## Types of Radiation produced in the x-ray tube are:

### 1- Bremsstrahlung Radiation:

Originates from the German word for "braking radiation". When high speed electrons are directed toward the tungsten target, they interact with the nuclei of the atoms in the tungsten target in two ways, namely,

- **Direct hit:** a high-speed electron hit the nuclei of the atoms in the tungsten target directly and produce X- ray photon energy equal to the kinetic energy of the high-speed electron. The closer the high-speed electron approaches the nuclei, the greater the electrostatic attraction between the nucleus and the electron, and the resulting bremsstrahlung photons have higher energy.
- **Near miss/wide miss:** (resulting in the deflection of the electron from its original path).

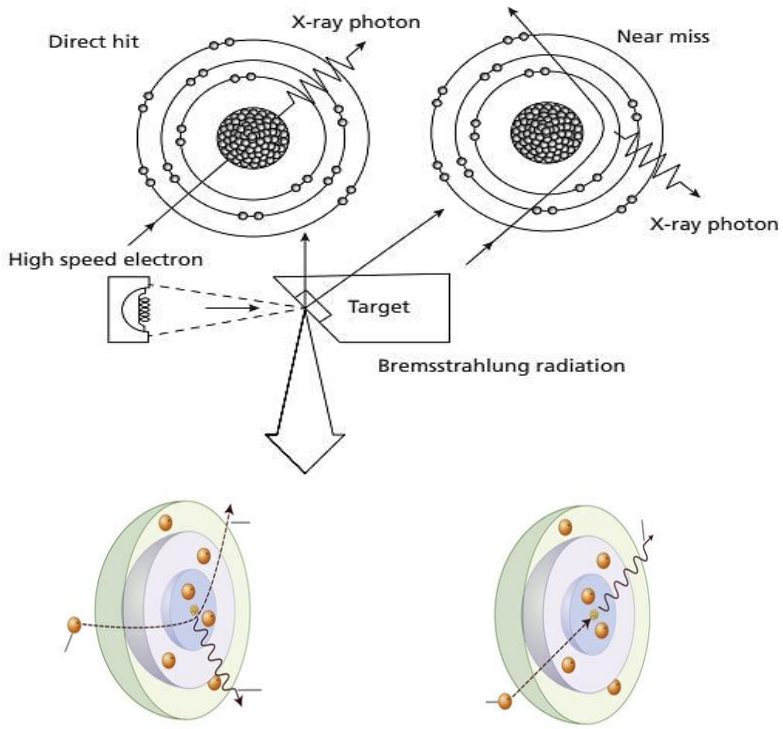


**Fig 1: Bremsstrahlung radiation is produced most often by the passage of an electron near a nucleus, which results in electrons being deflected and decelerated (A) or, less frequently, by the direct hit of an electron on a nucleus in the target (B).**

## 2- Characteristic radiation:

Characteristic radiation contributes only a small fraction of the photons in an x-ray beam. It is made when an incident electron ejects an inner electron from the tungsten atom. When this happens, an electron from an outer orbital is quickly attracted to the void in the deficient inner orbital. When the outer orbital electron replaces the displaced electron, a photon is emitted with energy equivalent to the ***difference in the binding energies of the two orbitals***.

The energies of characteristic photons are discrete because they represent the difference of the energy levels of specific electron orbitals and are characteristic of the target atoms. The production of characteristic radiation has no practical implications for dento-maxillofacial radiography.

