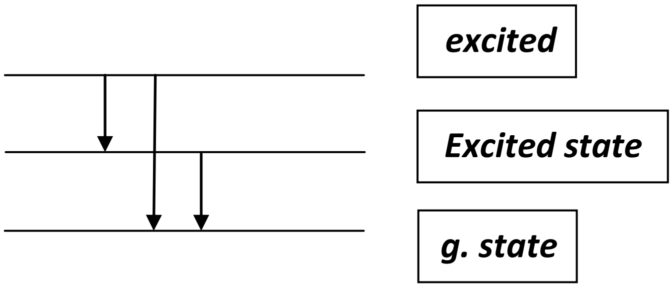
Gamma – decay

The importance of gamma – rays as a source of information about nuclear energy level , has been discussed in connection with α ***- decay*** and β ***– decay*** . In γ ***- ray decay*** the nucleus passes from an excited state to less excited state or to ground state of the nucleus.



Therefore γ **- rays** are radiation of nuclear origin with wavelength smaller than 10^5 **Fermi** (**1 Fermi =** 10^{-15}**m**) and energy larger than **0.1 MeV.**

$$E_\gamma = \frac{1.24\times10^3}{\lambda_{(F)}}$$

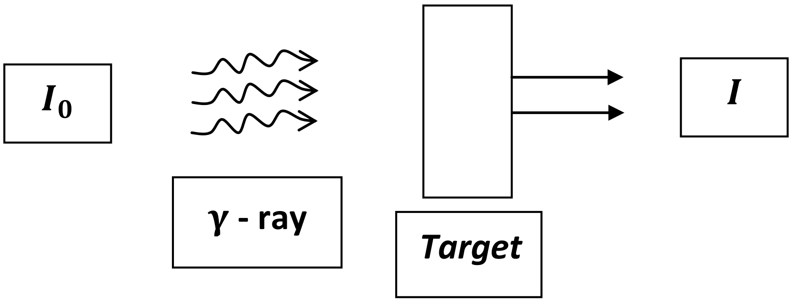
The study of **gamma – ray** depend on the ability to measure the energy and since the γ **- rays** are electromagnetic radiation and have no electric charge , they cannot be deflected by magnetic or electric fields so it's impossible to measure the energy of **γ – ray** directly.

$*$ ***<u>Interaction of gamma with matter</u>*** :-

The interaction of γ **– rays** with matter different from that of charge particle such as α or β **– particle**.

The difference in that the rays have much greater penetrating power, than that charged particles and in the absorption laws.

When a beam of γ **- ray** is incident on a thin absorber each photon of ***gamma – ray*** that is removed from the beam is removed individually.



, $I = I_0 e^{-\mu x}$

Where $(\mathbf{I_0})$, $(\mathbf{I})$ are the intensities of the incident and the transmitted beams respectively

$\boldsymbol{\mu} \Rightarrow$ Is the linear absorption coefficient

$\boldsymbol{x} \Rightarrow$ Thickness of the absorber

The event may be absorption in this case, the photon disappear for scattered out of the beam.

Three processes can occur in the absorption of ***gamma – ray*** :

① Photo electric effect

② Compton scattering (***Compton effect***)

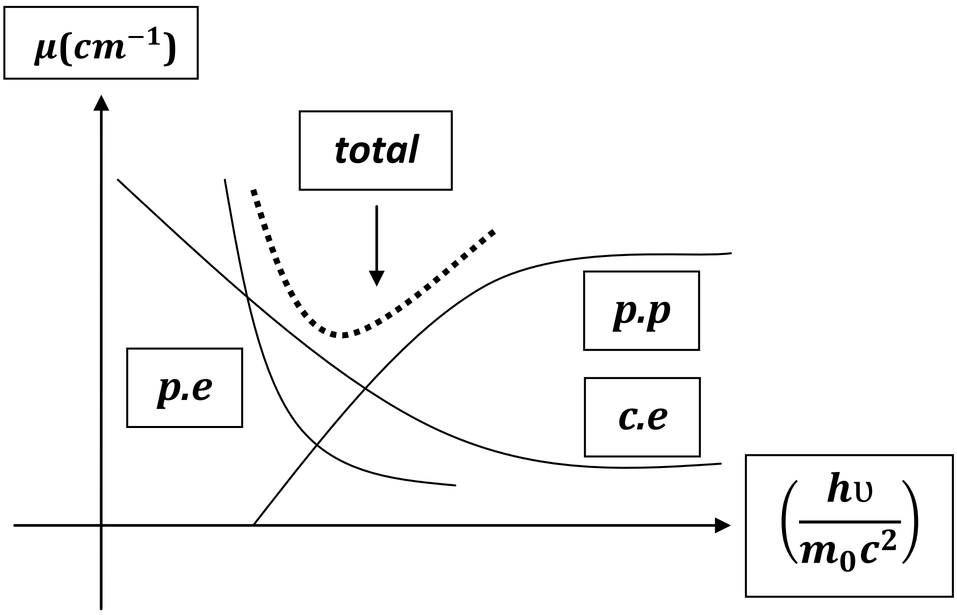
③ Pair production (***electron – position pair production***)

The probability of each process can be expressed as an absorption coefficient or as a cross – section.

