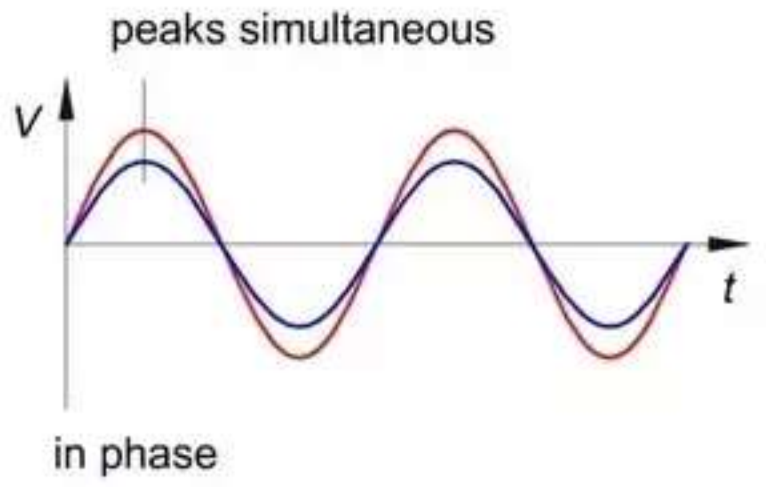
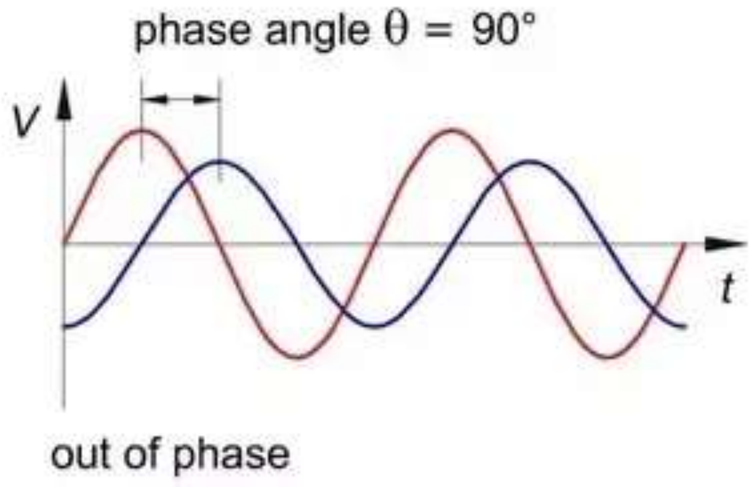
Thomson scattering

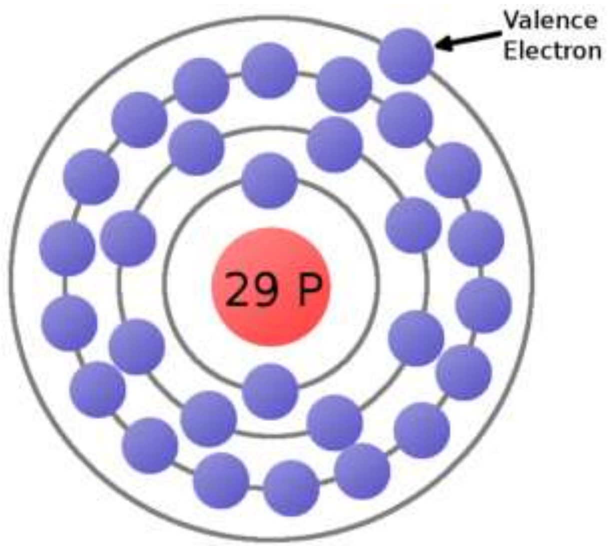
Thomson scattering is a fundamental process in physics that describes the interaction between electromagnetic radiation (such as light) and charged particles (typically electrons). It was first described by the Scottish physicist Sir J.J. Thomson in the late 19th century. When electromagnetic radiation wave of frequency ***f*** is incident and interacts with charged particles, such as electrons, These are electrons that are not tightly bound to atoms.

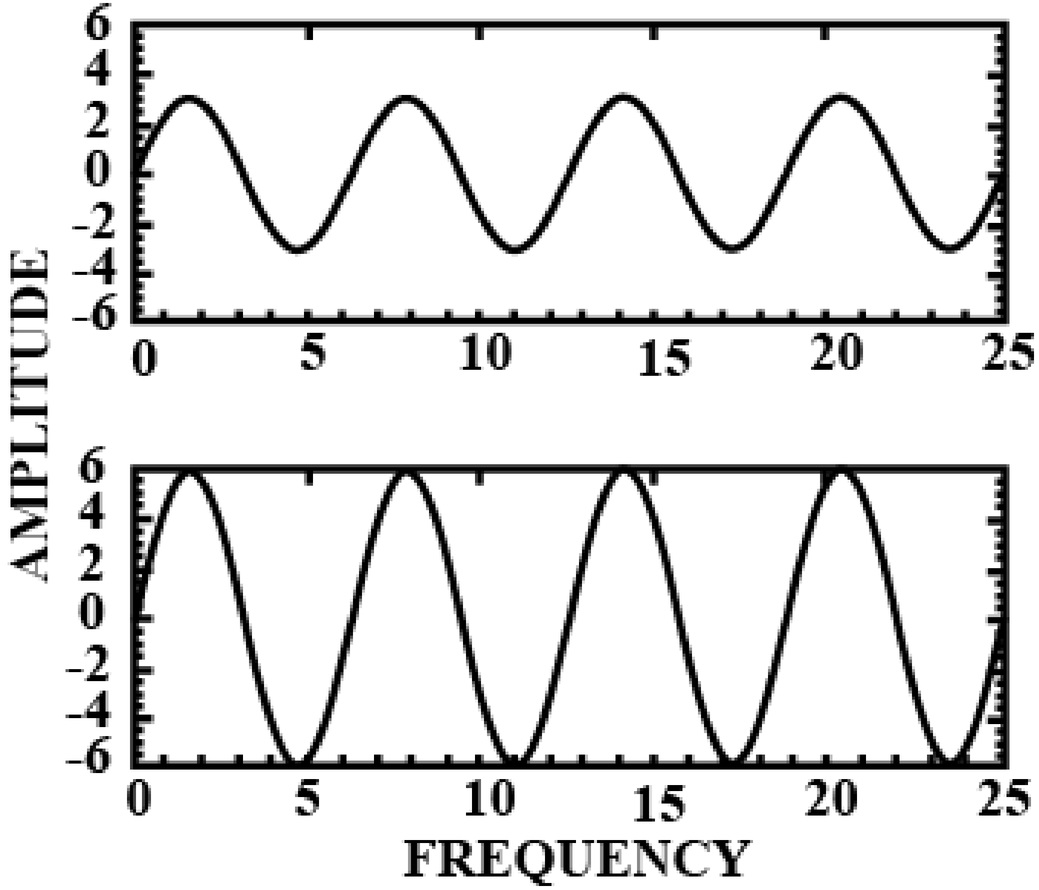
What happens to the electron?

