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| **Al-Mustansiriyah University**  **College of Science**  **Physics Department** |  | **Fourth Grade**  **Radioactivity**  **Dr. Ali Abdulwahab Ridha** |

**Semester-2 (Radioactivity syllabus)**

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1. Laws of Radioactivity
2. Alpha Decay
3. Selection Rules for Beta Decay
4. Selection Rules for Gamma Decay

**Chapter Two (Nuclear Reactions)**

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2. Binary Nuclear Reactions
3. Conservation Laws
4. Stopping Power, Range and Cross Section

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2. Scintillation Detectors
3. Solid State Detectors
4. Dosimeters

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1. Classification of Accelerators
2. Types of Accelerators
3. Modern Accelerator

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| **Al-Mustansiriyah University**  **College of Science**  **Physics Department** |  | **Fourth Grade**  **Radioactivity**  **Dr. Ali Abdulwahab Ridha** |

**Chapter One**

**(Radioactivity)**

* 1. **Laws of Radioactivity**

Radioactive decay is the process in which an unstable nucleus spontaneously loses energy by emitting ionizing particles and radiation. This decay, or loss of energy, results in an atom of one type, called the parent nuclide, transforming to an atom of a different type, named the daughter nuclide. The three principal modes of decay are called the alpha, beta and gamma decays.

The radioactive decay is statistical in nature, and we can only describe the evolution of the expectation values of quantities of interest, for example the number of atoms that decay per unit time. If we observe a single unstable nucleus, we cannot know when it will decay to its daughter nuclide. The time at which the decay happens is random, thus at each instant we can have the parent nuclide with some probability p and the daughter with probability 1-p. This process can only be described in terms of the quantum mechanical evolution of the nucleus. However, if we look at an ensemble of nuclei, we can predict at each instant the average number of parent and daughter nuclides. If we call the number of radioactive nuclei N, the number of decaying atoms per unit time is dN/dt. It is found that this rate is constant in time and it is proportional to the number of nuclei themselves:



The constant of proportionality λ is called the decay constant = probability of a nucleus decaying per second. We can also rewrite the above equation as:



The fact that this probability is a constant is a characteristic of all radioactive decay. It also leads to the exponential law of radioactive decay:

N(t)= N(0)e−λt

N(0)=N(t=0)≡No , which is the number of nuclei at t=0 (the time of manufacture)

We can also define the mean lifetime:

τ =1/λ

and the half-lifetime:

t1/2 = ln (2)/λ = 0.693/λ

Which is the time it takes for half of the atoms to decay. And the activity is:

A(t)= |dN/dt|=λNoe−λt =λN(t)

A(t)=Aoe-λt

Where Ao is the activity at t=0 (the time of manufacture)

Units of activity: 1 Becquerel (Bq) = 1decay/second

1 Curie (Ci) = 3.7 x 1010 decays/sec (Bq) = Activity (1g of radium)

A common situation occurs when the daughter nuclide is also radioactive. Then we have a chain of radioactive decays, each governed by their decay laws. For example, in a chain N1→N2→N3, the decay of N1 and N2 is given by:

dN1 = −λ1N1dt, dN2 =+λ1N1dt − λ2N2dt

Another common characteristic of radioactive decays is that they are a way for unstable nuclei to reach a more energetically favorable (hence stable) configuration. In α and β decays, a nucleus emits a α or β particle, trying to approach the most stable nuclide, while in the γ decay an excited state decays toward the ground state without changing nuclear species.

For nuclei which decompose by two types, i.e. the emission of alpha particles and gamma rays together, the activity of source are:

-dN=dNα+dNγ , or N

Where λtot=λα+λγ , Atot=Aα+Aγ

And the ratio is called Branching Ratio.

The most important radioactivity equation are:

1. , where A(t) in Bq, λ in sec-1, N is number of nuclei
2. , where m in gm

Where A(t): Activity, λ: decay constant, t: time, N: number of nuclei, m: mass of nuclei, NA: Avogadro number, A: mass number, t1/2: half-life time, n: number of half-life time.

**(1-2) Alpha decay**

The decrease in binding energy at high mass number (A) is due to Coulomb repulsion. Coulomb repulsion grows in fact as Z2, much faster than the other nuclear force which is A. This could be thought as a similar process to what happens in the fission process: from a parent nuclide, two daughter nuclides are created. In the α-decay we have specifically:

where α is the nucleus of He-4 () as shown in figure below.

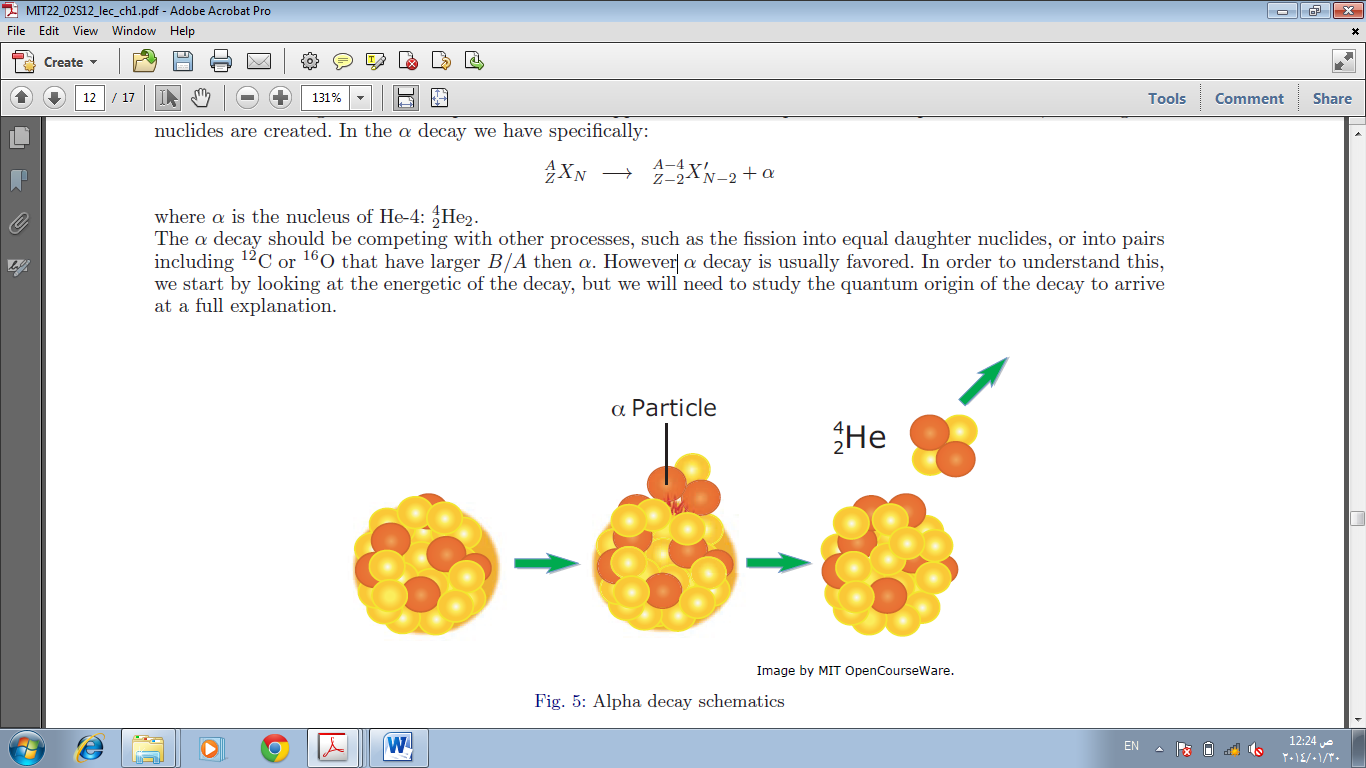


Figure (1-1): Alpha decay schematic.

**Energetics:**

In analyzing a radioactive decay (or any nuclear reaction) an important quantity is Q, the net energy released in the decay:

Qα=(mP−mD−mα)c2=931.5[m(A,Z)-m(A-4,Z-2)-mα]=-Sα

This is also equal to the total kinetic energy of the fragments, here Q=TD+Tα (here assuming that the parent nuclide is at rest). When Q>0 energy is release in the nuclear reaction, while for Q<0 we need to provide energy to make the reaction happen. As in chemistry, we expect the first reaction to be a spontaneous reaction, while the second one does not happen in nature without intervention. (The first reaction is exo-energetic the second endo-energetic). Q give the quality of the reaction, i.e. how energetically favorable, hence probable, it is. For example in the alpha-decay, , which is the Geiger-Nuttall rule (1928).

The alpha particle carries away most of the kinetic energy (since it is much lighter) and by measuring this kinetic energy experimentally it is possible to know the masses of unstable nuclides. We can calculate Q using the SEMF, Then:

Since we are looking at heavy nuclei, we know that Z≈0.41A (instead of Z≈A/2) and we obtain:

Where the second term comes from the surface contribution and the last term is the Coulomb term.

Then, the Coulomb term, although small, makes Q increase at large A. We find that Q ≥ 0 for A150, and it is Q ≈ 6MeV for A=200. Although Q>0, we find experimentally that α-decay only arise for A≥200. Further, take for example Francium-200(). If we calculate Qα from the experimentally found mass differences we obtain Qα≈7.6MeV (the product is 196At).

**Example:**

mU=238.050784u, mTh=234.043593u, mα=4.002602u

Qα=(mP-mD-mα)c2=(mU-mTh-mα)931.5=0.004589x931.5=4.275MeV

Note that:

1. Most of the energy (Q) is KE of α
2. Decay occurs if Q > 0 (energy released)
3. Spontaneous decay does not occur if Q < 0
4. Conservation of momentum (daughter + alpha) and Energy gives:

Q = KE(α)+ KE(daughter)

1. KE(α)=Q()

For 238U KE(α)=4.275x(234/238)=4.2MeV

**Energy spectrum of Alpha particle:**

Alpha particles have a linear spectrum of energy as shown in figure below:

Nα

Eα

Eαo

experimental

theoretical

Figure (1-2): spectrum of alpha particles.

We assumed that the parent nuclide is at rest i.e. PP=0

From the conservation law of linear momentum:

Pα=PD →mαvα=mDvD

T=1/2 mv2 = m2v2/2m=P2/2m



Pα=PD → 

This equation means that the two particles share of energy available to them by the inverse proportional with its masses.

Rewrite the last equation:







 are constant values, therefore Tα is a constant quantity, i.e. the alpha particles have the same energy and linear spectrum. By approximation the masses:





**H.W.:** Calculate Qα , Tα and TD for emission of alpha particle from Radium, Radon and Polonium, where the masses of 224Ra, 220Rn and 216Po are 224.020217u, 220.01140u and 216.001927u respectively, note that mα=4.002603u and m(212Pb)=211.991903u, then give your comment on the result.

**Range of alpha particle in materials:**

It is the distance which alpha particle moving in the material until loses all of its energy.



Where Eα in MeV, Rα in cm which is the range of alpha particle in air under pressure 76 cm.Hg at room temperature.



While R in any material of Z atomic number calculated from:



**(1-3) Beta decay**

The beta decay is a radioactive decay in which a proton in a nucleus is converted into a neutron (or vice-versa). Thus A is constant, but Z and N change by one. In the process the nucleus emits a beta particle (either an electron or a positron) and quasi-massless particle, the neutrino.