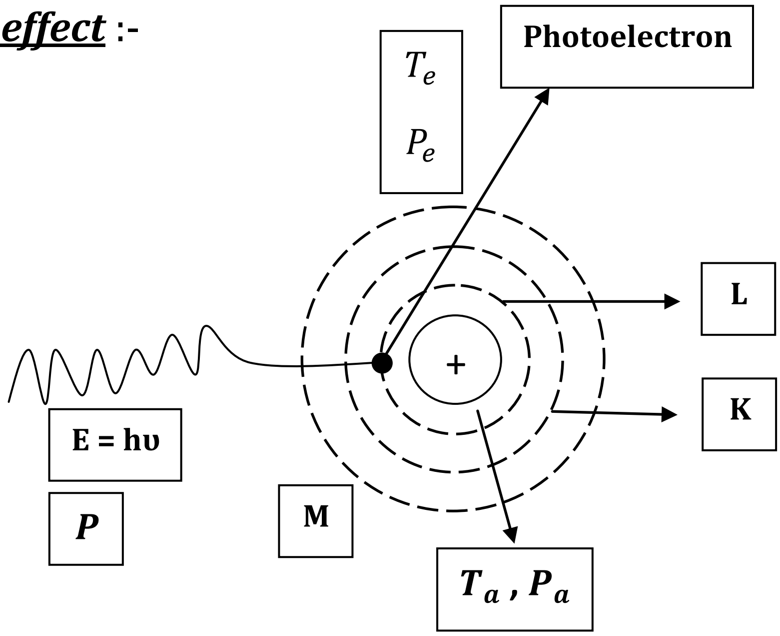
$$\boldsymbol{\mu_{tot}}\,(\mathbf{E}) = \boldsymbol{\mu_{p.e}} + \boldsymbol{\mu_{c.}} + \boldsymbol{\mu_{p.p.}}$$

$\boldsymbol{\mu_{tot}}\,(\mathbf{E}) \Rightarrow$ is the total absorption coefficient which depends on the energy of the incident $\boldsymbol{\gamma}$ **– ray**.

$\boldsymbol{\mu_{p.e}}$, $\boldsymbol{\mu_{c.}}$, $\boldsymbol{\mu_{p.p.}}$ are the photoelectric , Compton and pair production coefficient respectively.



① ***Photo electric effect*** :-



In the photoelectric effect all the energy (hυ) of the incident photon absorbed by a bound electron which is ejected from the atom with kinetic energy T_e equal to

$$T_e = (h\upsilon) - Be - T_a$$

Be ⇒ is the binding energy of the ejected electron

T_a ⇒ the recoil energy of the atom which can be neglected since $m_e \ll M_a$

$$T_a = \frac{m_e}{M_a} T_e$$

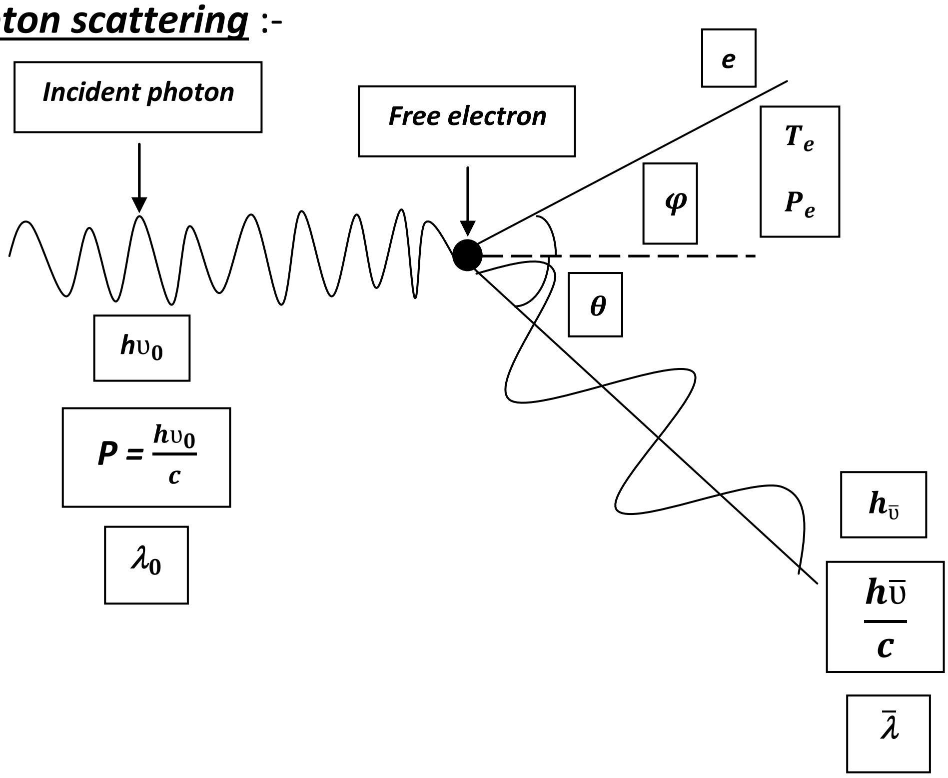
Therefore ⇒ $T_e = h\upsilon - Be$

The most tightly bound electrons has the greater probability of absorbing the incident photon. About **80%** of the photo effect take place (occur) in the K – shell , where the electrons strongly bounded than in the L – shell or any other shell.

$$\mu_{p.e} = const.\ \frac{Z^5}{(h\upsilon)^{7/2}}$$ ⟶ مهم كتطبيق سؤال

i.e. $\boldsymbol{\mu_{p.e}}$ decreases rapidly as $\boldsymbol{Z}$ decreases and $\boldsymbol{h\upsilon}$ increases.