Thus the electrons are accelerated by the electric field of the radiation. This emitted EM radiation waves is known as scattered radiation of the same frequency and in phase with the incident wave. The electron absorbs energy from the EM wave and scatters it in a different direction









6
4
2
0
-2
-4
-6
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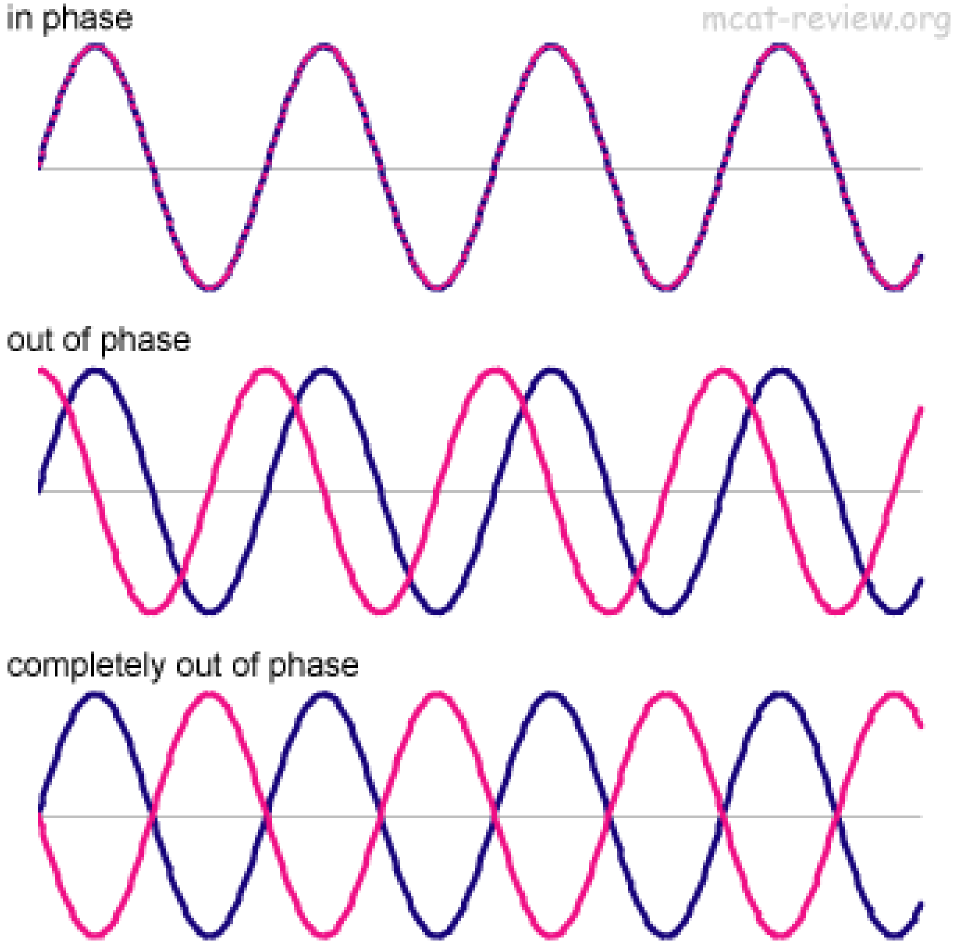
5
10
15
20
25
AMPLITUDE
FREQUENCY