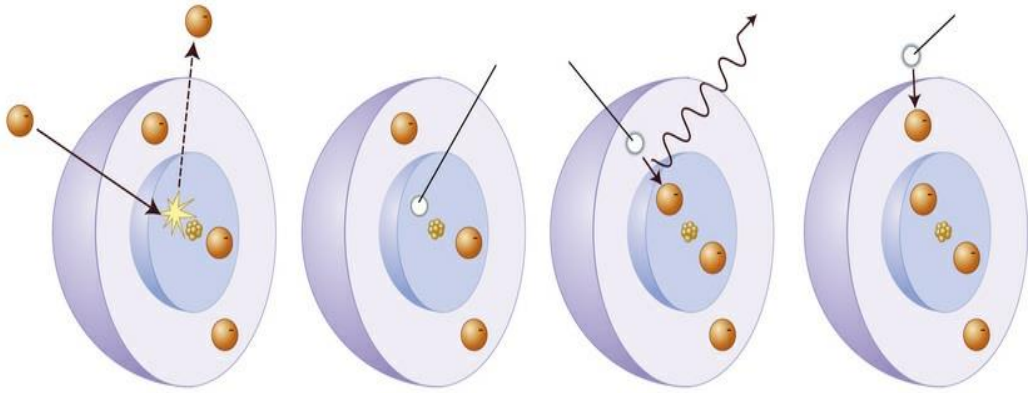

**Fig 2: Production of characteristic radiation. An incident electron (A) ejects an electron from an inner orbital creating an electron vacancy (B). (C) An electron from an outer orbital fills this vacancy, and a photon is emitted with energy equal to the difference in energy levels between the two orbitals. (D) Electrons from various orbitals may be involved, giving rise to other characteristic photons. The energies of the photons released are characteristic of the energy transitions for the target atom.**

## ❖ Factors controlling X-ray beam

X-ray beam may be modified by altering the beam exposure duration (timer), exposure rate (mA), energy (kVp and filtration), shape (collimation) and intensity (target–patient distance).

The term **beam quantity** refers to the number of photons in an x-ray beam.
The term **beam quality** refers to the mean energy of an x-ray beam.

1. **Tube voltage peak (kVp):** Increasing the kVp increases the potential difference between the cathode and the anode, increasing the kinetic energy of the electrons as they move toward the target. The greater the energy of an electron, the greater the probability it will be converted into x-ray photons at the target.

❖ Increasing the kVp of an x-ray machine increase:

- The number of photons generated.
- The mean energy of the photons.
- The maximal energy of the photons

High energy (short wavelength) are preferred as they have greater penetrating power (qualitative and quantitative).

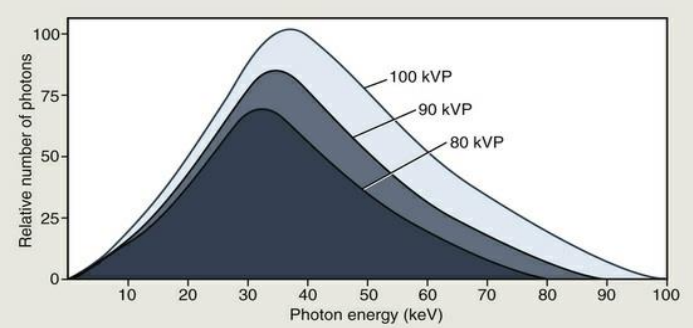


**Fig 3: Spectrum of photon energies generated in an x-ray machine showing that as the kVp is increased (mA and s held constant), there is a corresponding increase in the mean energy of the beam, the total number of photons emitted, and the maximal energy of the photons.**

2. **Exposure time:** typically measured in fractions of a second. When the time of exposure is doubled, the number of photons generated are doubled. The range of photon energies is unchanged.

Practically, it is desirable to keep the exposure time as short as possible to minimize blurring from patient motion. (quantitative).

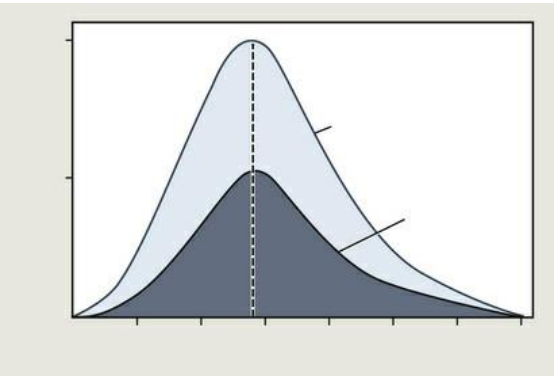

**Fig 4: Spectrum of photon energies generated in an x-ray machine showing that as exposure time increases (kVp and mA settings held constant).**

3. **Milliamperage Setting (mA, Tube current):** Like the effects of exposure time, the quantity of radiation produced by an x-ray tube (i.e., the number of photons that reach the patient) is directly proportional to the milliamperage setting. As the mA setting is increased, more power is applied to the filament, which heats up and releases more electrons that collide with the target to produce radiation, so, doubling the tube current will double the number of photons produced. The product of mA setting and exposure time (**mA × s**, or **mAs**) is often used as a single parameter to denote the total number of photons produced. For instance, a machine operating at 10 mA for 1 second (**10 × 1 = 10 mAs**) produces the same number of photons when operated at 20 mA for 0.5 second (**20 × 0.5 = 10 mAs**). The quantity is increased (quantitative).