② ***Compton scattering*** :-



In Compton effect and incident photon with energy $E = h\upsilon_0$ and momentum $\frac{h\upsilon_0}{c}$ struck an atomic electron (***assumed free***)

The scattered photon is emitted at an angle (θ) with energy ($h\bar{\upsilon}$) and the electron recoils at angle (φ) with momentum P_e and **K.E** $\rightarrow T_e$

The photon momentum $\frac{h\upsilon_0}{c}$ shared between the scattered photon and Compton electron.

المركبة الافقية $$\frac{h\upsilon_0}{c} = \frac{h\bar{\upsilon}}{c}\cos\theta + P_e\cos\varphi \quad \text{----------} \quad (1)$$

المركبة العمودية $$0 = \frac{h\bar{\upsilon}}{c}\sin\theta + P_e\sin\varphi \quad \text{----------} \quad (2)$$

The energy of the incident photon cannot be transferred totally to a free , but it also can be shared between the scattered photon and Compton electron.

(الطاقات) $h\upsilon_0 = h\bar{\upsilon} + T_e$ ---------- ③

using the relativistic relationship.

$$P_e = \sqrt{T(T + 2m_0c^2)}$$

And same algebra , a useful relationship can be obtained from the three eq. ① , ② , ③

A) **Compton shift** :-

واجب اثباتها (**H.W**) مهم مهم مهم

$$\Delta\lambda = \bar{\lambda} - \lambda_0 = \frac{c}{\bar{\upsilon}} - \frac{c}{\upsilon_0} = \frac{h}{m_0 c}(1-\cos\theta) \quad \text{--------} \quad *$$

Compton shift wave length $$\therefore \Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$$

Where $\lambda_0 , \bar{\lambda}$ are the wave length of the incident and the scattered photons respectively.

$(\frac{h}{m_0 c}) \Rightarrow$ is the Compton wave length of the electron.

$(\frac{h}{m_0 c}) \Rightarrow \mathbf{2.24 \times 10^{-10}\ cm = 0.024\ A^\circ}$

$$1\ A^\circ = 10^{-8}\ cm = 10^{-10}\ m$$

since $\lambda = \frac{c}{\upsilon}$, then

$$\frac{1}{\bar{\upsilon}} - \frac{1}{\upsilon_0} = \frac{h}{m_0 c^2}(1-\cos\theta)$$ $\rightarrow$ **Compton shift in frequency**

Note that the Compton shift in wave length in any direction is independent on the energy $(h\upsilon_0)$ of the incident photon

B) **Energy of the scattered photon** :-

From eq. $(*)$ $\Rightarrow \frac{c}{\bar{\upsilon}} - \frac{c}{\upsilon_0} = \frac{h}{m_0 c}(1-\cos\theta)$

$(\frac{c}{h\bar{\upsilon}} = \frac{1}{\bar{p}})$ $$\frac{1}{\bar{P}} - \frac{1}{P} = \frac{1}{m_0 c}(1-\cos\theta)$$

$$\frac{1}{\bar{P}} = \frac{1}{P} + \frac{1}{m_0 c}(1-\cos\theta)$$

$$= \frac{m_0 .c + P(1-\cos\theta)}{P\, m_0 c} \Rightarrow \bar{P} = \frac{P\, m_0\, c}{m_0 .c + P\,(1-\cos\theta)}$$

$$= \frac{P}{1+\frac{P}{m_0 c}(1-\cos\theta)}$$

$$\frac{h\bar{\upsilon}}{c} = \frac{h\upsilon_0 / c}{1+\frac{h\upsilon_0}{m_0 c^2}(1-\cos\theta)}$$

$$h\bar{\upsilon} = \frac{h\upsilon_0}{1+\alpha\,(1-\cos\theta)} \Rightarrow \text{where } \alpha = \frac{h\upsilon}{m_0 c^2}$$

* → when $\theta = 0 \Rightarrow \cos\theta = 1 \Rightarrow h\bar{\upsilon} = h\upsilon_0$

اعظم قدرة للفوتون المستطير $h\bar{\upsilon}_{max} = h\upsilon_0$ مهم

عوض هنا

** → when $\theta = 180 \Rightarrow \cos\theta = -1$, therefore

$$h\bar{\upsilon}_{min} = \frac{h\upsilon_0}{1+2\alpha}$$ مهم

C) <u>Energy of the struck electron</u> :- → (عكس الفوتون اعلاه)

$\therefore \quad T_e = h\upsilon_0 - h\bar{\upsilon}$

$$= h\upsilon_0 - \frac{h\upsilon_0}{1+\alpha\,(1-\cos\theta)} = \frac{h\upsilon_0\,\alpha\,(1-\cos\theta)}{1+\alpha\,(1-\cos\theta)} \text{ - } h\upsilon_0$$

$\theta = 180 \Rightarrow \cos\theta = -1$

عوض هنا

$$* \rightarrow T_e(\max) = \frac{h\upsilon_0[1+2\alpha]}{1+2\alpha} - h\upsilon_0 = \frac{h\upsilon_0\,[1+2\alpha-1]}{1+2\alpha}$$

$$= \frac{2\alpha\, h\upsilon_0}{1+2\alpha} = \frac{h\upsilon_0}{1+\frac{1}{2\alpha}}$$

