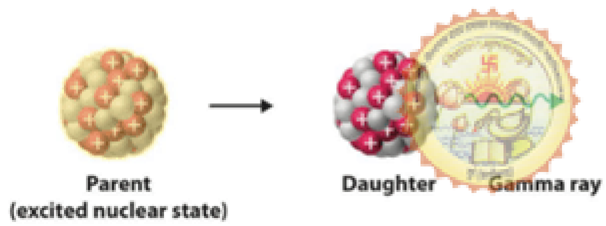
GAMMA RAY EMISSION

A **gamma ray**, or **gamma radiation** (symbol γ), is a penetrating electromagnetic radiation arising from the radioactive decay of atomic nuclei. It contains no matter, but only energy. It is the shortest wavelength electromagnetic waves and so imparts the highest photon energy. Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900 while studying radiation emitted by radium. In 1903, Ernest Rutherford named this radiation gamma rays based on their relatively strong penetration of matter

A nucleus which is in an excited state may emit one or more photons in the form of γ rays. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes. Being chargeless and massless , it causes no change in atomic number or mass number of the parent nucleus after emission. So the parent and daughter are nuclei of same element but in different energy states.

γ emission equation



$$^{Am}_{Z}X \rightarrow \ ^{A}_{Z}X + \ ^{0}_{0}\gamma$$

Fig. 3.1. γ emission equation

Example of gamma emission

1. $({}_{43}Tc^{99})^* \rightarrow {}_{43}Tc^{99} + {}_{0}\gamma^{0}$
2. $({}_{28}Ni^{60})^* \rightarrow {}_{28}Ni^{60} + {}_{0}\gamma^{0}$
3. $({}_{10}Ne^{22})^* \rightarrow {}_{10}Ne^{22} + {}_{0}\gamma^{0}$
4. $({}_{6}C^{12})^* \rightarrow {}_{6}Ni^{12} + {}_{0}\gamma^{0}$

Elementary theory of γ emission

The emission of alpha and beta particles from natural radioactive substances is invariably followed by γ emission. The emission of alpha and beta particles from a radioactive substance often leaves the daughter nucleus in excited state. When this nucleus stabilizes by undergoing transition from excited state to ground state or a lower excited state, it emits a high energy photon. This photon is known as a γ ray. The transition from an excited state to all the lower energy states, however does not occur as some transitions are forbidden by certain selection rules.

Examples

1. $_{88}Ra^{226} \rightarrow (_{86}Rn^{222})^* + {}_2He^4 \rightarrow {}_{86}Rn^{22} + {}_2He^4 + {}_0\gamma^0$

2. $_{27}Co^{60} \rightarrow (_{28}Ni^{60})^* + {}_{-1}e^0 \rightarrow {}_{28}Ni^{60} + {}_{-1}e^0 + {}_0\gamma^0$

Energy equation of γ emission

A γ emission is represented by the equation: $(_ZX^A)^* \rightarrow {}_ZX^A + {}_0\gamma^0$ ....(3.1)

The corresponding energy equation is: $M_Xc^2 + E_2 = M_Xc^2 + E_1 + h\nu$ ....(3.2)

,$M_X \rightarrow$ mass of the parent nucleus = mass of daughter nucleus

$M_Xc^2 \rightarrow$rest mass energy of parent nucleus = rest mass energy of daughter nucleus

$E_2 \rightarrow$ Energy level in which the parent atom in excited state belongs

$E_1 \rightarrow$ Lower energy level in which the daughter atom exists

$h\nu \rightarrow$ energy of the photon emitted in form of ν ray

From equation (3.2) : $E_2 - E_1 = h\nu$ ....(3.3)

<u>**Conservation laws in γ emission**</u>

1. Conservation of charge and nucleon number: In γ emission the daughter nucleus is same as the parent nucleus except for the difference in excitation energy. Also the γ ray photon does not have any charge or mass. So the charge and the number of nucleons are conserved.

2. Conservation of energy: The rest mass energy of the parent is same as the daughter. For being in a higher excited state the parent atom has an energy of $E_2 - E_1$ greater than the daughter. This extra energy is emitted as γ ray photon of energy $h\nu$ (equation 3.3). Thus energy is conserved in γ emission.

