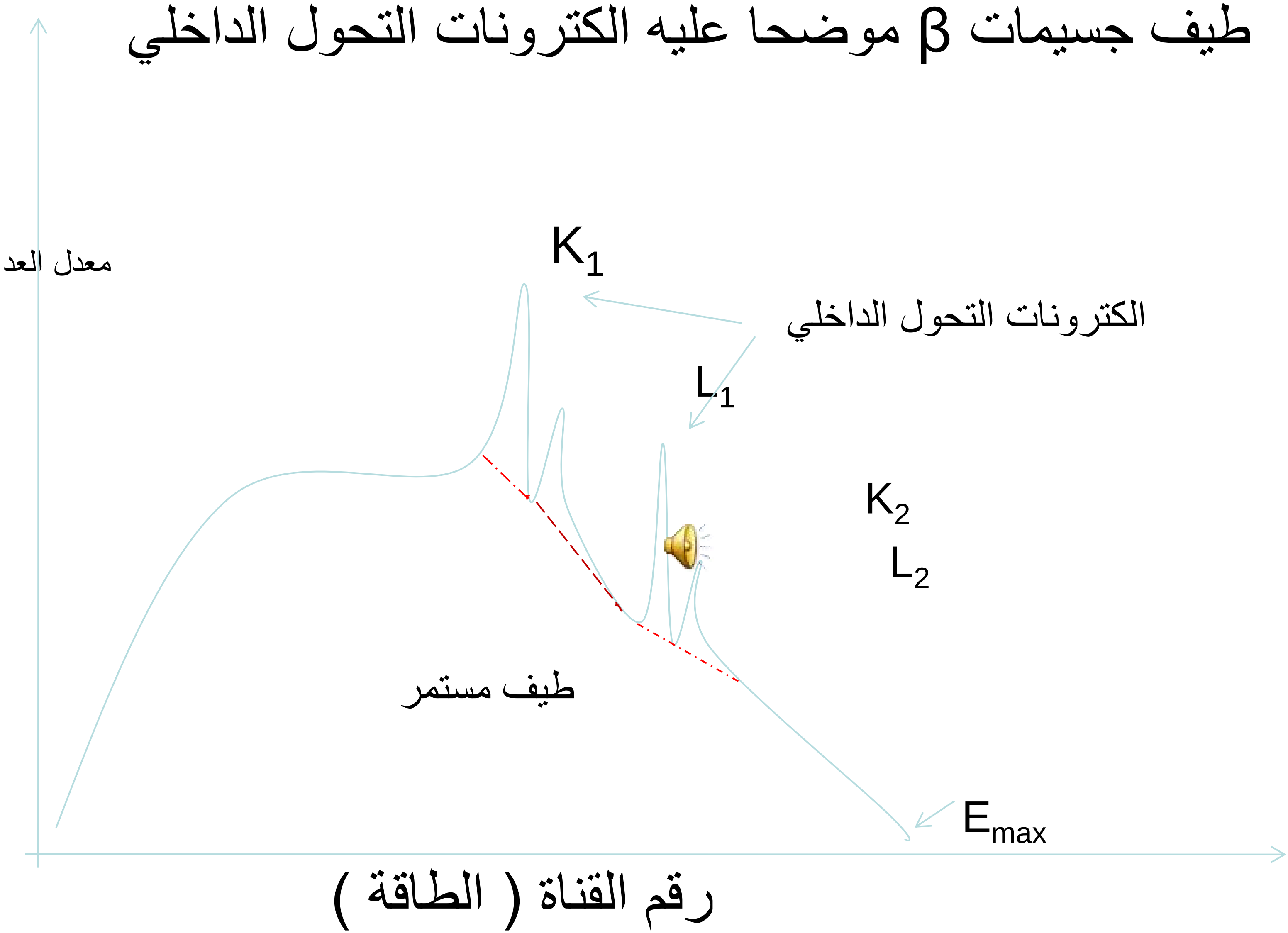
In the decay scheme literature, the conversion coefficient may be presented in a number of ways:



$$\alpha_K = \frac{\text{no. of K shell } e^-}{\text{no. of unconverted } \gamma} = \frac{e_K}{\gamma} = \frac{K}{\gamma} \qquad 3.35$$

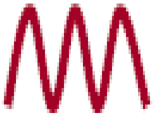
The conversion coefficients decrease with E_γ and increase with Z of nucleus.

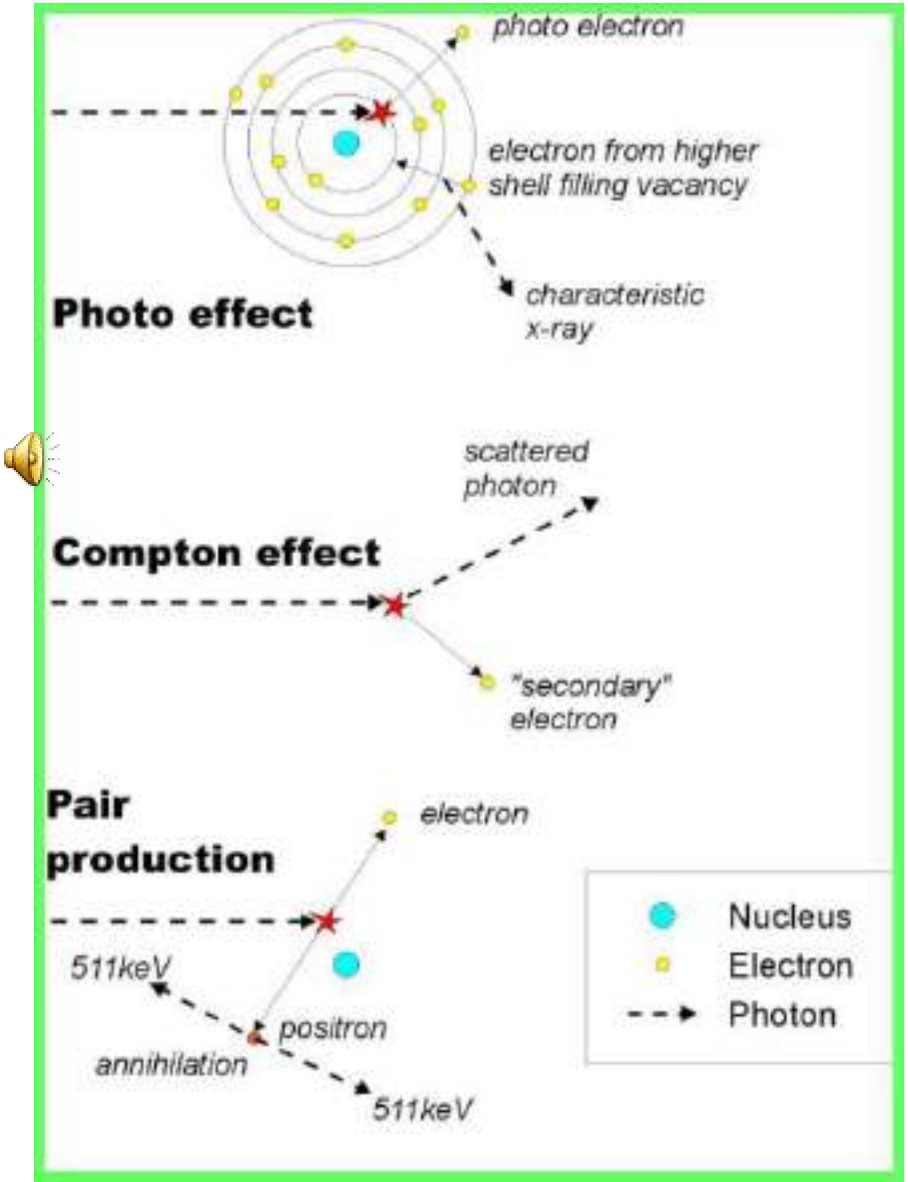
طيف جسيمات β موضحا عليه الكترونات التحول الداخلي



Interactions of γ and Matter

- Photoelectric
- Compton
- Pair Production





Interaction of Gamma rays with matter

When a photon interacts with matter, the collision may occur with a nucleus, an electron or with the field about the nucleus. This collision may be elastic, inelastic or may result in the complete

The Photoelectric effect occurs principally when the photon energy is low. The inelastic collision of the photon with the orbital electron results in the complete ejection of the electron and the production of an ion pair. The kinetic energy of the ejected electron is given by the equation,

$$1/2mv^2 = h\upsilon - \Phi$$

where Φ is the work function or binding energy of the electron. This means that the total energy imparted to the electron by the photon is equal to that required to remove it an infinite distance from the nucleus Φ plus the kinetic energy of the electron $1/2mv^2$. In this process, a K-electron is usually involved. The photoelectric effect is most pronounced if the atomic number Z of the absorbing material is high. (See Fig. 5).

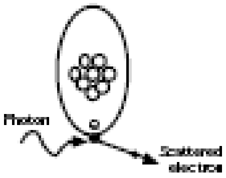
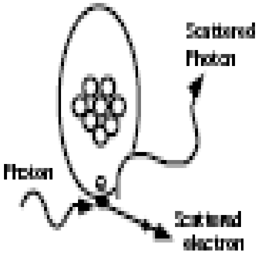


Figure 5 - Photoelectric effect

The Compton effect or Compton scattering is especially important for gamma rays of medium energy (0.5 to 1.0 MeV). It involves a collision between a photon and an electron in which a part of the energy of the photon is imparted to the electron. The photon emerges from the collision in a new direction and with reduced energy. Considering that both energy and momentum must be conserved in the collision, we can derive the following relationship:

$$\lambda' - \lambda = \frac{h}{mc}(1 - \cos(\Phi))$$

Thus, the change in wavelength of the photon is related to the cosine of the scattering angle Φ The term h/mc is called the Compton wavelength λ_0 and has the value 2.43 x 10^{-10} cm. (See Fig. 6).



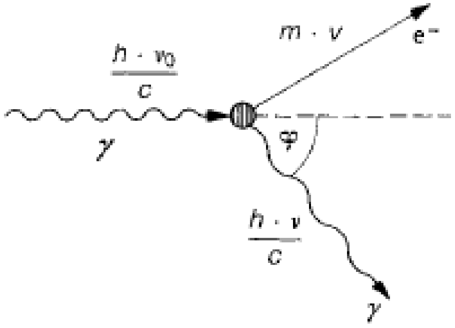
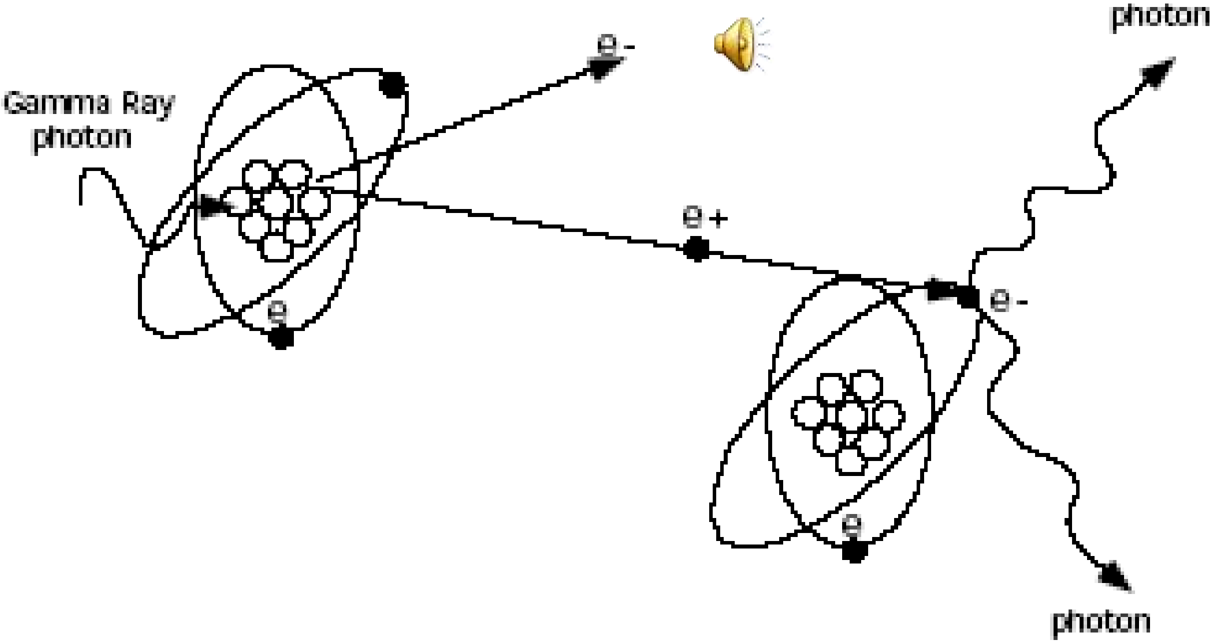


Figure 6 - Compton Scattering

Pair production is involved only with gamma rays having energies greater than 1.02 MeV. The energy of the gamma ray is converted into an electron and a positron in the region of a strong electromagnetic field such as that surrounding the nucleus. Photon energy in excess of 1.02 MeV appears as the kinetic energies of the electron and positron produced.

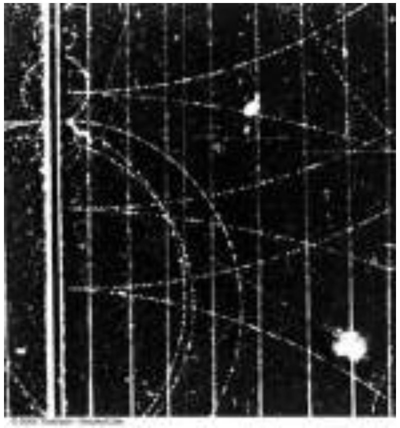
$$E = h\upsilon = 2mc^2 + T_{e^-} + T_{e^+}$$

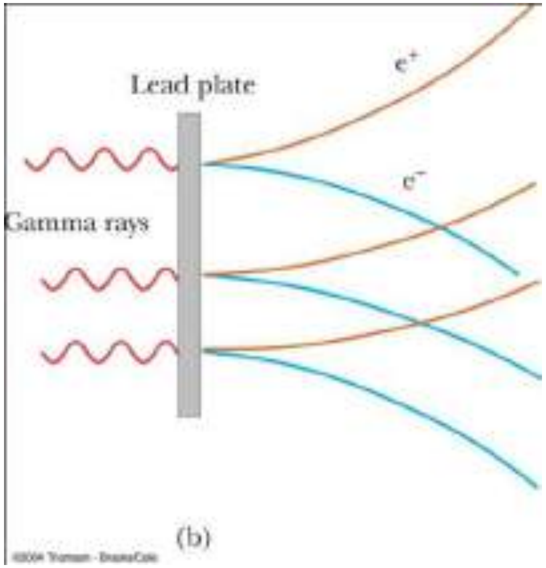
where 2 mc^2 = 1.02 MeV and represents the energy required to form the pair of particles according to the Einstein equation, E = mc^2. Te- and Te+ are the kinetic energies of the electron and positron, respectively. (See Fig. 7).



PAIR PRODUCTION.

Pair Production, cont





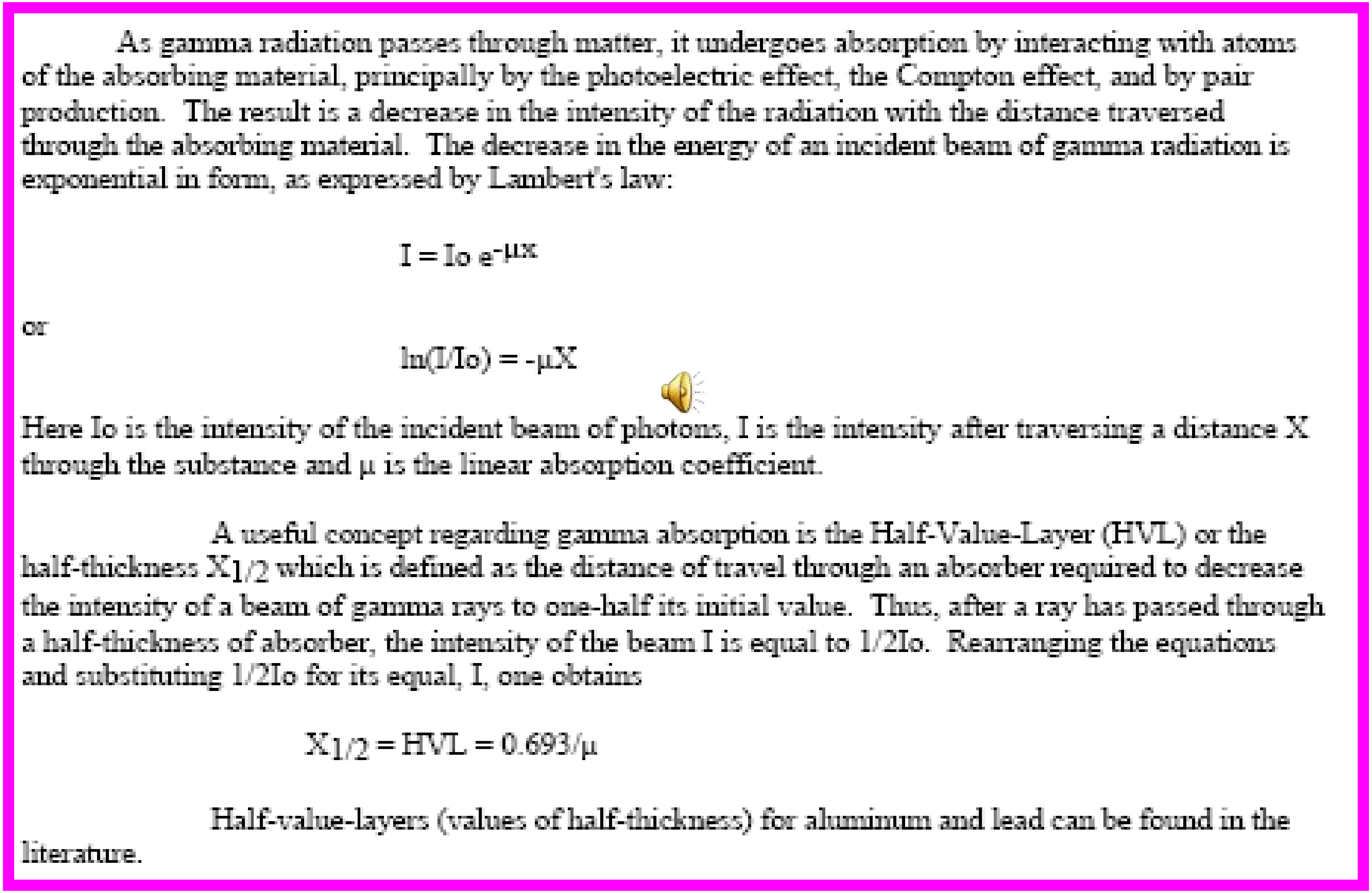
- A photograph of pair production produced by 300 MeV gamma rays striking a lead sheet
- The minimum energy to create the pair is 1.022 MeV
- The excess energy appears as kinetic energy of the two particles

Annihilation

- The reverse of pair production can also occur
- Under the proper conditions, an electron and a positron can annihilate each other to produce two gamma ray photons

$$e^- + e^+ \rightarrow 2\gamma$$

Intensity of Gamma



As gamma radiation passes through matter, it undergoes absorption by interacting with atoms of the absorbing material, principally by the photoelectric effect, the Compton effect, and by pair production. The result is a decrease in the intensity of the radiation with the distance traversed through the absorbing material. The decrease in the energy of an incident beam of gamma radiation is exponential in form, as expressed by Lambert's law:

$$I = Io\ e^{-\mu x}$$

or

$$\ln(I/Io) = -\mu X$$

Here Io is the intensity of the incident beam of photons, I is the intensity after traversing a distance X through the substance and μ is the linear absorption coefficient.

A useful concept regarding gamma absorption is the Half-Value-Layer (HVL) or the half-thickness $X_{1/2}$ which is defined as the distance of travel through an absorber required to decrease the intensity of a beam of gamma rays to one-half its initial value. Thus, after a ray has passed through a half-thickness of absorber, the intensity of the beam I is equal to 1/2Io. Rearranging the equations and substituting 1/2Io for its equal, I, one obtains

$$X_{1/2} = HVL = 0.693/\mu$$

Half-value-layers (values of half-thickness) for aluminum and lead can be found in the literature.

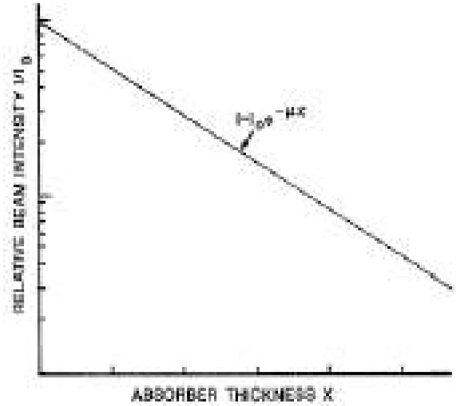
The linear absorption coefficient (μ)

The linear absorption coefficient μ, the value of which depends upon the nature of the absorbing material, has the units cm^{-1}. The mass absorption coefficient μ' is defined as μ/ρ and has the units cm^2/g, where ρ is the density of absorbing material. If ln(I) is plotted versus absorber thickness in centimeters, the slope of the curve gives -μ, the linear absorption coefficient. If ln(I) is plotted versus absorber thickness in grams per square centimeter (g/cm^2), the slope is equal to -μ/ρ, the mass absorption coefficient.

It has been shown that when the log of the intensity is plotted versus the absorber thickness, an essentially straight line is obtained, indicating a linear relationship and the constancy of the coefficient. That this should be so seems somewhat miraculous in view of the fact that μ is the sum of no less than three other coefficients showing dependency on the gamma ray energy; namely, the atomic number, the mass the density of the absorbing medium, as well as other factors. Thus,

$$\mu = \tau + \sigma + \kappa$$

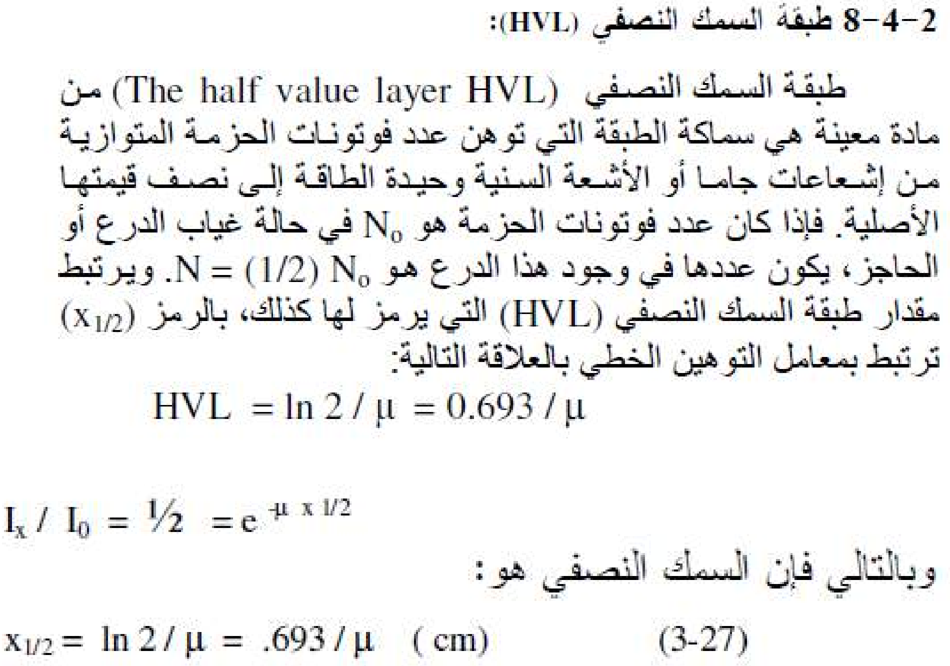
where τ = photoelectric absorption coefficient,
σ = Compton scattering coefficient,
and κ = pair production coefficient



gure 3.16 Absorption of X and γ rays. (R.E.Lapp / H.L.Andrews, NUCLEAR RADIATION PHYSICS, 2/e, 1964, p.109. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ)

Half Value Layer (HVL)

وفي بعض الأحيان يستخدم اصطلاح السمك النصفي من المـــادة $x_{1/2}$ (half-thickness) أو HVL (half-value layer) وهو عبارة عن سمك المادة المعينة اللازم لخفض شدة الإشعاعات إلى النصف، أي أن:



2-4-8 طبقة السمك النصفي (HVL):

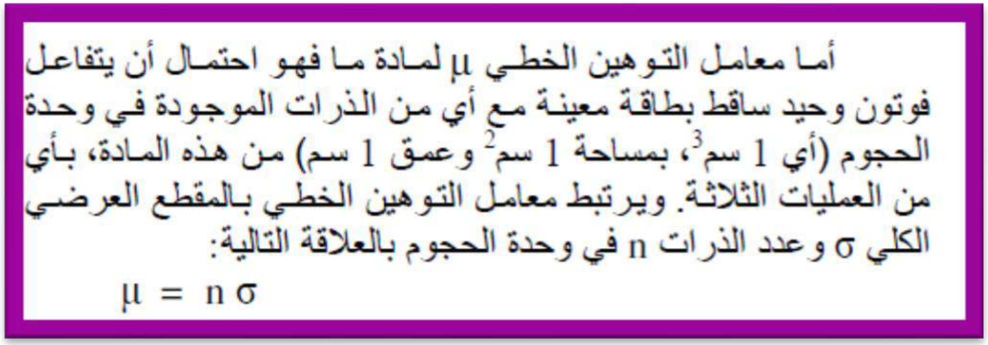
طبقة السمك النصفي (The half value layer HVL) من مادة معينة هي سماكة الطبقة التي توهن عدد فوتونات الحزمة المتوازية من إشعاعات جاما أو الأشعة السينية وحيدة الطاقة إلى نصف قيمتها الأصلية. فإذا كان عدد فوتونات الحزمة هو N_o في حالة غياب الدرع أو الحاجز، يكون عددها في وجود هذا الدرع هو $N = (1/2)\ N_o$. ويرتبط مقدار طبقة السمك النصفي (HVL) التي يرمز لها كذلك، بالرمز ($x_{1/2}$) ترتبط بمعامل التوهين الخطي بالعلاقة التالية:

$$HVL = \ln 2 / \mu = 0.693 / \mu$$

$$I_x / I_0 = ½ = e^{-\mu\ x\ 1/2}$$

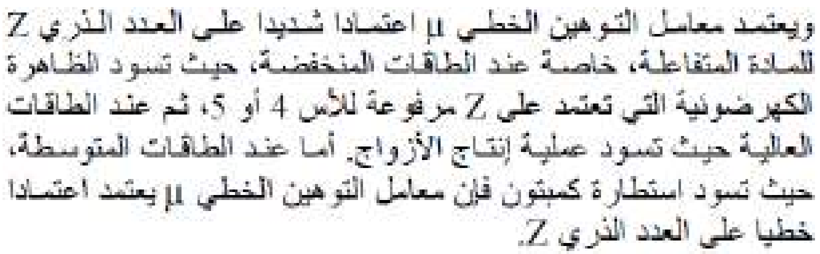
وبالتالي فإن السمك النصفي هو :

$$x_{1/2} = \ln 2 / \mu = .693 / \mu \quad (cm) \qquad (3\text{-}27)$$

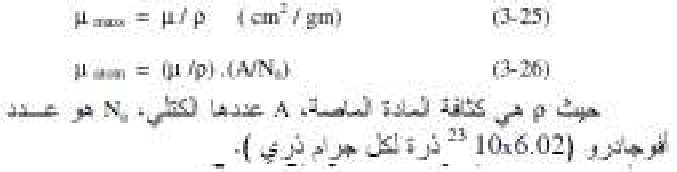


أما معامل التوهين الخطي μ لمادة ما فهو احتمال أن يتفاعل فوتون وحيد ساقط بطاقة معينة مع أي من الذرات الموجودة في وحدة الحجوم (أي 1 سم³، بمساحة 1 سم² وعمق 1 سم) من هذه المادة، بأي من العمليات الثلاثة. ويرتبط معامل التوهين الخطي بالمقطع العرضي الكلي σ وعدد الذرات n في وحدة الحجوم بالعلاقة التالية:

$$\mu = n\ \sigma$$



ويعتمد معامل التوهين الخطي μ اعتمادا شديدا على العدد الذري Z للمادة المتفاعلة، خاصة عند الطاقات المنخفضة، حيث تسود الظاهرة الكهرضوئية التي تعتمد على Z مرفوعة للأس 4 أو 5، ثم عند الطاقات العالية حيث تسود عملية إنتاج الأزواج. أما عند الطاقات المتوسطة، حيث تسود استطارة كمبتون فإن معامل التوهين الخطي μ يعتمد اعتمادا خطيا على العدد الذري Z.



$$\mu_{mass} = \mu / \rho \quad (cm^2 / gm) \qquad (3\text{-}25)$$

$$\mu_{atom} = (\mu / \rho) . (A/N_o) \qquad (3\text{-}26)$$

حيث ρ هي كثافة المادة الماصة، A عددها الكتلي، N_o هو عـــدد أفوجادرو ($10x6.02^{23}$ ذرة لكل جرام ذري).

2-4-9 طبقة السمك العشري (TVL):

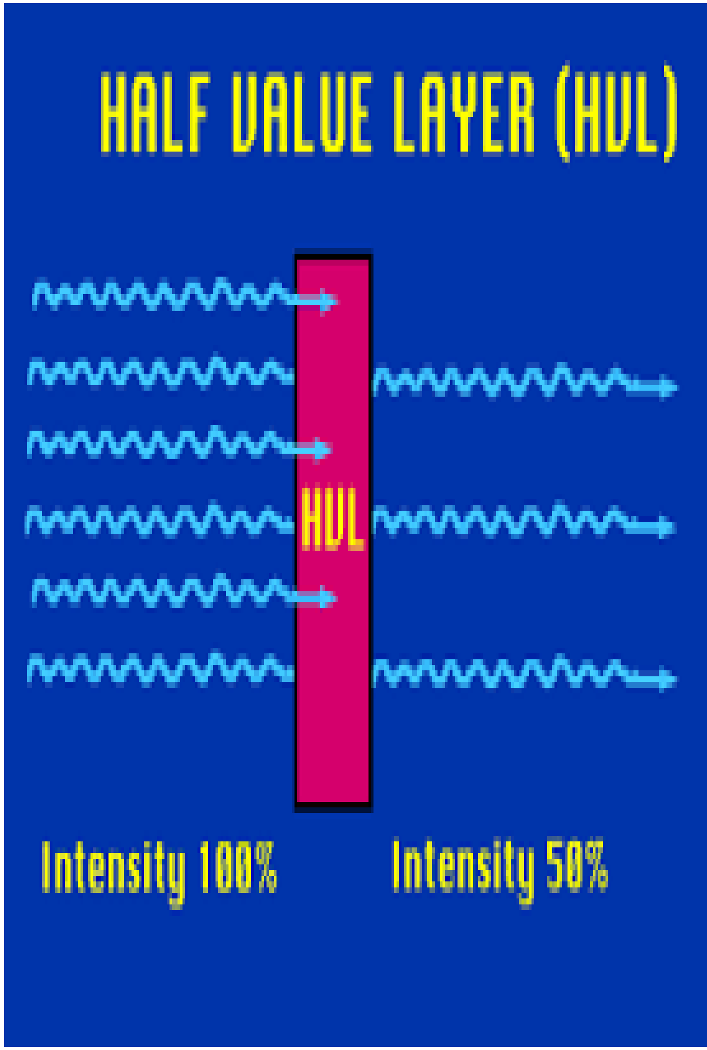
طبقة السمك العشري (Tenth value layer TVL) من مادة ما هي سمك الطبقة التي توهن عدد فوتونات الحزمة المتوازية من الأشعة إلى جزء من عشرة أجزاء من قيمتها الأصلية، أي أن: $N = (1/10)\ N_o$. ويرتبط مقدار طبقة السمك العشري (TVL) بطبقة السمك النصفي (HVL) بالعلاقة:

$$TVL = 3.32\ HVL$$

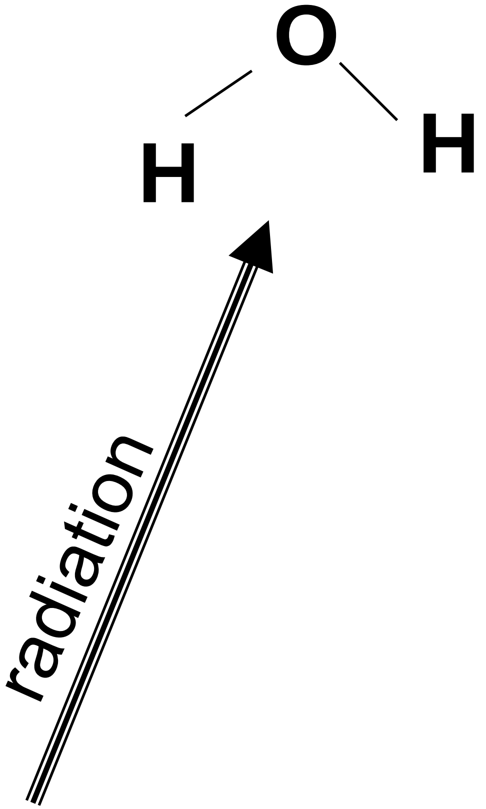
Half Value Layer (HVL)

- A material's **half-value layer (HVL)**, or **half-value thickness**,

- is the thickness of the material at which the intensity of radiation entering it is reduced by one half



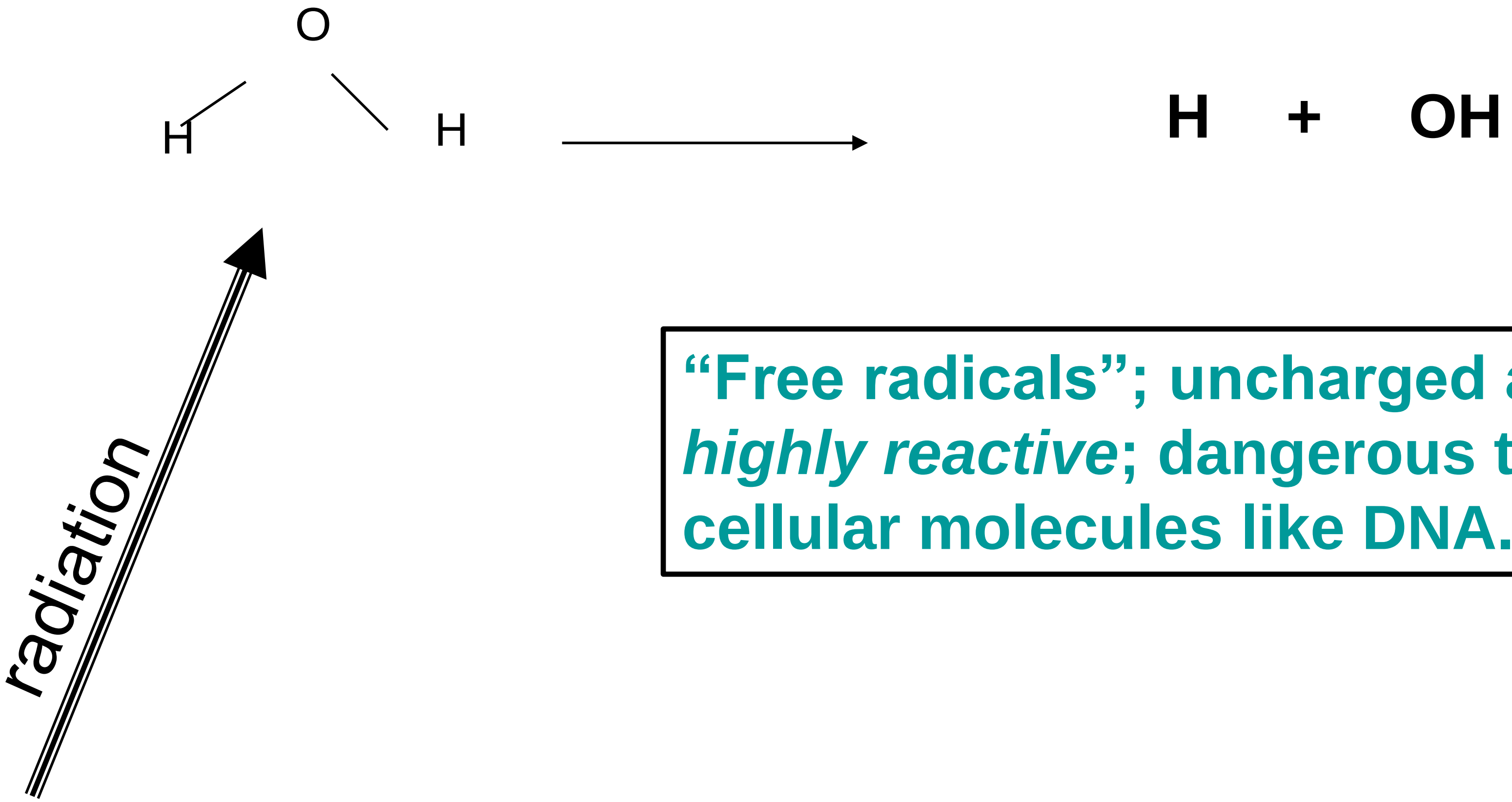
Radiation’s Effect on H_2O



$$\longrightarrow \quad H^+ \quad + \quad OH^-$$

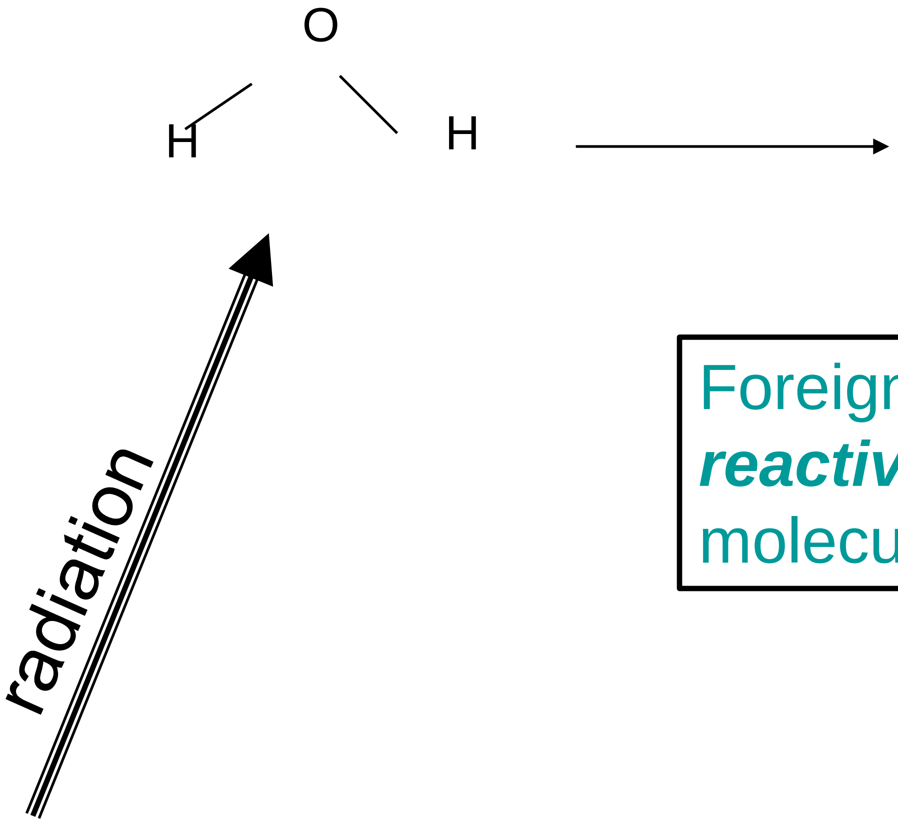
Ordinary ions; present in all cells. Radiation has been safely absorbed.

Radiation’s Effect on H_2O



“Free radicals”; uncharged and *highly reactive*; dangerous to cellular molecules like DNA.

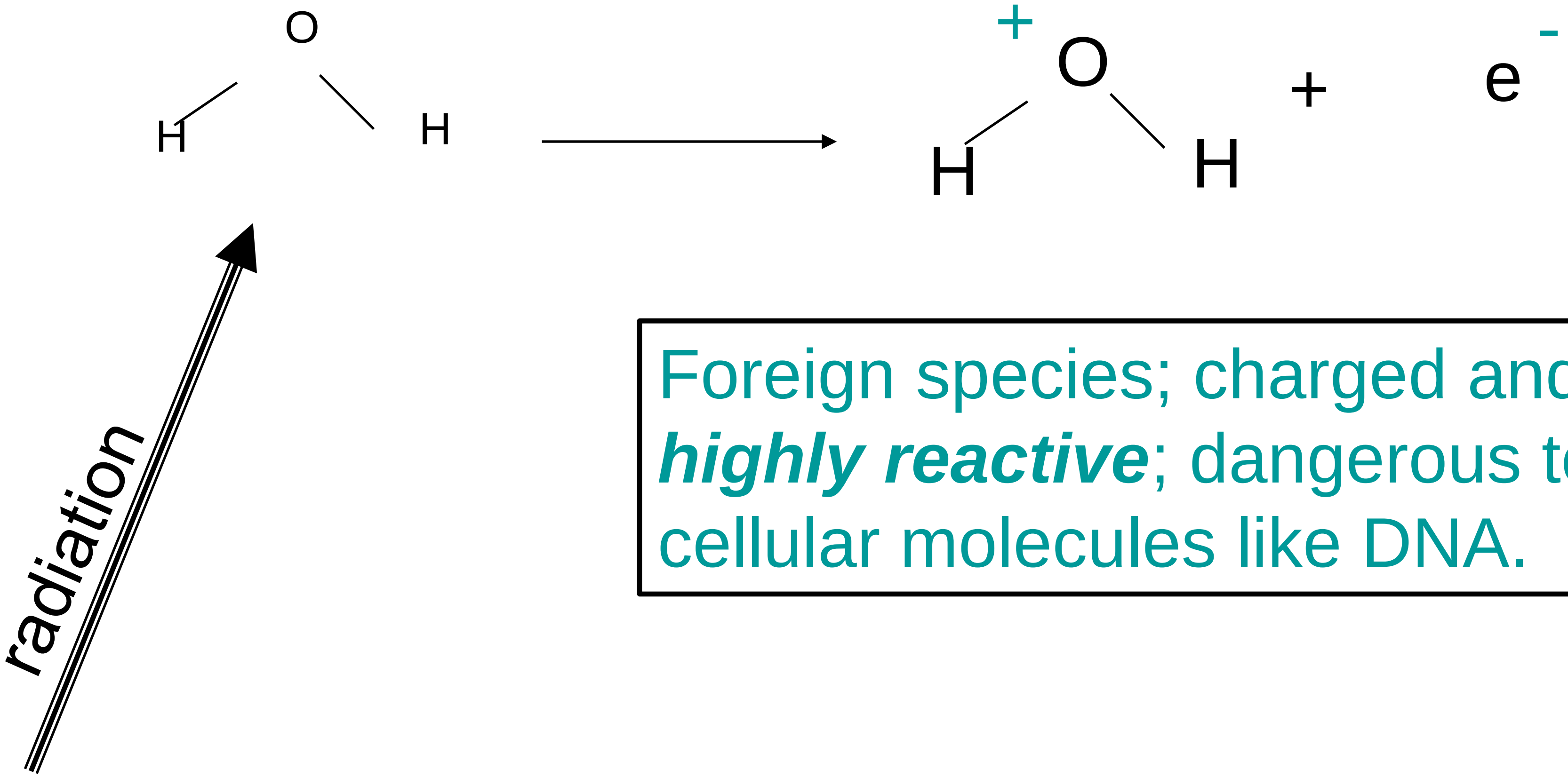
Radiation’s Effect on H_2O



$H^- + OH^+$

Foreign ions; charged and ***highly reactive***; dangerous to cellular molecules like DNA.

Radiation’s Effect on H_2O



Foreign species; charged and ***highly reactive***; dangerous to cellular molecules like DNA.

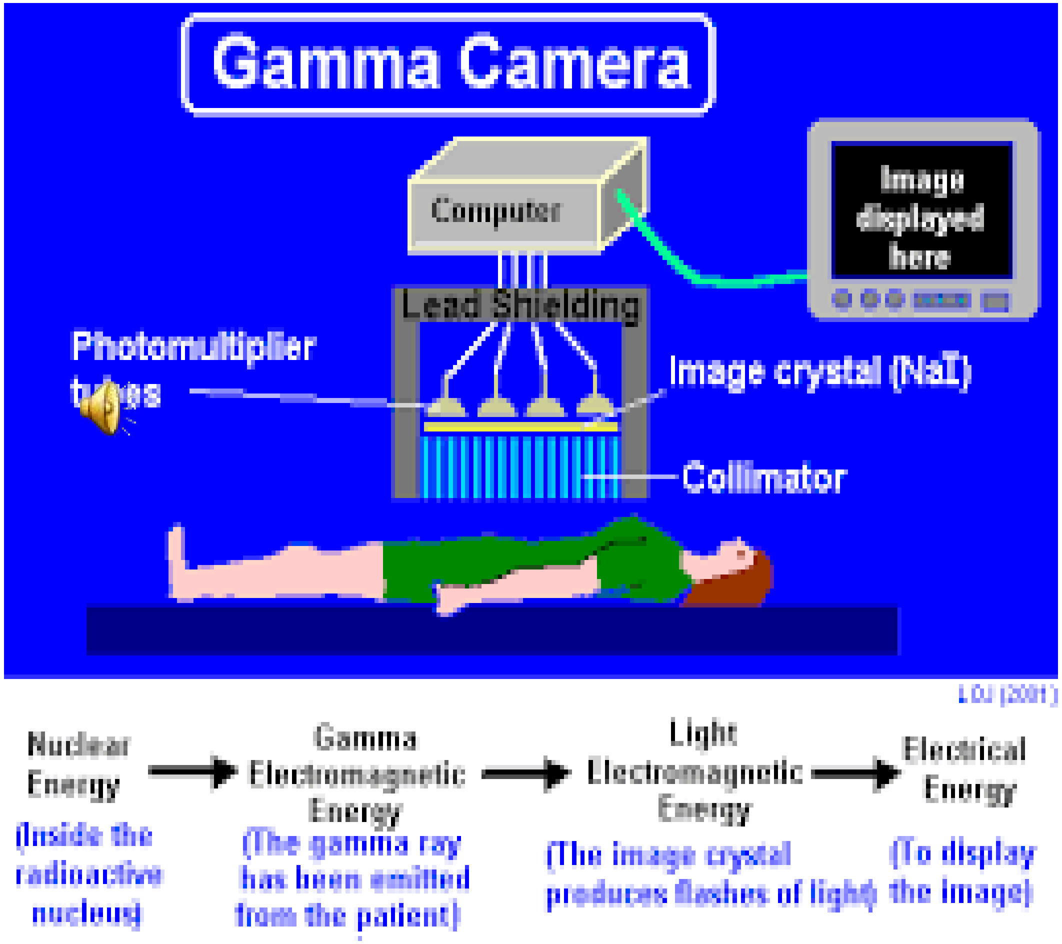
Application of Gamma Rays

- Gamma radiation is often used to kill living organisms, in a process called irradiation.
- gamma rays are also used to treat some types of cancer, since the rays kill cancer cells .
- Gamma rays are also used for diagnostic purposes in nuclear medicine in imaging techniques.
- sources of gamma are used in non-contact industrial sensors used in the Refining, Mining, Chemical, Food, Soaps and Detergents, and Pulp and Paper industries, in applications for measuring levels, density, and thicknesses commonly Typically these use Co-60 or Cs-137 isotopes as the radiation source.
- Gamma rays provide information about some of the most energetic phenomena in the universe such as the Fermi Gamma-ray Space Telescope provide our only view of the universe in gamma rays.

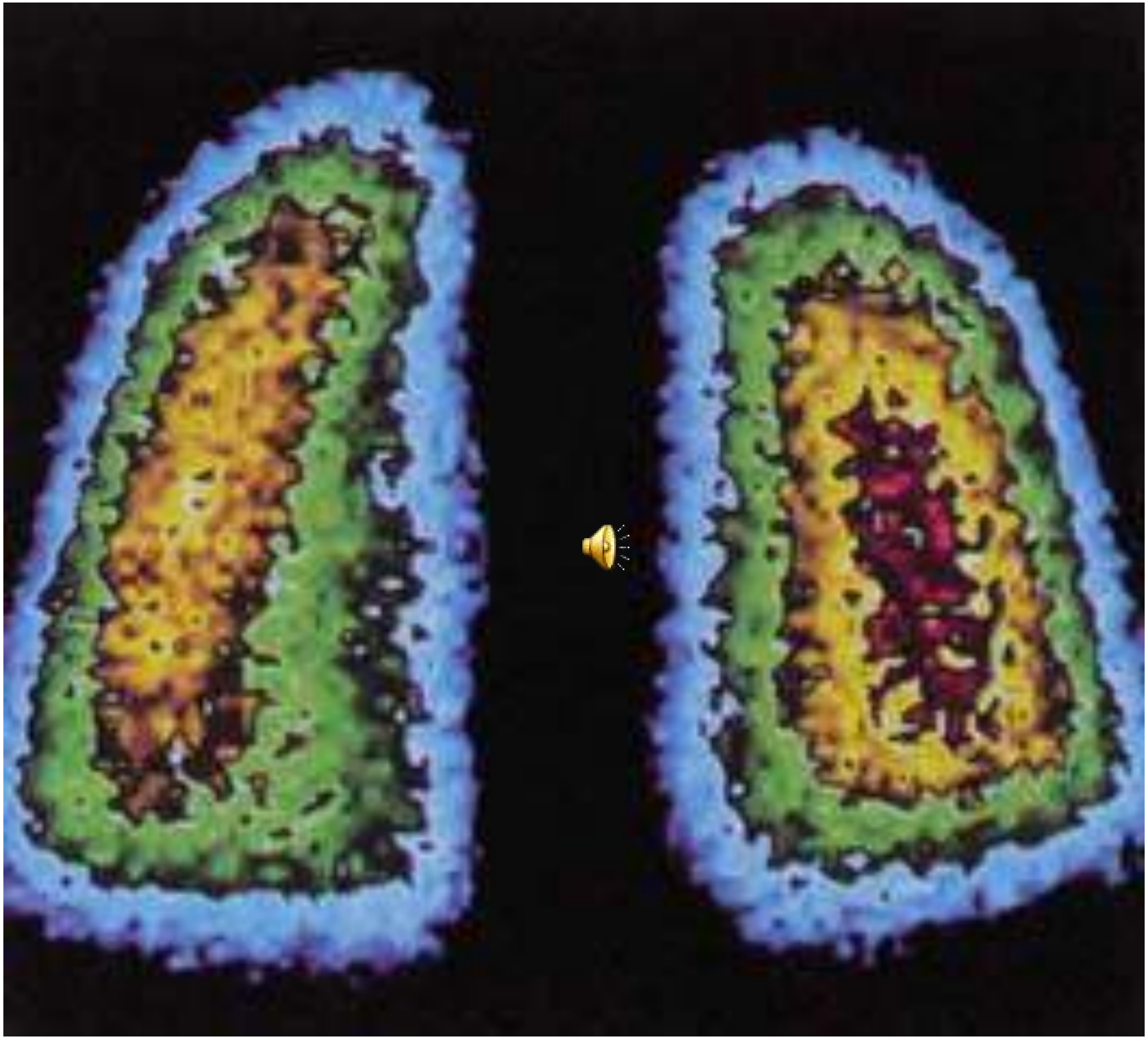
Courtesy Robert Maass/Corbis Images

X-ray examination of luggage at a security station.

Gamma Camera

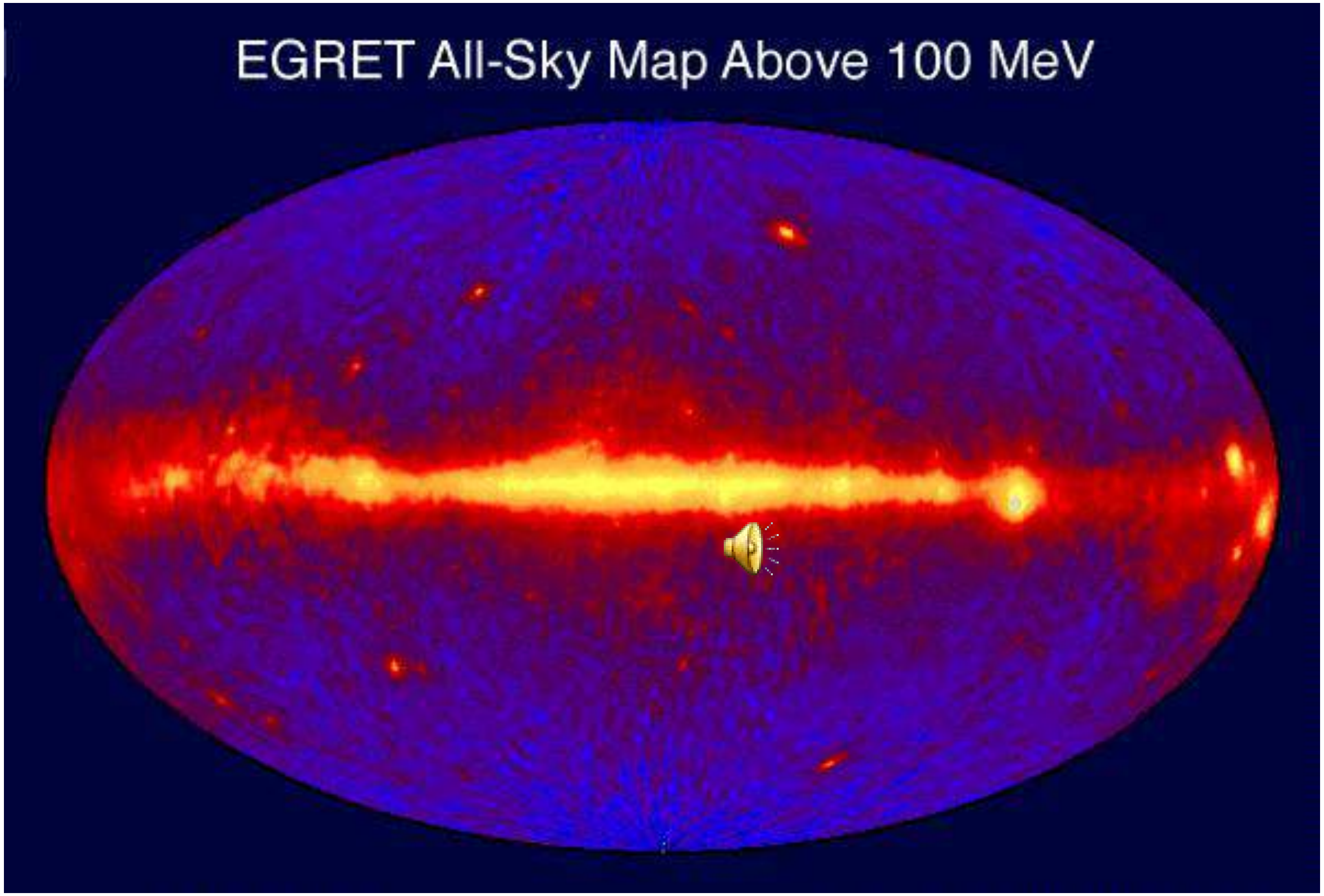


Nuclear Energy (Inside the radioactive nucleus) → Gamma Electromagnetic Energy (The gamma ray has been emitted from the patient) → Light Electromagnetic Energy (The image crystal produces flashes of light) → Electrical Energy (To display the image)

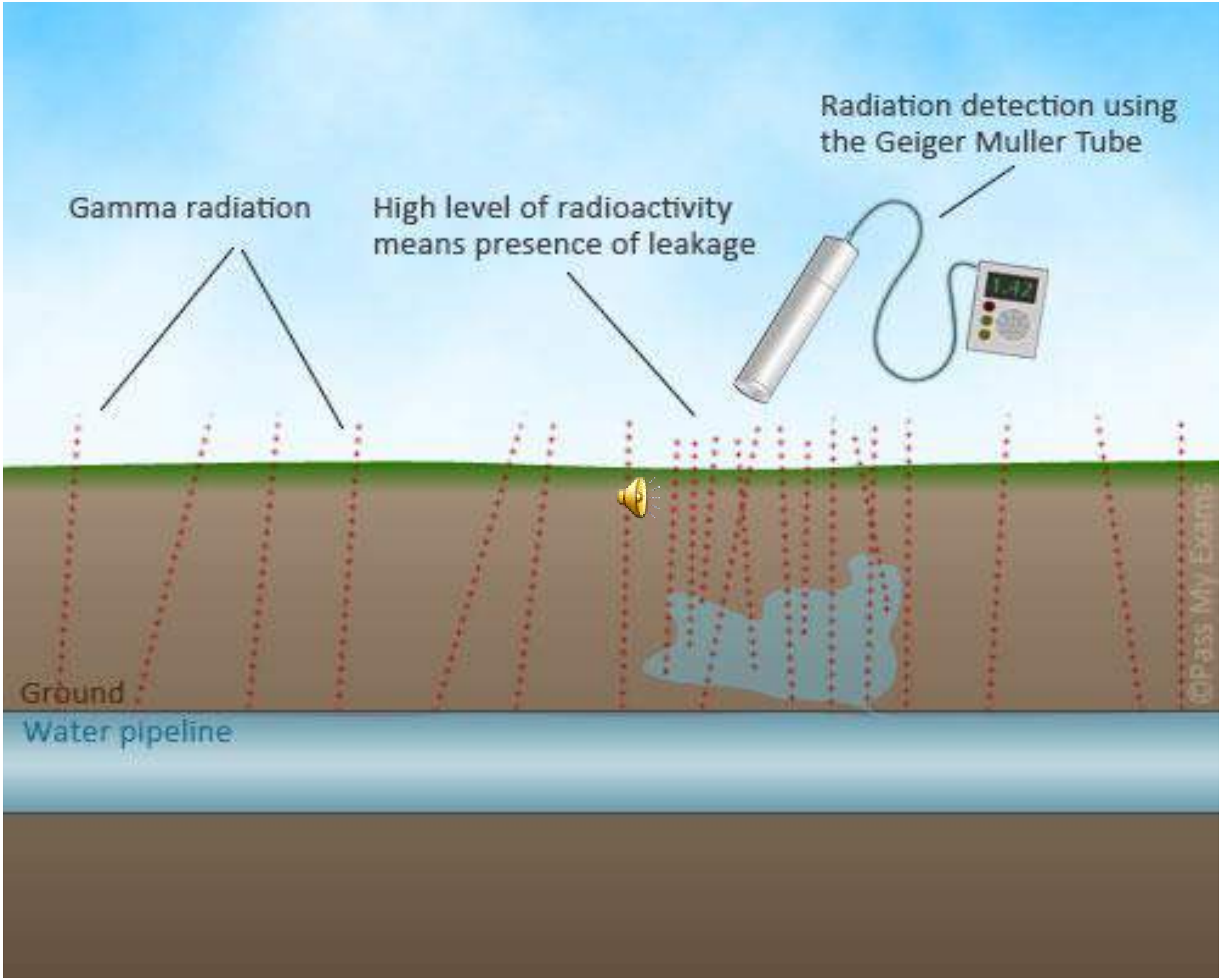


Courtesy CNRI/Phototake

Images of human lungs obtained from a γ-ray scan.



Egret_all_sky_gamma_ray_map_from_CGRO_spacecraft.gif



Radiation detection using the Geiger Muller Tube
Gamma radiation
High level of radioactivity means presence of leakage
1.42
Ground
Water pipeline
©Pass My Exams


Meter
Meter
Meter
Leak Point

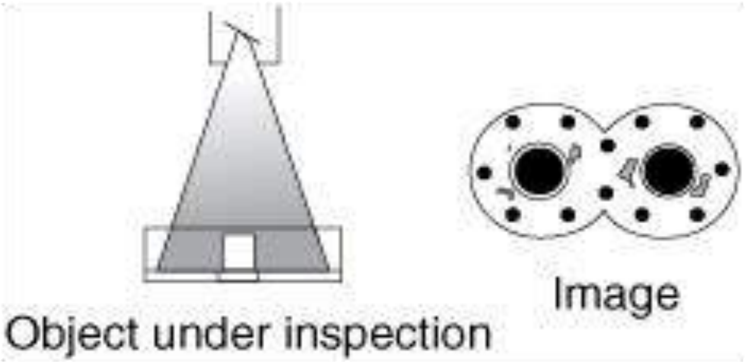
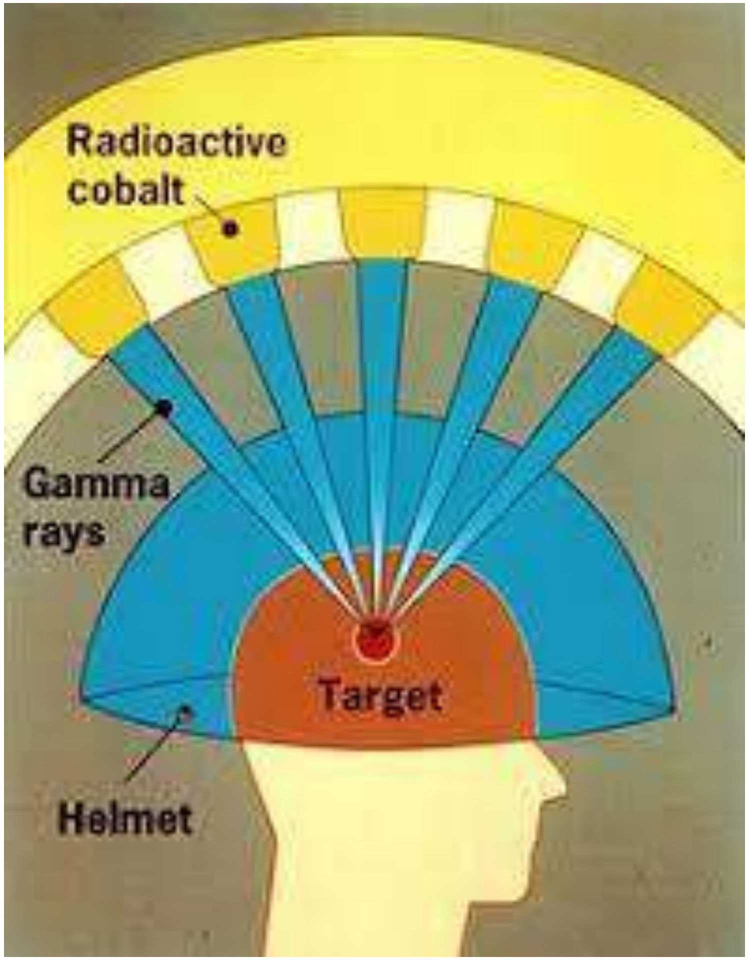


Image
Object under inspection

Gamma Knife

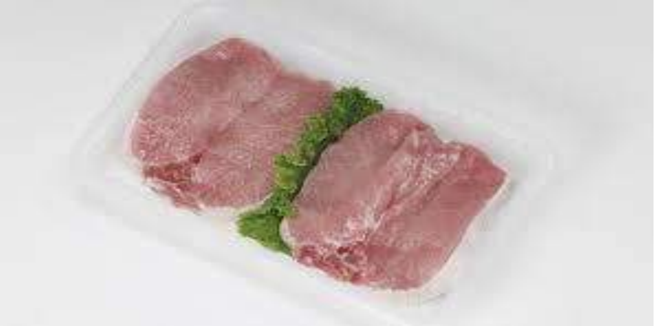


Sterilisation

Gamma rays can be used to sterilise all sorts of medical equipment to make sure that patients do not become infected by bacteria. Even a tiny amount of bacteria can grow to become a life threatening illness for a post operative patient.

Food Irradiation

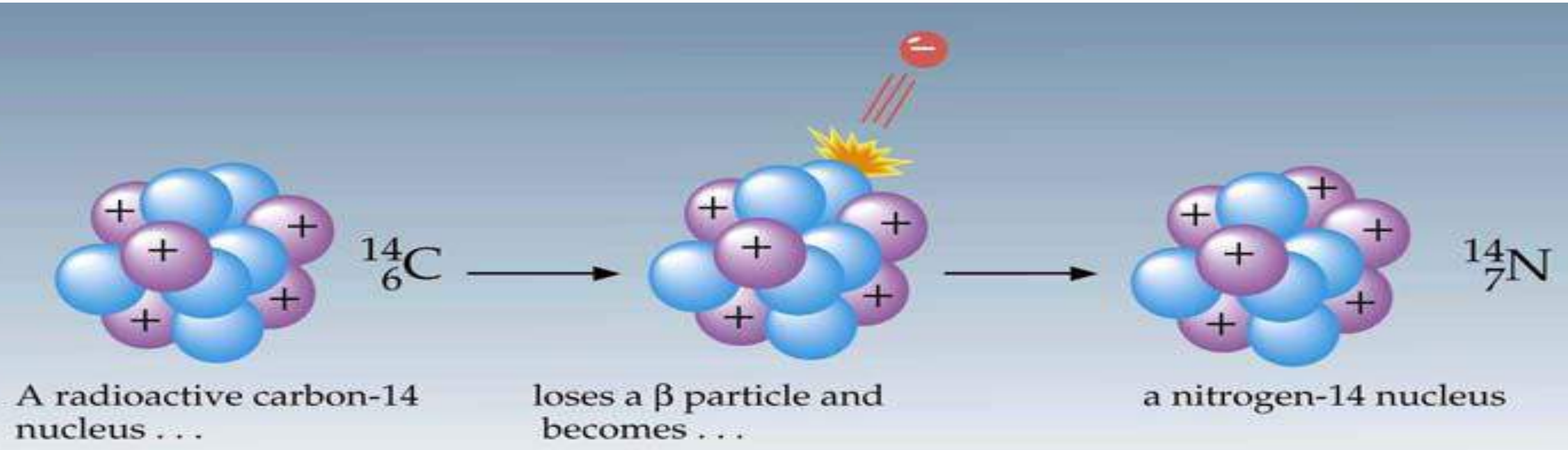
- Food can be irradiated with γ rays from ^{60}Co or ^{137}Cs.
- Irradiated milk has a shelf life of 3 mo. without refrigeration.
- USDA has approved irradiation of meats and eggs.



Types of Radioactive Decay

2- Beta Decay

- Beta Particle (β^-) (negatron decay)
- Positron (β^+)



Introduction

- دراسة صفات جسيمات بيتا عن طريق الانوية ذات النشاط الاشعاعى التلقائى و الاصطناعى أضاف الكثير عن تركيب الانوية الذرية وصفاتها.
- الاهتمام الرئيسى فى الوقت الحاضر هو المعلومات التى يعطيها انبعاث بيتا حول مستويات الطاقة النووية و مخططات الانحلال وعلاقتها بالمسائل النووية الرئيسية
- هذا فضلا عن أن دراسة اشعاعات بيتا لمنطقة العناصر ذات النشاط الاشعاعى الطبيعى (التلقائى) هى جزء مهم من تحليل الاطياف النووية.

Properties of Subatomic Particles

Properties of Baryons and Leptons

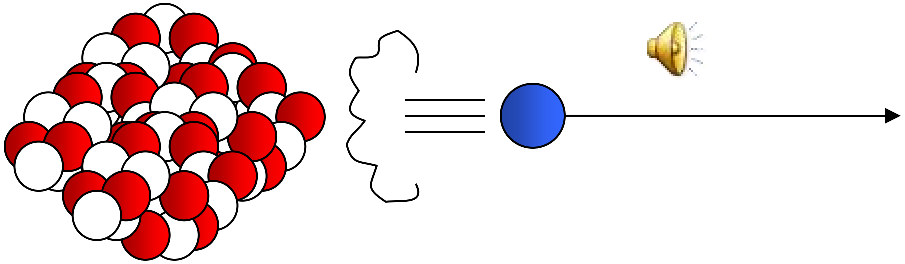
	Baryons		Leptons		
	Proton	**Neutron**	**Electron**	**Neutrino**	**Units**
Rest	1.00727647	1.0086649	5.485799e-4	$<10^{-10}$	amu
Mass	938.2723	939.5653	0.51899	$<5\text{x}10^{-7}$	MeV
Charge*	1	0	–1	0	e^{-}
Spin	½	½	½	½	$(^{h}/_{2\pi})$
Magnetic moment*	2.7928474 μ_N	-1.9130428 μ_N	1.00115965μ_B		

	Proton	**Neutron**	**Electron**	**Neutrino**	**Units**
Rest	1.00727647	1.0086649	5.485799e-4	$<10^{-10}$	amu
Mass	938.2723	939.5653	0.51899	$<5\text{x}10^{-7}$	MeV

It's a good idea to know the properties of these subatomic particles. You need not memorize the exact value for rest mass and magnetic moment, but compare them to get their relationship.

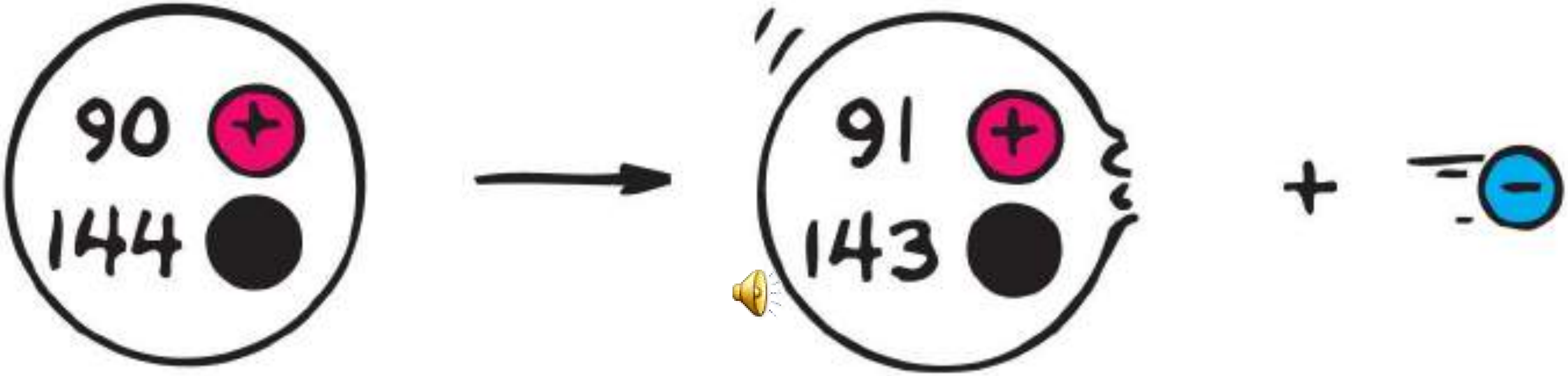
Beta Decay

A beta particle is a fast moving electron which is emitted from the nucleus of an atom undergoing radioactive decay.



- The atomic number, Z, **increases** by 1 and the mass number, **A, stays the same.**

Beta Decay



$$^{234}_{90}\mathrm{Th} \rightarrow \, ^{234}_{91}\mathrm{Pa} + \, ^{0}_{-1}e$$

Thorium Protactinium

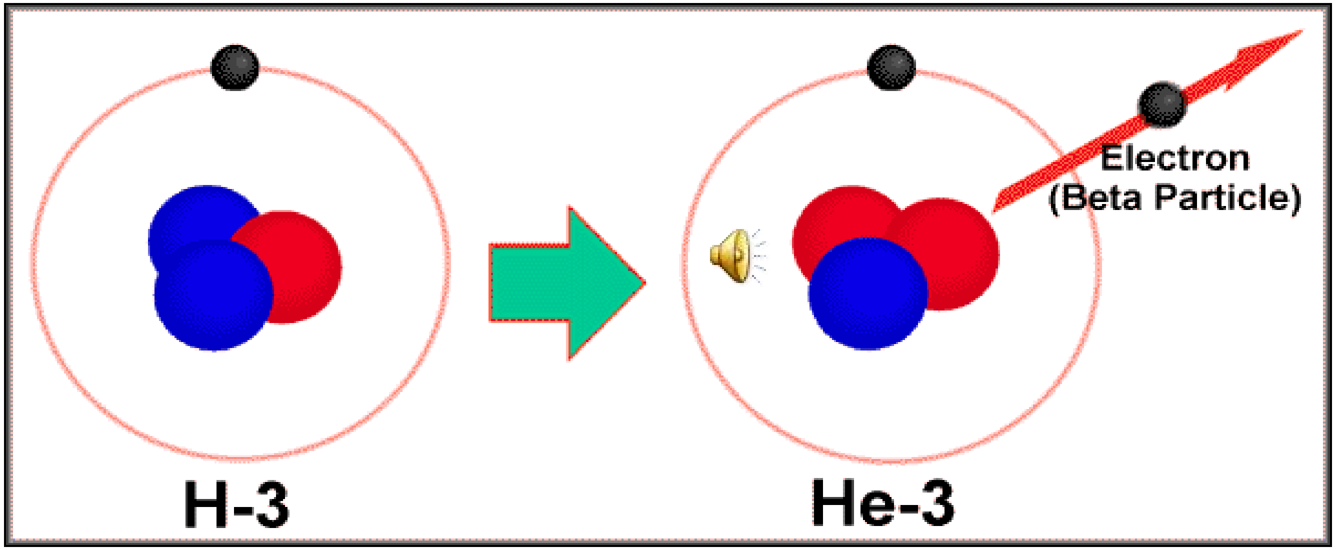
Beta decay

- **Beta decay** is a type of radioactive decay in which a beta particle (an electron or a positron) is emitted.

- In the case of electron emission, it is referred to as *beta minus* (β^{-}) while in the case of a positron emission as *beta plus* (β^{+}).

Beta Emission

- Occurs when there's too many neutrons in nucleus.
- A neutron is converted into a proton then an electron. Electron is then emitted.



$$^{131}_{53}\mathrm{I} \rightarrow \, ^{131}_{54}\mathrm{Xe} + \, ^{0}_{-1}\mathrm{e} \longleftarrow \text{electron}$$

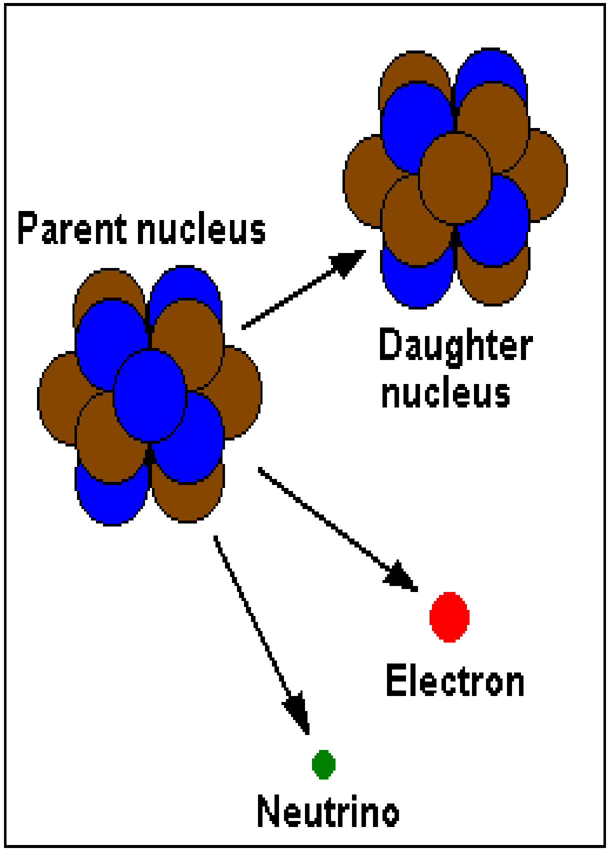
Beta Decay

- Beta particles β:
- electrons ejected from the nucleus when neutrons decay

$$n \longrightarrow p^+ + \beta^-$$

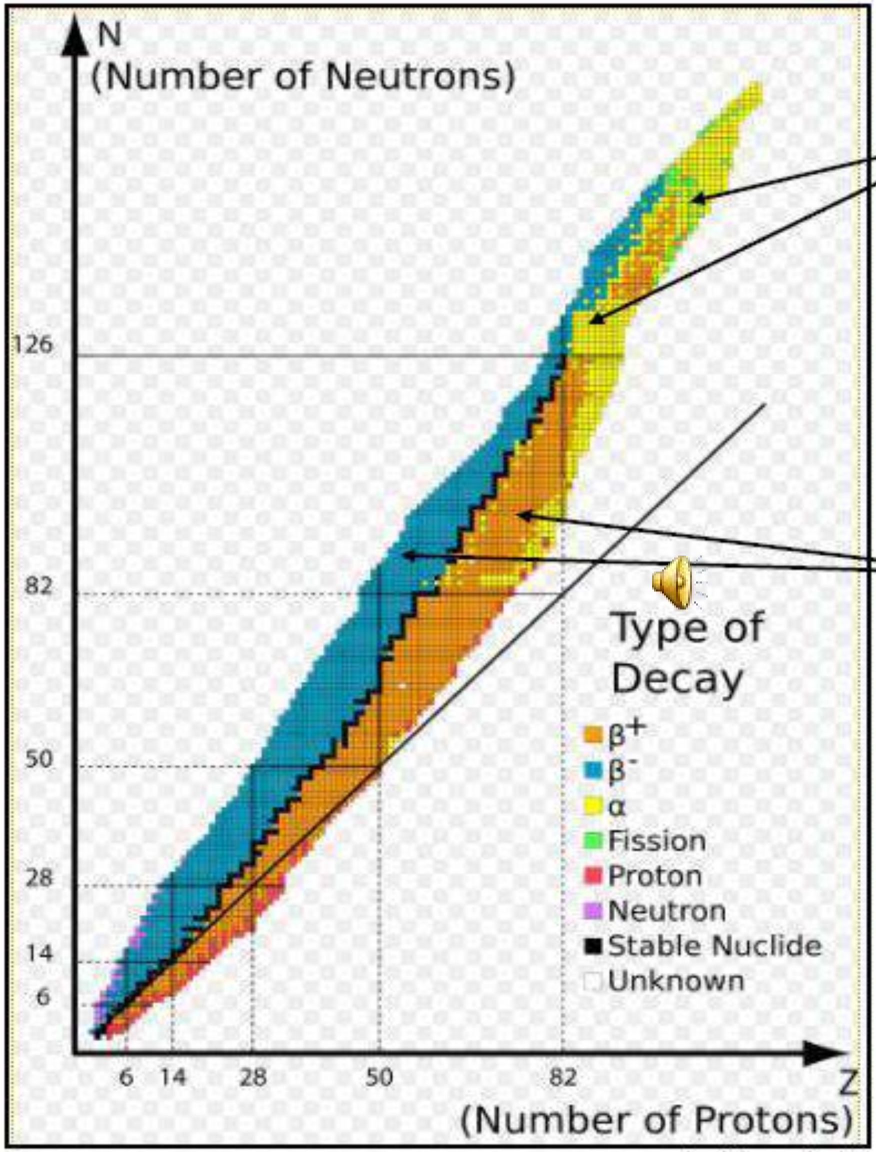
- **Beta particles have the same charge and mass as "normal" electrons.**

- Can be stopped by aluminum foil or a block of wood.