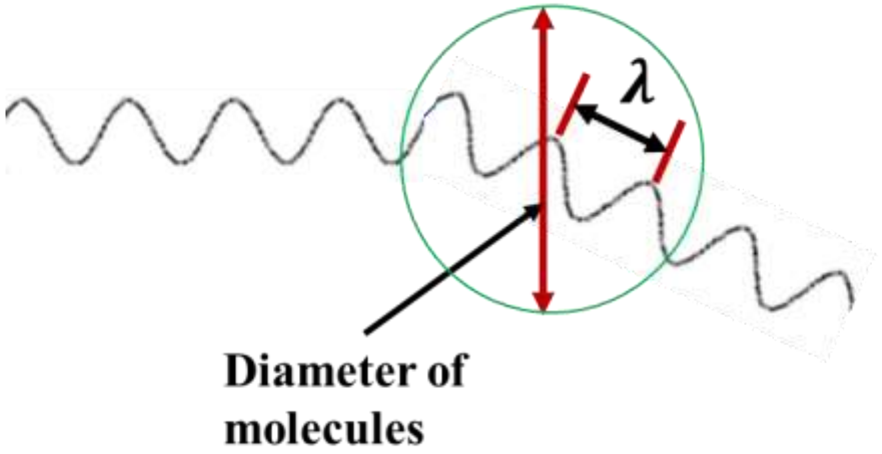
in phase
mcat-review.org
out of phase
completely out of phase

Coherent (Rayleigh) scattering

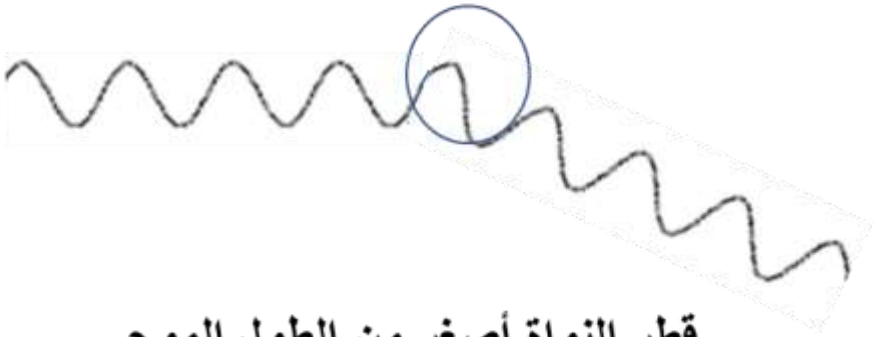
Coherent scattering, also known as Rayleigh scattering, is a phenomenon that occurs when light interacts with particles or molecules that are much smaller in size compared to the wavelength of the light. This scattering process is responsible for the blue color of the sky and the reddening of the sun during sunrise and sunset.

For example, molecules in the atmosphere, such as nitrogen and oxygen, are much smaller than the wavelengths of visible light.

The intensity of the scattered light is inversely proportional to the fourth power of the wavelength. This means that shorter wavelengths (such as blue and violet light) are scattered much more strongly than longer wavelengths (such as red and yellow light). This is why the sky appears blue: shorter blue wavelengths are scattered more by the atmosphere compared to longer wavelengths like red.



