Gamma Rays:–

emission of γ rays are analogous to emission of e.m. radiation from the excited states of atoms, due to the ~~radiation~~ transition of an orbital electron from higher to lower energy state and lies in visible, ultraviolet or infra-red region. After emission of α, β rays, the excited nucleus makes transition from higher to lower energy state by emission of γ rays.

$$E = h\nu = \frac{hc}{\lambda} = \frac{12412.5}{\lambda(A^\circ)} \text{ eV.}$$

(γ rays have much higher energies than those of characteristic X-rays).

Passage of γ rays through matter:–

While passing through matter, γ-ray photons are either completely absorbed or are deflected (scattered) from their path, usually at large angles. For both these reasons, the intensity of a collimated beam of γ-rays is reduced as it passes through matter.

$$dI = -\mu I\, dx \quad (\mu = \text{attenuation co-eff}).$$

$\mu \rightarrow$ dim $\rightarrow$ m^{-1}.

$$\mu_m = \frac{\mu}{\rho} = \text{mass attenuation co-eff.}$$

$$I = I_0 \exp\left(-\frac{\mu}{\rho}\rho x\right) = I_0 \exp(-\mu_m \rho x).$$

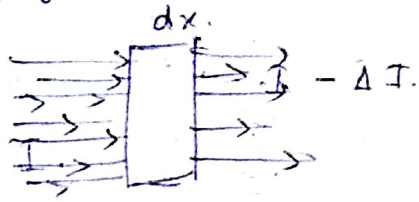
where the thickness of the absorber $(x\rho)$ is measured in terms of the mass per unit area.

$\mu_{ab} \rightarrow$ absorption co-eff, $\mu_{sc} \rightarrow$ scattering co-eff.

$$\mu = \mu_{ab} + \mu_{se}.$$

n = number of atomic centres producing attenuation per unit volume.

$$n = \frac{N_0 \rho}{M}.$$



$$\sigma_{ab} = \frac{\mu_{ab}}{n} \quad \text{and} \quad \sigma_{sc} = \frac{\mu_{sc}}{n}.$$

(cross section for absorption) (cross section for scattering)

experimentally, $\ln I = \ln I_0 - \mu x$.

$$\ln \frac{I}{I_0} = \ln \frac{1}{2} = -\mu\, d_{1/2}.$$

(If the intensity is reduced to half its initial value)

$$\mu = \frac{\ln 2}{d_{1/2}} = \frac{0.693}{d_{1/2}}.$$

($d_{1/2} \rightarrow$ half value thickness).

$$\sigma = \sigma_{ph} + \sigma_e + \sigma_p \rightarrow \text{pair production.}$$

σ_{ph} → photoelectric absorption. σ_e → compton scattering.

[γ rays interact with matter by these three processes]

In the first two cases, γ photons collide with atomic electrons, while in third mainly with nuclei. At low energies, first two processes are imp and at higher energies ($E_\gamma > 3$ MeV) pair production is important.

photoelectric absorption of γ rays

If a photon of energy $h\nu > B_e$, then the electron absorbs whole energy, and is emitted from the atom with KE, $E = h\nu - B_e$.

$E_K = h\nu - B_{eK}$; $E_L = h\nu - B_{eL}$ .....

$\therefore h\nu = E_K + B_{eK} = E_L + B_{eL} = E_M + B_{eM}$ .....

$\because B_{eK} > B_{eL} > B_{eM}$ .....

$E_K < E_L < E_M <$ .....

• photoelectric absorption takes place for an electron bound to atom not for free electrons. Since energy & momentum conservation can't be satisfied in latter case.

emission of K shell electron is more probable (80%).

Total photoelectric absorption cross section for K electron is →

for non relativistic limit → $\sigma_{ph} = \sigma_e Z^5 4\sqrt{2}\,\alpha^4 \left(m_0c^2/\hbar\omega\right)^{7/2}$. i.e. σ_{ph} falls off rapidly with increasing γ energy ($\hbar\omega$)

σ_e = thomson scatter cross section $= 8\pi r_0^2/3$

where r_0 = classical electron radius $= 2.81\times10^{-15}$ m, α is Sommerfeld's fine structure const.. Since $\lambda \propto \frac{1}{\hbar\omega}$ $\therefore \sigma_{ph} \propto Z^5\lambda^{7/2}$.

in relativistic limit ($\hbar\omega \gg m_0c^2$), $\sigma_{ph} \propto Z^5\lambda$

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Pair Production → Conversion of radition energy into mass energy when photon photon is completely absorbed energy exceed $2m_0c^2 = 1.02$ MeV., created particle must have equal and opposite charges.

$$E_\gamma = h\nu = 2m_0c^2 + E^+ + E^- = (E^- + m_0c^2) + (E^+ + m_0c^2)$$

where E^+ and E^- are K.E of positron and electron and $m_0c^2 = 0.51$ MeV.