Beta decay

Which types of nuclei decay by beta?



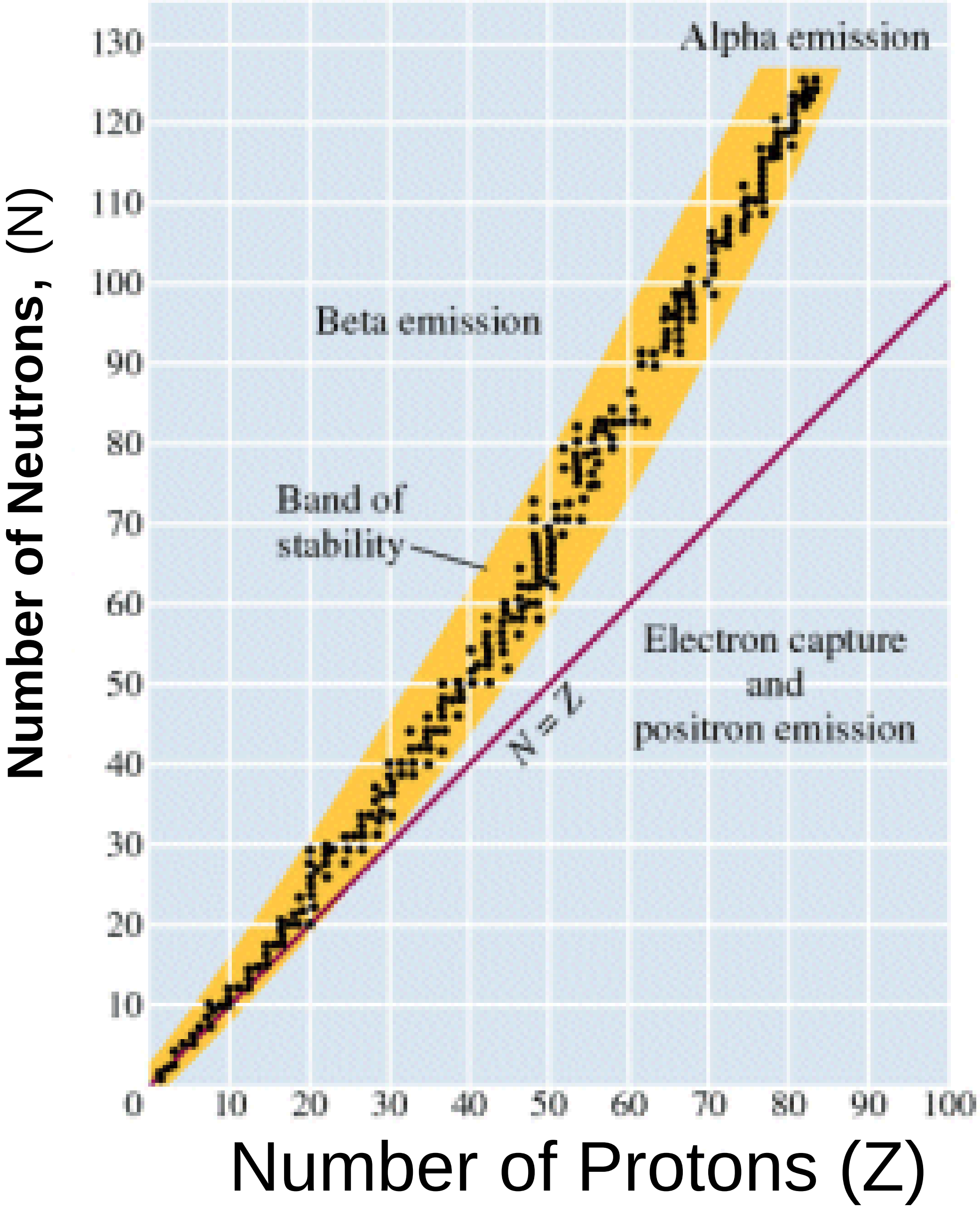
(wikipedia)

Fission and Alpha
– only **heavy** nuclei

Beta is the most common decay for nuclei which lie away from line of stability
- **energetically feasible** for these

Band of Stability

- **In nuclear stability, the neutron-proton ratio (N/P) is crucial.**
- **If it is too low or too high, the nucleus will eventually rearrange itself into a more stable configuration.**
- **Beta radiation, which is the emission of energetic electrons, results when an N/P ratio is too high for stability;**
- **positron emission or electron capture occurs when it is too low for stability.**
- **Beta emitters are above the stable nuclides, and positron emitters and electron capture nuclides are below .**



Nuclear Stability

This process decreases the neutron/proton ratio:

Beta emission: Neutron $\longrightarrow$ Proton + β^{-}

These processes increase the neutron/proton ratio:

Positron emission: Proton $\longrightarrow$ Neutron + β^{+}

Electron capture: Proton + Electron $\longrightarrow$ Neutron

Type of Beta Decay

Unlike alpha decay, which occurs primarily among nuclei in specific areas
The periodic table, beta decay is possible for certain isotopes of all elements

β^{-}: **change a neutron to a proton** (negatron decay)

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \beta^{-} + \bar{\nu} $$

β^{-} is an electron

β^{+}: **change a proton to a neutron** (positron decay)

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}Y_{N+1} + \beta^{+} + \nu $$

β^{+} is an anti-electron or positron

EC: **electron capture, change a proton to a neutron**

$$ {}^{A}_{Z}X_{N} + e^{-} \rightarrow {}^{A}_{Z-1}Y_{N+1} + \nu $$

Beta Emission

Ex. Polonium-210 undergoes beta decay to produce this daughter nuclide

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{A}_{Z}\mathrm{X} + {}^{0}_{-1}e$$

Atomic Mass: $210 = A + 0$

$210 - 0 = A = 210$

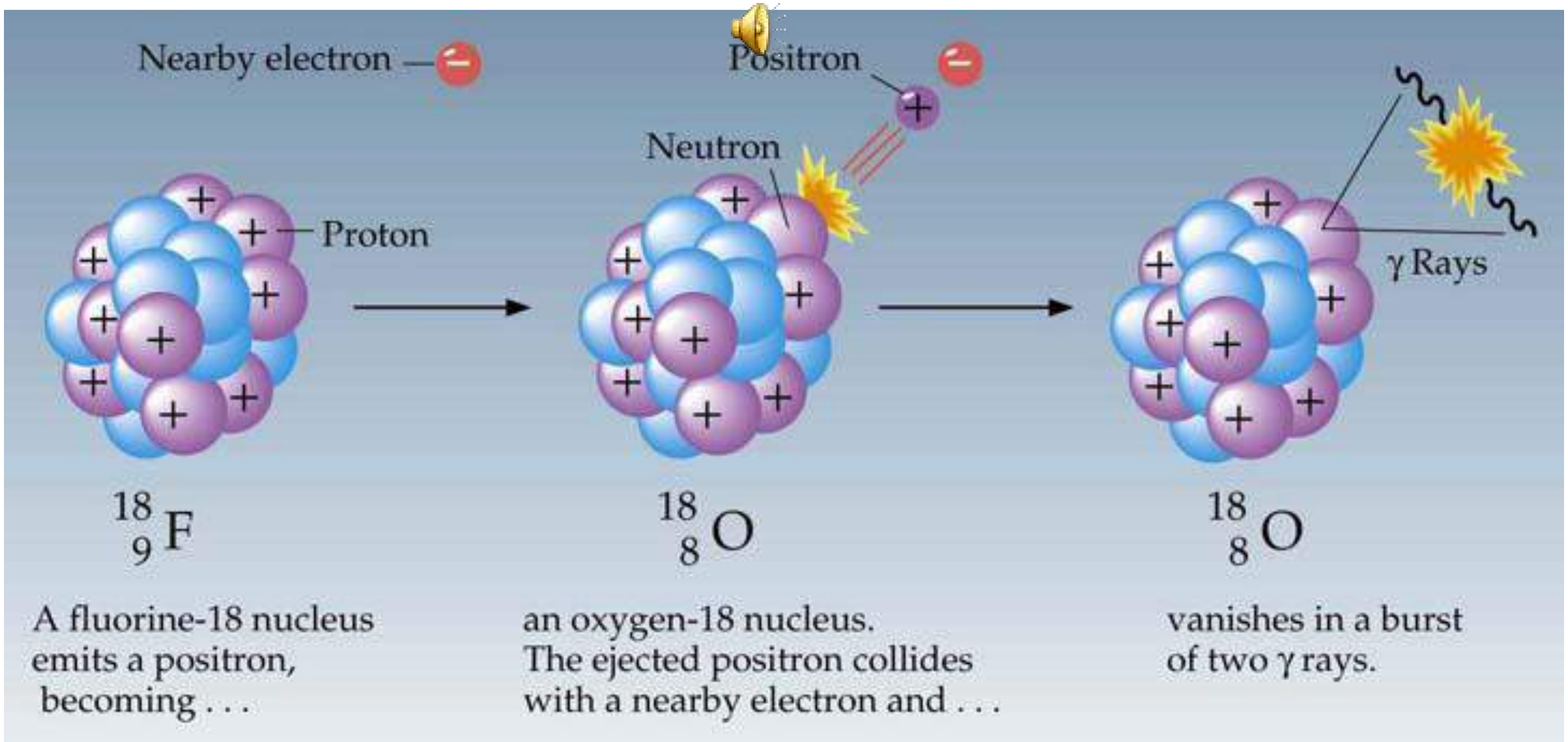
Atomic #: $84 = Z + -1$

$84 + 1 = Z = 85$

$$^{A}_{Z}\mathrm{X} = {}^{210}_{85}\mathrm{At}$$

Positron emission

- A proton kicks out p**o**sitive charge (a positron, β+) to become a neutron.
- The positron collides with an electron annihilating both and generating energy



A fluorine-18 nucleus emits a positron, becoming . . . an oxygen-18 nucleus. The ejected positron collides with a nearby electron and . . . vanishes in a burst of two γ rays.

Positron (β^+) Decay

β^+: change a proton to a neutron

$$^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}Y_{N+1} + \beta^{+} + \nu$$

β^+ is an anti-electron, or positron

$$^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + \beta^{+} + \upsilon \quad t_{1/2} = 2.605\,y$$

$$^{11}_{6}C \rightarrow {}^{11}_{5}B + \beta^{+} + \upsilon \quad t_{1/2} = 20.3\,\mathrm{min}$$

- **Proton rich nuclei**
- **Similar spectrum as in negatron decay**
- **Change a proton to a neutron → positive electron is emitted by the nucleus and an orbital electron originally present in the parent atom is lost to form a neutral daughter atom.**
- **equivalent to the creation of a positron-electron pair from the available transition**
- **2 x 0.511 MeV = 1.02 MeV necessary to create 2 electrons**
- **β^+ decay is possible only when the energy of the transition is greater than 1.02 M**

Positron Emission

Ex. Polonium-210 undergoes positron emission to produce this daughter nuclide

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{A}_{Z}\mathrm{X} + {}^{0}_{+1}e$$

Atomic Mass: $210 = A + 0$

$210 - 0 = A = 210$

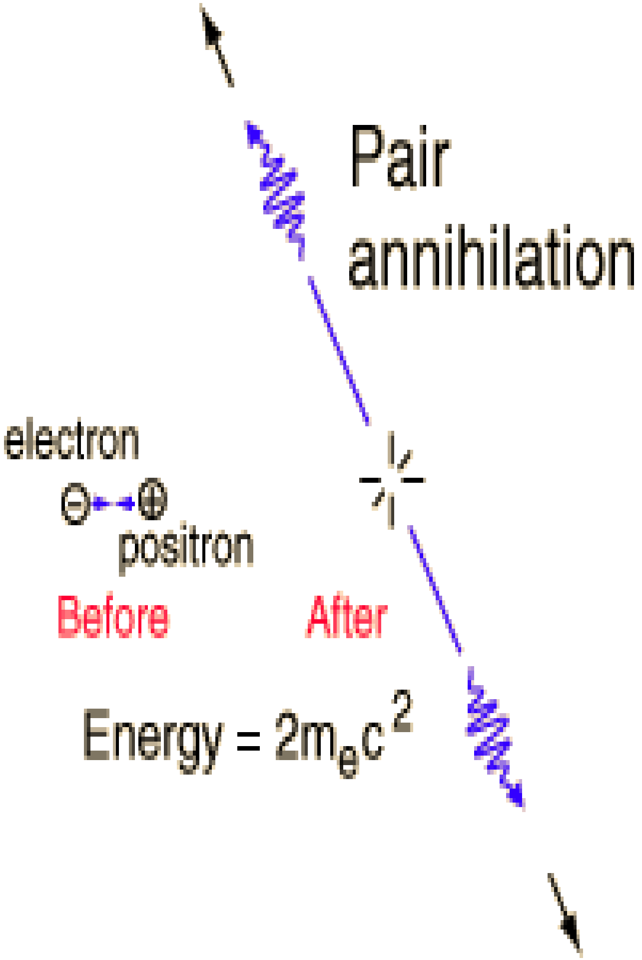
Atomic #: $84 = Z + {+1}$

$84 - 1 = Z = 83$

$${}^{A}_{Z}\mathrm{X} = {}^{210}_{83}\mathrm{Bi}$$

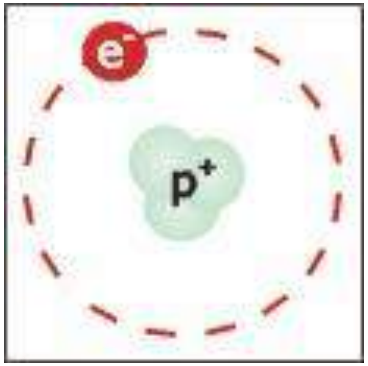
The fate of the positron

- The first positron was discovered in cosmic rays and then in radioactive disintegrations.
- Conversion to pure energy by positron annihilation

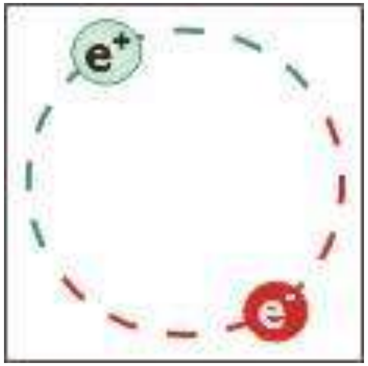


Positronium(Ps)

1. Metastable bound state of e^+ and e^-
2. An Exotic atom
3. Energy level : similar to the hydrogen atom (why?)
4. Exactly same as hydrogen? (reduce mass)



Hydrogen



Positronium

Electron Capture (EC)

EC: **electron capture, change a proton to a neutron**

$$ {}_{Z}^{A}X_{N} + e^{-} \rightarrow {}_{Z-1}^{\;\;A}Y_{N+1} + \nu $$

+ x-rays or Auger electrons
+ inner bremsstrahlung

excited
nucleus

$$ {}_{71}^{172}Lu \rightarrow {}_{70}^{172}Yb + \text{x rays} + \text{Auger electrons} + \upsilon; \quad t_{1/2} = 6.70\,d $$

$$ {}_{78}^{188}Pt \rightarrow {}_{77}^{188}Ir + \text{x rays} + \text{Auger electrons} + \upsilon; \quad t_{1/2} = 10.2\,d $$

Electron Capture

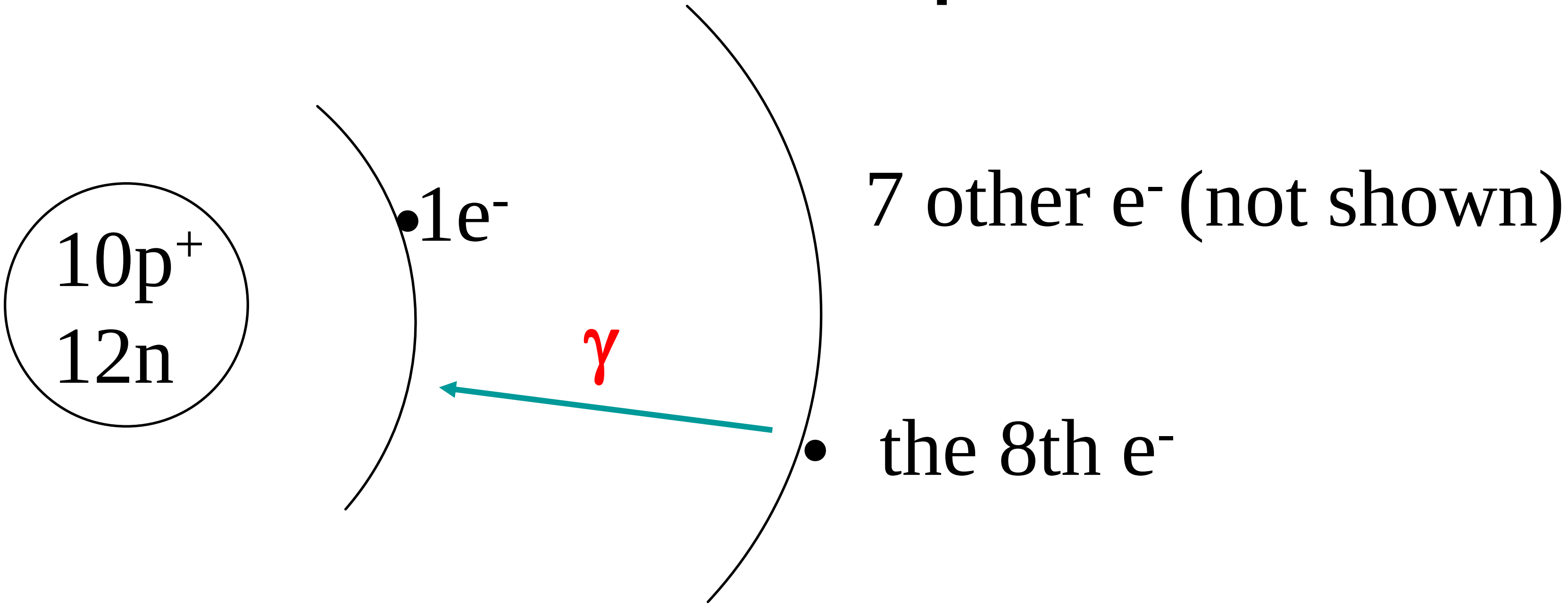
$$^{22}_{11}\text{Na} + {}^{0}_{-1}\text{e} \longrightarrow {}^{22}_{10}\text{Ne}$$

$2e^-$, $8e^-$, ...

$1e^-$, $8e^-$, ...

The captured electron usually comes from the 1st energy level (nearest the nucleus). This leaves a hole or void in the electron level of the daughter.

Electron Capture



A large ***release of energy*** occurs as the electron makes transition from level 2 to level 1. This release occurs as gamma radiation.

Electron Capture

Ex. Polonium-210 captures an electron to produce this daughter nuclide

$$^{210}_{84}\text{Po} + \, ^{0}_{-1}e \longrightarrow \, ^{A}_{Z}\text{X}$$

Atomic Mass: 210 + 0 = A

A = 210

Atomic #: 84 + -1 = Z

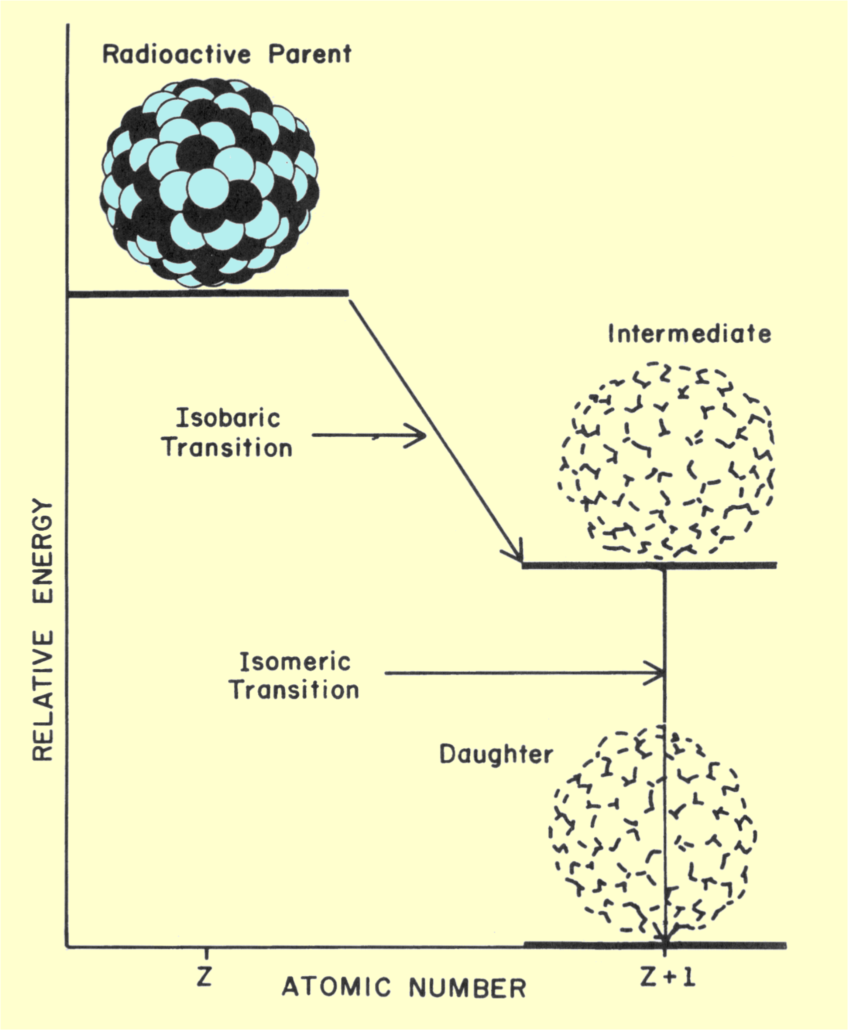
Z = 83

$$^{A}_{Z}\text{X} = \, ^{210}_{83}\text{Bi}$$

- **Beta decay does not change the number of nucleons, *A*, in the nucleus but changes only its charge, *Z*.**

- **Thus the set of all nuclides with the same *A* can be introduced; these *isobaric* nuclides may turn into each other via beta decay.**

ISOBARIC TRANSITIONS



Most radioactive transitions have several steps. For most radionuclides,

- The first step is an *isobaric* transition usually followed by an *isomeric* transition and interactions with orbiting electrons.
- The three types of isobaric transitions of interest to us are:

(1) beta emission,

(2) positron emission, and
(3) electron capture.

طاقة انحلال جسيمات بيتا

- لا تحدث العمليات التلقائية الا بتكوين جسيمات ذات كتلة (فعلية) أقل.
- طاقة انحلال β^- تساوى

$$E_{\beta^-} = [\, M_p(A, Z) - M_d\,(A, Z+1)]\, C^2$$

- طاقة انحلال β^+ تساوى

$$E_{\beta^+} = [\, M_p(A, Z) - \{\, M_d\,(A, Z-1) + 2\, m_e\}]\, C^2$$

- طاقة اقتناص الكترون k تساوى

$$E_{Ec} = [\, M_p(A, Z) - M_d\,(A, Z-1)]\, C^2$$

Mass Changes in Beta Decay OR Energy for beta particle

- β⁻ decay

$$^{14}C \rightarrow {}^{14}N + \beta^- + \overline{\nu_e}$$

$$Energy = [M(^{14}C) - M(^{14}N)]c^2$$

β⁺ decay •

$$^{64}Cu \rightarrow {}^{64}Ni^- + \beta^+ + \nu_e$$

$$Energy = [M(^{64}Cu) - M(^{64}Ni) - 2m_{electron}]c^2$$

EC decay

$$^{207}Bi^+ + e^- \rightarrow {}^{207}Pb + \nu_e$$

$$Energy = [M(^{207}Bi) - M(^{207}Pb)]c^2$$

احسب طاقة تحلل بيتا السالبة لكربون 14-

$$_6C^{14} \rightarrow {}_7N^{14} + \beta^-$$

- طاقة انحلال β^- تساوى

$Q_\beta = [M_p(A, Z) – M_d(A, Z+1)] C^2$

$Q_\beta = (14.00324 – 14.00307) 931.5$

$Q_\beta = 0.26$ MeV

احسب طاقة انبعاث البوزترون لتفاعل التحلل النووى: $_7N^{13}\rightarrow {}_6C^{13} + \beta^+$

- طاقة انحلال β^+ تساوى

$$Q_{\beta+} = [\, M_p(A, Z) - \{ M_d\,(A, Z-1) + 2\, m_e\}]\, C^2$$

$$=13.005738 - [(13.003354) + (2 \times 0.00055)] \times 931.5$$

$$=1.20 \text{ MeV}$$

احسب طاقة انحلال اسر الكترون للتفاعل

$$_{4}Be^{7} + {}_{-1}e^{0} \rightarrow {}_{3}Li^{7}$$

- طاقة اقتناص الكترون k تساوى

$$E_{\beta} = [M_p(A, Z) – M_d (A, Z\text{-}1)] C^2$$

$$Q_{EC} = (7.016929 - 7.016005) \times 931.5$$

$$= 0.961 \text{ MeV}$$

Why do we "need" neutrinos?

- Conservation of energy
- Conservation of angular momentum

Antineutrino in β^-

- No charge
- No magnetic moment
- Near zero rest mass(1/2000 m_e)
- Spin ½
- Conservation of angular momentum

الطاقة الحركية لجسيمات بيتا و اكتشاف النيوترينو

- لوحظ ان جسيمات بيتا لها طاقة حركة مختلفة اى انها تأخذ اى طاقة كانت حيث يتم تقاسم الطاقة المتوافرة بين هذة الجسيمات الناتجة.
- وحيث ان الطاقة قبل التفاعل و بعدة يجب ان تكون محفوظة لذا فان قيمة Q للفتتات المختلفة لابد ان تكون متساوية .
- هذة تنتج عن فرق الكتلة بين النواة الام و النواة الابنة و هو مقدار ثابت لجميع عمليات اضمحلال β
- ومن ثم لابد ان تكون طاقة الحركة لجميع جسيمات β متساوية على عكس ما بينت التجارب ؟ فأين يذهب الفرق؟
- ولذلك قد اقترح باولى ان هناك جسيما ثالثا غير معروف يحمل هذة الطاقة
- و قد اطلق فيرمى على هذا الجسيم اسم نيوترينو (تصغير نيوترون)
- و هو جسيم متعادل الشحنة و كتلتة الساكنة معدومة تقريبا

Discovery of the Neutrino

The solution

→ postulated by Wolfgang Pauli (1930)
Many important contributions to QM (noted for Pauli exclusion principle, Nobel prize 1945). Seldom published papers: most of results never published and appear only in his letters to colleagues.

$$\boxed{n \longrightarrow p + e^- + \bar{\nu}_e}$$

→ Hypothetical particle with no charge and (almost) no mass, but with angular momentum (spin=1/2)

→ Particle shares released energy with e-/e+, also solving recoil direction and angular momentum problems

→ Named neutrino by Fermi ("little neutral one" in Italian)
(In 1930, Pauli originally chose name "neutron", but the name had to change due to the discovery of real neutron in 1932)

Beta decays with neutrinos:

n	$\longrightarrow$	$p + e^-$	Negative β-decay
p	$\longrightarrow$	$n + e^+$	Positive β-decay
$p + e^-$	$\longrightarrow$	n	Orbital electron capture

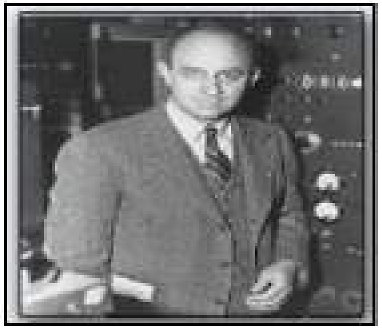
$$\boxed{n \rightarrow p + e^- + \bar{\nu}_e}$$

Anti neutrino

$$\boxed{p \rightarrow n + e^+ + \nu_e}$$

$$\boxed{e^- + p \rightarrow n + \nu_e}$$

Full theory developed by Enrico Fermi (1933)



Originally turned down on submission to Nature because "it contained speculations". Published in Italian and in German before it was eventually published in English.

→ predicted particle chargeless, ~massless, and interacts only by weak force

→ very small interaction cross-section, and so is extremely hard to detect

BUT, how do we know they are there?

Need to measure them!

However, need extremely large flux of them to detect any.......

→ Nuclear bomb tests: noise from other emissions, particularly neutrons & γ's

→ Could not be detected until the invention of the nuclear reactor......

Reines & Cowan: Project Poltergeist

(1956, Nobel prize 1995)

Nuclear reactor provides intense neutrino flux (due to decay of neutrons): $\boxed{n \longrightarrow p + e^- + \bar{\nu}_e}$

Detection by neutrino capture: $\boxed{\bar{\nu}_e + p \longrightarrow n + e^+}$

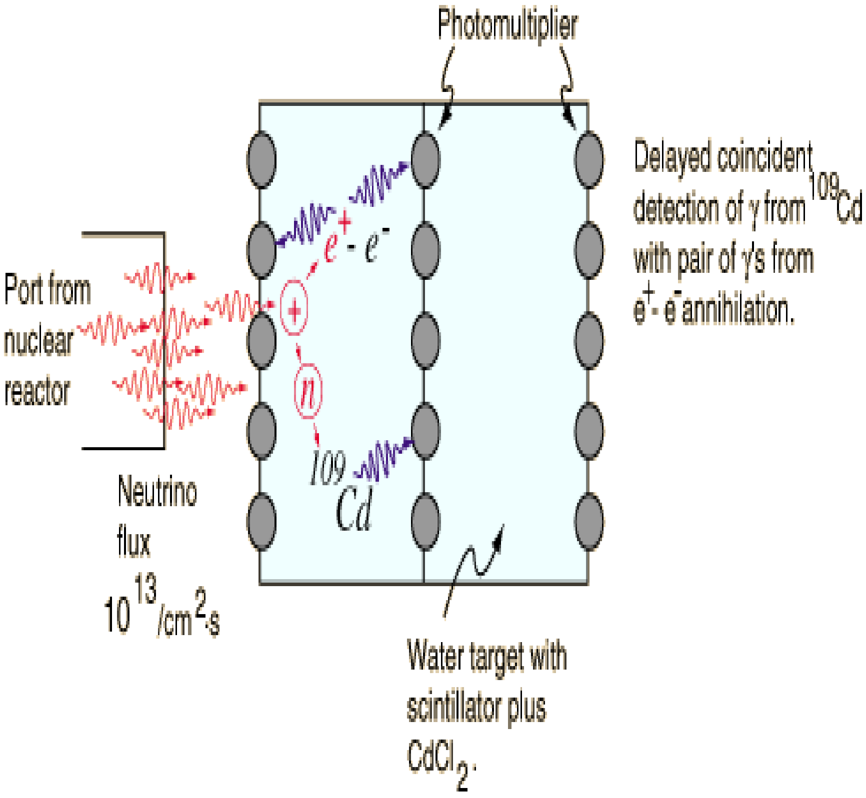
Fred Reines & Clyde Cowan

ما هو النيوترينو (Neutrino)

- النيوترينو يعتبر جسيم أولي بكتلة أصغر كثيرا من كتلة الإلكترون، وليست له شحنة كهربية.
- تم استنتاج وجود النيوترينو بسبب ظاهرة تحلل بعض النظائر المشعة من خلال إطلاق أشعة بيتا التي هي عبارة عن إلكترونات.
- فعند تحلل العنصر المشع إلي عنصر آخر يحدث فقد معين في الطاقة، هذا الفقد في الطاقة هو عبارة عن الفرق بين طاقة العنصر المشع، وطاقة العنصر الناتج.
- والمفروض، لاحترام قانون عدم فناء الطاقة، أن يحمل الإلكترون -المنطلق من نواة الذرة والخارج علي هيئة شعاع من أشعة بيتا - أن يحمل هذا الفرق في الطاقة،
- ولكن القياسات تبين، أن الإلكترون يحمل طاقة أقل من الطاقة المفروضة خلال التحلل، لهذا افترض العالم الأمريكي باولي عام 1930 وجود جسيم صغير يحمل تلك الطاقة الناقصة التي لا نراها واطلق عليه اسم "نيوترينو" حيث أنه لا يحمل شحنة كهربية
- تعتبر النيوترينوات من ضمن الليبتونات . وكل من اللبتونات يتكون من جسيم مشحون كهربائيا : الإلكترون و ميون و تاوون ويتمي لكل منهم نيوترينو متعادل الشحنة : نيوترينو-الإلكترون (), ونيوترينو-الميون () ، ونيوترينو-التاوون (). بالإضافة لكل هؤلاء توجد مضادتها ممثلة في 6 من مضاد المادة.
- كل جسيم من اللبتونات له عزم مغزلي 1/2 .

Antineutrino discovery neutrino-proton Reaction

$$\overline{\nu}+p\rightarrow n+\beta^{+}$$



1953 by F. Reines and C.L. Cowan Jr.

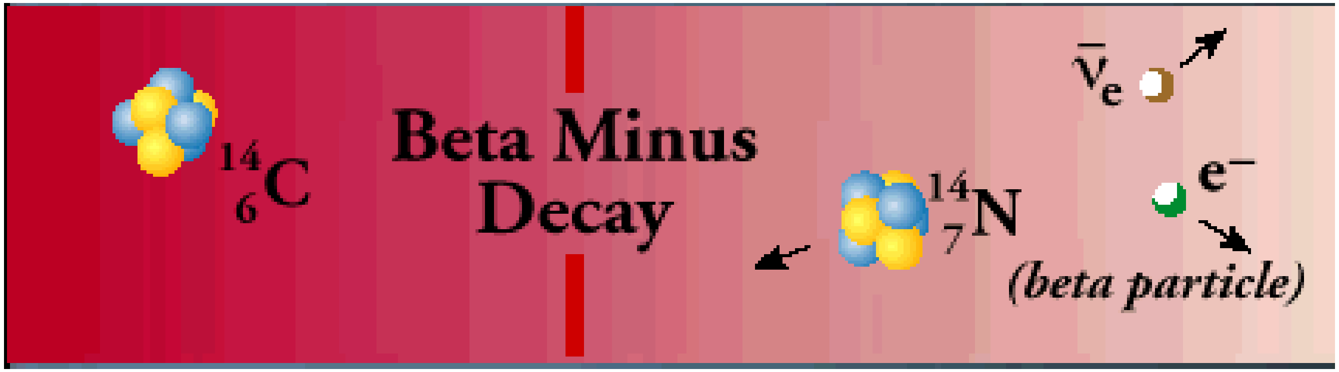
- وتعرف تلك التجربة الآن بتجربة كووان-راينس للنيوترينو، حيث صوبت نيوترينوات صادرة من مفاعل نووي ناشئة من تحلل بيتا إلى بروتونات
- ونتج عن التفاعل نيوترونات وبوزيترونات، طبقا لمعادلة التفاعل المذكورة
- والبوزيترون [الموجب الشحنة] سرعان ما يجد إلكترونا ويفنيا معا مصدران شعاعين من أشعة جاما ، ويمكن عد أشعة جاما الناشئة.
- ويمكن قياس النيوترون الناشئ عن طريق امتصاصه بنواة ذرة مناسبة ، وينتج عن الامتصاص أيضا شعاعا من أشعة جاما.
- ويؤكد التزامن بين اصدار أشعة جاما الناشئة من إفناء البوزيترون وأصدار شعاع جاما الناشئ عن امتصاص النيوترون _ أي حدوثهما وتسجيلهما في نفس اللحظة - التفاعل الذي قام به نقيض النيوترينو.
- وبذلك تحقق أن ما اقترحته النظرية وما وجدته التجربة إنما كان هو نقيض النيوترينو.

- A **neutrino** was "invented" to maintain conservation of energy, linear momentum, and angular momentum in beta decay.

- It has no mass, no charge, and virtually no interaction with matter.

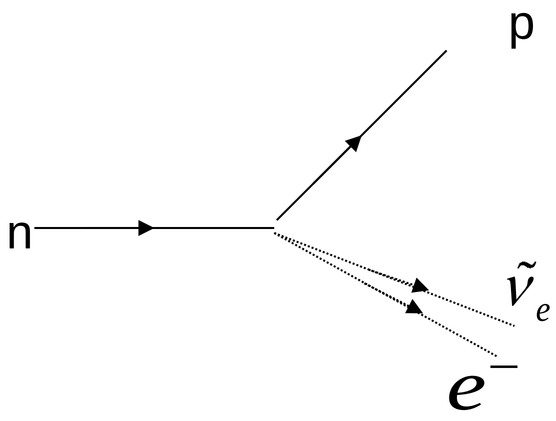
- It travels at the speed of light and carries off energy and momentum .

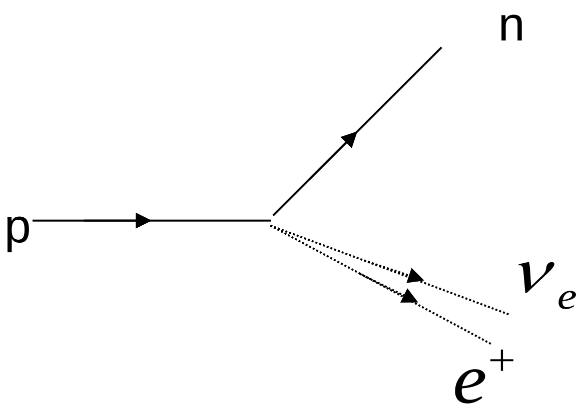
Angular Momentum in beta decay.



Who Carry the decay Energy?

BETA MINUS DECAY





BETA PLUS DECAY

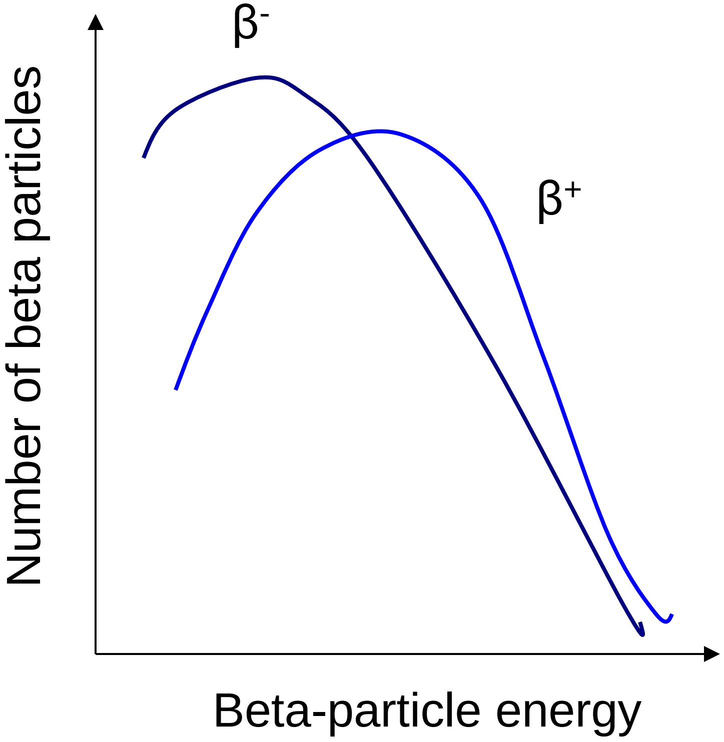
✓All these decay types are similar in structure

✓They all have **3 particles in the final state**

✓**The fact that the Q of the decay is shared between 3 particles means that the outgoing observed particle**

✓**[ie. electron or positron] has a spectrum of energies in the range (0 to Q).**

Beta decay – Energy spectrum



- الطيف يمثل عرض أو مخطط لكثافة الإشعاع (إشعاع جسيمات، أو فوتونات، أو صوتي) كتابع للكتلة، أو كمية الحركة، أو طول الموجة، أو التردد، أو بعض الكمية الأخرى ذات الصلة.

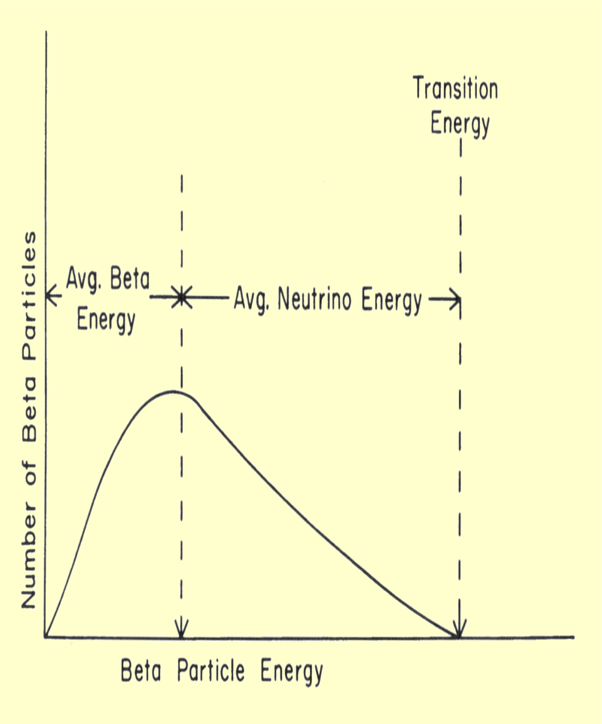
❑ يمثل طيف جسيمات بيتا توزيع الطاقة الحركية للإلكترونات سالبة الشحنة الصادرة تلقائيًا من بعض النوكليدات (nuclide) النشطة إشعاعيًا.

- E_{max}

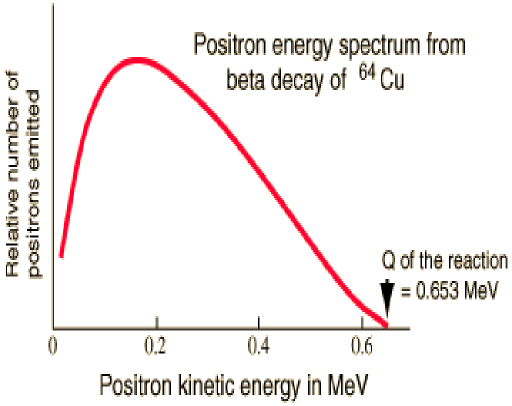
$$E_{trans} = E_{negatron} + E_{antineutrino} + E_{recoil}$$

Beta Energy Spectrum

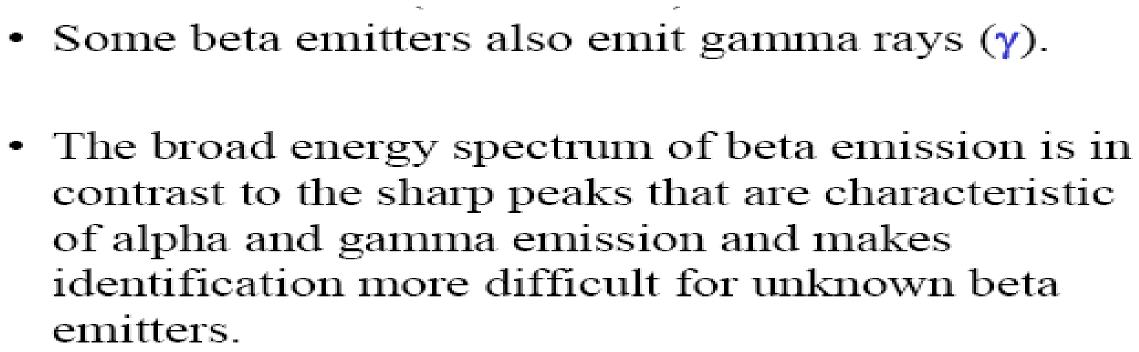
- •اطياف بيتا هى اطياف مستمرة
- •تتوزع جسيمات بيتا من حيث الطاقة بطاقات مختلفة تبدأ من الصفر حتى فيمة عظمى E_{max}
- •لوحظ ان معظم جسيمات β تمتلك طاقة اقل بكثير من القيمة العظمى E_{max}
- •الطاقة المتوسطة لطيف β تساوى تقريبا $1/3\ E_{max}$
- •الجزء الاكبر من طاقة انحلال β يحملة أخف الجسيمات الناشئة اثناء الانحلال و هو النيوترينو
- •هذا النيوترينو لا يعطى الطاقة للمادة و لا يتحول هذا الجزء من الطاقة الى حرارة



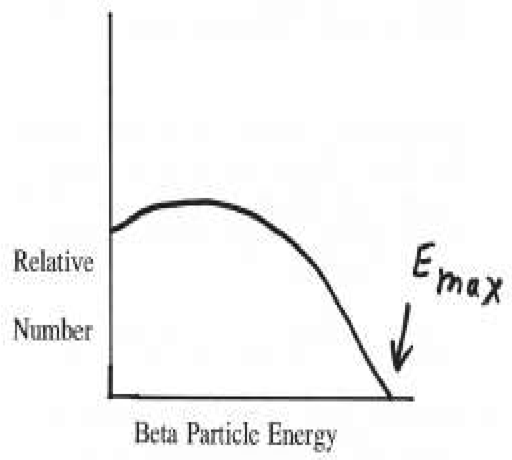
•the average beta energy is usually between 25% and 30% of the maximum energy .



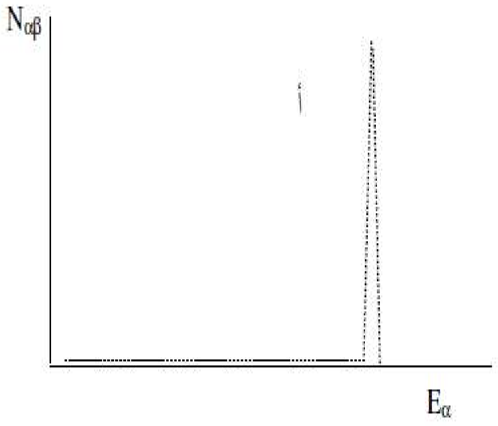
Kinetic Energy for beta particle



- Some beta emitters also emit gamma rays (γ).
- The broad energy spectrum of beta emission is in contrast to the sharp peaks that are characteristic of alpha and gamma emission and makes identification more difficult for unknown beta emitters.

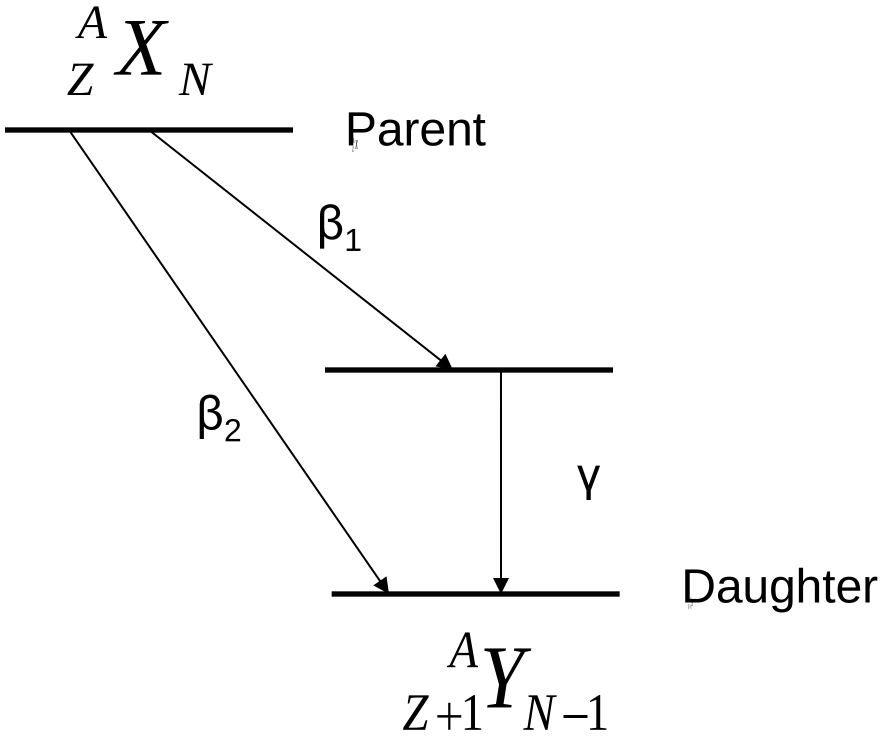


- Emitted beta particles have a continuous kinetic energy spectrum, ranging from 0 to the maximal available energy (*Q*),
- which depends on the parent and daughter nuclear states that participate in the decay.
- The continuous energy spectra of beta particle occurs because *Q* is shared between the beta particle and a neutrino.



Negatron (β⁻) Decay

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}Y_{N-1} + \beta^{-} + \bar{\nu} + \gamma $$



Neutron rich nuclei;
Large N/Z ratio

$$ {}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + \beta^{-} + \overline{\upsilon} \quad t_{1/2} = 29.1y $$

$$ {}^{32}_{15}P \rightarrow {}^{32}_{16}S + \beta^{-} + \overline{\upsilon} \quad t_{1/2} = 14.3\,d $$

Beta Decay

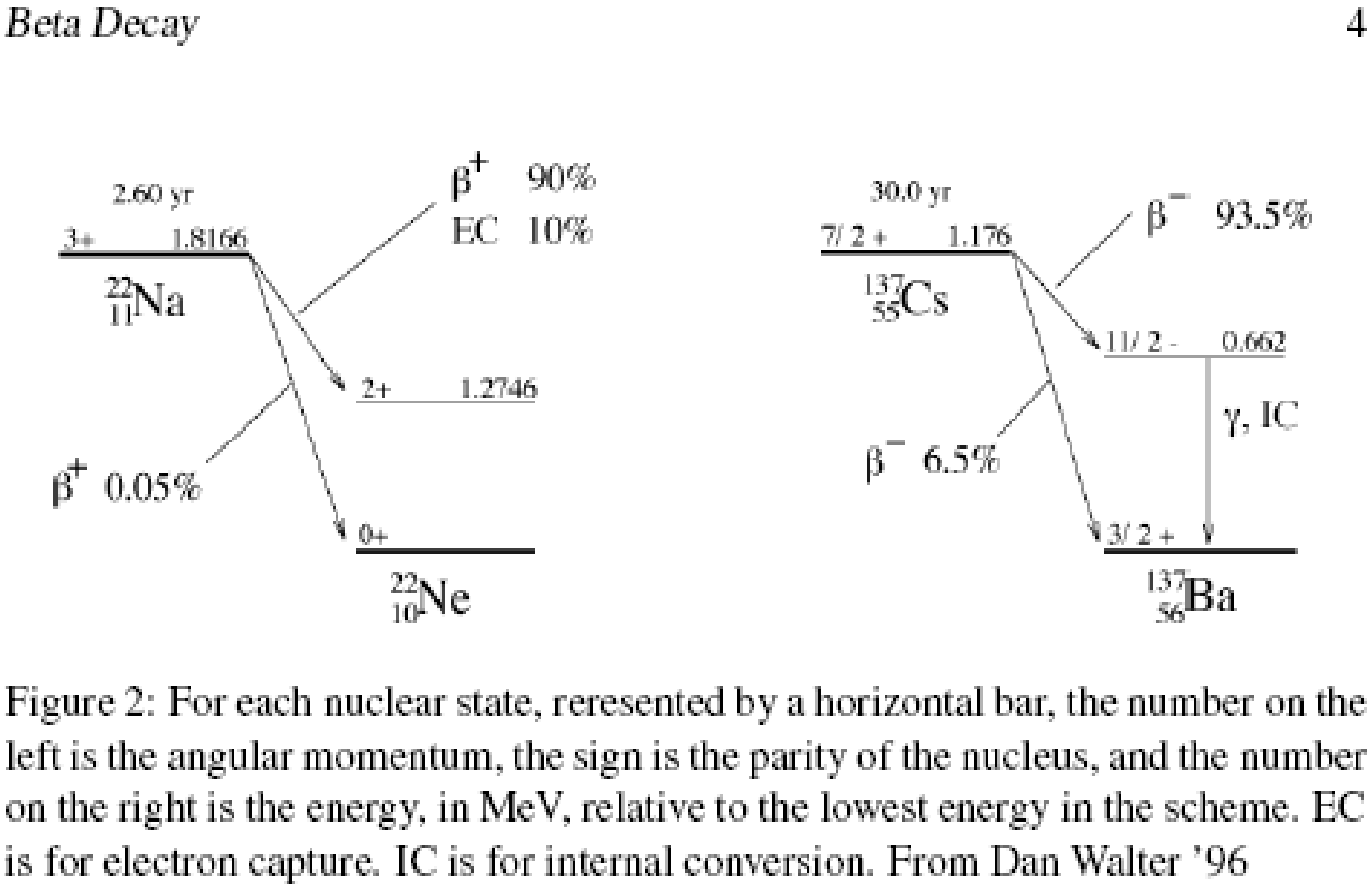
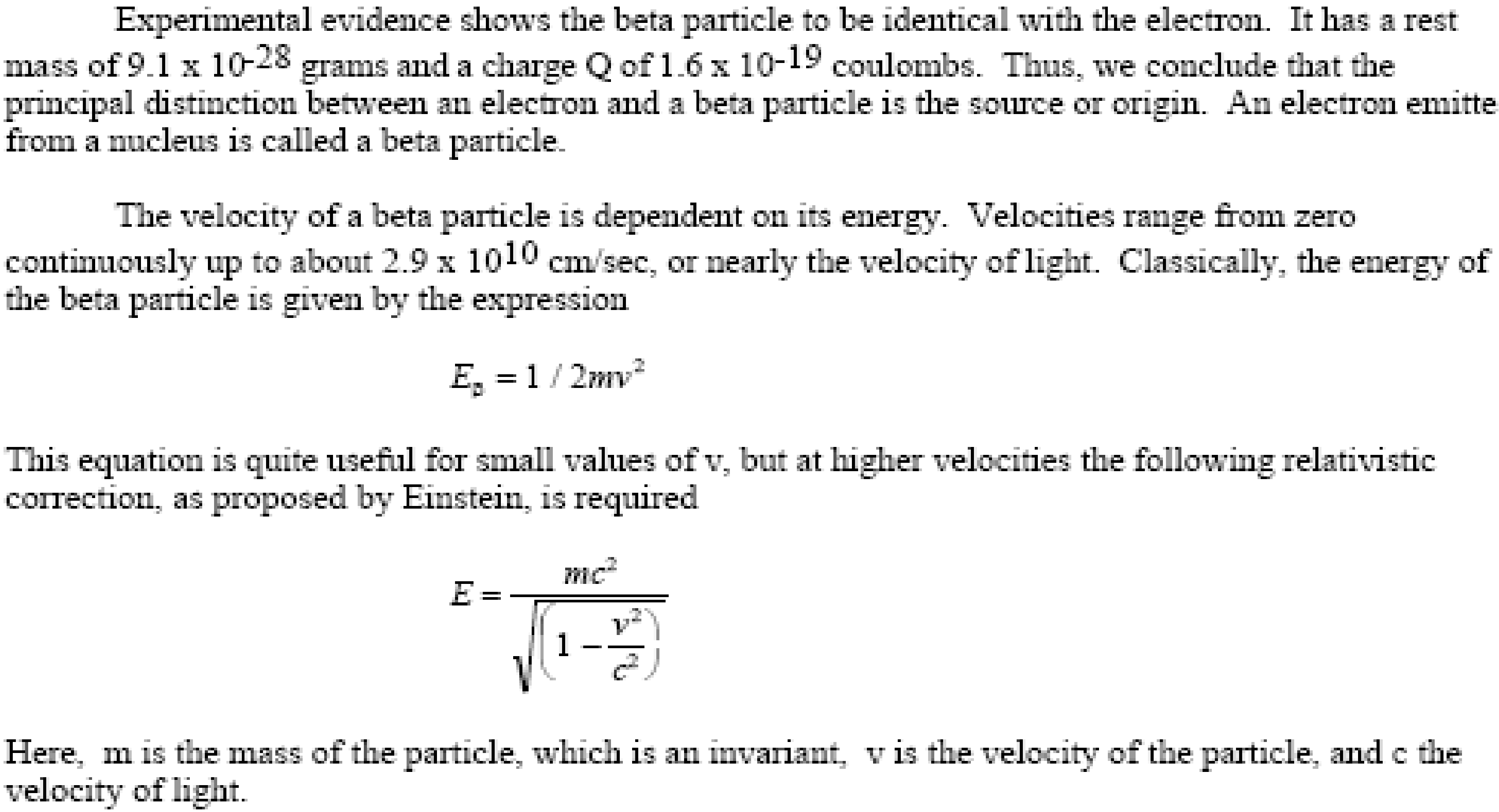

Beta Decay 4

Figure 2: For each nuclear state, reresented by a horizontal bar, the number on the left is the angular momentum, the sign is the parity of the nucleus, and the number on the right is the energy, in MeV, relative to the lowest energy in the scheme. EC is for electron capture. IC is for internal conversion. From Dan Walter '96

Beta Velocities



Experimental evidence shows the beta particle to be identical with the electron. It has a rest mass of 9.1 x 10^{-28} grams and a charge Q of 1.6 x 10^{-19} coulombs. Thus, we conclude that the principal distinction between an electron and a beta particle is the source or origin. An electron emitte from a nucleus is called a beta particle.

The velocity of a beta particle is dependent on its energy. Velocities range from zero continuously up to about 2.9 x 10^{10} cm/sec, or nearly the velocity of light. Classically, the energy of the beta particle is given by the expression

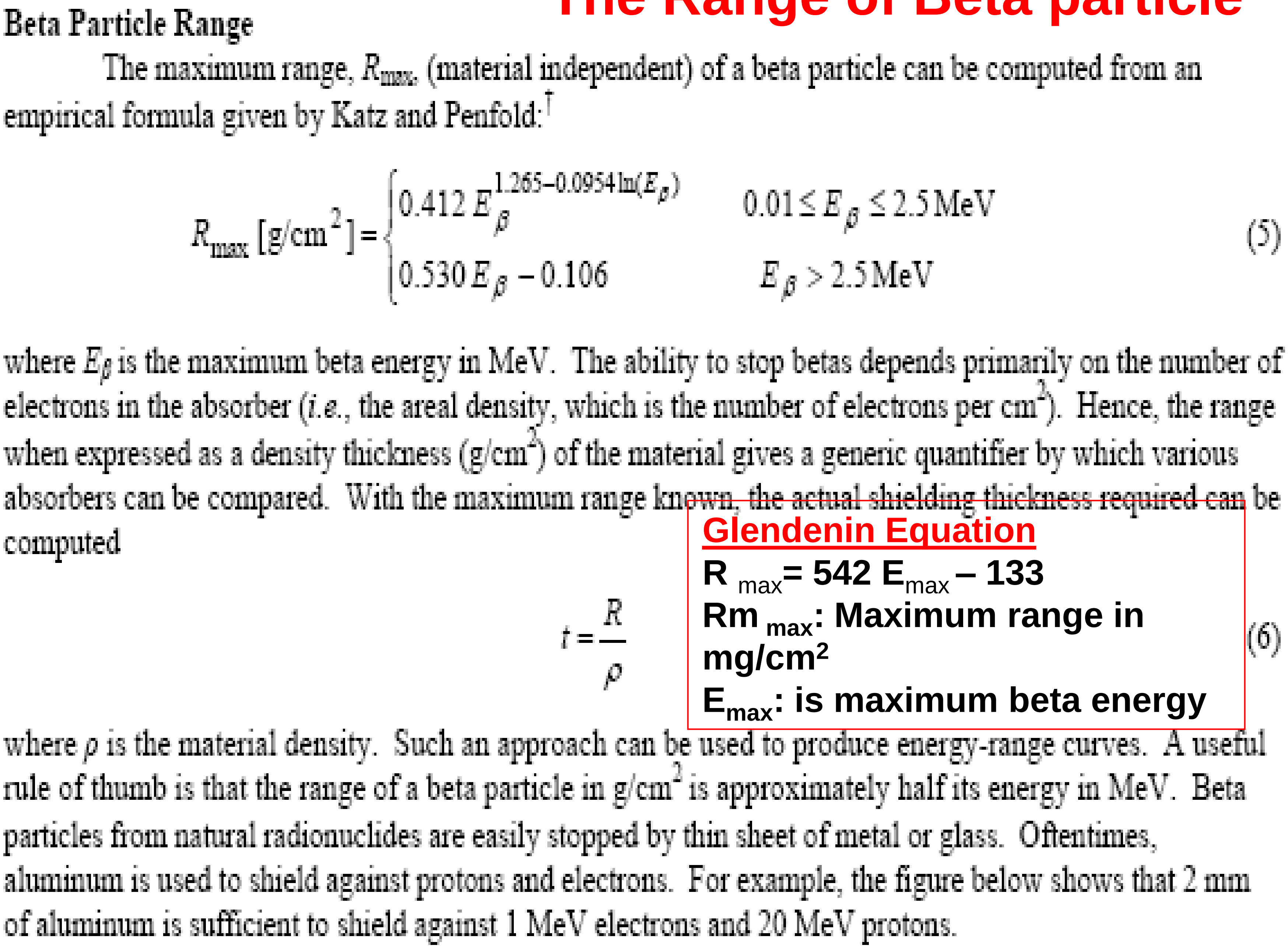
$$E_p = 1 / 2mv^2$$

This equation is quite useful for small values of v, but at higher velocities the following relativistic correction, as proposed by Einstein, is required

$$E = \frac{mc^2}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

Here, m is the mass of the particle, which is an invariant, v is the velocity of the particle, and c the velocity of light.

The Range of Beta particle



Beta Particle Range

The maximum range, R_{max}, (material independent) of a beta particle can be computed from an empirical formula given by Katz and Penfold:[†]

$$R_{max}\,[\mathrm{g/cm^2}] = \begin{cases} 0.412\,E_\beta^{1.265-0.0954\ln(E_\beta)} & 0.01 \le E_\beta \le 2.5\,\mathrm{MeV} \\ 0.530\,E_\beta - 0.106 & E_\beta > 2.5\,\mathrm{MeV} \end{cases} \quad (5)$$

where E_β is the maximum beta energy in MeV. The ability to stop betas depends primarily on the number of electrons in the absorber (*i.e.*, the areal density, which is the number of electrons per cm^2). Hence, the range when expressed as a density thickness (g/cm^2) of the material gives a generic quantifier by which various absorbers can be compared. With the maximum range known, the actual shielding thickness required can be computed

$$t = \frac{R}{\rho} \quad (6)$$

where ρ is the material density. Such an approach can be used to produce energy-range curves. A useful rule of thumb is that the range of a beta particle in g/cm^2 is approximately half its energy in MeV. Beta particles from natural radionuclides are easily stopped by thin sheet of metal or glass. Oftentimes, aluminum is used to shield against protons and electrons. For example, the figure below shows that 2 mm of aluminum is sufficient to shield against 1 MeV electrons and 20 MeV protons.

Glendenin Equation

R_{max} = 542 E_{max} – 133

Rm_{max}: Maximum range in mg/cm^2

E_{max}: is maximum beta energy

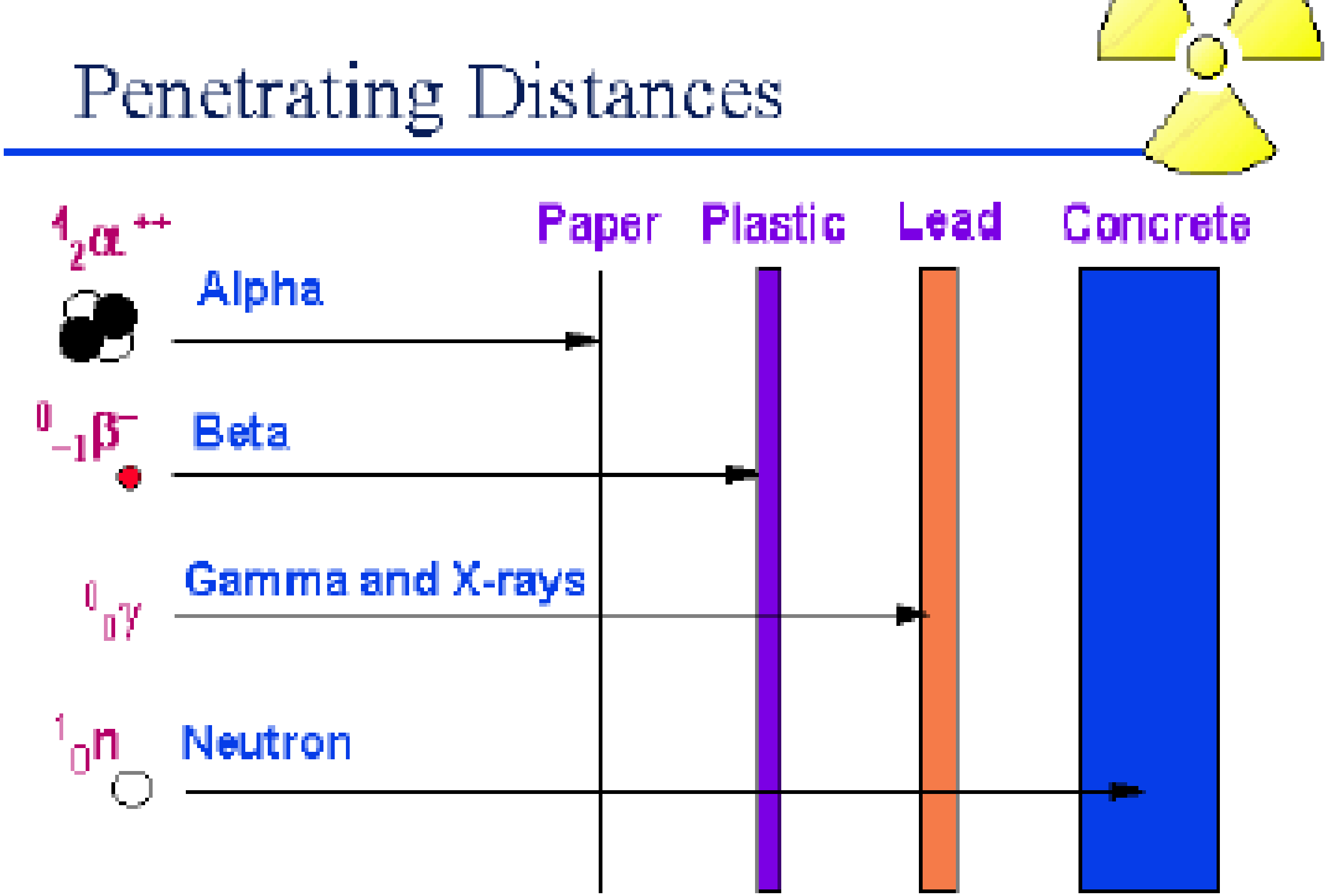


Figure 1 Effective Shielding Materials for Various Radiation Types

Like alpha particles, however, beta particles can get inside the body. Sometimes, this trait is used to advantage, as when radioactive elements are introduced to the body to treat a cancer.

Example:

Determine the copper thickness necessary to stop the beta particles emitted from Co-60.

Solution:

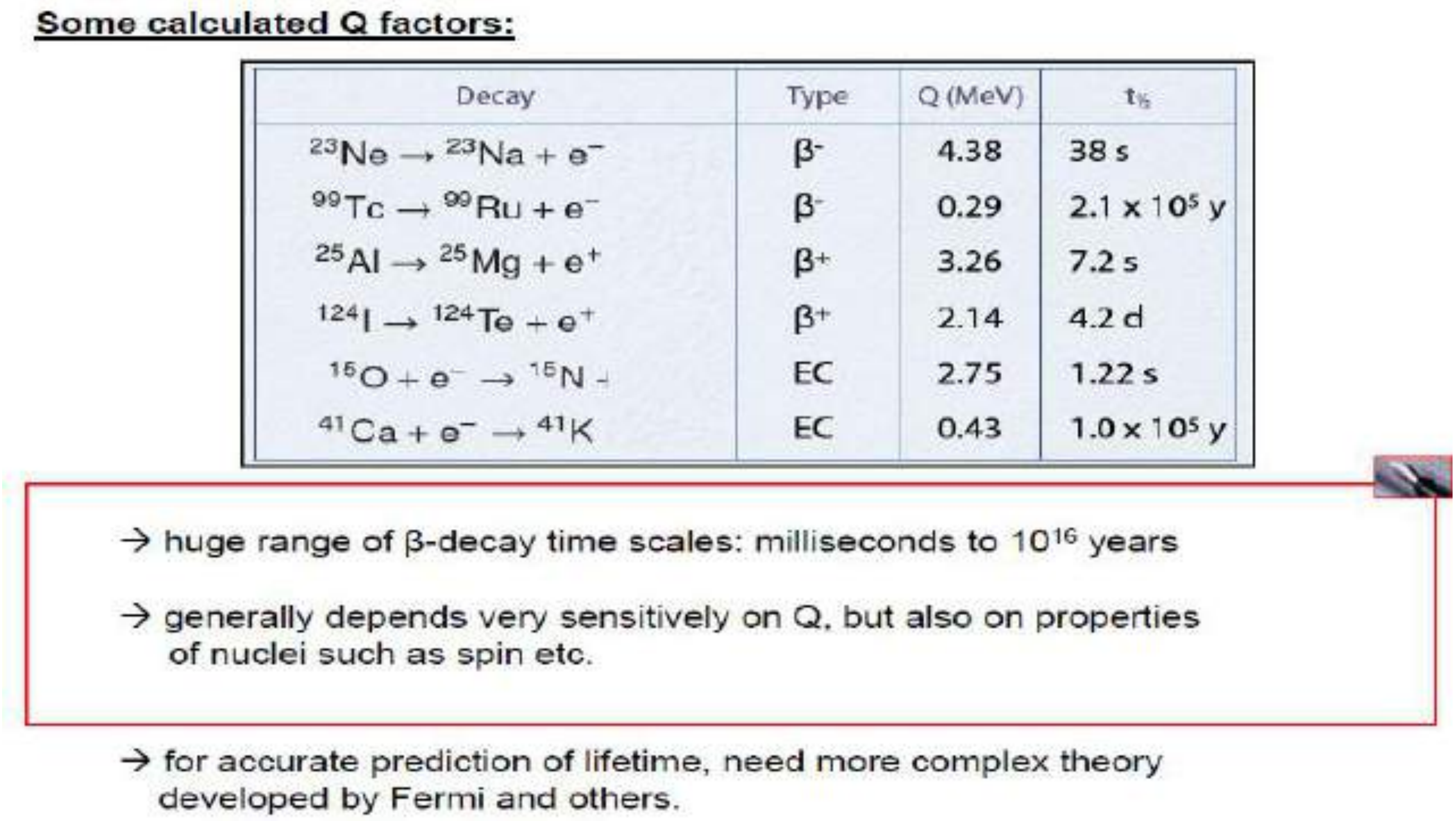
Cobalt-60 emits beta particles with a maximum energy of 0.3179 MeV, hence the maximum range of those particles is

$$R_{\max} = (0.412)\,(0.3179)^{1.265-0.0954\ln(0.3179)} = 0.08529\ \text{g/cm}^2$$

Copper has a density of 8.933 g/cm^3, so the actual shield thickness necessary is

$$thickness = \frac{R_{\max}}{\rho} = \frac{0.08529\,\text{g/cm}^2}{8.933\,\text{g/cm}^3} = 0.00955\ \text{cm}$$

Relationship between E_{max} and $t_{1/2}$



Some calculated Q factors:

Decay	Type	Q (MeV)	$t_{½}$
$^{23}\mathrm{Ne} \to {}^{23}\mathrm{Na} + e^-$	β^-	4.38	38 s
$^{99}\mathrm{Tc} \to {}^{99}\mathrm{Ru} + e^-$	β^-	0.29	2.1×10^5 y
$^{25}\mathrm{Al} \to {}^{25}\mathrm{Mg} + e^+$	β^+	3.26	7.2 s
$^{124}\mathrm{I} \to {}^{124}\mathrm{Te} + e^+$	β^+	2.14	4.2 d
$^{15}\mathrm{O} + e^- \to {}^{15}\mathrm{N}$ +	EC	2.75	1.22 s
$^{41}\mathrm{Ca} + e^- \to {}^{41}\mathrm{K}$	EC	0.43	1.0×10^5 y

→ huge range of β-decay time scales: milliseconds to 10^{16} years

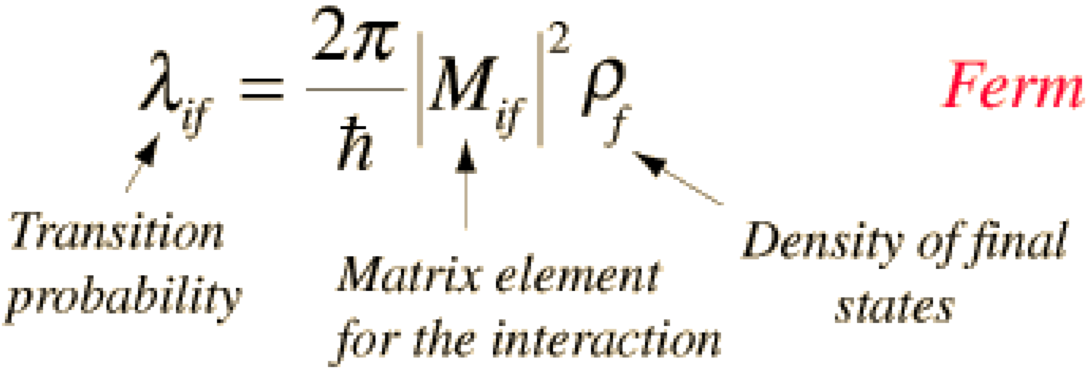
→ generally depends very sensitively on Q, but also on properties of nuclei such as spin etc.

→ for accurate prediction of lifetime, need more complex theory developed by Fermi and others.