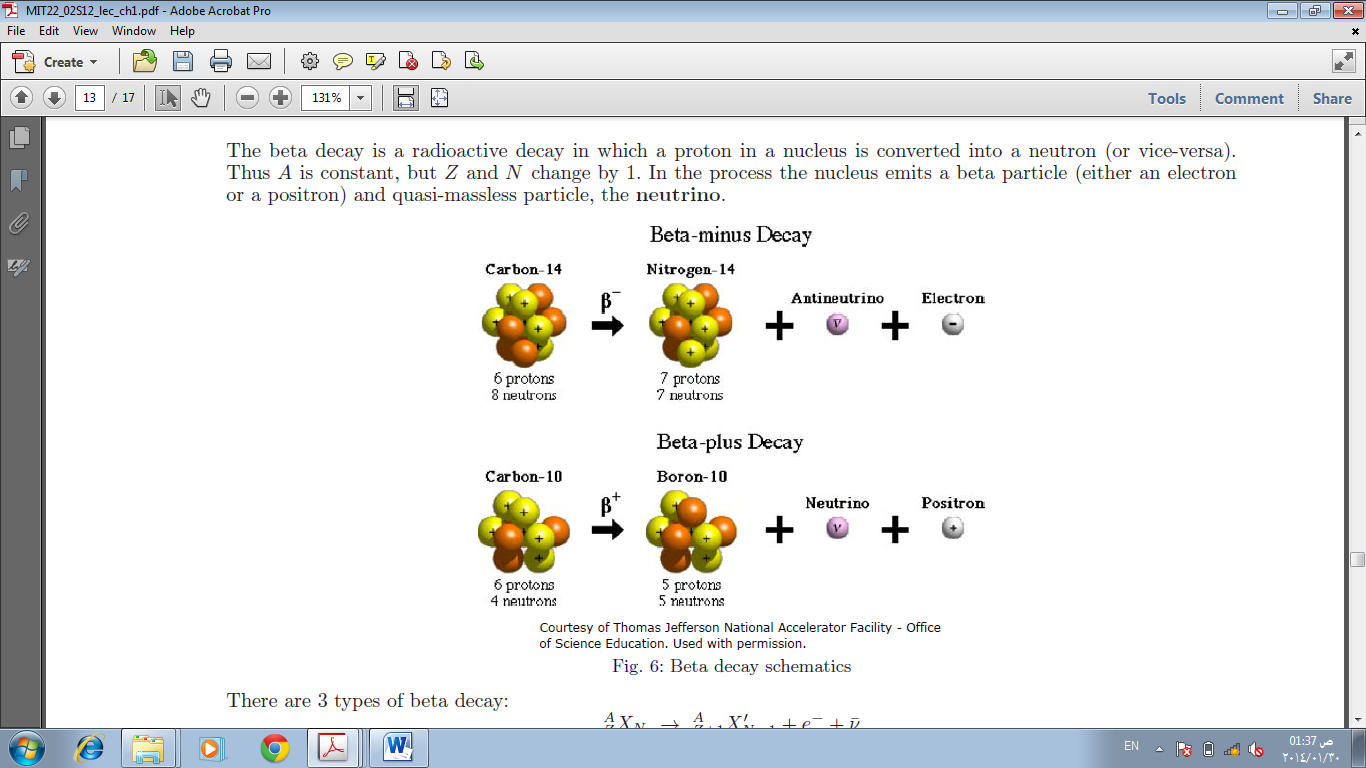


Figure (1-3): beta decay schematics.

There are 3 types of beta decay:

This is the β− decay (or negative beta decay). The underlying reaction is:

n → p + e- +

That corresponds to the conversion of a neutron to proton with the emission of an electron and an anti-neutrino. There are two other types of reactions, the β+ reaction is:

Which sees the emission of a positron (the electron anti-particle) and a neutrino, while the electron capture:

As the neutrino is hard to detect, initially the beta decay seemed to violate energy conservation. Introducing an extra particle in the process allows one to respect conservation of energy. The Q value of a beta-decay is given by the usual formula:

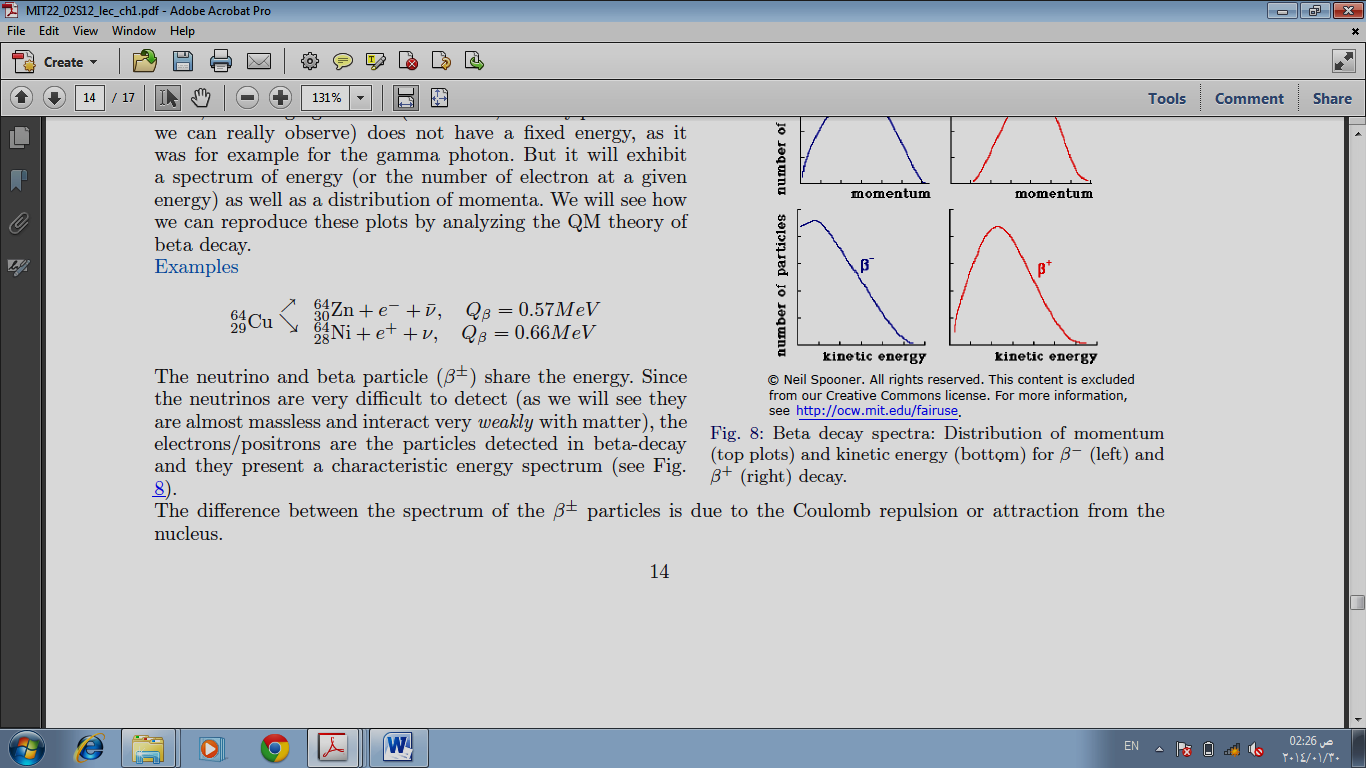
Using the atomic masses and neglecting the electron’s binding energies as usual we have:

i.e.

since TD ≈ 0

As the same method, we get the equations for β+ and electron capture as follows:

The kinetic energy (equal to the Q) is shared by the neutrino and the electron (we neglect any recoil of the massive nucleus). Then, the emerging electron (remember, the only particle that we can really observe) does not have a fixed energy, as it was for example for the alpha particle or gamma photon. But it will exhibit a spectrum of energy (or the number of electron at a given energy) as well as a distribution of momenta, for examples:



The neutrino and beta particle (β±) share the energy. Since the neutrinos are very difficult to detect (as we will see they are almost massless and interact very weakly with matter), the electrons/positrons are the particles detected in beta-decay and they present a characteristic continuous energy spectrum (see Fig. 5-4)

The difference between the spectrums of the β± particles is due to the Coulomb repulsion or attraction from the nucleus and the continuous spectrum of β decay is due to the random distribution of energy to β particle and neutrino as shown in figure below.

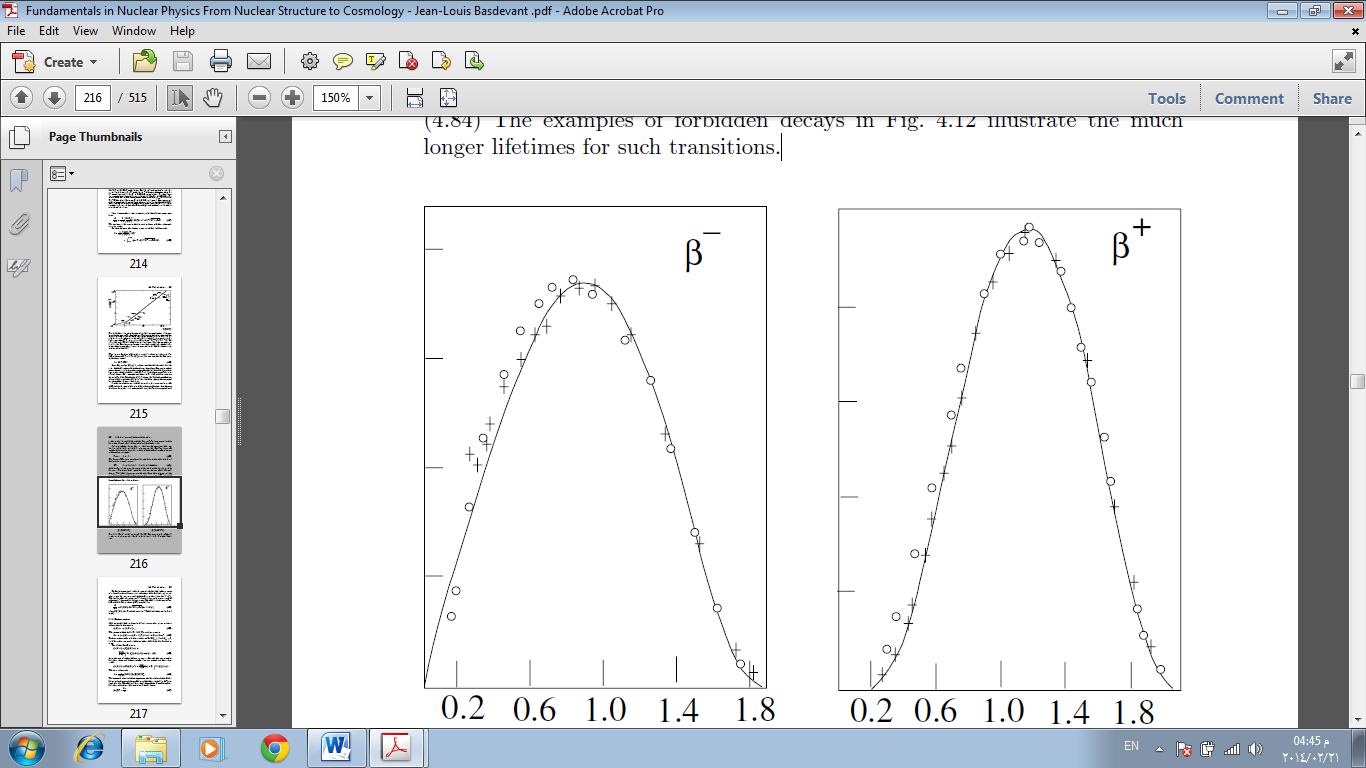


Figure (1-4): The β− and β+ spectra of 64Cu. The suppression of the β+ spectrum and enhancement of the β− at low energy due to the Coulomb effect is seen.