** → $\theta = 0 \Rightarrow \cos\theta = 1 \Rightarrow T_e(\min)$

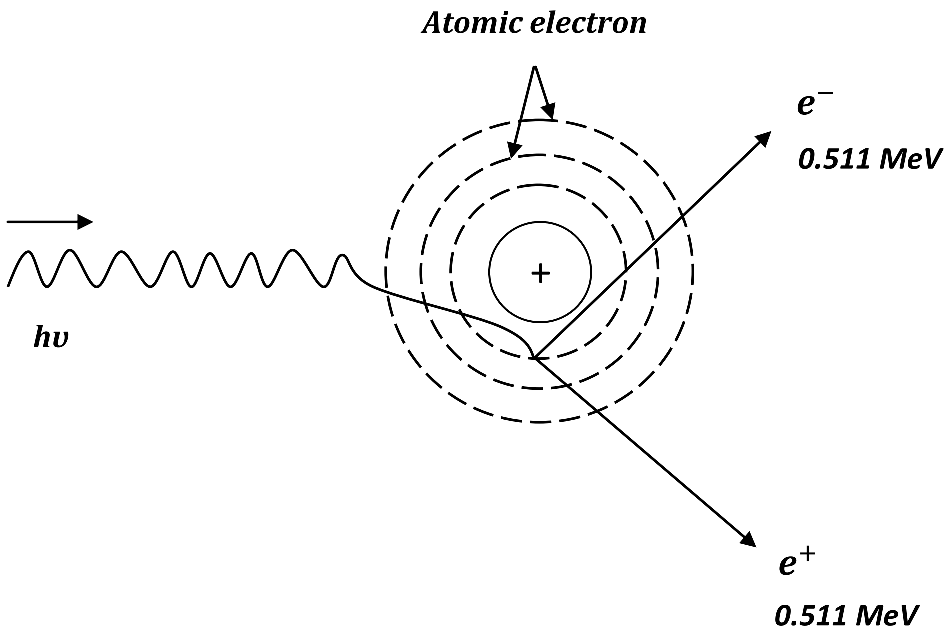
$$T_e(\min) = \frac{h\upsilon_0[1+\alpha(0)]}{1+\alpha(0)} - h\upsilon_0 = \frac{h\upsilon_0 - h\upsilon_0}{1} = 0$$ عكس حالة الفوتون

The **K.E** of the electron has its maximum value when **cos θ** = **-1 ,** when **θ** = **180°** i.e. when the photon scattered directly backward. The electron energy in this case is

$$T_e(max) = \frac{h\upsilon_0}{1+\frac{1}{2\alpha}}$$

The electron received the least energy ($T_e(min)$) when the photon continues with its initial frequency in the forward direction (**θ= 0**) and the electron is **ejected** with nearly **Zero** velocity in the direction perpendicular to that of the photon path.

③ **Pair Production** :- تكوين الازدواج



The pair production (electron – positron)

Production occurs when the incident photon $E_\gamma \geq$ **1.022 MeV** in this interaction the photon is completely absorbed and in its place appears a positron – electron pair whose total energy is jut equal to $h\upsilon$.

$$h\upsilon = (T_e + m_e c^2) + (T_p + m_p c^2)$$

$$= T_e + T_p + 2m_e c^2$$

$$h\upsilon = T_e + T_p + 1.022 \text{ MeV}$$

where T_e and T_p the **K.E** of e^- and e^+

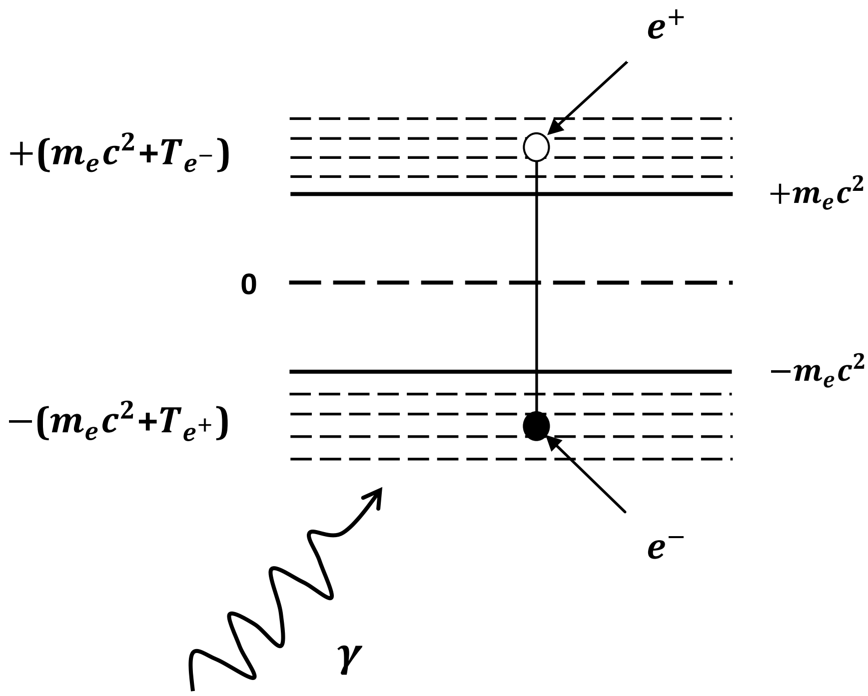
$m_e c^2 \Rightarrow$ **0.511 MeV** $\Rightarrow$ the rest energy of e^- and e^+

The minimum energy needed for pair production to occur is E_γ = **1.022 MeV** , in this case T_e and T_p equal to **<u>Zero</u>** $\Rightarrow$ $T_e + T_p = Zero$.