High-energy beta emitters have a short half-life

Radioactive decay constant of beta

- **Fermi Theory of Beta Decay**



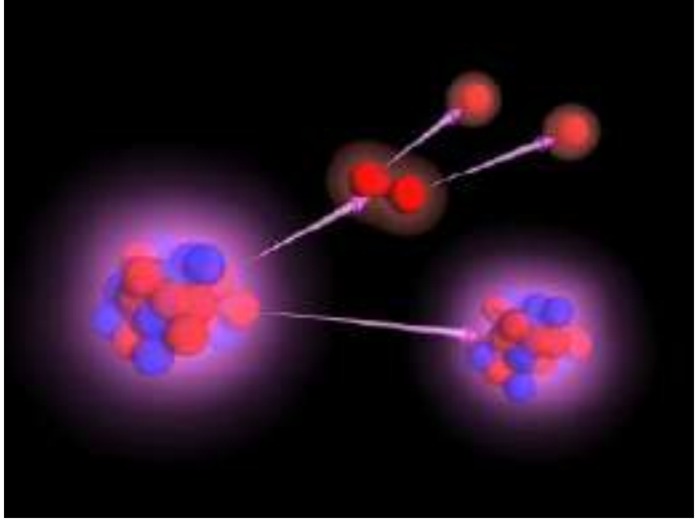
$$\lambda_{if} = \frac{2\pi}{\hbar} \left| M_{if} \right|^2 \rho_f$$

Fermi's Golden Rule

High-energy beta emitters have a short half-life
Enrico Fermi derived an equation give the relation between λ and E_{max}

$$\lambda = K\ E_{\max}$$

Double-Beta Decay



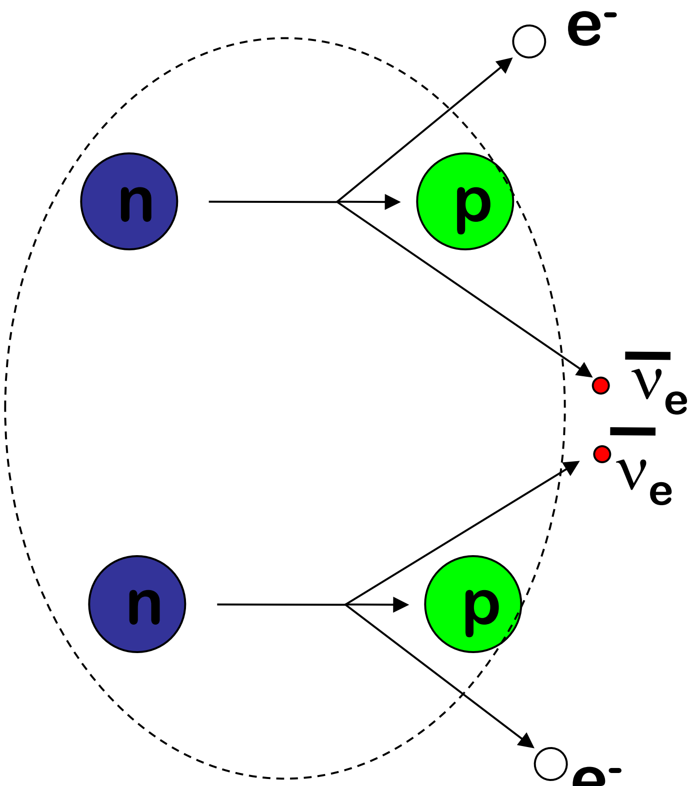
- ^{130}Te, ^{82}Se stable to ordinary beta decay, but unstable toward 2-beta decay

$$ {}^{130}_{52}Te \xrightarrow{2.5x10^{21}\ \text{y}} {}^{130}_{54}Xe + 2\beta^{-} $$

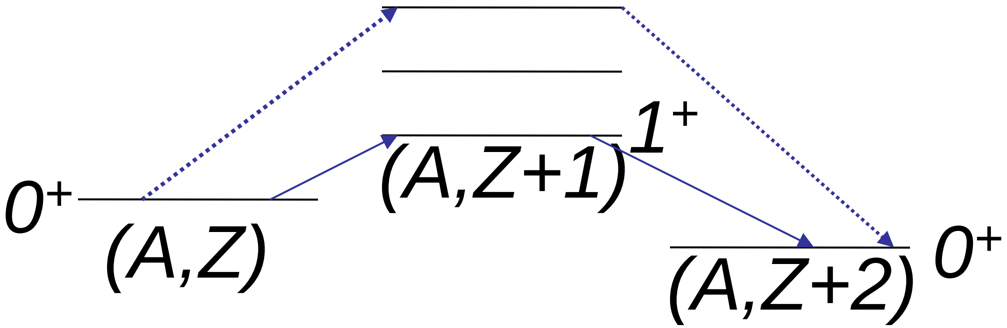
$$ {}^{82}_{34}Se \xrightarrow{1.4x10^{20}\ \text{y}} {}^{82}_{36}Kr + 2\beta^{-} $$

- Simultaneous 2 beta emission

Double Beta Decay ($2\nu\beta\beta$)



$(A,Z) \rightarrow (A,Z+2) + 2\ e^- + 2\bar{\nu}_e$



Only 35 isotopes known in nature

Double beta decay

- **Double beta decay is a radioactive decay process where a nucleus releases two beta rays as a single process.**

  In double-beta decay, two neutrons in the nucleus are converted to protons, and two electrons and two electron antineutrinos are emitted.

- **In order for beta decay to be possible, the final nucleus must have a larger binding energy than the original nucleus.**

- **Double-beta decay is the rarest known kind of radioactive decay; it was observed for only 35 isotopes, and all of them have a mean life time of more than 10^{19} yr.**

- **If the mass difference between the parent and daughter atoms is more than 1.022 MeV/c2 (two electron masses), another decay branch is accessible, with capture of one orbital electron and emission of one positron.**
- **When the mass difference is more than 2.044 MeV/c2 (four electron masses), the emission of two positrons is possible.**

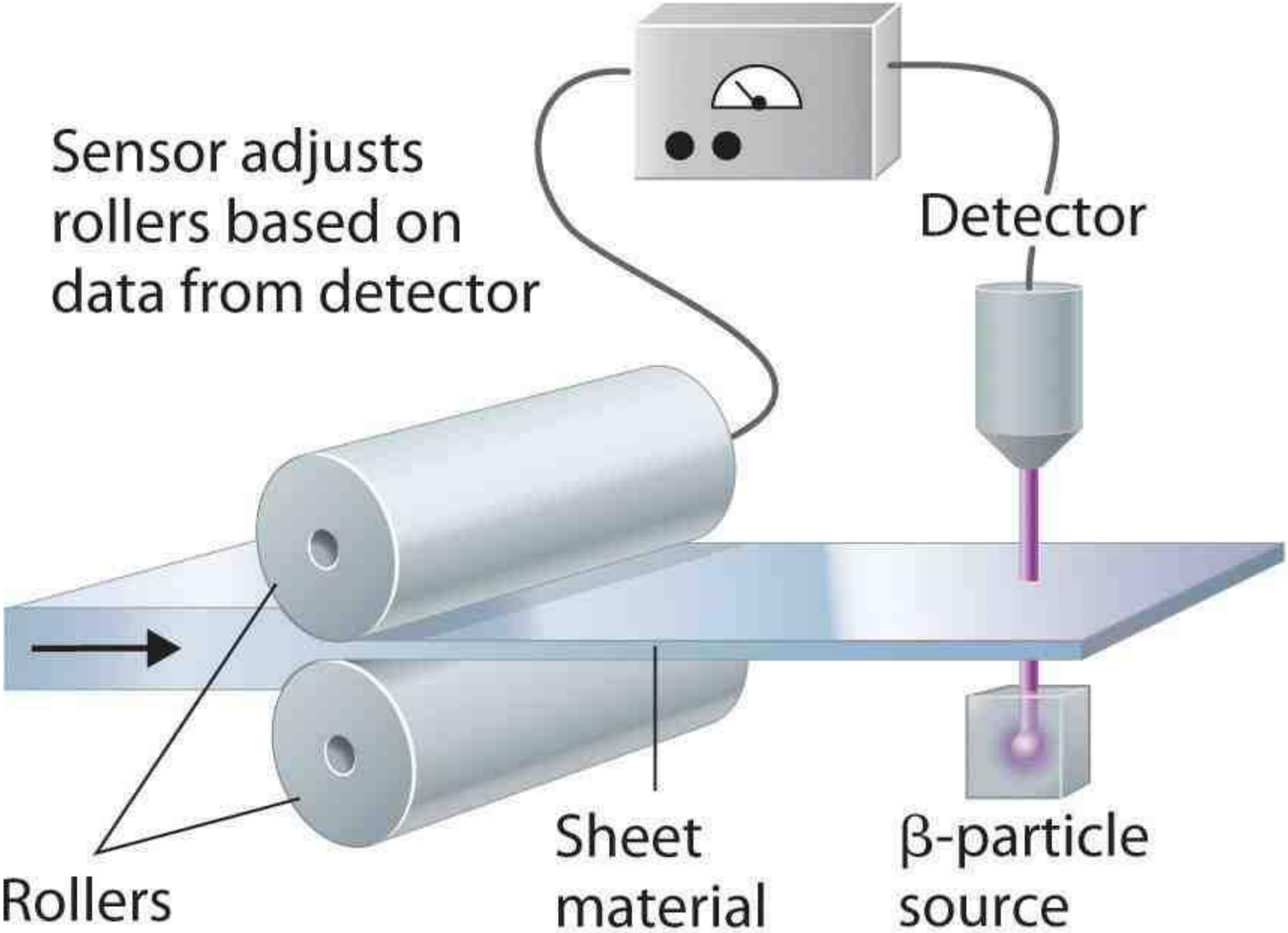
Interaction of B^- and Matter

- Charge –1, mass 0.000,584 u
- Travel very fast (90-99% c)
- 100-300 ion pairs per cm in air
- Lose their energy in 20 m in air.
- Create x-rays from bremsstrahlung

Uses of Beta radiation

- Beta particles can be used to treat health conditions such as eye and bone cancer and are also used as tracers. Strontium-90 is the material most commonly used.

- Beta particles are also used in quality control to test the thickness of an item, such as paper, coming through a system of rollers


Sensor adjusts rollers based on data from detector
Detector
Rollers
Sheet material
β-particle source

Application of

Beta plus (or positron) decay of a radioactive tracer isotope is the source of the positrons used in positron emission tomography (PET scan).

What machine uses this concept?

Nuclear Cardiology: Technical Applications

By Gary V Heller, April Mann, Robert C. Hendel
Edition: illustrated
Published by McGraw Hill Professional, 2008
ISBN 0071464751, 9780071464758
352 pages

Positron emission tomography (PET)

1. A nuclear medicine imaging technique which produces a three-dimensional image of functional processes in the body

2. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer)

Image of a typical positron emission tomography (PET) facility

PET (cont.)

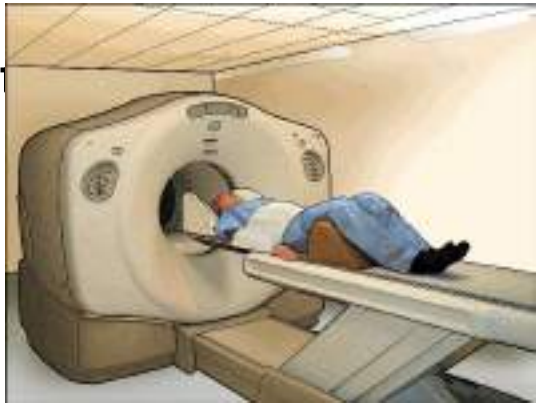
How does it work?

1. **A short-lived radioactive tracer isotope is injected into the living subject**

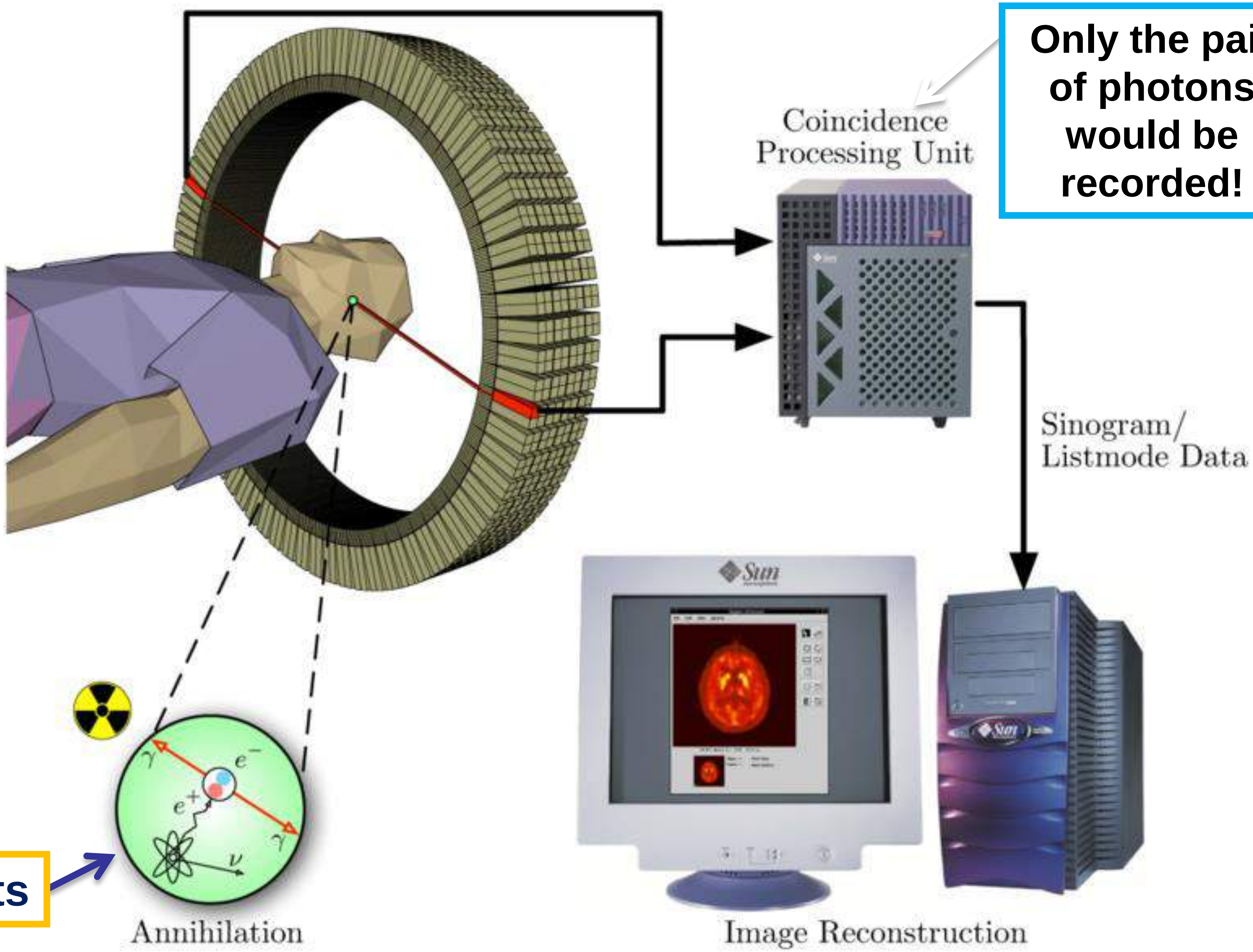
2. **Waiting for a while until the active molecule becom concentrated in tissues of interest**

3. **The object is placed in the imaging scanner**

4. **During the scan a record of tissue concentra is made as the tracer decays**



PET (cont.)



Only the pair of photons would be recorded!

Positron emits

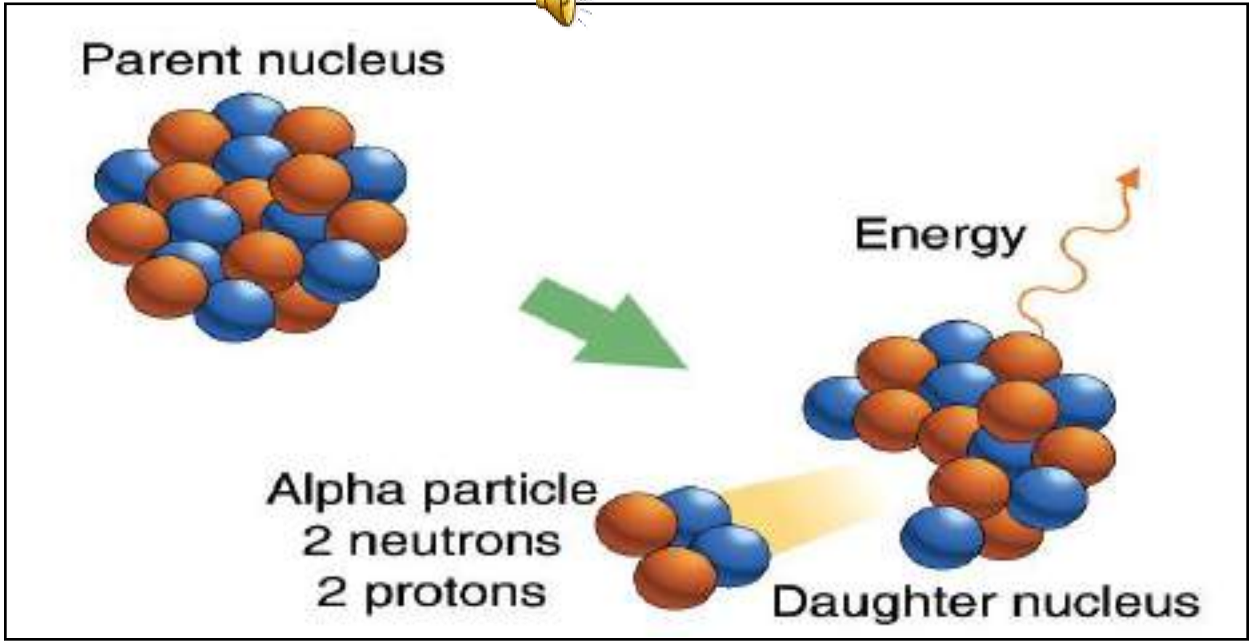
Future application of beta radiation

- لنتصور وجود خلايا بيتا الفولتية لتوفير الطاقة للأجهزة الإلكترونية كالاب توب والهاتف المحمول دون الحاجة لإعادة شحنها مدى الحياة
- An illumination device called a *betalight* contains tritium and a phosphor.
- As tritium decays, it emits beta particles; these strike the phosphor, causing the phosphor to give off photons, much like the cathode ray tube in a television.
- The illumination requires no external power, and will continue as long as the tritium exists (and the phosphors do not themselves chemically change);
- the amount of light produced will drop to half its original value in 12.32 years, the half-life of tritium.

Radioactive Decay

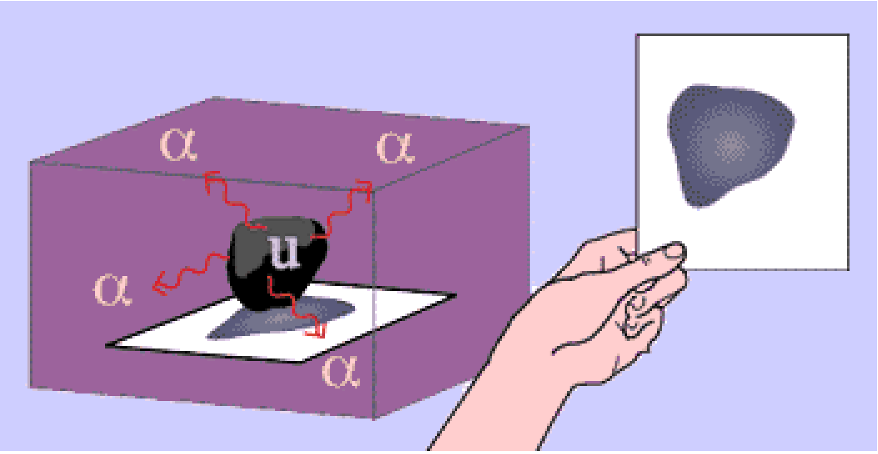
الانحلال الاشعاعى

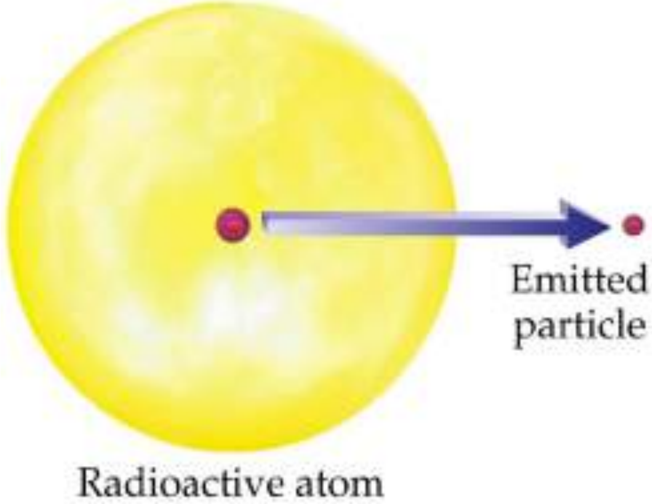
الاضمحلال النووى



Radioactive Decay

- Discovered by **Antoine Henri Becquerel, a French scientist** in 1896
  - He saw that photographic plates developed bright spots when exposed to uranium metals





Antoine Henri ,Becquerel

Courtesy Culver Pictures, Inc.

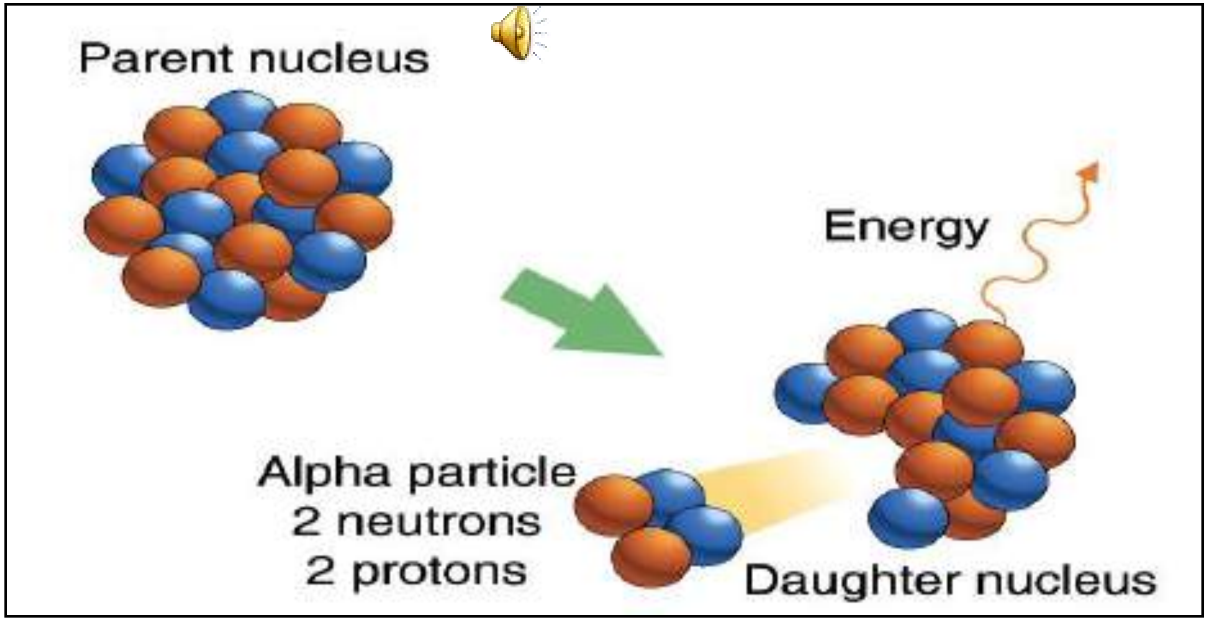
- بينت البحوث التى أجراها العديد من العلماء أن هناك الكثير من المواد التى لها صفة النشاط الاشعاعى
- اكتشف النشاط الاشعاعى و الاصطناعى على يد جوليت وكورى عام 1934

- أدى ذلك الى تصنيع مئات العناصر المشعة بطرق متعددة.

- قوانين التغيرات الاشعاعية تم استنتاجها من معلومات عن العناصر ذات النشاط الاشعاعى التلقائى لكنها تسرى ايضا على العناصر ذات النشاط الاشعاعى الاصطناعى

Radioactive decay

- \- spontaneous change of one kind of atom to another.



Radioactive Decay

Unstable parent isotope decays

Stable daughter isotope created

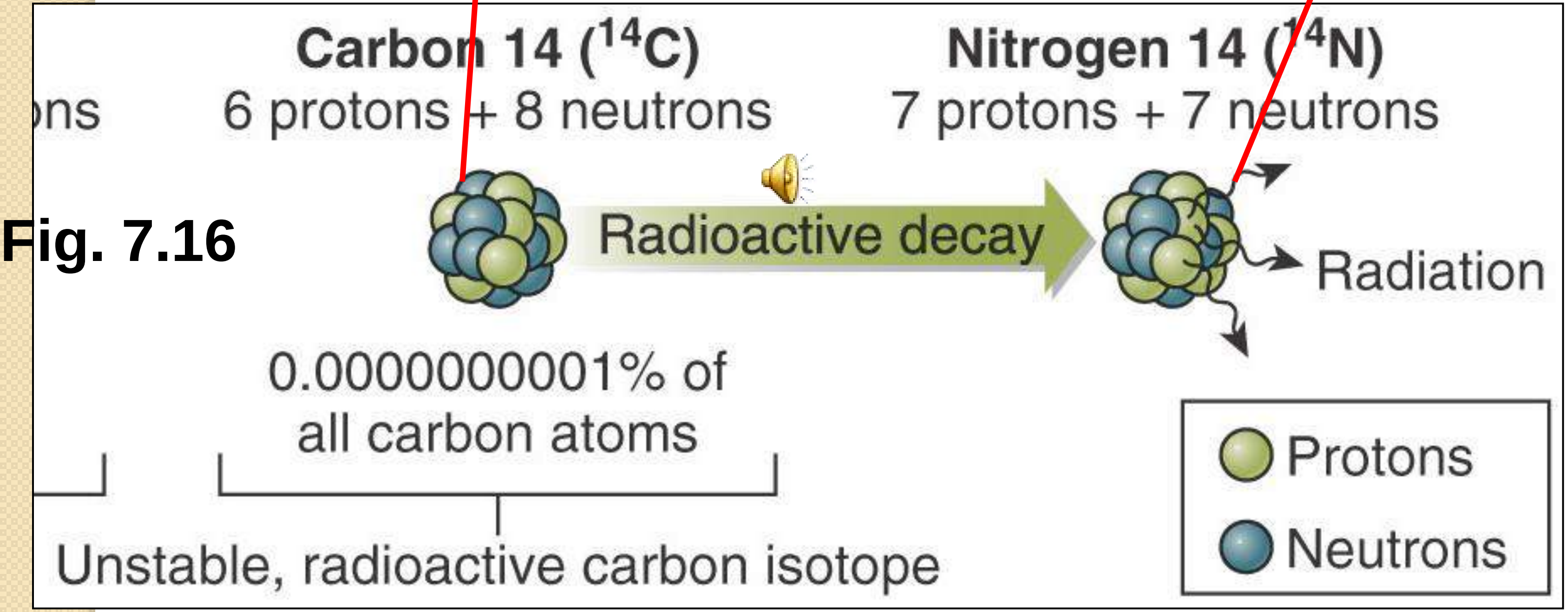


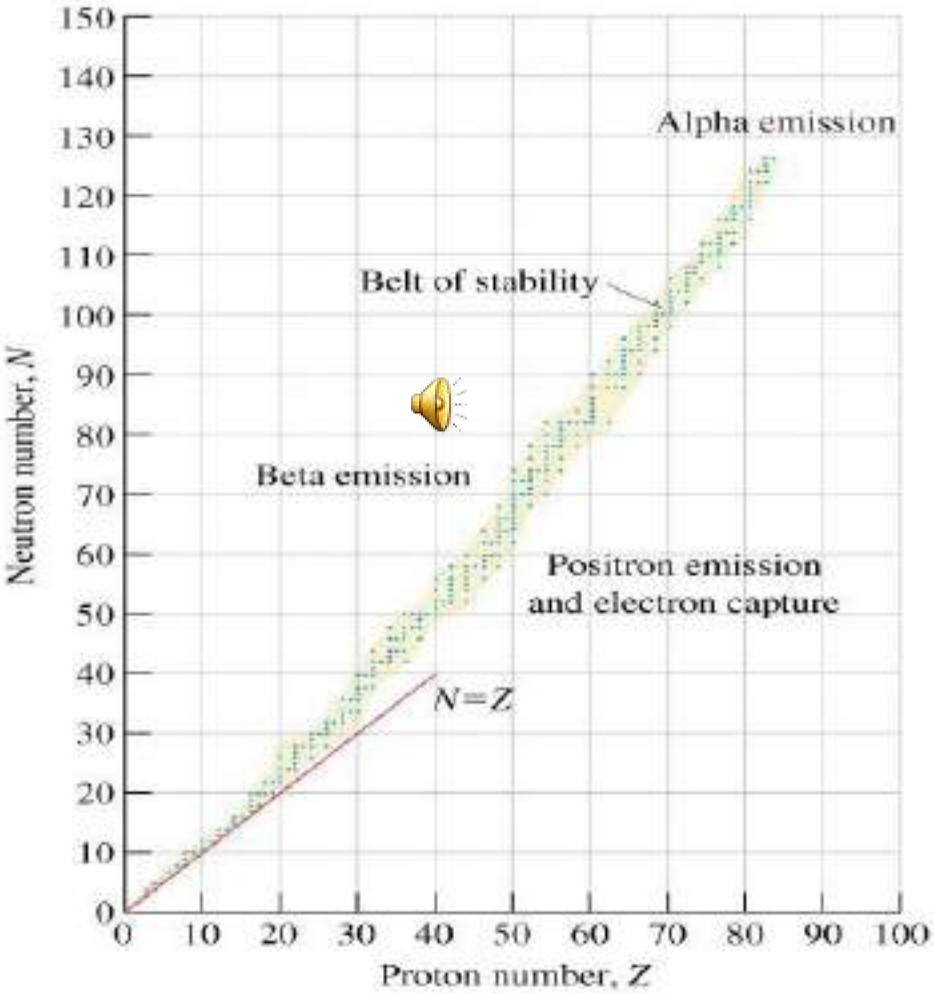
Fig. 7.16

Over time, parent decreases, daughter increases.

RADIOACTIVE DECAY

- Radioactive decay refers to the spontaneous emission of radiation from the nucleus of an unstable atomic nucleus
- The ratio of neutrons to protons is largely determinant of the stability of the nucleus and the tendency for radioactive decay to occur

Neutron-to-Proton Ratio



Nuclear Stability

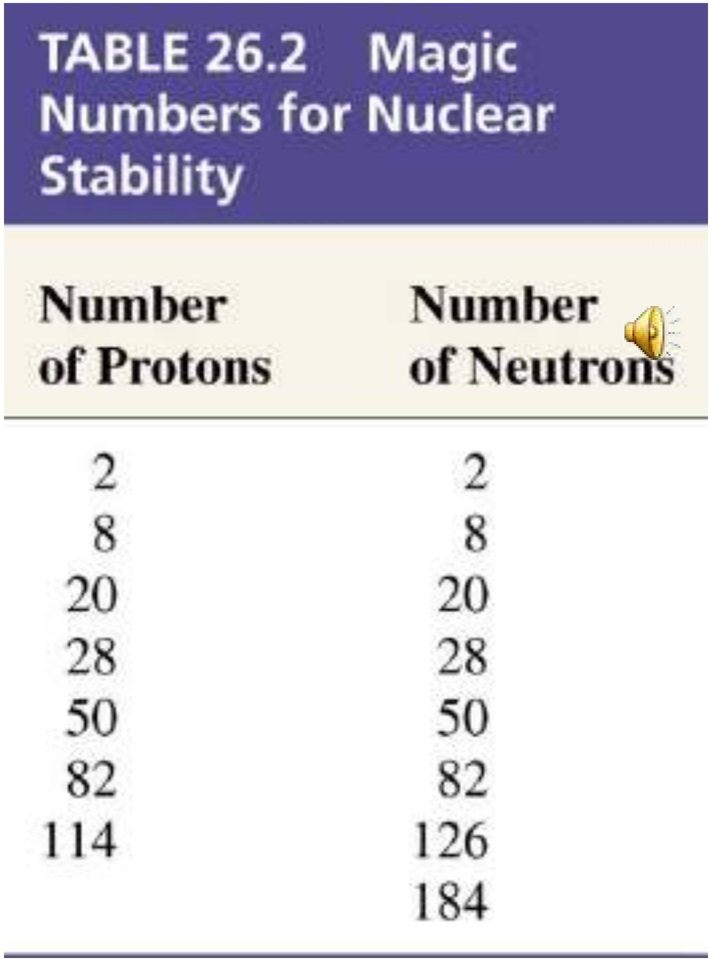


TABLE 26.2 Magic Numbers for Nuclear Stability

Number of Protons	Number of Neutrons
2	2
8	8
20	20
28	28
50	50
82	82
114	126
	184

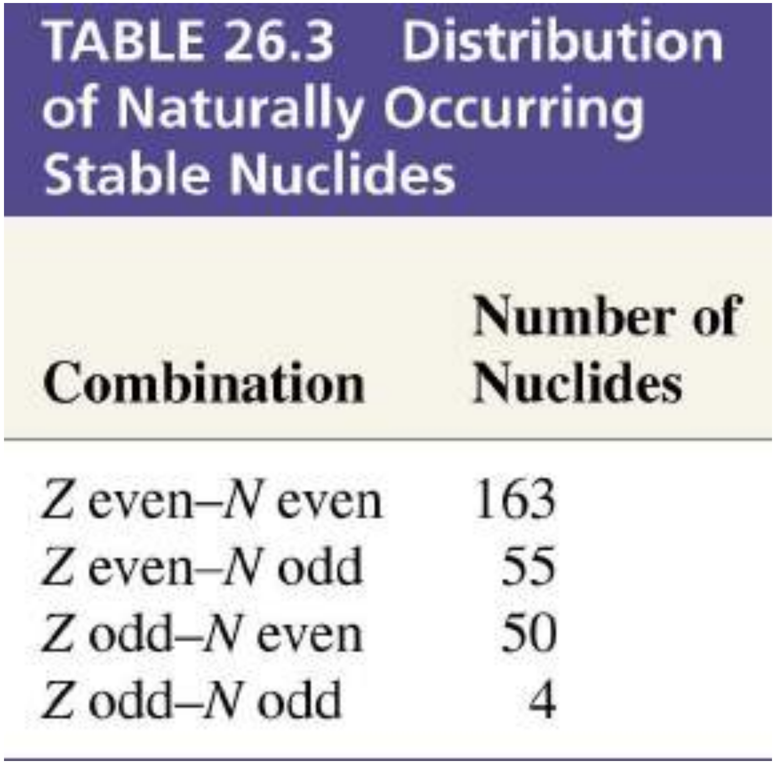


TABLE 26.3 Distribution of Naturally Occurring Stable Nuclides

Combination	Number of Nuclides
Z even–N even	163
Z even–N odd	55
Z odd–N even	50
Z odd–N odd	4

The Radioactive Decay Law

Law for Decay a single radioactive nuclide

- نفترض عينة تحتوى على عدد كبير من النوى المشعة
- كلها من نفس النوع
- و ايضا هذة النوى المشعة تتحلل بنفس العملية سواء كانت بانبعاث ألفا , بيتا أو جاما
- نفرض ايضا أنة عند زمن **t** قدرة يكون لدينا عدد **(N)** من النوى غير منحلة
- فنجد أن معدل النشاط الاشعاعى لمادة مشعة يتوقف على عدد النوى المشعة الموجودة فى المادة أى عدد النوى **(N)** التى لم تضمحل
- ولا يمكن تحفيز النواة المتهيجة على الانحلال أو حتى منعها من الانحلال
- اذن معدل الانحلال لايتأثر بأى عوامل خارجية مثل درجة الحرارة العالية أو الضغط أو المجالات الكهربية و المغناطسية
- ايضا النواة المنحلة ليس لها أى علاقة بماضيها أو كيفية تكوينها
- هناك طريقتين لحساب العمر الزمنى لعملية الانحلال التلقائى و هما عمر النصف **half-life time** و معدل العمر الزمنى **average time**

- **Radioactive decay is the spontaneous release of energy in the form of radioactive particles or waves.**
- **It results in a decrease over time of the original amount of the radioactive material.**
- **Any radioactive isotope consists of a vast number of radioactive nuclei.**
- **Nuclei does not decay all at once.**
- **Decay over a period of time.**
- **We can not predict when it will decay, its a random process but…**
- **We can determine, based on probability, approximately how many nuclei in a sample will decay over a given time period, by asuming that each nucleus has the same probability of decaying in each second it exists.**

Nuclear decay is spontaneous and random because:

- The decay of one nucleus does not affect any other
- The decay of one nucleus is not affected by any external factors (pressure/temp etc.)
- Each nucleus in a sample has the same chance of decaying per unit time
- This makes it impossible to predict when any particular nucleus will decay

Rate of Radioactive Decay

Law for decay of a single radioactive nuclide

Parent (N) $\longrightarrow$ daughter

If N is the number of nuclei present at time t which is not decayed yet

$$\text{Rate of Decay} = -\frac{dN}{dt}$$

Since the number of nuclei which decay in unit time is proportional to N

$$-\frac{dN}{dt} \alpha N$$

$$\frac{dN}{dt} = -\lambda \cdot N$$

$$\frac{dN}{N} = -\lambda \cdot dt \longrightarrow$$

Both sides are integrated

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{0}^{t} dt$$

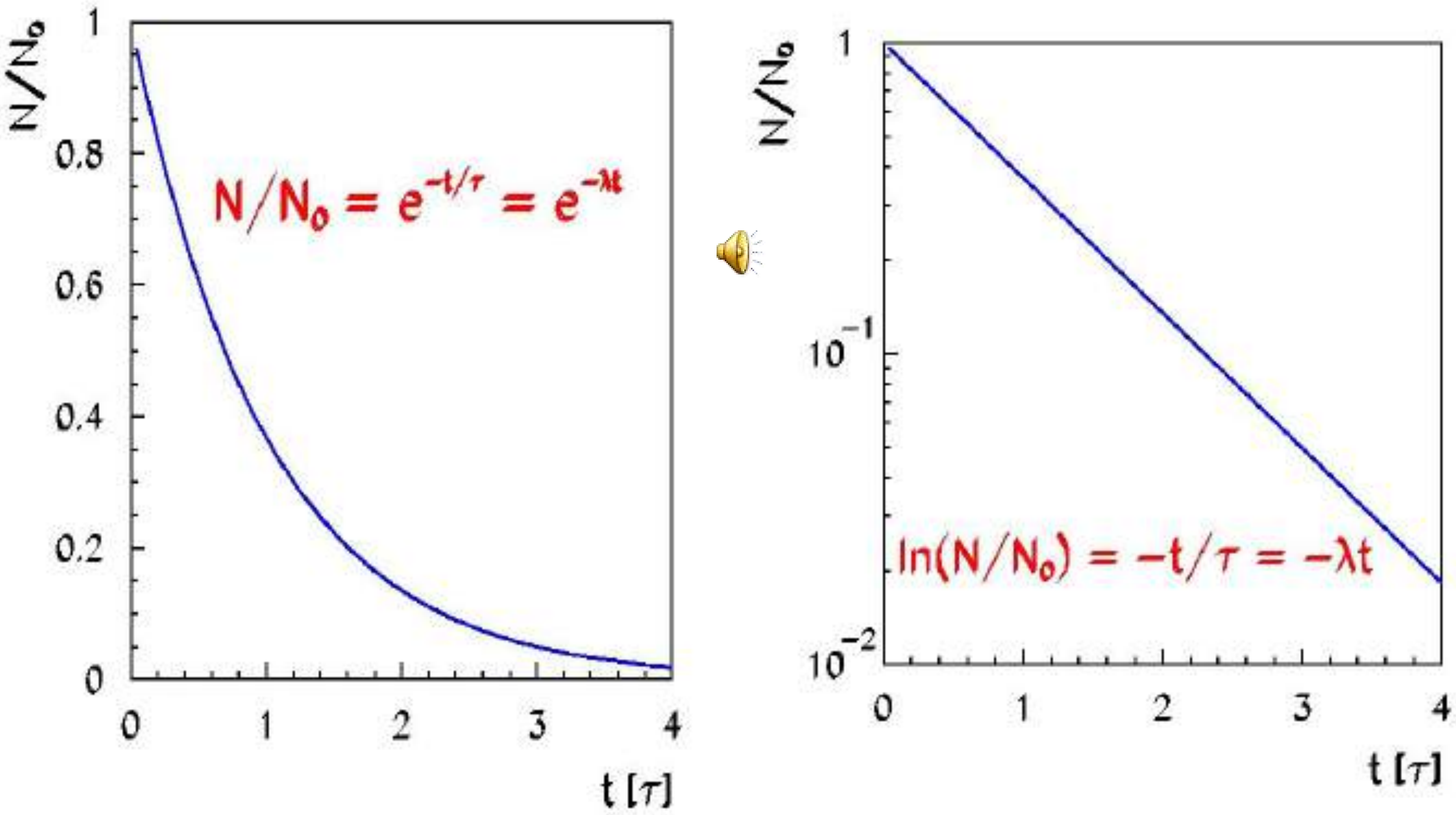
λ is the decay constant

$$\ln N - \ln N_0 = -\lambda t \longrightarrow \ln \frac{N}{N_{\circ}} = -\lambda t \longrightarrow \boxed{N = N_0 e^{-\lambda t}}$$

$$\frac{N}{N_{\circ}} = e^{-\lambda t}$$

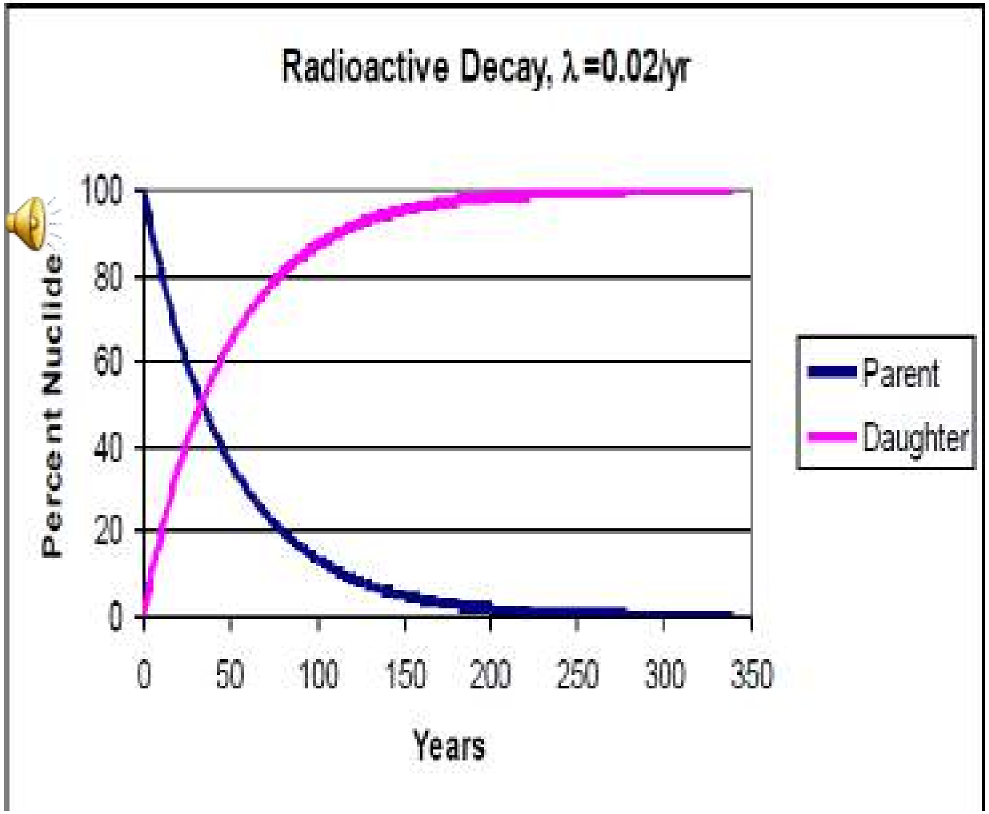
ثابت التفكك الإشعاعي The decay constant

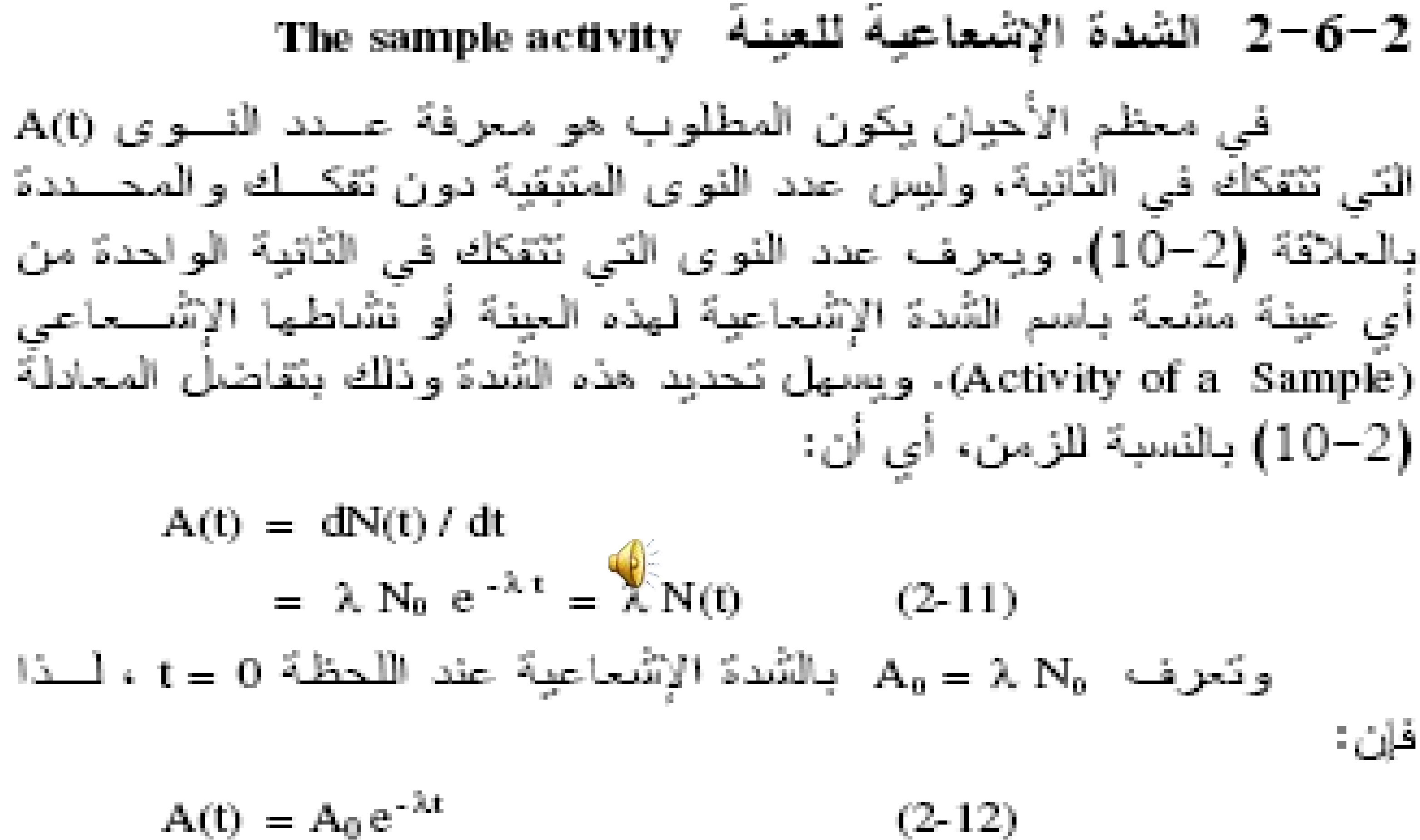
يعرف المعامل λ في العلاقة (1-3) باسم ثابت التفكك الإشعاعي. وهو عبارة عن احتمال تفكك نواة واحدة معينة في ثانية واحدة. ووحدة قياس هذا المعامل هي مقلوب الثانية أي (1/ثانية)، حيث أنها تعبر عن احتمال تفكك النواة في الثانية.



Parent (N) → daughter

- The number of daughter nuclide can be express by the relationship as following:
- $N_d = N_0 - N$
- $N_d = N_0 - N_0\, e^{-\lambda t}$
- $\mathbf{N_d = N_0\,(I - e^{-\lambda t})}$





2-6-2 الشدة الإشعاعية للعينة The sample activity

في معظم الأحيان يكون المطلوب هو معرفة عدد النوى A(t) التي تتفكك في الثانية، وليس عدد النوى المتبقية دون تفكك والمحددة بالعلاقة (2-10). ويعرف عدد النوى التي تتفكك في الثانية الواحدة من أي عينة مشعة باسم الشدة الإشعاعية لهذه العينة أو نشاطها الإشعاعي (Activity of a Sample). ويسهل تحديد هذه الشدة وذلك بتفاضل المعادلة (2-10) بالنسبة للزمن، أي أن:

$$A(t) = dN(t) / dt$$

$$= \lambda N_0 e^{-\lambda t} = \lambda N(t) \qquad (2\text{-}11)$$

وتعرف $A_0 = \lambda N_0$ بالشدة الإشعاعية عند اللحظة $t = 0$ ، لذا فإن:

$$A(t) = A_0 e^{-\lambda t} \qquad (2\text{-}12)$$

$$\boxed{A = \lambda N}$$

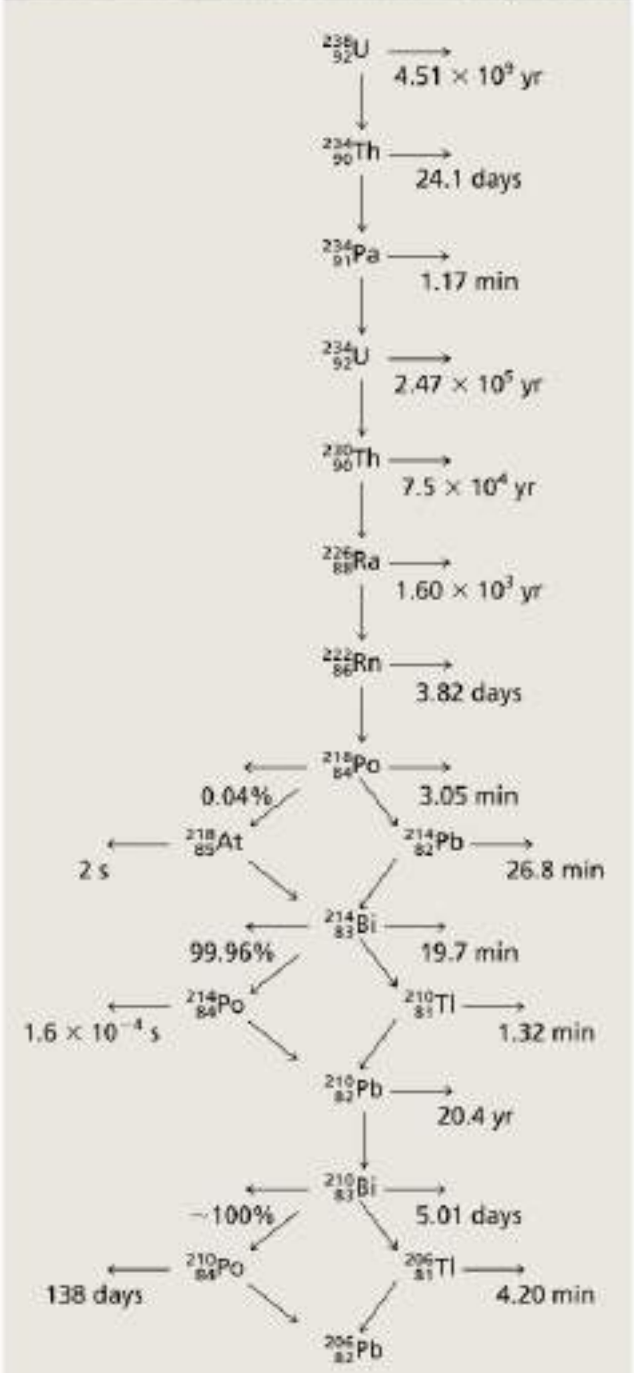
$$\boxed{N = N_0 e^{-\lambda t}}$$

Then for radioactivity we obtain:

$$\boxed{A = \lambda N_0 e^{-\lambda \cdot t} = A_0 e^{-\lambda \cdot t}}$$

where $A_0 = \lambda N_0$

Table 22.3 The Uranium Decay Series



Kinetics of Radioactive Decay

$$A \longrightarrow \text{daughter}$$

$$\text{rate} = -\frac{\Delta A}{\Delta t}$$

$$\boxed{A = A_0 e^{(-\lambda t)}}$$

$$\ln A = \ln A_0 - \lambda t$$

A = the amount(activity) of atoms at time t

A_0 = the amount(activity) of atoms at time $t = 0$

k is the decay constant (sometimes called λ

$$t_{1/2} = \frac{\text{Ln } 2}{\lambda} \qquad \boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

Measured Activity

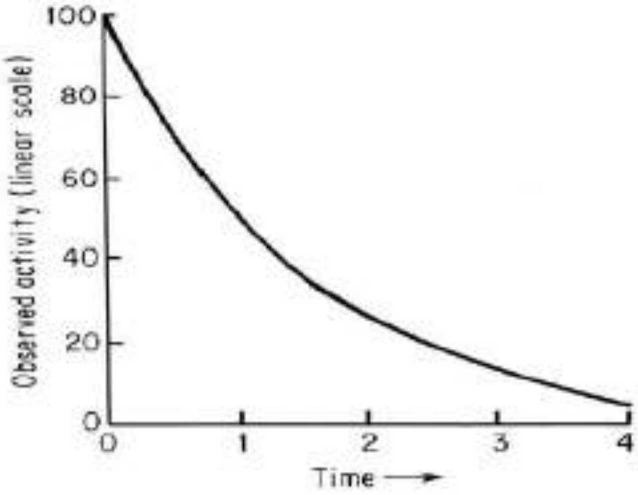
- **In practicality, activity (A) is used instead of the number of atoms (N).**

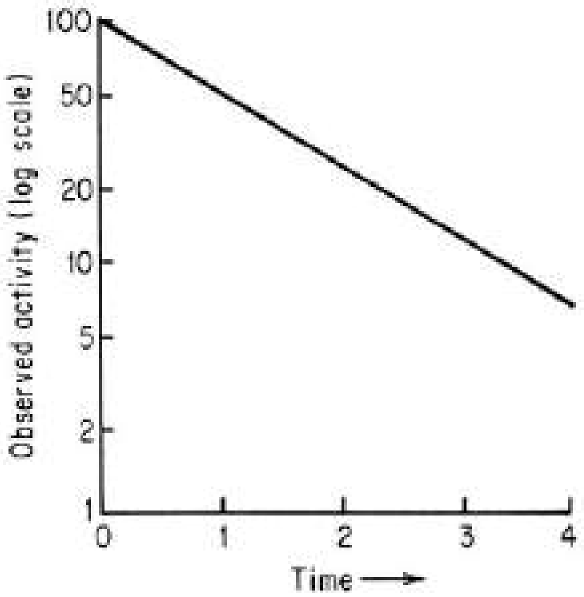
$$A = \lambda N_0 e^{-\lambda \cdot t} = A_0 e^{-\lambda \cdot t}$$

$$\ln \frac{A}{A_o} = -\lambda t$$

$$\ln A = -\lambda t + \ln A_o$$

$$\frac{A}{A_o} = e^{-\lambda t}$$





Units of Activity

- Curie (Ci) = no. of dis/s occurring in a mass of 1 g of ^{226}Ra
- Now 1 Ci = 3.7×10^{10} dis/s = 0.988 mg ^{226}Ra
- New SI units → 1 Bq = 1 dis/s

11-1 وحدات قياس الشدة الإشعاعية (النشاط الإشعاعي)

كانت الوحدة الأساسية لقياس الشدة الإشعاعية للعينة هي الكوري **Curie (Ci)** وأجزاؤه، وهي الميللي كوري **mCi** ، والميكروكوري **μCi**. والكوري وحدة كبيرة، حيث أن العينة التي تبلغ شدتها 1 كوري هي تلك العينة التي يحدث فيها 3.7×10^{10} تفككا في الثانية في الجيل الأول من تفككها إذا كانت العينة من النوع الذي يتميز بالتفكك المتتابع، ويبين الجدول التالي العلاقة بين بعض أجزاء الكوري ووحدة النظام المعياري العالمي المعروفة بالبكرل.

1 كوري = 3.7×10^{10} تفكك في الثانية أو بكرل
1 ميللي كوري = 3.7×10^{7} تفكك في الثانية أو بكرل
1 ميكروكوري = 3.7×10^{4} تفكك في الثانية أو بكرل

وتستخدم الآن الوحدة المعيارية الدولية لقياس الشدة الإشعاعية في النظام المعياري الدولي وهذه الوحدة هي البكرل **bequerel** . والبكرل الواحد عبارة عن تفكك واحد في الثانية. ونظراً لصغر هذه الوحدة تستخدم في كثير من الأحيان مضاعفاتها وهي:

الكيلو بكرل والميغا بكرل والغيغا بكرل وهي:

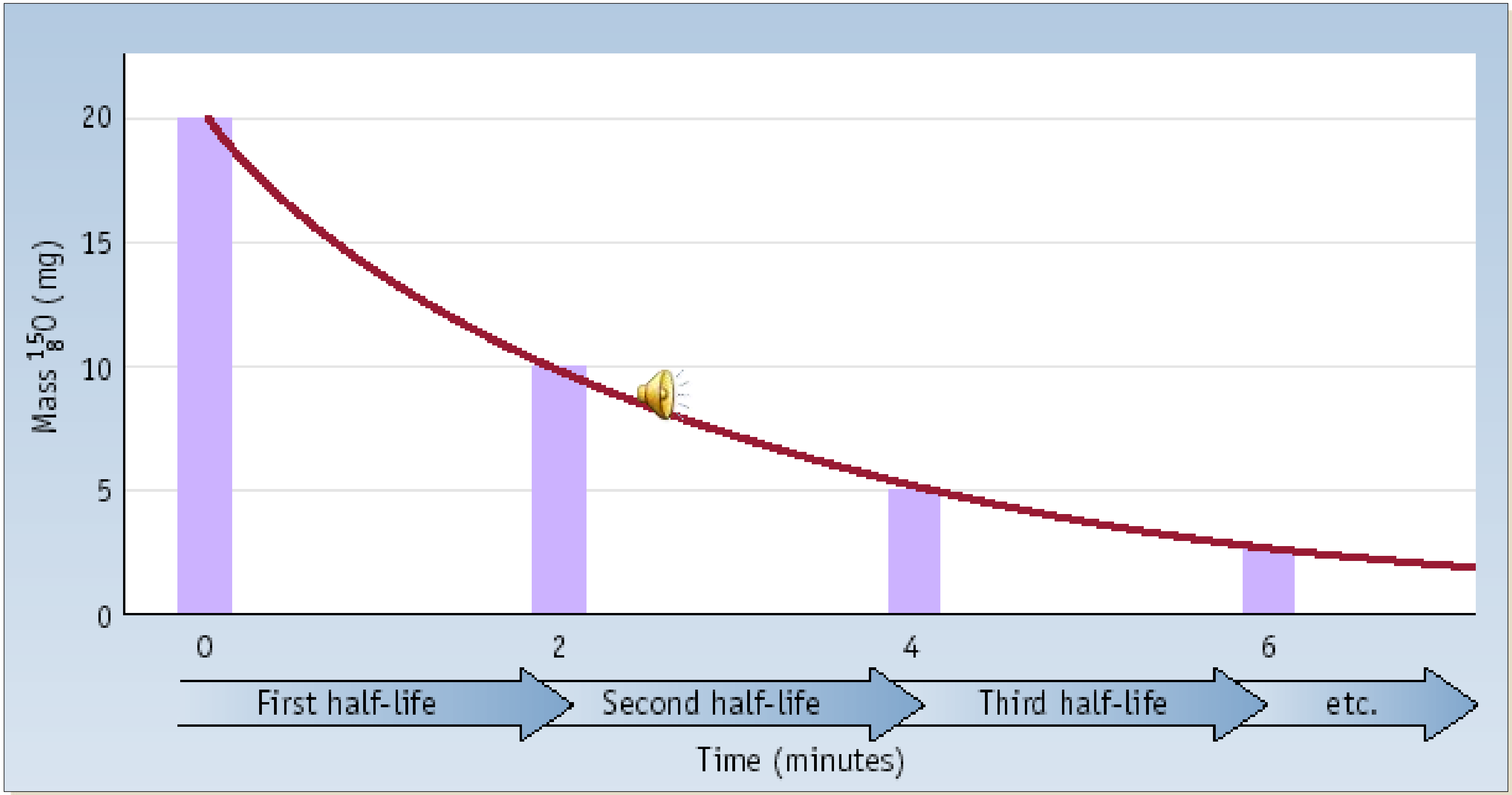
1 كيلوبكرل = 10^{3} بكرل
1 ميغا بكرل = 10^{6} بكرل
1غيغا بكرل = 10^{9} بكرل

Rate of Decay

- Frequently measured as the radioisotope's ***half life***
    - the time required for one-half of the sample of radioisotope to decay
    - half life depends on the identity of the isotope but ***not* on** the original amount.

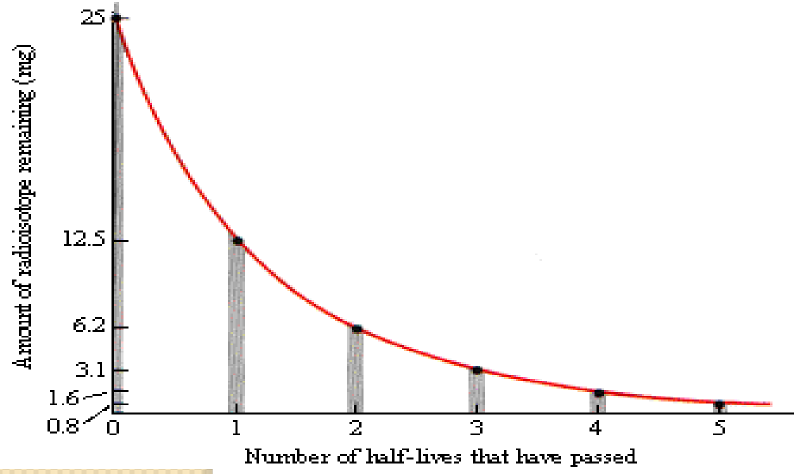
- Short half life ⇒ rapid decay
- Long half life ⇒ slow decay

Half-Life



Decay of 20.0 mg of ^{15}O. What remains after 3 half-lives? After 5 half-lives?

Half Life and decay constant



Half-life is time needed to decrease nuclides by 50%

- **Half life** – time it takes for ½ of the parent to decay to the daughter

•Relationship between $t_{1/2}$ and λ

$N/N_o = e^{-\lambda t} = \frac{1}{2}$ where $N = \frac{1}{2} N_\circ$

$\ln (1/2) = -\lambda\, t_{1/2}$ $\ln 2 = \lambda\, t_{1/2}$

$t_{1/2} = (\ln 2) / \lambda$

$t_{1/2} = 0.693/ \lambda$

Exponential Decay

- Average Life (τ) for a radionuclide
  - found from sum of times of existence of all atoms divided by initial number of nuclei

$$\tau = -\frac{1}{N_o}\int_{t=0}^{t=\infty} t \cdot dN = \frac{1}{\lambda}$$

  - **$1/\lambda=1/(\ln 2/t_{1/2}) = 1.443t_{1/2}= \tau$**
- Average life greater than half life by factor of 1/0.693
- during time 1/λ activity reduced to 1/e it's initial value

2–6–3 عمر النصف ومتوسط العمر The half-life and mean-life

عمر النصف (أو العمر النصفي) للنظير المشع المعين هو عبارة عن الفترة الزمنية التي تنخفض خلالها الشده الإشعاعية لعينة من هذا النظير إلى النصف. وبمعنى آخر فإن عمر النصف هو الزمن اللازم لتفكك نصف عدد نوى العينة. ويرمز للعمر النصفي، عموما، بالرمز $t_{1/2}$. وباقتفاء هذا التعريف فإنه بوضع $N(t) = N_o/2$ ، $t = t_{1/2}$ في العلاقة (2–10) يتبين أن:

$$N_0 / 2 = N_0 e^{-\lambda t1/2}$$

ومنها يتبين أن:

$$t_{1/2} = \ln 2 / \lambda$$

$$= 0.693 / \lambda \qquad (2\text{-}13)$$

وحيث إن وحدة الزمن هي الثانية فإن وحدة قياس ثابت التفكك λ هي 1/ ثانية (أي ثانية$^{-1}$).

أما متوسط العمر لعينة مشعة والذي يرمز له عادة بالرمز τ (تاو) فهو عبارة عن مجموع أعمار جميع النوى العينة مقسوما على عددها ويسهل تحديده باستخدام العلاقة(2–10) كالآتي:

$$\tau = (1 / N_0 \int_{0}^{\infty} dN(t).t = 1/ \lambda = t_{1/2} / 0.693 \qquad (2\text{-}14)$$

وهكذا نجد أن كلا من λ ، $t_{1/2}$ ، τ مرتبطة ببعضها بعلاقة بسيطة، ومعرفة إحداها يعين باقيها.

Table 1 :Some Representative Half-Lives

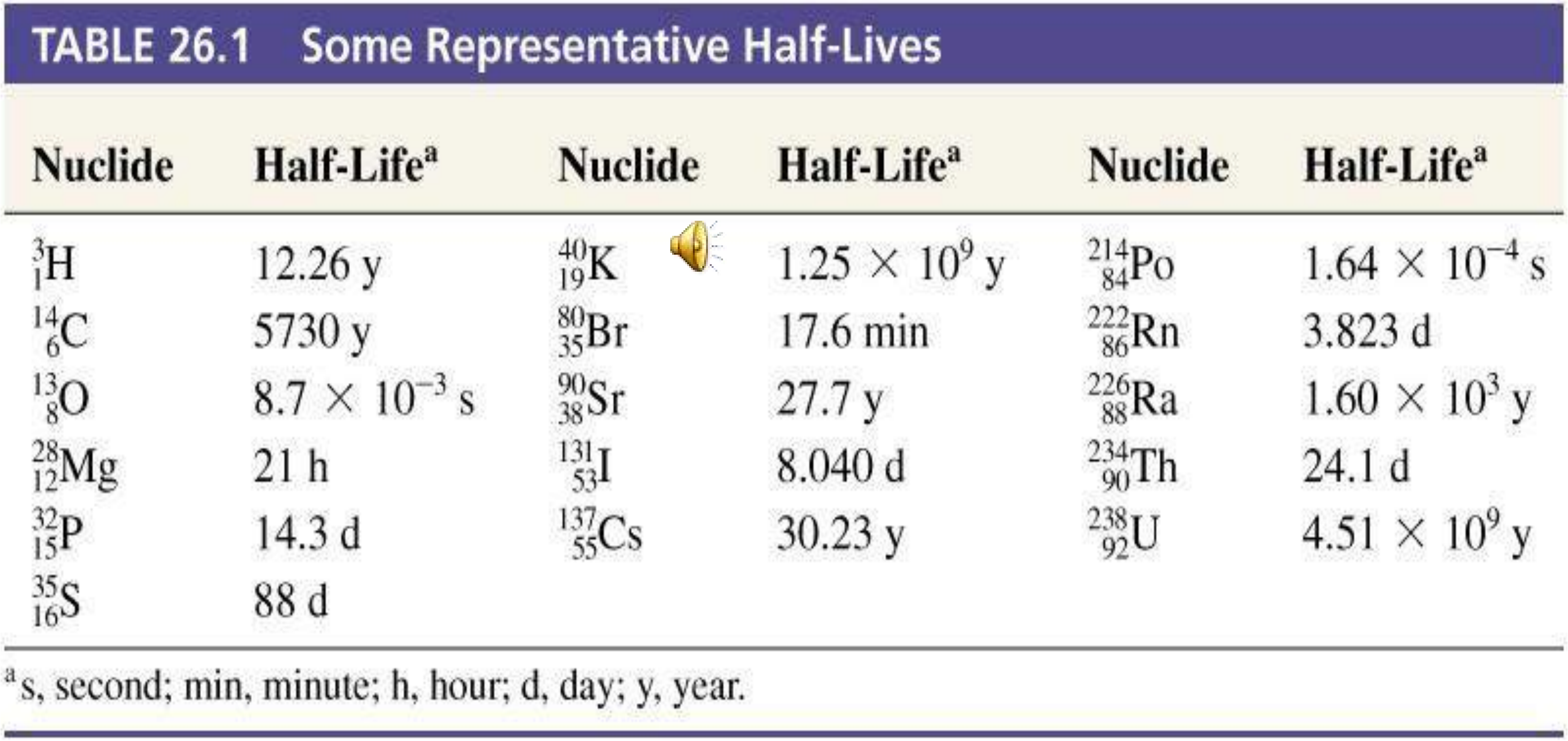


TABLE 26.1 Some Representative Half-Lives

Nuclide	Half-Life[a]	Nuclide	Half-Life[a]	Nuclide	Half-Life[a]
$^{3}_{1}H$	12.26 y	$^{40}_{19}K$	1.25×10^{9} y	$^{214}_{84}Po$	1.64×10^{-4} s
$^{14}_{6}C$	5730 y	$^{80}_{35}Br$	17.6 min	$^{222}_{86}Rn$	3.823 d
$^{13}_{8}O$	8.7×10^{-3} s	$^{90}_{38}Sr$	27.7 y	$^{226}_{88}Ra$	1.60×10^{3} y
$^{28}_{12}Mg$	21 h	$^{131}_{53}I$	8.040 d	$^{234}_{90}Th$	24.1 d
$^{32}_{15}P$	14.3 d	$^{137}_{55}Cs$	30.23 y	$^{238}_{92}U$	4.51×10^{9} y
$^{35}_{16}S$	88 d				

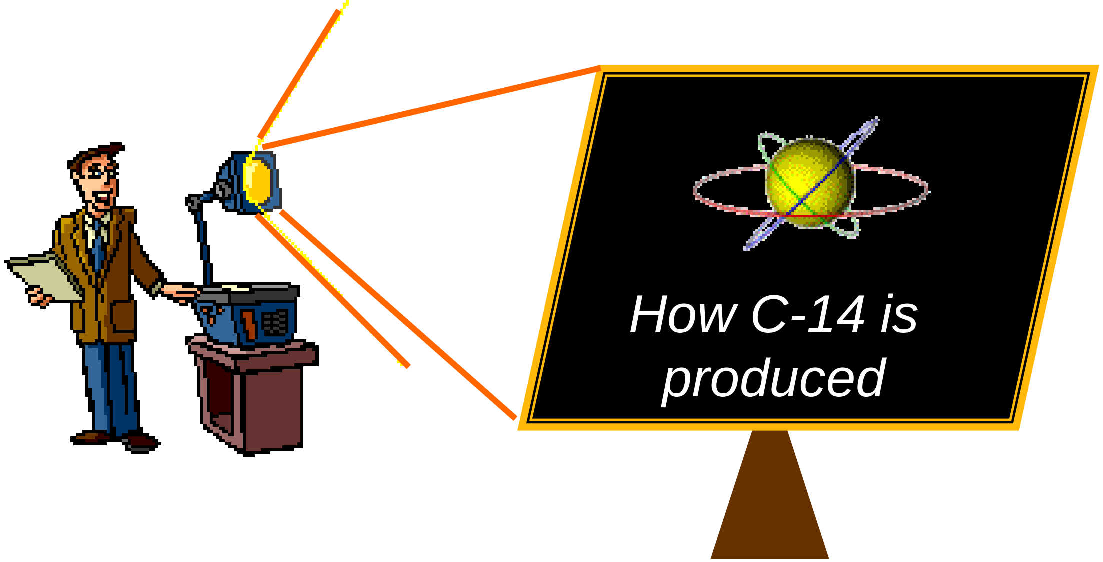
[a] s, second; min, minute; h, hour; d, day; y, year.

Dating Using Radioactive Decay

- Half-life measured in lab by detecting energy released during decay.
    - independent of T and P.
- Radioactive clock starts when rock first forms.
- Age calculation assumes that no parent isotope has been lost/gained.