Notice that the neutrinos also carry away angular momentum. They are spin-1/2 particles, with no charge (hence the name) and very small mass. For many years it was actually believed to have zero mass. However it has been confirmed that it does have a mass in 1998. Other conserved quantities are:

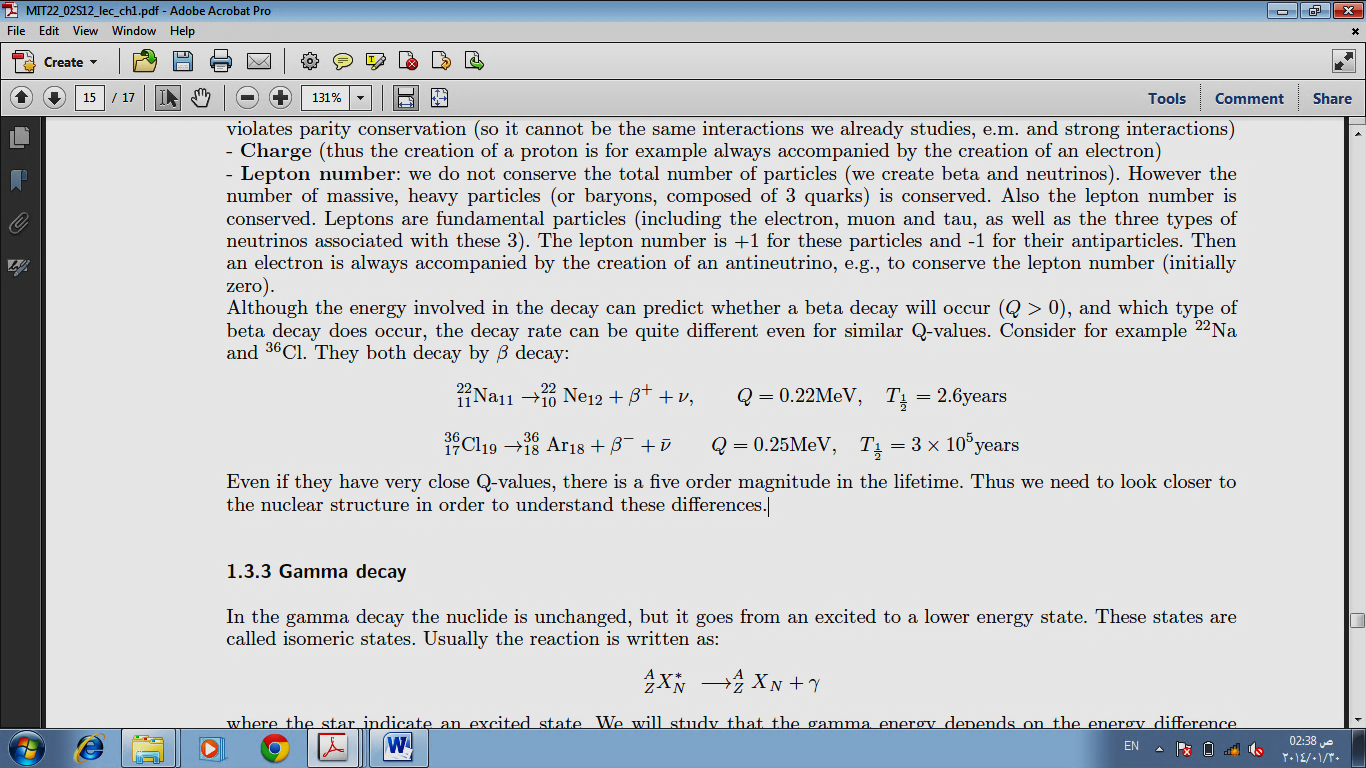
1-Momentum and Energy: The momentum and energy is also shared between the electron and the neutrino. Thus the observed electron momentum or energy ranges from zero to a maximum possible transfer.

2- Angular momentum: both the electron and the neutrino have spin 1/2.

3- Parity: It turns out that parity is not conserved in this decay. This hints to the fact that the interaction responsible violates parity conservation (so it cannot be the same interactions we already studies, electromagnetic and strong interactions).

Thus the neutrino hypothesis is required to satisfy the energy, linear and angular momentum conservation laws.

Consider for example 22Na and 36Cl. They both decay by β decay:



**Classification of beta decay:**

1. Charge: there is two type of beta particle; β-  and β+
2. Spin momentum (): there is two type as follow:
3. Fermi decay (F)

In this type of decay, the direction of spin momentum for beta particle is opposite to that for neutrino i.e.

1. Gammow-Teller decay (G.T.)

In this type of decay, the direction of spin momentum for beta particle is the same to that for neutrino i.e.

1. Orbital angular momentum :
2. If , the decay is called (allowed decay)
3. If , the decay is called (1st forbidden decay)
4. If , the decay is called (2nd forbidden decay)

Note that the 1st and 2nd forbidden decays, not means there are not happened, but the probability of their decay are very small due to the large values of which lead to increasing in half life time (t1/2) for the exited state, which making the decay in small probability.

**Selection rules for beta decay:**

1. momentum conservation:



Where 

And 

1. parity conservation:



**Example:** classify the following beta decays:

* the transition 2-→1+ , 2. the transition , 3. the transition 0+→0+

**Solution:**

1. for 2-→1+ : 
2. for : 

1. 

2. 

For the higher probability of decay, we must take the lowest value of Lβ to correspond to I value.

1.  1st forbidden F.D

 1st forbidden G.T decay

Therefore the beta decay for 2-→1+ transition is 1st forbidden F.D & G.T (mixed).

2.  allowed F.D

 allowed G.T

Therefore the beta decay for transition is allowed F.D & G.T (mixed).

1. If we have 0+→0+ transition, this decay is allowed fermi decay.





i.e. 0+→0+ transition, this decay is allowed fermi decay

**(1-4) Gamma decay**

In the gamma decay the nuclide is unchanged, but it goes from an excited to a lower energy state. These states are called isomeric states. Usually the reaction is written as:

Where the star indicates an excited state, we will study that the gamma energy depends on the energy difference between these two states, but which decays can happen depend, once again, on the details of the nuclear structure and on quantum-mechanical selection rules associated with the nuclear angular momentum.

Gamma ray spectroscopy is a basic tool of nuclear physics, for its ease of observation (since it’s not absorbed in air), accurate energy determination and information on the spin and parity of the excited states.

Qγ=[M\*(A,Z) - M(A,Z)]931.5= Ei –Ef=Eγ ,  Where TD=0

Since the gamma decay produces two types of particles, gamma ray (electromagnetic radiation or photons) and daughter nuclide, therefore the energy spectrum for gamma ray is linear spectrum as shown in the figure below.

Nγ

Eγ

Eαo

experimental

theoretical

Nmax

Nmax/2

Γ

Figure (1-5): spectrum of gamma ray.

The percentage ratio between the full width at half maximum (FWHM=Γ) and the gamma energy Eγ is called Energy Resolution (R). R=Γ/Eγ (%)

Ei , Ii , πi

Ef , If , πf

Eγ=ħω=Ei –Ef

πγ=πiπf

Lγ

Figure (1-6): Schematics of gamma decay.

**Nuclear multipole moments**

The nuclide has electric multipole moments due to its positive charge, non-spherical shape and the energy levels arrangement. The ranking of the electric moment is determined based on the orbital angular momentum value and is equal:

P=2L  (number of poles)

if L=1 → P=2 → 2 poles → electric dipole moments≡E1

if L=2 → P=4 → 4 poles → electric quadrupole moments≡E2

if L=3 → P=8 → 8 poles → electric octapole moments≡E3

And due to the vibration of the charges, there is an electromagnetic radiation emitting which called electric multipole radiation.

It also may happen that; rotation of the charges in closed paths (Loops) to make magnetic multipole moments and emitting an electromagnetic radiation which called magnetic multipole radiation.

if L=1 → P=2 → 2 poles → magnetic dipole moments≡M1

if L=2 → P=4 → 4 poles → magnetic quadrupole moments≡M2

if L=3 → P=8 → 8 poles → magnetic octapole moments≡M3

We must know that the probability of emitting the multipole radiation is as follow:

E1>M1>E2>M2>E3>M3…

**Selection rules for gamma decay:**

1. conservation of energy

Eγ =Ei –Ef

1. conservation of angular momentum

The angular momentum must be conserved during the decay. Thus the difference in angular momentum between the initial (excited) state and the final state is carried away by the photon emitted.



Where Sγ =1 for bosons (gamma ray)





Since Lγ ≠0 , because of, if Lγ=0 the number of polarities which is P=2L was equal 1, i.e. there is a one or a single pole and that is impossible, then there is no multipol momentum and no energy emitting.

ΔI=0,±1 and Ii=0→If=0 is forbidden to gamma decay

1. conservation of parity

The parity of the gamma photon is determined by its character, either magnetic or electric multipole, we have:

πi. πf=(−1)L for Electric multipole

πi. πf=(−1)L+1 for Magnetic multipole

This of course limits the type of multipole transitions that are allowed given an initial and final state, the character (magnetic or electric) of the multipole is found by looking at the parity. In general then, the most important transition will be the one with the lowest allowed L. Higher multipole are also possible, but they are going to lead to much slower processes.

For example: 4+---2+

Sol. Lγ=|4-2| --- |4+2| = 2,3,4,5,6

πi. πf= + .+ = +

For Lγ=2 (-1)2 = + E2

For Lγ=3 (-1)3+1 = + M3

For Lγ=4 (-1)4 = + E4

For Lγ=5 (-1)5+1 = + M5

For Lγ=6 (-1)6 = + E6

Table (1-1): Angular momentum and parity of the gamma multipole.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Multipolarity | Angular  Momentum L | Parity  π | Multipolarity | Angular  Momentum L | Parity  π |
| M1  M2  M3  M4  M5 | 1  2  3  4  5 | +  -  +  -  + | E1  E2  E3  E4  E5 | 1  2  3  4  5 | -  +  -  +  - |

**Dominant Decay Modes**

In general we have the following predictions of which transitions will happen:

1. The lowest permitted multipole dominates

2. Electric multipole is more probable than the same magnetic multipole by a factor ≈102 (however, which one is going to happen depends on the parity)

3. Emission from the multipole L+1 is 10-5 times less probable than the L multipole emission.

4. Combining 2 and 3, we have:

Thus E2 competes with M1 while that’s not the case for M2 vs. E1

**Attenuation or absorption of gamma ray**

When the gamma rays fall on a substance and transmitted, the intensity will be reduced according to the equation:

I=Ioe-μx

Where x is a thickness and μ is a linear absorption coefficient of the substance.

Note that the thickness of any substance which reduces the intensity to the half of its value was called a half thickness x1/2.

x1/2=0.693/λ

**Branching Ratios**

Some nuclei only decay via a single process, but sometimes they can undergo many different radioactive processes, that compete one with the other. The relative intensities of the competing decays are called branching ratios. Branching ratios are expressed as percentage or sometimes as partial half-lives. For example, if a nucleus can decay by beta decay (and other modes) with a branching ration bβ, the partial half-life for the beta decay is λβ = bβλ.

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**Chapter Two**

**(Nuclear Reactions)**

**(2-1) Introduction**

A large fraction of our knowledge on the properties of nuclei is derived from nuclear reactions. When an incoming particle is scattered off a target nucleus, the outcome depends on a combination of three factors: the reaction mechanism, interaction between the projectile and the target, and the internal structure of the nuclei involved. There are two main categories of nuclear reactions. In the first category, the initial reactant X is a single atom or nucleus that spontaneously changes by emitting one or more particles, i.e.

X→b+Y

Such a reaction is called radioactive decay. As we have seen from the Chart of the Nuclides, the vast majority of known nuclides are radioactive.

In the second broad category of nuclear reactions are binary reactions in which two nuclear particles (nucleons, nuclei or photons) interact to form different nuclear particles.

For bombarding energies below 100 MeV, nuclear reactions usually produce two products, i.e. they are of the type

a+X→b+Y

Where a = bombarding particle

X = target (at rest in the lab. system)

b = light reaction product

Y = heavy reaction product

To shorten the notation a reaction of the type above is designated by:

X(a,b)Y

Commonly, one reaction product is light and the other heavy because of the binding energies of the nuclei involved. In some cases b and Y have comparable masses (spallation reaction or fission), or are identical. If b is a gamma ray, we speak of a capture reaction in which Y is the compound nucleus.