The photon energy in excess of this amount is shared almost equally betn. the two particles, with the positron receiving slightly more $\simeq 0.0075Z$ MeV. than the negatron as it is rebelled by the nucleus while the negatron is attracted.

- It is necessary that $h\nu > 2m_0c^2$ or, 1.02 MeV because this amount of electrons is required to supply the rest energy of the two particles.

The process inverse to pair production is annihilation.

for charge conservation, the paired particle is of opposite charge.

Radiative transition :- When a nucleus makes a transition from excited state to lower state, it usually emit e.m (γ ray) radiation without change of A or Z. This is known as radiative transition.

Internal Conversion:- After α or β decay, the nucleus is left in an excited state. The transition from an excited state is accomplished by the emission of γ rays i.e. $h\nu = E_1 - E_2$. But the transition from an excited state of a nucleus to a lower state of the same nucleus can also be acheived without the emission of a photon.

The energy of excitation is directly transferred to a bound electron of the same atom.

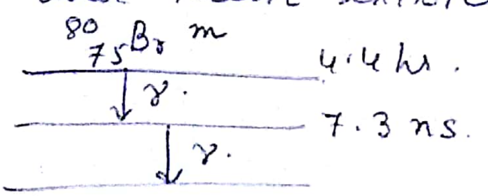
The energy diff (W) between excited state and ground state is converted to energy of an atomic electron which is ejected from the atom with K.E. E_K'

$$E_K' = W - B_K = E_1 - E_2 - B_K$$

or, $W - B_L$ etc. where B_K, B_L are the binding energies of an electron from K, L shell respectively.

Nuclear Isomerism.

The life time of most of the γ ray transitions have been found to be very small but in few cases (about 250) it has been found that life time for γ decay is measurable with observed half lifes varying from 10^{-10} to many years. These delayed transitions are known as isomeric transitions and states from which such transition takes places are known as isomeric state. For this delayed transition, such pairs of nuclides exist which have the same atomic number and mass number i.e. they are isotopic and isobaric but have different radioactive properties. Such nuclides are called nuclear isomers and their existence is termed as nuclear isomerism.



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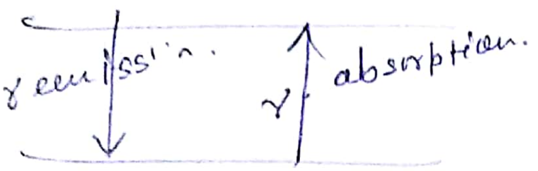
γ rays.

Nuclear resonance Absorption and Fluorescence

The phenomenon of nuclear resonance absorption occurs when γ radiation emitted during a transition from excited state to ground state is reabsorbed by another nucleus of the same kind.



In case of atomic physics such resonance effects are very easy to obserbe and. emission and absorption curves almost overlap with each other. In nuclear physics, the line width of γ radiation is very small ($\approx 6.55 \times 10^{-9}$ eV for $\tau = 10^{-7}$ sec) and therefore a slight perturbation displaces the overlapping emission and absorption lines thus destroying the resonance absorption. The two factors which affect the position and shape of the emission and absorption lines are (1) Nuclear recoil effect (2) doppler effect.

Fluorescence is the phenomenon of the emission of longer wavelength radiation induced by radiation of shorter wavelength. When a radiating system like an atom or a nucleus undergoes radiative transition from an initially excited state 2 to final state 1, the energy difference $E_0 = E_2 - E_1$ between the two states is distributed between the emitted photon and the recoiling emitter, $E_0 = E_\gamma + E_R$, Thus the energy E_γ of the emitted photon is slightly lower than E_0.

Mossbauer effect

In 1958, R. L. Mossbauer observed that under certain circumstances, γ rays could be emitted from nuclei without any loss of energy due to recoil of the emitting nucleus. These γ rays have the same energy as the transition energy between the two states. This type of transition is known as the recoilless transition and the effect is Mossbauer effect.

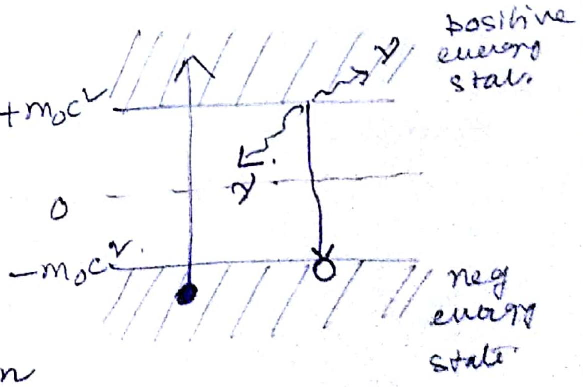
Mossbauer could produce recoilless transitions by embedding the emitting atoms in a solid lattice. The recoil energy is low enough (~ 0.05 eV) so that the emitting atoms are not dislodged from their lattice sites. In this case, the recoil is taken up not by the target atom, but by the entire crystal.