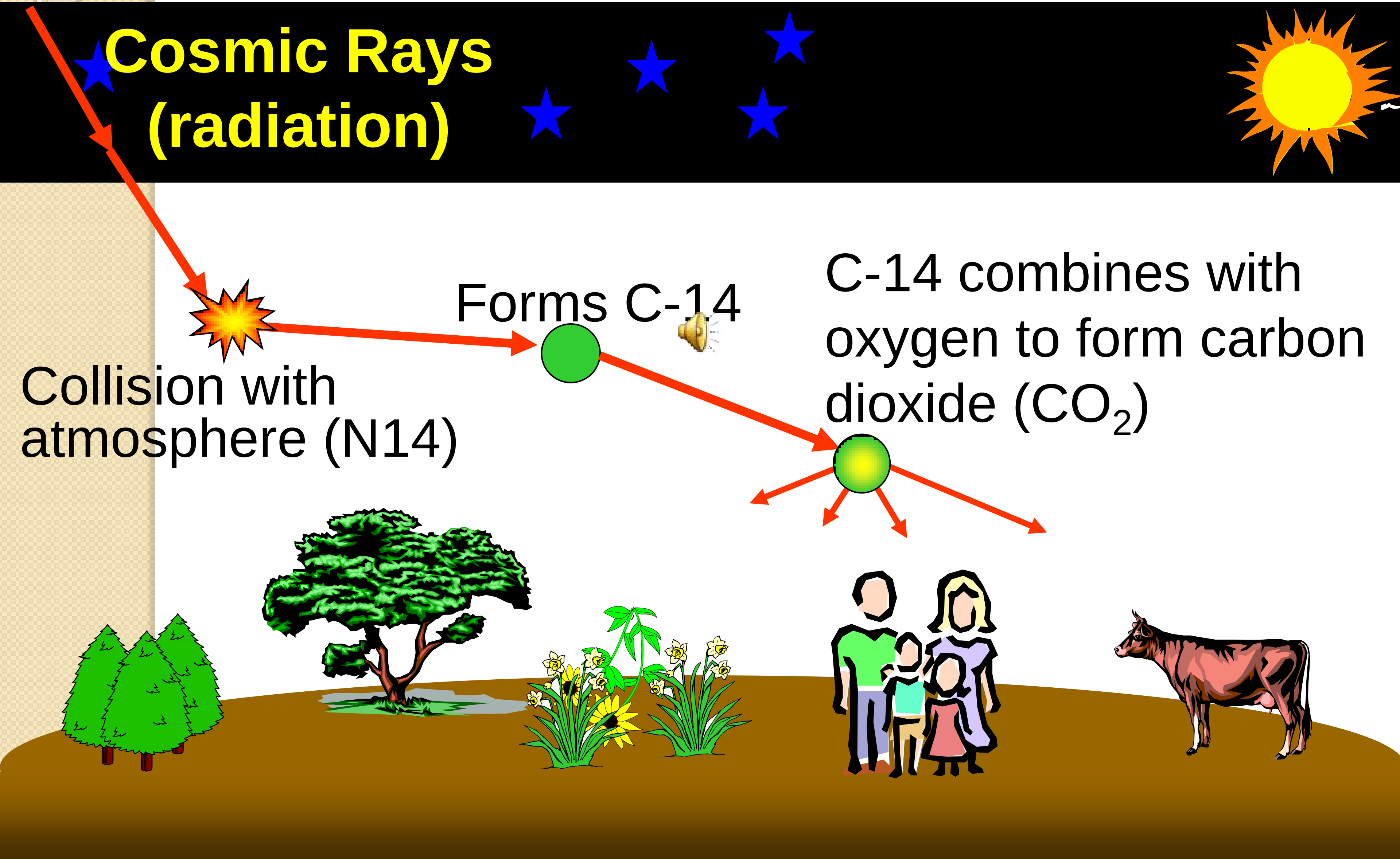
Carbon-14

This is your life: Starring Carbon-14



How C-14 is produced

How Carbon-14 Is Produced



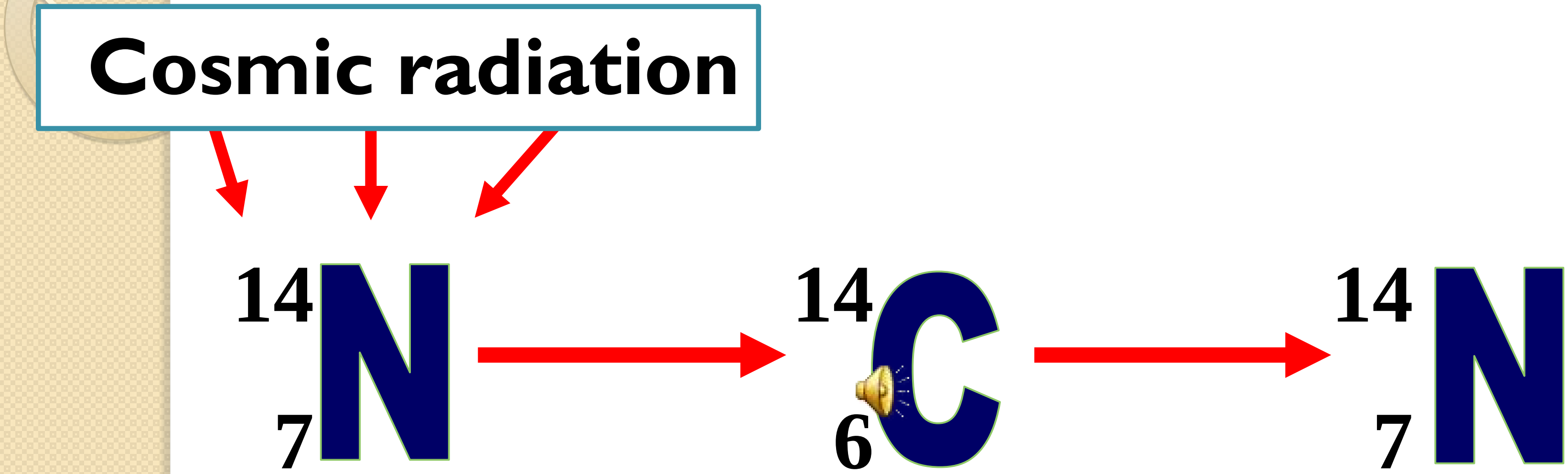
Cosmic Rays (radiation)

Collision with atmosphere (N14)

Forms C-14

C-14 combines with oxygen to form carbon dioxide (CO_2)

Carbon-14 Life Cycle



Cosmic radiation

$${}^{14}_{7}\mathrm{N} \longrightarrow {}^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N}$$

Carbon-14 is produced in the atmosphere

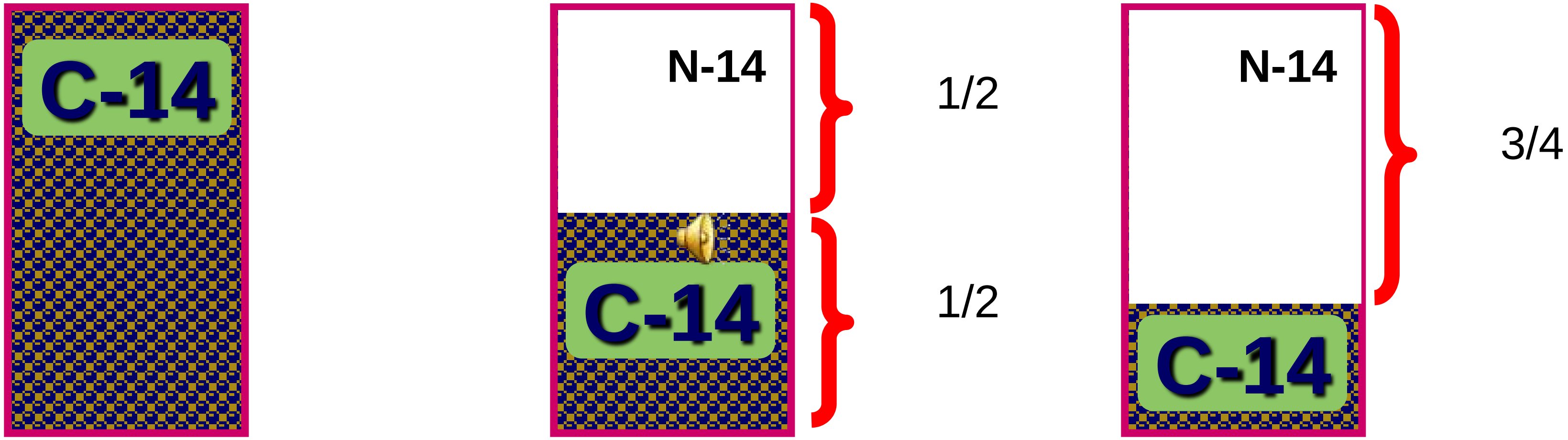
Carbon-14 decays into Nitrogen-14

Half-Life Illustration

Time = 0

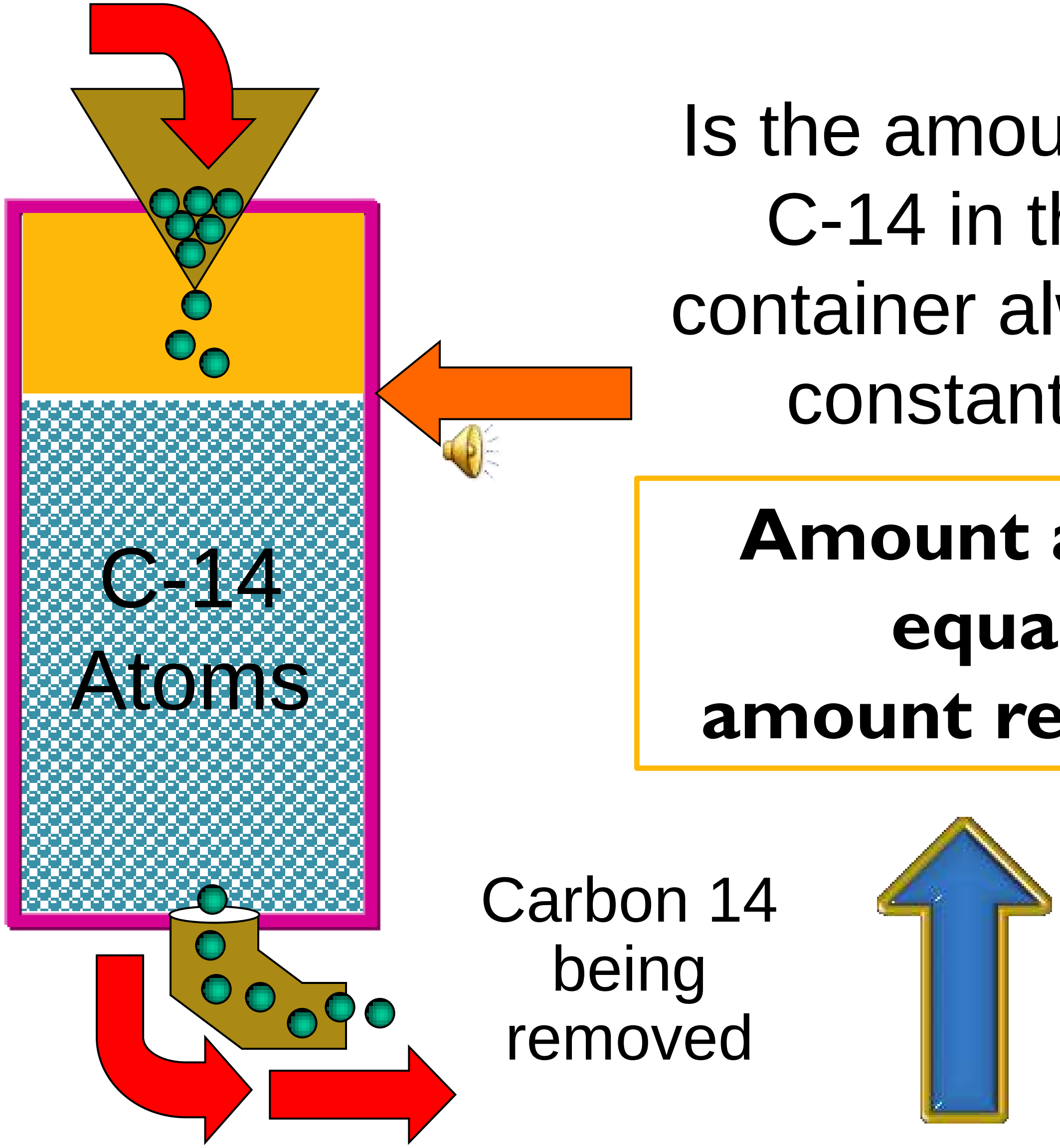
5,730 years
1 half-life

11,460 years
2 half-lives



If C-14 is constantly decaying,
will we run out of C-14 in the atmosphere?

Recognize Any Assumptions



Carbon 14 being added

C-14 Atoms

Is the amount of C-14 in the container always constant?

Amount added equals amount removed

Carbon 14 being removed

When Does the Clock Start?

Once a plant or animal dies the clock starts

Organism dies

No more C-14 intake

→

C-14 continues to decay

Radiocarbon Dating

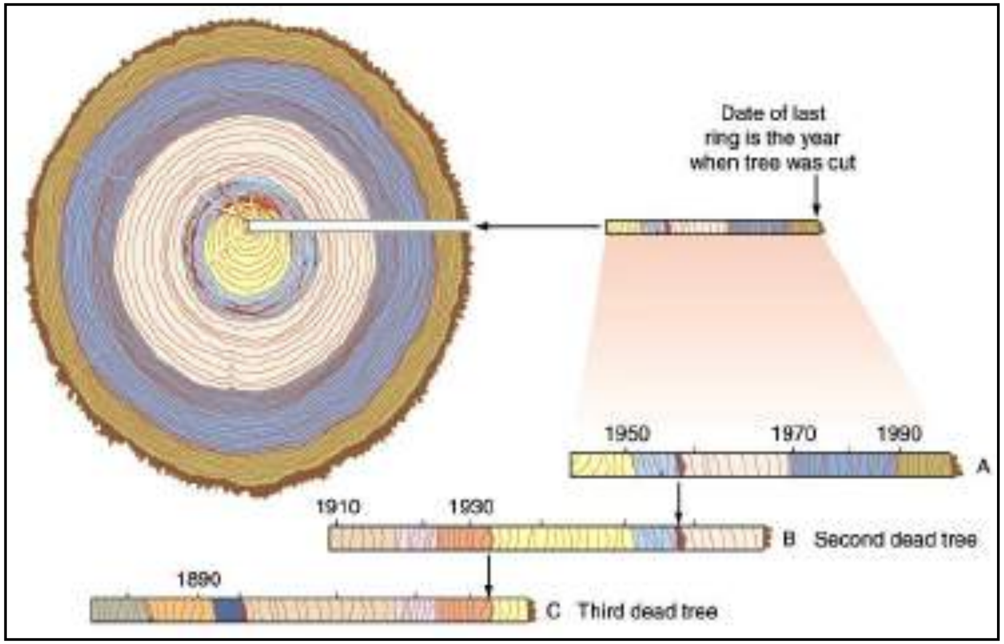
- In the upper atmosphere ^{14}C forms at a constant rate:

$$ {}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}H $$

$$ {}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta \qquad T_{1/2} = 5730 \text{ Years} $$

- Live organisms maintain $^{14}C/^{12}C$ at equilibrium $=1.3 \times 10^{-12}$.
- Upon death, no more ^{14}C is taken up and ratio changes.
- Measure ratio and determine time since death.

- Many living and dead trees are cored.
- Trees of overlapping ages provide continuous 10,000 year record.
  - Also give climate and fire information
  - Independent check on ^{14}C dating



Common Dating Techniques

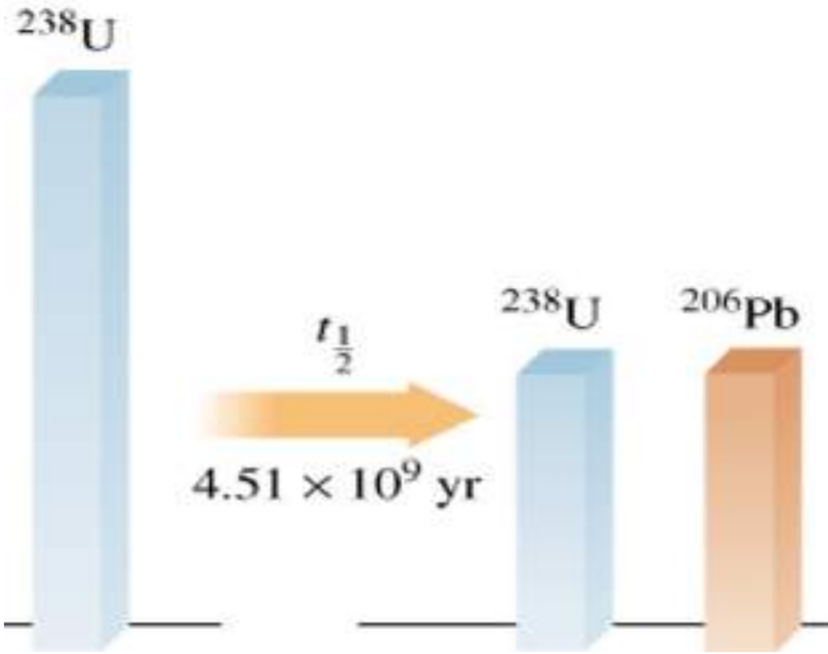
Method	½ Life (yrs)	Dating Range (yrs)	Material Dated
^{3}H	12.4	1 to 50	Water
^{14}C	5730	100 to 70,000	Organic material
^{238}U	4.5 billion	10 million to 4.5 billion	Igneous/meta. rocks

Mineral Dating

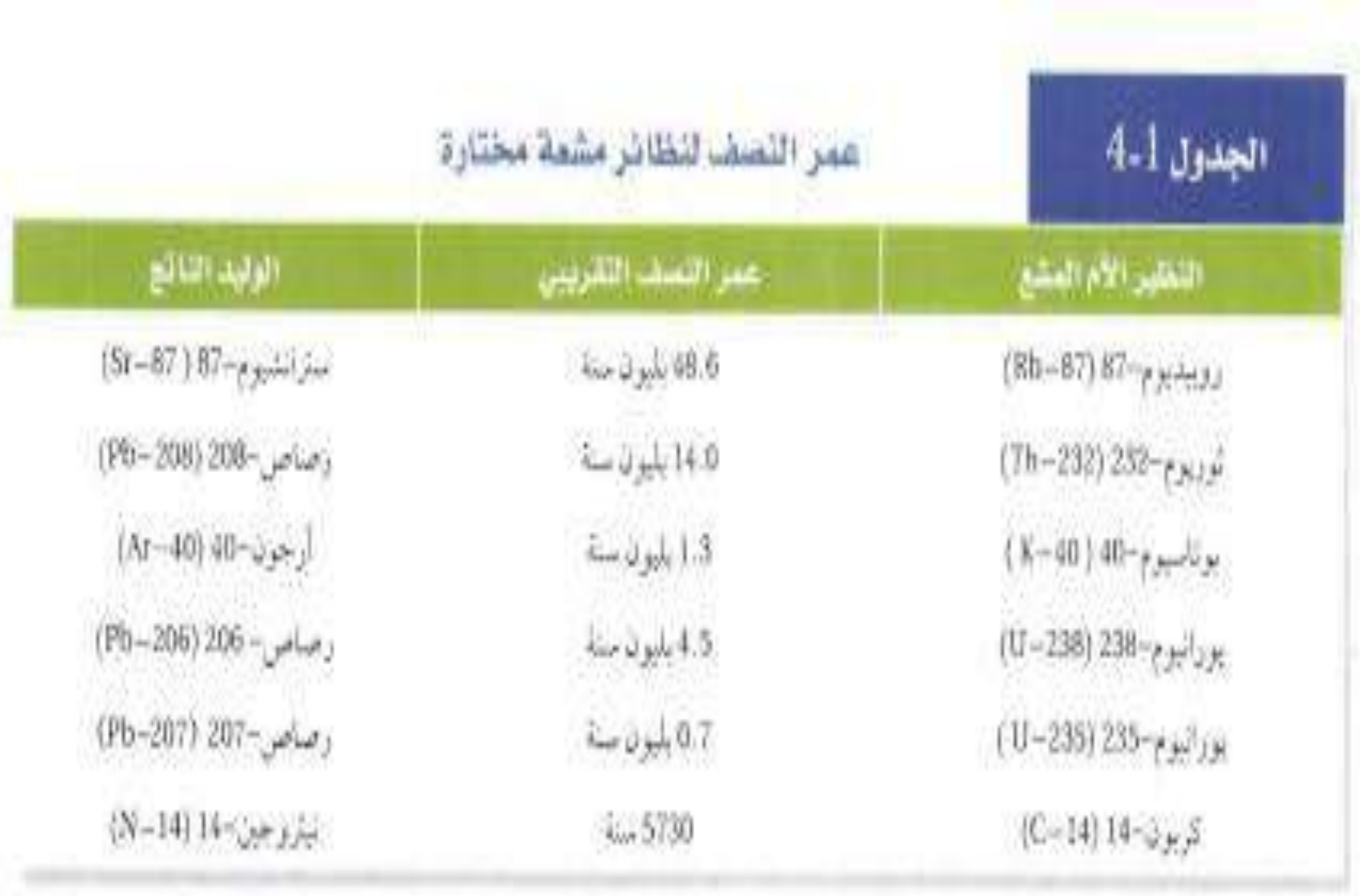
- Ratio of ^{206}Pb to ^{238}U gives an estimates of the age of rocks. The overall decay process (14 steps) is:

- The oldest known terrestrial mineral is about
  4.5 billion years old.
  - This is the time since that mineral solidified.

$$^{238}_{92}\text{U} \longrightarrow {}^{206}_{82}\text{Pb} + 8\,{}^{4}_{2}\alpha + 6\,{}^{0}_{-1}\beta$$



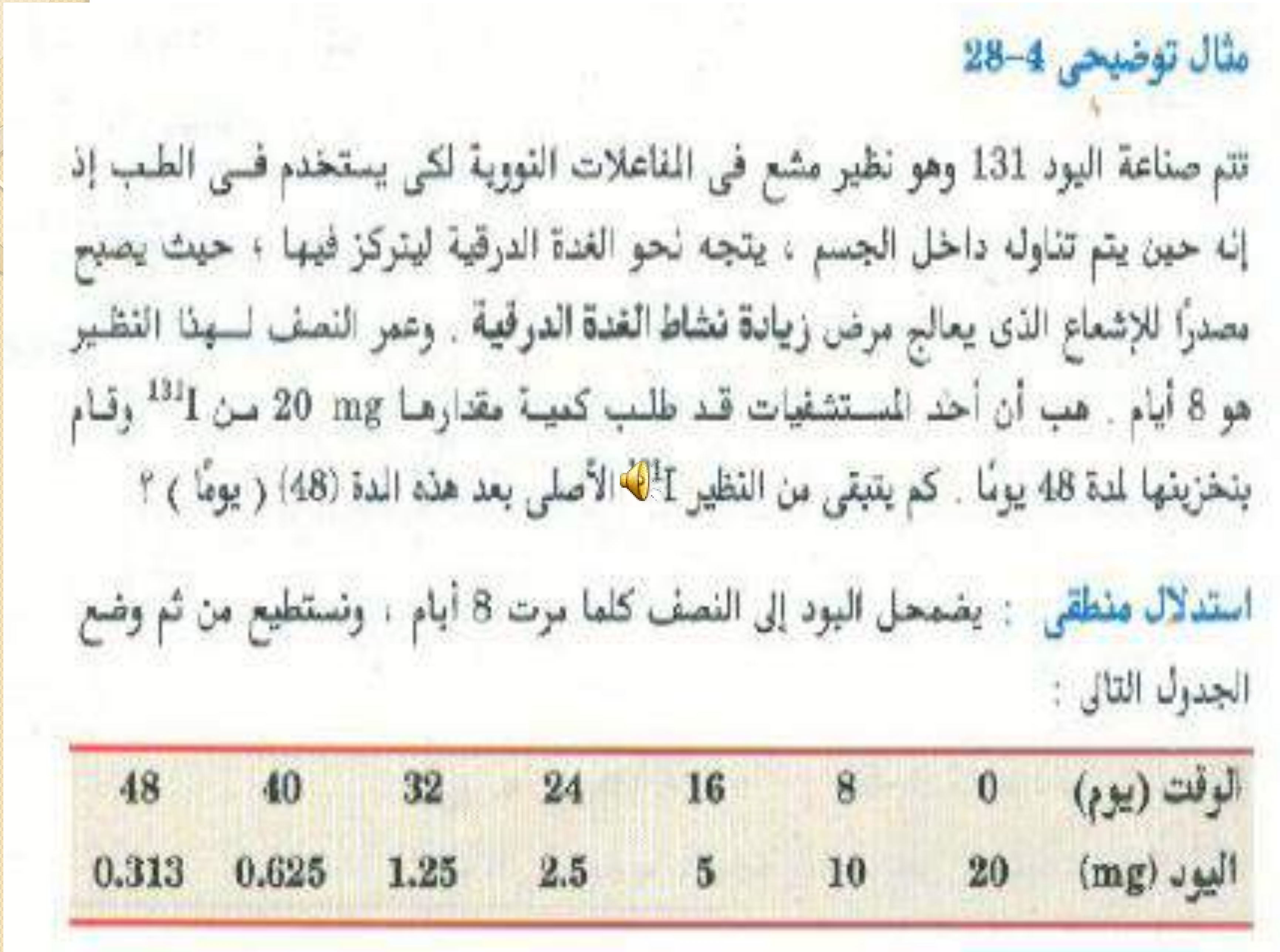
$t_{½}$ = 4.51 x 10^{9} years



الجدول 4-1 عمر النصف لنظائر مشعة مختارة

النظير الأم المشع	عمر النصف التقريبي	الوليد الناتج
روبيديوم-87 (Rb-87)	48.6 بليون سنة	سترانشيوم-87 (Sr-87)
ثوريوم-232 (Th-232)	14.0 بليون سنة	رصاص-208 (Pb-208)
بوتاسيوم-40 (K-40)	1.3 بليون سنة	أرجون-40 (Ar-40)
يورانيوم-238 (U-238)	4.5 بليون سنة	رصاص- 206 (Pb-206)
يورانيوم-235 (U-235)	0.7 بليون سنة	رصاص-207 (Pb-207)
كربون-14 (C-14)	5730 سنة	نيتروجين-14 (N-14)

بعض الأمثلة المحلولة



مثال توضيحى 4–28

تتم صناعة اليود 131 وهو نظير مشع فى المفاعلات النووية لكى يستخدم فى الطب إذ إنه حين يتم تناوله داخل الجسم ، يتجه نحو الغدة الدرقية ليتركز فيها ، حيث يصبح مصدراً للإشعاع الذى يعالج مرض **زيادة نشاط الغدة الدرقية** . وعمر النصف لهذا النظير هو 8 أيام . هب أن أحد المستشفيات قد طلب كمية مقدارها 20 mg من ^{131}I وقام بتخزينها لمدة 48 يومًا . كم يتبقى من النظير ^{131}I الأصلى بعد هذه المدة (48) (يومًا) ؟

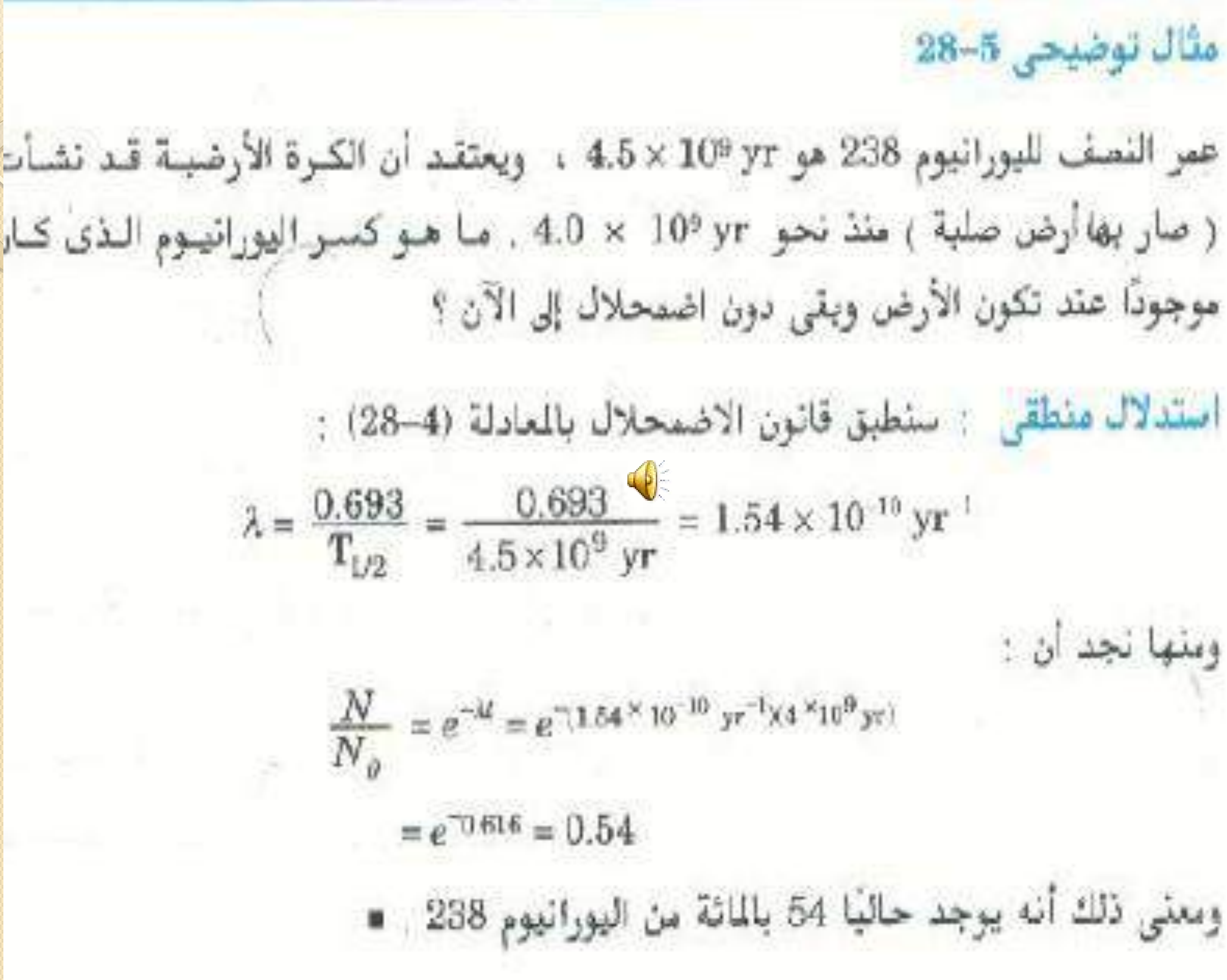
استدلال منطقى : يضمحل اليود إلى النصف كلما مرت 8 أيام ، ونستطيع من ثم وضع الجدول التالى :

الوقت (يوم)	0	8	16	24	32	40	48
اليود (mg)	20	10	5	2.5	1.25	0.625	0.313

- The half life of a specific element was calculated to be 5200 yr. Calculate the decay constant (λ).

Half - Life Solution :

$$k = \frac{.693}{5200} = 1.33 x 10^{-4}$$



مثال توضيحى 5-28

عمر النصف لليورانيوم 238 هو 4.5×10^9 yr ، ويعتقد أن الكرة الأرضية قد نشأت (صار بها أرض صلبة) منذ نحو 4.0×10^9 yr . ما هو كسر اليورانيوم الذى كان موجودًا عند تكون الأرض وبقى دون اضمحلال إلى الآن ؟

استدلال منطقى : سنطبق قانون الاضمحلال بالمعادلة (4-28) :

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{4.5 \times 10^9 \text{ yr}} = 1.54 \times 10^{-10} \text{ yr}^{-1}$$

ومنها نجد أن :

$$\frac{N}{N_0} = e^{-\lambda t} = e^{-(1.54 \times 10^{-10} \text{ yr}^{-1})(4 \times 10^9 \text{ yr})}$$

$$= e^{-0.616} = 0.54$$

ومعنى ذلك أنه يوجد حاليًا 54 بالمائة من اليورانيوم 238 . ■

- If a watch contains a radioactive substance with a decay constant of 1.40×10^{-2} and after 50 years only 25 mg remain, calculate the amount originally present.

Decay Solution:

$$\ln\frac{25}{N_0} = -(1.4x10^{-2})(50)$$

$$N_0 = 50.3\ \text{mg}$$

احسب عمر النصف لبلوتونيوم- 239 الذى يتحلل بانبعاث جسيمات الفا اذا علم ان نشاط عينة وزنها 0.1 مجم من النظير النقى يساوى 1.4×10^{7} dpm

- The Solution

239 g (1mole) of Po → contain Avogadro no of atoms(6.023 $*10^{23}$

239 g → (6.023 $*10^{23}$) atoms

0.1 mg → X atoms

$$\lambda = \frac{\ln 2}{t_{1/2}} \rightarrow \quad t_{1/2} = \frac{\ln 2}{\lambda}$$

$$A = \lambda N = \frac{\ln 2}{t_{1/2}} N = 1.4 \times 10^{7} \ dpm$$

$$t_{1/2} = \frac{(\ln 2) \ N}{A}$$

$$N = \frac{(1 \times 10^{-4} g)(6.023 \times 10^{23} atoms \ mol^{-1})}{(239 \ g \ mol^{-1})}$$

$$N = 2.51 \times 10^{17} \ atoms$$

$$t_{1/2} = \frac{(\ln 2) \ N}{A} = \frac{(0.693)(2.51 \times 10^{17})}{1.4 \times 10^{7}} =$$

$$t_{1/2} = 1.24 \times 10^{10} \ \mathrm{min} = 2.38 \times 10^{4} \ y$$

يتحلل النظير المشع الاشترانشيوم-90 بانبعاث دقائق بيتا السالبة وبعمر نصف 28.5 سنة و اذا كان لديك عينة تزن 0.01 جم كم يتبقى من العينة بعد خمس سنوات ثم بعد مائة عام؟

الحل

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.639}{28.5} = 0.0243y^{-1}$$

the not decay ratio $\frac{N}{N_\circ}$ *after* 5 *y is*

$$\ln\frac{N_\circ}{N} = \lambda t = 0.0243\times 5 = 0.1215$$

$$\frac{N_\circ}{N} = e^{\lambda t} = e^{0.1215} = 1.129$$

$$\frac{N}{N_\circ} = \frac{1}{1.129} = 0.886 = 88.6\%$$

the weight of Sr after 5 *y is*

$$wt(Sr^{90}) = 0.886\times 0.01 = 0.0088\,g$$

$$\mathrm{N} = \mathrm{N}_0 e^{-\lambda \mathrm{t}}$$

$$\frac{N}{N\circ} = e^{-\lambda \mathrm{t}}$$

$$\frac{N}{N\circ} = e^{-0.0243\times 5}$$

$$\frac{N}{N\circ} = 0.886 =$$

$$\frac{N}{N\circ} = 88.6\%$$

ما هو النشاط الاشعاعى الناجم عن اضمحلال 1 جم من الكربون-14 فى عضو حى؟ $t_{1/2}$= 5730 سنة

$$activity\left(A\right)=\lambda N$$

$$\lambda=\frac{\ln 2}{t_{1/2}}$$

$$\lambda=\frac{0.693}{5730\,yr}=2.3\times 10^{10}\min^{-1}$$

$$N=\frac{mN_A}{A}\times 1.3\times 10^{-12}$$

$^{14}C/^{12}C$ at equilibrium =1.3 × 10^{-12}.

$$N=\frac{(1)(6.023\times 10^{23}atoms\ mol^{-1})}{(12\ g\ mol^{-1})}\times 1.3\times 10^{-12}$$

(الكربون الطبيعي يحتوي على أغلبية من الكربون-
12 ونسبة معينة من الكربون-14).

$$N=6.52\times 10^{10}\ atoms$$

$$activity\left(A\right)=\lambda N$$

$$A=2.3\times 10^{10}\times 6.52\times 10^{10}$$

$$A=15\quad decay/\min/\,gm$$

If you know that the half life time for Na^{22} is 2.58 yrs what is the percentage for the Na^{22} decay in one year?

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{2.58} = 0.2686 y^{-1}$$

$$N = N_0 e^{-\lambda t}$$

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$\frac{N}{N_\circ} = e^{-\lambda t} = e^{-0.268\times 1}$$

$$\frac{N}{N_\circ} = 0.7644 = 76.44\%$$

Calculate the number of disintegrations per sec in 1 gm of Radium-226. if you know that the half life time is 1622 year.

$$\lambda N = -\frac{dN}{dt} = A$$

$$The\,number\,atoms\,of\;radium\,in\,1\,gm$$

$$N = \frac{1}{226} \times 6.023 \times 10^{23}$$

$$N = 2.665 \times 10^{21}\ atom$$

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

$$\lambda = \frac{0.693}{1622 \times 365 \times 24 \times 60 \times 60}$$

$$\lambda = 1.355 \times 10^{-11} \sec$$

$$\frac{dN}{dt} = (1.355 \times 10^{-11}\ ) \times (2.665 \times 10^{21})$$

$$\frac{dN}{dt} = 3.611 \times 10^{10} dis./\sec$$

إذا عثرنا على عينة (أحفورة) ووجدناها تصدر 4 تحللات /دقيقة/جرام من الكربون فيها ، فما هو عمرها ؟

- يتميز النظير كربون-14 بعمر نصف مقداره 5730 سنة ، **ويتحلل بمعدل 14 تحللا فى الدقيقة الواحدة لكل جرام من الكربون الطبيعي**

$$\frac{A}{A_0} = e^{-\lambda t}$$

- (الكربون الطبيعي يحتوي على أغلبية من الكربون-12 ونسبة معينة من الكربون-14).
- لحساب العمر نستخدم المعادلة المذكورة أعلاه :

$$\frac{4}{15} = 0.286$$

- حيث:

$$0.286 = e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{t_{1/2}} = 1.2 \times 10^{-4}\ y^{-1}$$

- $$t = 10.36\ year$$
- أي, أن متوسط عمر العينة هو 10.360 years

Answer the following problems?

- 12 gm of radioactive material kept in a safe place, only 0.75 gm were remained after 50 days, calculate the half life time for this material?
- 10 gm of radioactive element remain after 20 days, calculate the original weight if you know that $t_{1/2}$ for this element is 5 days.

- Mixtures of radionuclides
- ***Successive radioactive decay (Radioactive Equilibrium)***

التفكك الاشعاعى المتتابع

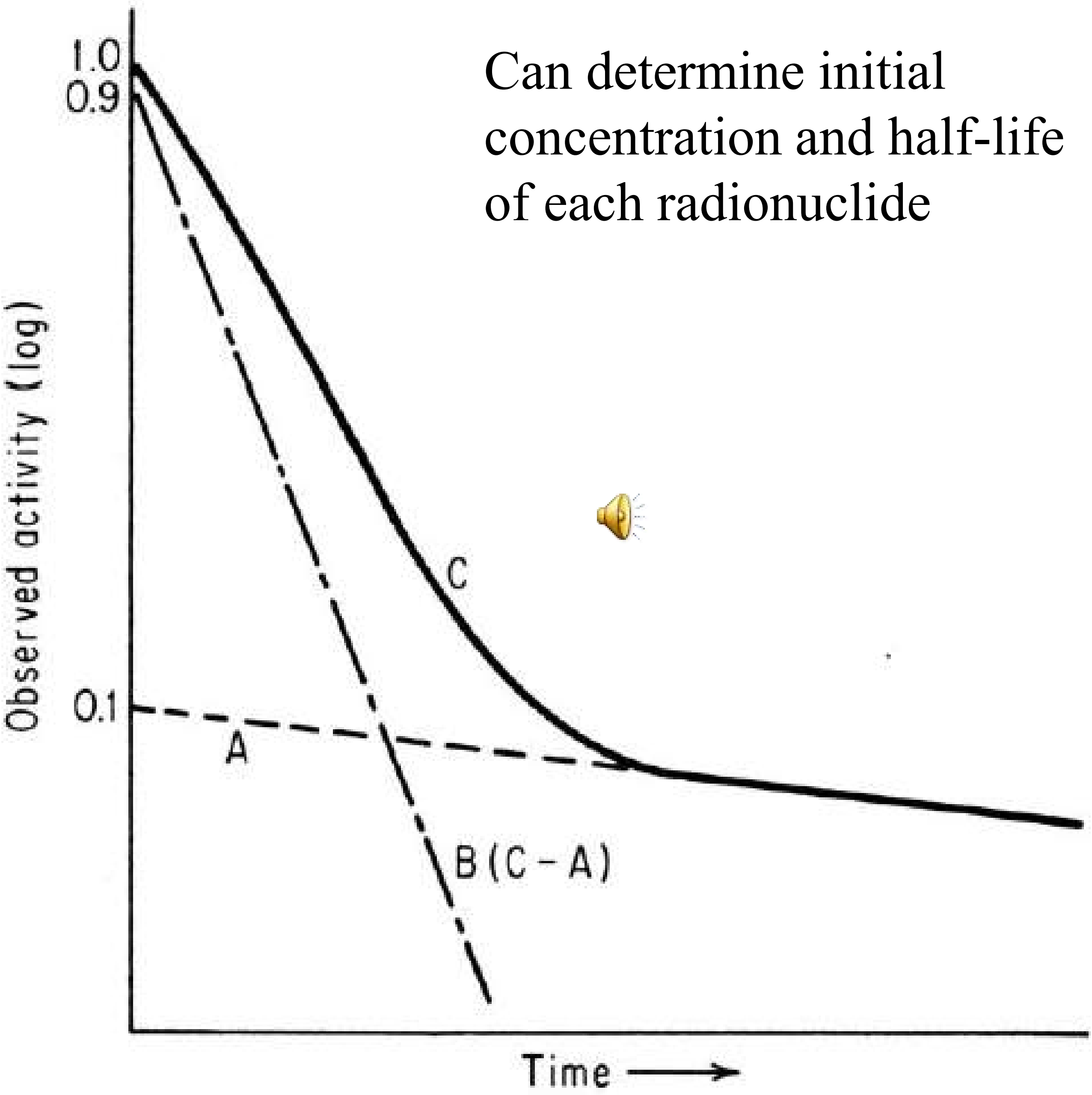
(إتزان الانوية المشعة)

Mixtures of radionuclides

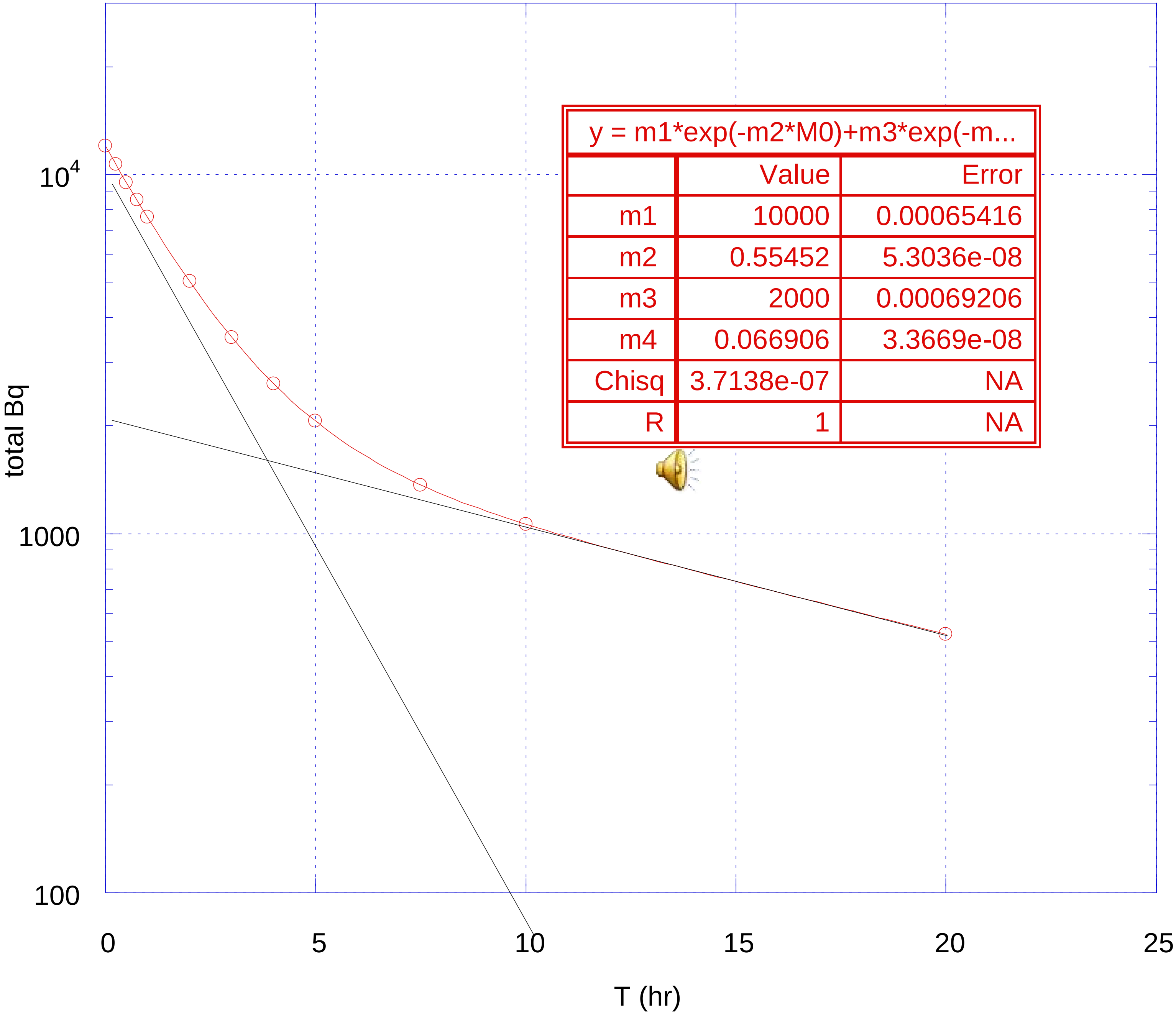
- **Mixtures of Independently Decaying Activities**
  - if two radioactive species mixed together, observed total activity is sum of two separate activities:

$$A= A_1+ A_2 = c_1\lambda_1N_1 + c_2\lambda_2N_2$$

  - any complex decay curve may be analyzed into its components
    - Graphic analysis of data is possible
- Composite decay
  - Sum of all decay particles



Can determine initial concentration and half-life of each radionuclide



y = m1*exp(-m2*M0)+m3*exp(-m...

	Value	Error
m1	10000	0.00065416
m2	0.55452	5.3036e-08
m3	2000	0.00069206
m4	0.066906	3.3669e-08
Chisq	3.7138e-07	NA
R	1	NA

λ=0.554

$t_{1/2}$=1.25 hr

λ=0.067

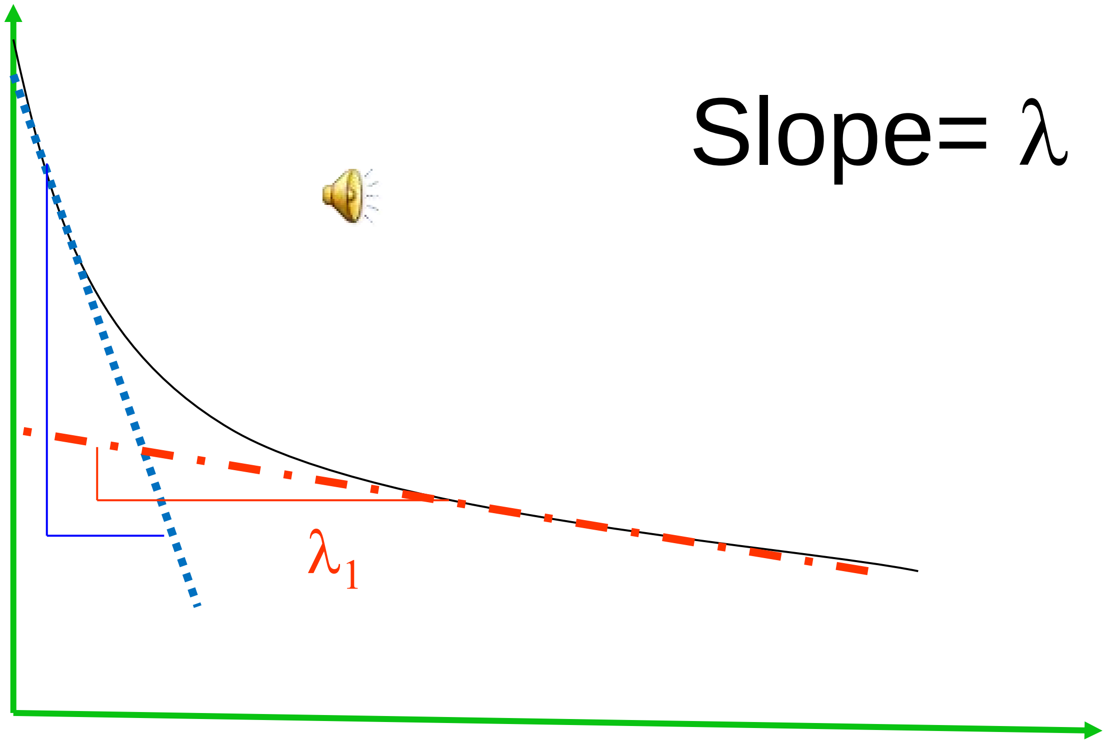
$t_{1/2}$=10.4 hr

قانون التفكك الإشعاعى

$$N(t) = N_o e^{-\lambda t}$$

$$\ln N - \ln N_0 = -\lambda t$$

$$\ln N = -\lambda t + \ln N_0$$



Slope= λ

عينة مشعة تتكون

من عنصرين λ_2

Successive radioactive decay

التفكك الإشعاعى المتتابع

6–6–2 التفكك الإشعاعي المتتابع

The successive radioactive decay

عند تفكك النواة الأم إلى نواة وليدة فإنه قد تكون النواة الوليدة نشطة إشعاعيا. عندئذ تتفكك النواة الوليدة إلى ان نواة تعرف باسم الحفيدة (grand-daghter). وهكذا، تستمر العملية إلى تصل في النهاية إلى نواة مستقرة. وتعرف هذه العملية بالتفكك الإشعاعي المتتابع .

فعلى سبيل المثال تتفكك نواة الراديوم 226(عمرها النصفي 1.6 x 10 ^{3} سنة) إلى الرادون 222. وتتفكك هذه الأخيرة (عمرها النصفي 3.82 يوم) إلى نواة البولونيوم 218، التي تعتبر هي الأخرى مشعة (عمرها النصفي 3.05 دقيقة). وهكذا تستمر العملية إلى أن تصل في النهاية إلى نواة الرصاص 206 المستقرة.

والغرض من دراسة التفكك المتتابع هو معرفة عدد الذرات (النوى) في كل عضو من أعضاء هذه السلسلة.

فإذارمزنا لعدد ذرات النويدة الأم عند الزمن t بالرمز N_1 وثابت التفكك لها بالرمز λ_1 ، وعدد ذرات النويدة الوليدة N_2 التي يعتبر بدورها نشطة وثابت التفكك لها هو λ_2 ، وعدد ذرات النويدة الحفيدة N_3 واعتبارها مستقرة، وإذا فرضنا أنه عند اللحظة $t = 0$ كان عدد ذرات كل جيل هو:

$$N_1 = N_{10}, \qquad N_2 = 0, \qquad N_3 = 0$$

أي أنه عند تحضير العينة كانت كلها من ذرات النويدة الأم، وباستخدام العلاقة (2–11)، والأخذ في الحسبان أن معدل تفكك النويدة الأم يساوي تماما معدل تكوين النويدة الوليدة، وأن معدل تفكك النويدة

الوليدة مساو لمعدل تكوين النويدة الحفيدة، فإنه يمكن التعبير عن العملية كلها بالمعادلات الثلاث التالية:

$$d\,N_1 / d\,t = -\lambda_1 N_1 \qquad (2\text{-}17)$$

$$d\,N_2 / d\,t = \lambda_1 N_1 - \lambda_2 N_2 \qquad (2\text{-}18)$$

$$d\,N_3 / d\,t = \lambda_2 N_2 \qquad (2\text{-}19)$$

وتحدد العلاقة (17−2) معدل التفكك بالنسبة للنويدة الأم وذلك طبقا للقانون الأساسي للتفكك الإشعاعي. وأما العلاقة (18−2) فتعني أن النويدة الوليدة تتكون بمعدل $\lambda_1 N_1$. في حين أن العلاقة (19−2) تحدد معدل تكوين الذرات الحفيدة المستقرة N_3.

وبحل مجموعة المعـــادلات (17−2)، (18−2)، (19−2) فإنـــه يمكن تحديد عدد ذرات كل نوع من الأعضاء الثلاثة للسلسلة كدالة مـــن الزمن t، وذلك كالآتي:

$$N_1 = N_{10}\, e^{-\lambda_1 t}$$

$$N_2 = \{ \lambda_1 / (\lambda_2 - \lambda_1) \}\ N_{10} (e^{-\lambda 1 t} - e^{-\lambda 2 t}) \qquad (2\text{-}20)$$

$$N_3 = N_{10} [1 + \{\lambda_1 / (\lambda_2 - \lambda_1)\}]\ e^{-\lambda 2t} - \{\lambda_2 / (\lambda_2 - \lambda_1)\}\ e^{-\lambda 1t}] \qquad (2\text{-}21)$$

وهذه العلاقة صحيحة إذا كان $N_{20} = N_{30} = 0$ عند لحظة الصـــفر. أما إذا اختلف كل من N_{20} ، N_{30} عن الصفر فيصبح عدد الذرات الوليدة والحفيدة كدالة من الزمن هو:

$$N_2 = \{ \lambda_1 / (\lambda_2 - \lambda_1) \}\ N_{10} (e^{-\lambda 1t} - e^{-\lambda 2t}) + N_{20}\, e^{-\lambda 2t} \qquad (2\text{-}22)$$

$$N_3 = N_{30} + N_{20} (1 - e^{-\lambda 2t})$$

$$+ N_{10} [1 + \{ \lambda_1 / (\lambda_2 - \lambda_1) \} e^{-\lambda 2t} - \{ \lambda_2 / (\lambda_2 - \lambda_1) \} e^{-\lambda 1t}] \qquad (2\text{-}23)$$

Successive radioactive decay

- Equilibrium is used to describe the condition where the donatives of a function is equal to zero.
- In radioactive decay it relates to the situation where the number of atoms of a particular kind does not change with time.
- Clearly, this is a contradiction, since radioactive decay implies change, whereas equilibrium does not. Whereas absolute equilibrium is not possible,
- Equilibrium is adequately approximated in many important situations whenever the parent species is substantially longer-lived than the daughter nuclides.
- The various approximations to equilibrium give rise to terms *transient equilibrium and* secular *equilibrium .*

الاتزان في التفكك الإشعاعي المتتابع

التوازن لأى كمية فيزيائية يعنى أن هذه الكمية لا تتغير بالنسبة للزمن

$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = \frac{dN_3}{dt} = 0$$

التفكك الإشعاعى المتتابع

- افترض نموذج تفكك يتكون من ثلاثة أنوية

$$N_1 \xrightarrow{\lambda_1} N_2 \xrightarrow{\lambda_2} N_3$$

الأم

parent

الوليدة الوسطى

daughter

الوليدة الأخيرة مستقرة

Grand daughter

تعيين عدد الأنوية من كل نوع يعتمد على المعادلات التالية:

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

$$\frac{dN_3}{dt} = \lambda_2 N_2$$

$$N_1(t) = N_1^o e^{-\lambda_1 t}$$

$$\frac{dN_2}{dt} = \lambda_1 N_1^o e^{-\lambda_1 t} - \lambda_2 N_2$$

Radioactive equilibrium
Parent – daughter decay

- Isotope can decay into radioactive isotope
    - Uranium decay series
    - Lower energy
    - Different properties
        - A
        - Z
        - Spin

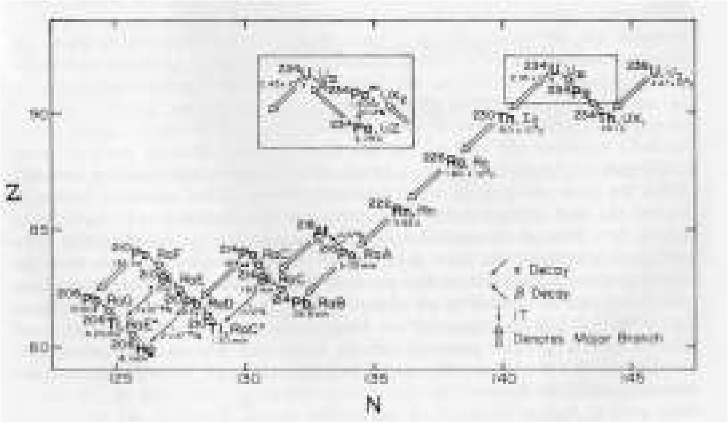
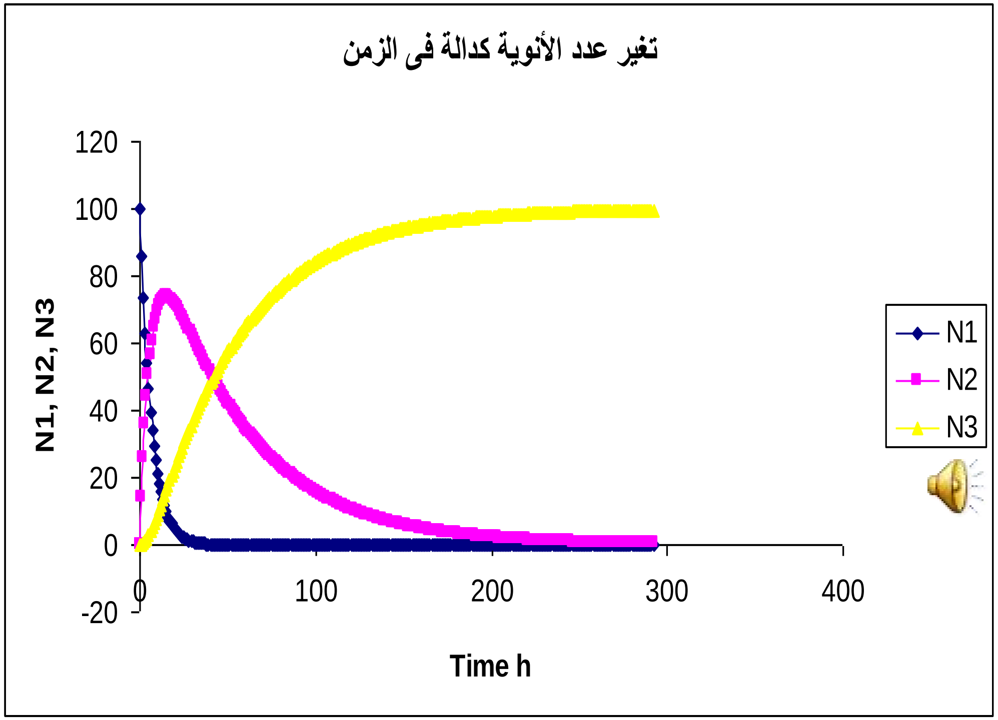


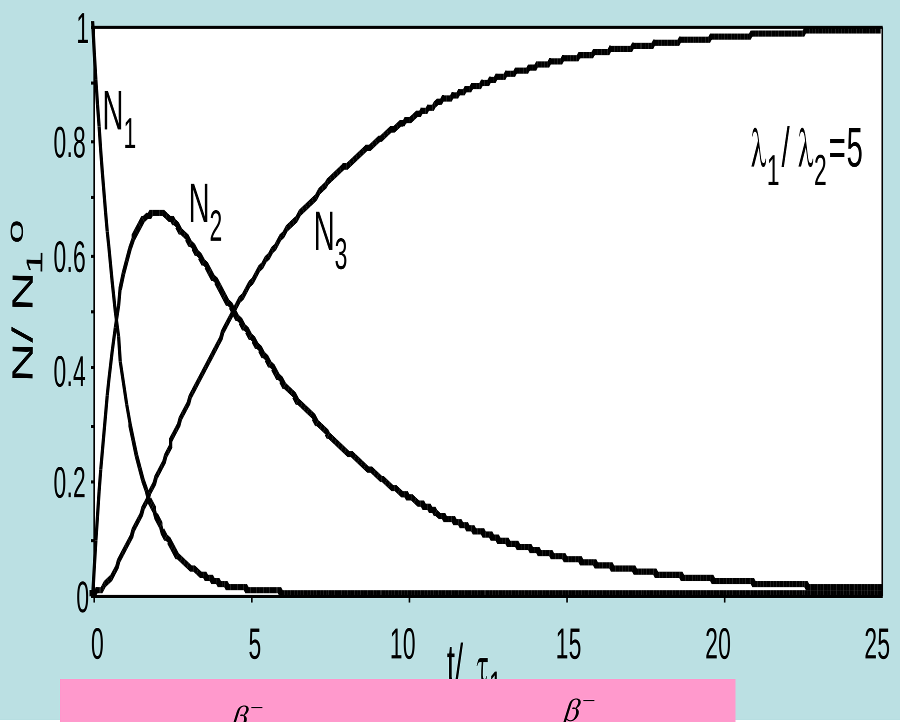
Fig. 1-1. The uranium series. IT stands for isomeric transition.

- For a decay parent > daughter
    - **Rate of daughter formation dependent upon parent decay rate - daughter decay rate**

$$\boxed{\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2}$$

التفكك الإشعاعي المتتابع





$$^{105}_{44}Ru\xrightarrow[t_{1/2}=4.5h]{\beta^-}\,^{105}_{45}Rh\xrightarrow[t_{1/2}=35h]{\beta^-}\,^{105}_{46}Pd$$

لقانون التفكك الإشعاعي. أما N_2 فيكون صفرا عند $t = 0$ ثم يزداد طبقا للعلاقة (2–20) إلى أن يصل إلى أقصى قيمة عند زمن يساوي تقريبا ثلاثة أضعاف العمر النصفي ثم ينخفض من جديد.

أما بالنسبة للنوى الحفيدة N_3 فتكون أولا مساوية للصفر ثم تزداد ببطء كبير ولا تقترب من نهايتها (أي 100%) إلا بعد انقضاء زمن طويل (حوالي 5 أضعاف العمر النصفي للنظير الوليد).

Parent – daughter System

- For the system 1 decays into 2 Parent(N1) $\xrightarrow{\lambda_1}$ daughter(N2

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

- Rearranging gives:

$$\frac{dN_2}{dt} + \lambda_2 N_2 = \lambda_1 N_1$$

- Solve and substitute for N_1 using → $N_1 = N_{1o}\, e^{-\lambda_1 t}$

$$\frac{dN_2}{dt} + \lambda_2 N_2 = \lambda_1 N_{1o} e^{-\lambda_1 t}$$

- Multiply by $e^{\lambda_2 t}$

$$e^{\lambda_2 t}\frac{dN_2}{dt} + \lambda_2 N_2 e^{\lambda_2 t} = e^{\lambda_2 t}(\lambda_1 N_{1o} e^{-\lambda_1 t})$$

- then

$$e^{\lambda_2 t}\frac{dN_2}{dt} + \lambda_2 N_2 e^{\lambda_2 t} = \lambda_1 N_{1o} e^{(\lambda_2 - \lambda_1)t}$$

$$\frac{d}{dt}(N_2 e^{\lambda_2 t}) = \lambda_1 N_{1o} e^{(\lambda_2 - \lambda_1)t}$$

- Integrate from 0 → t

$$\int dN_2 e^{\lambda_2 t} = \int \lambda_1 N_{1o} e^{(\lambda_2 - \lambda_1)t} dt$$

$$N_2 e^{\lambda_2 t} = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} e^{(\lambda_2 - \lambda_1)t} + C$$

- **Multiply by $e^{-\lambda_2 t}$**

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} e^{-\lambda_1 t} + Ce^{-\lambda_2 t}$$

- and solve for C at t = 0 then→ $N_2 = 0$

$$C = -\frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} e^{-\lambda_1 t} - (\frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}) e^{-\lambda_2 t}$$

$$\boxed{N_2(t) = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} (e^{-\lambda_1 t} - e^{-\lambda_2 t})}$$

Growth of daughter from parent

Then

$$\mathbf{N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}(e^{-\lambda_1 t} - e^{-\lambda_2 t})}$$

The Final form is

$$\boxed{N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} e^{(\lambda_2 - \lambda_1)t}}$$

Maximum Daughter Activity

Case I: $t_{1/2}$ (Parent) < $t_{1/2}$ (daughter) $\lambda_1 > \lambda_2$

The time **(t_{max})** necessary for the maximum daughter intensity is found when $dN_2/dt = 0$ then → $t = t_{max}$

$$\boxed{N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}(e^{-\lambda_1 t} - e^{-\lambda_2 t})}$$

- **If parent is shorter-lived than daughter ($\lambda_1 > \lambda_2$),**
- **No equilibrium attained at any time**

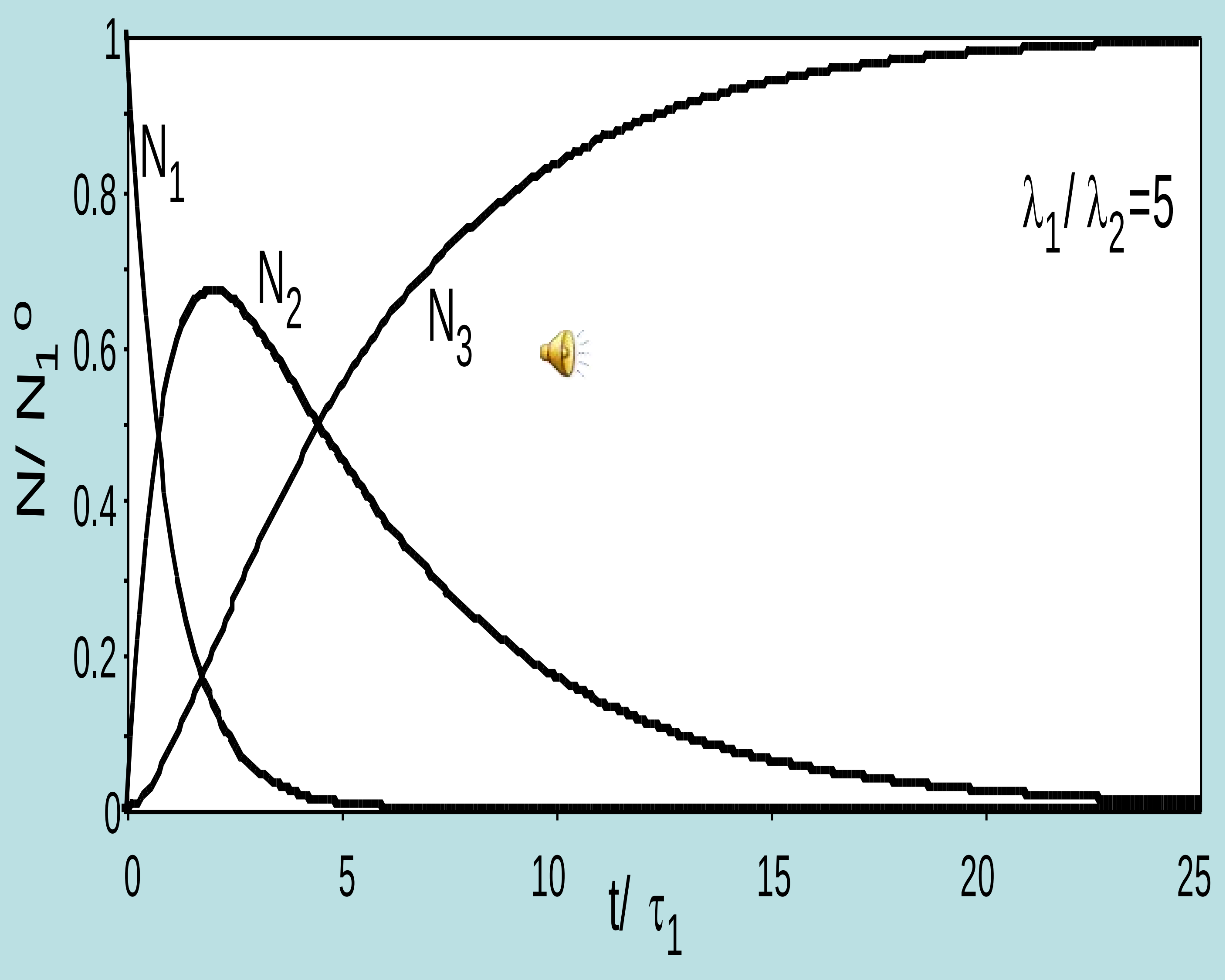
$$\frac{dN_2}{dt} = \frac{\lambda_1 N_{1o}}{\lambda_2 - \lambda_1}(-\lambda_1 e^{(-\lambda_1 t_{\max})} + \lambda_2\ e^{-\lambda_2 t_{\max}}) = 0$$

$$\frac{\lambda_1 N_{1o}}{\lambda_2 - \lambda_1}\lambda_1 e^{(-\lambda_1 t_{\max})} = \frac{\lambda_1 N_{1o}}{\lambda_2 - \lambda_1}\lambda_2\ e^{-\lambda_2 t_{\max}} \longrightarrow \frac{\lambda_1}{\lambda_2} = e^{(\lambda_1 - \lambda_2)\, t_{\max}}$$

$$\frac{\lambda_1}{\lambda_2} = e^{(\lambda_1 - \lambda_2) t_{\max}} \longrightarrow \boxed{t_{\max} = \frac{\ln(\lambda_1 / \lambda_2)}{\lambda_1 - \lambda_2}}$$

$$\ln(\lambda_1 / \lambda_2) = (\lambda_1 - \lambda_2)\, t_{\max}$$

Maximum Daughter Activity



Case I: $t_{1/2}$ (Parent) < $t_{1/2}$ (daughter) $\lambda_1 > \lambda_2$

No equilibrium attained at any time

Maximum Daughter Activity

$$t_{\max} = (\lambda_2 - \lambda_1)^{-1} \ln(\lambda_2/\lambda_1)$$

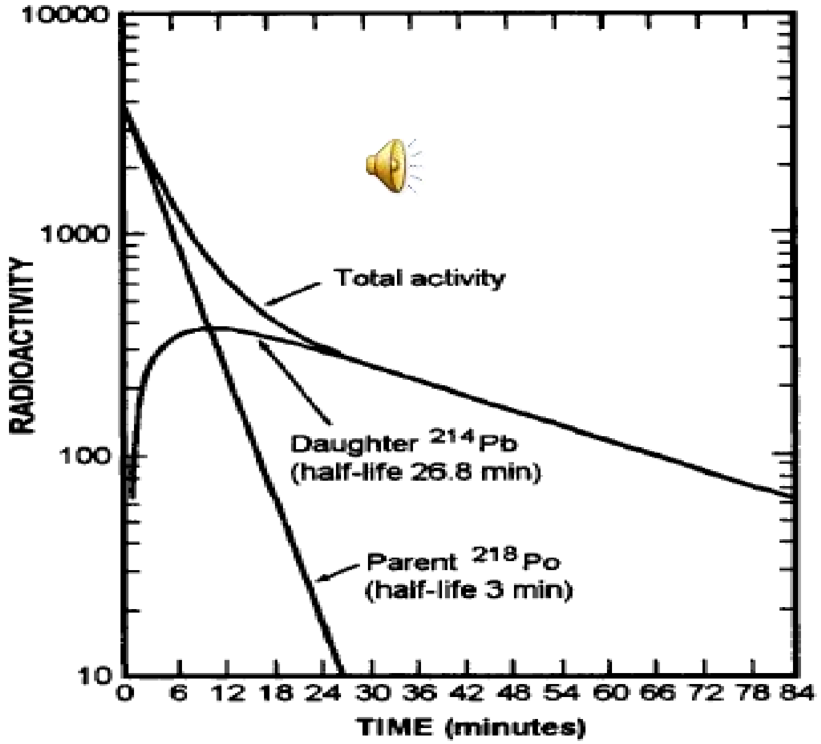


FIG. 4.13. Case of no equilibrium: successive decay chain ^{218}Po($t_{1/2}$ 3 min) → ^{214}Pb($t_{1/2}$ 26.8 min) → stable.

الاتزان في التفكك الإشعاعي المتتابع

سلوك هذا النظام يعتمد على قيم ثوابت التفكك

التوازن لأى كمية فيزيائية يعنى أن هذه الكمية لا تتغير بالنسبة للزمن

$$\frac{dN_1}{dt} = \frac{dN_2}{dt} = \frac{dN_3}{dt} = 0$$

$$\frac{dN_1}{dt} = -\lambda N_1 = 0$$

$$\frac{dN_2}{dt} = 0 = \lambda_1 N_1 - \lambda_2 N_2$$

$$\lambda_1 N_1 = \lambda_2 N_2$$

$$A_1 = A_2$$

Radioactive Equilibriums

- ***Transient equilibrium***
  - Case II: $t_{1/2}$ (Parent) > $t_{1/2}$ (daughter) $\lambda 1 < \lambda 2$
  - Parent half life greater than 10 x daughter half life
- Parent -daughter ratio becomes constant over time
  - As t goes toward infinity

$$e^{-\lambda_2 t} << e^{-\lambda_1 t}$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}(e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

$$N_2 \approx \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o} e^{-\lambda_1 t}$$

$$N_1 = N_{1o} e^{-\lambda_1 t}$$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1$$

$$\boxed{\frac{N_2}{N_1} = \frac{\lambda_1}{\lambda_2 - \lambda_1}}$$

Transient equilibrium

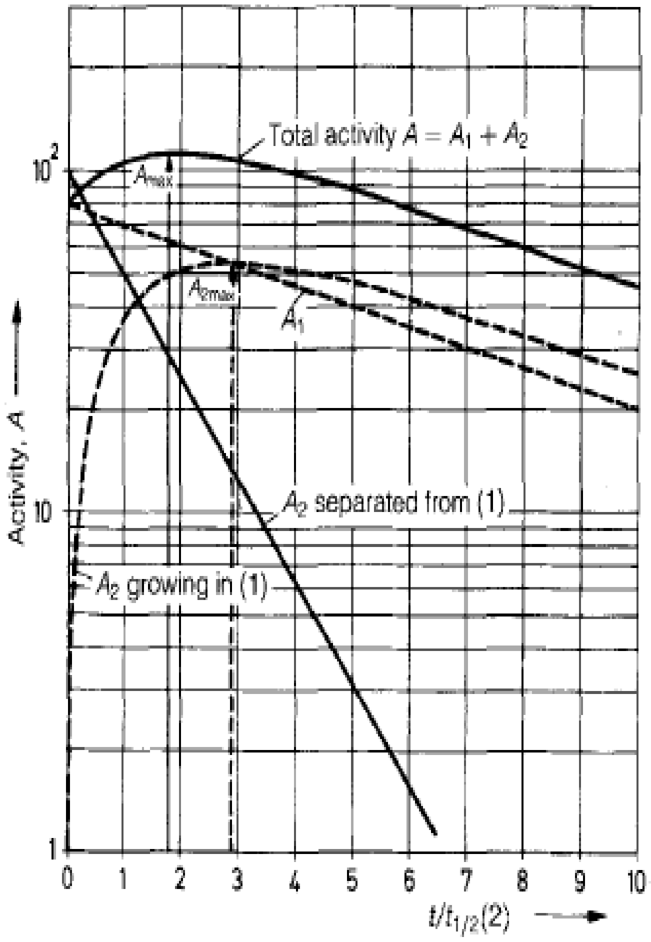


Figure 4.5. Transient equilibrium: activities of mother and daughter nuclide as a function of $t/t_{1/2}(2)$ $(t_{1/2}(1)/t_{1/2}(2) = 5)$.

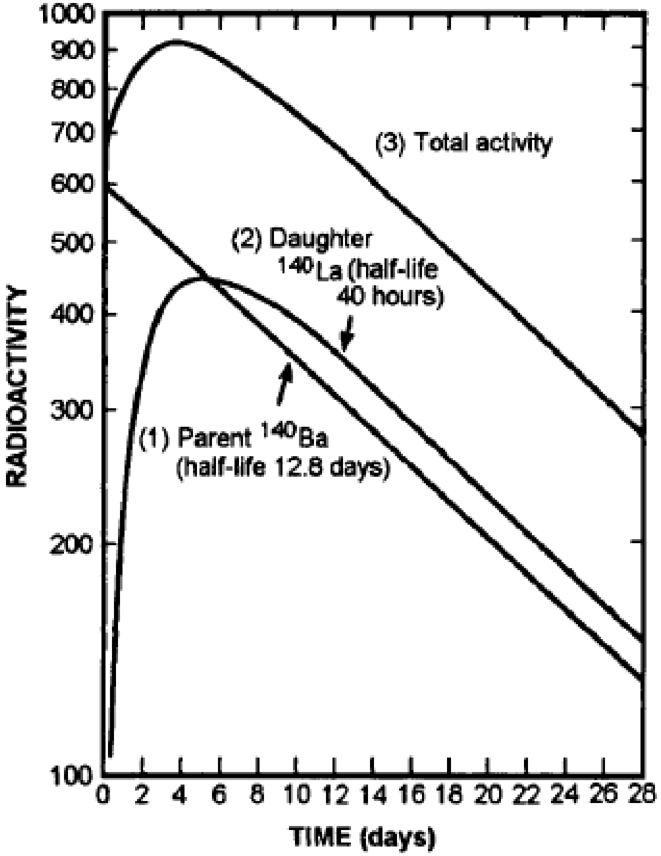


FIG. 4.12. Case of transient equilibrium: successive decay chain ^{140}Ba($t_{½}$ 12.75 d) → ^{140}La($t_{½}$ 1.678 d) → stable.

- ***Secular equilibrium***
- Case III: $t_{1/2}$ (Parent) >> $t_{1/2}$ (daughter)
- $(\lambda_1 << \lambda_2)$ $\lambda_1 \xrightarrow{\hspace{2cm}} 0$
  - – Parent much longer half-life than daughter
    - 1E4 times greater

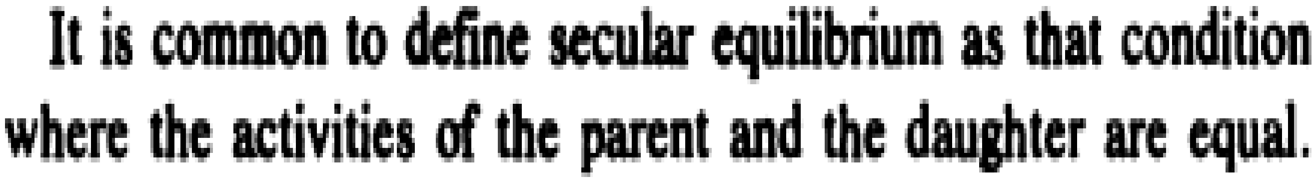
$$\frac{N_2}{N_1} = \frac{\lambda_1}{\lambda_2 - \lambda_1}$$

$$\frac{N_2}{N_1} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{N_1}{N_2} = \frac{\lambda_2}{\lambda_1} = \frac{t_1}{t_2}$$

$$N_2\lambda_2 = N_1\lambda_1$$

$$A_2 = A_1$$



It is common to define secular equilibrium as that condition where the activities of the parent and the daughter are equal.