∗ electron – positron pair is generally projected in the forward direction relative to the direction of an incident photon i.e. in small angle.

As the energy of photon increases the angle decreases

∗ The pair production process can be described by **Dirac** theory.



Dirac theory for pair production

Electron exist in negative energy state transmitted to the positive state , where can be considered as real or observable particle.

The vacancy in the negative state appears as particle with positive energy and positive charge

This imply place or **Dirac** hole would have had a position.

∗ The cross – section is zero for photon energies less than **1.022 MeV**, for greater energies if increases at first slowly then may rapidly $\boldsymbol{\mu_{p.p} \propto Z^2}$

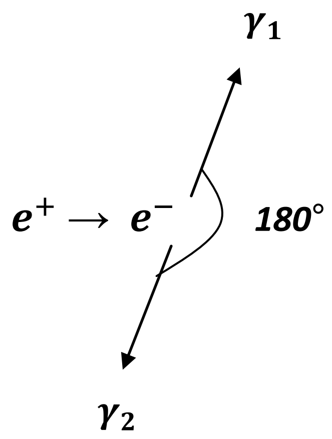
(مهم)

The $(\boldsymbol{e}^{-}, \boldsymbol{e}^{+})$ pair can be produced only in the neighborhood of third particle which can take some momentum so that the conservation law of energy and momentum can be satisfied together.

Interaction of positron (e^+) with matter :-

The energy loss of positron passing through matter as the of electron occur by **ionization** and **Bremsstraglung** in addition , positron can **annihilate** with electron a process which is the inverse of pair production . In the annihilation process the positron after being formed by pair production is solved down by collision with atoms , then interacts with electron which is also practically at rest . The two particles **(e^-, e^+)** disappear and two photons **(2γ)** appear moving in opposite direction **($\theta = 180°$)** as the conservation of linear momentum requires , each photon with the energy of **0.511 MeV** . This radiation **(photons)** is called **annihilation radiation**

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



The annihilation probability increases as the positron slows down and it is **maximum for very slow ($\upsilon_{e^+} \cong 0$)**

∗ ***Positronium*** :-

A positron and electron **can form a type of atom** , in which each of the two particles moves about its **common center ,** a positronium is short – lived (**10^{-10}*sec.* or 10^{-7}*sec.***) , depending on the relative spin orientation of the two particles because of the electron and positron annihilate each other.

<u>Decay constant of γ – decays</u> :-

Electromagnetic waves are an oscillating electric and magnetic field . The changing electric field induces a magnetic field , and the changing magnetic field induces an electric field , and soon such a wave can be generated by oscillating electric charge which sets up an oscillating ***E*** field or by oscillating ***E – current*** which sets up oscillating ***M – field*** . In the first case we have what called **<u>electric multipole radiate (أشعة كهربائية متعددة الاقطاب)</u>** discreted as ***EL*** , and in the second case it is **<u>magnetic multipole radiate (أشعة مغناطيسية متعددة الاقطاب)</u>** discreted as ***ML*** .

In a given transition usually one and at most two. multiple radiation are of importance.

$$\lambda_\gamma = \lambda_\gamma\,(E_1) + \lambda_\gamma\,(M_1) + \lambda_\gamma\,(E_2) + \lambda_\gamma\,(M_2) + \ldots\ldots\ldots\ldots$$

a certain set of terms is eliminated by the selection rules.

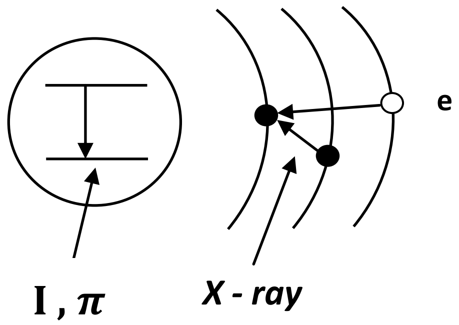
The decay constant of the multiple of lowest order usually exceeds that of all other multiples , by a factor of at least $\mathbf{10^2}$ to $\mathbf{10^4}$ i.e.

$$\frac{\lambda(E_1)}{\lambda(E_2)}\ or\ \frac{\lambda(\mathrm{E_1})}{\lambda(M_1)} \cong \mathbf{10^2 - 10^4}$$

This means that , the magnetic multipole radiation is less probable than the electric multipole radiation of the same order , but the **two multipoles** E_1 and M_1 for example can never occur together because their parities are different.