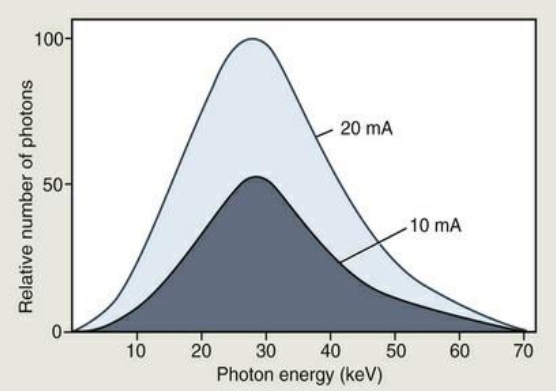


**Fig 5: Spectrum of photon energies generated in an x-ray machine showing that as the mA setting increases (kVp and exposure time held constant).**

4. **Filtration:** filters used will remove the long wavelength with low-energy photon with less penetrating power and allows short wavelength with high-energy photons (qualitative and quantitative) (reduces the quantity). X – ray used in dentistry must be able to penetrate dental hard tissues (teeth and bone). The longer wave length X – ray (soft X – ray) are not useful in diagnostic radiology thus removal of these long wave length photons from the beam by passing the beam through a metallic disk filter made from Aluminum which absorb most of long wave length photons (soft X – ray), the resulting X – ray beam will consist mainly of X – ray photons with short wave length, high energy photons and high penetrating power that's why they named (hard X – ray beam).

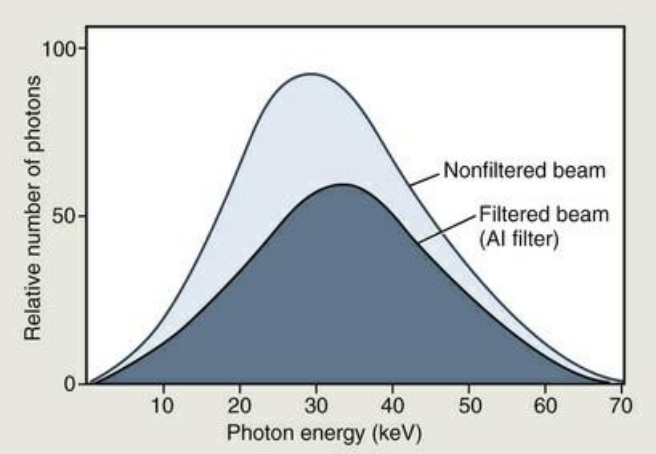


**Fig 6: Spectrum of filtered x-ray beam generated in an x-ray machine showing that an aluminum filter preferentially removes low-energy photons, reducing the beam intensity, while increasing the mean energy of the residual beam.**

## ❖ Types of filtration:

1. Inherent filtration: done by filter built-in to the X–ray machine by manufacturer (as glass wall, the insulating oil and the metal housing of the tube). The inherent filtration of most x-ray machines ranges from the equivalent of 0.5 to 2 mm of aluminum.
2. Added filtration: may be supplied in the form of aluminum disks placed over the port in the head of the x-ray machine.

[total filtration = inherent filtration + added filtration]

❖ Federal regulations in the United States require the total filtration in the path of a dental x-ray beam to be equal to the equivalent of 1.5 mm of aluminum for a machine operating at up to 70 kVp and 2.5 mm of aluminum for machines operating at higher voltages.




**Fig 7: aluminum filter attached to the tube head.**

5. **Collimation:** A collimator is a metallic barrier with an aperture in the middle used to shape and restrict the size of the x-ray beam and the volume of tissue irradiated. Round and rectangular collimators are most frequently used in intraoral radiography. Dental x-ray beams are usually collimated to a circle 2.75 inches (7 cm) in diameter at the patient's face. A round collimator is a thick plate of metal with a circular opening centered over the port in the x-ray head through which the x-ray beam emerges. Typically, round collimators are built into open-ended aiming cylinders. Rectangular collimators limit the size of the beam to just larger than the intraoral receptor, further reducing patient exposure.

### ❖ Types of collimators:

1. diaphragms (round or rectangular shape).
2. metal cylinders, cones and rectangular tubes.

- **Diaphragm:** Consists of a metal plate or disk made from lead with a hole in the center of the disk which allow the beam to pass through it only. The shape of X – ray beam determines by the shape of the diaphragm hole such diaphragm is placed over the opening in the head of X–ray machine.