Secular equilibrium

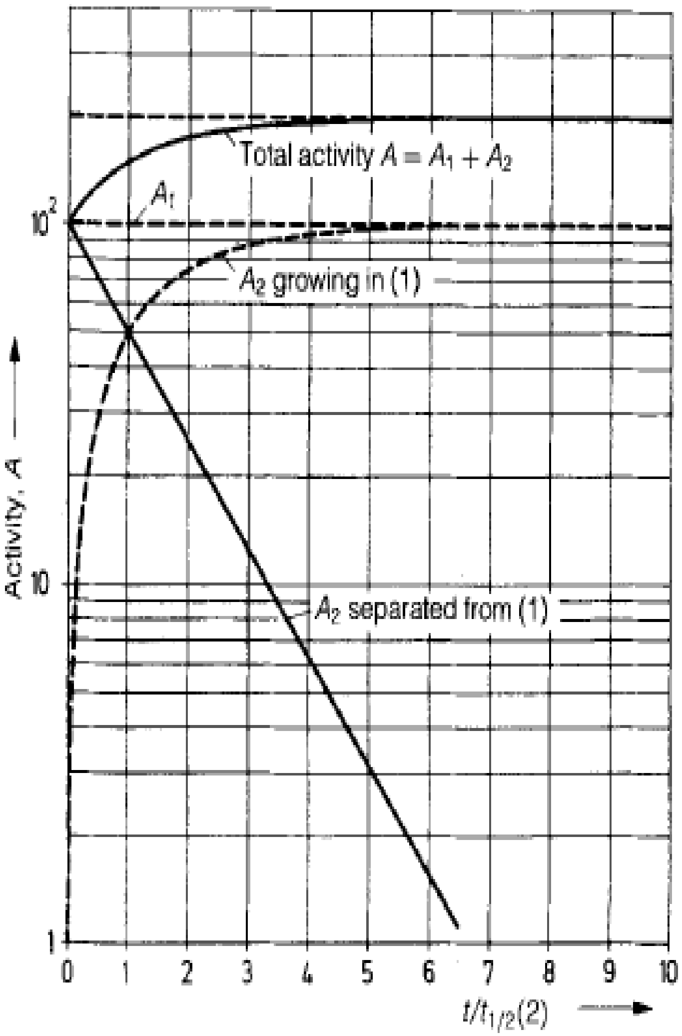


Figure 4.4. Secular equilibrium: activities of mother and daughter nuclide as a function of $t/t_{1/2}(2)$.

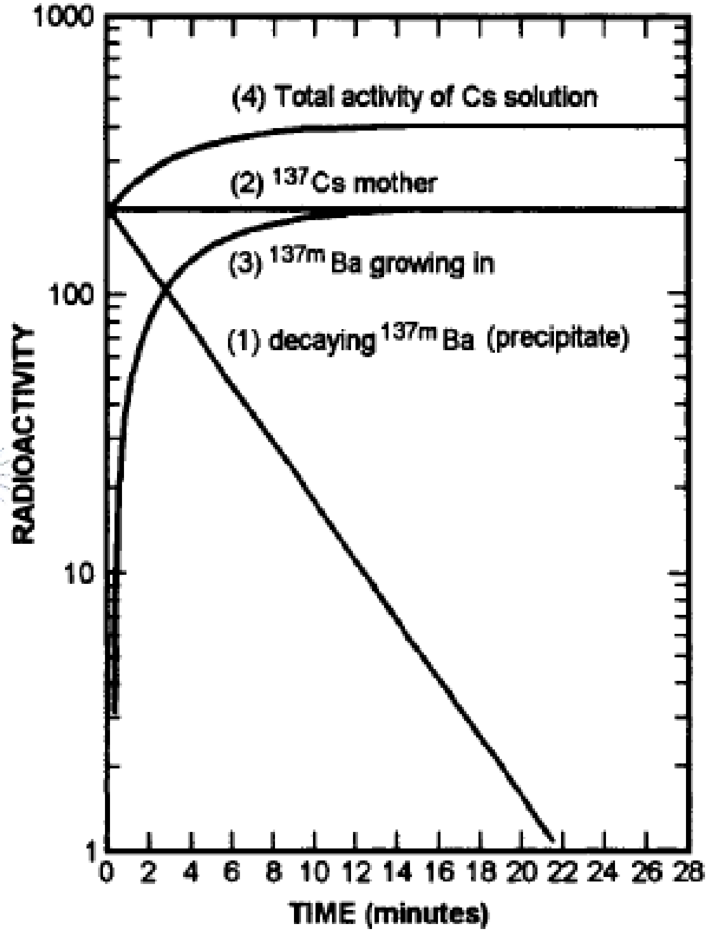


FIG. 4.11. Case of radioactive equilibrium: successive decay chain ^{137}Cs($t_{½}$ 30 y) → ^{137m}Ba($t_{½}$ 2.6 min) → stable.

- When No daughter decay (Stable daughter)
  - No activity of daughter
  - Number of daughter atoms due to parent decay $\lambda_2 \rightarrow 0$

$$\boxed{N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}(e^{-\lambda_1 t} - e^{-\lambda_2 t})} \longrightarrow N_2 = N_{1o}(1 - e^{-\lambda_1 t})$$

Also, we can get the above from the following equation

$$N_d = N_0 - N$$

$$N = N_{1o} e^{-\lambda_1 t}$$

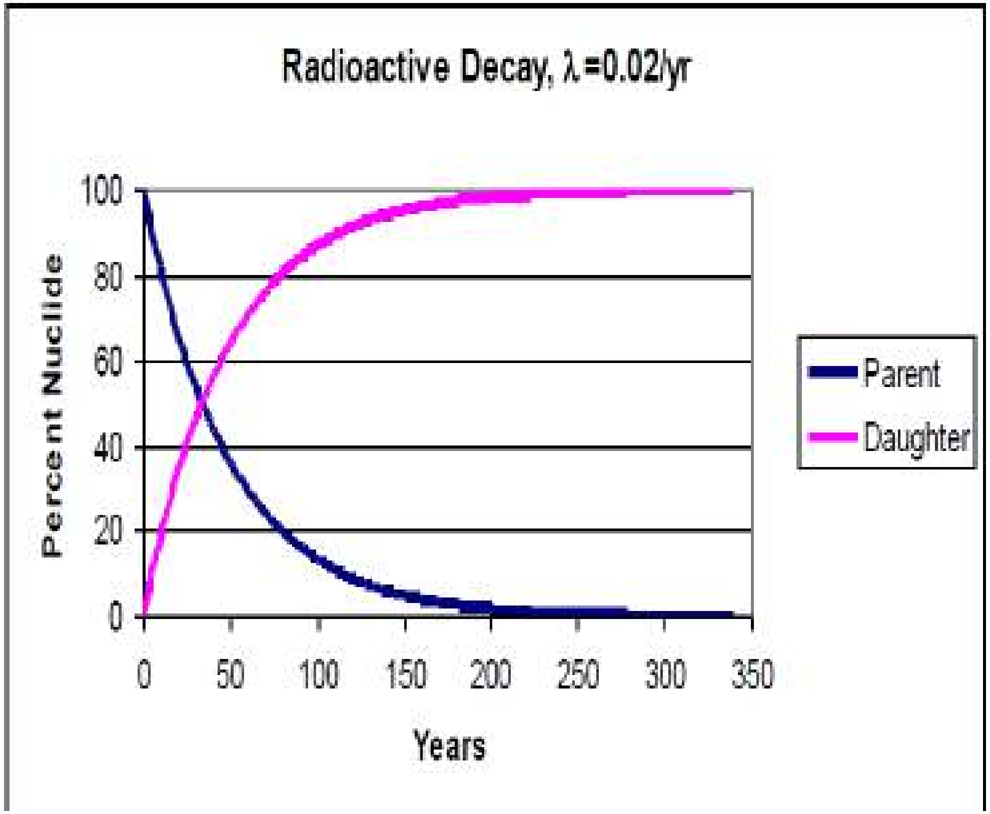
$$N_d = N_{1o} - N_{1o} e^{-\lambda_1 t}$$

$$N_d = N_{1o}(1 - e^{-\lambda_1 t})$$

كما سبق دراسته و استنتاجة فى المحاضرة السابقة
for single nuclide

Parent (N) → daughter

- The number of daughter nuclide can be express by the relationship as following:
- $N_d = N_0 – N$
- $N_d = N_0 – N_0 e^{–\lambda t}$
- $\mathbf{N_d = N_0 (1– e^{–\lambda t})}$



مثال:

ملح من أملاح اليورانيوم 238 وجد أنه يحتوي على نسبة ضئيلة جدا من الراديوم 226 وهذا الراديوم يتكون نتيجة للتفكك المتتابع لليورانيوم 238. فإذا كانت هذه النسبة هي عبارة عن ذرة واحد لكل 2.8 x 10^6 ذرة يورانيوم، وإذا علمت أن العمر النصفي للراديوم هو 1620 سنة فما هو العمر النصفي لليورانيوم.

الحل:

من قانون الاتزان الأبدي:

$$\lambda_1 N_1 = \lambda_2 N_2$$

أي أن:

$$N_1 / N_2 = \lambda_2 / \lambda_1 = t_1 / t_2$$

حيث ، يرمزان للعمر النصفي لليورانيوم والراديوم بالترتيب، وبالتعويض في طرفي العلاقة الأخيرة فإن:

$$2.8 x 10^6 x 1620 = 1 x t_1$$

أي أن:

$$t_1 = 4.54 x 10^9 \text{ years}$$

Example

- For the following successive decay:

$$^{226}Ra \xrightarrow{1622y} {}^{222}Rn \xrightarrow{3.825d} {}^{218}Po$$

If you leave 10^{-3} g of ^{226}Ra for 24 h, What is the weight of of ^{222}Rn and calculate his activity?

The Solution

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{1o}(e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

$$N_{1o}(\,for\,Ra^{226}) = \frac{10^{-3} \times 6.023 \times 10^{23}}{226}$$

$$N_{1o} = 0.027 \times 10^{20}\,atom$$

$$\lambda_1 = \frac{0.693}{1622 \times 365} = 1.17 \times 10^{-6}\,day^{-1}$$

$$\lambda_2 = \frac{0.693}{3.825} = 0.18\,day^{-1}$$

$$N_2 = \frac{1.17 \times 10^{-6} \times 0.027 \times 10^{20}}{0.18}\left[e^{-1.17\times10^{-6}\times1} - e^{-0.18\times1}\right]$$

$$N_2 = 0.03 \times 10^{14}\ atom$$

$$The\ weight = \frac{0.03 \times 10^{14} \times 222}{6.023 \times 10^{23}}\,g = 1.105 \times 10^{-9}\,g$$

$$A_2(activity) = \lambda_2\ N_2$$

$$A_2 = 0.18 \times 0.03 \times 10^{14}$$

$$A_2 = 5.4 \times 10^{11}\,dp\ day = 3.75 \times 10^{8}\,dpm$$

If you know that ^{226}Ra is decay to ^{222}Rn by is decay to ^{222}Rn by emission of alpha particles also the ^{222}Rn is decay to ^{218}Po by emission of alpha particles, calculate the equilibrium ratio for ^{226}Ra. (note that: t_{1l2} for ^{226}Ra = 1620 y and
t_{1l2} for ^{222}Rn = 3.83 day

$$\frac{N_1}{N_2} = \frac{\lambda_2}{\lambda_1} = \frac{T_1}{T_2}$$

$$\frac{N_1}{N_2} = \frac{1620\times12\times30}{3.83} = 1.55\times10^5$$

The naturally occurring heavy element decay chains (see below) where $^{238}U \rightarrow {}^{206}Pb$, $^{235}U \rightarrow {}^{207}Pb$, and $^{232}Th \rightarrow {}^{208}Pb$ and the extinct heavy element decay series $^{237}Np \rightarrow {}^{209}Bi$ are examples of secular equilibrium because of the long half-lives of the parents. Perhaps the most important cases of secular equilibrium are the production of radionuclides by a nuclear reaction in an accelerator, a reactor, a star, or the upper atmosphere. In this case, we have

$$\text{Nuclear reaction} \rightarrow (2) \rightarrow \tag{3.38}$$

Many Decays

$$N_1 \xrightarrow{\lambda_1} N_2 \xrightarrow{\lambda_2} N_3$$

الأم
parent

الوليدة الوسطى
daughter

الوليدة الأخيرة مستقرة
Grand daughter

$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3$$

- Bateman solution
- Only parent present at time 0

$$N_n = C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} + C_n e^{-\lambda_n t}$$

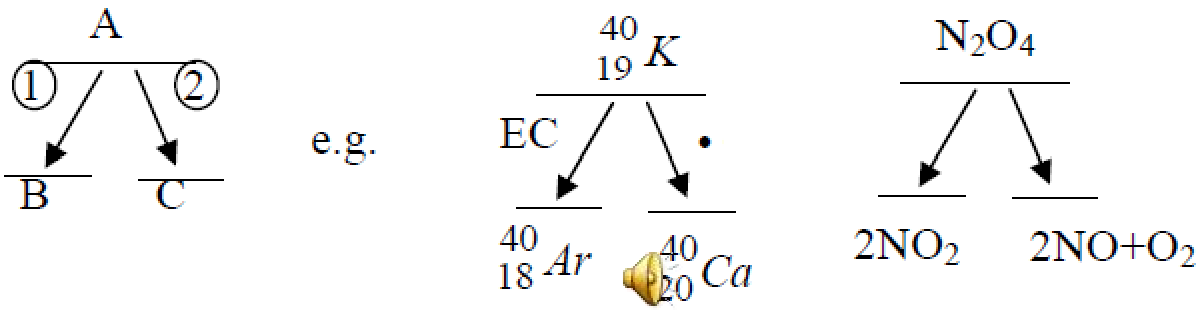
$$C_1 = \frac{\lambda_1 \lambda_2 \ldots\ldots \lambda_{(n-1)}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)\ldots(\lambda_n - \lambda_1)} N_{1o}$$

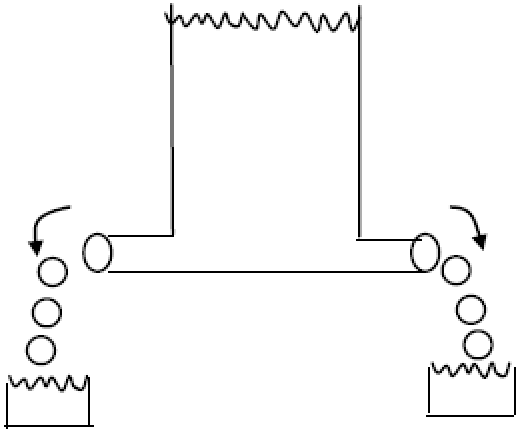
$$C_2 = \frac{\lambda_1 \lambda_2 \ldots\ldots \lambda_{(n-1)}}{(\lambda_1 - \lambda_2)(\lambda_3 - \lambda_2)\ldots(\lambda_n - \lambda_2)} N_{1o}$$

Long term decay is governed by parent

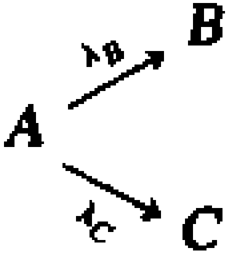
Branching Decay

Competitive Decay Modes for the same nucleus





Branching decay

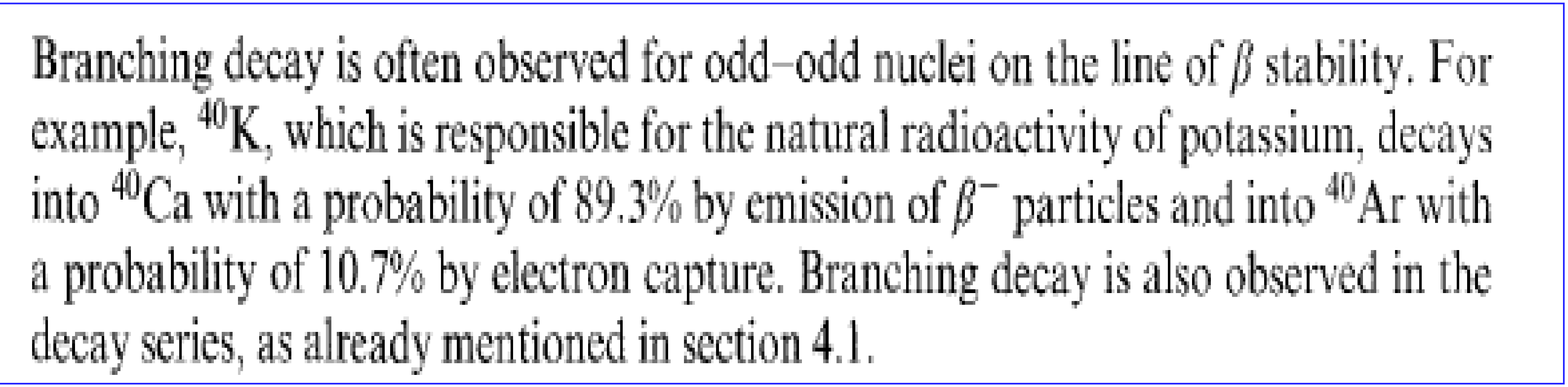


- Competitive Decay Modes

for the same nucleus

  - partial decay constants must be considered
    - A has only one half life

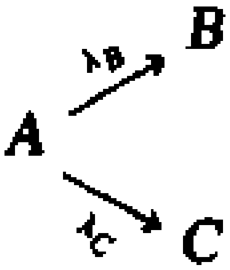
$$\lambda = \sum_{i=1}^{N} \lambda_i ; \frac{1}{t_{1/2}} = \sum_{i=1}^{N} \frac{1}{t_{1/2}^{i}}$$



Branching decay is often observed for odd–odd nuclei on the line of β stability. For example, ^{40}K, which is responsible for the natural radioactivity of potassium, decays into ^{40}Ca with a probability of 89.3% by emission of β^- particles and into ^{40}Ar with a probability of 10.7% by electron capture. Branching decay is also observed in the decay series, as already mentioned in section 4.1.

Branching Decay

- For a branching decay



$$\text{Rate of Decay} = -\frac{\text{dN}}{\text{dt}} = N_A\,\lambda \longrightarrow \frac{dN_A}{dt} = -N_A(\lambda_B + \lambda_C)$$

as $\lambda = \lambda_B + \lambda_C$

$$\frac{dN_B}{dt} = N_A\lambda_B \qquad \frac{dN_C}{dt} = N_A\lambda_C$$

$$t_{1/2} = \frac{0.693}{(\lambda_B + \lambda_C)}$$

Example Problem Consider the nucleus ^{64}Cu ($t_{1/2} = 12.700$ h). ^{64}Cu is known to decay by electron capture (61%) and β^- decay (39%). What are the partial half-lives for EC and β^- decay?

Solution

$$\lambda = \ln 2/12.700\,\mathrm{h} = 5.46 \times 10^{-2}\,\mathrm{h}^{-1}$$

$$\lambda = \lambda_{\mathrm{EC}} + \lambda_{\beta} = \lambda_{\mathrm{EC}} + (39/61)\,\lambda_{\mathrm{EC}}$$

$$\lambda_{\mathrm{EC}} = 3.329 \times 10^{-2}\,\mathrm{h}^{-1}$$

$$t_{1/2}^{\mathrm{EC}} = (\ln 2)/\lambda_{\mathrm{EC}} = 20.8\,\mathrm{h}$$

$$\lambda_{\beta} = (39/61)\lambda_{\mathrm{EC}} = 2.128 \times 10^{-2}\,\mathrm{h}^{-1}$$

$$t_{1/2}^{\beta} = (\ln 2)/\lambda_{\beta} = 32.6\,\mathrm{h}$$

NATURAL RADIOACTIVITY

There are three naturally occurring decay series. They are the uranium ($A = 4n + 2$) series, in which ^{238}U decays through 14 intermediate nuclei to form the stable nucleus ^{206}Pb, the actinium or ^{235}U ($A = 4n + 3$) series in which ^{235}U decays through 11 intermediate nuclei to form stable ^{207}Pb, and the thorium ($A = 4n$) series in which ^{232}Th decays through a series of 10 intermediates to stable ^{208}Pb (Fig. 3.11).

Because the half-lives of the parent nuclei are so long relative to the other members of each series, all members of each decay series are in secular equilibrium, that is, the activities of each member of the chain are equal at equilibrium if the sample has not been chemically fractionated. Thus, the activity associated with ^{238}U in secular equilibrium with its daughters is 14× the activity of the ^{238}U. The notation $4n + 2$, $4n$, $4n + 3$ refers to the fact that the mass number of each member of a given chain is such that it can be represented by $4n$, $4n + 2$, $4n + 3$ where n is an integer. (There is an additional decay series, the $4n + 1$ series, that is extinct because its longest lived member, ^{237}Np, has a half-life of only 2.1×10^6 y, a time that is very short compared to the time of element formation.)

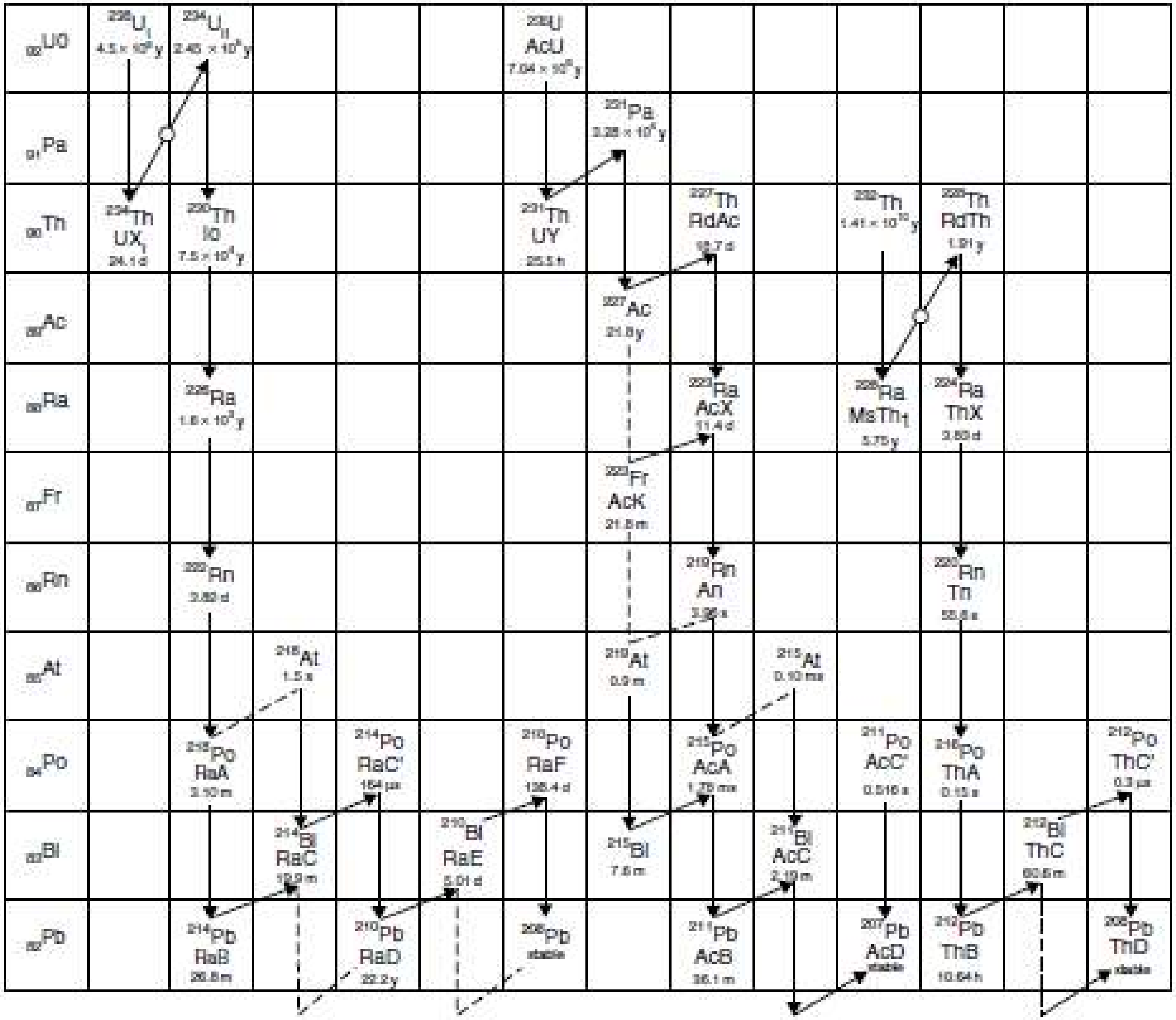
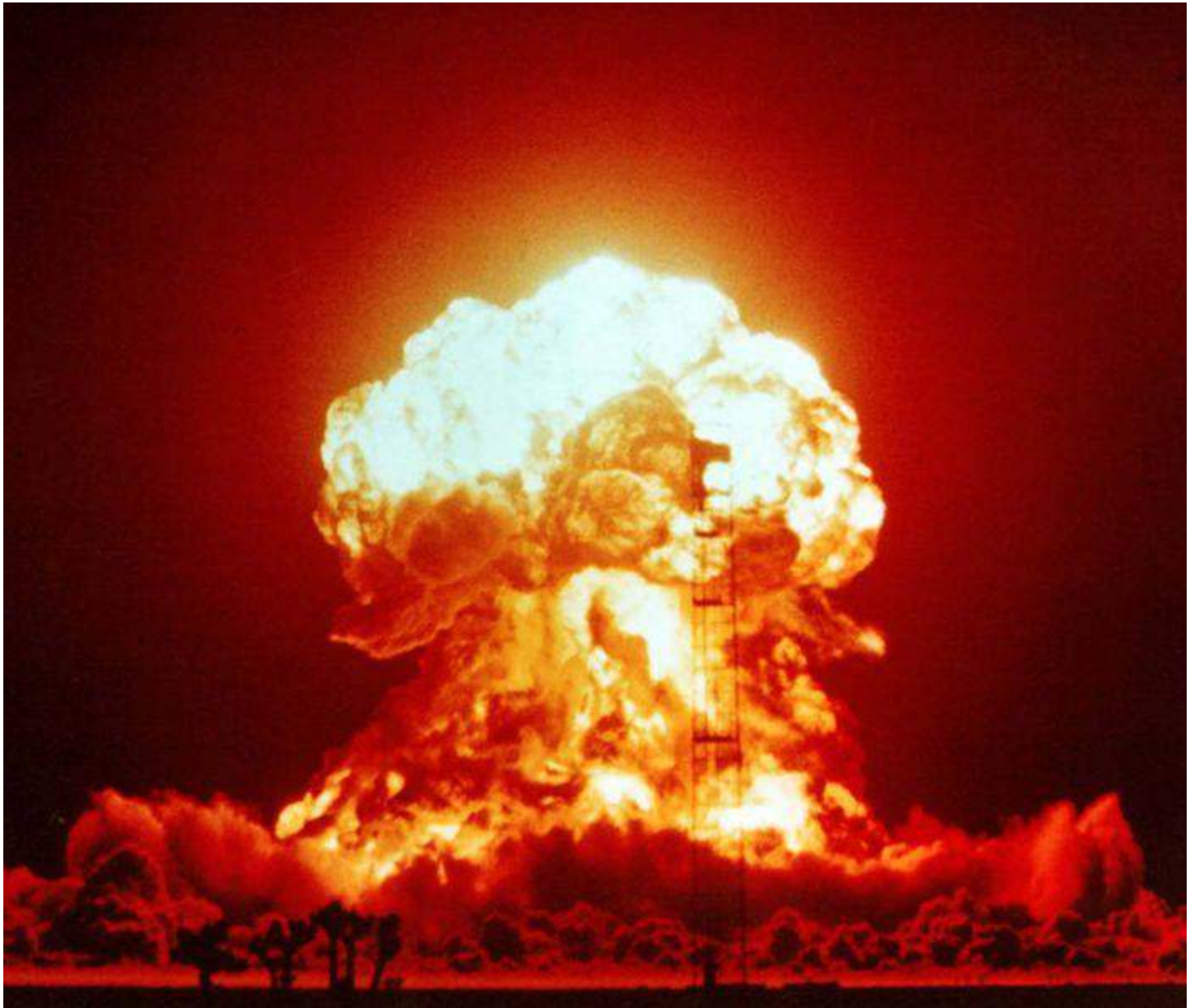


Figure 3.11 The decay series of U^{238}, U^{235}, and Th^{232}. Not shown are several intermediate daughter products of little significance in geochemical applications. For the sake of completeness, old notations still referred to frequently in present-day texts, e.g., RaA for Po^{218}, Io for Th^{230}, are given in the scheme.

Nuclear Reactions



Nuclear Reaction

- **Nuclear Chemistry: The study of the properties and The Reactions of atomic nuclei.**

- **A Nuclear reaction is the process in which two nuclei or nuclear particles collide to produce products different from the initial particles.**

- **While the transformation is spontaneous in the case of radioactive decay, it is initiated by a particle in the case of a nuclear reaction.**

Applications of Nuclear Reactions

Based on nuclide productions:

synthesis of radioactive nuclides - for various applications

synthesis of missing elements Tc, Pm and At

synthesis of transuranium (93-102) elements

synthesis of transactinide (103 and higher) elements

Activation analyses

non-destructive methods to determine types and amounts of elements

Nuclear Reaction

1. Is the process in which two nuclei, or else a nucleus of an atom and a subatomic particle (such as a proton, neutron, or high energy electron) from outside the atom, collide to produce one or more nuclides that are different from the nuclide(s) that began the process.
2. a nuclear reaction must cause a transformation of at least one nuclide to another.
3. If a nucleus interacts with another nucleus or particle and they then separate without changing the nature of any nuclide, the process is simply referred to as a type of nuclear scattering, rather than a nuclear reaction.

Another Definition for nuclear Reactions

- The interaction between nuclear radiation and matter is called a "nuclear reaction" .
- There are several different kinds of "radiation" that can cause nuclear reactions such as gamma rays, neutrons(n), proton(p) , light ions (d,t, α), heavy ions

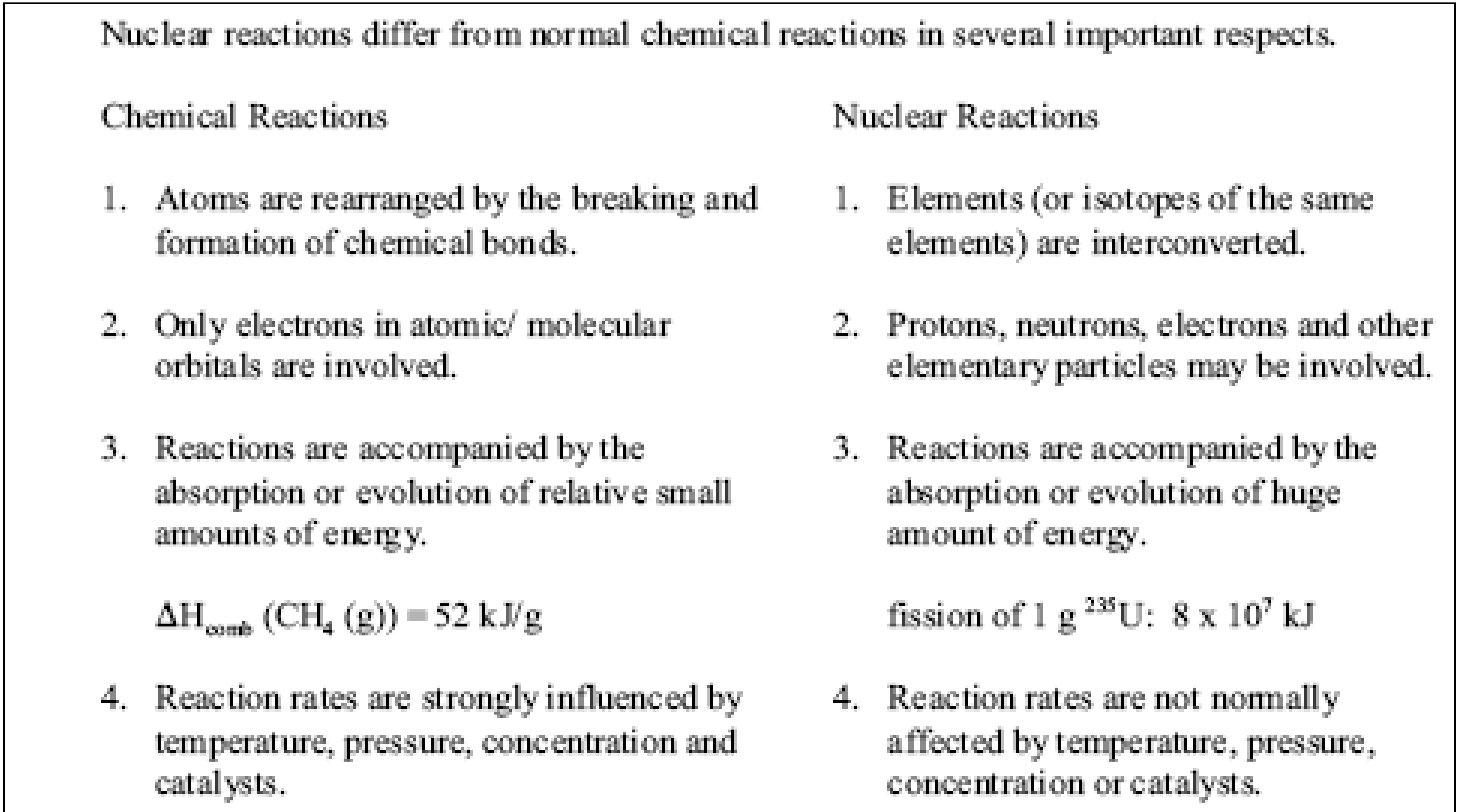
- "Nuclear reaction" is a term implying an **induced change in a nuclide**,

  and thus it does not apply to any type of radioactive decay (which by definition is a spontaneous process).

Natural nuclear reactions occur in the interaction between cosmic rays and matter e.g. :

$$_0n^1 + {}^{14}N \rightarrow {}^{14}C + p$$

Differences between Nuclear Reactions and Chemical Reaction



Nuclear reactions differ from normal chemical reactions in several important respects.

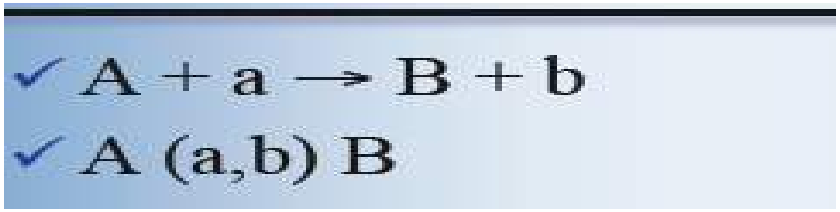
Chemical Reactions	Nuclear Reactions
1. Atoms are rearranged by the breaking and formation of chemical bonds.	1. Elements (or isotopes of the same elements) are interconverted.
2. Only electrons in atomic/ molecular orbitals are involved.	2. Protons, neutrons, electrons and other elementary particles may be involved.
3. Reactions are accompanied by the absorption or evolution of relative small amounts of energy. ΔH_{comb} (CH_4 (g)) = 52 kJ/g	3. Reactions are accompanied by the absorption or evolution of huge amount of energy. fission of 1 g ^{235}U: 8 x 10^7 kJ
4. Reaction rates are strongly influenced by temperature, pressure, concentration and catalysts.	4. Reaction rates are not normally affected by temperature, pressure, concentration or catalysts.
5. Isotopes react the same.	**5. Isotopes react differently.**

•*Heat of reaction* for a nuclear reaction is given per nucleus transformed While the heat of a chemical reaction is given per mole.

Another difference : we keep in mined that the nuclear reactions are very rare events compared with chemical reactions (because of the small size of nuclei)

Notation

- Instead of using the full equations as shown in the previous section, in many situations a compact notation is used to describe nuclear reactions.
- This is **A(a,b)B,** which is equivalent to A + a gives b + B.



✓ $A + a \rightarrow B + b$

✓ A (a,b) B

- Common light particles are often abbreviated in this shorthand, typically p for proton, n for neutron, d for deuteron, α representing an alpha particle or helium-4, β for beta particle or electron, γ for gamma photon, etc.

Notation for Nuclear Reactions

- A nucleus is specified by its chemical symbol (e.g. C for carbon), a superscript A (sum of Z protons and N neutrons in the nucleus) and a subscript Z (protons, often omitted)
  - Examples: ^{12}C, ^{4}He, $^{56}_{26}Fe$
- Usual shorthand for a reaction:

$$a + A \rightarrow b + B \text{ is also written as } \mathbf{A(a,b)B}$$

- General shorthand rule:

Target(Incident Before,Detected After)Undetected leftovers

- Examples:
  - Elastic scattering: $^{12}C(p,p)^{12}C$
  - Inelastic scattering (“inclusive” reaction): $^{16}O(e,e')^{16}O^*$
  - Knockout (“exclusive”) reaction: $^{3}He(e,e'p)^{2}H$
  - Stripping reaction: $^{7}Li(d,p)^{8}Li$
  - Photodisintegration: $^{2}H(\gamma,p)n$

Conservation Laws

In Nuclear Reactions

- Conservation total number of nucleons
  Conservation of Total Energy
- Conservation total charge
- Conservation of Linear momentum
- Conservation of total angular momentum

Balancing the Nuclear Reactions – Example

- Alpha particle colliding with nitrogen:

$$ {}_{2}^{4}He + {}_{7}^{14}N \rightarrow X + {}_{1}^{1}H $$

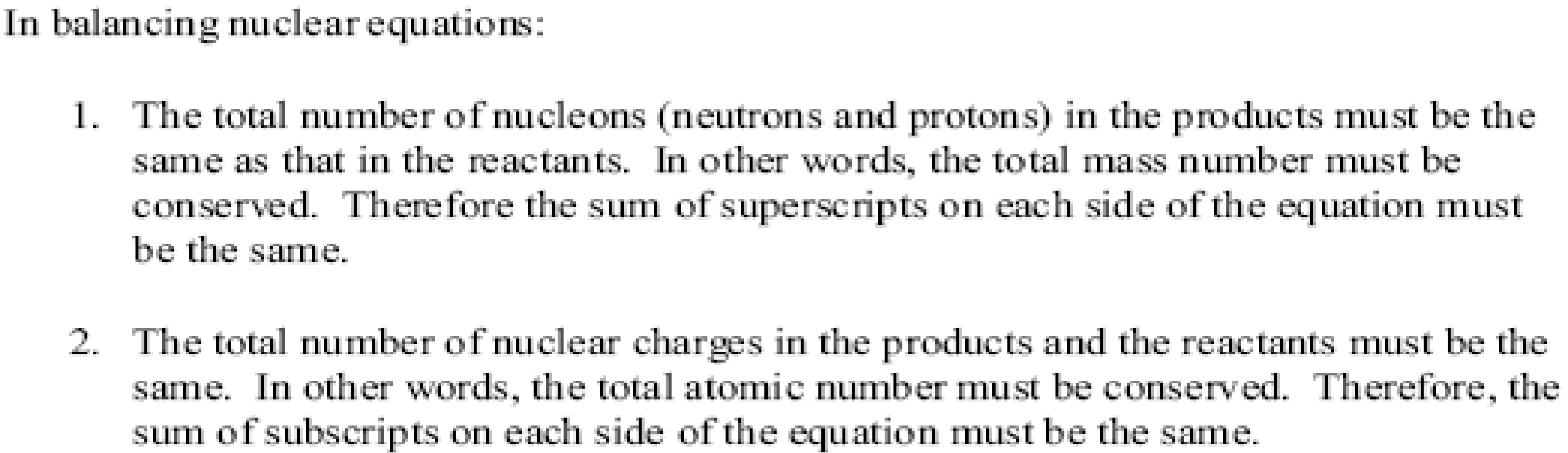
- Balancing the equation allows for the identification of X

$$ X \rightarrow {}_{8}^{17}X \rightarrow {}_{8}^{17}O $$

- So the reaction is

$$ {}_{2}^{4}He + {}_{7}^{14}N \rightarrow {}_{8}^{17}O + {}_{1}^{1}H $$

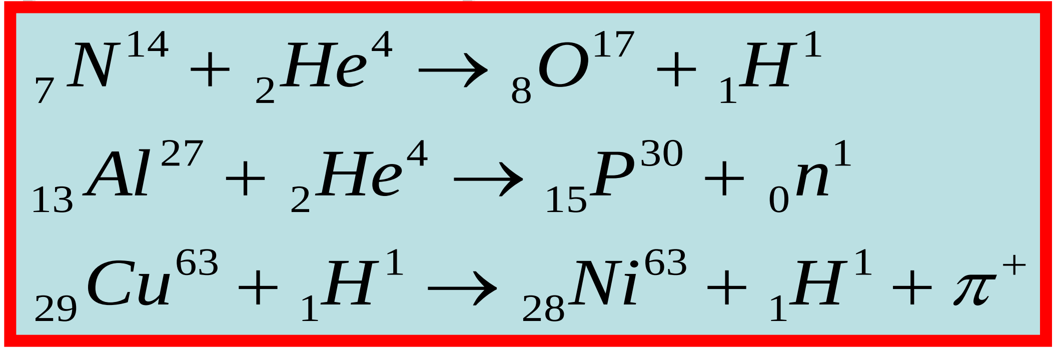
Balancing the Nuclear Reaction



In balancing nuclear equations:

1. The total number of nucleons (neutrons and protons) in the products must be the same as that in the reactants. In other words, the total mass number must be conserved. Therefore the sum of superscripts on each side of the equation must be the same.

2. The total number of nuclear charges in the products and the reactants must be the same. In other words, the total atomic number must be conserved. Therefore, the sum of subscripts on each side of the equation must be the same.



$$_7N^{14} + {_2He^4} \rightarrow {_8O^{17}} + {_1H^1}$$

$$_{13}Al^{27} + {_2He^4} \rightarrow {_{15}P^{30}} + {_0n^1}$$

$$_{29}Cu^{63} + {_1H^1} \rightarrow {_{28}Ni^{63}} + {_1H^1} + \pi^+$$

- **If the reaction equation is balanced, that does not mean that the reaction really occurs.**
- The rate at which reactions occur depends on the ***particle energy***, **the particle flux** and **the reaction cross section**

Q-value in Reactions

- The Q-value in reactions is the difference between the mass energies of the entrance channel particles and the exit channel particles.

$$Q = [M(\text{Entrance}) - M(\text{Exit})]c^2$$

- The Q-value is the energy release in the reaction.
- For elastic collisions $Q = 0$ in inelastic collisions $Q < 0$.

Energy conservation

- **In a nuclear reaction, the total energy is conserved.**
- **The "missing" rest mass must therefore reappear as kinetic energy released in the reaction; its source is the nuclear binding energy.**
- **By using Einstein's mass-energy equivalence formula $E = mc^2$**
- **the amount of energy released can be determined.**

The energy released in a nuclear reaction can appear mainly in one of four ways:

1. energy is eventually released through nuclear reaction (fission reaction)

   $$^{235}U + {}^{1}n \rightarrow {}^{90}Sr + {}^{143}Xe + 3{}^{1}n + \text{Energy}$$

2. kinetic energy of the product particles
3. emission of very high energy photons, called gamma rays
4. some energy may remain in the nucleus, as a metastable energy level.

- When the product nucleus is metastable, this is indicated by placing an asterisk ("*") next to its atomic number. This energy is eventually released through nuclear decay.

Q-value and the Heat of Reaction

- **In writing down the reaction equation, in a way analogous to a chemical equation, one may in addition give the reaction energy on the right side:**

Target nucleus + projectile → Final nucleus + ejectile + *Q*.

- **The reaction energy (the "Q-value") is positive for exothermic reactions and negative for endothermic reactions.**

1. **On the one hand, it is the difference between the sums of kinetic energies on the final side and on the initial side.**
2. **But on the other hand, it is also the difference between the nuclear rest masses on the initial side and on the final side (in this way, we have calculated the Q-value above).**

Q Values

- Energy must also be conserved in nuclear reactions
- The energy required to balance a nuclear reaction is called the *Q value* of the reaction

(In thermodynamic term Q is called H, the change of heat content)

  - An *exothermic* reaction
    - There is a mass "loss" in the reaction
    - There is a release of energy
    - Q is positive
  - An *endothermic* reaction
    - There is a "gain" of mass in the reaction
    - Energy is needed, in the form of kinetic energy of the incoming particles
    - Q is negative

•*Heat of reaction* for a nuclear reaction is given per nucleus transformed

While the heat of a chemical reaction is given per mole.

Example in page 67

- When Li is bombarded with protons having energies up to 0.7 MeV, two alpha particles emerge at 180 °, each having an energy of 8.66 MeV. Show that the total energy of this reaction is 17.32 MeV in agreement with change in the following reaction:

$$Li_3^7 + H_1^1 \to 2\,He_2^4 + Q$$

7.01322   1.00814   2(4.0038)

Δm = 0.01863 amu

ΔE = 0.01863 × 931

Q   = 17.32 Mev

Energetic of nuclear reactions

- Energy, mass number, momentum conservation
- *Q*-value : positive exoergic; negative endoergic
- **Example of endoergic**

$$^{14}\text{N} + {}^{4}\text{He} \rightarrow {}^{1}\text{H} + {}^{17}\text{O} + Q$$

$$14.0075 + 4.00387 \rightarrow 1.00814 + 17.0074$$

$$18.0113 \rightarrow 18.0126$$

$$Q = -1.19 \text{ MeV}$$

$$Q \approx -1.2 \text{ MeV}$$

Is it enough to start the reaction?

- Calculate the Energy released for the following reaction ${}_7N^{14}$ (α, p)${}_8O^{17}$ formed by 1 gm.

The answer

$${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1$$

$$14.00751 + 4.00387 \rightarrow 17.00453 + 1.00814$$

$$\Delta m = 0.00129\ amu$$

$$Q = 931.5 \times 0.00129$$

$$Q = 1.2\ MeV$$

$$
\begin{aligned}
&{}_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{8}O^{17} + {}_{1}H^{1} \\
&14.00751 + 4.00387 \rightarrow 17.00453 + 1.00814 \\
&18.01138 \rightarrow 18.01267 \\
&\Delta m = 0.00129\ amu \\
&Q = 931.5 \times 0.00129 \\
&Q = 1.2\ MeV
\end{aligned}
$$

We found that the Q Value of the reaction $_{7}N^{14}$ (α, p)$_{8}O^{17}$ is -1.2 MeV.

Does that mean this reaction can actually be produced by alpha particles whose kinetic energies are just over 1.2 MeV?

The answer is No for two reason.

First, part of kinetic energy of alpha particle must be retained by the product as kinetic energy.

This is because momentum must be conserved

Total Linear momentum (Kinetic Energy)

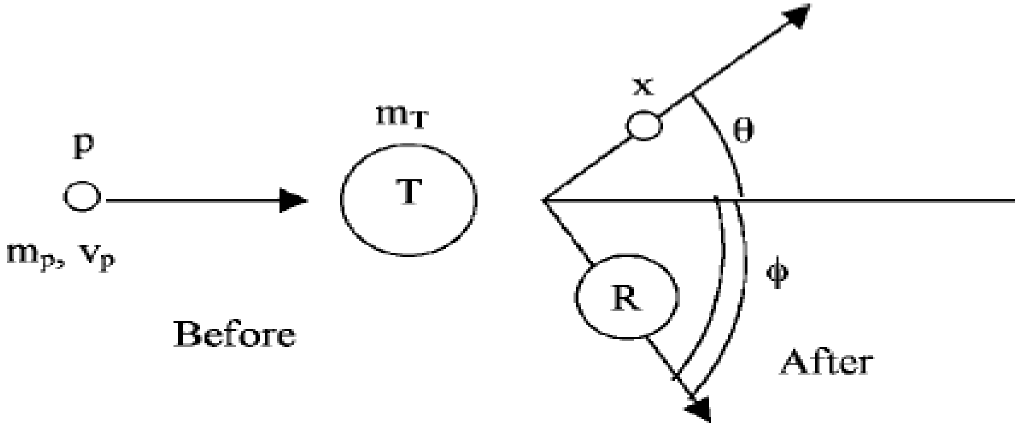


Figure 10.1 Schematic diagram of a nuclear reaction.

- If a particle of mass m and velocity v strikes a nucleus of mass M and is absorbed , then the product nucleus whose mass will be (m + M) must move in the same direction with a velocity V:

$$m\,v = (m + M)\,V$$

- The kinetic energy T_r of product nucleus will be

$$T_r = \frac{m}{(m+M)} T_i$$

Kinetic energy of incident particle

The Minimum Kinetic Energy For Bombarding Particle

- Suppose the following reaction which is endoergic nuclear reaction, the reacting system will absorb an amount Q of kinetic energy

$$N_7^{14} + He_2^4 \rightarrow O_8^{17} + H_1^1 - Q$$

- The minimum required kinetic energy (T_m) must be greater than Q by the amount T_r

$$-Q = Tm - Tr$$

$$-Q = \frac{M}{(M+m)} Tm$$

$$Tm = -Q \frac{(M+m)}{M}$$

Tm for the above reaction is
Tm =1.2 (14 + 4) / 14
= 1.55 Mev

Threshold Energy

- To conserve both momentum and energy, **incoming particles must have a minimum** amount of kinetic energy, called the *threshold energy*

$$KE_{\min} = \left(1 + \frac{m}{M}\right)|Q|$$

  - *m is the mass of the incoming particle*
  - *M is the mass of the target particle*
- If the energy is less than this amount, the reaction **cannot occur**

The Second reason why the alpha particles must have higher energies than is evident from the Q value of the reaction $_7N^{14}$ (α, p) $_8O^{17}$ is the Coulomb repulsion between alpha particles and $_7N^{14}$ nucleus.

Coulomb Repulsion

$$B = Z_1 Z_2 e^2 / R$$

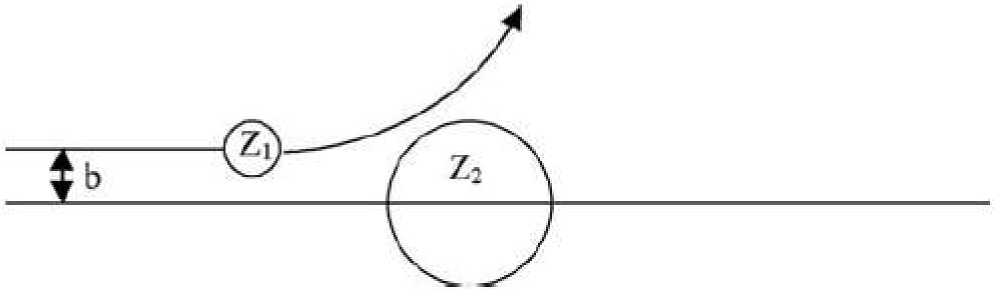
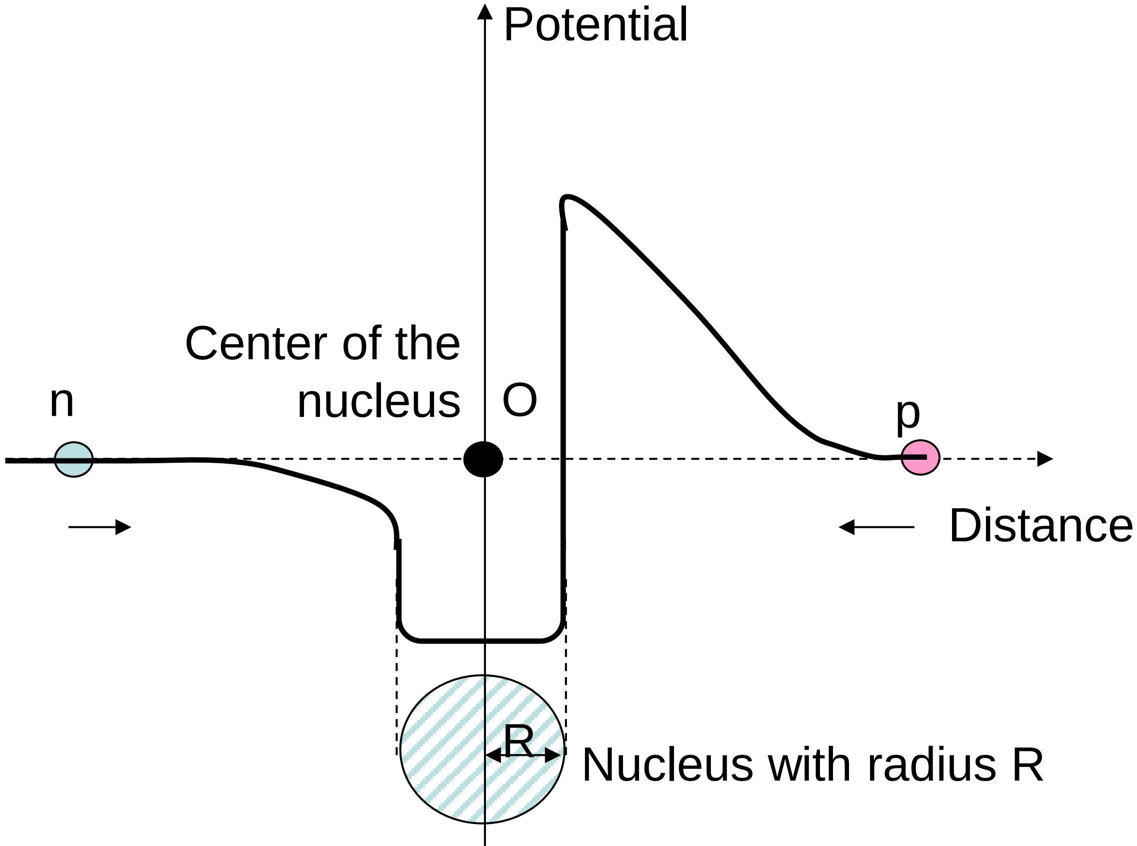


Figure 10.9 Schematic diagram of a charged-particle-induced reaction.



Coulomb Potential barrier

- **For reaction between two nuclei to take place, extremely high energies are needed to overcome the repulsive electrostatic Coulomb force, known as the Coulomb barrier, between the positively charged nuclei, to force the nuclei close enough to each other to come within the influence of the strong nuclear force which hold the nucleons in each nucleus together.**

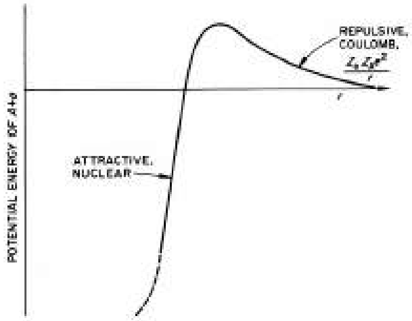
صفحة 19و 18 فى المذكرة

$$E_B = \frac{Z_1 Z_2 e^2}{(R_1 + R_2)}$$

$R = 1.5 \times 10^{-13} A^{1/3}$

Z_1 and Z_2 are the charges of the incident particles and nucleus (Target)

Coulomb effects



E.g. a proton on a lead nucleus: 13 MeV barrier.

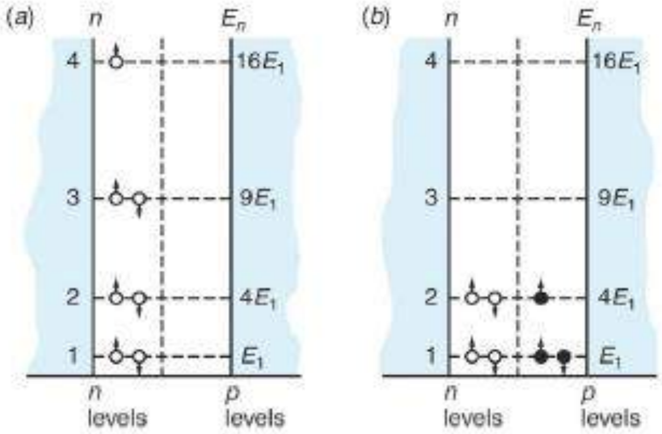
The Coulomb barrier is very important for ion beams.

In the reaction ${}_7N^{14}$ (α, p) ${}_8O^{17}$

- The height of the potential barrier (E_B) between α and ${}_7N^{14}$ is estimated of about 3.4 MeV.
- The Tm of α particles is (14+4)/14 × 3.4 = 4.4 MeV.
- The Coulomb barrier for protons and deuterons is about half the values for alpha particles .
- The highest of the barrier increases with increasing Z of the target (it is proportional to $Z^{2/3}$)

Centrifugal Potential

- In the above discussion we have assumed that the incident particle collides head on with the nucleus.
- Interaction does not occur in the origin direction of motion of the particle and does not pass through the centre of the target nuclei
- Such systems have angular momentum
- The angular momentum is quantized in integral multiples of the universal unit h/2π
- The resulting hindrance to the close centrifugal barrier
- The centrifugal barrier V is given by equation
- The The centrifugal barrier for the reaction $_7N^{14}$ (α, p) $_8O^{17}$ is 0.29 MeV
- The potential barriers (coulomb and centrifugal) is effective not only on particle entering but also, for particles leaving.



$$V = \frac{h^2 l^2}{8\pi^2 M (R_1 + R_2)^2}$$

$$V = \frac{h^2 l(l+1)}{8\pi^2 M (R_1 + R_2)^2}$$

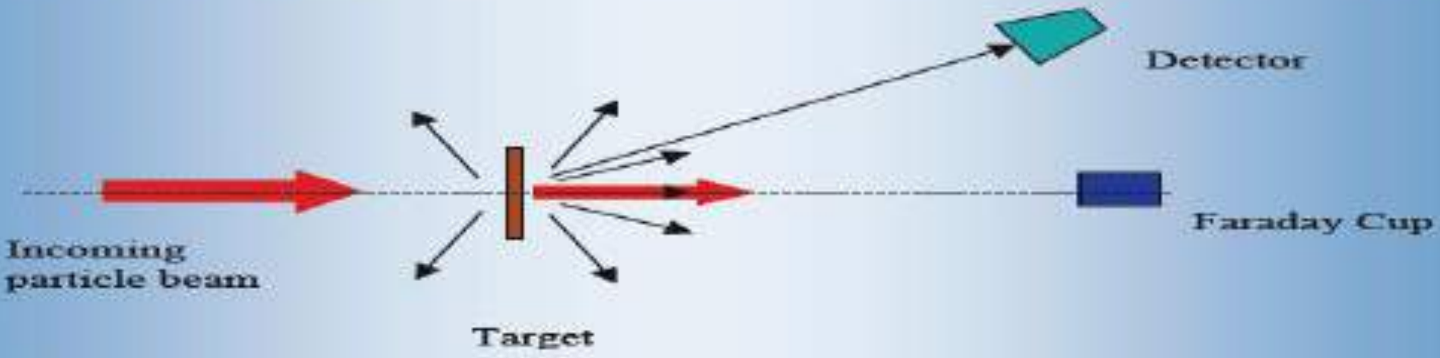
where $l\hbar$ is the orbital angular momentum of the incident projectile.

Types of nuclear reactions

1. Radioactive Decay – nucleus decays spontaneously giving off an energetic particle

2. Nuclear Bombardment – shoot a high energy particle at the nucleus of another atom and watch what happens

A Typical Experiment



What do we measure?

- ✓ Detector might measure the outgoing particle's:
  - Type of particle
  - Energy
  - Momentum (direction and magnitude)
  - Number of particles (of each type)

Number of particles

- ✓ The number of particles detected depends on a variety of factors:
    - Beam flux
    - Number of “targets” – target thickness
    - Detector placement, size and efficiency
    - Physical properties of the reaction

Bombardment Transmutation

  - particles “shot” at nuclei; create new atoms
- Fission
  - large atoms split, forming smaller atoms
  - neutrons and energy also formed
- Fusion
  - very small atoms fused together
  - relative large amounts of energy produced

Types of Nuclear Reactions

According to type of incident particles

1- Charged-particle reactions
2-Neutron reactions
3-Photonuclear reactions
4-Electron-induced reactions

According to Target

1-Light nuclei (A≤ 40)
2-Intermediate nuclei (40< A<150)
3-Heavy nuclei (A≥150)

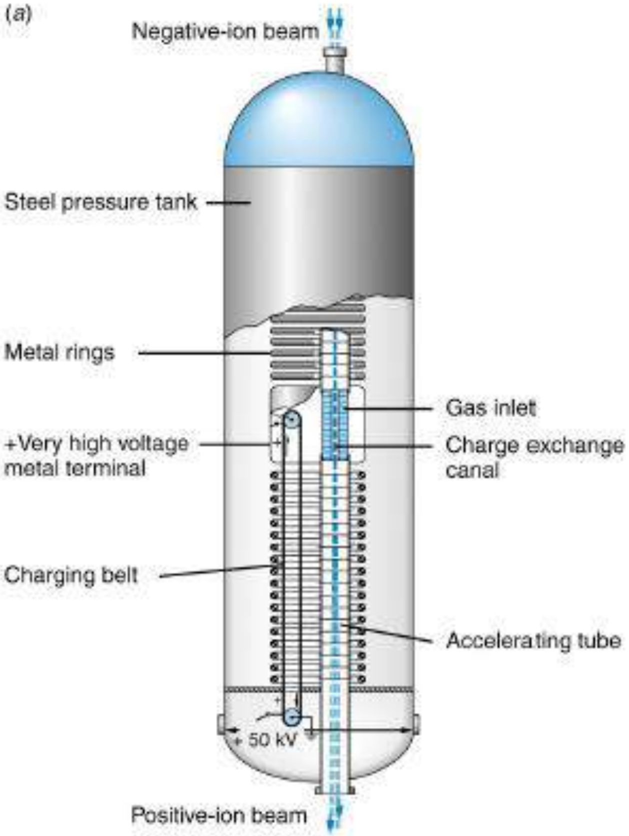
According to the Reaction

1-Fission reactions
2-capture reactions (Proton and electrons)
3- photonuclear reactions

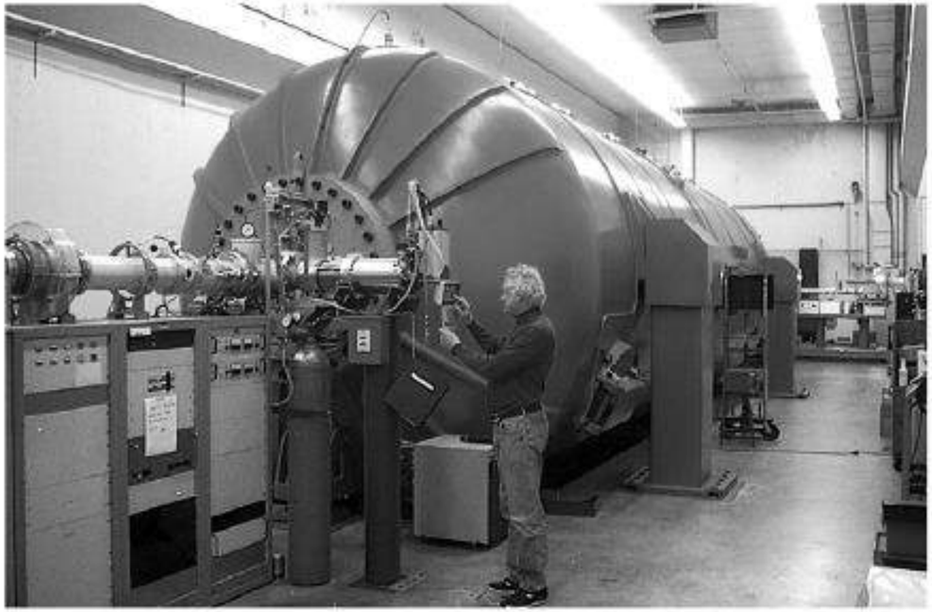
Nuclear Bombardment Reactions

- All transuranium elements (more than 92 protons) were created synthetically in particle accelerators.
- **Particle accelerators are where most of the bombarding takes place.**
- **The accelerators move the particles toward each other at great speeds, to overcome the repulsive forces.**

Particle Induced Nuclear Reactions: are used mostly for nuclear physics research, and for analytical purposes

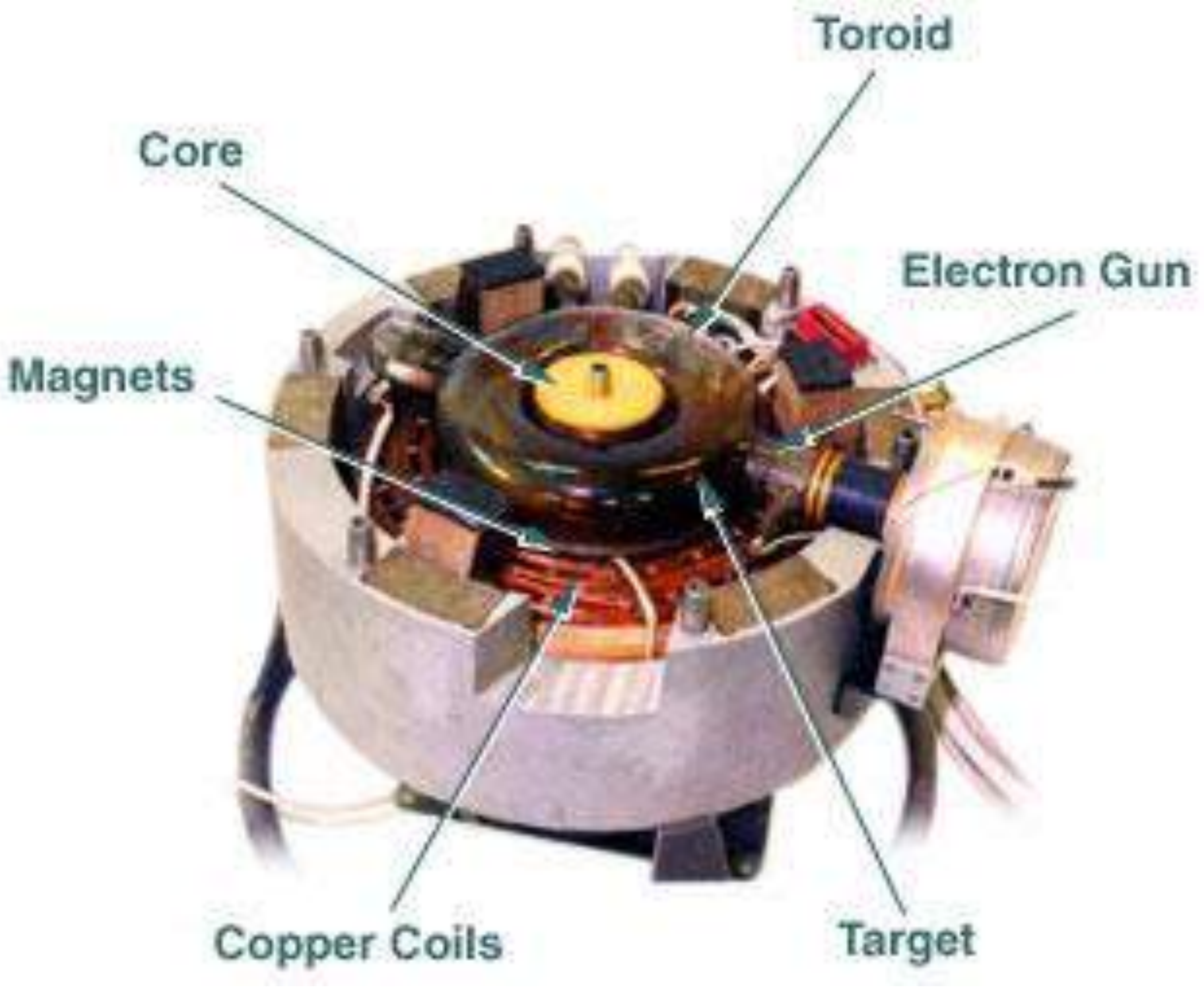


The reaction $^{7}Li(p,\alpha)^{4}He$ can be used to detect Li in solids [1-2 MeV protons]



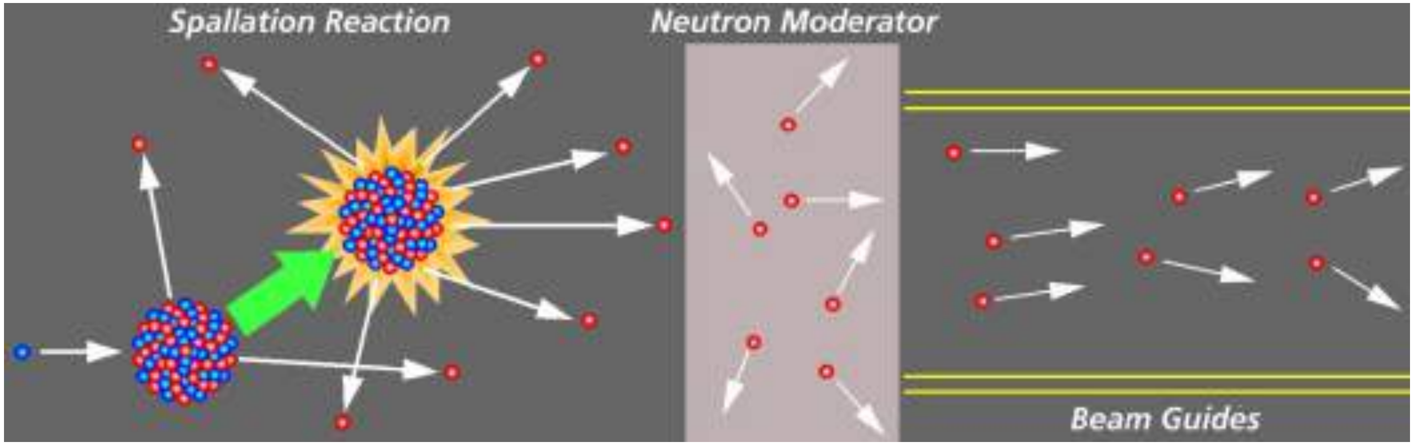
SLAC :linear accelerator

Circular acceleration: **Betatron**



Neutrons Reactions

Neutron Bombardment



Nuclear Reactions Induced by Cosmic Rays

Cosmic rays consist of mainly high energy protons, and they interact with atmospheres to produce neutrons, protons, alpha particles and other subatomic particles.

One particular reaction is the production of ^{14}C,

^{14}N(n, p)^{14}C - β emitting, half-life 5730 y

Ordinary carbon active in exchange with CO_2 are radioactive with 15 disintegration per minute per gram of C.

Applying decay kinetics led to the ^{14}C-dating method.

Neutron -Induced Reactions

- Using neutrons from the reaction, ^{27}Al (α, n)^{31}P, Fermi's group in Italy soon discovered these reactions:

^{19}F (n, α) ^{16}N ^{27}Al (n, α) ^{24}Na (n , β) ^{24}Mg.

- They soon learned that almost all elements became radioactive after the irradiation by neutrons, in particular

^{10}B (n, α) ^{7}Li releasing 2.3-2.8 MeV energy

is used in classical neutron detectors. Now, detectors use,

^{3}He (n, p) ^{3}H

Neutron Interactions

- neutrons essentially interact only with the atomic nucleus
- cross-sections can vary dramatically based on complex interactions between all the nucleons in the nucleus and the incident neutron
- huge effort and money has been spent to measure these cross-sections for many materials and a wide range of neutron energies

Benefits of Neutron Interactions

Needed for

1- shielding calculations

2- for many basic and applied type s of research:

- **neutron scattering, crystal studies, DNA**
- **neutron activation analysis**
- **neutron radiography, paintings**
- **weapons research, neutron bombs**
- **Nuclear Reactor for producing Energy**
- **nuclear structure**
- **neutron depth profiling**
- **neutron dosimetry**

Neutron Induced Nuclear Reactions

التفاعلات النووية المستحثة بواسطة النيترونات

Nuclear reactions induced by neutron bombardment are used:

a) In analytical techniques such as **neutron activation analysis**
b) In the generation of energy by **Fission** or **Fusion**

It is convenient to distinguish between fast and slow neutrons

Fast neutron → kinetic energy ≥ 1 MeV
Slow neutron or thermal neutron → kinetic energy ~ 0.025 eV

The probability for a reaction to proceed or **Cross Section** depends strongly on the energy of the neutrons

Neutron Activation Analyses (NAA)

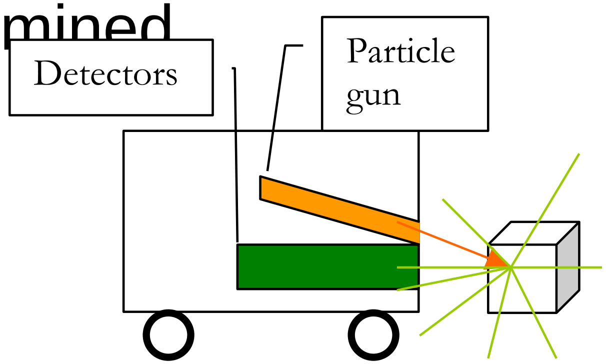
- **Activation analyses**
  - non-destructive methods to determine types and amounts of elements

❖ Advantages of NAA

- Simultaneous analysis for many elements
- Chemical preparation rarely necessary
- Non-destructive testing
- Reliable quantitative results
- Very high sensitivity (for *some* elements)

Neutron Activation Analyses (NAA)

- Since most elements <u>capture neutrons </u>and produce radioactive isotopes, these reactions made them detectable.
- After β emission, the daughter nuclides usually emit γ rays.
- Each nuclide has a unique γ-ray spectra.
- Presence of their spectra after irradiation implies their being in the sample, and Intensities of certain peaks enable their amounts to be determined.



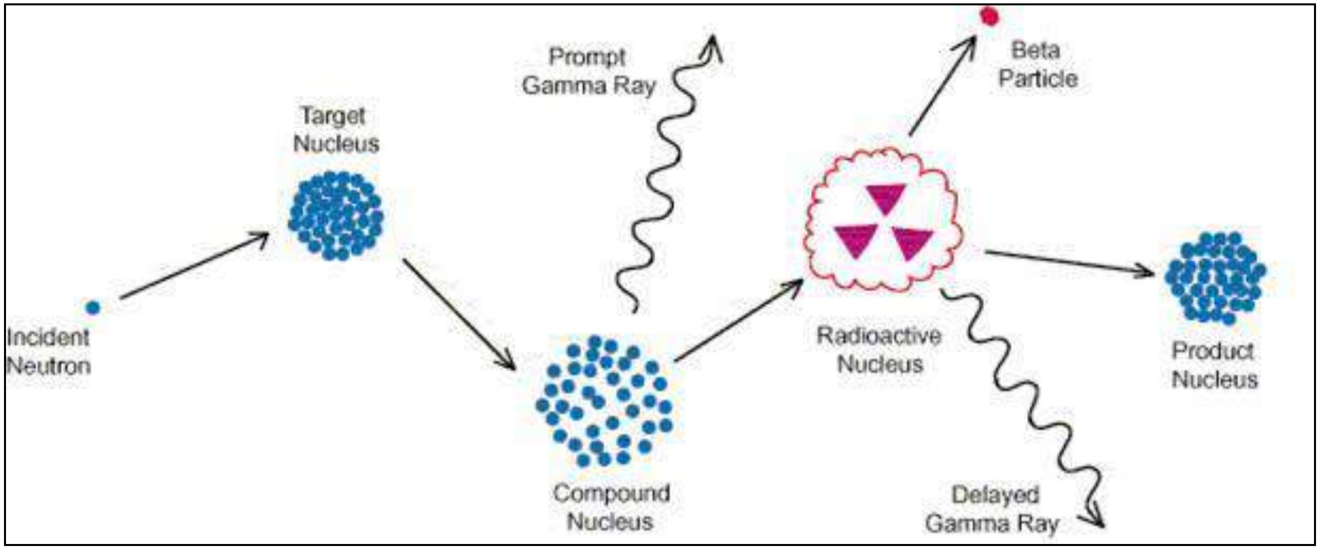
NAA can be applied to explore planets and satellites and other objects in space.

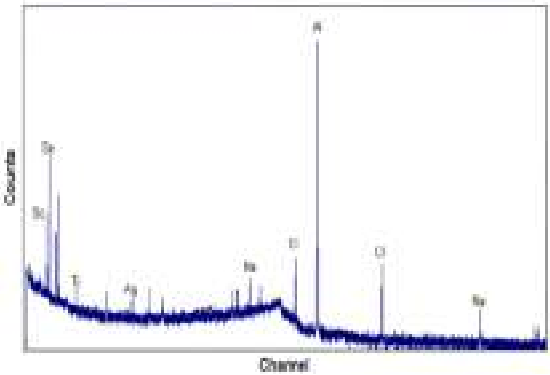
How is NAA?