3. Conservation of linear momentum: The linear momentum associated with a γ ray photon of energy $h\nu$ is : $p = \frac{h\nu}{c}$. Hence momentum conservation demands that the parent atom is at rest, the daughter nucleus should recoil with same momentum in a direction exactly opposite to the γ ray photon. If M_X be the mass of the daughter nucleus it should recoil with a velocity 'v' given by the momentum conservation relation: $\frac{h\nu}{c} + M_X v = 0$ ………………………………(3.4)

4. Conservation of angular momentum: The spin angular momentum of a photon is ħ. So it contributes integer spin. Hence if the angular momentum daughter side, whether integer or half odd integer multiple of ħ, will be same as that of parent side. Hence angular momentum is conserved.

Positron

The existence of positron was first suggested by Dirac in his attempt to solve the Dirac equation for an electron. The energy eigenvalue for a free electron obtained from Dirac's relativistic wave equation is

$$E = \pm(p^2c^2 + m_e^2c^4)^{1/2} \quad \text{………………………………………………(3.5)}$$

The relation shows the existence of both positive and negative energy states. The energy of electron moving in the conduction band is by convention positive. To account for the negative energy Dirac proposed the existence of an antiparticle of electron – the **positron**. It was proposed that, Positron is an elementary particle with negative energy states, having the same mass and equal and opposite charge and spin as that of an electron. If an electron combines with a positron annihilation occurs and energy is released.

Electron positron Pair production by γ rays.

Pair production is the process of production of electron-positron pair from a γ ray photon in presence of a strong electromagnetic field. This, in effect, is the direct conversion of electromagnetic energy to mass from vacuum, which was first observed by Anderson in 1932, in cloud chamber photographs. **A nucleus, due to its positive charge produces a strong electromagnetic field around its vicinity. So if a γ ray photon passes through the zone of strong field there, it will get transformed to electron-positron pair at the expense of its own existence. All the conservation laws hold in this process.**

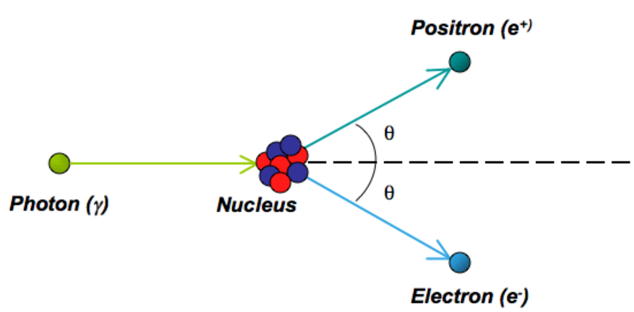


Fig. 3.2. Pair production from a γ ray photon in the vicinity of nucleus

The equation of pair production

From energy conservation the equation of pair production is given by:

$$E_\gamma = h\nu = 2m_ec^2 + E^+ + E^- \quad \text{...(3.6)}$$

Where $E_\gamma = h\nu \rightarrow$ the energy of γ ray photon

$E^+ \rightarrow$ kinetic energy of positron

$E^- \rightarrow$ kinetic energy of electron

$m_e \rightarrow$ rest mass of electron = rest mass of positron

$m_ec^2 \rightarrow$ rest mass energy of electron = rest mass energy of positron.

Here, the small amount of energy carried away by the recoil nucleus is ignored. Equation (3.6) shows that **the minimum amount of energy required for electron – positron pair production is $2m_ec^2$.** So this process can occur only if the photon energy exceeds $2m_ec^2$. Because an electron has a rest mass energy equivalent to 0.511 MeV of energy, a minimum gamma-energy of 1.02 MeV is required for pair production. Any excess energy of the pair-producing gamma-ray is almost equally shared between the electron–positron pair as kinetic energy, with positron receiving a slight more (≈ 0.0075MeV) than the electron as it is repelled by the nucleus while the electron is attracted. Such differences become insignificant as photon energy increases.