In most cases in which more than two products appear, it is possible to describe the process as a rapid sequence of two-product reactions

a+X→b1+Y1

Y1→b2+Y2

Y2→b3+Y3

For example, see the reaction: 4He + 14N → 1H + 17O

Note that the number of neutrons and protons is conserved. Presently the number of known reactions is in the thousands.

There are two frames to classify the nuclear reactions, consider an elastic collision with a nucleus of mass M. In the lab frame, the nucleus is initially at rest and the particle has energy Eo and momentum mvo. After the scattering, energy of the particle is E1, speed v1 at an angle ϕ with vo, while the nucleus recoil gives a momentum MV at an angle ψ.

The collision is better analyzed in the center of mass frame, where the condition of elastic scattering implies that the relative velocities only change their direction but not their magnitude. The center of mass velocity is defined as

Relative velocities in the center of mass frame are defined as

where we defined ϑ as the scattering angle in the center of mass frame, see the figures below:

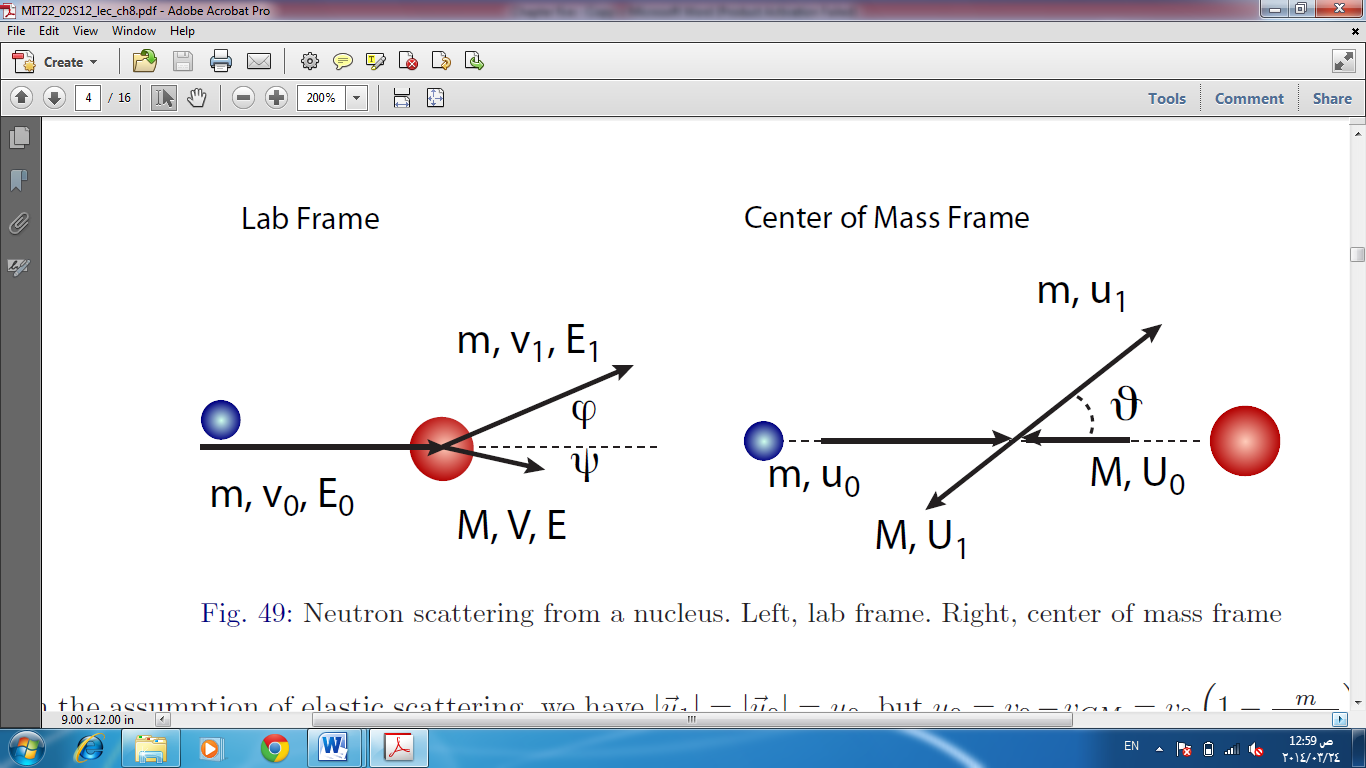


Figure (2-1): Neutron scattering from a nucleus. In left, laboratory frame, in right, center of mass frame.

**(2-2) Types of Nuclear Reactions**

Depending on the circumstances, it is convenient to classify nuclear reactions by the type of bombarding particle, bombarding energy, target, or reaction product. In the first case we distinguish:

* + - 1. Heavy charged-particle reactions: produced by p, D, T and α
      2. Heavy-ion reactions: produced by 12C, 16O ...
      3. Neutron reactions: produced by n
      4. Photonuclear reactions: produced by gamma rays
      5. Light charged particle: electron or positron reactions

If the bombarding energy is specified we speak informally of

Thermal energies ≈ 0.025 eV

Epithermal energies ≈ 1 eV

Slow-neutron energies ≈ 1 KeV

Fast-neutron energies ≈ 0.1 → 10 MeV

Low-energy charged particles ≈ 0.1 → 10 MeV

High energies ≈ 10 → 100 MeV

Targets are often called

Light nuclei, if A ≤ 40

Medium-weight nuclei, if 40 < A < 150

Heavy nuclei, if A ≥ 150

If the light reaction product is identical to the incident particle and has identical energy (in the c.m. system), the reaction is called elastic scattering. If only the energy is different, inelastic scattering occurs. If only gamma rays are emitted, we speak of a capture reaction. If the product nuclei have comparable masses, the reaction is called spallation or fission.

As an illustration, we give the following examples in the shorthand notation

* 14N(p,p)14N elastic scattering
* 14N(p,p)14N\* inelastic scattering
* 14N(p,α)11C or 11C\* heavy charged particle reaction
* 14N(p,γ)15O or 15O\*  capture reaction
* 14N(γ,p)13C or 13C\* photonuclear reaction
* 14N(n,6Li)9Be or 9Be\* spallation reaction
* 9Be(6Li,n)14N or 14N\* heavy-ion reaction
* 235U(n,2n)140Cs,93Rb fission
* 16O(n,p)16N\* neutron reaction
* 2H(D,p)3H fusion

**(2-3) Binary Nuclear Reactions**

For every nuclear reaction, we can write a reaction equation. These reaction equations must be balanced, just as chemical reactions must be. Charge (the number of protons) and mass number (the number of nucleons) must be conserved. The number of protons and the number of neutrons must be the same before and after the reaction. We shall illustrate this with some examples of typical nuclear reactions.

1. (α,p) reaction: The first nuclear reaction was reported by Rutherford. He bombarded nitrogen in air with alpha particles (helium nuclei) and observed the production of protons (hydrogen nuclei),

14N + 4He → 17O + 1H or 14N(α,p)17O

The product of this reaction is 17O and there are nine protons and nine neutrons on both sides of the equation, so the equation is balanced.

1. (α,n) reaction: In 1932, Chadwick discovered the neutron by bombarding beryllium with alpha particles to produce neutrons from the reaction

4He + 5Be → 8C + n or 5Be(α,n)8C.

1. (γ,n) reaction: Energetic photons (gamma rays) can also interact with a nucleus. For example neutrons can be produced by irradiating deuterium with sufficiently energetic photons according to the reaction

2H + γ → 1H + n or 2H(γ,n)1H

1. (p,γ) reaction: Protons can cause nuclear reactions such as the radiative capture of a proton by 7Li, namely

7Li + 1H → 8Be + γ or 7Li(p,γ)8Be\*

The product nucleus 8Be is not bound and breaks up (radioactively decays) almost immediately into two alpha particles.

1. (γ,αn) reaction: As an example of a reaction in which more than two products are produced, a high-energy photon can cause 17O to split into 12C, an α particle and a neutron through the reaction

17O + γ → 12C + α + n

1. (n,p) reaction: Fast neutrons can cause a variety of nuclear reactions. For example, in a reactor core, fast neutrons can interact with 16O to produce 16N, which radioactively decays (half-life of 7.12s) with the emission of a 6.13MeV (69%) or a 7.11MeV (5%) photon. The radionuclide 16N is produced by the reaction

16O + n → 16N + 1H or 16O(n,p)16N\*.

1. Proton-Proton Cycle

i.e. the result of three interactions: , Q=24.7MeV

1. Carbon-Nitrogen Cycle

By reduce the Carbon and Nitrogen, Which worked as catalysts we get:

, Q=26.7MeV

1. Fusion (Deuterium-Deuterium and Deuterium-Tritium interactions)
2. Fission

**(2-4) Conservation laws**

These may be listed as follows.

(i) Conservation of linear momentum,

(ii) Conservation of total angular momentum i.e.

Where denote the angular momenta in the initial and final nuclei and denote the relative angular momenta in the entrance (X,a) and final (Y,b) channels.

(iii) Conservation of proton (charge) and neutron number is not a strict conservation law. Under general conditions, one has conservation of charge and conservation of nucleon or baryon (strongly interacting particles) number.

(iv) Conservation of parity, π, such that

Where the parities of the initial and final nuclei and projectiles (incoming, outgoing) are considered.

(v) Conservation of total energy, which becomes

With T the kinetic energy and m.c2 the mass energy, in the non-relativistic situation, the kinetic energy . One defines the Q-value of a given reaction as

which can be rewritten using the kinetic energies as:

**(2-5) Stopping Power, Range & Cross Section**

1. ***Stopping power***: A more important quantity is the average energy loss of the particle per unit path length, which is called the stopping power.
2. ***Range:*** The range is more precisely defined as the distance a particle travels before coming to rest.

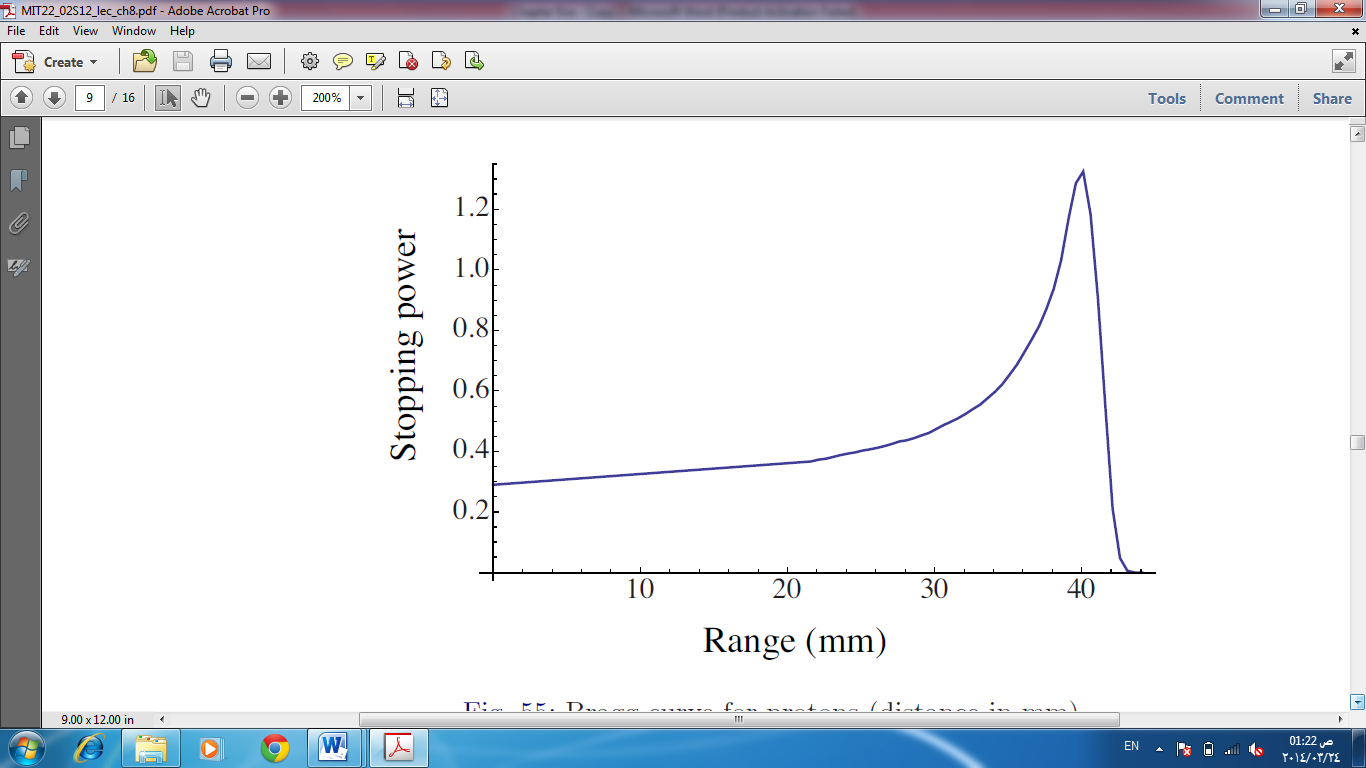


Figure (2-2): Bragg curve for protons (distance in mm)