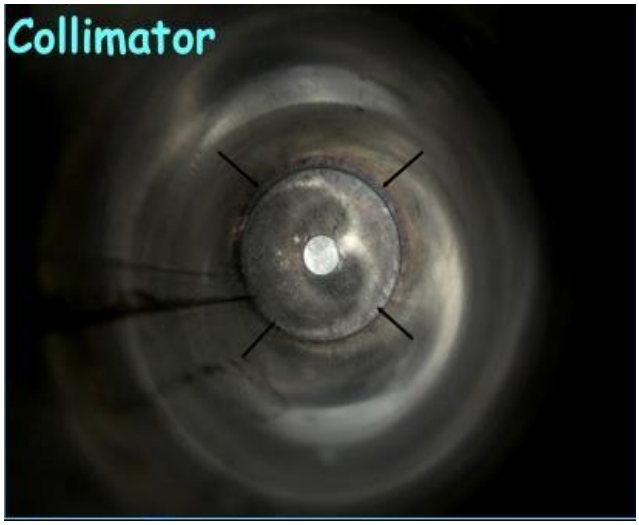


**Fig 8: collimator attached to the end of tube head.**

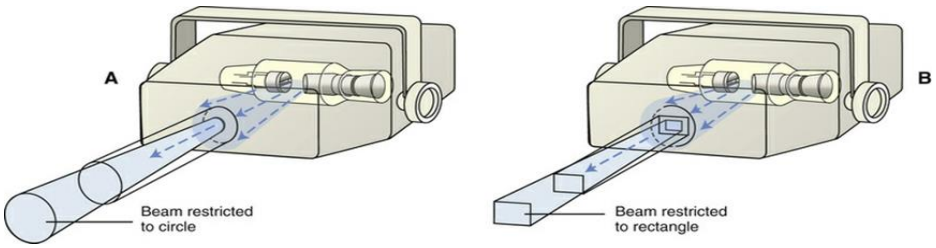


**Fig 9: Collimation of an x-ray beam *(blue)* is achieved by restricting its useful size. (A) Circular collimator. (B) Rectangular collimator restricts area of exposure to just larger than the detector size and thereby reduces unnecessary patient exposure.**

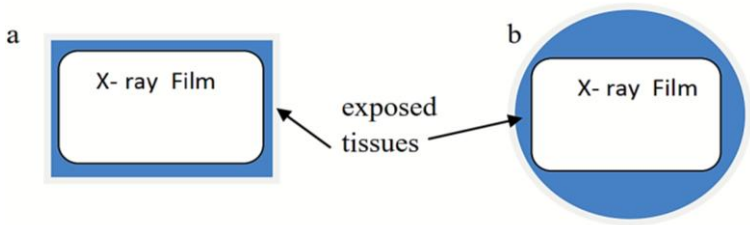


**Fig 10: comparison between exposed tissues with (a)rectangular and (b)round collimators.**

**6. Target–patient distance:** Intensity of X-ray beam (the number of photons per cross sectional area) at a given point is inversely proportional to square of distance from the source of radiation. (quantitative) and this is explained by inverse square law

- What is inverse square law?

It states that the intensity of radiation is inversely proportional to the square of the distance from the source of radiation. The intensity of an X-ray beam at a given point (number of photons per cross-sectional area per unit exposure time) depends on the distance of the measuring device from the focal spot. The reason for this decrease in intensity is that the X-ray beam spreads out as it moves from the source. The relationship is as follows :

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

where I is intensity and D is distance. Therefore, if a dose of 1 gray (Gy) is measured at a distance of 2 m, a dose of 4 Gy will be found at 1 m, and 0.25 Gy at 4 m.

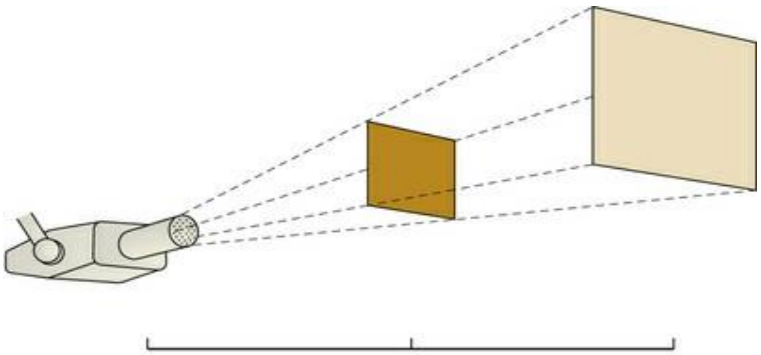

**Fig 11: Intensity of an x-ray beam is inversely proportional to the square of the distance between the source and the point of measure. When the distance from the focal spot is doubled, the intensity of the beam decreases to one quarter.**

7. **Rectification:** The main supply to the X- ray machine of 240 volts has 2 functions:

- Generate the high potential difference (kV) to accelerate the electrons across the X- ray tube via the step-up transformer.
- Provide the low-voltage current to heat the filament via the step-down transformer.