قطر النواة أكبر من الطول الموجي



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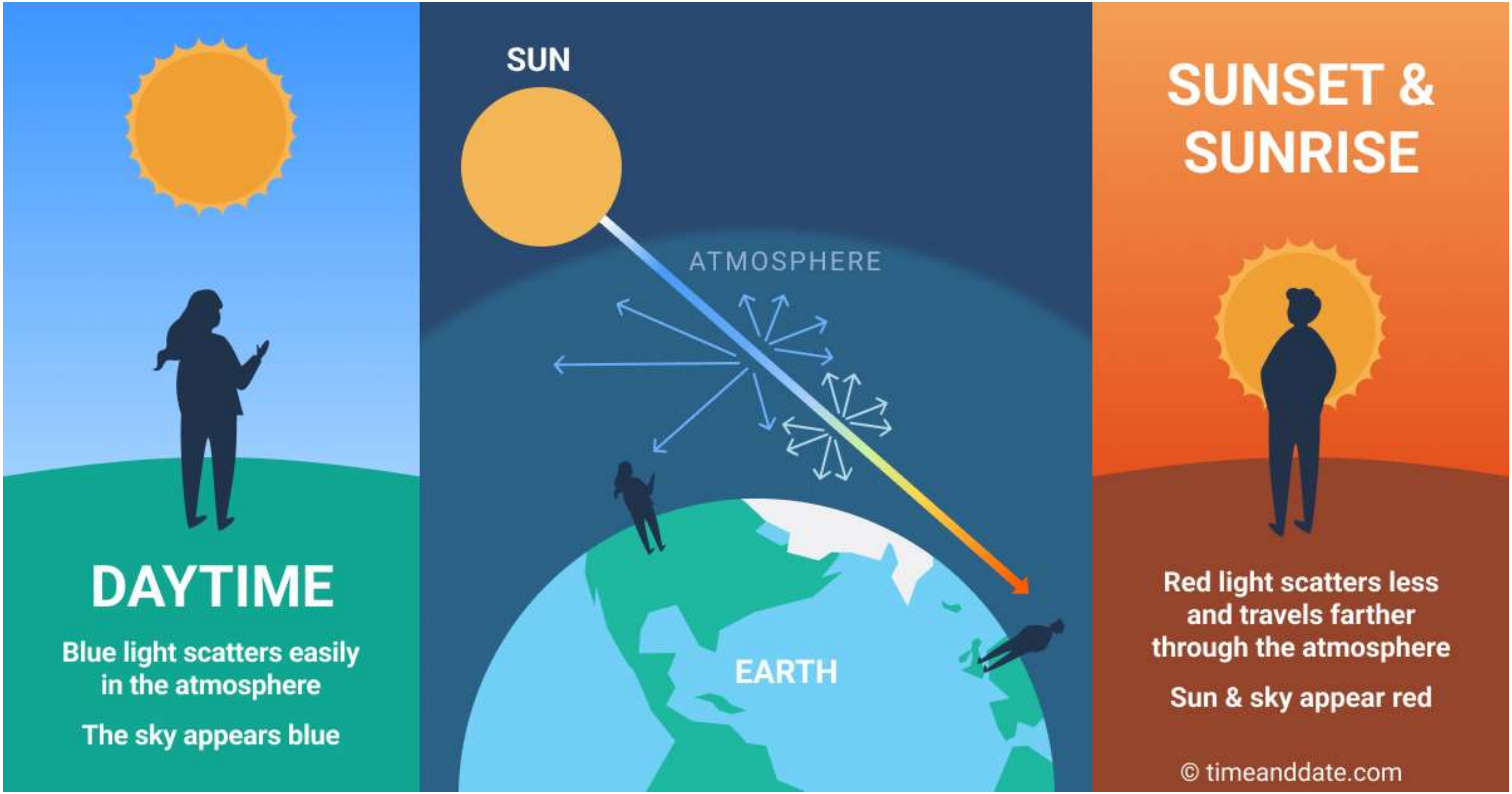
DAYTIME
Blue light scatters easily in the atmosphere
The sky appears blue
SUN
ATMOSPHERE
EARTH
SUNSET & SUNRISE
Red light scatters less and travels farther through the atmosphere
Sun & sky appear red
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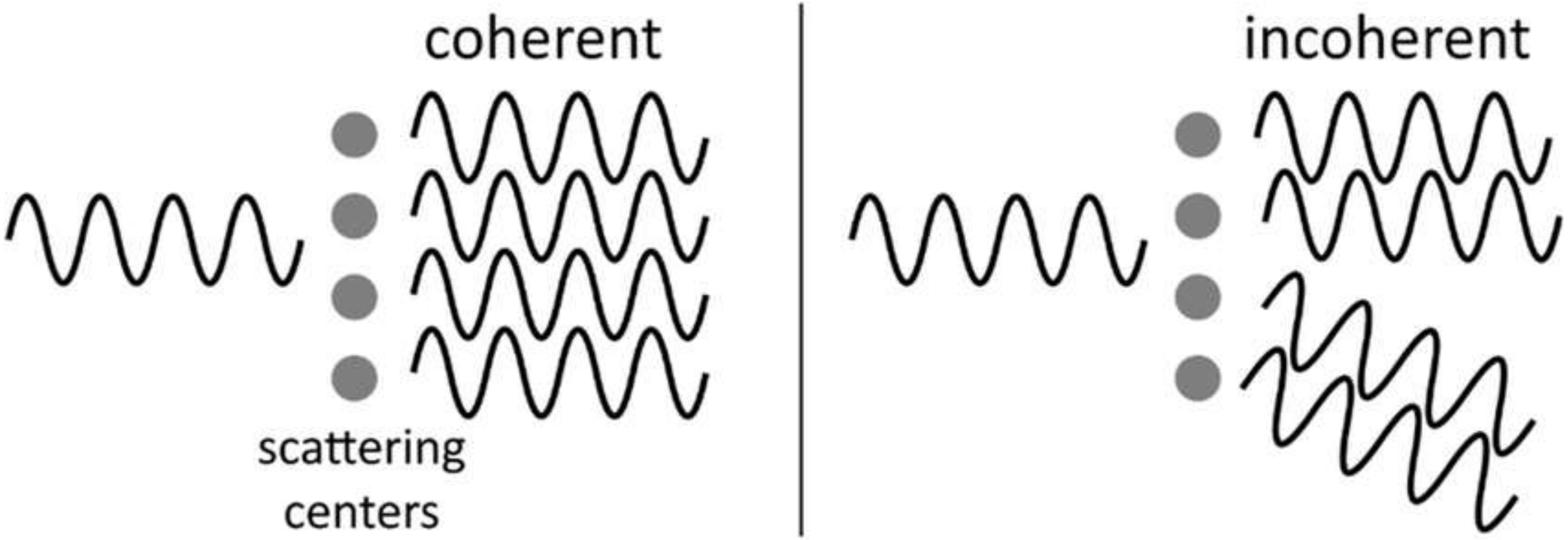
Incoherent scattering

Incoherent scattering refers to the process where electromagnetic radiation, such as light or X-rays, interacts with matter in a way that disrupts the phase relationship between the incoming and outgoing waves. This disruption results in a scattered pattern that lacks a consistent phase relationship, hence the term "incoherent."

Imagine throwing a handful of pebbles into a calm pond. Each pebble creates ripples that spread outwards, interfering with each other. If you were to observe these ripples, you would notice that they don't maintain a consistent pattern; instead, they seem chaotic and disorganized. This is analogous to incoherent scattering, where incoming waves interact with particles in a material, causing them to scatter in various directions with no specific phase relationship. Incoherent scattering occurs when the wavelength of the incident radiation is much larger than the spacing between atoms or molecules in the material. As a result, the scattering is dominated by interactions with individual electrons rather than the entire atomic structure. where the scattered radiation provides information about the internal structure of tissues.


coherent
scattering
centers
incoherent

Pair and triplet production

Pair production and triplet production are two processes in particle physics that occur when a high-energy photon interacts with matter

1.Pair Production: A gamma ray photon with energy greater than the rest mass energy of the particle-antiparticle pair (at least 1.02 MeV for electron-positron pair production) enters the vicinity of an atomic nucleus. The electric field of the nucleus interacts with the photon, typically near the nucleus, due to its strength. The energy of the photon is converted into the mass of the particle-antiparticle pair according to Einstein's famous equation, $E=mc^2$, where E is energy, m is mass, and c is the speed of light. The photon disappears, and in its place, an electron-positron pair emerges from the energy. This process must conserve both energy and momentum.