Dirac's theory :–

The relativistic relation between energy and momentum of electron is $E^2 = p^2c^2 + m_0^2c^4$

$$\therefore E = \pm\sqrt{p^2c^2 + m_0^2c^4}.$$

This relation shows that, the total energy of an electron can be either greater than m_0c^2 or less than $-m_0c^2$ where m_0 is the rest mass of electron.



To lift an electron from negative energy state, electrons have to cross an energy barrier of $2m_0c^2$.

As the negative energy states are completely filled with electron so there is no possibility for electron to make a transition from +ve energy state to −ve energy state. However if by some means an electron is removed from a negative energy state, then a vacancy or hole is created in the sea of negative energy states filled with electrons which is called positron.

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Since such a hole is created due to the absence of a negatively charged electron, it will behave as a positively charged particle, with charge $-(-e)$ or $+e$.
Further, the absence of a particle in the state of negative energy $-E$ and of negative momentum $-p$. will manifest as a particle of positive energy $-(-E)$ or $+E$ and positive momentum $(+p)$ or $-(-p)$.

Thus the action of γ-ray of energy greater than $2m_0c^2$ is to create simultaneously an <u>electron-positron pair</u>.

Electron-positron pair production cannot take place in vacuum, since energy and momentum are not conserved in this case. Pair creation usually occurs in the immediate vicinity of the nucleus of an atom, where Coulomb electric field is very strong. Due to the interaction between this electric field and photons, the latter sometimes materializes into an electron-positron pair. So pair production is an example of the transformation of energy into matter.

Selection Rules:-

All nuclear transitions are governed by certain selection rules and these selection rules are based on conservation laws.

According to law of conservation of energy, the emitted γ ray photon energy is governed by the rule, $E_f - E_i = \hbar\omega$.

Conservation of Charge:- Since the emitted photons do not carry any charge, the conservation of charge requires that the final state must have the same charge as that of the initial state.

Conservation of Angular momentum:- As photon carries its ang momentum in multipole radiation of γ rays, the conservation of angular momentum requires that the vector diff of the angular momentum of the initial and final states must be; $I_i - I_f = l$

The condition for E-l and M-l radiation,

$$|I_i - I_f| < l \leq |I_i + I_f|$$

where l is ang momentum of photon.

Conservation of parity:-

The rule is $\Delta\pi = (-1)^{l}$ →(a) for (E - l) radiation

$\Delta\pi = (-1)^{l-1}$ → (b) (M - l) ,,

e.g. for $l = 1$, $\Delta\pi = -1$ → odd parity.

$l = 2$. $\Delta\pi$ = even parity (for E_2 radiation electric quadrupole)

Elect dipole	E_1	Ang momentum $\hbar$	parity change → Yes
Mag ,,	M_1	,, $\hbar$	No.
Elect quadrupole	E_2	,, $2\hbar$	No
Mag ,,	M_2	,, $2\hbar$	Yes
Elect	Octapole.	,, $3\hbar$	Yes
Mag	Octupole	,, $3\hbar$	No.

e.g. If $I_f = 5$, $I_i = 3$

∴ l can have values from $5-3 = 2$ to $5+3 = 8$ but disintegration const for higher l falls of rapidly retaining only $l = 2$.

Multipole Radiations:-

A γ ray is an electromagnetic wave similar to light or radio waves and their emission from the nucleus arises from the interaction of the nucleus with the e-m radiation field just as light emission results from an interaction of atomic electrons with that field. In the interaction the energy is transferred from the nucleus to the field and this excitation of the field appears as γ rays.

An e-m wave is an oscillating electric and mag field; a changing electric field gives rise to mag-field and vice versa. Such an e-m wave can be produced by an oscillating electric charge (which produced oscillating electric field) or by an oscillating electric current (which produced oscillating mag field). These oscillating charges and current elements not only radiate energy but they also radiate angular momentum. i.e. the angular momentum is carried by photon equal to $l\hbar = \sqrt{l(l+1)}\,\hbar$.

Thus for diff values of $l = 0, 1, 2$ etc, the ang momentum with photon in Z dir. will be $\hbar, 2\hbar, 3\hbar$ etc.

The radiation emitted from the oscillating electric field is called electric multipole radiation. (E-l)

Similarly, radiation emitted from oscillating mag field and carrying angular momentum l is called magnetic multipole radiation. (M-l)