1. ***Cross Section***:

Classically, the cross section is the area on which a colliding projectile can impact. Thus for example the cross section of a spherical target of radius r is just given by πr2. The cross section has then units of an area. Let’s consider for example a nucleus with mass number A. The radius of the nucleus is then R=RoA1/3=1.2A1/3fm and the classical cross section would be σ = πRo2A2/3 ≈ 5A2/3fm2. For a typical heavy nucleus, such as gold, A = 197, we have σ ≈ 100fm2=1barn (symbol b, 1b = 10−28m2= 10−24cm2= 100fm2. When scattering a particle off a target however, what becomes important is not the head-on collision (as between balls) but the interaction between the particle and the target (e.g. Coulomb, nuclear interaction, weak interaction etc.). For macroscopic objects the details of these interactions are lumped together and hidden. For single particles this is not the case, and for example we can as well have a collision even if the distance between projectile and target is larger than the target radius. Thus the cross section takes on a different meaning and it is now defined as the effective area or more precisely as a measure of the probability of a collision. Even in the classical analogy, it is easy to see why the cross section has this statistical meaning, since in a collision there is a certain (probabilistic) distribution of the impact distance. The cross section also describes the probability of a given (nuclear) reaction to occur, are action that can be generally written as:

a+X→Y+b or X(a,b)Y

where X is an heavy target and (a) a small projectile (such as a neutron, proton, alpha...) while Y and b are the reaction products (again with b being nucleons or light nucleus, or in some cases a gamma ray). Then let Ia be the current of incoming particles, hitting on an heavy (hence stationary) target. The heavy product Y will also be almost stationary and only (b) will escape the material and be measured. Thus we will observe the (b) products arriving at a detector at a rate Rb. If there are (n) target nuclei per unit area, the cross section can then be written as:

This quantity does not always agree with the estimated cross section based on the nucleus radius. For example, proton scattering x-section can be higher than neutrons, because of the Coulomb interaction. Neutrinos x-section then will be even smaller, because they only interact via the weak interaction.

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| **Al-Mustansiriyah University**  **College of Science**  **Physics Department** |  | **Fourth Grade**  **Radioactivity**  **Dr. Ali Abdulwahab Ridha** |

**Chapter Three**

**(Nuclear Detectors)**

Ionizing radiation is rarely detected directly. Instead, detectors usually measure the secondary products arising from the interactions of the radiation with the detector material. For example, as an alpha or beta particle traverses a detector's sensitive volume, electron-ion pairs or electron-hole pairs are created and the subsequent movement and collection of charges gives rise to an electrical pulse or current. Indirectly ionizing radiation such as gamma photons and neutrons must first undergo interactions in the detector material that produce secondary charged particles, recoil atoms or electrons that, in turn, produce charge pairs as they slow down.

The collection of the ionization created by radiation in a detector volume can be used simply to detect the passage of a radiation particle. The rate of generation of radiation-induced pulses can then be used to measure the rate at which radiation particles traverse the detector. Such detectors are termed radiation counters. In some detectors, the magnitude of the radiation induced pulse is related to the type of radiation particle and its energy. By measuring both the number of pulses and the distribution of pulse sizes produced by a given type of radiation, both the number and energy distribution of the incident radiation can be determined. These detectors can then be used as energy spectrometers. In some detectors the average current can be used as a measure of the amount of ionization or energy deposition, per unit mass of detector material, caused by incident radiation. These detectors can then be calibrated to measure radiation absorbed doses and are thus called dosimeters. In this chapter, the properties of some of the most common radiation detectors are reviewed.

An important aspect of radiation detection is an assessment of the uncertainties associated with ionization measurements. Both the release of radiation by radioactive decay and the interactions of radiation with matter are stochastic in nature. Thus, repeated measurements of radiation emitted by a source of constant activity, in a given detector volume in a given time interval, exhibit random statistical fluctuations. The quantification of such statistical fluctuations is a necessity in radiation measurements.

**(3-1) Gas-Filled Radiation Detectors**

The idea of measuring the radiation induced ionization in a gas volume dates to the nineteenth-century. These early gas-filled detectors became known as ionization chambers. As ionizing radiation passes through a chamber, the motion within an electric field of the ion pairs formed inside the chamber produces an electrical current. The magnitude of the current is measured and correlated (calibrated) to the intensity of the radiation field. A very common geometry is a coaxial detector that consists of a thin, positively charged, center wire anode (held in place by insulators) surrounded by an outer, negatively-charged, cathode tube. The outer tube contains the gas and defines the active volume of the chamber. Air filled chambers may or may not be sealed from the ambient environment. A gas-filled chamber is illustrated in Fig. (3-1).

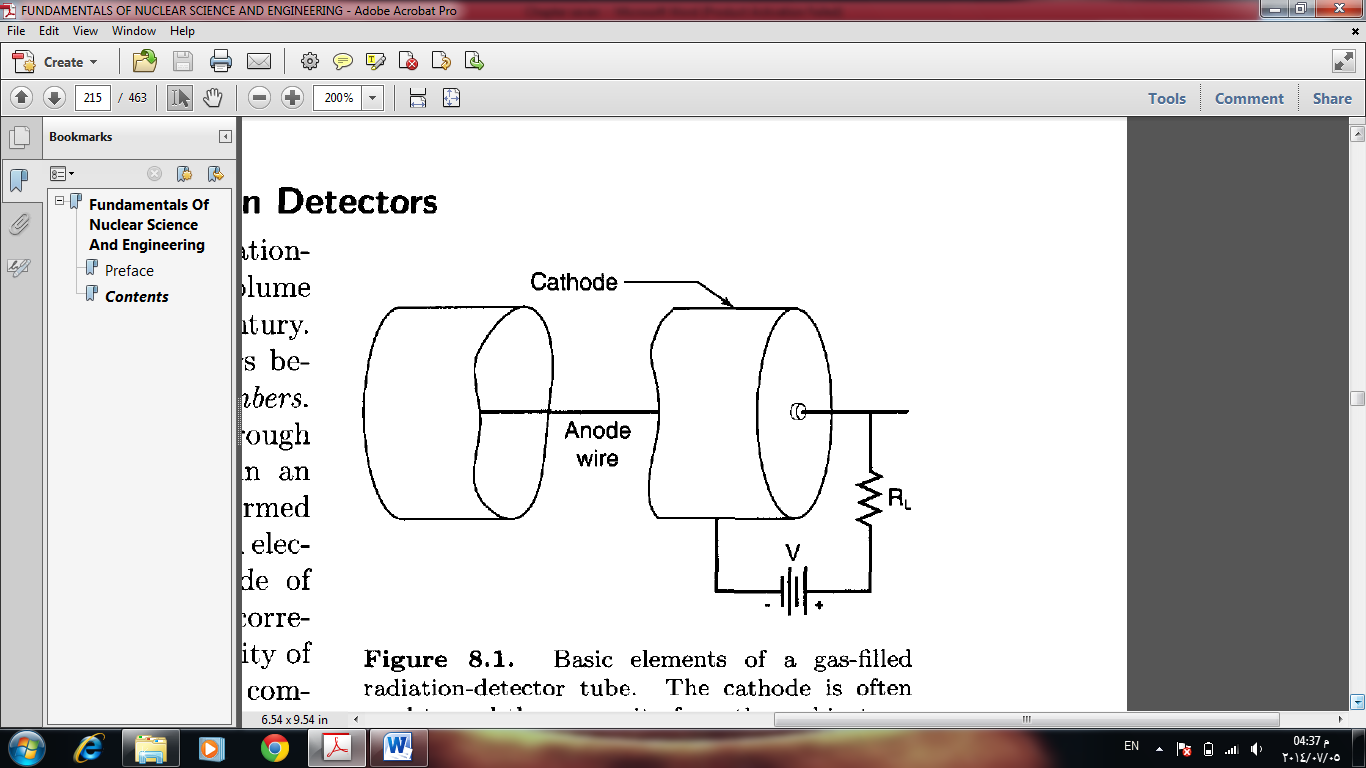


Figure (3-1) Basic elements of a gas-filled radiation-detector tube. The cathode is often used to seal the gas cavity from the ambient environment. The output voltage pulse is produced across the load resistor.

Radiation either interacts in the wall of the chamber or directly in the filling-gas. For incident electromagnetic radiation the dominant interactions, photoelectric effect, Compton scatter, and pair production, occur primarily in the chamber wall material. If the electrons released from the atoms in the wall material escape from the wall and enter the active gas volume of the chamber, then these charged particles (secondary radiation) produce ionization as they pass through the gas. The potential difference between the anode wire and the cathode establishes an electric field that causes positive and negative charges to move in opposite directions. Electrons rapidly drift toward the anode and positive ions migrate more slowly toward the cathode. The motion of these ion pairs causes a flow of current in the external circuit and establishes a voltage across the load resistance. If the incident radiation field contains beta particles, for example, then the chamber must be constructed so that these particles can enter the volume. This is achieved by placing a very thin "window" on one end of the tube.

There are three basic types of gas-filled radiation detectors: ionization chambers, proportional counters and Geiger-Mueller counters. All three are known as ionization chambers, but they each have a unique process for forming the total number of ion pairs that are collected at the electrodes. All three operate by forming initial ion pairs from the incident radiation. Once these ion pairs are formed, it is important that they do not recombine and thereby fail to contribute to the electrical signal.

Figure (3-2) shows the various operational regions of gas-filled chambers. Region I represents the recombination region where the potential difference between the anode and cathode is not sufficient to collect all the initial ion pairs. Ion chambers operating in this region are not useful radiation detectors.