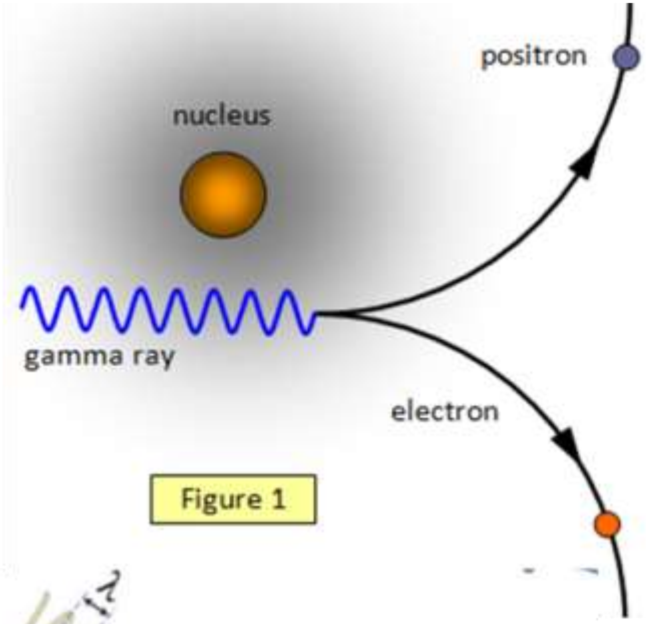
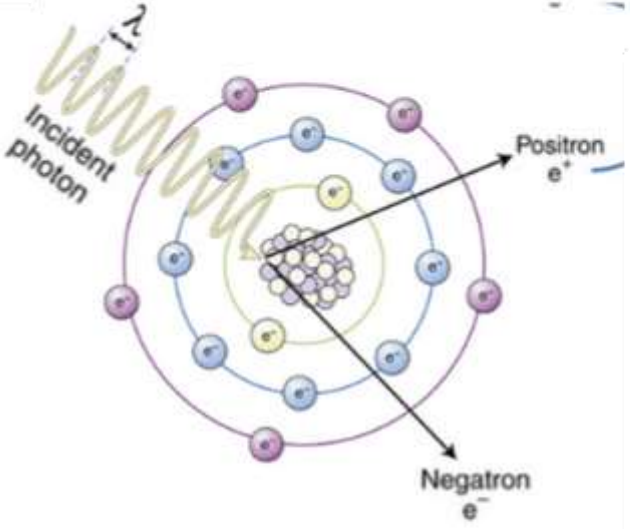