عندما تنتقل النواة من مستوى اثارة أعلى الى مستوى اثارة أقل تبعث أشعة كهرومغناطيسية (أشعة كاما مثلا) ان سبب هذا الانتقال هو التفاعل بين النواة المثارة و المجال المغناطيسي الخارجي و يمكن اعتبار النوة بأنها تكون من نيكلونات نقطية ذات عزم مغناطيسي ثنائي الاقطاب $(\mathbf{nn})$ $(\mathbf{pp})$ $(\mathbf{np})$ اما البروتونات فتمتلك اضافة الى ذلك شحنة ايضا . و ان توزيع الشحنة يمكن ان يتفاعل مع المجال الخارجي و يتسبب انتقالات كهربائية $(\mathbf{EL})$, كما ان المغناطيسية الذاتية لكل نيكلون بالإضافة الى المغناطيسية الناتجة عن حركة البروتونات في مدارات مغلقة يمكن ان تسبب انتقالات مغناطيسية $(\mathbf{ML})$ و هكذا فالانتقالات الكهرومغناطيسية بانبعاث أشعة كاما. فلإيجاد احتمالية الانتقالات الكهرومغناطيسية (ثابت الانحلال) لابد من ايجاد علاقة تربط بين احتمالية الانتقال (λ) وعنصر المصفوفة النووي $(\mathbf{M})$. و هذا اعنصر المصفوفة $(\mathbf{M})$ حساس الى مرتبة القطبية $(\mathbf{L})$ بالإضافة الى نوع الانتقال فيما اذا كان كهربائيا او مغناطيسيا و هكذا.

Internal conversion :-   التحول الداخلي



When a nucleus transmitted from an excited state to a lower state without the emission of photon ($\gamma - ray$) , this process called the **internal conversion** .

The energy transition ($E_i - E_f$) can be transferred directly to a bound electron of the same atom , the kinetic of ejected electron is called the internal conversion electron (**I.C.**), is equal to :

$$T_e = (E_i - E_f) - E_B$$

Where $E_B \Rightarrow$ is the binding energy of the ejected in the atomic shell from which electron it has been ejected.

∗ **Internal conversion** is produced by the **time varying** coulomb field of the nucleus which has a radiate direction , which the $\gamma - ray\ emission$ is caused by transverse electric and magnetic field.

∗ التحول الداخلي ← ينتج عن مجال كولومي الذي يتغير مع الزمن داخل النواة باتجاه قطري

∗ تحلل كاما ← ينتج عن مجالات كهربائية و مغناطيسية في الاتجاه المستعرض.

The two processes (**I.C.** and $\gamma - \boldsymbol{emission}$) are independent

$$\lambda_{tot.} = \lambda_\gamma + \lambda_e = \lambda_\gamma(1 + \alpha)$$

Where $\alpha_t = \alpha_K + \alpha_L + \alpha_M + \ldots$

Where $\Rightarrow \lambda_\gamma$ the probability per unit time for the emission of photon (decay constant)

$\Rightarrow \lambda_e$ decay constant of electron or the probability per unit time for transformation of energy $(E_i - E_f)$ to a bound electron

$$\lambda_e = \lambda_K + \lambda_L + \lambda_M + \ldots$$

Experimentally these processes can be distinguished by the different energies of the emitted electrons from different shells.

The total internal conversion coefficient (α) is defined as

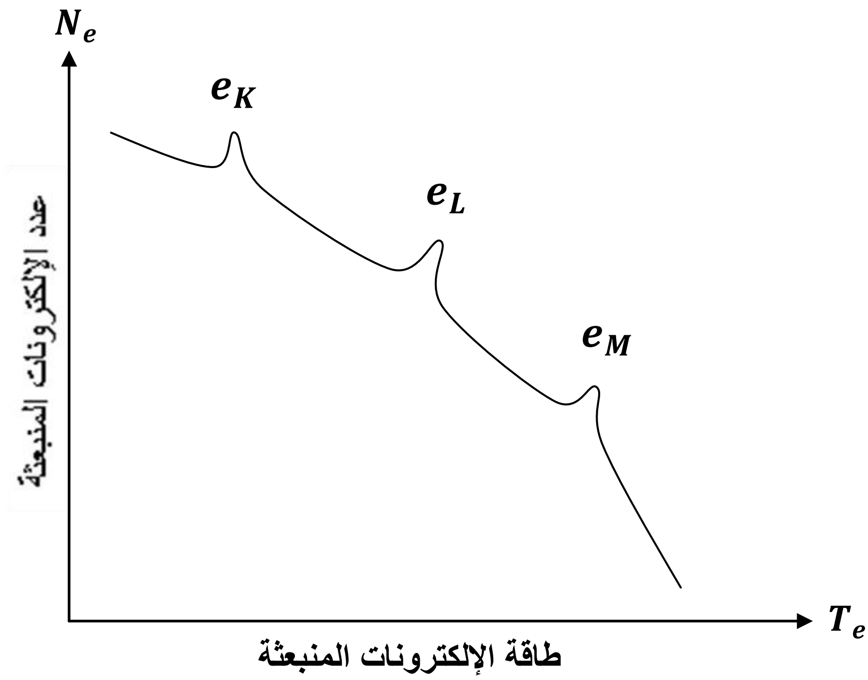
$$\alpha = \frac{\lambda_e}{\lambda_\gamma} = \frac{N_e}{N_\gamma}$$

where N_e and N_γ are the numbers of conversion electrons and photons emitted in the same time internal.

$\alpha \Rightarrow$ increases as L and Z increases and decreases as $(E_i - E_f)$

* تزداد عملية التحول الداخلي للنوى الثقيلة بسبب ان أقطار المدارات الداخلية للالكترونات هي اصغر بسبب المجال الكولومي القوي المجهز من قبل النواة الثقيلة و الالكترونات المنتزعة تكون في الاغلفة القريبة

* المجال القوي يظهر تأثير كبير على المحيط.