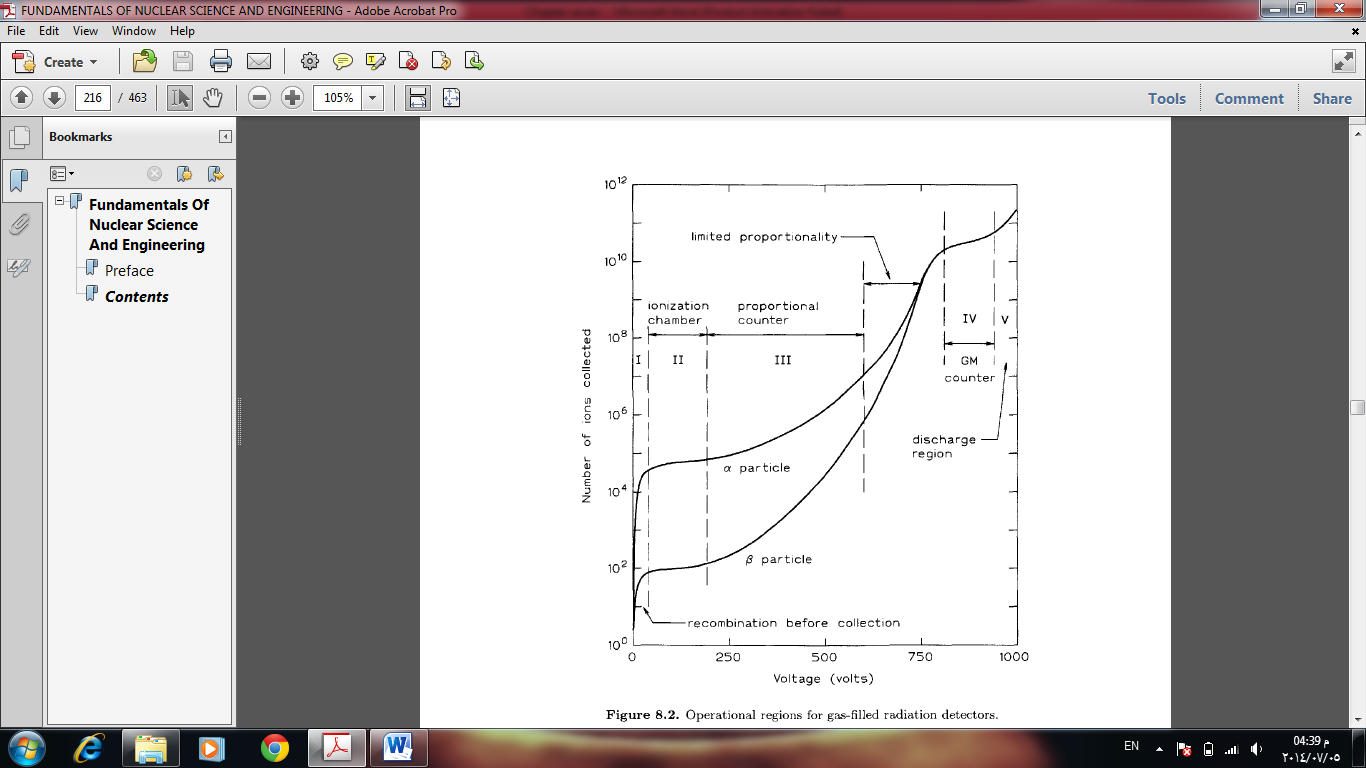


Figure (3-2) Operational regions for gas-filled radiation detectors.

As the potential difference between the anode and cathode is increased, the ionization chamber Region II is entered. In this region the resulting output current is referred to as the ionization chamber saturation current. Region III represents the proportional counter region. In this region, electrons acquire sufficient energy to induce secondary ionization, and hence multiplication. This internal ion-pair multiplication increases the total number of ion pairs in the active volume and, hence, the output current increases by a multiplicative factor M > 1. This region is called the proportional counter region since the output current, or total collected charge per interaction, is proportional to the initial number of ion pairs created by the incident radiation. Next is entered a limited proportionality region where the number of ion-electron pairs collected is relatively independent of the initial number of ion-electron pairs created by the incident radiation. This region generally is not useful operationally.

The region of Geiger-Mueller (GM) counter operation, Region IV, exhibits a "plateau" over which M reaches a nearly constant value. In this region one avalanche produces secondary photons whose interactions produce other local avalanches until the entire anode is surrounded by ion-electron pairs. In this region, the charge collected per interaction is no longer proportional to the initial number of ion pairs created. Therefore, it is very difficult to distinguish between different types of incident radiation or to gain knowledge about the energy of the incident radiation.

If the tube voltage is too large, the tube undergoes continuous avalanches around the central anode, one leading to another. This region V, is known as the continuous discharge region. Its entry normally leads to failure of the ion chamber.

**(3-1-1) Ionization Chambers**

Ionization chambers or ion chambers are widely used as radiation monitors. They can be designed to respond to alpha particles, beta particles, gamma rays, x rays, and neutrons. The ion chamber is the most basic type of gas-filled radiation detector since it operates without gas multiplication. They are often operated by directly measuring the output current. When operated at the saturation current level (region II of Figure (3-2)), the output current level is proportional to the intensity of the incident radiation and permits a direct measurement of the exposure rate. In an ion chamber with parallel-plate electrodes and a uniform electric field, current pulses from individual events can be registered, thereby allowing energy spectroscopy of the incident radiation. In their most common cylindrical geometry, however, ionization chambers cannot be used for this purpose since the pulse amplitude is dependent upon where the ion-electron pairs are formed in the detector.

**(3-1-2) Proportional Counters**

Proportional counters are gas-filled chambers operated in region III of Figure (3-2). In this region, there is an internal multiplication in the chamber gas of the original ion-electron pairs created by the incident radiation. The physical mechanism for this multiplication process is discussed in the next section. This internal multiplication M is typically from 10 to 10,000. Because of the location of the gas multiplication avalanche, near the central wire, the output voltage pulse is not only amplified by a factor of M but the pulse amplitude is proportional to the total ionization energy deposited inside the active volume of the detector. This feature allows the proportional counter to be used as a spectrometer by using the output pulse amplitude to infer the energy of the incident radiation. Also, since the number of ion pairs is proportional to the initial ionization caused by the incident radiation, proportional counters can be used to distinguish between different types of charged particles. For example, one common application is to use a gas-flow counter to distinguish between beta particles and alpha particles.

**(3-1-3) Geiger-Mueller Counters**

Geiger and Mueller developed the Geiger-Mueller (GM) detector in 1928. These radiation detectors are simple and robust devices that continue to be an important tool for sensing the presence of ionizing radiation. These gas filled detectors operate in region IV of Fig. (3-2), and have the remarkable property that the size of the pulse, or total charge produced in the active volume is independent of the ionization energy deposited by the initial ion pairs. Consequently, these detectors do not have the inherent capability of distinguishing between different types of radiation or measuring radiation energy. They can, however, be configured so that they are sensitive to both charged particles (alpha particles and beta particles) and electromagnetic radiation (x rays and gamma rays).

A GM detector's sensitivity to charged particles is limited only by the thickness of the entrance window. The entrance window must be just thick enough to ensure that the chamber's filling gas does not escape. Once charged particles enter the active volume of the detector, they are detected with almost 100% efficiency since it takes only one ion-electron pair to initiate the pulse formation process.

***Operating Voltage***

One of the first steps in characterizing the operation of any gas-filled radiation detector is establishing the correct operating voltage. GM counters have a fairly wide range over which they can be operated. However, each counter should be operated near the center of its plateau within the GM region shown as region IV in Fig. (3-2), this assures the best long-term performance because, at this voltage, small changes in the applied voltage have an insignificant effect on the amplitude of the output pulse. If the applied voltage is too low, then the gas multiplication is less than desired and the counting rate is very sensitive to small changes in voltage.

***Applications***

GM counters are often the detectors of choice for applications requiring information about only the magnitude or intensity of the radiation field. As such they find wide application in hand-held survey meters used to detector radiation fields. Other types of radiation detectors are more suitable if information is needed on the type or energy of the radiation. GM counters can be made in essentially any size and shape. Their low cost and high efficiency make them suitable as sensors of beta particles, x-rays and gamma rays. This is especially true if the radiation level is low enough that dead time losses are not a concern. These detectors are seldom used to detect neutrons although, with a cadmium cover surrounding the tube, the GM detector is sensitive to thermal neutrons and may be calibrated for thermal neutron flux density. Because of their poor energy response, inability to distinguish among different types of radiation, care must be taken to assure that some knowledge of the radiation field is available before making measurements with these counters.

**(3-2) Scintillation Detectors**

There are two types of scintillation detectors, (1) solid crystals of inorganic material, and (2) plastics and liquids consisting of organic molecules. Their modes of excitation differ but the final result is the same. As charged particles pass through the material the energy that they lose is transferred into excitation energy of the inorganic crystals or molecular excitation of the organic molecules. The excitation energy is released in fluorescence, i.e., scintillation. The number of light photons emitted in any one event is proportional to the energy lost by the initial charged particle in that event. The time dependence of the fluorescence emission, and hence the output pulse shape, is dependent upon the specific type of material. Although scintillator material has been used for almost 100 years to detect ionizing radiation, their widespread application dates from the development of the photomultiplier tube (PMT) some 50 years ago. This vacuum tube device allows the measurement of extremely low levels of light. In a PMT the incident photons strike a photocathode thereby liberating photoelectrons. These photoelectrons are then accelerated towards another electrode at a higher potential where the energetic impinging electrons cause more electrons to be emitted. This electron multiplication process continues along a series of electrodes, each at higher potential than the previous and, at each, the electron population is increased. The number of electrons finally collected at the last electrode may be millions of times greater than the number of electrons that began the cascade. In essence, the PMT is a photon to electron amplifier.

A typical scintillator detector assembly consists of a hermetically sealed scintillation material optically mounted to the PMT's photocathode, a voltage divider string in the PMT, and a preamplifier to produce a voltage pulse from the electrons collected at the last PMT electrode. These components are usually bound together in a single assembly By using this common configuration, the detector assembly is a stand-alone device that only requires an external voltage for the PMT and an external power supply for the preamplifier. Such an assembly is often called a scintillation detector.

The amplitudes of the output voltage pulses are proportional to the energy deposited by charged particles produced in the scintillation material. A gamma ray penetrating the scintillator material may give up its energy to the scintillator material through photoelectric interactions, Compton scattering and pair production reactions. If all of the incident gamma-ray energy is deposited in the scintillator material, the number of scintillation photons produced is proportional to the incident gamma-ray energy. Thus, by measuring the distribution of pulse sizes or the pulse height distribution (PHD) produced by the scintillation detector, the energy distribution of the incident gamma rays can be determined. Thus, one of the most important applications of scintillation detectors is gamma-ray spectroscopy.

**NaI(Tl) Scintillation Detectors**

The most popular inorganic scintillation material is NaI(Tl). These detectors are available in a variety of sizes and shapes. Because the maximum wavelength of light emitted by this material is 415 nm, it is easy to find commercially available PMTs whose maximum sensitivity matches the fluorescence emission spectrum. The relatively large decay time constant is normally not a problem since a very high efficiency for x-rays and gamma-rays dominates their radiation response. Of all the different NaI(Tl) detectors available to characterize gamma-ray radiation fields, the 3x3 inch right circular cylindrical detector, has historically been the favorite. This is the most extensively characterized NaI(Tl) detector and extensive efficiency data are available in the literature. A typical NaI(Tl) pulse height distribution is shown in Fig. (3-3). Because of its very high efficiency for electromagnetic radiation, NaI(Tl) is widely used to measure x rays and gamma rays. X-ray detectors with a thin entrance window containing a very thin NaI(Tl) detector are often used to measure the intensity and/or spectrum of low energy electromagnetic radiation. Because NaI(Tl) detectors do not require cooling, they can be used in a great variety of applications. Field applications are possible since they can operate over a long time period in warm and humid environments, resist a reasonable level of mechanical shock, and are resistant to radiation damage. Basically, for any application requiring a detector with a high gamma-ray efficiency and a modest resolution, the NaI(Tl) detector is clearly a good choice.