Figure 1

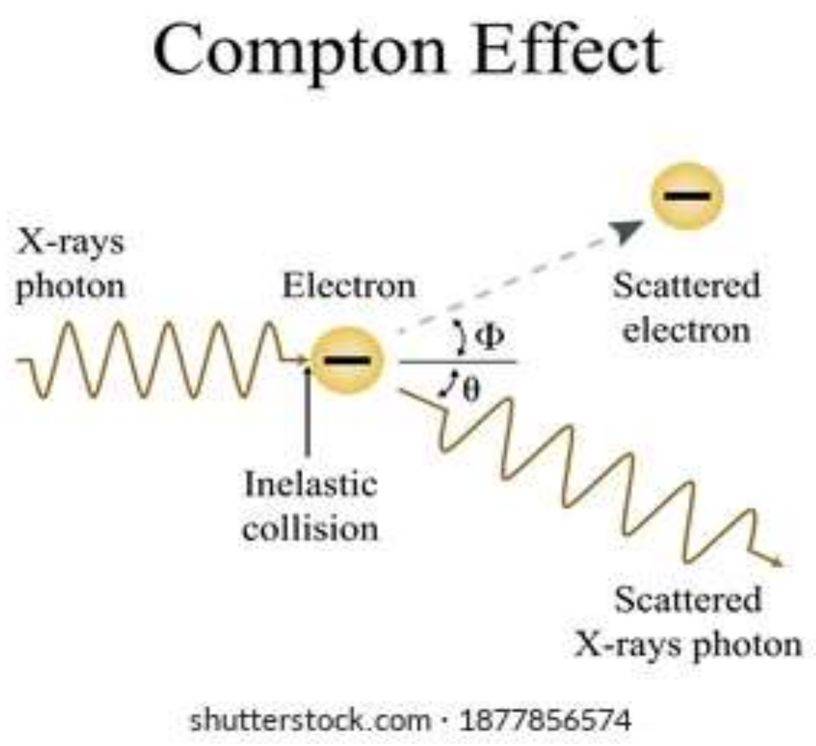


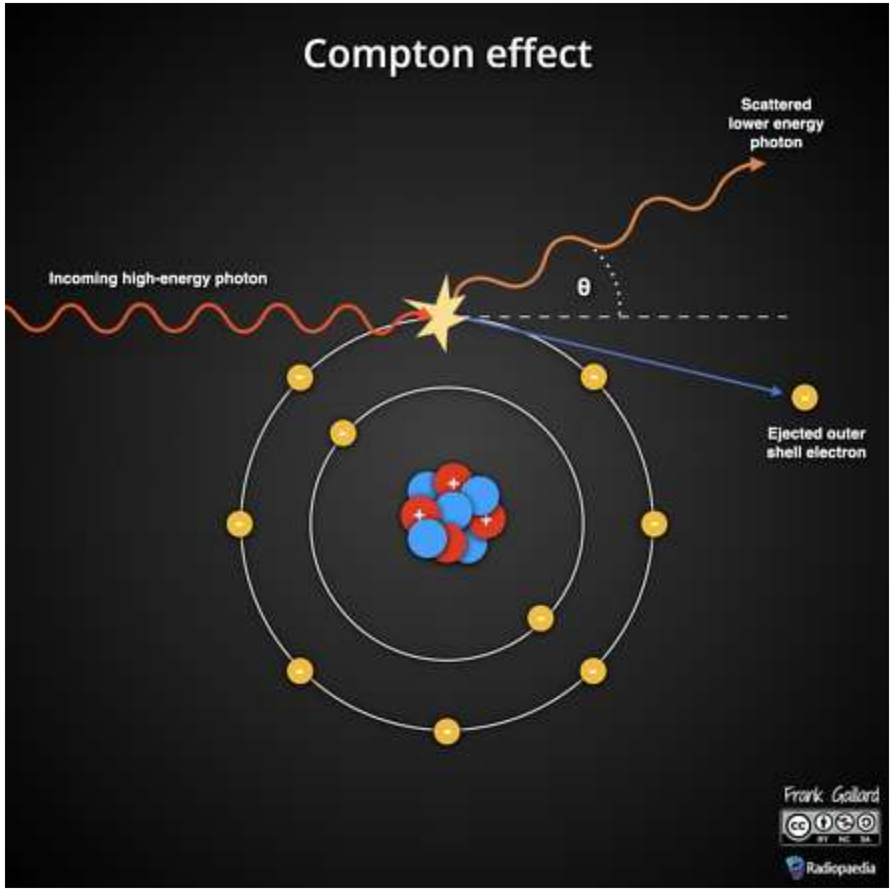
2- Triplet production: is a process similar to pair production but involves the creation of two particles and one antiparticle. This process typically occurs when a high-energy photon interacts with the strong electric field of an atomic nucleus. Here's how triplet production interacts with matter:

1. **High-energy photon**: A gamma ray photon with energy greater than the total rest mass energy of the particles involved in triplet production enters the vicinity of an atomic nucleus.
2. **Electric field interaction**: The strong electric field of the nucleus interacts with the photon due to its strength.
3. **Energy conversion**: The energy of the photon is converted into the mass of two particles and one antiparticle, typically an electron, a positron, and an electron or positron (depending on the energy threshold).
4. **Creation of particles and antiparticle**: The photon disappears, and in its place, two particles and one antiparticle emerge from the energy. This process must conserve both energy and momentum.
5. **Interaction with matter**: The newly created particles and antiparticle may travel some distance through matter, undergoing interactions such as scattering, ionization, and energy loss through bremsstrahlung radiation or annihilation if they encounter their respective antiparticles.
6. **Further interactions**: The particles and antiparticle may continue to interact with matter, losing energy and potentially creating secondary particles through interactions with atomic nuclei or electrons.

Compton scattering by free electrons

Compton scattering: is a phenomenon in physics where a photon (a quantum of electromagnetic radiation) collides with a charged particle, typically an electron, resulting in the photon losing energy and changing its direction. This process is significant in understanding the interaction between photons and matter, especially in the context of X-ray and gamma-ray interactions.





When a photon interacts with a free electron through Compton scattering, several things can occur:

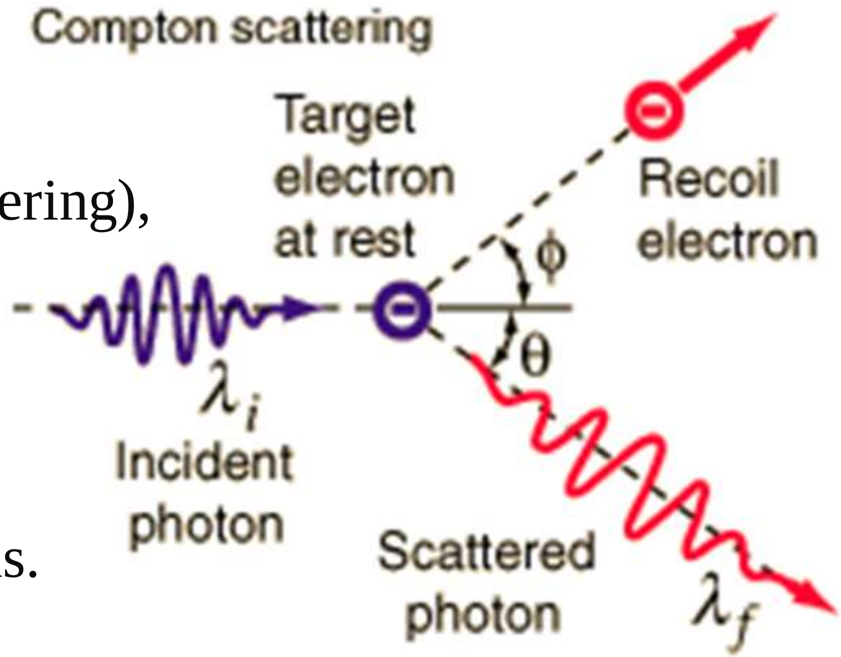
1. **Photon-electron interaction**: The incident photon interacts with the electron, transferring some of its energy and momentum to the electron.
2. **Scattered photon**: The photon emerges from the interaction, but with reduced energy and altered direction compared to its original trajectory. This change in energy and direction is a consequence of momentum and energy conservation laws.
3. **Energy transfer**: The energy lost by the photon is transferred to the electron, causing it to recoil.