ملاحظة : عندما تكون عملية انحلال كاما غير ممكنة فتكون عملية التحول الداخلي ممكنة

∗ For non relativistic calculation of internal conversion coefficient for electric and magnetic multipolarity giving the following values :

$$\alpha(E_L) = \frac{Z^3}{n^3}\left(\frac{L}{L+1}\right)\left(\frac{1}{137}\right)^4\left(\frac{2m_ec^2}{E_i - E_f}\right)^{L+5/2} \quad \text{..........} \; *$$

$$\alpha(M_L) = \frac{Z^3}{n^3}\left(\frac{1}{137}\right)^4\left(\frac{2m_ec^2}{E_i - E_f}\right)^{L+3/2} \quad \text{..........} \; **$$

Where **n** is the principle quantum number of the atomic shell (**n = 1 , 2 , 3** for **K , L , M** alternatively).

From what it shown , we can notice the following characteristics for the internal conversion coefficient.

1 – The internal conversion coefficients increases with $\boldsymbol{Z^3}$, so , the internal conversion process is much important for heavy nuclei than for light nuclei.

2 – The internal conversion coefficient decreases much rapidly as the transition energy $(\boldsymbol{E_i - E_f})$ increased , while the probability of $\boldsymbol{\gamma - emission}$ increases rapidly with the increase of excitation energy.

3 – The internal conversions increase rapidly with the increase degree of multiples , i.e. as $(\boldsymbol{L})$ increases , that is $\lambda_e \gg \lambda_\gamma$.

4 – Internal conversion coefficients for high atomic shell $(\mathbf{n > 1})$ decreases with $\frac{1}{n^3}$ so what we expect that the $\alpha_K > \alpha_L > \alpha_M$ and $\frac{\alpha_K}{\alpha_L} \cong \infty$, while the experimental values the α_K/α_L are about (**3 – 6**).

<u>Auger electron</u> :

Internal conversion is always accompanied with secondary process because the atom left in an excited sate of energy $\boldsymbol{E_B}$

The energy released by the ***x – rays*** or auger electrons which are released from the outer atomic shell and they carry away the available excitation energy.

Selection Rules :-

The selection rules are conditions which are necessary for a given process to occur. A photon emitted or (absorbed) by a nucleus carries an angular momentum $\hbar\sqrt{\ell(\ell+1)}$ in **Z – direction** with a magnitude ($m_\ell \hbar$). That is the vector difference between the angular momentum of the initial state (J_i) and the final state (J_f). This means that angular momentum of **Y – direction** determined by the quantum numbers "ℓ" and "**m**" . For photon can have only non zero values i.e. $\ell = 1, 2, 3, 4$

∗ The angular momentum is conserved between γ **- rays** and the emitting system (nucleus). So that

"ℓ" is the vector difference between the angular momentum "J_i" and "J_f"

$$|J_i - J_f| \leq L \leq |J_i + J_f|$$

If $\quad J_i = J_f \Rightarrow$ i.e. $\quad L = 0 \quad$ (**forbidden**)

In this case there is no γ **- radiation** because of the nature of electromagnetic wave in which no **L = 0**

∗∗ From the consideration of parity when the transition is occurring , we have

$$\pi_i = \pi_f + \Delta\pi \quad \rightarrow \quad \text{first selection rule}$$

∗∗ From the consideration of angular momentum requires that

$$J_i = J_f + L_\gamma \quad \rightarrow \quad \text{second selection rule}$$

Where $L_\gamma \Rightarrow$ is the angular momentum carried by **γ – radiation**

⇒ The parity change ($\Delta\pi$) is directly related to "**L**" and equal to

① $\Delta\pi = (-1)^{\ell}$ for electric multiple radiation (E_L).

② $\Delta\pi = (-1)^{L+1}$ for magnetic multiple radiation (M_L).

Name	Abbreviation	L	$\Delta\pi$
Electric dipole	E_1	1	-1 (yes)
Magnetic dipole	M_1	1	$+1$ (No change)
Electric quadruple	E_2	2	$+1$ (No)
Magnetic quadruple	M_2	2	-1 (Yes)
Electric octuple	E_3	3	-1 (Yes)
Magnetic octuple	M_3	3	$+1$ (No)

جدول (1) يمثل اسماء متعدد القطبية و مختصراتها و قيمة الزخوم الزاوية و تغير التماثل

$*$ ***Examples of gamma – decays***

Initial state	Final state	All possible decay Models	Predominate decay models
2^+	0^+	$E_2\ ,M_3$	E_2
1^+	0^+	$M_1\ ,E_2$	M_1
$\frac{1^-}{2}$	$\frac{1^+}{2}$	$E_1\ ,m_2$	E_1
2^+	2^+	$M_1\ ,E_2$	M_1
$\frac{9^+}{2}$	$\frac{1^-}{2}$	$M_4\ ,E_5$	M_4
0^+	0^+	**No change**	

① اذا حدث تغيير في التماثل ($\Delta\pi$ ← نعم) فالانتقالات الممكنة كهربائي فردي و مغناطيسي زوجي .

② اذا لم يحدث تغيير في التماثل ($\Delta\pi$ ← لا) فالانتقالات الممكنة كهربائي زوجي و مغناطيسي فردي .