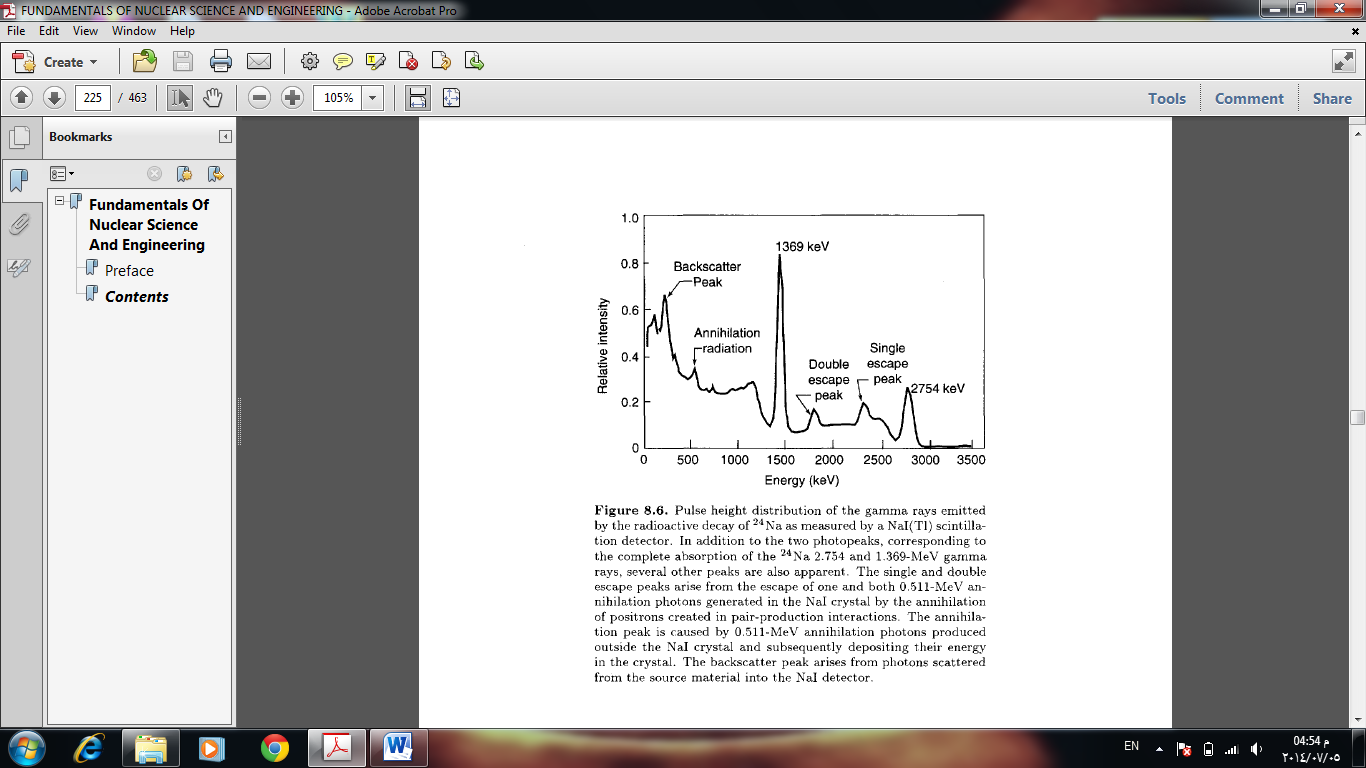


Figure (3-3) Pulse height distribution of the gamma rays emitted by the radioactive decay of 24Na as measured by a NaI(Tl) scintillation detector. In addition to the two photopeaks, corresponding to the complete absorption of the 24Na 2.754 and 1.369-MeV gamma rays, several other peaks are also apparent. The single and double escape peaks arise from the escape of one and both 0.511MeV annihilation photons generated in the NaI crystal by the annihilation of positrons created in pair-production interactions. The annihilation peak is caused by 0.511MeV annihilation photons produced outside the NaI crystal and subsequently depositing their energy in the crystal. The backscatter peak arises from photons scattered from the source material into the NaI detector.

**(3-3) Solid State Detectors**

**(3-3-1) Semiconductor Ionizing-Radiation Detectors**

Functioning of these radiation detectors is based upon the newest technologies. The impact on radiation detection and measurement has been revolutionary because of unique semiconductor properties, especially outstanding energy resolution. New semiconductor detectors continue to be introduced into the market place.

**Germanium Semiconductor Detectors**

There are two main types of germanium semiconductor detectors: (1) Ge(Li) a germanium crystal doped with lithium ions to cancel the effect of natural impurities in the germanium crystal, and (2) the more recent (HPGe) high purity germanium crystal in which impurity atom concentration are less than 1010 atom/cm3. The more expensive HPGe detectors have replaced the older Ge(Li) technology since they can be kept at room temperature when not in use whereas Ge(Li) crystals must always be kept at liquid nitrogen temperatures (-196 oC).

Germanium detectors, besides having exceptional energy resolution, are very efficient for detecting photons. Their efficiency ranges from excellent for low energy x-rays too good for medium to high-energy gamma rays over an energy range of 1 keV to 10 MeV. The performance of these detectors is often compared to NaI(Tl) and Cd/Zn telluride (CZT) detectors. Because of the higher atomic number arid larger size, NaI(Tl) detectors often have a higher efficiency for high energy gamma rays than do germanium detectors, but a much poorer energy resolution. The dramatic difference in the energy resolution between NaI(Tl) and Ge(Li) spectrometers is shown in Fig. (3-4).

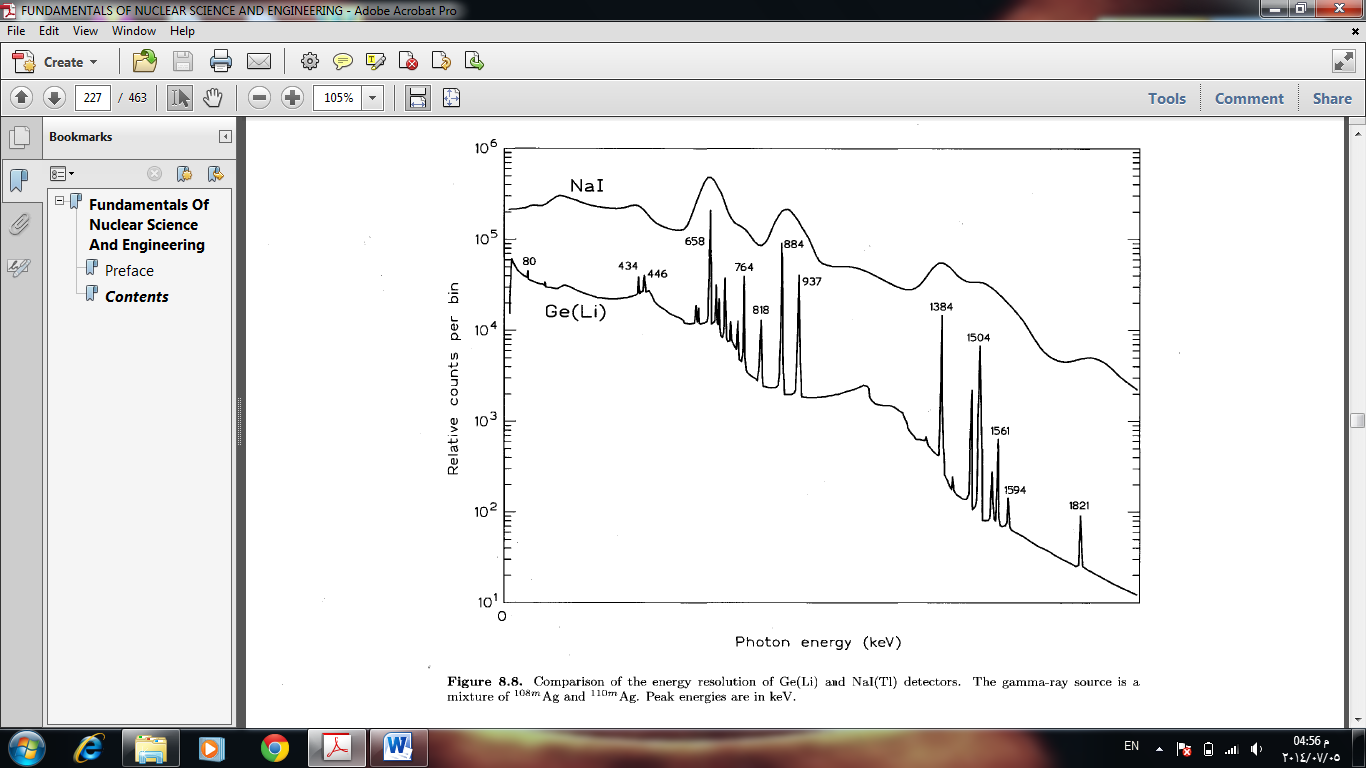


Figure (3-4) Comparison of the energy resolution of Ge(Li) and NaI(Tl) detectors. The gamma-ray source is a mixture of 108mAg and 110mAg.

**Silicon Semiconductor Detectors**

Si(Li) detectors with thin entrance windows are commonly used in alpha and beta particle spectrometers. They can be configured to achieve essentially 100% intrinsic efficiency and have excellent resolution. They also offer an inexpensive option for x-ray spectroscopy. Since Si(Li) detectors have a much lower atomic number than CZT. NaI(Tl), and HPGe, their relative efficiency per unit thickness is significantly lower for electromagnetic radiation. However, for x-ray or gamma ray energies less than about 30 keV, commercially available Si(Li) detectors are thick enough to provide performance which is superior to CZT, NaI(Tl), and HPGe. For example, a 3 to 5 mm-thick detector with a thin entrance window has an efficiency of 100% near 10 keV. Based upon the fact that a majority of the applications require a thin window, Si(Li) detectors are often manufactured with very thin beryllium windows.

**(3-3-2) Cadmium Zinc Telluride Detectors**

Cadmium zinc telluride (CZT) is a new high-resolution and high-atomic number semiconductor detector material. A reasonable degree of cooling for the detector and the directly coupled preamplifier enhances detector system performance. CZT detectors offer an excellent option for low energy x-ray spectroscopy where cooling is not possible. Keeping the detector and preamplifier at about -30 °C, is adequate to achieve optimum energy resolution. By contrast, HPGe detectors must be cooled at liquid nitrogen temperatures to achieve optimum resolution. These detectors are not available in large sizes. Their small size diminishes the possibility of making detectors with large efficiencies for high-energy electromagnetic radiation. Therefore, the major application is low energy x or gamma-ray spectroscopy.

**(3-4) Dosimeters**

**(3-4-1) Pocket Ion Chamber**

Very familiar to radiation workers over many, many years are the self-reading pocket ionization chamber (PIC) and the film badge dosimeter. The pocket ionization chamber is an ion chamber, as described in section (3-1), in the form of a cylinder about the size of a fountain pen. A charge is placed on the electrodes of the ion chamber and the corresponding voltage is displayed through an eyepiece using an electroscope. As the ion chamber receives radiation exposure, the electrodes are discharged and the voltage change of the electroscope is presented in a reticule scaled to radiation dose or exposure. More commonly, the PIC is sensitive only to gamma radiation. However, neutron sensitive ionization chambers are also used, calibrated in dose equivalent.

**(3-4-2) Film Badge**

The film badge consists of a packet of photographic film sealed in a holder with attenuating filters. Ionizing radiation darkens the film, as in the production of an x-ray image. The filtration is designed to render the degree of film darkening as nearly as possible a known function of gamma-ray exposure, independent of the energy of the incident gamma rays. After the badge is carried by a radiation worker for a period of time, the film is processed, along with calibration films with the same emulsion batch exposed to known radiation doses. The worker's radiation dose for the period is assessed and ordinarily maintained in a lifetime record of exposure. In some cases special attenuation filters are used to relate the darkening of portions of the film to beta-particle or even neutron dose. Special badge holders in the form of rings or bracelets are used to monitor the radiation exposure of hands, wrists, and ankles.

**(3-4-3) Thermo luminescent Dosimeter (TLD)**

The thermo luminescent dosimeter (TLD) is a solid state radiation detector, whose radiation dose may be gauged by measurement of the release of light upon heating of the detector after exposure. TLDs are inorganic crystals such as LiF or CaSO4 to which impurity elements, or dopants, such as Mg. P, Mn, or Cu are added in small concentrations. The TLD matrix is an insulator but the dopant adds hole and electron with energy levels within the insulator band gap. Upon radiation exposure, traps are filled. They remain filled until the TLD is heated, thereby releasing the trapped charge carriers. Recombination of newly mobile charged carriers leads to light emission. Natural Li, in which the abundance of 6Li is 7.4%, is somewhat sensitive to thermal neutrons. TLD neutron sensitivity may be enhanced by increasing the abundance of the lighter isotope. Similarly, neutron insensitive LiF employs only 7Li. Dosimetry of mixed neutron and gamma-ray radiation may be accomplished by using pairs of neutron-sensitive and neutron-insensitive TLDs.