- Hit source with neutrons

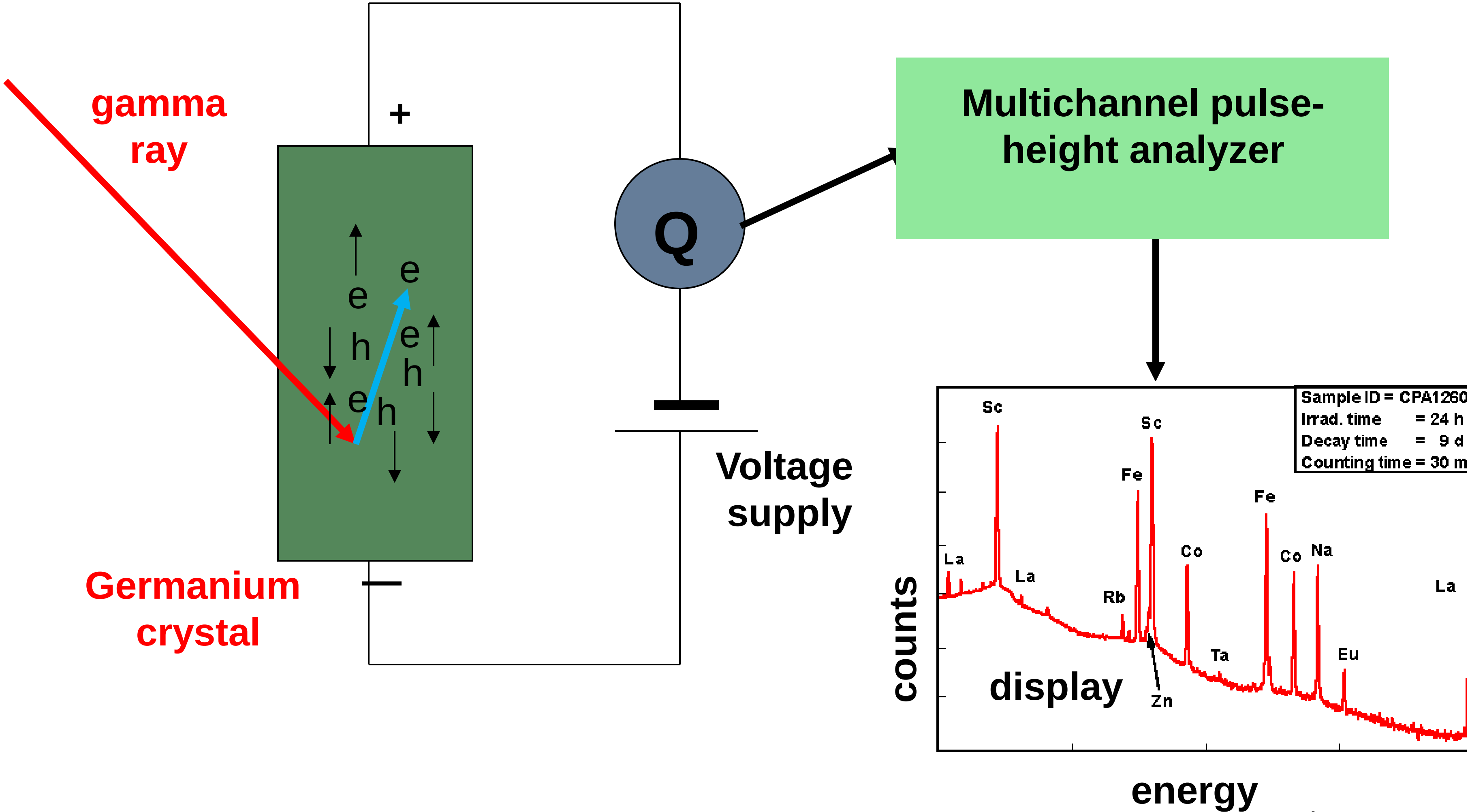
$$\mathcal{A} = \lambda n(t) = \Phi\sigma N(1 - e^{-\lambda t})$$

- Sources become radioactive
- Then decay in predictable ways
- Detect the gamma-rays (prompt and delayed) - with gas detector, scintillators وميض, semiconductors
- Bin number of counts at each energy





Gamma-ray spectrometer



gamma ray

Germanium crystal

Q

Multichannel pulse-height analyzer

Voltage supply

display

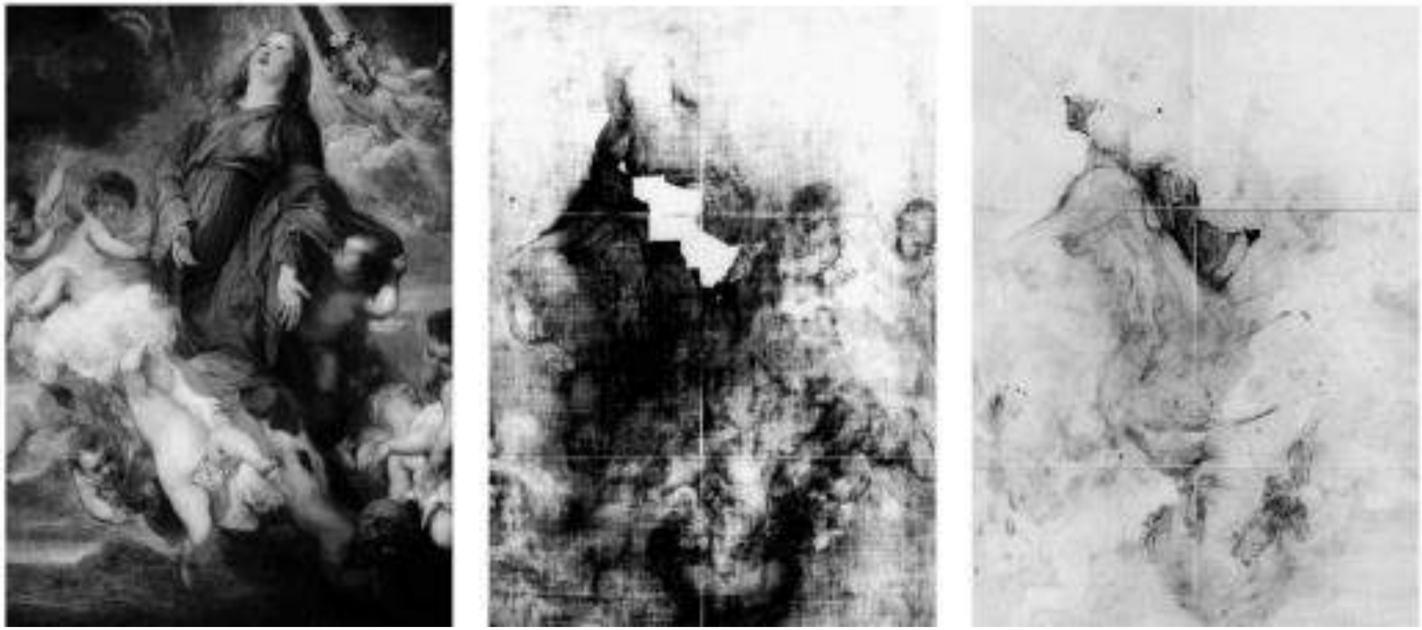
counts

energy

Neutron Activation Analysis

Low energy neutrons are likely to be captured by nuclei, with emission of radiation from the excited nucleus, as in X(n,γ)Y. The emitted radiation is a signature for the presence of element X

Various layers of a painting are revealed using NAA



2-5-3 انتقال الطاقة من النيوترونات لجسم الإنسان:

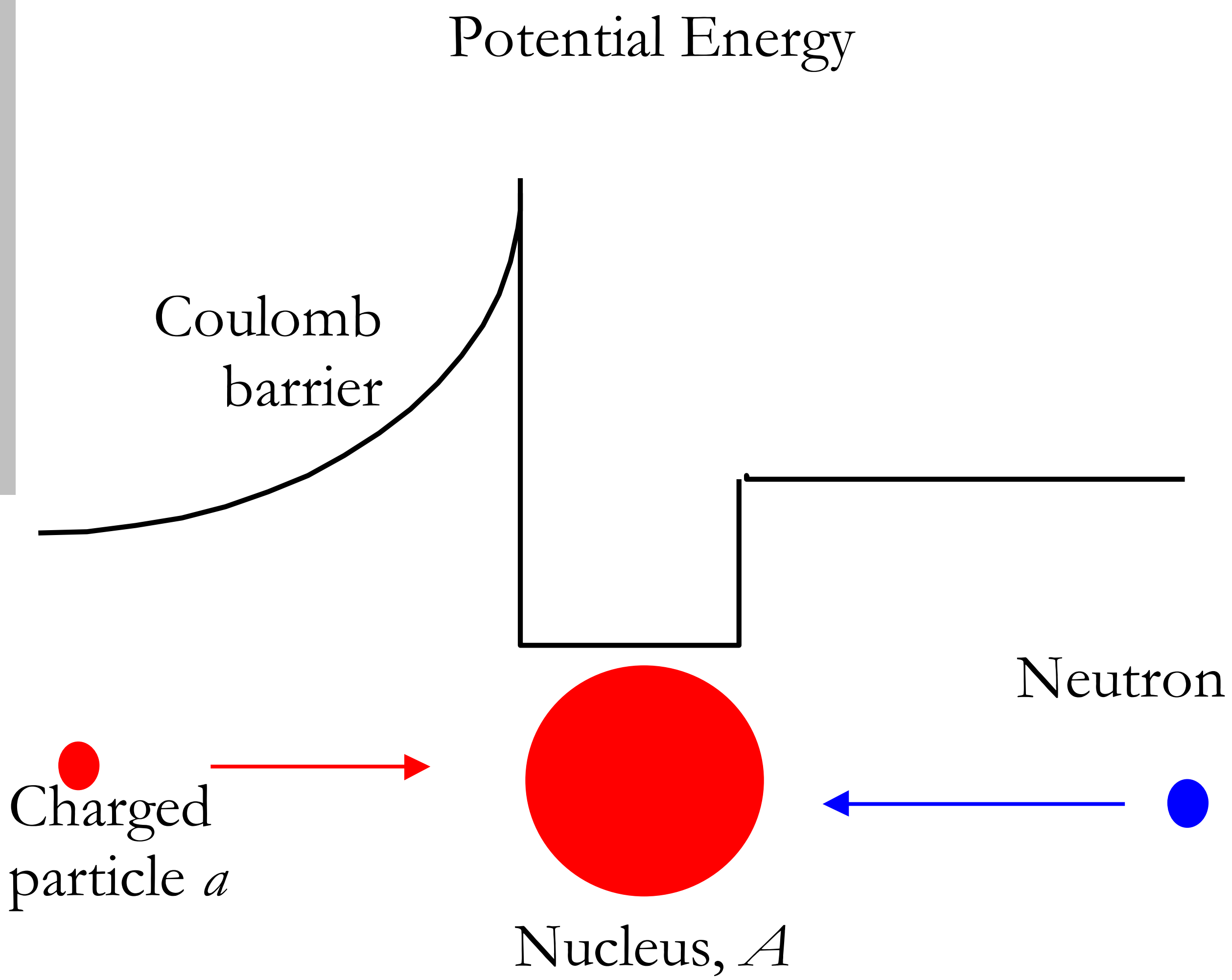
بالنسبة للنيوترونات السريعة، فإنها يمكن أن تنقل كامل طاقتها إلى جسم الإنسان من خلال التصادمات المرنة مع نوى الهيدروجين. فطاقة النيوترون السريع تنتقل بالكامل بعد حوالي 18 تصادما إلى نوى ذرات الهيدروجين (أي إلى البروتونات) الذي يعتبر المكون الرئيس والسائد في جسم الإنسان، حيث يحتوي كل كيلو جرام واحد من جسم الإنسان على حوالي 6×10^{25} ذرة هيدروجين. وعندما تكتسب البروتونات طاقات النيوترونات تقوم هذه البروتونات المشحونة بتأيين ذرات أو جزيئات خلايا الجسم البشري. لذلك، يقال أن النيوترونات تنتمي للإشعاعات المؤينة رغم أنها تحدث التأيين بطريقة غير مباشرة.

Neutron-induced Reactions

- A) Thermal neutrons and its velocities
- B) Moderation of Neutrons
- C) Slow-neutron Reactions cross sections
- D) one –over V law And The Resonance Process

Neutron-induced Reactions

The Potential Energy of a Positively Charged Particle as it Approaches a Nucleus.



- Since a neutron has no charge, it **is not** resisted by the nucleus it is bombarding.
- Because of this, neutrons **do not need** to be accelerated to high energies before they can undergo a nuclear reaction.
- Nuclear reactions involving neutrons are thus **easier** and **cheaper** to perform than those requiring positively charged particles.

Classification of Neutrons

النيوترونات تبعا لطاقتها الحركية إلى الأنواع التالية:

نيوترونات حرارية ونيوترونات بطيئة: النيوترونات الحرارية هي النيوترونات التي تقل طاقتها الحركية عن حوالي 1 إلكترون فولت في حين أن النيوترونات البطيئة هي التي تتراوح طاقتها بين 1 إلكترون فولط، 0.1 كيلو إلكترون فولت.

نيوترونات بينية الطاقة: هي النيوترونات التي تتراوح طاقتها بين 0.1 ، 20 كيلو إلكترون فولت.

نيوترونات سريعة: هي النيوترونات التي تتراوح طاقتها بين 0.2 – 10 ميغا إلكترون فولت.

نيوترونات عالية الطاقة: هي النيوترونات التي تزيد طاقتها على 10 ميغا إلكترون فولت.

ونظرا لعدم وجود شحنة للنيوترون فإنه يتميز بخصائص تختلف كثيرا عن خصائص الجسيمات المشحونة. ومن هذه الخصائص أنه لا يمكن تعجيله (تسريعه) ولا يمكن أن يؤين النيوترون ذرات المادة ولا يحدث عنه أية تفاعلات كهروستاتيكية مع النواة أو الإلكترونات. لذا، فإنه إن لم يتفاعل النيوترون تفاعلا نوويا مع نوى الذرات تكون المادة بالنسبة لهذا النيوترون كالفراغ، مما يجعل له قدرة كبيرة على اختراق المادة. ويتفكك النيوترون تلقائيا بعد خروجه من النواة إلى بروتون وجسيم بيتا ونيوترينو مضاد وفقا لتفاعل التفكك:

$$^{o}n \longrightarrow P^{+} + \beta^{-} + \acute{\upsilon}$$

ويبلغ عمره النصفي 15 دقيقة.

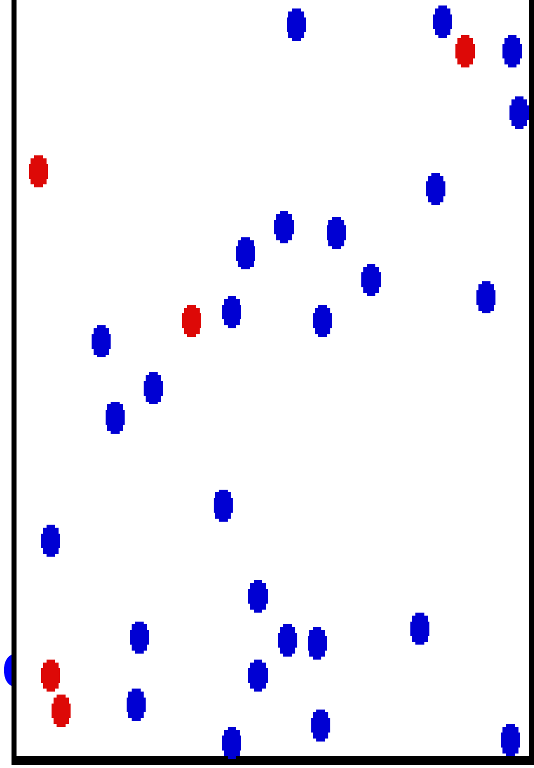
Classification of Neutrons

Neutrons are classified according to their energy:

- **thermal neutrons have an energy of about ~ 0.025 eV**
- “Thermal neutrons” :
- is neutrons whose energy distribution equal to that of gas molecules in thermal agitation at ordinary temperatures.

- **slow neutrons have energies between 0.01 KeV and 0.1 KeV**
- **Moderate neutrons have energy of about 0.2 Kev to 20 Kev**
- **fast neutrons - 0.1 MeV and 20 MeV**
- **epithermal neutrons, resonance neutrons,**
- **relativistic neutrons**

Thermal energies of neutrons



“Thermal neutrons” :
is neutrons whose energy distribution equal to that of gas molecules in thermal agitation at ordinary temperatures.

- **at thermal energies neutrons are indistinguishable from gas molecules at th same temperature and follow the Maxwell-Boltzman distribution:**

$$f(E) = \frac{2\pi}{(\pi kT)^{3/2}} e^{-E/kT} E^{1/2}$$

- **where:**

f (E) = fraction of neutrons of energy e/unit energy interval

k = Boltzman constant × 10^{-23} J/ºK

T = absolute temperature ºK

The neutron sources مصادر النيوترونات

لا توجد في الطبيعة نظائر طبيعية مشعة للنيوترونات. ولكن أمكن في السنوات الأخيرة إنتاج نظير الكاليفورنيوم 252($_{98}Cf^{252}$) الذي يعتبر حتى الآن النظير الصناعي الوحيد للنيوترونات بعمر نصف يبلغ 2.65 سنة. وقد استخدمت التفاعلات النووية المختلفة، خاصة تفاعل جسيم ألفا نيوترون (α,n) على العناصر الخفيفة كمصدر للنيوترونات منذ الثلاثينيات. وحتى الآن تعتبر هذه التفاعلات مع تفاعلات الانشطار والاندماج النووي هي المصادر الوحيدة للنيوترونات، ولنستعرض بعض هذه المصادر.

Neutron Sources for Nuclear Reactions

Neutrons are the most important subatomic particles for inducing nuclear reactions. These sources are:

1- Neutrons from α induced nuclear reactions

2- Neutrons from γ-photon excitations

3- Neutrons from nuclear reactions induced by accelerated particles

4- Neutrons from spontaneous and n-induced fission reactions (nuclear reactors)

The neutron sources مصادر النيوترونات

أ- مصدر الكاليفورنيوم Californium 252 Sources

يتم إنتاج الكاليفورنيوم 252 في الوقت الحالي في المفاعلات النووية. ويتفكك نظير الكاليفورنيوم 252 تلقائيا مصدرا جسيم ألفا أحيانا وقد يتفكك مصدرا نيوترونا طبقا للمعادلة:

$$^{252}_{98}Cf \longrightarrow {}^{251}_{98}Cf + {}^{1}_{0}n$$

ب- مصدر الراديوم - بريليوم Radium-beryllium source

يعتبر هذا المصدر من أرخص مصادر النيوترونات. وتنتج النيوترونات في هذا المصدر عند قذف نواة البريليوم 9 بجسيم ألفا فينطلق نيوترون طبقا للتفاعل التالي:

$$\alpha + {}^{9}_{4}Be \longrightarrow {}^{12}_{6}C + n + 5.76 \ MeV$$

ج- مصدر البولونيوم بريليوم أو الأميريشيوم بريليوم

د- مصدر النيوترونات الفوتوني The photoneutron source

يتلخص مبدأ عمل هذا المصدر على قذف بعض النوى بالفوتونات فينتج عن ذلك انبعاث النيوترونات. ويقوم عمل معظم المصادر من هذا النوع على استخدام التفاعلين التاليين.

$$\gamma + {}^{9}_{4}Be \longrightarrow 2\alpha + n - 1.67 \ MeV$$

$$\gamma + {}^{2}_{1}H \longrightarrow {}^{1}_{1}H + n - 2.23 \ MeV$$

1-Neutrons from α Induced Reactions

The discovery of neutron by James Chadwick in 1932 by reaction

$^{9}Be\ (\alpha, n)\ ^{12}C$,

was applied to supply neutrons for nuclear reactions by mixing α-emitting nuclides with Be and other light nuclides.

Mixtures used as neutron sources

Source	Reaction	n energy / MeV
Ra & Be	$^{9}Be(\alpha, n)^{12}C$	up to 13
Po & Be	$^{9}Be(\alpha, n)^{12}C$	up to 11
Pu & B	$^{11}B(\alpha, n)^{14}N$	up to 6
Ra & Al	$^{27}Al\ (\alpha, n)^{31}P$	

Sources of Neutrons (α,n)

Source	Avg Neutron Energy (MeV)	Half-Life	$\frac{\text{n}}{\text{sec}}/\text{Ci}$
^{210}PoBe	4.2	138 d	9×10^5
^{210}PoB	2.5	138 d	4×10^5
^{226}RaBe	3.9	1602 yr	1.7×10^7
^{226}RaB	3.0	1602 yr	6.8×10^6
^{239}PuBe	4.5	24,400 yr	1×10^6

2-Neutrons by γ Excitation

- High-energy photons excites light nuclides to release neutrons.
- To avoid α- and β-ray excitation, radioactive materials are separated from these light nuclides in these two-component neutron sources to supply low energy neutrons for nuclear reactions.

Two-component neutron sources

Source	Reaction	n energy / MeV
^{226}Ra, Be	^{9}Be(γ, n)^{12}C	0.6
^{226}Ra, D_2O	^{2}D(γ, n)^{1}H	0.1
^{24}Na, Be	^{9}Be(γ, n)^{8}Be	0.8
^{24}Na, H	^{2}D(γ, n)^{1}H	0.2

3-Neutrons from Accelerators and Reactors

3. Accelerator Neutrons

- **particle accelerators are used to generate neutrons by means of nuclear reactions such as: D-T, D-N, P-N**

$^{3}H(d,n)^{4}He$ - Q-value = 17.6 MeV →14.1MeV neutrons

$^{2}H(d,n)^{3}He$ - Q-value = 3.27 MeV

$^{7}Li(p,n)^{7}Be$ - Q-value = 1.65 MeV

- **Q-values means the nuclear reaction can be induced with only several hundred keV ions**

هـ معجلات الجسيمات المشحونة كمصادر للنيوترونات

Particle accelerators as neutron sources

يمكن الحصول على نيوترونات ذات طاقة محددة وذلك بقذف بعض النوى الخفيفة بالجسيمات المشحونة والمعجلة في معجل حتى طاقة معينة طبقًا لبعض التفاعلات التالية:

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + n + 3.29 \text{ MeV}$$

$$^{1}_{1}H + ^{2}_{1}Li \longrightarrow ^{7}_{4}Be + n - 1.65 \text{ MeV}$$

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + n + 17.6 \text{ MeV}$$

$$^{2}_{1}H + ^{12}_{6}C \longrightarrow ^{13}_{7}N + n - 0.26 \text{ MeV}$$

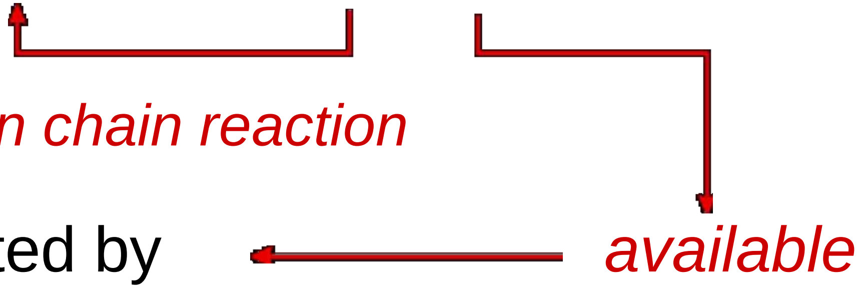
$$^{2}_{1}H + ^{9}_{4}Be \longrightarrow ^{10}_{5}B + n + 4.35 \text{ MeV}$$

وهكذا، فإنه يمكن اختيار التفاعل المناسب للحصول على النيوترونات ذات الطاقة المحددة. وبتغيير طاقة الجسيمات المعجلة يمكن تغيير طاقة النيوترونات للقيمة المطلوبة. وعموما، يستخدم التفاعل الثالث في عمل مصادر النيوترنات المعروفة باسم مولدات النيوترونات (neutron generators) . ولهذا الغرض يتم تعجيل الديوترونات لطاقة تصل إلى 150 كيلو إلكترون فولت ويقذف بها هدف من التريتيوم فتنبعث النيوترونات بطاقة 14.1 ميغا إلكترون فولت. ويمكن الحصول من مثل هذا المصدر على تدفق نيوتروني (neutronflux) تصل شدته إلى حوالي $10^{10} - 10^{12}$ نيوترون/ثانية. سم^{2}.

4- Neutrons by fission reaction

- Fission:

$$n + {}^{235}U = n + n + \text{fragments}$$



Sustain chain reaction

200 MeV/n

moderated by *available*

D_2O (H_2O) to

E = T (Maxwellian)

- **some heavy nuclei fission and emitting neutrons**

- **Neutrons from nuclear fission reactions**
  - **^{252}Cf spontaneous fission to yield 3 or more neutrons**
  - **^{235}U and ^{239} Pu induced fission reactions release 2 to 3 neutrons in each fission**

Interaction of Neutrons with matter

- neutrons are uncharged and can travel appreciable distances in matter without interacting

neutrons interact mostly by

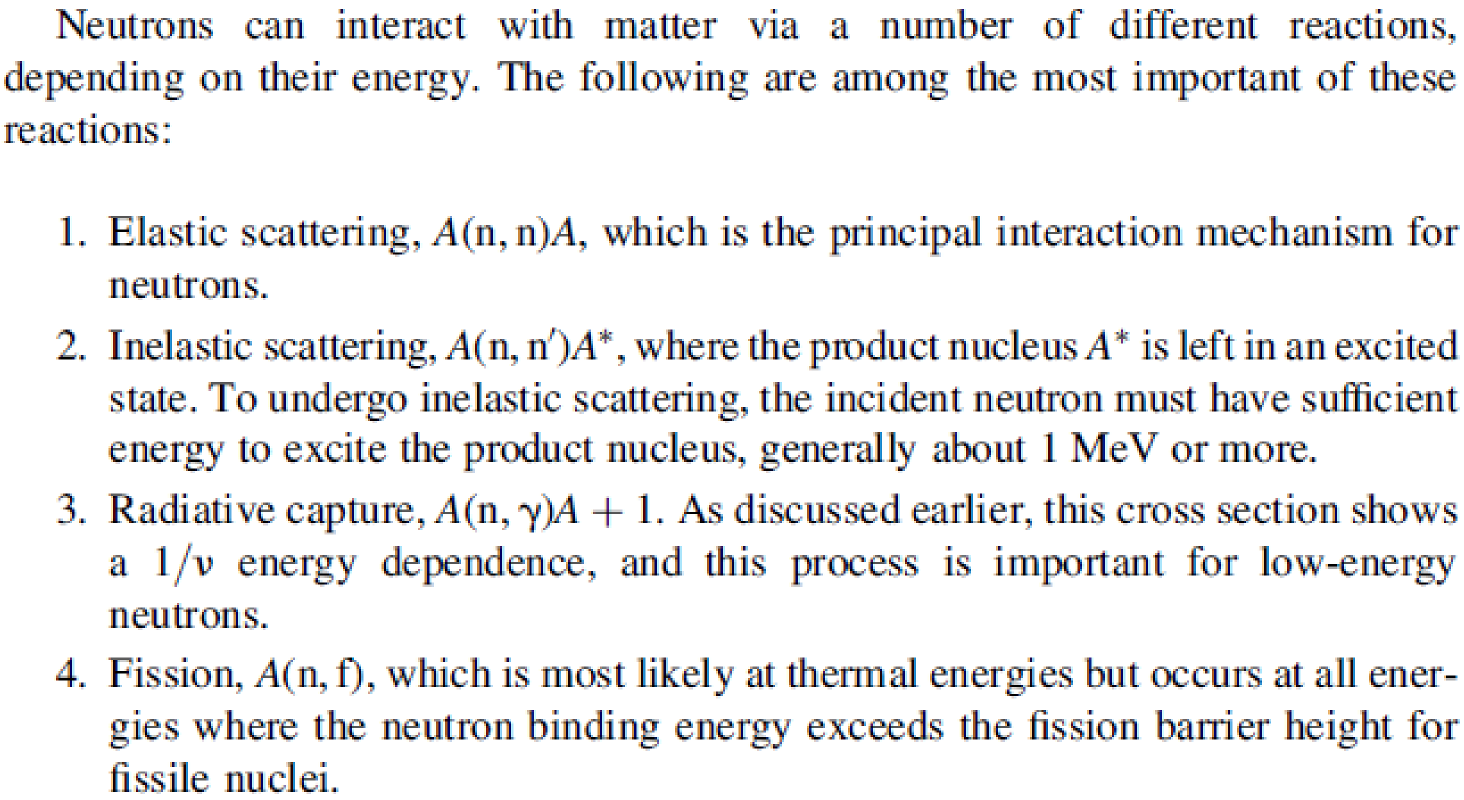
1-elastic

2-inelastic scattering,

3- absorption or capture

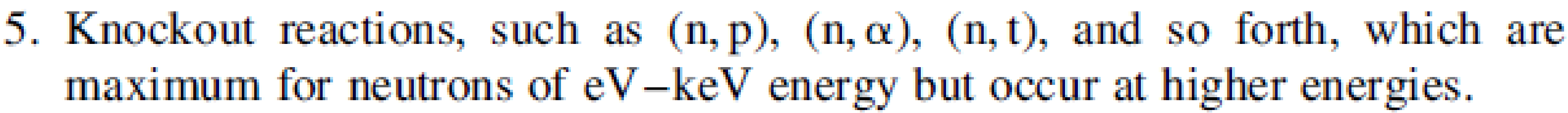
4- fission

Neutron interaction with matter



Neutrons can interact with matter via a number of different reactions, depending on their energy. The following are among the most important of these reactions:

1. Elastic scattering, $A(\mathrm{n},\mathrm{n})A$, which is the principal interaction mechanism for neutrons.
2. Inelastic scattering, $A(\mathrm{n},\mathrm{n}')A^*$, where the product nucleus A^* is left in an excited state. To undergo inelastic scattering, the incident neutron must have sufficient energy to excite the product nucleus, generally about 1 MeV or more.
3. Radiative capture, $A(\mathrm{n},\gamma)A+1$. As discussed earlier, this cross section shows a $1/v$ energy dependence, and this process is important for low-energy neutrons.
4. Fission, $A(\mathrm{n},\mathrm{f})$, which is most likely at thermal energies but occurs at all energies where the neutron binding energy exceeds the fission barrier height for fissile nuclei.



5. Knockout reactions, such as (n,p), (n,α), (n,t), and so forth, which are maximum for neutrons of eV–keV energy but occur at higher energies.

Moderation of Neutrons

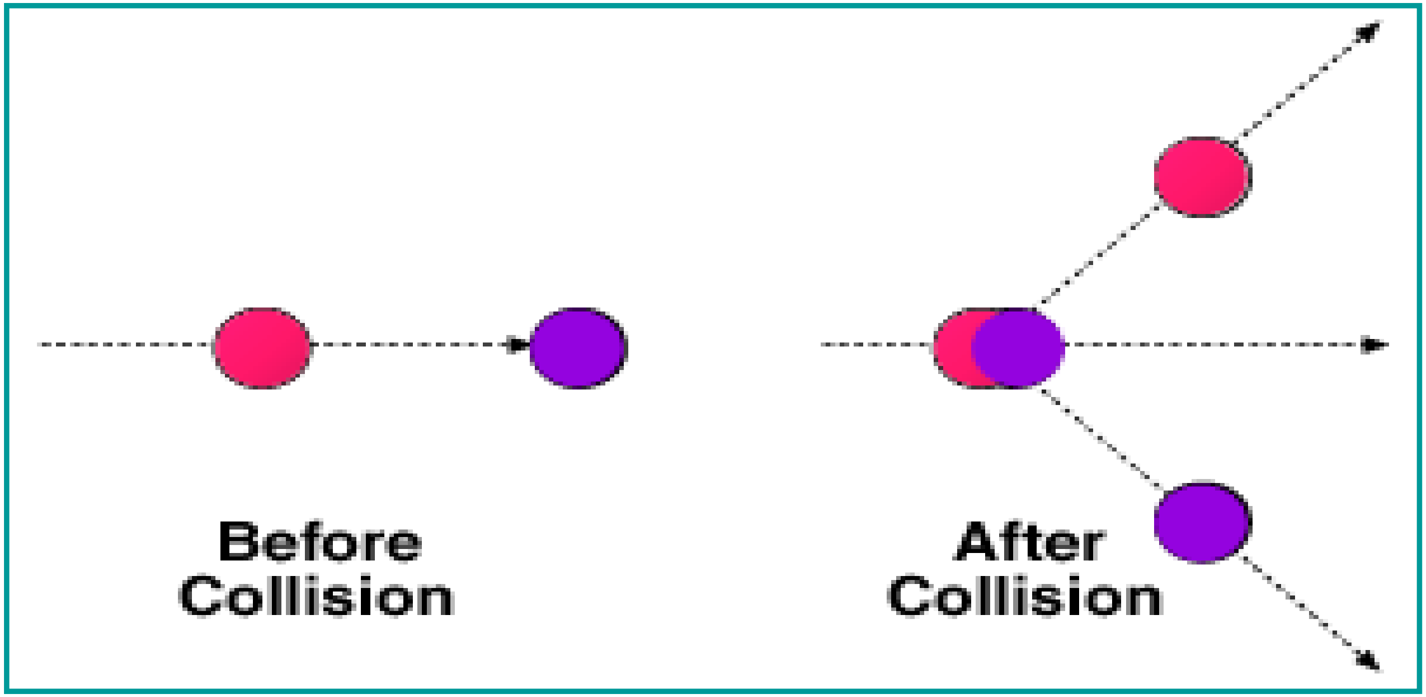
- Usually a neutron source consists of an α emitter such as $^{222}Rn_{86}$ mixed with Be, an element whose nuclei produce neutrons when bombarded by α particles:

$$^{9}_{4}\mathrm{Be} + ^{4}_{2}\mathrm{He} \rightarrow ^{12}_{6}\mathrm{C} + ^{1}_{0}n$$

- The neutrons produced by Eq. (1) have a very high energy and are called fast neutrons.

- For many purposes the neutrons are more useful if they are **first slowed down** or **moderated** by passing them through **paraffin wax** or some other substance containing light nuclei in which they can dissipate most of their energy by collision.

Elastic Scattering

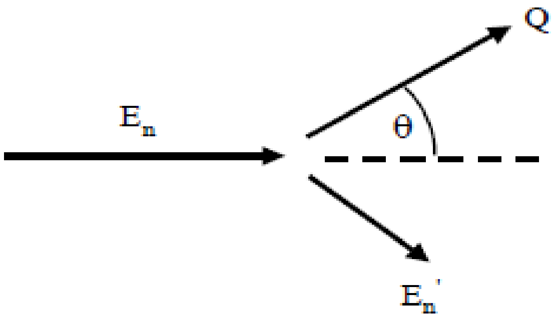


- In collision with protons, neutrons lose half their energy on average.
- This reaction makes hydrogenous materials (materials rich in protons) good shields (e.g. concrete, wax, water, and various plastics).

Elastic scatter: The most important process for slowing down of neutrons.

- Total kinetic energy is conserved
- E lost by the neutron is transferred to the recoiling particle.
- Maximum energy transfer occurs with a head-on collision.
- Elastic scatter cross sections depend on energy and material.

$$Q_{\max} = \frac{4mME_n}{(M+m)^2}$$



- (Max. energy Transferred) Q max= $4A\ E_0\ /(A + 1)^2$
- The average lost in a single collision is ½ Q max = $2A\ E_0\ /(A + 1)^2$
- The ratio $E/E_0 = 1 - 2A\ /(A + 1)^2 = (A^2 + 1)\ /(A + 1)^2$
- By integration of E/E_0 between min. and max. limits
- $\mathrm{Ln}\ E/E_0 = [1 - (A - 1)^2 / 2A]\ \ln [(A + 1) / (A - 1)]$ for a single collision
- $\mathrm{Ln}\ E/E_0 = n \times [1 - (A - 1)^2 / 2A]\ \ln [(A + 1) / (A - 1)]$
- For collision with proton A = 1 → $E_n = E_0\ e^{-n}$

3-5-3 التشتت المرن للنيوترونات

The neutron elastic scattering

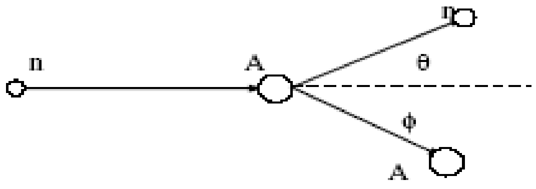
عند سقوط نيوترون طاقته E_0 على نواة عددها الكتلي A ينحرف النيوترون عن مساره ويفقد جزءا من طاقته بفعل القوى النووية. فإذا لم تتغير الطاقة الداخلية للنواة (أي عندما يحدث تغير في طاقتها الحركية فقط) يسمى هذا التشتت بالتشتت المرن أو الاستطارة المرنة شكل (3-11).

وباستخدام قانوني بقاء الطاقة والزخم يمكن إيجاد طاقة النيوترون بعد التشتت كالآتي:

$$E = E_0 (A^2 + 2A \cos \phi +1) / (A + 1)^2 \qquad (3\text{-}40)$$

حيث E هي طاقة النيوترون بعد التشتت، ϕ هي زاوية التشتت في مجموعة إحداثيات مركز الثقل، وهي مرتبطة بزاوية التشتت θ في مجموعة الإحداثيات المعملية بالعلاقة التالية:

$$\cos \theta = (1 + A \cos) / (A^2 + 2 A \cos \phi + 1) \quad (3\text{-}41)$$



شكل (11−3)
التشتت المرن للنيوترونات

وتبين العلاقة (3−40) أن طاقة النيوترون بعد التشتت تكون أقل ما يمكن للمادة نفسها إذا كانت زاوية التشتت = 180° (أي ارتداد النيوترون للخلف تماما) حيث أن جيب تمام 180 يساوي (−1). عندئذ تصبح طاقة النيوترون بعد التشتت هي:

$$E = E_0 (A^2 - 2A +1) / (A + 1)^2 \qquad (3\text{-}42)$$

كذلك، يتضح أنه إذا كانت المادة التي تتشتت عليها النيوترونات هي الهيدروجين (A = 1) فإنه عند التشتت للخلف تكون طاقة النيوترون E مساوية للصفر. أي أن النيوترون في هذه الحالة يمنح كل طاقته لنواة الهيدروجين ويتوقف.

وهكذا يفقد النيوترون طاقة أكبر بعد التشتت كلما كانت زاوية التشتت كبيرة. وبالنسبة للزاوية المعينة تزداد قيمة الطاقة التي يفقدها النيوترون في التصادم الواحد كلما انخفض العدد الكتلي للنواة التي يحدث التشتت المرن عليها. لذا، تعتبر المواد المكونة من الهيدروجين أو التي تحتوي على نسبة كبيرة منه في تكوينها أفضل المهدئات للنيوترونات (neutron moderators). وهكذا، يمكن أن يفقد النيوترون جزءا كبيرا أو صغيرا من طاقته في التصادم الواحد. ويستخدم في النواحي العملية قيمة أخرى تعرف باسم متوسط لوغاريتم انخفاض الطاقة في التصادم الواحد، أو الانخفاض اللوغاريتمي المتوسط للتصادم الواحد ζ. ويعرف الانخفاض اللوغاريتمي المتوسط كالآتي:

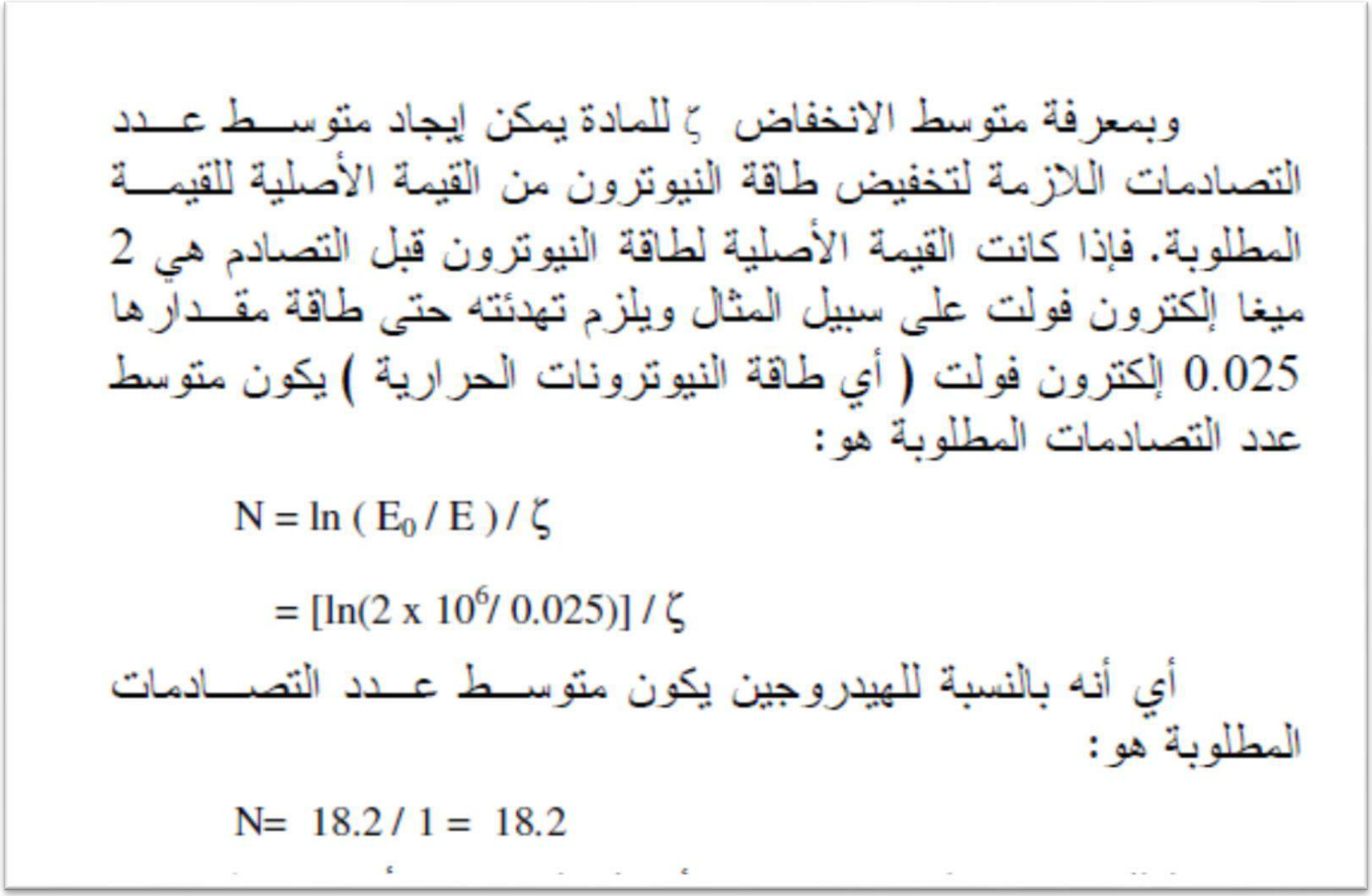
$$\zeta = \ln E_0 - \ln E = \ln (\overline{E_0} / E) \qquad (3\text{-}43)$$

وبحساب هذه القيمة باستخدام العلاقة (3−40) نجد أن:

$$\zeta = 1- [(A-1)^2 / 2A] \ln [(A+1) / (A-1)] \qquad (3\text{-}44)$$

وبالنسبة للهيدروجين حيث A = 1 ، نجد أن $\zeta = 1$. وهذا يعني أن طاقة النيوترون تنخفض في المتوسط بعد كل تصادم بمقدار 2.71 مرة (أي مايساوي الأساس اللوغاريتمي الطبيعي). أي أن طاقة النيوترون بعد كل تصادم تصبح في المتوسط مساوية 37% من طاقته قبل التصادم.

Moderation of Neutrons



وبمعرفة متوسط الانخفاض ζ للمادة يمكن إيجاد متوسط عدد التصادمات اللازمة لتخفيض طاقة النيوترون من القيمة الأصلية للقيمة المطلوبة. فإذا كانت القيمة الأصلية لطاقة النيوترون قبل التصادم هي 2 ميغا إلكترون فولت على سبيل المثال ويلزم تهدئته حتى طاقة مقدارها 0.025 إلكترون فولت (أي طاقة النيوترونات الحرارية) يكون متوسط عدد التصادمات المطلوبة هو:

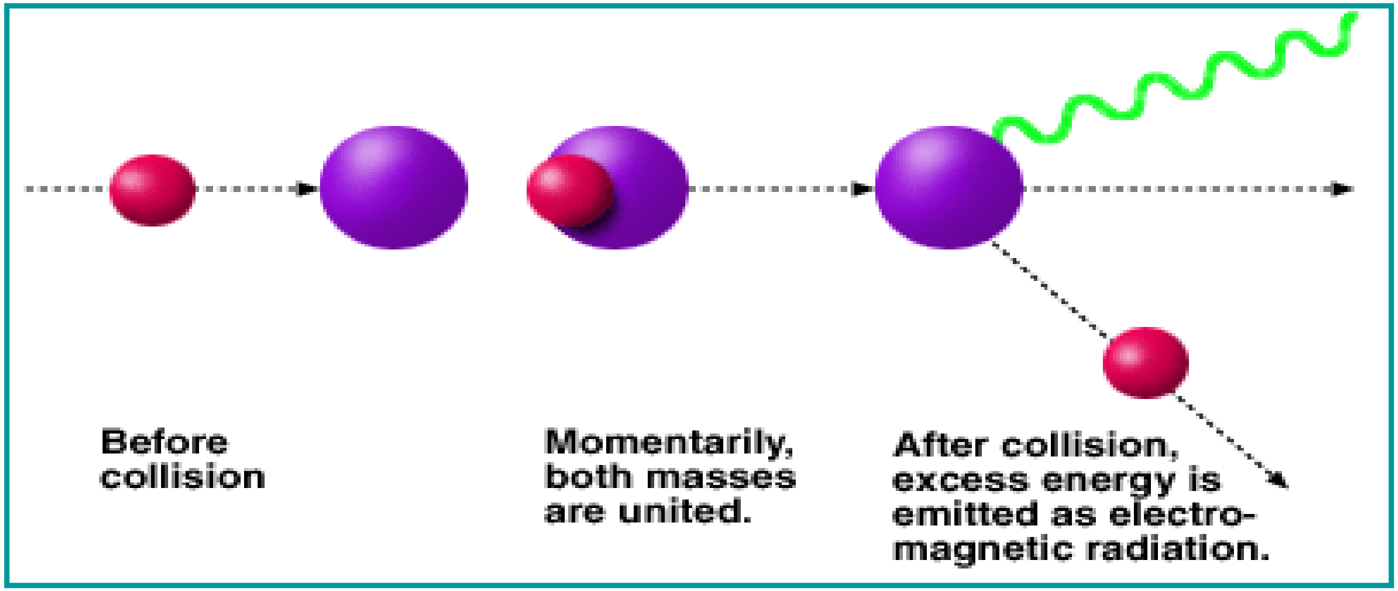
$$N = \ln (E_0 / E) / \zeta$$

$$= [\ln(2 \times 10^6 / 0.025)] / \zeta$$

أي أنه بالنسبة للهيدروجين يكون متوسط عدد التصادمات المطلوبة هو:

$$N = 18.2 / 1 = 18.2$$

Inelastic Scattering



The neutron is captured, then re-emitted by the target nucleus together with the gamma photon. It has lesser energy

This interaction is best described **by the compound nucleus model**, in which the neutron is captured, then re-emitted by that target nucleus together with the gamma photon.

4-5-3 التشتت غير المرن للنيوترونات

The neutron inelastic scattering

عند حدوث تشتت غير مرن للنيوترونات تنتقل النواة التي حدث عليها التشتت من الحالة الأرضية إلى الحالة المثارة. ولا يحدث هذا النوع من التشتت إلا إذا كانت طاقة النيوترون مساوية أو أكبر من قيمة حدية معينة. لذا، فإن التشتت غير المرن لا يحدث إلا للنيوترونات التي تزيد طاقتها على عدة عشرات بل ربما عدة مئات من الكيلو إلكترون فولت. وبذلك، لا يلعب التشتت غير المرن دورا مهما في عملية تهدئة النيوترونات عند الطاقات الصغيرة.

5-5-3 الأسر النيوتروني The neutron capture

يحدث في العديد من العناصر أن تأسر نواة العنصر نيوترونا مكونة بذلك نواة نظير جديد. وتتكون هذه النواة الجديدة عادة في الحالة المثارة. وتعتمد قيمة المقطع العرضي للأسر σ_c (capture cross-section) على طاقة النيوترون وتزداد زيادة كبيرة عند قيم معينة للطاقة تختلف من نواة لأخرى. ويعرف الأسر عند هذه القيم بالأسر أو الامتصاص التجاوبي (resonance absorption). وتعود النواة المتكونة من الحالة المثارة إلى الحالة الأرضية مصدرة بذلك إشعاعات جاما. لذلك، يعرف أحيانا هذا النوع من الامتصاص بالأسر الإشعاعي (radiative capture)

$${}_{0}^{1}n + {}_{47}^{114}Cd \rightarrow {}_{47}^{115}Cd + \gamma$$

Types of nuclear reactions induced by neutrons

- 1-neutron captures

$$_1H^1 + {}_on^1 \rightarrow {}_1H^2 + \gamma$$

$$_{49}In^{115} + {}_on^1 \rightarrow {}_{49}In^{116} + \gamma$$

$$_{49}In^{115} \rightarrow {}_{50}Sn^{116} + \beta + \bar{v}_e$$

- احتمالية حدوث الاسر للنيترونات تكون عالية للنيترونات البطيئة و غالبا تكون النواة الناتجة غير مستقرة و تبعث جسيمات بيتا السالبة و يستخدم هذا النوع من التفاعلات على الكشف عن هذا النوع من النيترونات

- 2- reaction with emission of proton

$$_7N^{14} + {}_on^1 \rightarrow {}_6C^{14} + {}_1H^1$$

- تتم التفاعلات من النوع (n,p) عندما تتراوح طاقة النيترونات ما بين 0.5 و10 Mev (نيترونات حرارية) حتى تستطيع هذة البروتونات تتغلب على الجهد الكولومى لنواة الهدف

- 3- reaction with emission of alpha particles

$$_{17}Cl^{35} + {}_on^1 \rightarrow {}_{15}P^{32} + \alpha$$

- 4- fission reactions

$$_zY^A + {}_on^1 \rightarrow {}_{z1}{'}Y^{A1} + {}_{z2}{''}Y^{A2}$$

- تتم هذا النوع من التفاعلات الانشطارية بقذف الانوية الثقيلة باستخدام نيترونات ذات طاقة اكبر من 1 Mev و هذا النوع من التفاعلات فى الحصول على الطاقة النووية

- 5- reactions of the type (n, 2n), (n, np), (n, 3n)

$$_6C^{12} + {}_on^1 \rightarrow {}_6C^{11} + 2n$$

- التفاعلات التى تؤدى الى انتاج نيوكليونين أو أكثر لابد ان تكون طاقة النيترونات أكبر من 10 Mev و يستخدم هذا النوع من التفاعلات على الكشف عن النيترونات السريعة

❑ **The neutron cross section,** and therefore the **probability of an interaction,** **depends on:**

1. the target type (hydrogen, uranium…),
2. the type of nuclear reaction (scattering, fission…).
3. the incident particle energy, also called speed or temperature (thermal, fast…),

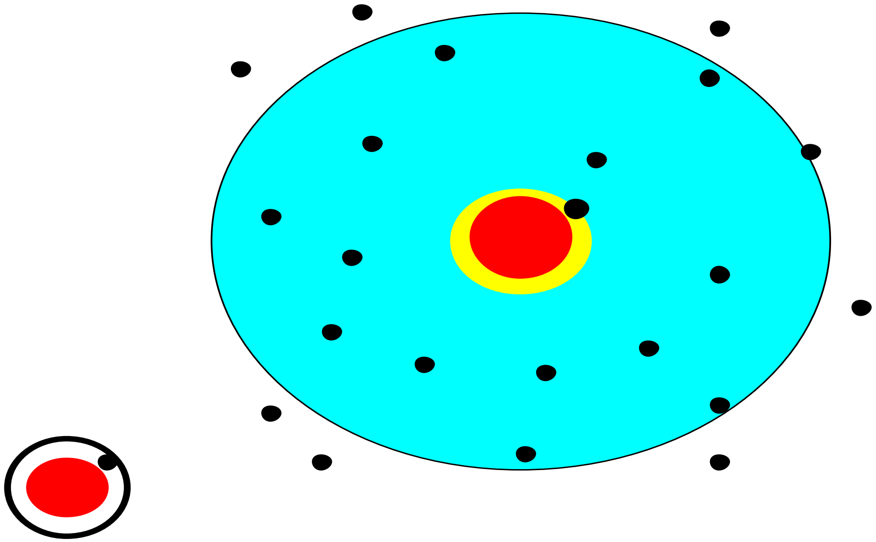
❑ and, to a lesser extent, of:

1. its relative angle between the incident neutron and the target nuclide,
2. the target nuclide temperature.

Cross Sections of Nuclear Reactions

Cross Section of the Target and the Random Target Shooting

(Don't be too serious about the crossection)



Nuclear Reactions

- The interaction between nuclear radiation and matter is called a "nuclear reaction"

❑Nuclear reactions are described by:

1. specifying the type of the incident radiation,
2. the nuclear target,
3. the products of the reaction,
4. **the probability** that the reaction will take place, which is called the "cross section,"
5. and the distributions in energy and angle of the reaction products

Cross Sections

- You can visualize a target material as an array of little disks. Larger disks would be easy to hit (large cross section, large reaction probability), and smaller disks would be hard to hit.
- in physics; an atom with a large cross section would be "as easy to hit as the side of a barn

- The name *cross-section* arises because it has the dimensions of area.
- The probability that a nuclear reaction will take place is measured in units of "barns," where 1 barn equals 10^{-24} cm^2.
- This is a unit of area.

Slow- neutron reaction Cross sections

- **In the reactions with <u>slow neutrons</u>, The area of the target is negligible in comparison with the cross sectional area estimated from its de Broglie wavelength**

Schematic diagram of a grazing collision of a neutron with a nucleus.

$$\sigma = \pi\left(R + \frac{2\pi}{\lambda}\right)^{2}$$

$$\sigma = \pi\left(R + \bar{\lambda}\right)^{2} \quad But\ when \quad \bar{\lambda} \rangle\rangle R$$

$$\sigma = \pi\,\bar{\lambda}^{2}$$

- **<u>For fast particle</u> reactions the total cross section for the target nucleus is π R$^{2.}$**
- **The measured cross sections for thermal-neutron reactions are often much greater than π R^{2}**
- **<u>The largest thermal neutron capture cross section observed for Cd (19500 barns), so Cd used as absorber for thermal neutrons.</u>**
- **Nuclei <u>which contain a magic number of neutrons</u> have small cross sections for the capture of another neutrons**
- **For example: the cross section for Pb^{208} (N =126) is 0.0006 barn , while Pb^{207} is 0.69 barn. Also, Xe^{136} (N = 82) is 0.15 barn while for Xe^{135} is 3.5 × 10^{6} barns**

- The most important neutron absorber is ^{10}boron as $^{10}B_4C$ in control rods, or boric acid as a coolant water additive in PWRs.
- Other important neutron absorbers that are used in nuclear reactors are xenon, cadmium, hafnium, gadolinium, cobalt, samarium, titanium, dysprosium, erbium, europium, molybdenum and ytterbium

Absorption / Radiative Capture (n,γ)

- capture cross-sections for low energy neutrons generally decreases as the reciprocal of the velocity as the neutron energy increases
- phenomenon called 1/v law
- valid up to 1000 eV

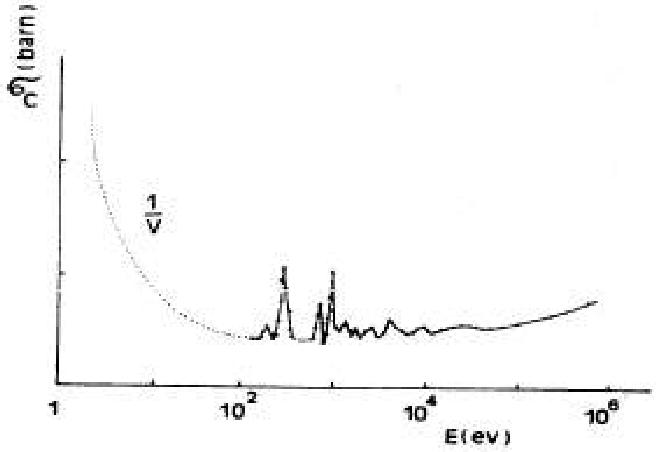
Absorption (Neutron Capture)

- Low energy neutrons (thermal or near thermal) are likely to undergo absorption reactions.
- In this energy range, the absorption cross-section of many nuclei, has been found to be inversely proportional to the square root of the energy of the neutron.
  - one-over-v law for slow neutron absorption

$$\boxed{\sigma \propto \frac{1}{\sqrt{E}} \propto \frac{1}{v}}$$

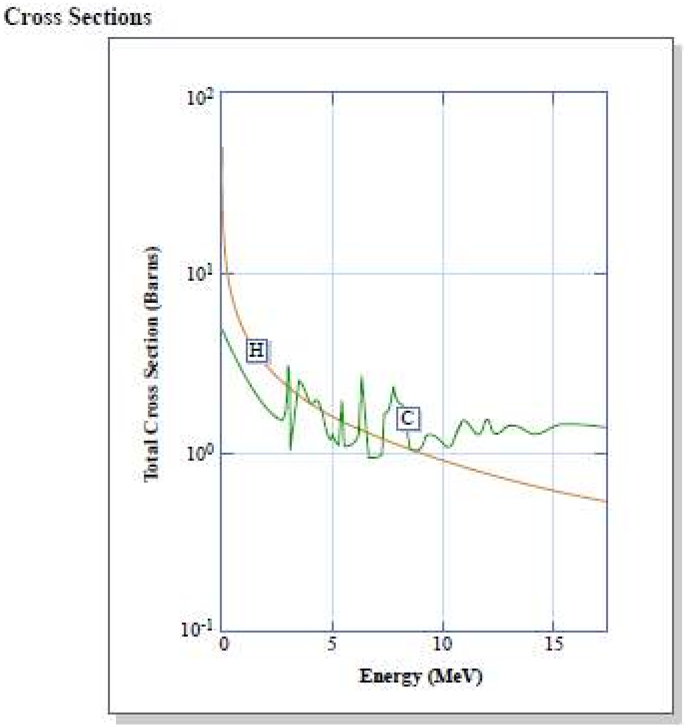
الرنين

- يعبر مصطلح **الرنين** في الفيزياء (Resonance) عن الظاهرة التي من خلالها يميل النظام الفيزيائي إلى الاهتزاز بأقصى شدة، وذلك عند ترددات معينة تعرف بترددات الرنين (Resonance frequencyأو الترددات الرنانة).
- وهذه الترددات يحدث عندها اهتزازات عالية الشدة حتى عند أقل قدر من قوى الدفع الترددية، حيث أن النظام الفيزيائي يقوم بتخزين طاقة الاهتزازات. وعندما يقل امتصاص الاهتزازات، فإن تردد الرنين يقترب من التردد الطبيعي للنظام، الذي هو تردد الاهتزازات الحرة
- فمثلا إذا ما وافق تردد ما تردد الجسم الطبيعي جعله يهتز بحالة رنين معه إذ ان سعة الاهتزاز ستكون أكبر ما يمكن لان التداخل الحاصل بين الموجات هو تداخل بناء بالكامل وهنا تكمن خطورة الرنين إذ تصل السعة إلى حد لا يمكن للجسم تحمله مما يؤدي إلى انهيار الجسم في الغالب كما يحدث في ظاهرة الكأس الزجاجي حيث تسلط على الزجاج موجة صوتية مساوية لتردده الطبيعي مما يؤدي إلى تكسر الكأس.



شكل (٣ ـ ١٣)

تغير المقطع العرضي للامتصاص بزيادة طاقة النيوترون

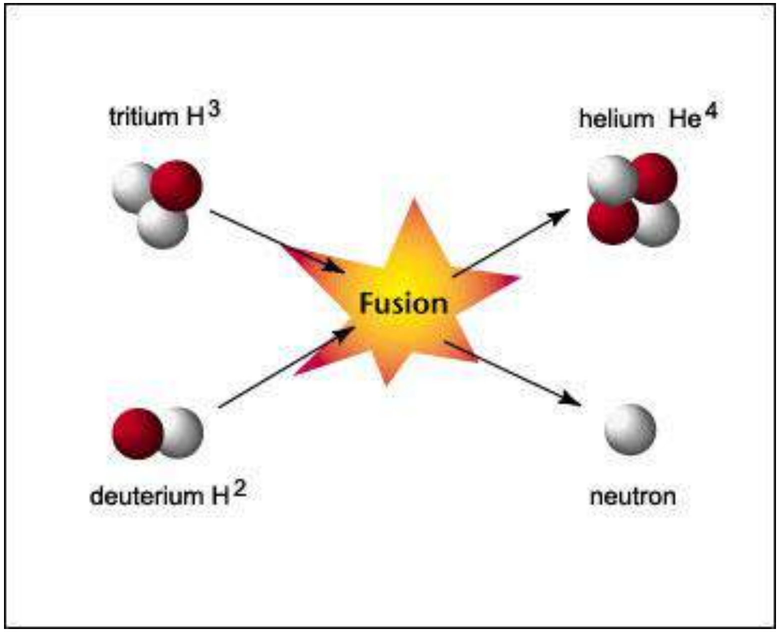


$$\sigma_c = 1 / E^{1/2v} = 1 / v$$

ويوضح شكل (3-13) كيفية تغير المقطع العرضي للامتصاص بزيادة طاقة النيوترون حيث تتضح عليه المنطقة ($\sigma_c = 1/v$) للطاقات الحرارية ثم منطقة الأسر التجاوبي. وعند الطاقات العالية يزداد المقطع العرضي بسبب فتح قنوات جديدة للتفاعل بين النيوترون والمادة مع إصدار الجسيمات المشحونة الثقيلة.

وعند الطاقات العالية للنيوترونات يمكن أن تفتح قنوات جديدة للتفاعل. فبعد امتصاص النيوترون يمكن أن تصدر النواة المركبة أحد الجسيمات المشحونة الثقيلة مثل جسيمات ألفا أو البروتونات أو غيرها، وذلك حسب طاقة النيوترونات ونوع النواة. ومن أمثلة هذه التفاعلات

What is Nuclear Fusion?



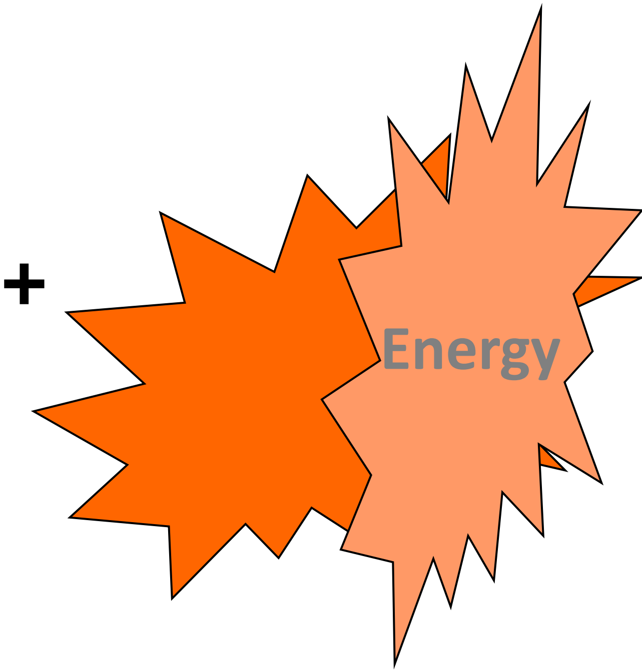
- **Fusion is the process in which two light atoms are fused together generating a heavier atom with the aim of generating energy**

- In physics, nuclear fusion (a thermonuclear reaction) is a process in which two nuclei join to form a larger nucleus, thereby giving off energy.
- Nuclear fusion is the energy source which causes stars to "shine", and hydrogen bombss to explode.
- Any two nuclei can be forced to fuse with enough energy.
- When lighter nuclei fuse, the resulting nucleon has too many neutrons to be stable, and the neutron is ejected with high energy.
- Most lighter nuclei will produce more energy than initially required to cause them to fuse, making the reaction exothermic and chain or transiently self-sustaining, and generating net power.

Nuclear Fusion

Fusion

small nuclei combine



$$^{2}_{1}H \quad + \quad ^{3}_{1}H \longrightarrow \quad ^{4}_{2}He \quad + \quad ^{1}_{0}n \quad + \text{ Energy}$$

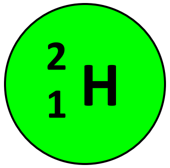
Fusion is like lighting a match to a bucket of gasoline. You need that input energy (the match), but what you get as a result is far more powerful.

The Fusion Process

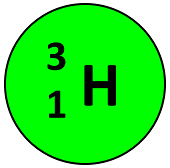
$^{2}_{1}\mathrm{H}$

$^{3}_{1}\mathrm{H}$

The Fusion Process

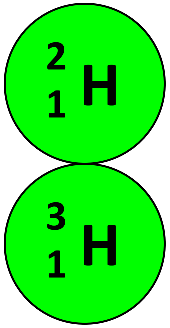


$^{2}_{1}\text{H}$

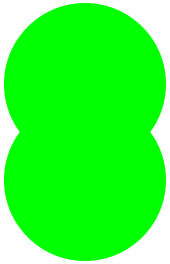


$^{3}_{1}\text{H}$

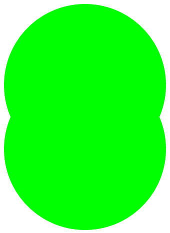
The Fusion Process



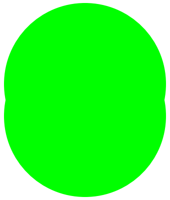
The Fusion Process



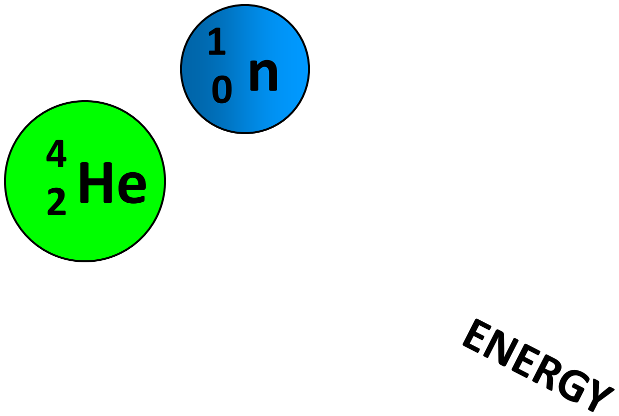
The Fusion Process



The Fusion Process



The Fusion Process

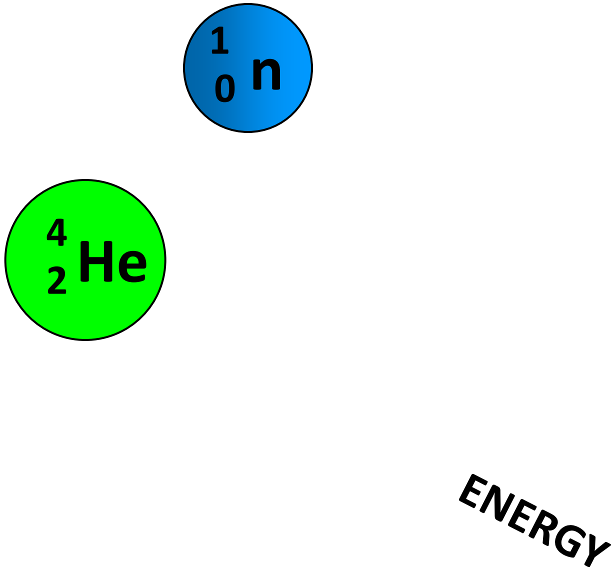


$^{4}_{2}He$

$^{1}_{0}n$

ENERGY

The Fusion Process

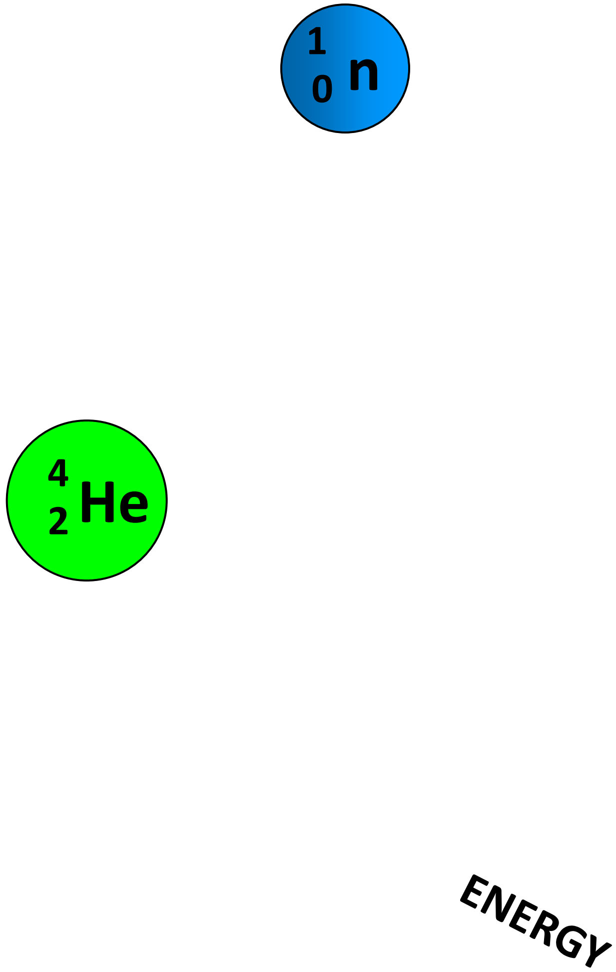


$^{1}_{0}n$

$^{4}_{2}He$

ENERGY

The Fusion Process



${}^{1}_{0}n$

${}^{4}_{2}He$

ENERGY

Fusion Reaction

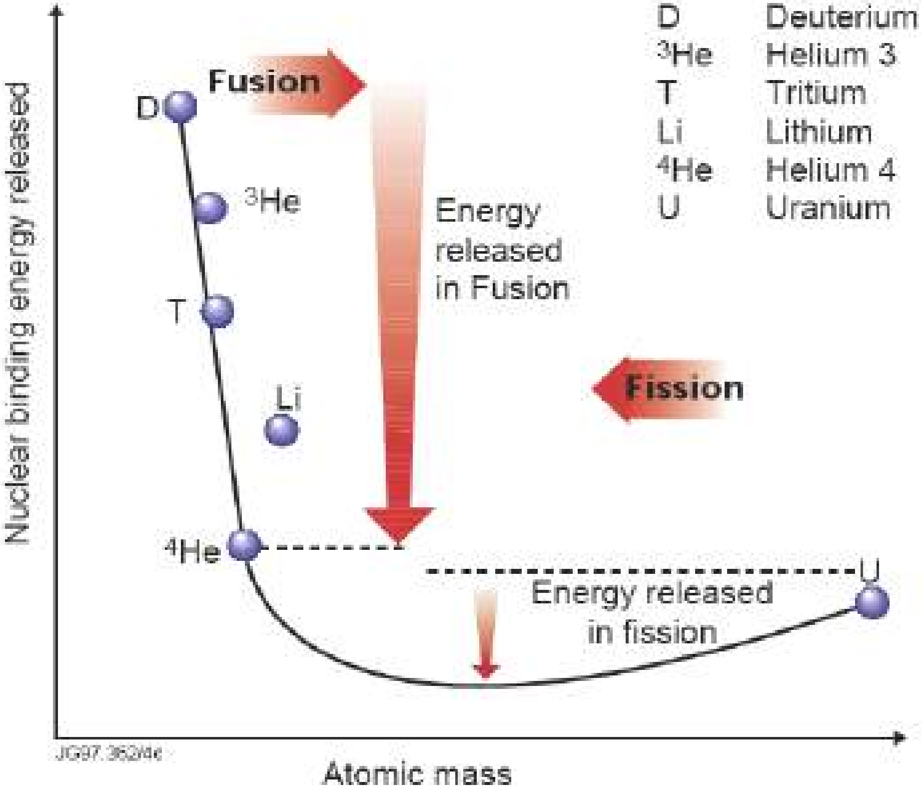
$$ {}^{2}H + p \rightarrow {}^{3}He + \gamma + Q $$

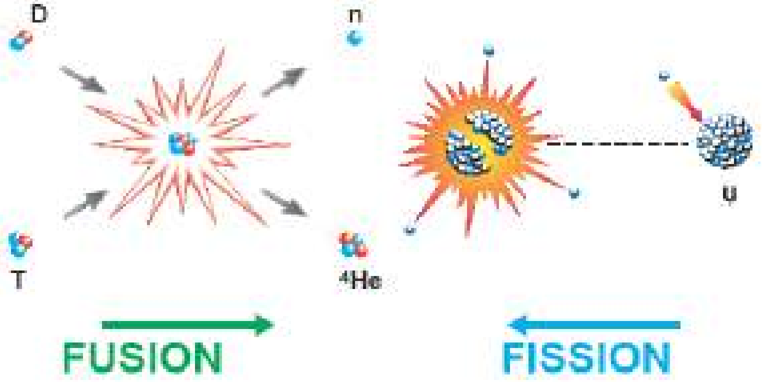
$$ {}^{2}H + {}^{2}H \rightarrow {}^{3}He + n + Q $$

$$ {}^{2}H + {}^{3}H \rightarrow {}^{4}He + n + Q $$

Energy Released by Nuclear Fusion and Fission

- ***Fusion reactions*** release much higher energies than ***Fission reactions***





وتتركز صعوبة الحصول على تفاعل اندماجى مستقر فى أن التفاعل الاندماجى لا يمكن أن يحدث إلا إذا جعلت البروتونات على مسافة مساوية لمدى القوى النووية الشديدة وهى نحو 5×10^{-15} m . وعند مثل هذه المسافة تصبح قوى كولوم التنافرية هائلة جداً . وبعبارة أخرى فإن طاقة الوضع الكهربية عند هذه المسافات ، كبيرة جداً ومن رتبة 1 MeV ، وهى مقاربة لطاقة الحركة التى يجب إعطاؤها للبروتونات حتى تندمج قبل أن تتنافر بواسطة قوة كولوم . ومن السهل الحصول على هذه الطاقة بواسطة المعجلات الضخمة للجسيمات . إلا أن كفاءة تلك الآلات لا زالت أقل من أن تجعل هذه التفاعلات عملية . وعلينا أن نستغل التصادمات **الحرارية** بين البروتونات فى الغاز الحار للغاية . وسنحاول أن نعرف ما هى درجات الحرارة التى قد تلزم لإتمام الاندماج بهذه الطريقة .

Requirements for fusion

- **A substantial energy barrier opposes the fusion reaction. The long range Coulomb repulsion between the nuclei is offset by strong nuclear force.**
- **The magnitude of the repulsion of the nuclei depends on their total electrical charge, and thus the total number of protons they contain.**
- **The simplest way to provide such energies is to heat the nuclei.**
- **Temperature is a measure of the average kinetic energy of a substance**
- **For any particular temperature, a certain percentage of the nuclei will have enough energy to fuse.**

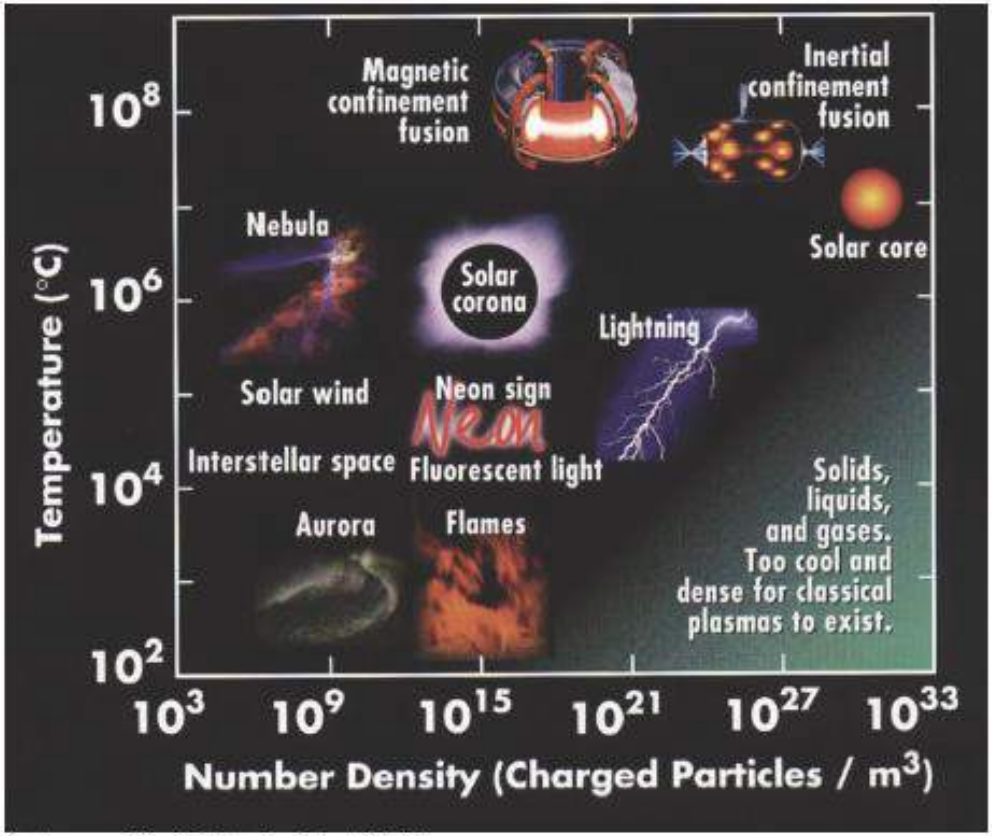
Requirements for fusion

- The reaction cross section combines the effects of the potential barrier and thermal velocity distribution of the nuclei into an "effective area" for fusion collisions.
- The cross section depend on **n** is the density of nuclei, **v** is the thermal velocity, and **f** is the frequency of fusion producing collisions.
- The cross section is also itself a function of thermal energy in the nuclei. Cross section increases from virtually zero at room temperatures up to meaningful magnitudes at temperatures of 10 - 100 keV. At these temperatures, well above typical ionization energies, the fusion reactants exist in a plasma state.
- the amount of time they remain together (the confinement time),
- This can be quantified by what is commonly called the fusion triple product, nTτ OR pτ where p=nT.