① $2^+ \longrightarrow 0^+$

$$* \rightarrow |J_i - J_f| \le L \le |J_i + J_f|$$

$$|2-0| \le L \le |2+0|$$

$$2 \le L \le 2 \;\;\Rightarrow\;\; L = 2$$

$** \Rightarrow \Delta\pi = (-1)^2 = + \Rightarrow E_L$

$\Delta\pi = (-1)^{2+1} = - \Rightarrow M_L$ حدث تغيير

∗ اذا لم يحدث تغيير في التماثل (الكهربائي)

∴ الانتقالات الممكنة ← كهربائي زوجي

↙ مغناطيسي فردي (بعده مباشرة) M_3

∴ $M_3 + E_2$ انتقالات ممكنة

و لكن المهيمن E_2 (الاقل زخم زاوي مداري).

② $1^+ \longrightarrow 0^+$

$$|J_i - J_f| \leq L \leq |J_i + J_f|$$

$$|1 - 0| \leq L \leq |1 + 0|$$

$$1 \leq L \leq 1 \Rightarrow L = 1$$

$\Delta\pi = (-1)^1 = - \rightarrow E$ حدث تغيير ل

$\Delta\pi = (-1)^{1+1} = + \rightarrow M$ لم يحدث تغيير ل

∴ الممكن كهربائي $M_1 + E_2$

و المهيمن M_1

③ $\frac{1}{2}^- \longrightarrow \frac{1}{2}^+$

$$\left|\frac{1}{2} - \frac{1}{2}\right| \leq L \leq \left|\frac{1}{2} + \frac{1}{2}\right|$$

$$0 \leq L \leq 1$$

غير ممكن $L = 0$

$\Delta\pi = (-1)^1 = -$ حدث تغيير

$\Delta\pi = (-1)^2 = +$ لم يحدث تغيير

نحن نأخذ الذي حدث فيه تغيير فيكون فردي كهربائي و زوجي مغناطيسي يعني E_1 و M_2 و المهيمن E_1

④ $2^+ \longrightarrow 2^+$

$$|2-2| \le L \le |2+2|$$

$$0 \le L \le 4$$

$$L = 1 , 2 , 3 , 4$$

عندما

$L = 1 \Rightarrow \Delta\pi = (-1)^1 = -$ يهمل لان الأصل لم يحدث تغيير

$L = 1 \Rightarrow \Delta\pi = (-1)^2 = +$ ✓

اذا لم يحدث تغيير يعني كهربائي زوجي و مغناطيسي فردي يعني E_2 و M_1

المهيمن M_1 أقل مرتبة

عندما

$L = 2 \Rightarrow \Delta\pi = (-1)^2 = +$ ✓

لأن لم يحدث تغيير فالكهربائي زوجي و المغناطيسي فردي

M_3 , E_4 ممكنين

و المهيمن M_3 $\Delta\pi = (-1)^3$ حدث تغيير

عندما

$L = 3 \Rightarrow \Delta\pi = (-1)^3 = -$ يهمل لأن حدث تغيير

يأخذ $= \Delta\pi = (-1)^4 = +$

يكون M_5 , E_6 ممكنين

M_5 مهيمن

عندما

$L = 4 \Rightarrow \Delta\pi = (-1)^4 = +$ ✓ يؤخذ بالاعتبار

فيكون M_7 , E_8 ممكنين

المهيمن M_7

$$\Delta\pi = (-1)^5 = -$$

حدث تغيير يهمل

ولكن المهيمن الأكبر على كل الانماط هو M_1

⑤ $\frac{9}{2}^{+} \longrightarrow \frac{1}{2}^{-}$

$$\left|\frac{9}{2} - \frac{1}{2}\right| \leq \mathbf{L} \leq \left|\frac{9}{2} + \frac{1}{2}\right|$$

$$4 \leq \mathbf{L} \leq 5 \qquad \therefore\ \mathbf{L} = 4 , 5$$

عندما

$\mathbf{L} = 4 \Rightarrow \Delta\pi = (-1)^4 = +$ يهمل لأن الأصل حدث تغيير

$\Delta\pi = (-1)^5 = -$ يؤخذ بالاعتبار

$\therefore$ اذا حصل تغيير فيكون الكهربائي فردي و المغناطيسي زوجي

M_4 , E_5 ممكنين

M_4 المهيمن

عندما

$\mathbf{L} = 5 \Rightarrow \Delta\pi = (-1)^5 = -$ ✓

يؤخذ بالاعتبار لأن الاصل حدث تغيير

فإذا حدث تغيير فالكهربائي فردي و المغناطيسي زوجي M_6 , E_7 يكونان ممكنين

و المهيمن الرئيسي M_4

⑥ $0^{+} \longrightarrow 0^{+}$

$$|0 - 0| \leq \mathbf{L} \leq |0 + 0|$$

$$\mathbf{L} = 0$$

لا يمكن لأن فوتون كاما لا يحمل زخما زاويا = صفر

$\therefore$ البديل تحول الكترون داخلي

أو تكوين زوج e^{+} , e^{-} اذا كان

$$E_i - E_f \geq 1.022 \text{ MeV}$$

∗ But the transition ← مهم

$$0^+ \longrightarrow 0^-$$

This transition can occur only by two photons emission , but it has not detected yet.

∗ In the $0^+ \longrightarrow 0^+$ ← مهم

→ ① **No $\gamma - decay$ (absolutely forbidden)**

No **E.M.** waves with **L = 0**

② **Internal conversion can occur**

③ **Decay by $e^- - e^+$ pair can occur**

If $E_i - E_f \geq 1.022$ MeV , it can predominate over I.C. if the decay energy $(E_i - E_f)$ is high enough