The scattered photon typically has a longer wavelength (lower energy) than the incident photon.

Compton scattering is an essential process in various fields, including medical imaging (such as CT scans)

Compton wavelength

$$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{m_e c}(1 - cos\theta)$$



- $\Delta\lambda$ is the change in wavelength of the photon (resulting from scattering),
- λ_f is the wavelength of the scattered photon,
- λ_i is the wavelength of the incident photon,
- h is the Planck constant ($6.62607015 \times 10^{-34}$ m² kg/s),
- m_e is the mass of the electron ($9.10938356 \times 10^{-31}$ kg),and
- θ is the scattering angle between the incident and scattered photons.

Ex: An X-ray photon with an initial wavelength of 0.02 nm scatters off a free electron and emerges with a wavelength of 0.025 nm. Calculate the angle by which the scattered photon deviates from its original direction.

$$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{m_e c}\ (1 - cos\theta)$$

$$(0.025nm - 0.020nm) = \frac{6.626 \times 10^{-34} m^2 Kg/s}{(9.109 \times 10^{-31} Kg) \times (3 \times 10^8 m/s)}(1 - cos\theta)$$

$$cos\theta \approx 0.773$$

$$\theta = cos^{-1} 0.773 \approx 39.6°$$

Q) An X-ray photon with an initial wavelength of 0.030 nm is scattered at an angle of 90°. What is the wavelength of the scattered photon?

Photon Attenuation Coefficients

The photon attenuation coefficient, often denoted as μ, represents the probability of a photon being absorbed or scattered per unit length as it travels through a medium. It's a fundamental parameter in the study of photon interactions with matter, crucial in various fields such as medical imaging, radiation therapy, and industrial radiography.

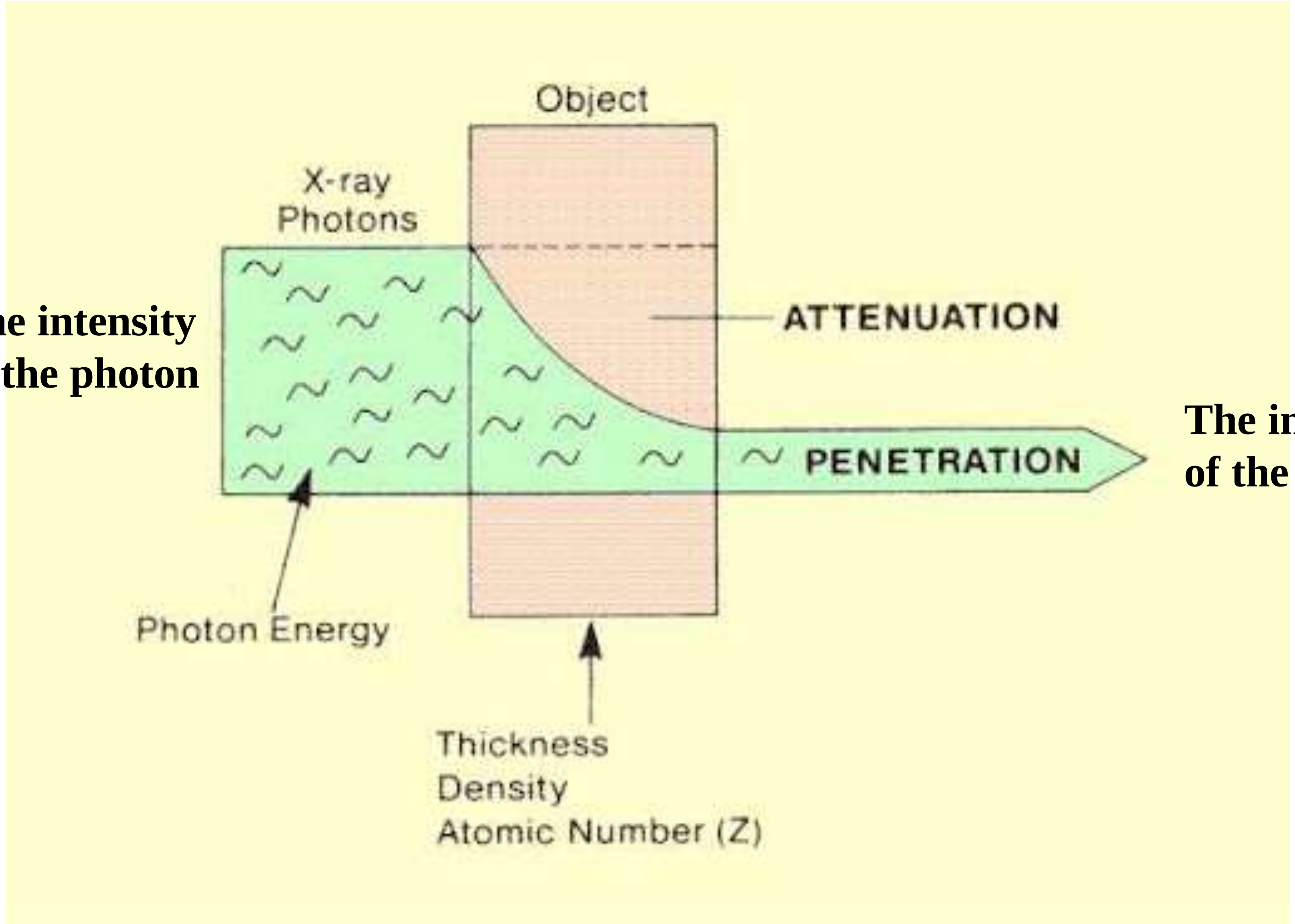
The linear attenuation coefficient is a measure of how a material attenuates or reduces the intensity of a beam of radiation as it passes through. It's typically denoted by the Greek letter μ (mu) and has units of length^{-1}. Mathematically, it represents the fraction of a beam's intensity that is attenuated per unit thickness of the material.