- The problems with utilizing fusion as an energy source are:
  - **Temperature**.
    - The amount of energy required to bring two nuclei together is enormous.
  - **Density**
    - The density of the reacting hydrogen nuclei must be significantly high so that there are enough reactions occurring in a short period of time.
  - **time**
    - These nuclei need to be confined to up to a second or more at 10 atmospheres of pressure in order for enough reactions to take place.

Plasmas

- A ***Plasma*** is an ionized gas. A mixture of ***positive ions*** and ***negative electrons*** with overall ***charge neutrality***
- Plasmas constitute the 4th state of matter, obtained at temperatures in excess of 100,000 degrees
- Plasmas conduct ***electricity*** and ***heat***



Contemporary Physics Education Project (CPEP)

Four State of matter

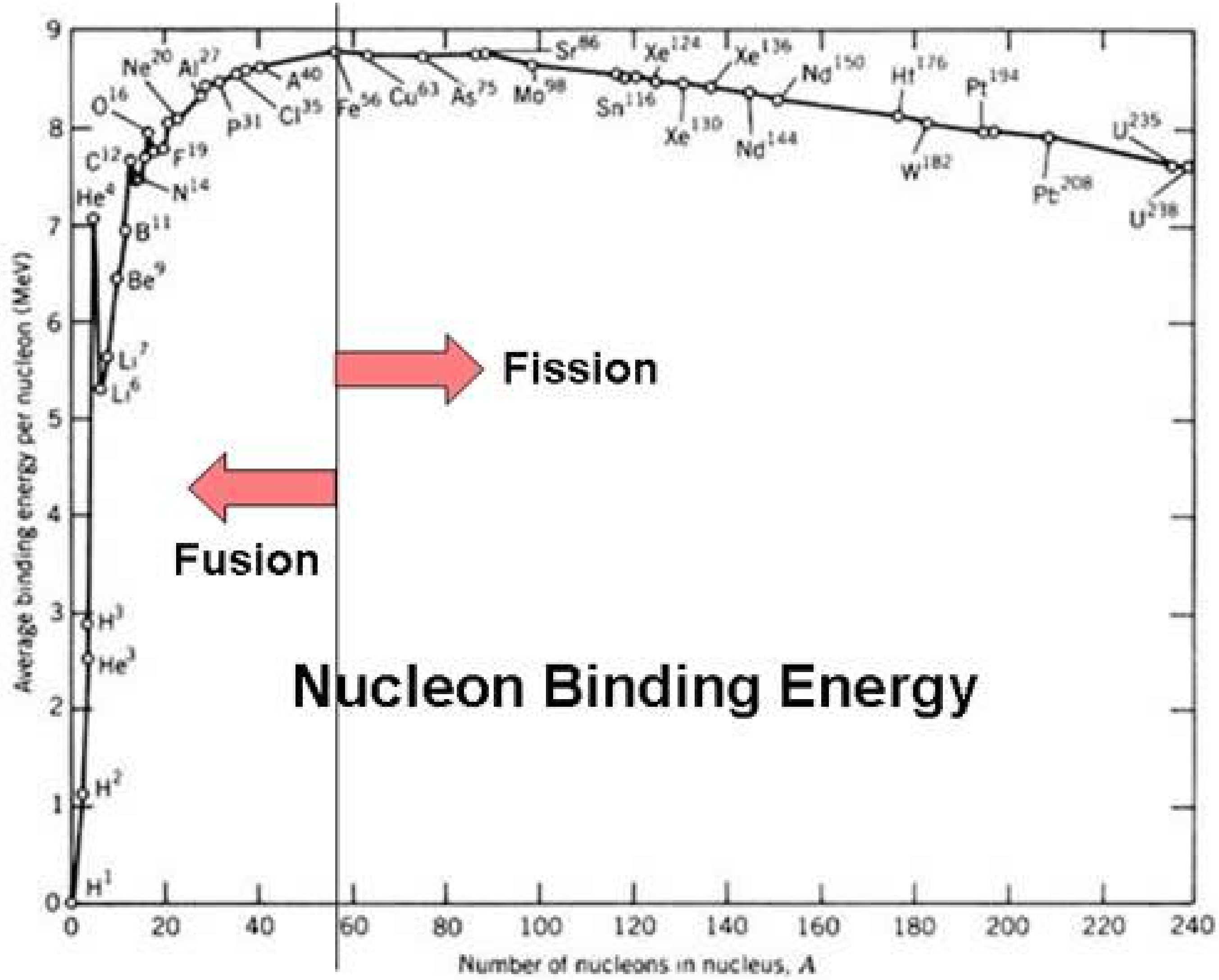
- البلازما (Plasma) أو الهَيُولَى هي حالة متميزة من حالات المادة يمكن وصفها بأنها غاز متأين تكون فيه الإلكترونات حرة وغير مرتبطة بالذرة أو بالجزيء.
- فإذا كانت المادة توجد في الطبيعة في ثلاث حالات: صلبة وسائلة وغازية، فإنه بالإمكان تصنيف البلازما على أنها الحالة الرابعة التي يمكن أن توجد عليها المادة.
- على النقيض من الغازات، فإن للبلازما صفاتها الخاصة. يؤدي التأين لخروج واحد أو أكثر من الإلكترونات عند تسليط حرارة أو طاقة معينة. هذه الشحنة الكهربية تجعل البلازما أو الهيولى موصلة للكهرباء ولذلك ستستجيب بقوة للمجال الكهرومغناطيسى.
- تأخذ البلازما شكل غاز محايد (معتدل) شبيه بالغيوم، على سبيل المثال النجوم. أو قد يأتي كحزم متأينة ولكنها تحتوي على غبار وحبيبات (وتسمى البلازما المغبرة) وهذه قد تشكلت بواسطة الحرارة والغاز المتأين. فعند قذف الإلكترون بعيدا عن النواة ستصبح الشحنات الموجبة والسالبة أكثر حرية.

Why Will Fusion Power Be Important ?

- **The deuterium in the earth's oceans is sufficient to fuel advanced fusion reactors for *millions* of years.**
- **The waste product from a deuterium-tritium fusion reactor is *ordinary harmless helium*.**
- **Solar and renewable energy technologies will play a role in our energy future. Although they are inherently safe and feature an unlimited fuel supply**
- **Another option, nuclear fission, suffers from a negative public perception. High-level radioactive waste disposal, and the proliferation threat of weapons-grade nuclear materials, are major concerns. The fuel supply in this case, uranium, is large, but ultimately limited to several hundred years.**

- **Nuclear fusion indeed looks like it may be the power source of the future!**
- **Fusion energy can be used to produce electricity and hydrogen, and for desalination**

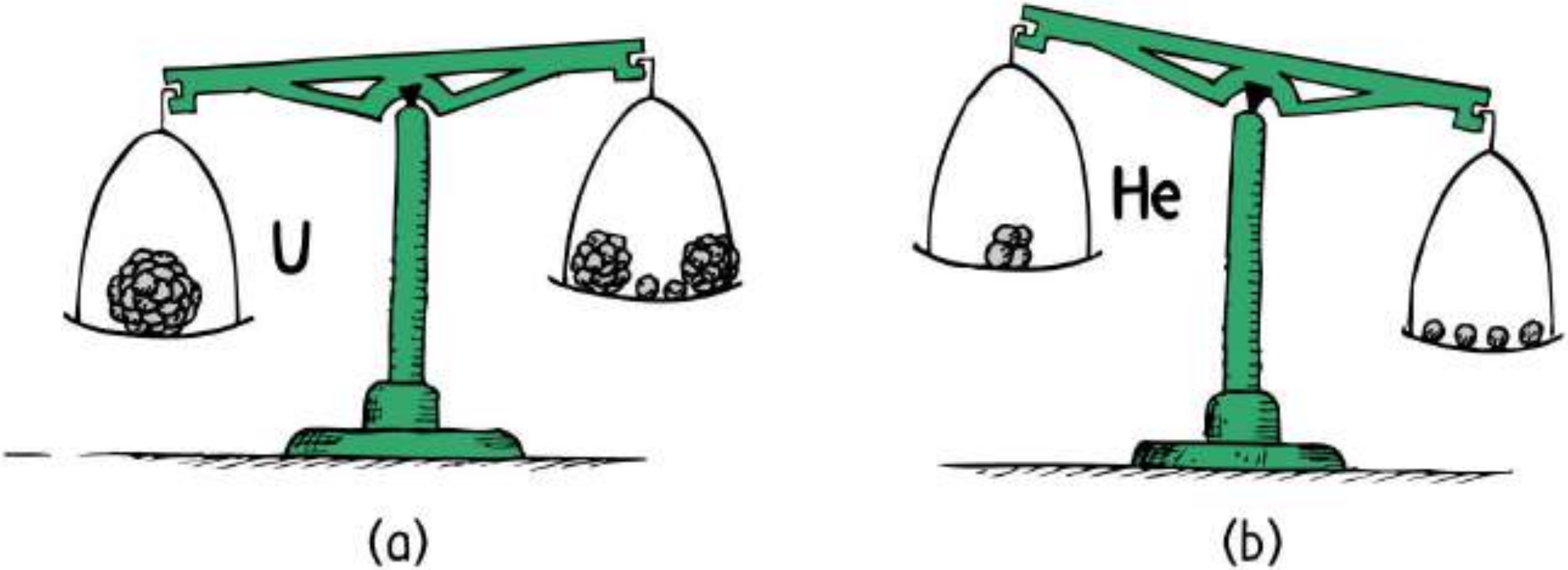
Nucleon Binding Energy



Fission

Fusion

Nuclear Energy



Energy from Fusion

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + \text{Energy} $$

The total mass before fusion (LHS of the equation):

$3.345 \times 10^{-27} + 5.008 \times 10^{-27} = \underline{8.353 \times 10^{-27}\ \text{kg}}$

The total mass after fission (RHS of the equation):

$6.647 \times 10^{-27} + 1.675 \times 10^{-27} = \underline{8.322 \times 10^{-27}\ \text{kg}}$

m = total mass before fission – total mass after fission

$m = 3.1 \times 10^{-29}$ kg $E = mc^2$

The energy released per fusion is 2.79×10^{-12} J.

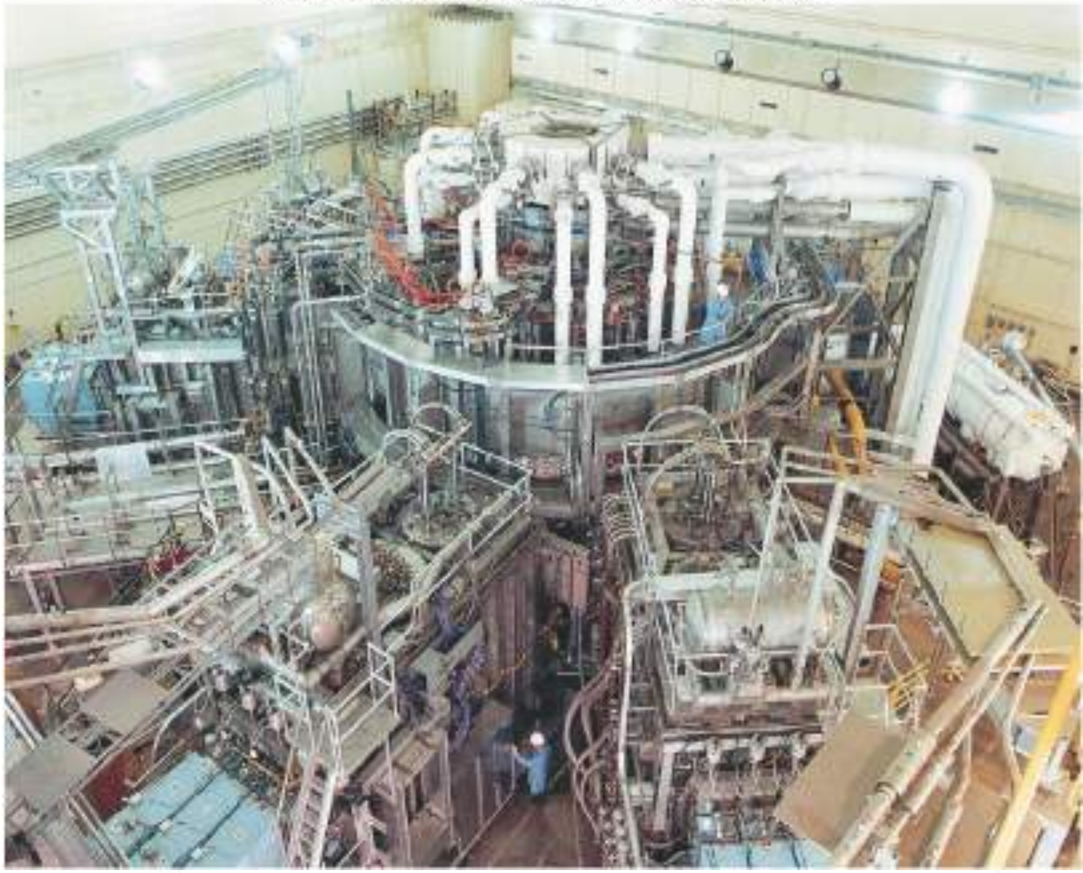
Fusion Applications

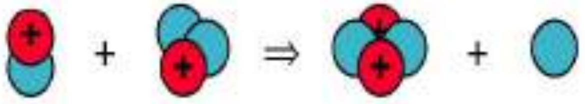
- Power Plants
  - 2 Liters of Water + 250 Grams of rock provide enough resources for a one energy supply of a European family

- Nuclear Weapons
  - 500 times more powerful then first fusion weapons
  - Different Process Then Power Generation

FUSION

A deuterium nucleus and a tritium nucleus combine to form a helium-4 nucleus and a neutron. The difference in the masses is converted to the kinetic energy of the emerging particles.

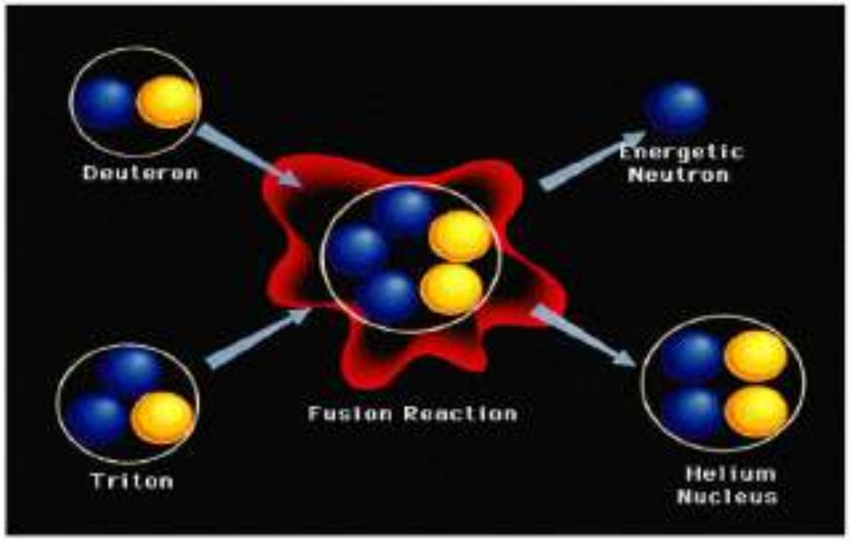




$$_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1$$

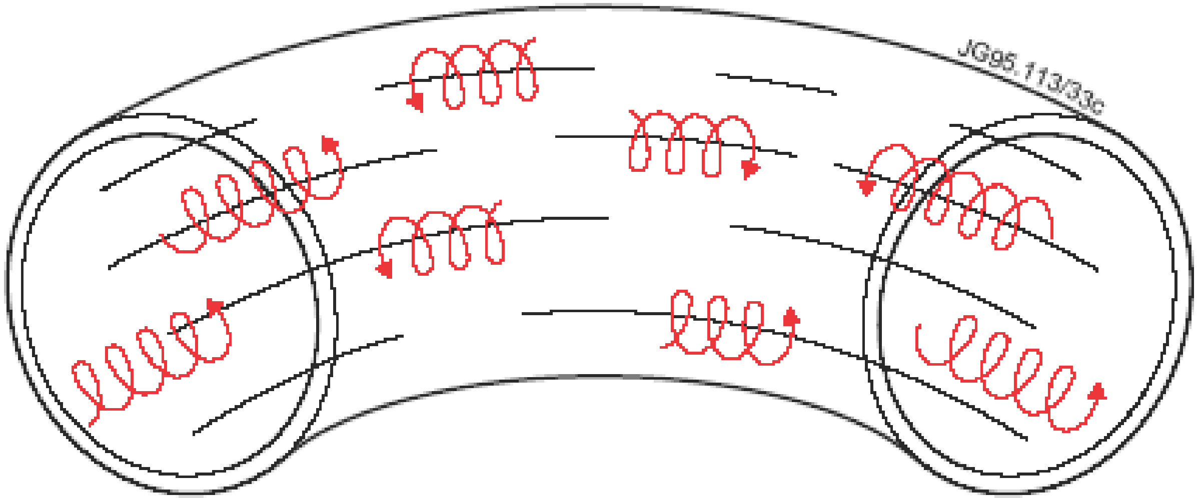
Masses

$_1H^2$	2.014102 u	$_2He^4$	4.002603 u
$_1H^3$	3.016050 u	$_0n^1$	1.008665 u
	5.030152 u		5.011268 u



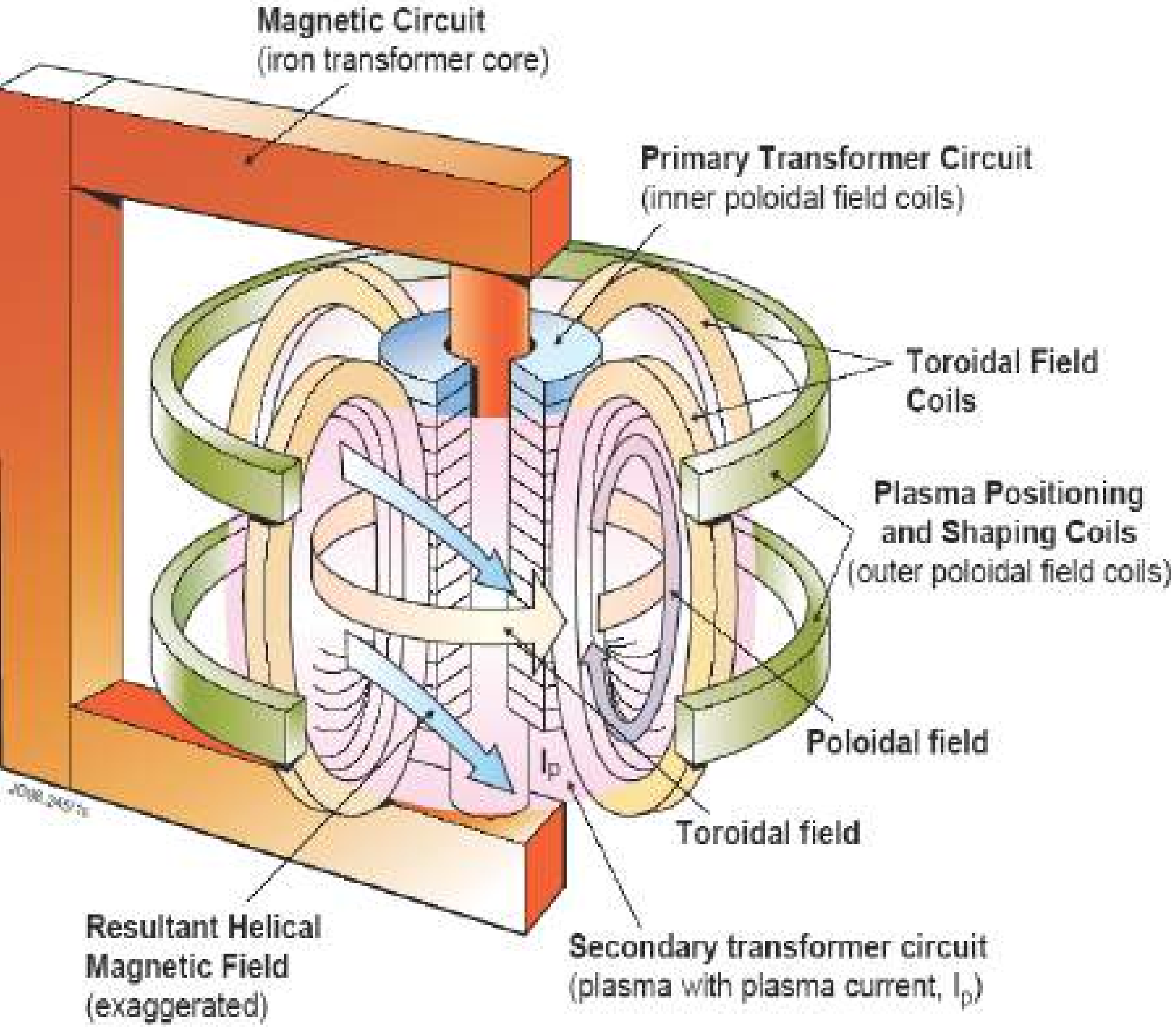
Magnetic Confinement

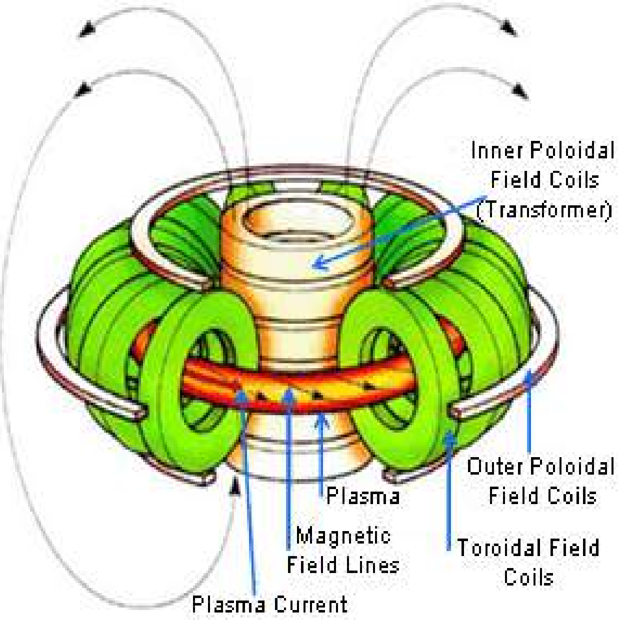
- ***Magnetic fields*** cause charged particles to spiral around field lines. Plasma particles are lost to the vessel walls only by relatively slow diffusion ***across*** the field lines

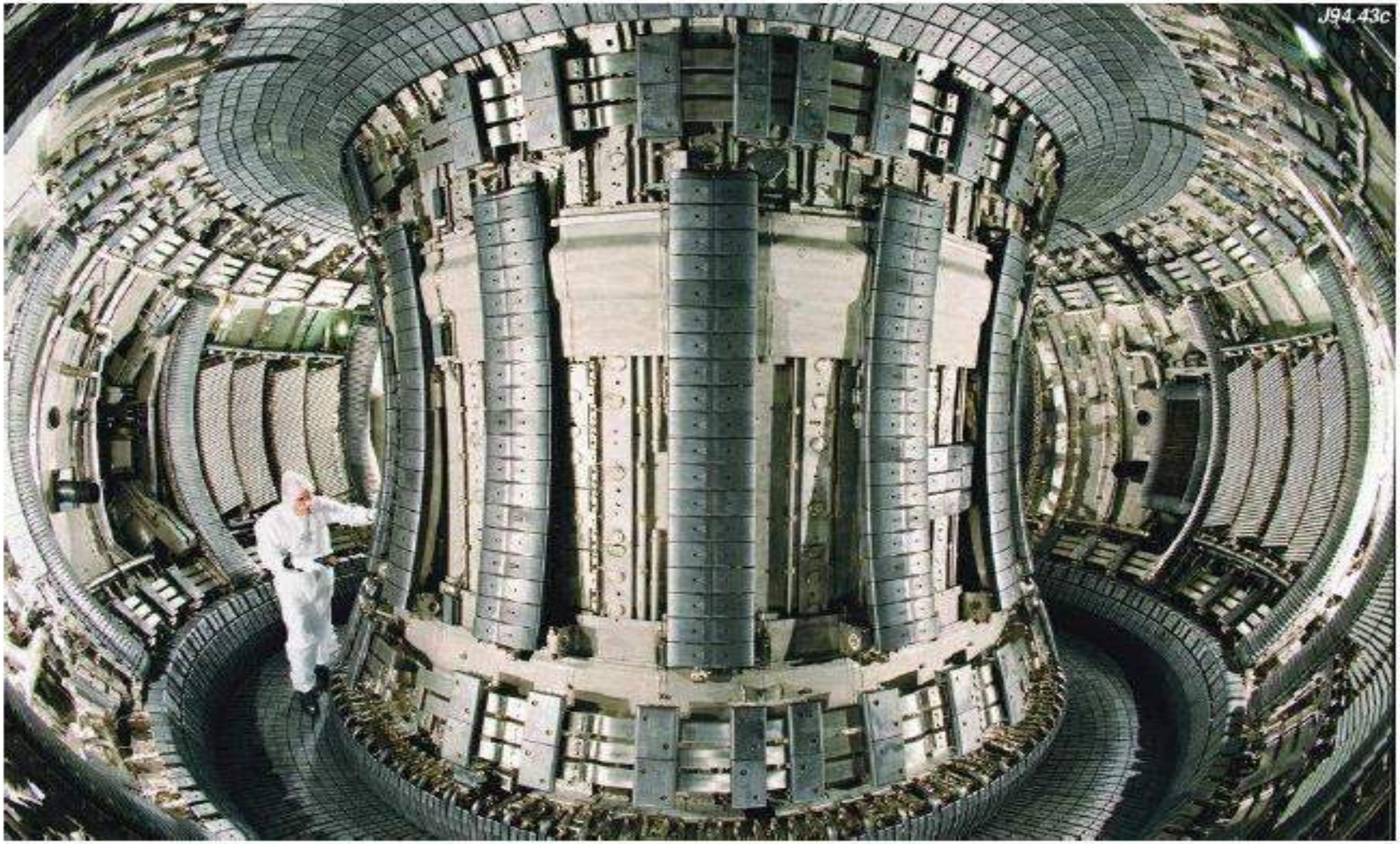


- ***Toroidal*** (ring shaped) system avoids plasma hitting the end of the container
- The most successful Magnetic Confinement device is the ***TOKAMAK*** (Russian for ***'Toroidal Magnetic Chamber'***)

The Tokamak:
A Transformer Device



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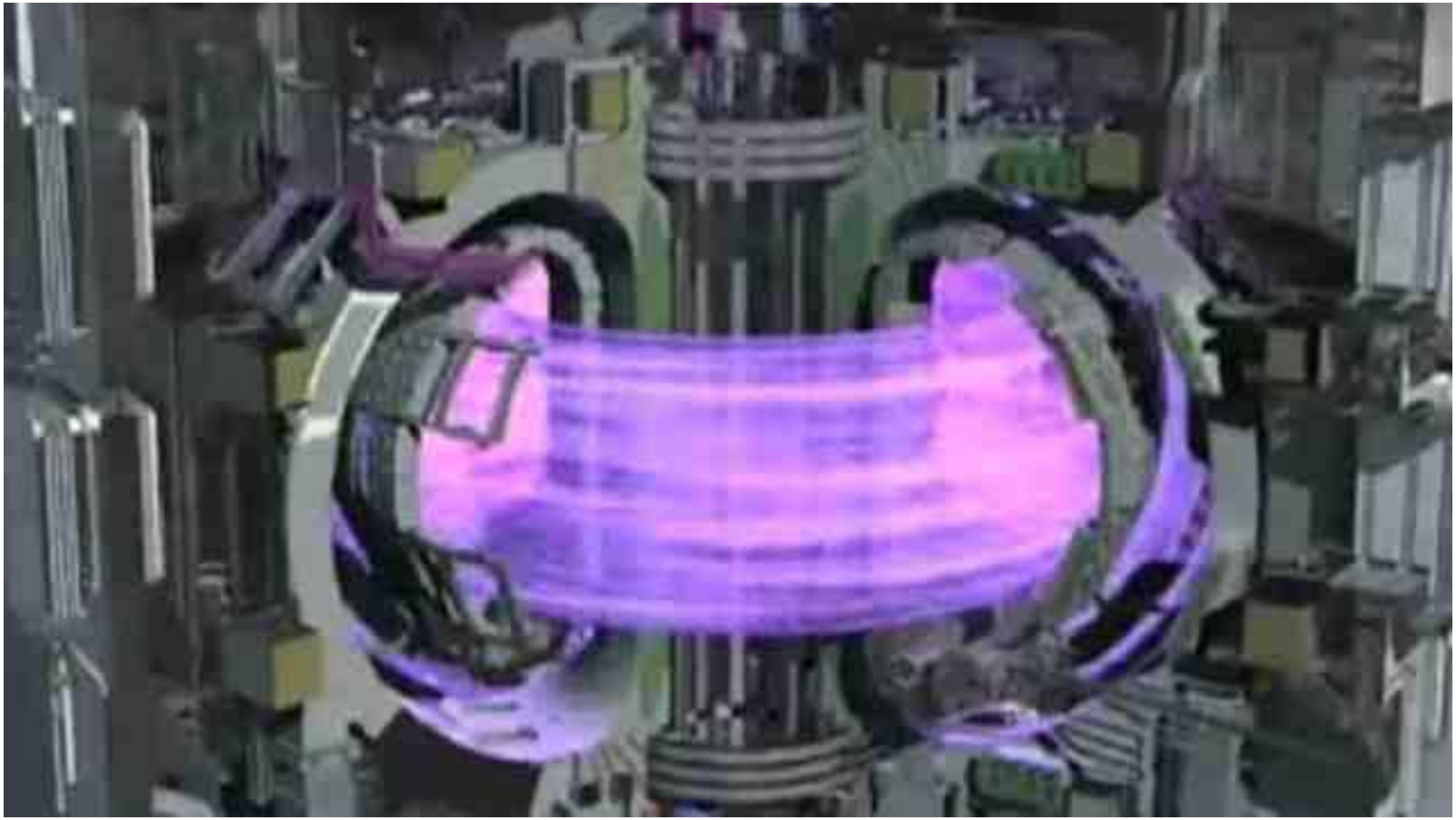


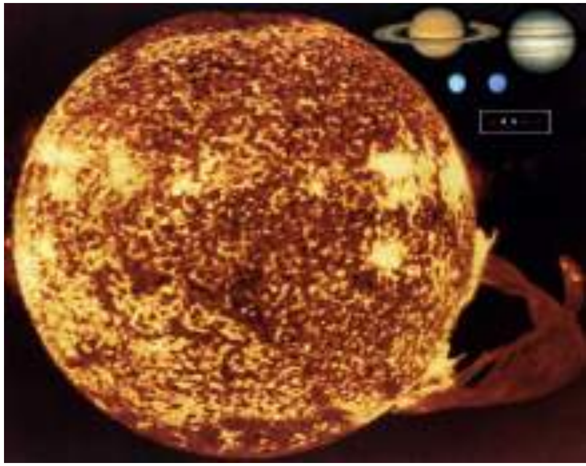
How the Sun generates energy... and converts itself from hydrogen to helium

high energy protons released, which then participate in new reactions) is one way:

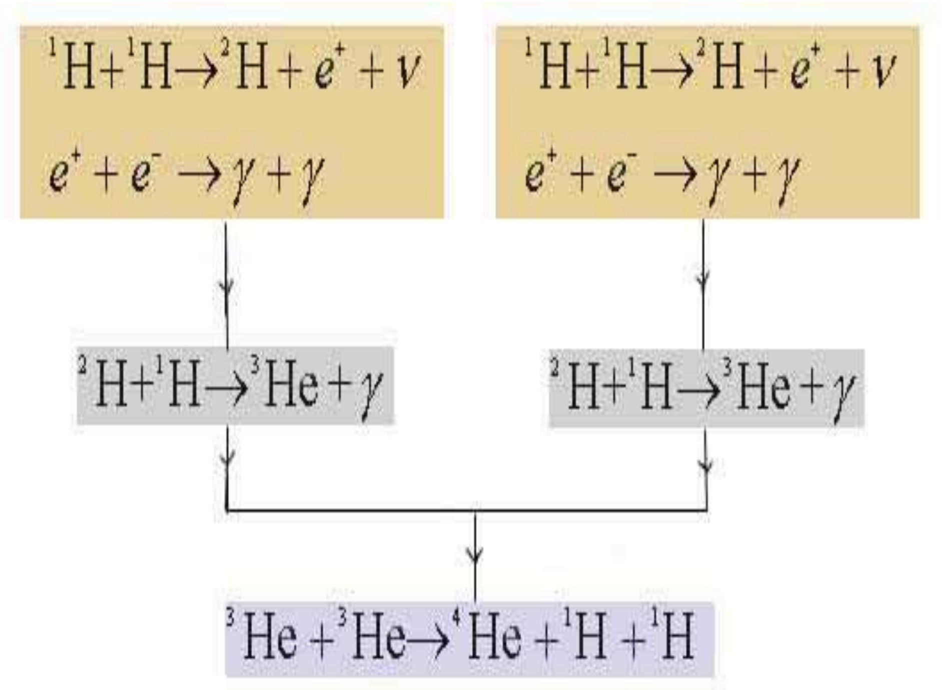
- Proton-Proton (pp) chain

- And there is the CNO cycle (Bethe cycle)
- The best evidence available at present indicate that:
- In the center of the sun, the carbon nitrogen cycle is faster

- And In a large interior region at slightly lower temperatures, the proton-proton chain is important because of its smaller temperature dependence.



Proton-Proton (pp) Chain



$$^{1}H+^{1}H\rightarrow^{2}H+e^{+}+\nu$$

$$e^{+}+e^{-}\rightarrow\gamma+\gamma$$

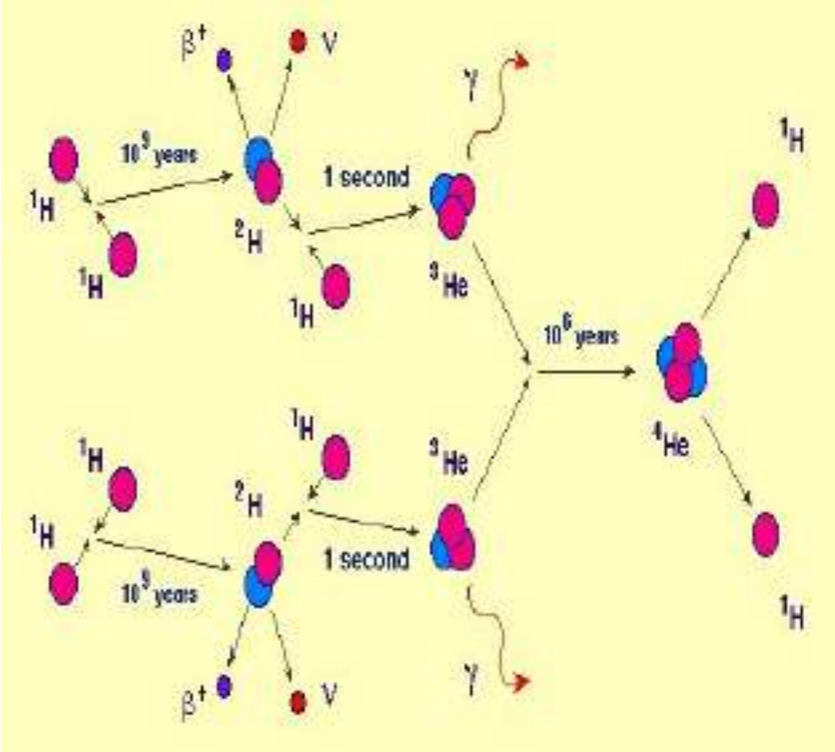
$$^{1}H+^{1}H\rightarrow^{2}H+e^{+}+\nu$$

$$e^{+}+e^{-}\rightarrow\gamma+\gamma$$

$$^{2}H+^{1}H\rightarrow^{3}He+\gamma$$

$$^{2}H+^{1}H\rightarrow^{3}He+\gamma$$

$$^{3}He+^{3}He\rightarrow^{4}He+^{1}H+^{1}H$$



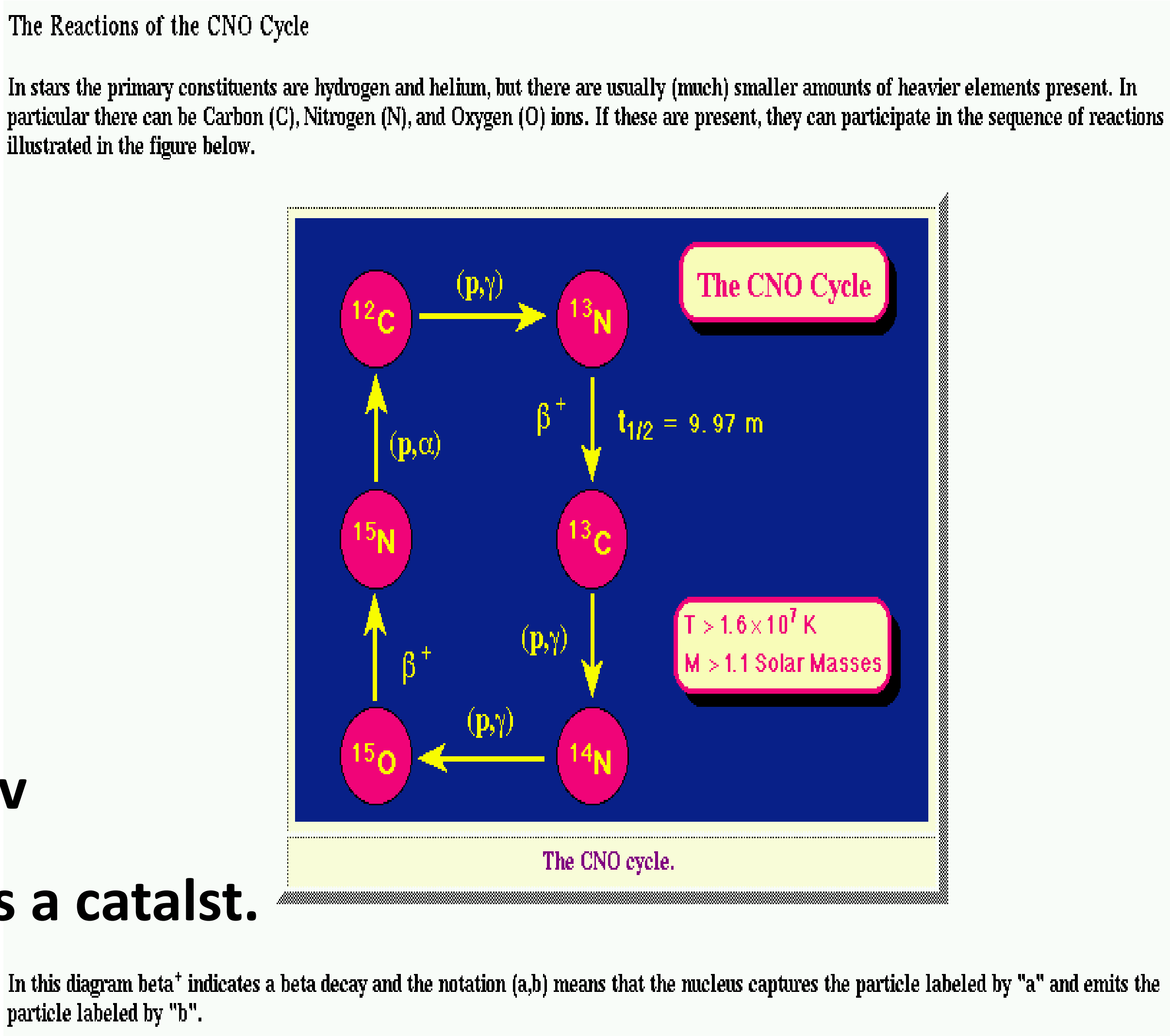
- (D is a shorthand notation for deuterium, ^{2}H, and T is short for tritium, ^{3}H)
- $H^{1} + H^{1} \rightarrow D^{2} + e^{+}$
- $D^{2} + H^{1} \rightarrow T\ (He^{3}) + \gamma$
- $T + H^{1} \rightarrow He^{4} + e^{+}$
- $4\ H^{1} \rightarrow He^{4} + 2\ e^{+} + 26$ Mev

CNO cycle (Bethe cycle)

- The sun is believed to contain ≈ 80% hydrogen, 19 % Helium and 1 % C, N, O and other element
- $C^{12} + H^{1} \rightarrow N^{13} + \gamma$
- $N^{13} \rightarrow C^{13} + e^{+}$
- $C^{13} + H^{1} \rightarrow N^{14} + \gamma$
- $N^{14} + H^{1} \rightarrow O^{15} + \gamma$
- $O^{15} \rightarrow N^{15} + e^{+}$
- $N^{15} + H^{1} \rightarrow C^{12} + He^{4}$

$$4\,H^{1} \rightarrow He^{4} + 2\,e^{+} + 26\ \text{Mev}$$

- The carbon serves only as a catalst.



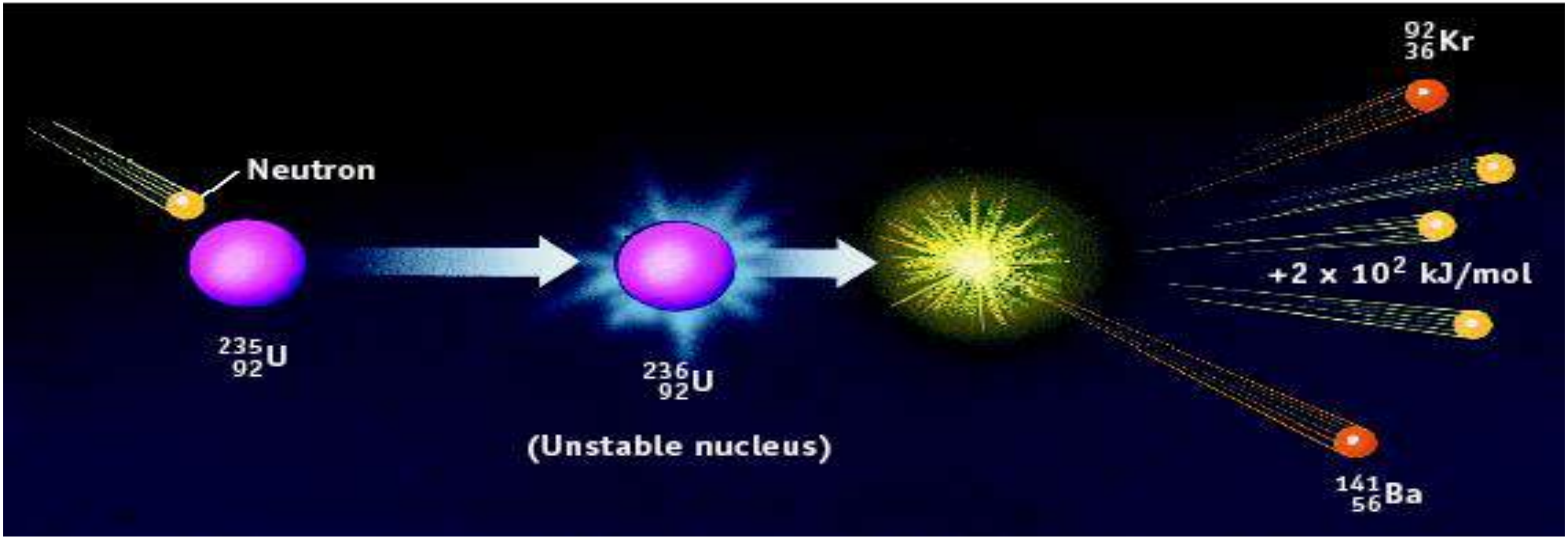
The Reactions of the CNO Cycle

In stars the primary constituents are hydrogen and helium, but there are usually (much) smaller amounts of heavier elements present. In particular there can be Carbon (C), Nitrogen (N), and Oxygen (O) ions. If these are present, they can participate in the sequence of reactions illustrated in the figure below.

The CNO cycle.

In this diagram beta^{+} indicates a beta decay and the notation (a,b) means that the nucleus captures the particle labeled by "a" and emits the particle labeled by "b".

Nuclear Fission



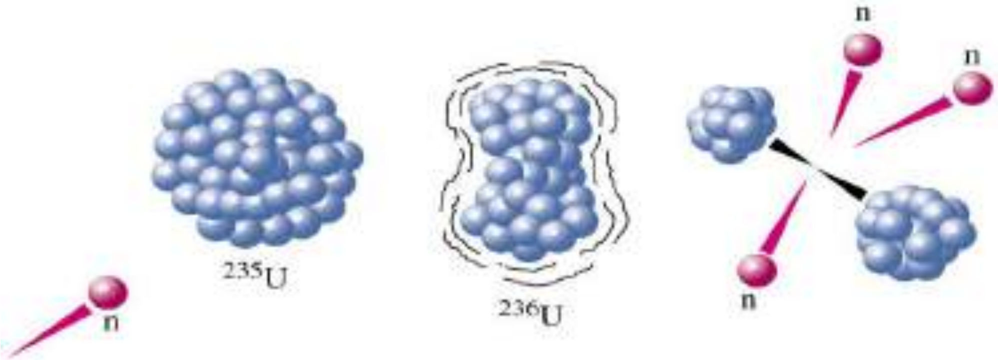
- **Fission reactions — a very heavy nucleus, after absorbing additional light particles (usually neutrons), splits into two or sometimes three pieces. (α decay is not usually called fission.)**

$$^{A}_{Z}X \rightarrow {}^{A_1}_{Z_1}Y_1 + {}^{A_2}_{Z_2}Y_2$$

Spallation

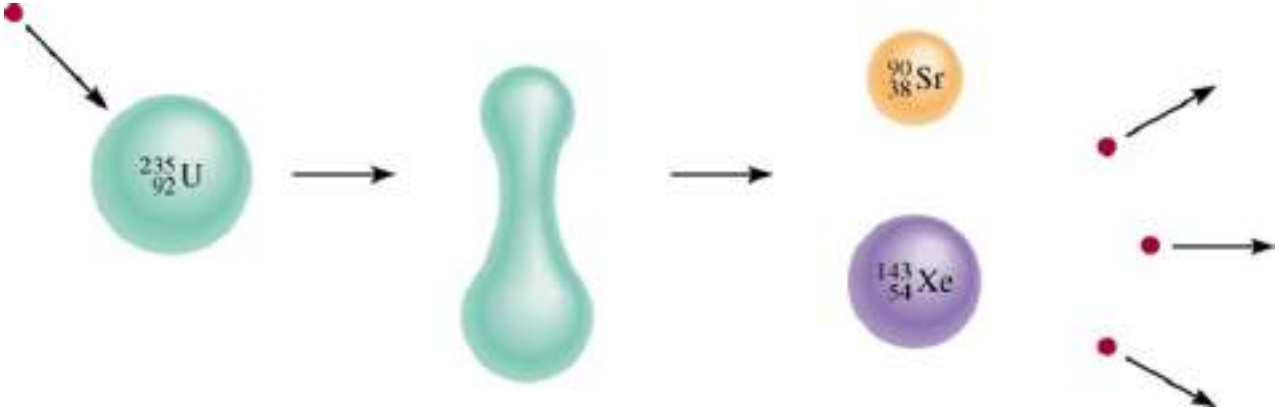
- In general ,**spallation** is a process in which fragments of material (spall) are ejected from a body due to impact or stress.
- In nuclear physics, spallation is the process in which a heavy nucleus emits a large number of nucleons as a result of being hit by a high-energy particle, thus greatly reducing its atomic weight.
- Note that: ***Spallation reactions*** is the reactions occur with emission of a large number of fragments corresponding to a very highly excited compound nucleus (fission processes).

Nuclear Fission



وأفضل الطرق لفهم عملية الأنشطار هي باعتبار النواة الثقيلة كما لو كانت تسلك سلوك قطرة من سائل. وكما يتضح من الشكل 28-12 ، فإن إضافة نيوترون إلى النواة يجعل النواة تأخذ في الاهتزاز بشكل عشوائي مما يجعل موقفاً يطرأ كالذى يصوره الشكل 28-12 (د) . وفى هذه الحالة يتضاءل تأثير قوة التجاذب بسبب الزيادة الكبيرة فى مساحة سطح النواة. وفيما يلى ذلك فإن قوى كولوم التنافرية تتولى دفع جزئي النواة بعيداً عن بعضهما أكثر فأكثر ، ويحدث الانشطار للنواة ، كما هو موضح فى الشكل 28-12 (هـ). وتنطلق النيوترونات وتكون شظيتا الانشطار على درجة عالية من الاستثارة وعدم الاستقرار.

The liquid Drop Model of Fission



- The nucleus is tended to assume the spherical shape like the water drop under the influence of surface tension.
- The surface tension causes a lowering of total binding energy which is proportional to the surface area.
- In case of electrical charged drop (such as a nucleus) , The coulomb repulsion is greatest for the very compact spherical shape.
- The coulomb repulsion tries to make drop assume a nonspherical shape, while the surface tension tries to keep the drop spherical.

Symmetric and asymmetric fission

1) Symmetric fission to equal fragments with masses $M_1(A_1,Z_1) = M_2(A_2,Z_2)=M(A/2,Z/2)$:

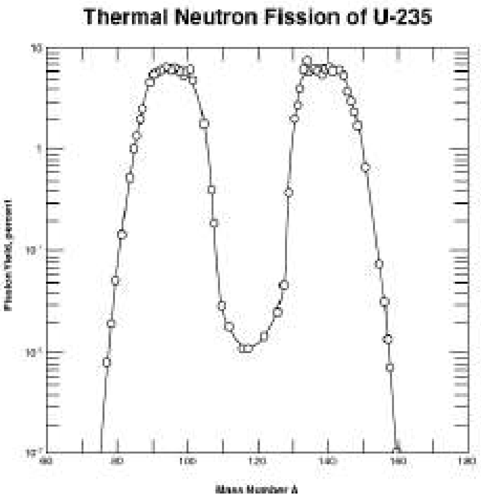
$$Q_f = 2W(A/2, Z/2) - W(A, Z) \approx \left[E_s(A, Z) + E_c(A, Z)\right] - 2\left[E_s(A/2, Z/2) + E_c(A/2, Z/2)\right]$$

Fission is energetically favourable if $Q_f > 0$ ➔

E_S - surface energy
E_C – Coulomb energy

fission parameter $\boxed{\dfrac{Z^2}{A} \geq 17}$ for nuclei with A > 90

2) Asymmetric fission to fragments with nonequal masses $M_1(A_1,Z_1)$, $M_2(A_2,Z_2)$,



it produces the fission products at
$A_{light}=95\pm15$ and $A_{heavy}=135\pm15$.

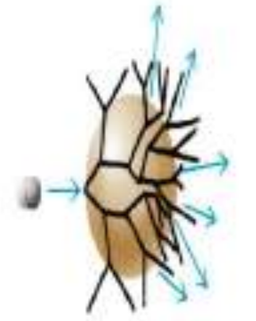
The reason:
to form closed shells for the fission products!

$$\boxed{\frac{A_{light}}{A_{heavy}} \approx \frac{Z_{light}}{Z_{heavy}} \approx \frac{2}{3}}$$

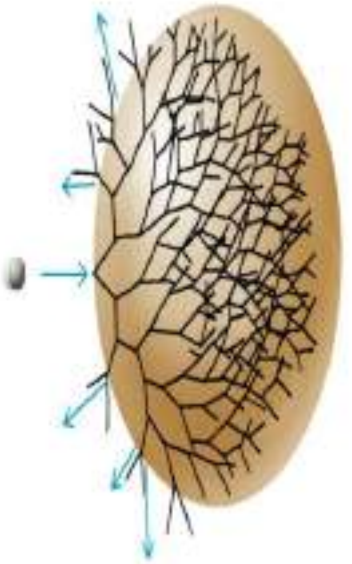
$$n + {}^{235}_{92}U \rightarrow {}^{236}_{92}U \rightarrow {}^{95}_{38}Sr + {}^{139}_{54}Xe + 2n.$$

Critical Size
(Fission Parameter)

- For very heavy nuclei, the repulsion is much stronger.
- so, it was shown that there will be a certain critical size for nuclei depending on $Z^2/A \geq 17$.
- Above that ,the electrostatic repulsion force will be greater than the surface force holding the nucleus together.
- The critical size has been calculated to occur for Z near 100, so a small excitation should be sufficient to induce breakup into to fragments
- Ratio Z^2/A (fission parameter) is critical for stability against spontaneous fission



Neutrons escape surface



Neutrons trigger more reactions

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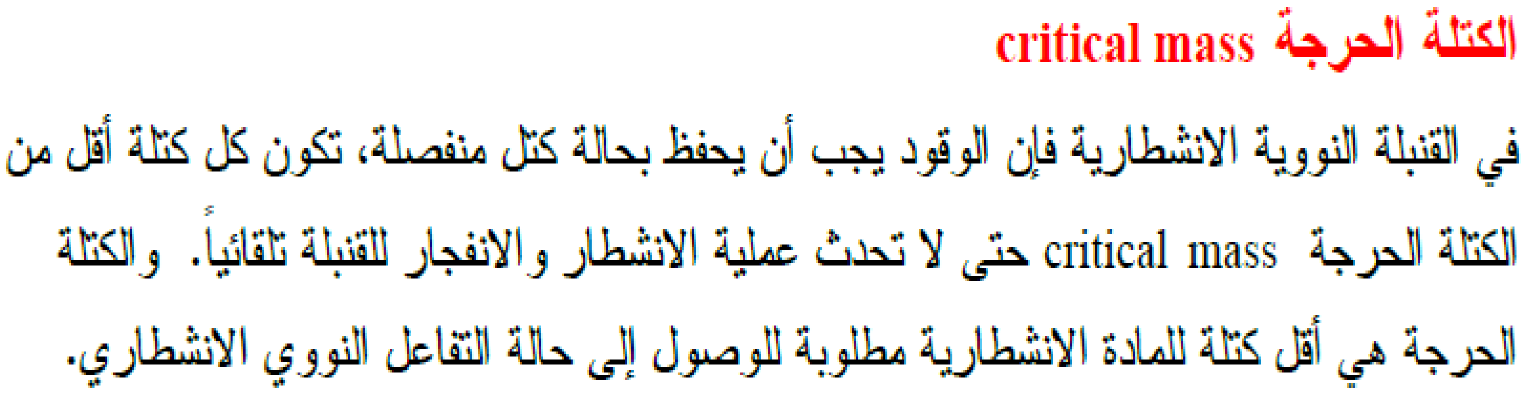
Critical Mass

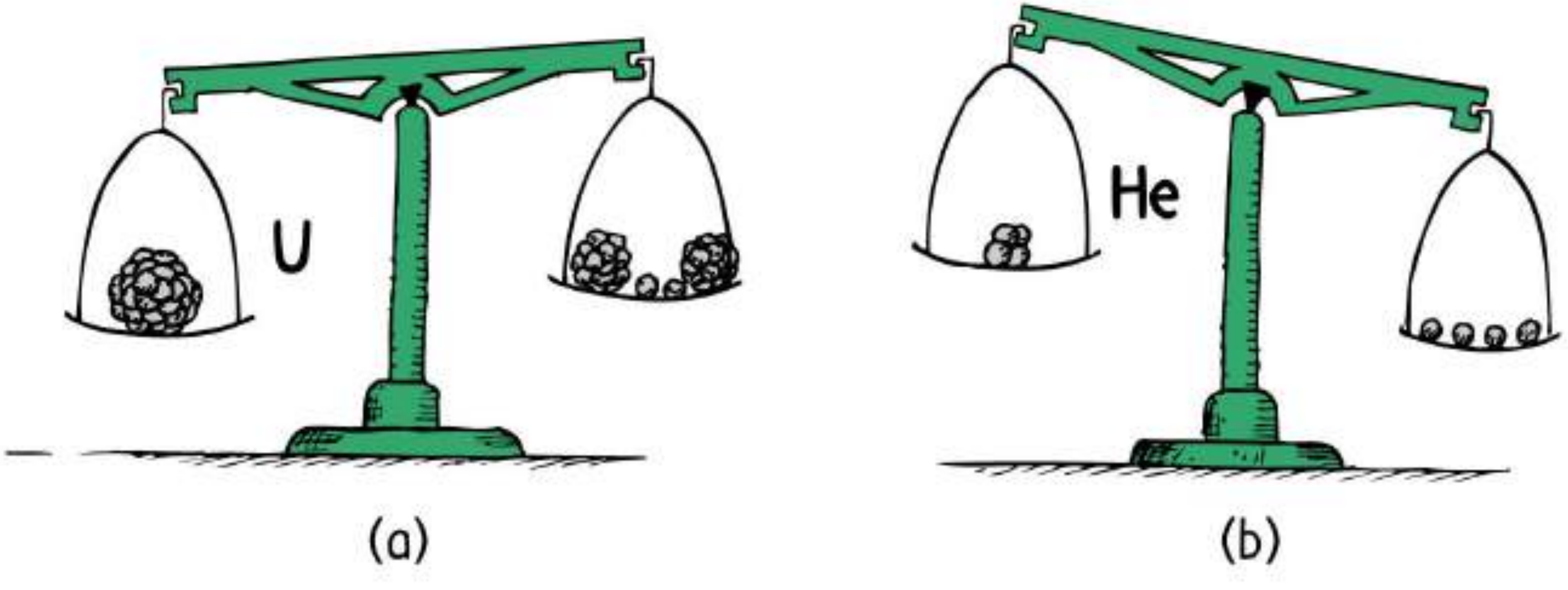
- The minimum mass of fissionable material required to generate a self-sustaining nuclear chain reaction is the *critical mass*.
- In practical terms the effective critical mass depends on many other attributes, such as the degree of enrichment of the fuel, its shape, temperature, density, and whether it is contained within a neutron-reflective s



الكتلة الحرجة critical mass

في القنبلة النووية الانشطارية فإن الوقود يجب أن يحفظ بحالة كتل منفصلة، تكون كل كتلة أقل من
الكتلة الحرجة critical mass حتى لا تحدث عملية الانشطار والانفجار للقنبلة تلقائياً. والكتلة
الحرجة هي أقل كتلة للمادة الانشطارية مطلوبة للوصول إلى حالة التفاعل النووي الانشطاري.

Nuclear Energy



Nuclear Fission Energy

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{90}_{38}\mathrm{Sr} + {}^{143}_{54}\mathrm{Xe} + 3\,{}^{1}_{0}\mathrm{n} + \text{Energy}$$

Energy = [mass ^{235}U + mass n – (mass ^{90}Sr + mass ^{143}Xe + 3 x mass n)] x c^2

Energy = 3.3 x 10^{-11}J per ^{235}U

= 2.0 x 10^{13} J per mole ^{235}U

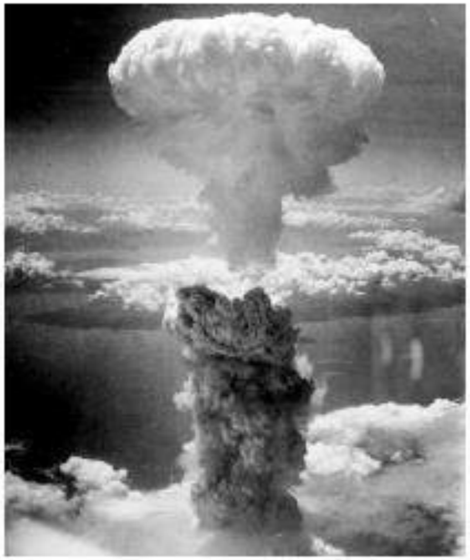
Combustion of 1 ton of coal = 5 x 10^{7} J

Fission chain reactions

Fission chain reactions are used:

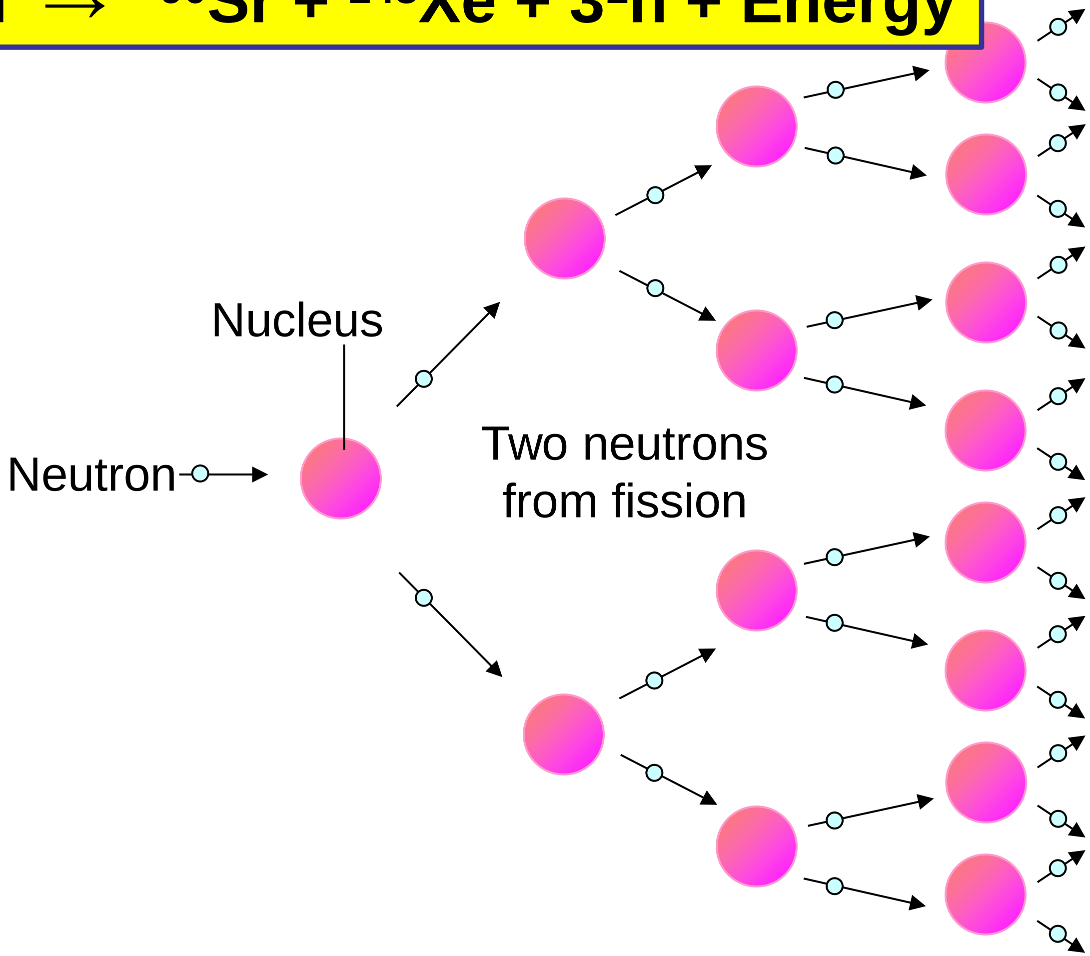
Nuclear power plants operate by precisely controlling the rate at which nuclear reactions occur, and that control is maintained through the use of several redundant layers of safety measures.
Moreover, the materials in a nuclear reactor core and the uranium enrichment level make a nuclear explosion impossible, even if all safety measures failed.

Nuclear weapons are specifically engineered to produce a reaction that is so fast and intense that it cannot be controlled after it has started.
When properly designed, this uncontrolled reaction can lead to an explosive energy release.



The Chain Reaction of Fission Process

$^{235}U + ^{1}n \rightarrow \; ^{90}Sr + ^{143}Xe + 3^{1}n + Energy$



Zumdahl, Zumdahl, DeCoste, World of Chemistry 2002, page 620

Reactor Multiplication Constant

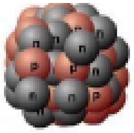
- Self-sustainability of chain reaction depends on relative rates of production and elimination of neutrons.
- Measured by the effective reactor multiplication constant:

k_{eff} = Rate of neutron production/Rate of neutron loss

Reactor Multiplication Constant

- Three possibilities for k_{eff}:

- $k_{eff} < 1$: Fewer neutrons being produced than eliminated. Chain reaction not self-sustaining, reactor eventually shuts down. Reactor is subcritical.
- $k_{eff} = 1$: Neutrons produced at same rate as eliminated. Chain reaction exactly self-sustaining, reactor in steady state. Reactor is critical.
- $k_{eff} > 1$: More neutrons being produced than eliminated. Chain reaction more than self-sustaining, reactor power increases. Reactor is supercritical.



Nuclear chain reactions

The **effective neutron multiplication factor, k**, is the average number of neutrons from one fission that causes another fission:

$$\boxed{k = \frac{\text{number of neutrons in one generation}}{\text{number of neutrons in preceding generation}}}$$

The remaining neutrons either are absorbed in non-fission reactions or leave the system without being absorbed.
The value of k determines how a nuclear chain reaction proceeds:

- **$k < 1$ (subcriticality):** The system cannot sustain a chain reaction, and any beginning of a chain reaction dies out in time. For every fission that is induced in the system, an average total of $1/(1 - k)$ fissions occur.

- **$k = 1$ (criticality):** Every fission causes an average of one more fission, leading to a fission (and power) level that is constant. Nuclear power plants operate with $k = 1$ unless the power level is being increased or decreased.

- **$k > 1$ (supercriticality):** For every fission in the material, it is likely that there will be k fissions after the next mean generation time. The result is that the number of fission reactions increases exponentially, according to the equation $e^{(k-1)\,t/\Lambda}$, where t is the elapsed time. Nuclear weapons are designed to operate in this state.

Nuclear chain for Fission

•The key to keeping the reaction going is that at least one of the neutrons given off, must cause another fission

•How many of created neutrons produced further fission depends on arrangement of setup with fission material

•Ratio between neutron numbers in n and n+1 generations of fission is named as multiplication factor k_{eff}:

May be defined as:* *the ratio of the average number of fission in one step or (generation) to the number of fissions in the previous generation

OR* *the ratio of the number of neutrons in one generation to the number of neutrons in the previous generation.

Its magnitude is split to three cases:

$k_{eff} < 1$ – subcritical – without external neutron source
reactions stop → accelerator driven transmutors
– external neutron source

$k_{eff} = 1$ – critical – can take place controlled chain reaction
→ nuclear reactors

$k_{eff} > 1$ – supercritical – uncontrolled (runaway) chain
reaction → nuclear bombs

Reactivity (ρ) of a Reactor

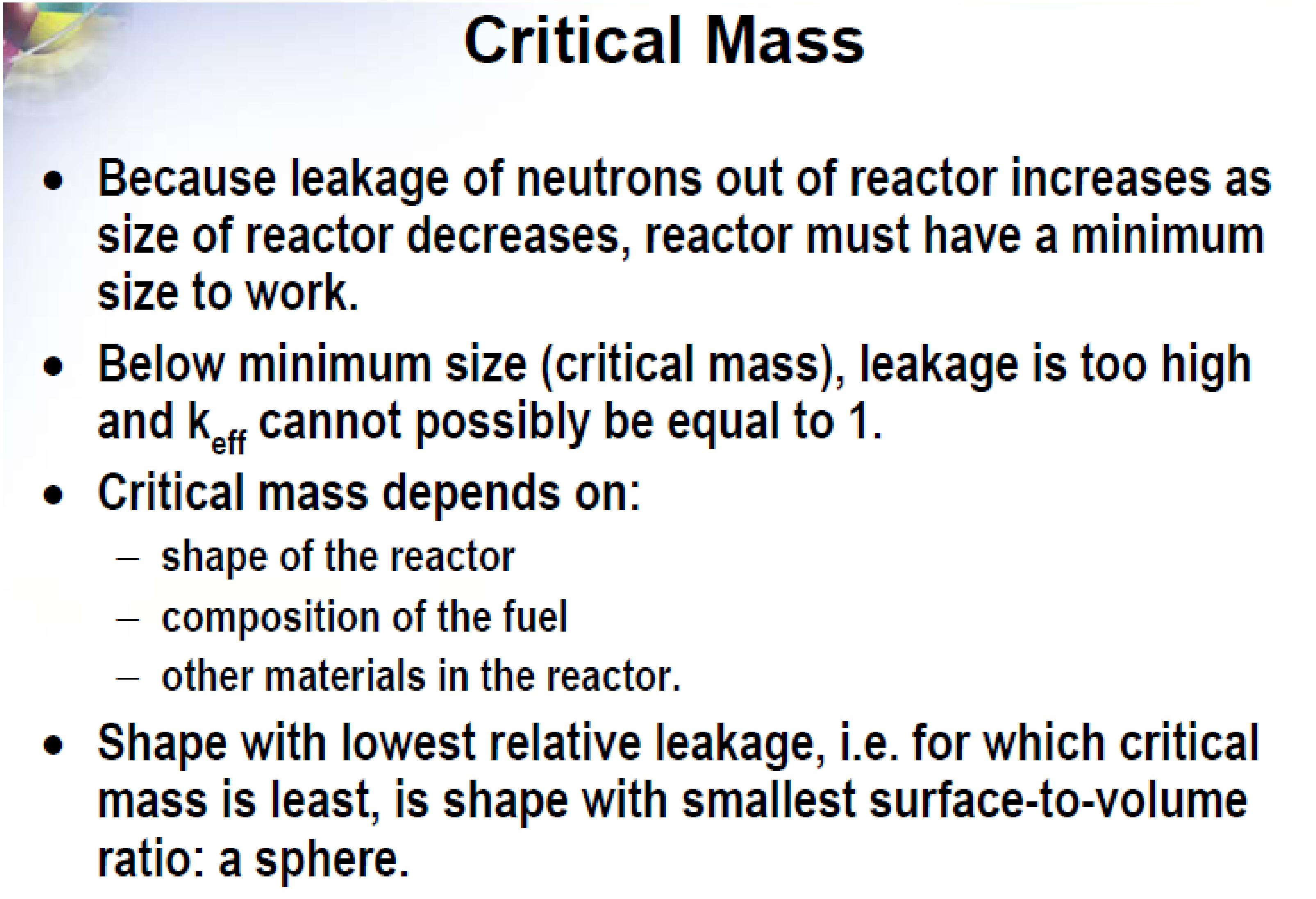
- If ρ is positive , the reaction rate will increase.
- If ρ is negative , the reaction rate will decrease.
- If ρ = 0, the reaction rate will steady constant
- In nuclear Reactors , It is essential that the reaction rate and ρ values is around ≈ 0

Excess effective multiplication factor

$$K_{ex} = K_{eff} - 1$$

$$\rho = \frac{K_{ex}}{K_{eff}}$$

Critical Mass of Reactor



Critical Mass

- Because leakage of neutrons out of reactor increases as size of reactor decreases, reactor must have a minimum size to work.
- Below minimum size (critical mass), leakage is too high and k_{eff} cannot possibly be equal to 1.
- Critical mass depends on:
  - shape of the reactor
  - composition of the fuel
  - other materials in the reactor.
- Shape with lowest relative leakage, i.e. for which critical mass is least, is shape with smallest surface-to-volume ratio: a sphere.

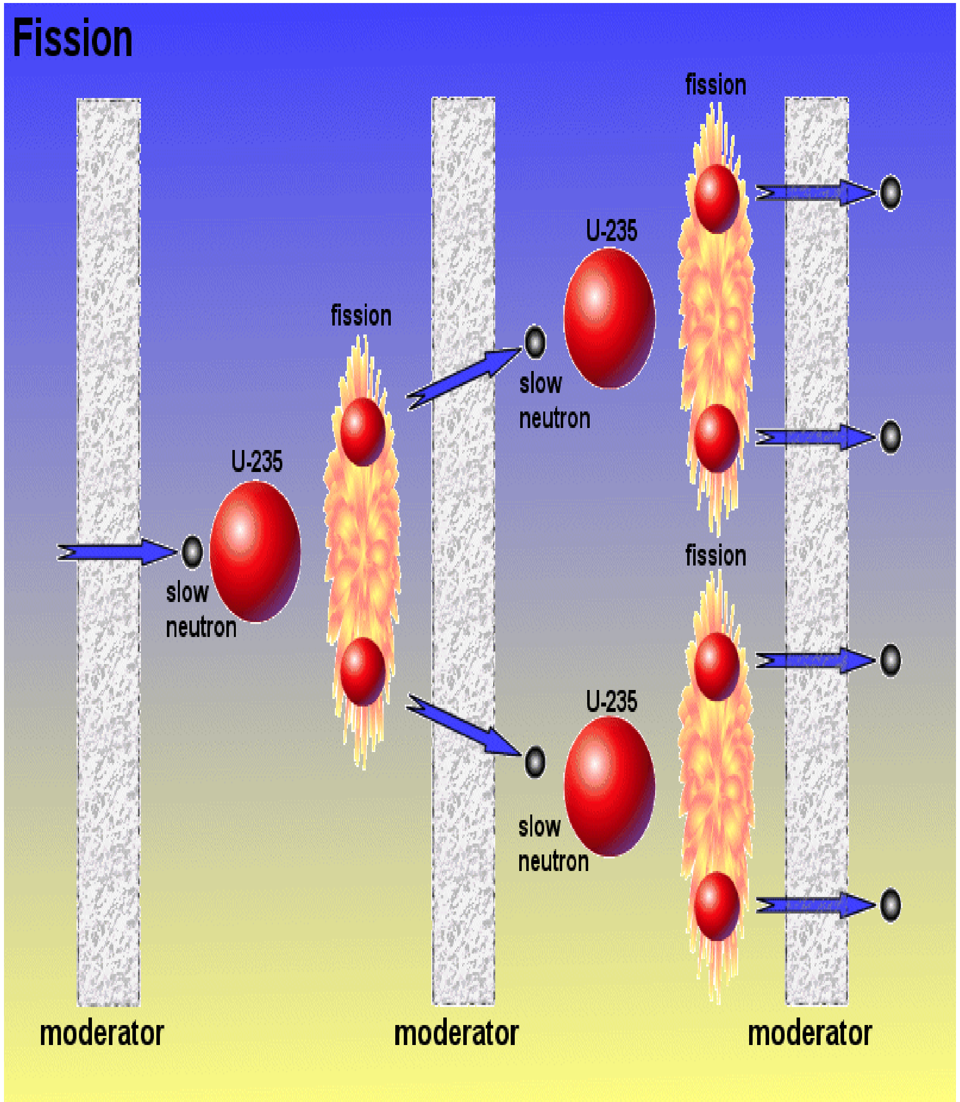
Critical Mass

- The minimum mass of fissionable material required to generate a self-sustaining nuclear chain reaction is the *critical mass*.
- In practical terms the effective critical mass depends on many other attributes, such as the degree of enrichment of the fuel, its shape, temperature, density, and whether it is contained within a neutron-reflective substance

Control the fission Chain Reaction Rate

The efficiency of controlling the rate of fission chain reaction depend on :

The delayed neutron fraction



Energy from Fission

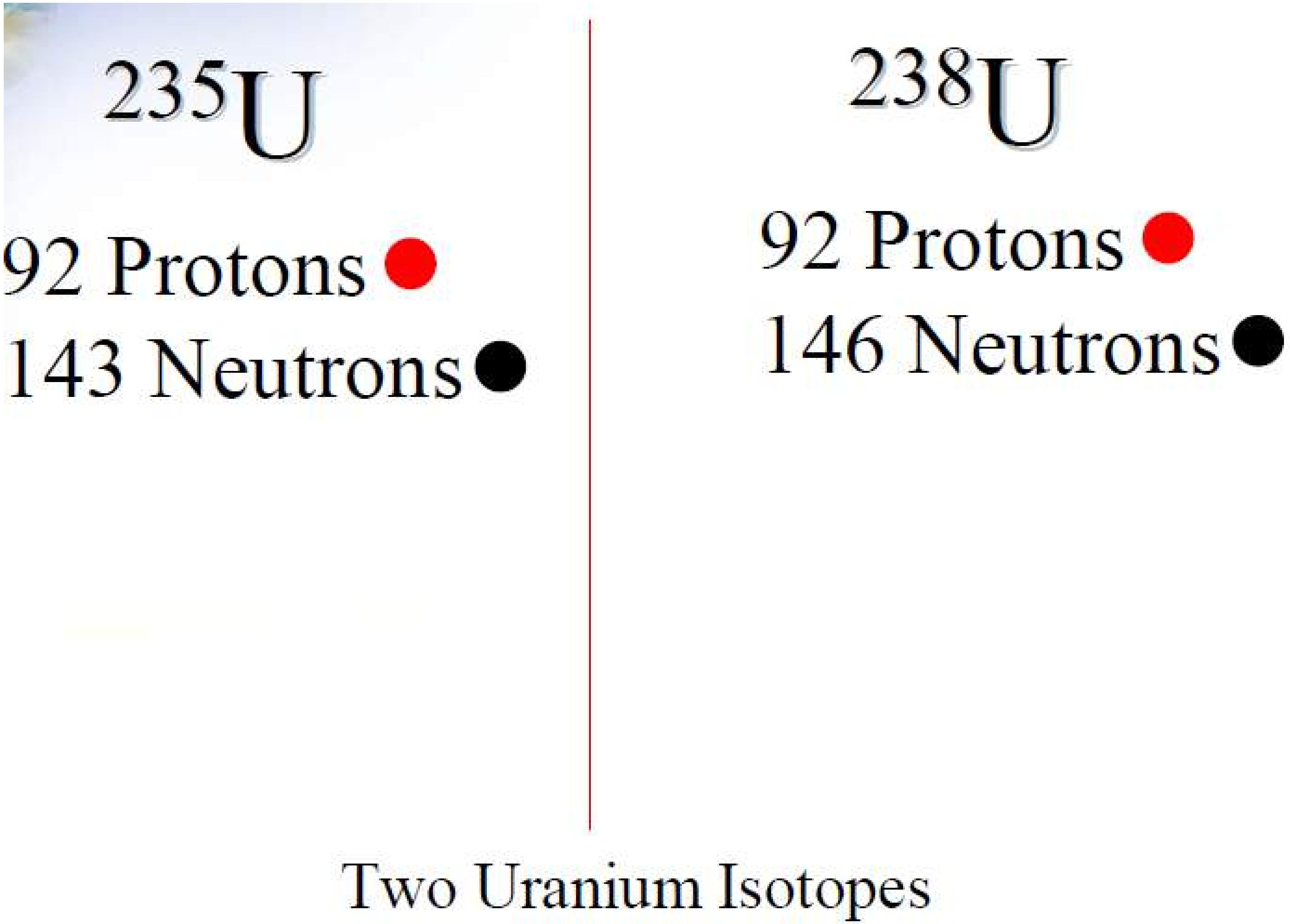
Energy released per fission ~ 200 MeV [~ $3.2*10^{-11}$ J].