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| **Al-Mustansiriyah University**  **College of Science**  **Physics Department** |  | **Fourth Grade**  **Radioactivity**  **Dr. Ali Abdulwahab Ridha** |

**Chapter Four**

**(Accelerators)**

The objective of nuclear accelerators, directing the beam of charged objects form movement of energy toward the goal through the application of electric and magnetic fields, and there are several types of these accelerators.

Accelerated are generally the source of charged particles such as electrons emitted from the hot filament or ionized atoms, where the charged particles released under the influence of voltage up to 10 million volts teams. To be the beam stems toward the goal is to determine the path of the accelerated particles, and have accelerated inside a vacuum (low pressure) to avoid the dispersion of particles accelerated when colliding with atoms of air.

**(4-1) Classification of Accelerators**

Accelerators are classified into three sections based on the energy used to accelerate and is as follows:

(1) Low power: where accelerated particles produce a capacity ranging from 10 to 100 million electron volts accelerators. In most cases these accelerators are used to study the dispersion of particles accelerated their interaction with the target substance

(2) Medium energy accelerators: the beam produced by particles accelerated card above 100 million electron volts to reach 1000 million electron volts. When this energy with the nuclei of elements are studied collision nucleons, will result from these collisions generate other particles, such as accelerators Almjons In this study are nuclear powers and verify the installation of the kernel.

(3) High-energy accelerators: It produces a beam of particles accelerated card exceed 1000 million electron volts. The purpose of these accelerators is Antajeh new particles through the collision of these particles accelerated Bonoah elements and then study the properties of the resulting particles.

The nuclear accelerators to accelerate the energy up to 10000000 electron volt design.

**Key parts of the reactor**

(1) Charged particle source Ion source: It is the main source of accelerated particles composed of ionized gas by electric discharge and is extracted positively charged particles through a negative electrode with a 10,000-volt effort.

(2) The carrier beam optics: It is a number of routers, consisting of electric and magnetic devices for guiding the accelerated particles in the specified path has accelerated within which such lenses in the light depends on the strength of Lorenz Lorentz force.

(3) Target: a material which are placed at the end of the accelerated aim of the experiment under study, for example, nuclear experience spectroscopy where the study of the energy levels and the space section, the objective in this case have a thickness of 10 micron chip, either in the case study of the production of secondary particles from the collision of nuclei accelerated with objective, the target is thick up to 10 centimeter thick so that absorbs energy of accelerated particles. In both cases, the goal is cooled until its temperature does not change with the collision with the accelerated particles.

(4) Detector: which is the basic part on which measurements to be obtained from the experiment, such as determining the quality of the resulting particles from the collision and the energy and the time of survival and angular distribution of these reagents based science in itself and we will devote a separate article to talk about.

**(4-2) Types of accelerators**

(1) Electrostatic accelerator

(2) Cyclotron accelerator

(3) Linear accelerator

(4) Accelerator Alsnctorn Synchrotrons

(5) Accelerated confrontational Colliding-Beam accelerator

**1. Electrostatic accelerator**

The simplest types of accelerators that are used to accelerate charged particles through a fixed voltage differential through the relationship E = qV where V teams to accelerate the effort and up to 10 million volts and q shipment particles accelerated and E the kinetic energy of the particle. This means that the energy that can be gained by a particle accelerated up to 10 million electron volts per unit charge and this is sufficient energy to the study of nuclear structure of the nucleus.

First accelerator was designed on this basis it was in 1932 by two scientists Cockcroft and Walton where the voltage differential arrived accelerate to 800,000 volts and adopted the principle of his work on the charging capacitors in parallel and then convert them to deliver straight through the circle.

At present, this kind of accelerators based on Vandegrav the birth of the world developed by Van de Graaff in 1932. The idea worked Vandegrav generator on static electricity principles, where we know that the electric charge resting on the surface of the connector in the electrostatic case and the movement of electric charge through a belt of insulating material and in most cases silk and gets the belt on the electric charge of the corona discharge device, a tapered head of conductive material applied by the high-voltage differential up to 20,000 volts and pointed at the head where increasing charge density attic unloading electrical work on the air ionization occurs Vtendf cation strongly disharmony in the direction of the moving belt carrying a positive charge to the spherical shell that form an electrical capacitor from the ground.

The idea of ​​this generator When are shipped Mosul internal shipment passed on to the cortex career related with internal Mosul and stabilizes the cargo on the outer surface of the crust and the shipment value depends on the relationship

V = Q / C

Where C condenser capacity charge, Q and V output voltage.

***Electrostatic nuclear accelerator***

An electrostatic nuclear accelerator is one of the two main types of particle accelerators, where charged particles can be accelerated by subjection to a static high voltage potential. The static high voltage method is contrasted with the dynamic fields used in oscillating field particle accelerators. Owing to their simpler design, historically these accelerators were developed earlier. These machines are operated at lower energy than some larger oscillating field accelerators, and to the extent that the energy regime scales with the cost of these machines, in broad terms these machines are less expensive than higher energy machines, and as such they are much more common. Many universities worldwide have electrostatic accelerators for research purposes.

**2. Cyclotron Accelerator**

A cyclotron is a type of particle accelerator invented by Ernest O. Lawrence in 1934 in which charged particles accelerate outwards from the center along a spiral path. The particles are held to a spiral trajectory by a static magnetic field and accelerated by a rapidly varying (radio frequency) electric field. Lawrence was awarded the 1939 Nobel Prize in physics for this invention. Cyclotrons were the most powerful particle accelerator technology until the 1950s when they were superseded by the synchrotron, and are still used to produce particle beams in physics and nuclear medicine. The largest single-magnet cyclotron was the 4.67 m (184 in) synchrocyclotron built between 1940 and 1946 by Lawrence at the University of California at Berkeley, which could accelerate protons to 730 MeV. The largest cyclotron is the 17.1 m (56 ft) multimagnet TRIUMF accelerator at the University of British Columbia in Vancouver, British Columbia which can produce 500 MeV protons.

There are over 1200 cyclotrons used in nuclear medicine worldwide for the production of radionuclides.

**3. Linear accelerator**

A linear particle accelerator (often shortened to linac) is a type of particle accelerator that greatly increases the kinetic energy of charged subatomic particles or ions by subjecting the charged particles to a series of oscillating electric potentials along a linear beamline. The principles for such machines were proposed by Gustav Ising in 1924, while the first machine that worked was constructed by Rolf Widerøe in 1928 at the RWTH Aachen University. Linacs have many applications: they generate X-rays and high energy electrons for medicinal purposes in radiation therapy, serve as particle injectors for higher-energy accelerators, and are used directly to achieve the highest kinetic energy for light particles (electrons and positrons) for particle physics.

The design of a linac depends on the type of particle that is being accelerated: electrons, protons or ions. Linacs range in size from a cathode ray tube (which is a type of linac) to the 3.2-kilometre-long (2.0 mi) linac at the SLAC National Accelerator Laboratory in Menlo Park, California

**4. Accelerator Alsnctorn Synchrotrons**

cended from the cyclotron, in which the accelerating particA synchrotron is a particular type of cyclic particle accelerator, desle beam travels around a fixed closed-loop path. The magnetic field which bends the particle beam into its closed path increases with time during the accelerating process, being synchronized to the increasing kinetic energy of the particles. The synchrotron is one of the first accelerator concepts to enable the construction of large-scale facilities, since bending, beam focusing and acceleration can be separated into different components. The most powerful modern particle accelerators use versions of the synchrotron design. The largest synchrotron-type accelerator is the 27-kilometre-circumference (17 mi) Large Hadron Collider (LHC) near Geneva, Switzerland, built in 2008 by the European Organization for Nuclear Research (CERN).

The synchrotron principle was invented by Vladimir Veksler in 1944. Edwin McMillan constructed the first electron synchrotron in 1945, arriving at the idea independently, having missed Veksler's publication (which was only available in a Soviet journal, although in English). The first proton synchrotron was designed by Sir Marcus Oliphant and built in 1952.

**5. Accelerated confrontational Colliding-Beam accelerator**

whA particle accelerator is a machine that uses electromagnetic fields to propel charged particles to nearly light speed and to contain them in well-defined beams. Large accelerators are used in particle physics as colliders (e.g. the LHC at CERN, KEKB at KEK in Japan, RHIC at Brookhaven National Laboratory, and Tevatron at Fermilab), or as synchrotron light sources for the study of condensed matter physics. Smaller particle accelerators are used in a wide variety of applications, including particle therapy for oncological purposes, radioisotope production for medical diagnostics, ion implanters for manufacture of semiconductors, and accelerator mass spectrometers for measurements of rare isotopes such as radiocarbon. There are currently more than 30,000 accelerators in operation around the world.

There are two basic classes of accelerators: electrostatic and electrodynamic (or electromagnetic) accelerators. Electrostatic accelerators use static electric fields to accelerate particles. The most common types are the Cockcroft–Walton generator and the Van de Graaff generator. A small-scale example of this class is the cathode ray tube in an ordinary old television set. The achievable kinetic energy for particles in these devices is determined by the accelerating voltage, which is limited by electrical breakdown. Electrodynamic or electromagnetic accelerators, on the other hand, use changing electromagnetic fields (either magnetic induction or oscillating radio frequency fields) to accelerate particles. Since in these types the particles can pass through the same accelerating field multiple times, the output energy is not limited by the strength of the accelerating field. This class, which was first developed in the 1920s, is the basis for most modern large-scale accelerators.

Rolf Widerøe, Gustav Ising, Leó Szilárd, Max Steenbeck, and Ernest Lawrence are considered pioneers of this field, conceiving and building the first operational linear particle accelerator, the betatron, and the cyclotron.

Because colliders can give evidence of the structure of the subatomic world, accelerators were commonly referred to as atom smashers in the 20th century. Despite the fact that most accelerators (but not ion facilities) actually propel subatomic particles, the term persists in popular usageen referring to particle accelerators in general.

**(4-3) The most important accelerators**

**Hadron accelerator**

The Large Hadron Collider (LHC) is the world’s largest and most powerful particle accelerator. It first started up on 10 September 2008, and remains the latest addition to CERN’s accelerator complex. The LHC consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way.

Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam pipes – two tubes kept at ultrahigh vacuum. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets. The electromagnets are built from coils of special electric cable that operates in a superconducting state, efficiently conducting electricity without resistance or loss of energy. This requires chilling the magnets to ‑271.3°C – a temperature colder than outer space. For this reason, much of the accelerator is connected to a distribution system of liquid helium, which cools the magnets, as well as to other supply services.

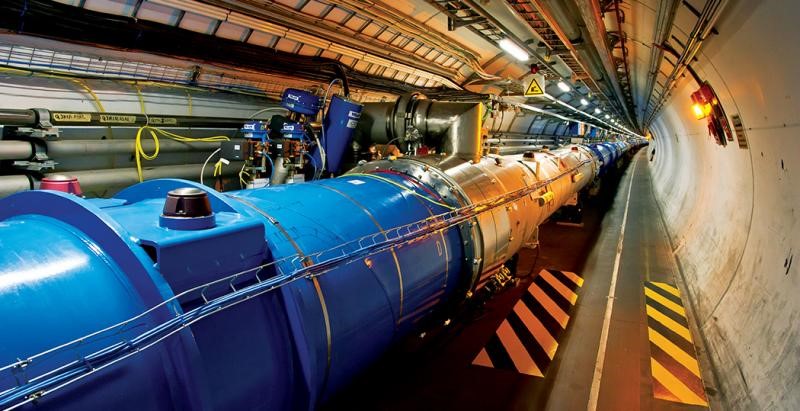


Figure (4-1): Picture of Hadron Accelerator.