In the context of X-rays or gamma rays passing through a material, the linear attenuation coefficient depends on several factors, including the type of radiation, the energy of the radiation, and the composition and density of the material.

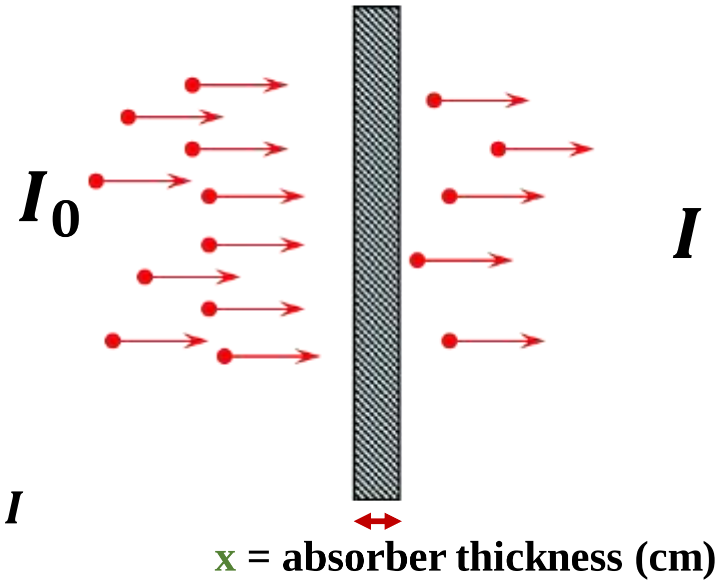
The equation that describes attenuation of a beam of radiation as it passes through a material is:

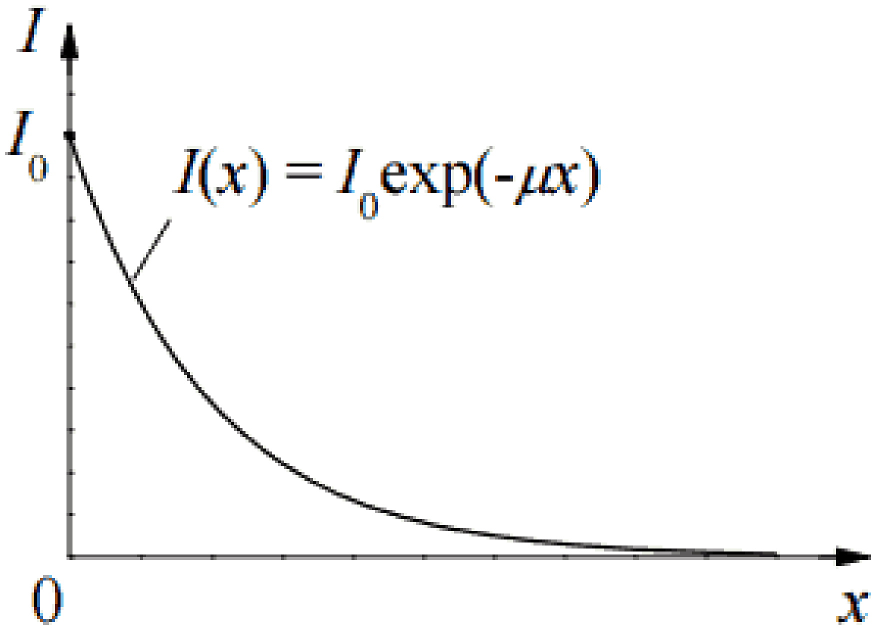
$$I = I_0 e^{-\mu x}$$

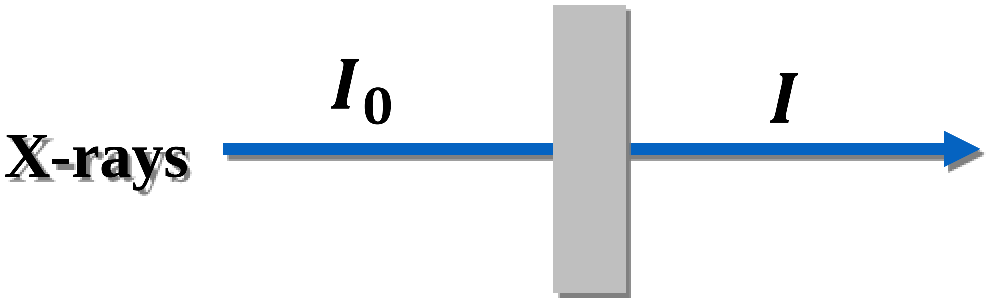
The intensity of the photon I_0



The intensity of the photon I







Where:

- I is the intensity of the radiation after passing through a thickness x of the material.
- I_0 is the initial intensity of the radiation before passing through the material.
- μ is the linear attenuation coefficient of the material.
- x is the thickness of the material.

EX: An X-ray beam with an initial intensity of I_0=150 units passes through a 3 cm thick layer of tissue with an attenuation coefficient μ=0.2 cm^{-1}. Calculate the intensity of the X-ray beam after passing through the tissue.

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

$I = 150 \times e^{-0.2\times 3}$ $\quad \rightarrow I = 150 \times 0.5488 \approx 32.82\, units$