This is hundreds of thousands, or millions, of times greater than energy produced by combustion, but still only ~0.09% of mass energy of uranium nucleus!

Energy appears mostly (85%) as kinetic energy of fission fragments, and in small part (15%) as kinetic energy of other particles.

- The energy is quickly reduced to heat,
- The heat is used to make steam by boiling water,
- The steams turns a turbine and generates electricity.

Uranium as a Fuel



^{235}U

92 Protons 🔴

143 Neutrons ●

^{238}U

92 Protons 🔴

146 Neutrons ●

Two Uranium Isotopes

Fissionable and Fissile Nuclides

- Only a few nuclides can fission.
- A nuclide which can be induced to fission by an incoming neutron of any energy is called fissile. Only one naturally occurring fissile nuclide: ^{235}U.
- Other fissile nuclides: ^{233}U, some isotopes of plutonium, ^{239}Pu and ^{241}Pu; none of these occurs in nature to any appreciable extent.
- Fissionable nuclides: can be induced to fission by neutrons only of energy higher than a certain threshold. e.g. ^{238}U and ^{240}Pu.

[Note the fissile nuclides have **odd** A. This is because of the greater binding energy for **pairs** of nucleons.]

Nuclear Fuel

– Fissile Material

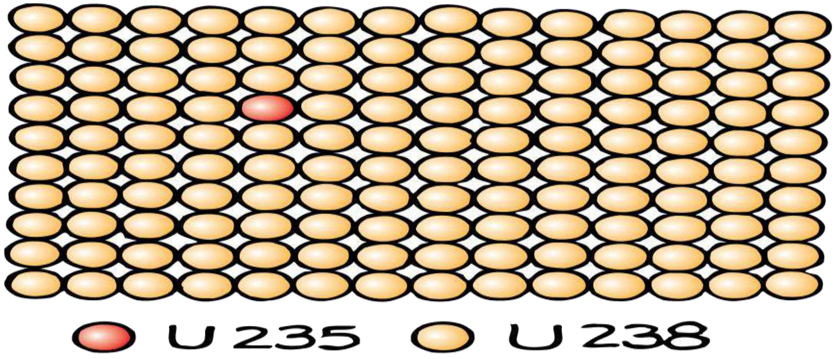
- Fissile materials are those fissionable materials which are capable of sustaining a chain reaction when struck by neutrons with *low kinetic energy* (Slow or thermal neutrons)
- The three most important fissile materials which can be obtained in large enough useful quantities are Uranium-233 and Uranium-235, both dense soft silvery metals and Plutonium-239, also a dense silvery white metal.

– Fertile Material

- Fertile materials are isotopes which are capable of becoming fissile by capturing fast moving neutrons possibly followed by radioactive decay. Examples are Uranium-238, Plutonium-240 and Thorium-232.
-
- Fissionable materials are not necessarily fissile. Thus, although Uranium-238 is fissionable, it is fertile but not fissile.

Uranium Enrichment

- The nuclear fuel is uranium, with its fissionable isotope U-235 enriched to about 3%.
- Because the U-235 is so highly diluted with U-238, an explosion like that of a nuclear bomb is not possible.
- Uranium-235 undergoes fission when it absorbs a neutron, but uranium-238 normally doesn't.
- To sustain a chain reaction in uranium, the sample must contain a higher percentage of U-235 than occurs naturally.
- Since atoms U-235 and U-238 are virtually identical chemically, they cannot be separated by a chemical reaction. They must be separated by physical means.



Nuclear Reactions as an Energy Source

Uranium-235, a source of nuclear power.

Fission Nuclear Reactors Classification

- **According to Neutron Energy:**
  - Thermal Reactors
  - Fast Reactors
  - intermediate Reactors
- **According to the reactor core structure :**
  - Homogenous Reactors (fuel and moderators are homogenous)
  - Heterogeneous Reactors
- **According to Produce new fissionable Material:**
  - Burner (Conversion) Reactors (produce fissionable material less than consumed in the reactor)
  - Breeder Reactors (produce fissionable material more than consumed in the reactor)
- **According to The applications :**
  - Energy production Reactors
  - Investigation Reactors
  - Research Reactors
  - Military Reactors
  - Practice (educated) Reactors

The main Components of Nuclear Reactors for producting Energy

- **1-Reactor Core**
  - Fuel
  - moderator
  - Control Rods (Safety Rods)
  - Cooler System
  - Neutrons refractors

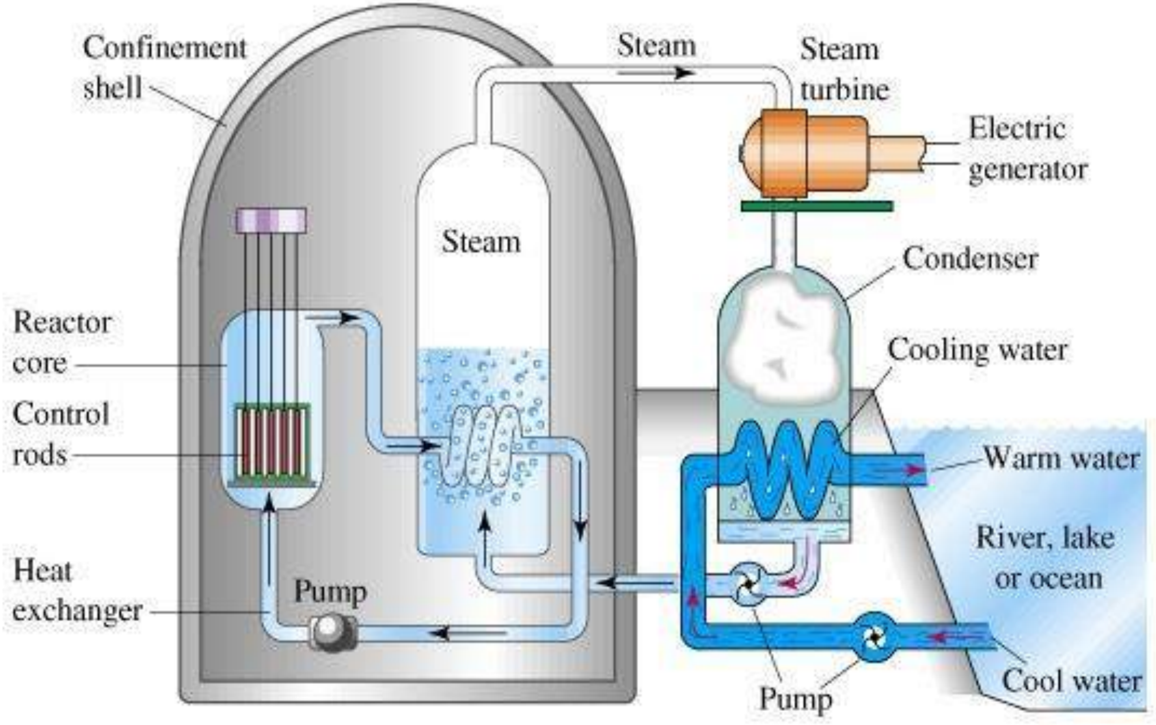
- **2- Heat Exchanger**
- **3- Confinements Shell**

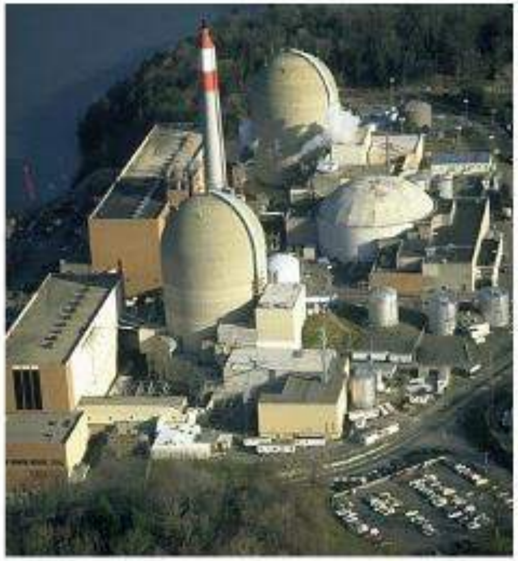
- **The control rods are made of a material (usually cadmium or boron) that readily absorbs neutrons.**

- **The moderator may be graphite or it may be water.**

- Heated water around the nuclear fuel is kept under high pressure and is thus brought to a high temperature without boiling.
- It transfers heat to a second, lower-pressure water system, which operates the electric generator in a conventional fashion.

Nuclear Reactors





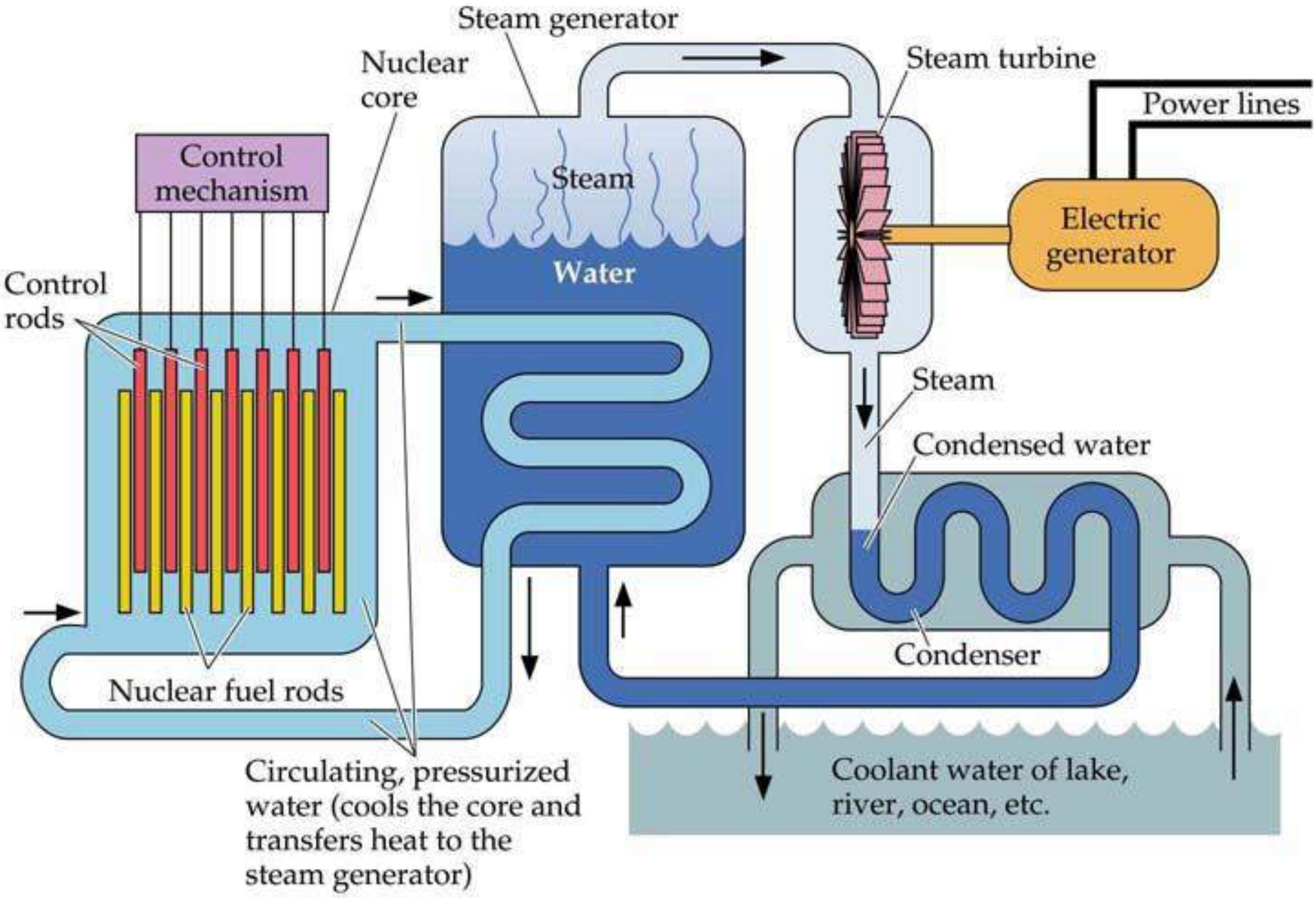
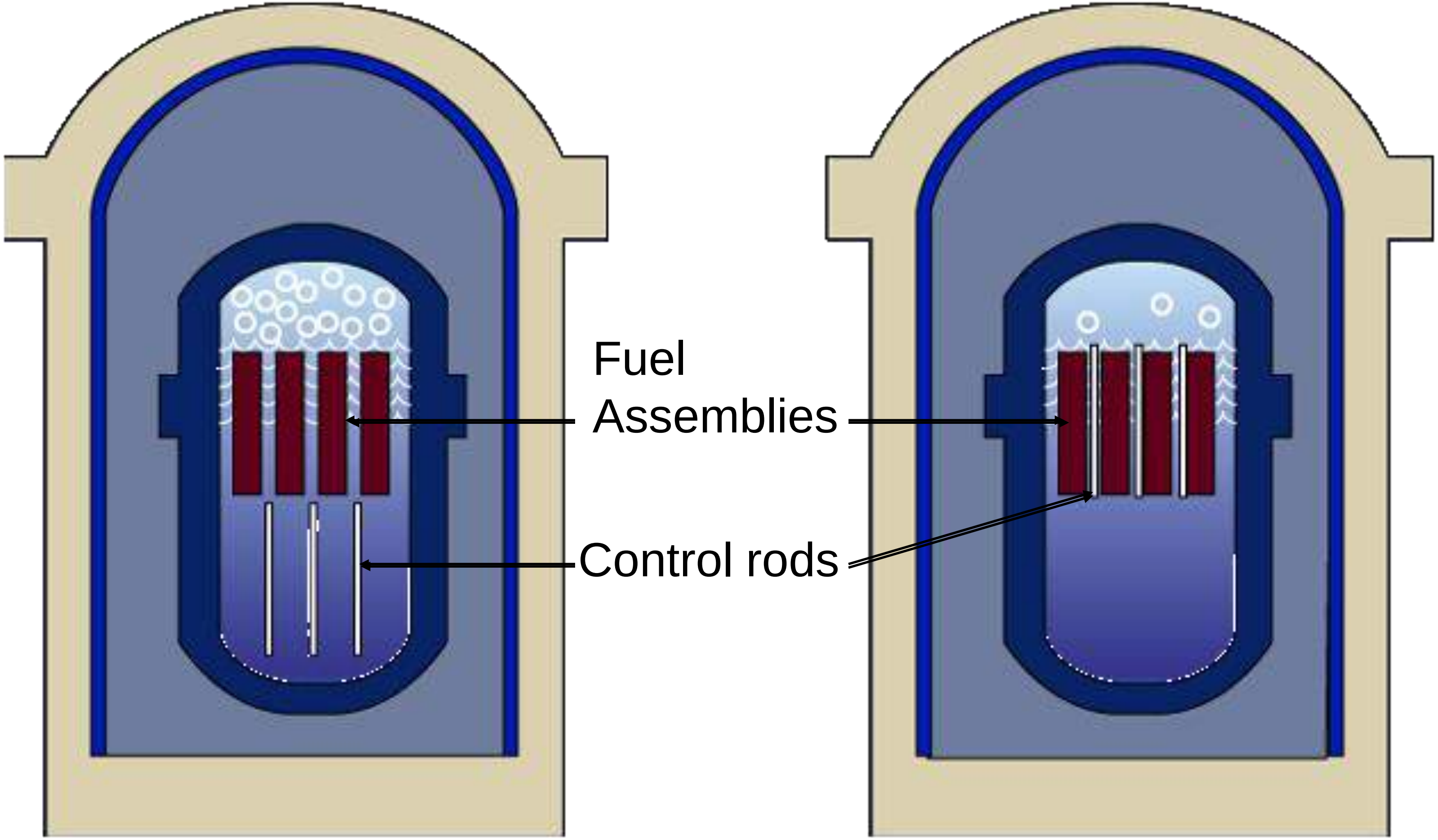


Figure 5.1: Schematic diagram of a nuclear power plant.

Controlling the Chain Reaction



Withdraw control rods,
reaction increases

Insert control rods,
reaction decreases

Controlling the Chain Reaction

- Plant operators can control the chain reaction. Long rods are inserted among the fuel assemblies.
- These "control rods" are made to absorb neutrons, so the neutrons can no longer hit atoms and make them split.
- To speed up the chain reaction, plant operators withdraw the control rods, either partially or fully. To slow it, they insert the control rods.

Energy production Reactors
(Thermal Reactors)

- **Cooling Systems**

- Light Water Reactor (LWR)
- Heavy Water Reactor (HWR)
- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR)
- Gas Cooled Reactor (GCR)
- High Temperature Gas Cooled Reactor (HTGR)

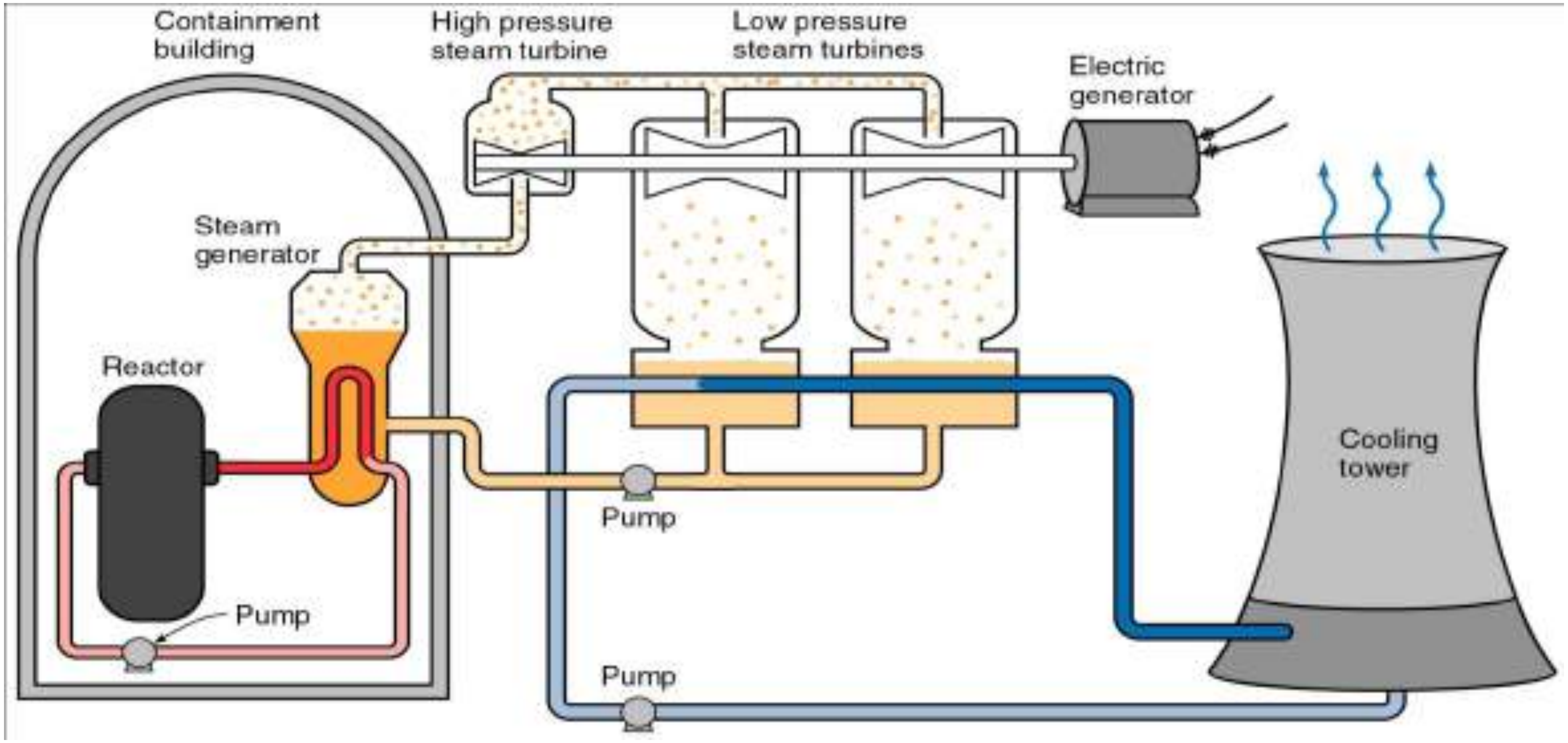
U.S. Reactors

The Reactors are based on water moderator. The reactor get hot the water turns to steam and the reactor stops.

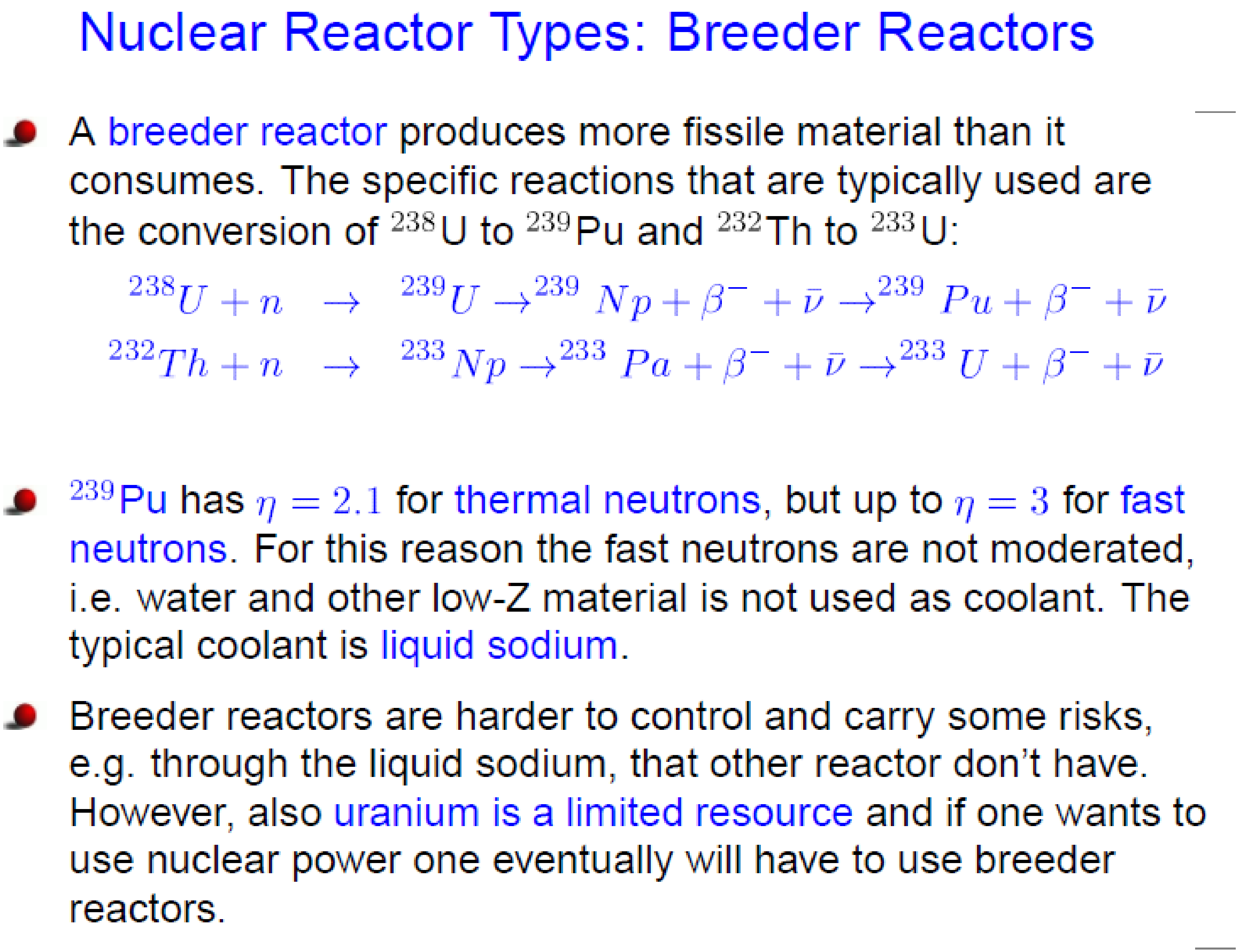
If the reactor cools the water becomes more dense and the reactor warms up.

This is a “naturally” stable system.

- ▪A diagram of a modern pressurized-water nuclear reactor.
- Hot water coming from the reactor is converted to steam when the pressure is reduced in the steam generators.
- •The steam turns the turbines, which power the electric generator.



Breeders and Burners Reactors



Nuclear Reactor Types: Breeder Reactors

- A breeder reactor produces more fissile material than it consumes. The specific reactions that are typically used are the conversion of ^{238}U to ^{239}Pu and ^{232}Th to ^{233}U:

$$
\begin{aligned}
{}^{238}U + n &\rightarrow {}^{239}U \rightarrow {}^{239}Np + \beta^- + \bar{\nu} \rightarrow {}^{239}Pu + \beta^- + \bar{\nu} \\
{}^{232}Th + n &\rightarrow {}^{233}Np \rightarrow {}^{233}Pa + \beta^- + \bar{\nu} \rightarrow {}^{233}U + \beta^- + \bar{\nu}
\end{aligned}
$$

- ^{239}Pu has $\eta = 2.1$ for thermal neutrons, but up to $\eta = 3$ for fast neutrons. For this reason the fast neutrons are not moderated, i.e. water and other low-Z material is not used as coolant. The typical coolant is liquid sodium.
- Breeder reactors are harder to control and carry some risks, e.g. through the liquid sodium, that other reactor don't have. However, also uranium is a limited resource and if one wants to use nuclear power one eventually will have to use breeder reactors.

Breeder Reactors

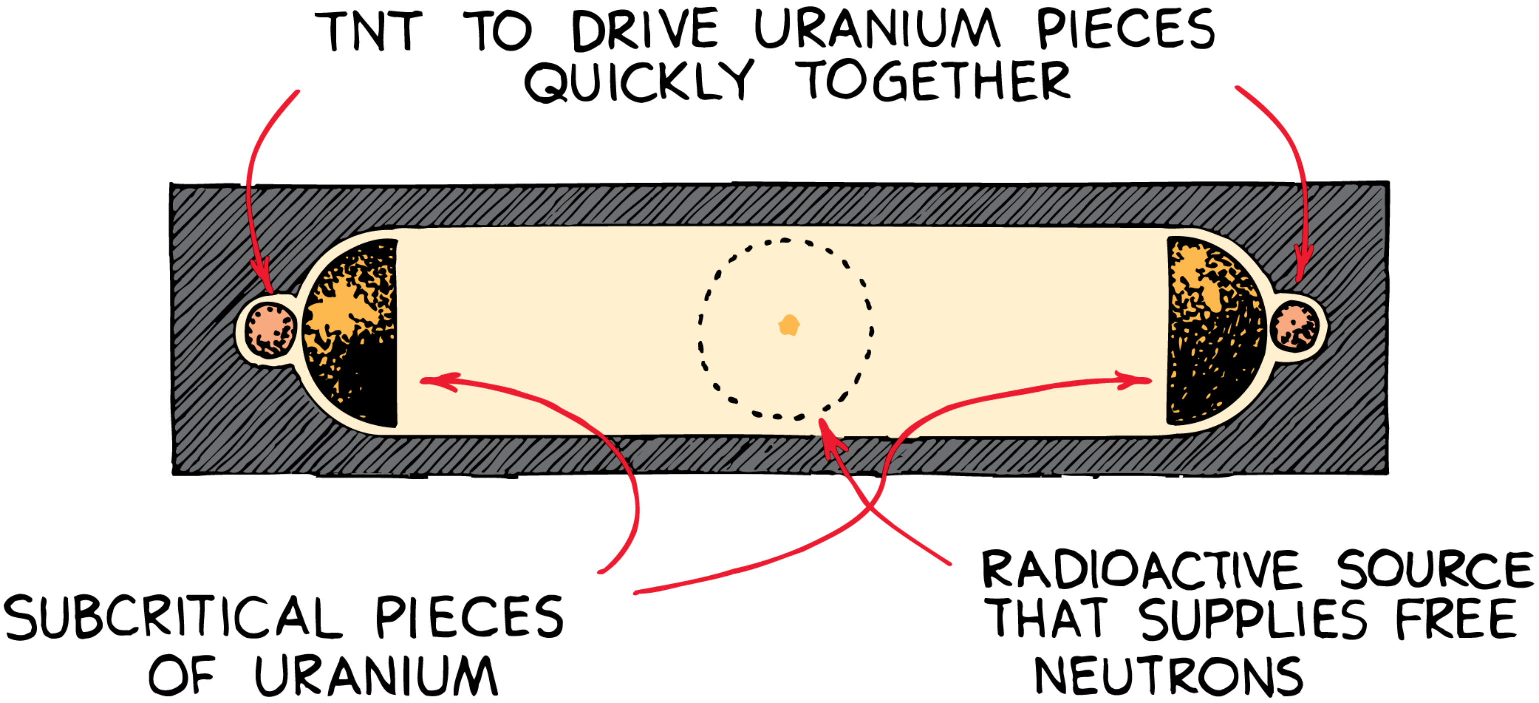
- **Breeder Reactors in Summary**
  - Fuel is U 238
  - Fission process is the same as the U 235 reactor
  - Breeder process
    - U 238 absorbs fast neutrons to become U 239
    - U 239 sometimes beta decays twice to form Pu 239 , which fissions
    - U 239 sometimes absorbs another neutron to become U 240
    - U 240 beta decays twice to form Pu 240 , which fissions
  - **Advantages of the breeder over a conventional reactor**
    - U 238 is most abundant isotope, ~99% of all uranium
    - Fuel needs much less processing
    - Virtually indefinite supply available
    - Fuel can be "mined" from oceans
  - **Disadvantages of the breeder reactor**
    - Pu 239 can be used in nuclear bomb
    - Pu is highly toxic and radioactive
    - Creates nuclear waste as does U 235 fission reactor

Courtesy National Archives,
photo no. 77-BT-187

The uranium bomb, 3m (10 ft) long and 0.7 m (2.3 ft) in diameter, was called “Little Boy.”

Nuclear Fission Bomb

A simplified diagram of a uranium fission bomb is shown here.



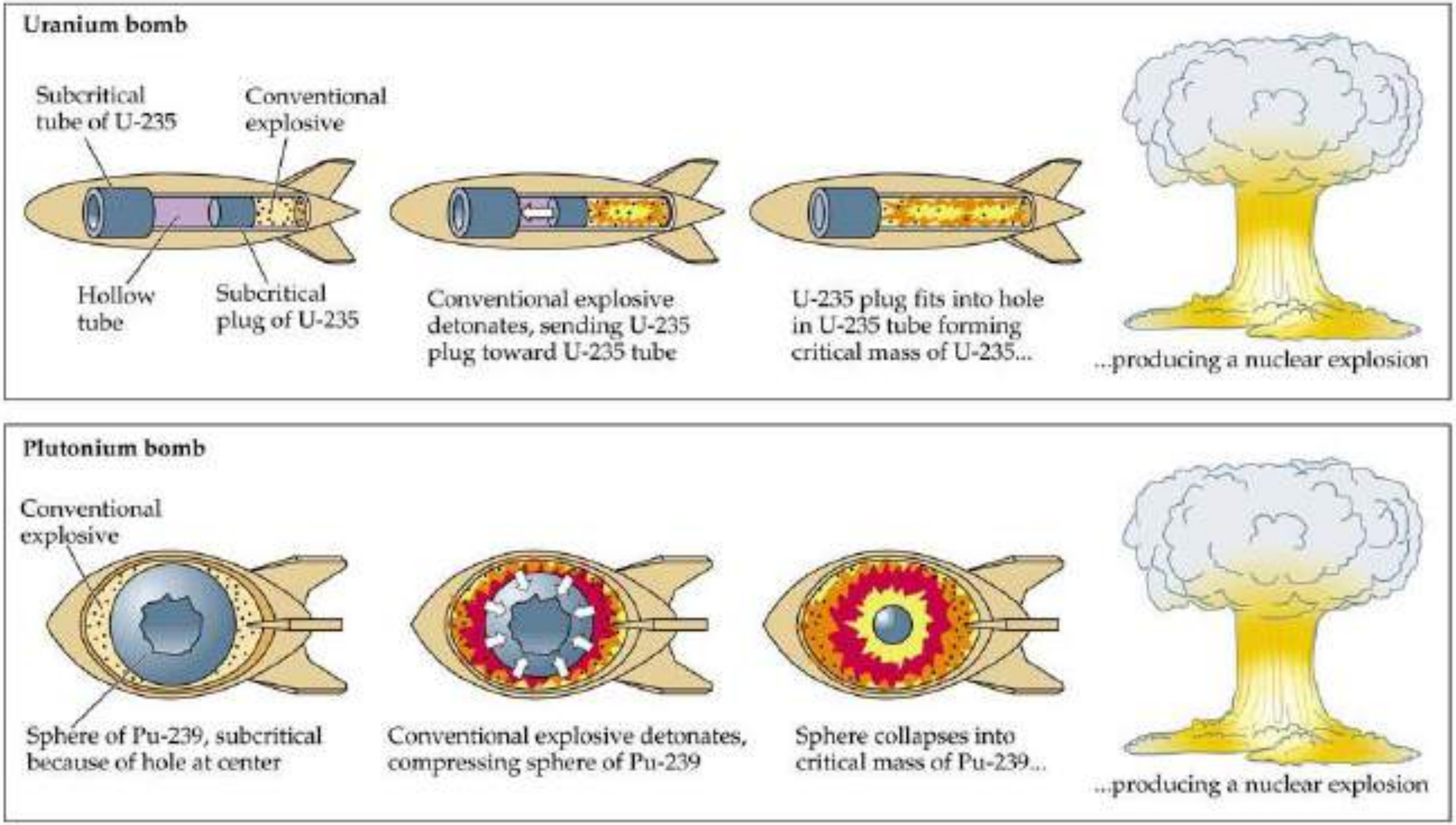
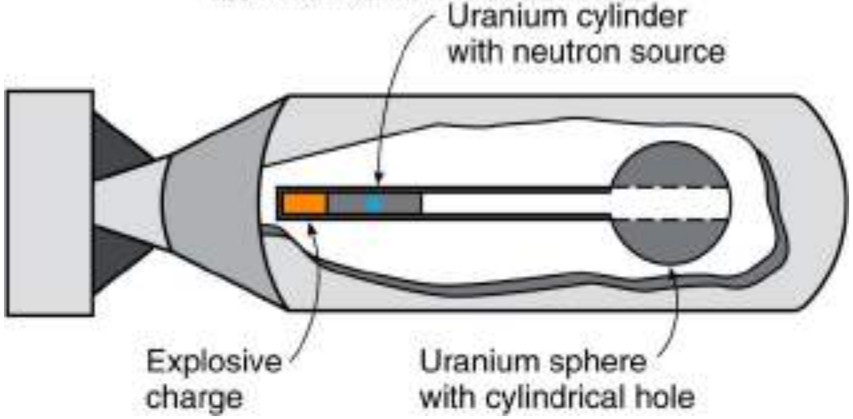
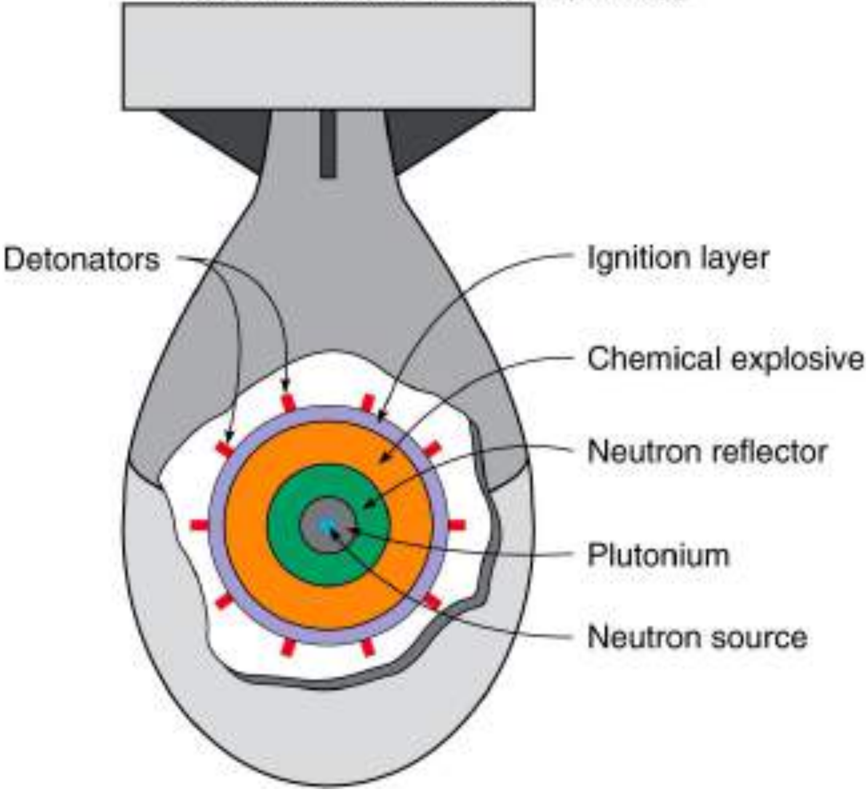
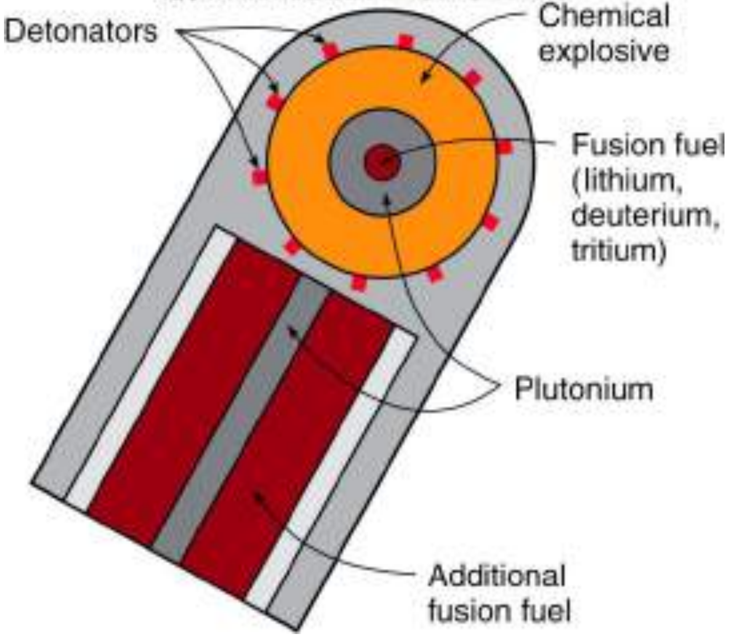


Figure 4.11: The operation of fission bombs.





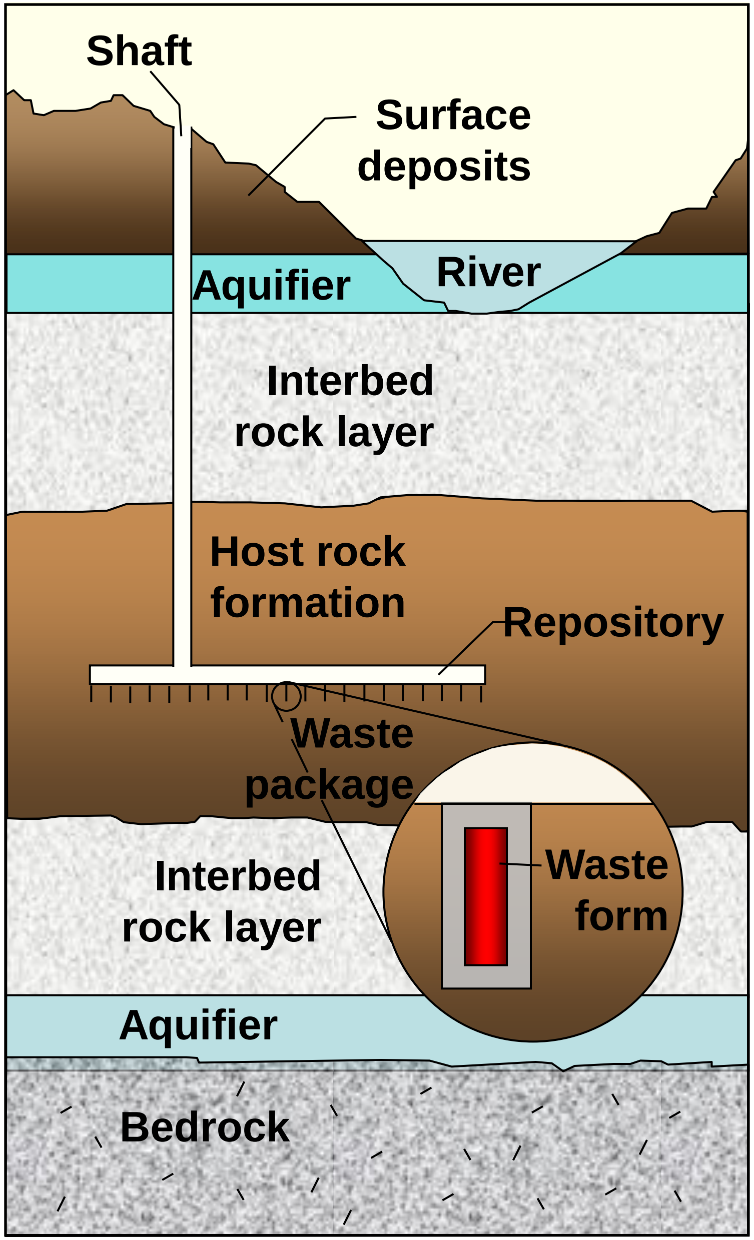


$$_1H^2 + {}_1H^3 \Rightarrow {}_2He^4{}_1 + {}_0n^1$$

Advantages and disadvantage of Nuclear Reactors

- **Advantages**
- **Unlike fossil fuels, nuclear fuels do not produce carbon dioxide or sulphur dioxide.**
- **1 kg of nuclear fuel produces millions of times more energy than 1 kg of coal.**
- **Disadvantages**
- **like fossil fuels, nuclear fuels are non-renewable energy resources**
- **if there is an accident, large amounts of radioactive material could be released into the environment. Although modern reactor designs are extremely safe.**
- **Nuclear waste remains radioactive and is hazardous to health for thousands of years. It must be stored safely.**

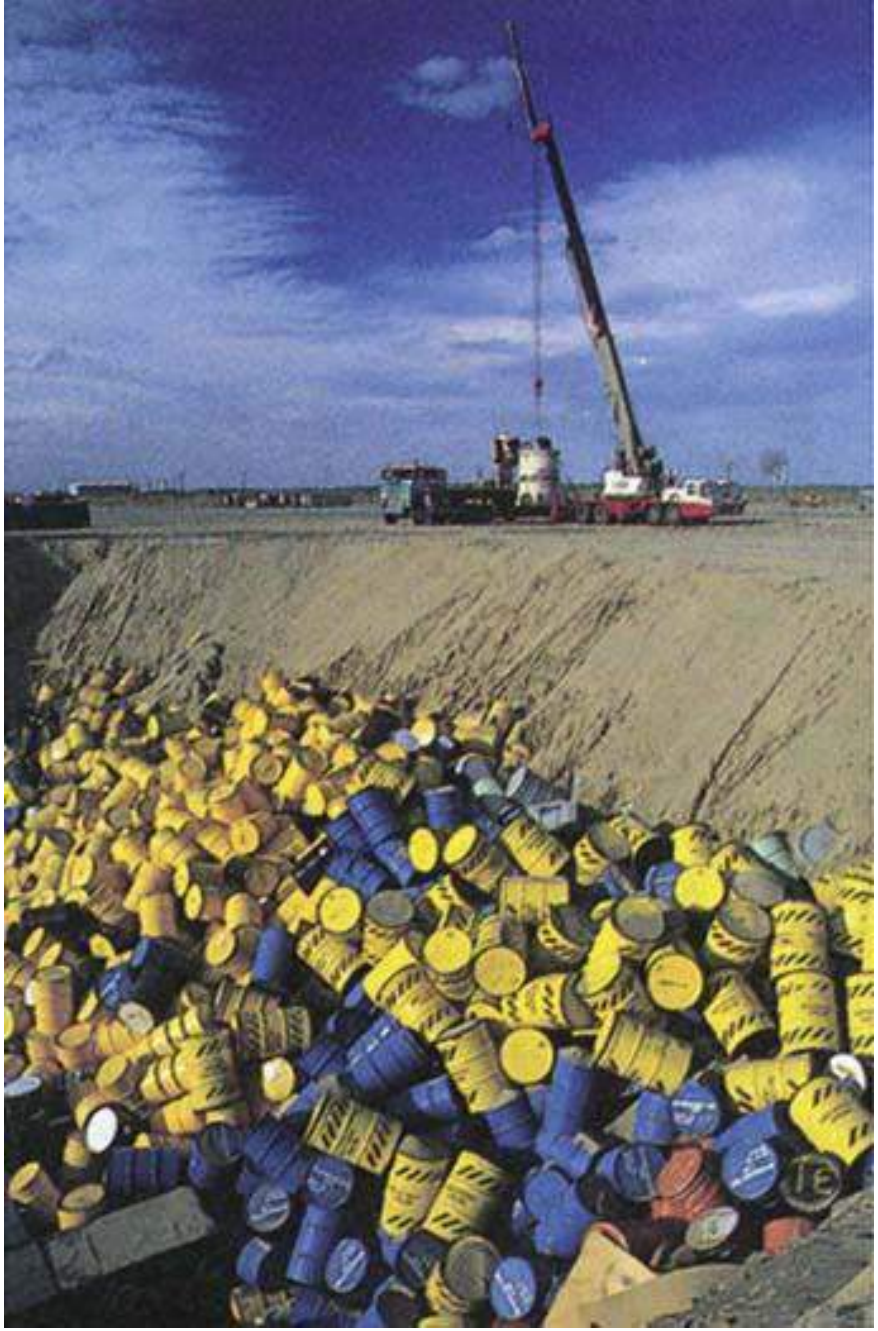
Nuclear Waste Disposal



Zumdahl, Zumdahl, DeCoste, World of Chemistry 2002, page 626

Courtesy Yucca Mountain Project

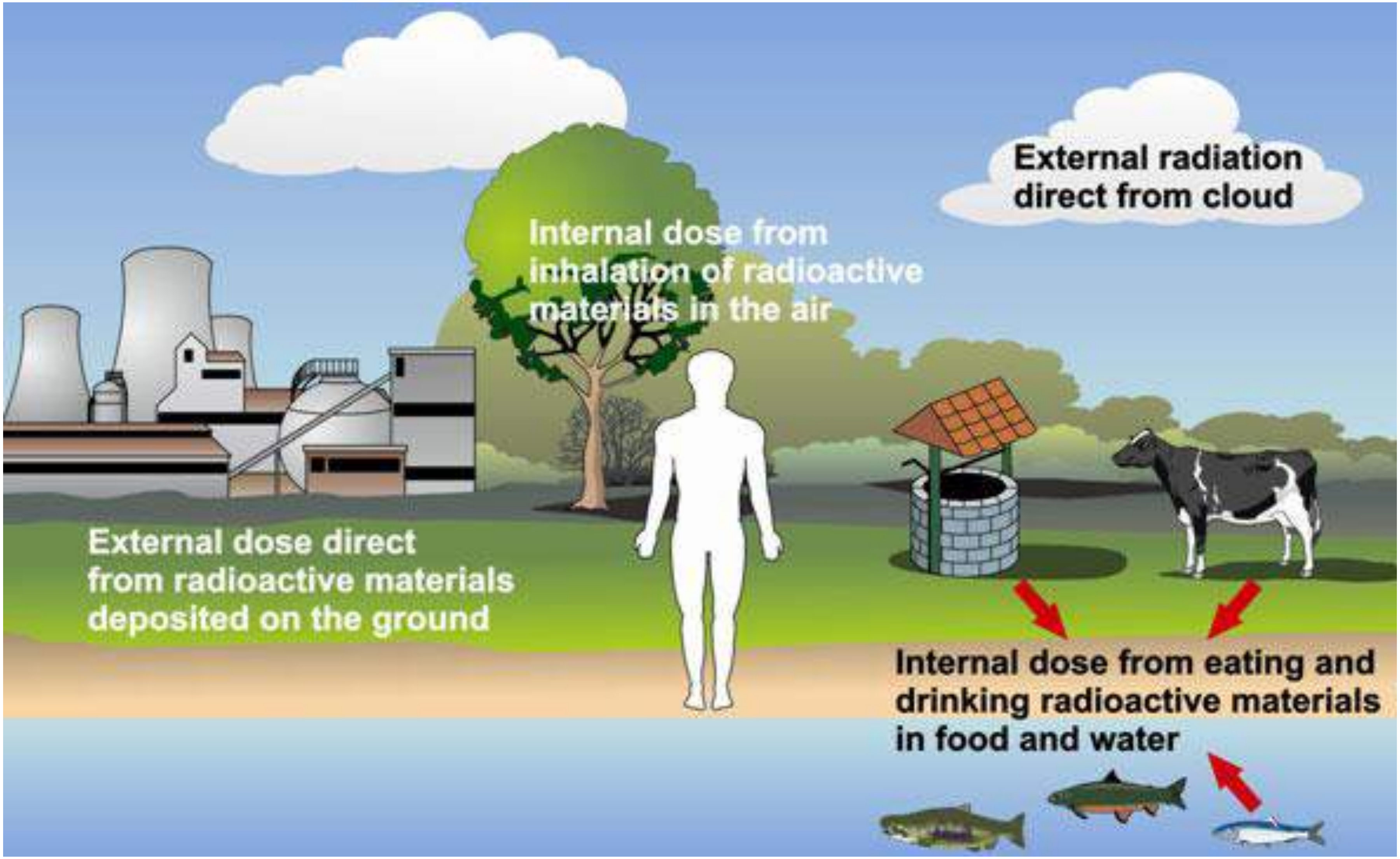
Construction of a tunnel that will be used for burial of radioactive wastes deep within Yucca Mountain, Nevada.



Courtesy Matthew Neal McVay/Stone/Getty Images

Disposal of radioactive wastes by burial in a shallow pit.

Pathways Of Exposure To Man From Release of Radioactive Materials



Applications For Nuclear Chemistry

- Medicine
  - Chemotherapy
  - Power pacemakers
  - Diagnostic tracers
- Agriculture
  - Irradiate food
  - Pesticide
- Energy
  - Fission
  - Fusion

Applications of Nuclear Chemistry

Medical Uses of Radioactivity

- In Vivo Procedures
  - **Determination of whole-blood volume using red blood cells labeled with chromium-51.**
- Therapeutic Procedures
  - **Irradiation of tumors using gamma rays emitted from cobalt-60.**
  - **Beta emission of iodine-131 to treat thyroid disease.**

Radionuclide in Medicine

- Radionuclides are used in imaging for diagnosis and treatment.
- In addition to PET, there are other nuclides specifically accumulated in organs for image and diagnoses.

- Radionuclide therapy selectively deliver radiation doses in target tissues.
- Radiopharmaceuticals - DNA, sugar, protein, and drug molecules, eg. ^{131}I or I-MIBG
- Radionuclide therapy still finds itself in a last position among other treatments.

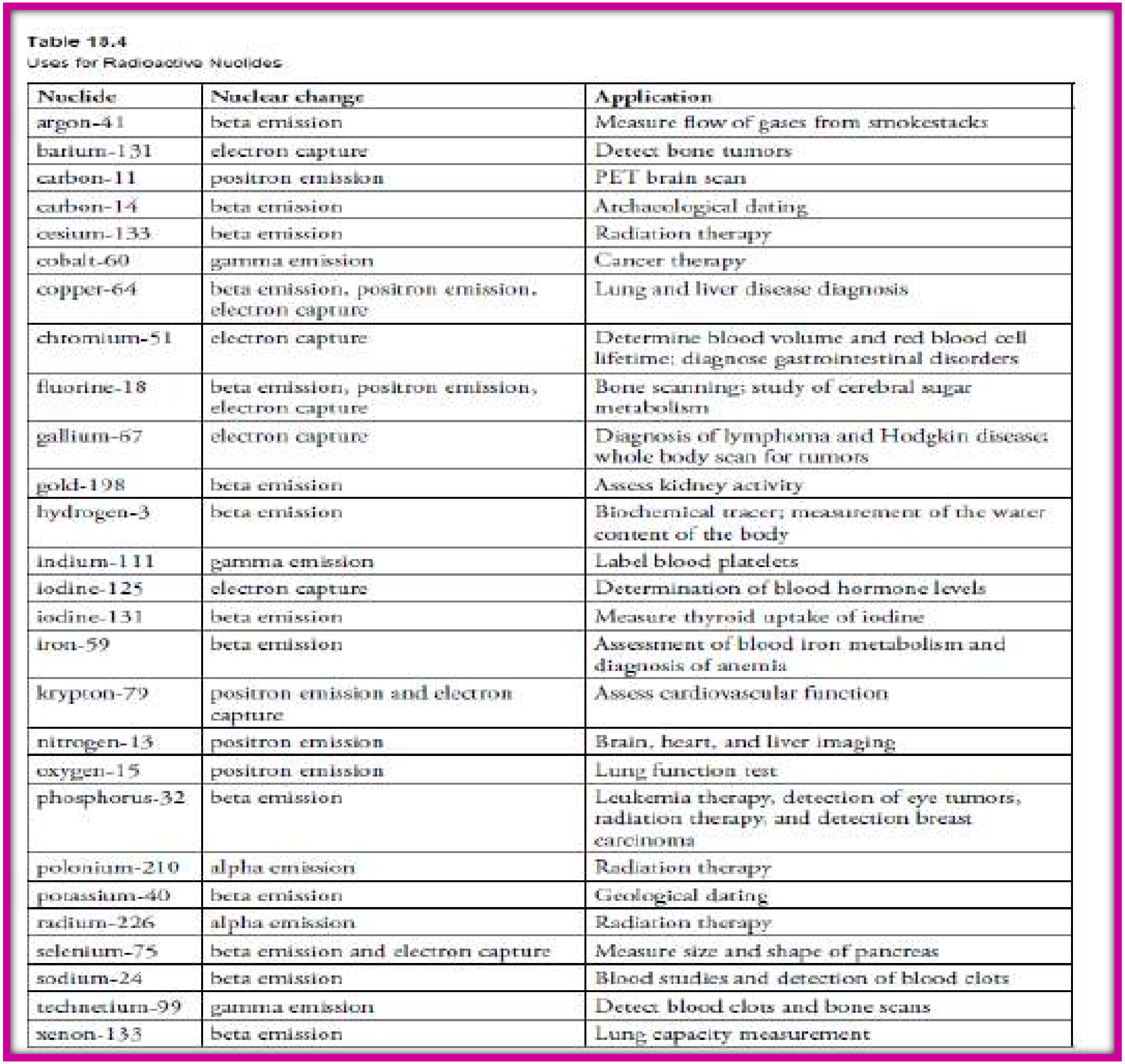


Table 18.4

Uses for Radioactive Nuclides

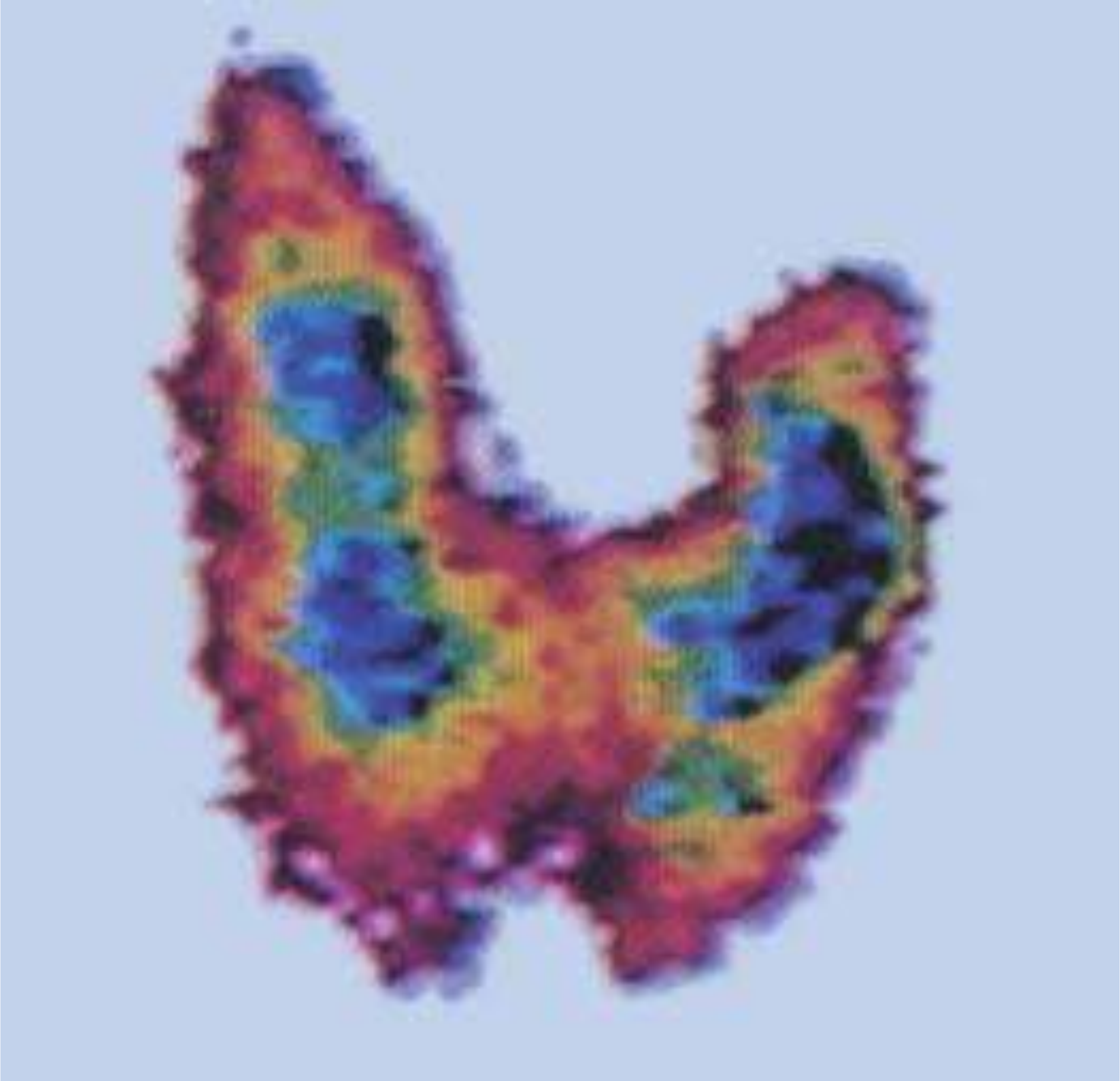
Nuclide	Nuclear change	Application
argon-41	beta emission	Measure flow of gases from smokestacks
barium-131	electron capture	Detect bone tumors
carbon-11	positron emission	PET brain scan
carbon-14	beta emission	Archaeological dating
cesium-133	beta emission	Radiation therapy
cobalt-60	gamma emission	Cancer therapy
copper-64	beta emission, positron emission, electron capture	Lung and liver disease diagnosis
chromium-51	electron capture	Determine blood volume and red blood cell lifetime; diagnose gastrointestinal disorders
fluorine-18	beta emission, positron emission, electron capture	Bone scanning; study of cerebral sugar metabolism
gallium-67	electron capture	Diagnosis of lymphoma and Hodgkin disease; whole body scan for tumors
gold-198	beta emission	Assess kidney activity
hydrogen-3	beta emission	Biochemical tracer; measurement of the water content of the body
indium-111	gamma emission	Label blood platelets
iodine-125	electron capture	Determination of blood hormone levels
iodine-131	beta emission	Measure thyroid uptake of iodine
iron-59	beta emission	Assessment of blood iron metabolism and diagnosis of anemia
krypton-79	positron emission and electron capture	Assess cardiovascular function
nitrogen-13	positron emission	Brain, heart, and liver imaging
oxygen-15	positron emission	Lung function test
phosphorus-32	beta emission	Leukemia therapy, detection of eye tumors, radiation therapy, and detection breast carcinoma
polonium-210	alpha emission	Radiation therapy
potassium-40	beta emission	Geological dating
radium-226	alpha emission	Radiation therapy
selenium-75	beta emission and electron capture	Measure size and shape of pancreas
sodium-24	beta emission	Blood studies and detection of blood clots
technetium-99	gamma emission	Detect blood clots and bone scans
xenon-133	beta emission	Lung capacity measurement

X-ray Imaging

Absorption of X-ray and gamma-ray by different material for image: today, 2-dimensional solid state detectors are used in place of films for X-ray and gamma-ray imaging as shown in this image by Varian

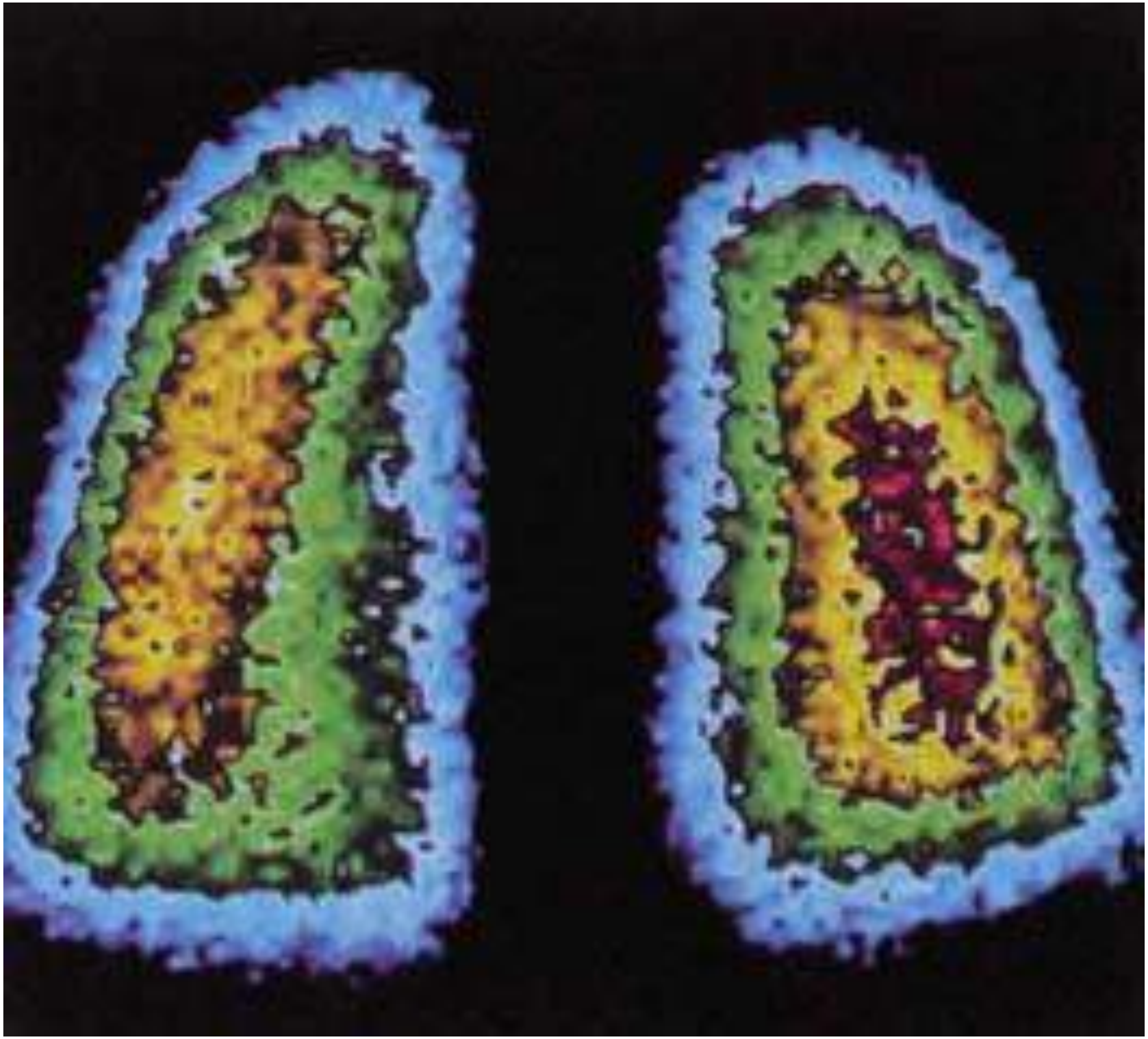
Mammography التصوير الاشعاعى للثدى and CT Scan الاشعة المقطعية

X-rays provide the sharpest images of the breast's inner structure. Mammogram detects small tumors and changes in the breast tissues.



Courtesy Custom
Medical Stock Photo

An image of a thyroid gland obtained through the use of radioactive iodine.



Courtesy
CNRI/Phototake

Images of human lungs obtained from a γ-ray scan.

Courtesy Kelley Culpepper/Transparencies, Inc.

A cancer patient receiving radiation therapy.

Irradiation Sterilization

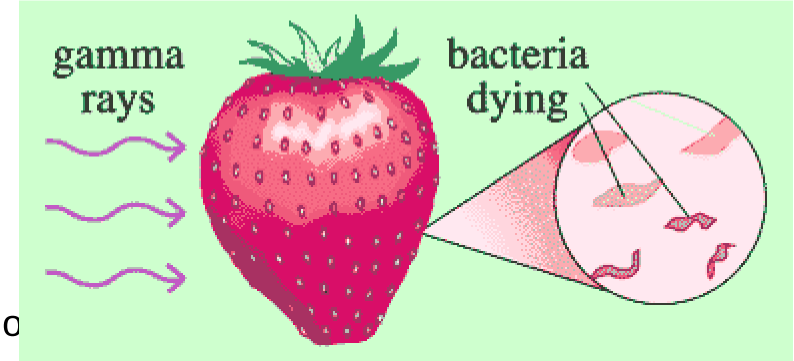
Irradiation by ionizing radiation kills bacteria and cells. This effect has been applied for the following areas:

sterilize medical equipment

sterilize consumer products such as baby bottle, pacifiers, hygiene products, hair brush, sewage

sterilize common home and industry products

food preservation



Irradiation for Food Processing

Soon after discovery, X-rays were used to kill insects and their eggs.

After WWII, spent fuel rod were used to sterilize food, but soon, ^{60}Co was found easier to use in th 1950s.

In 1958, USSR granted irradiation of potatoes for sprout inhibition. Canada granted irradiation of potatoes, onions, wheat, dry spices.

At 1980 meeting, a committee considered a dose of 10 kGy safe.

However, food processing has many other problems such as regulation, labelling, marketing and public acceptance to deal with.

Food Irradiation

- Food can be irradiated with γ rays from ^{60}Co or ^{137}Cs.
- Irradiated milk has a shelf life of 3 mo. without refrigeration.
- USDA has approved irradiation of meats and eggs.

Applications of Nuclear Chemistry

Dating with Radioisotopes

Radioactive carbon-14 is constantly being generated in the upper atmosphere by neutron bombardment:

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

Carbon-14 eventually enters the food chain via the formation of carbon dioxide and its uptake by plants via photosynthesis. Eating these plants distributes carbon-14 throughout all living organisms.

The half-life of carbon-14 is 5730 years:

$$_{6}C^{14} \rightarrow {}_{7}N^{14} + {}_{-1}e^{0}$$

The measured ratio of carbon-14/carbon-12 after death can determine how long ago the organism died.

Neutron Activation Analysis (NAA)

Neutron activation analysis is a multi-, major-, minor-, and trace-element analytical method for the accurate and precise determination of elemental concentrations in materials.

Sensitivity for certain elements are below nanogram level.

The method is based on the detection and measurement of characteristic gamma rays emitted from radioactive isotopes produced in the sample upon irradiation with neutrons.

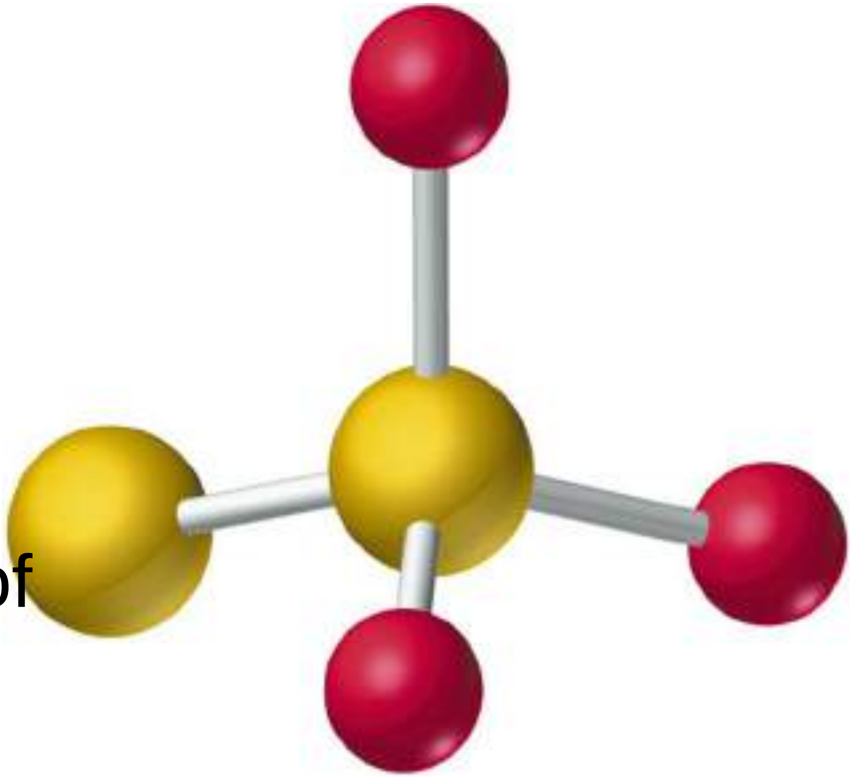
High resolution germanium semiconductor detector gives specific information about elements.

Radioactive Tracers

- Tag molecules or metals with radioactive tags and monitor the location of the radioactivity with time.
  - Feed plants radioactive phosphorus.
  - Incorporate radioactive atoms into catalysts in industry to monitor where the catalyst is lost to (and how to recover it or clean up the effluent).
  - Iodine tracers used to monitor thyroid activity.

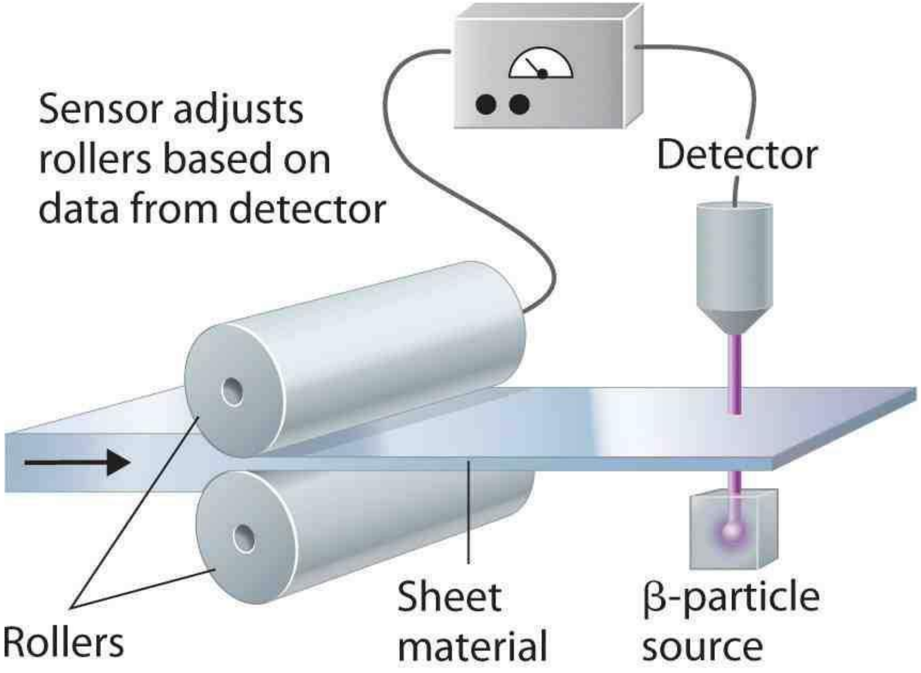
Structures and Mechanisms

- Radiolabeled (or even simply mass labeled) atoms can be incorporated into molecules.
- The exact location of those atoms can provide insight into the chemical mechanism of the reaction.



Uses of Radioactive isotopes in industry

- This process is used in common industrial applications such as:
  - the automobile industry–to test steel quality in the manufacture of cars and to obtain the proper thickness of tin and aluminum
  - the aircraft industry–to check for flaws in jet engines
  - construction–to gauge the density of road surfaces and subsurfaces
  - pipeline companies–to test the strength of welds
  - oil, gas, and mining companies–to map the contours of test wells and mine bores,
  - cable manufacturers–to check ski lift cables for cracks.
  - Measuring the thickness of materials in, for example, a Paper Mill


Sensor adjusts rollers based on data from detector
Detector
Rollers
Sheet material
β-particle source