## ➢ Interactions of X-Rays with Matter:

In dental and maxillofacial imaging, the x-ray beam enters the face of a patient, interacts with hard and soft tissues, and strikes a digital sensor or film. The incident beam contains photons of many energies. As the beam goes through the patient, it is reduced in intensity (attenuated). This **attenuation** results from absorption of individual photons in the beam by atoms in the tissues or by photons being scattered out of the beam, so **attenuation is reduction in intensity of X- ray beam caused by absorption and scattering** (Attenuation = absorption + scattering).

In **absorption interactions,** photons interact with tissue atoms and cease to exist. In **scattering interactions,** photons also interact with tissue atoms but then move off in another direction.

➢ The frequency of these interactions depends on the type of tissue exposed (e.g., bone vs. soft tissue). Bone is more likely to absorb x-ray photons, whereas soft tissues are more likely to let them pass through.

- ❖ **Central ray:** in the beam X- ray photons that traveling in very center of the cone of radiation, called [central ray] and this is commonly used to fix and locate the position of X- ray beam.
- ❖ **Primary radiation:** radiation emerging from the X- ray machine in form of collimated useful X- ray beam.
- ❖ **Secondary radiation:** radiation result from interaction of primary beam with matter. It is less penetration than the primary beam.
- ❖ **Absorption interactions,** photons interact with tissue atoms and deposition of energy (removal of energy from the beam).
- ❖ **Scattered radiation:** it is a form of secondary radiation which is deflected from its path after interaction with matter. photons interact with tissue atoms and move in another direction with or without loss of energy.

## ➢ Interactions of Photons from a Diagnostic X-Ray Beam:

- **Photoelectric absorption**
- **Compton scattering**
- **Coherent scattering**
- **No interaction**

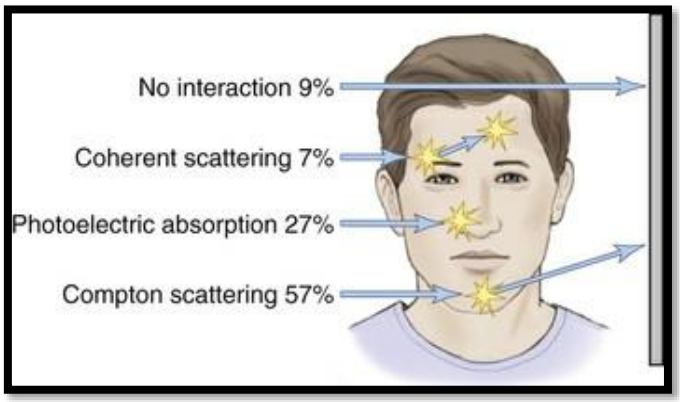


**Fig 12: Photons in an x-ray beam interact with the object primarily by Compton scattering (57% of primary interactions), in which case the scattered photon may strike the film and degrade the radiographic image by causing fog. The next most frequent interaction is photoelectric absorption (27%), in which the photons cease to exist. A radiographic image is produced by photons passing through low atomic number structures (soft tissue) and preferentially undergoing photoelectric absorption by high atomic number structures (bone, teeth, and metallic restorations). Relatively few photons undergo coherent scattering (7%) within the object or pass through the object without interaction (9%) and expose the image receptor.**

**1) Photoelectric Absorption (27-30 %):**

Photoelectric absorption is critical in diagnostic imaging because it is the basis of image radiographic formation. This process occurs when an incident photon interacts with an electron in an inner orbital of an atom in the patient. The incident photon loses all its energy to the electron and ceases to exist. The energy absorbed by the electron is expended to overcome the binding energy, and the remainder energy remains as the kinetic energy of the electron. The kinetic energy imparted to the electron (termed recoil electron or photoelectron) is equal to the energy of the incident photon minus the binding energy of the electron. Most photoelectric interactions occur in the 1s orbital because the density of the electron cloud is greatest in this region, and there is a higher probability of interaction. Approximately (27-30 %) of interactions in a dental x-ray beam exposure involve photoelectric absorption. The photoelectric interaction causes ionization of the atom because of the loss of an electron.

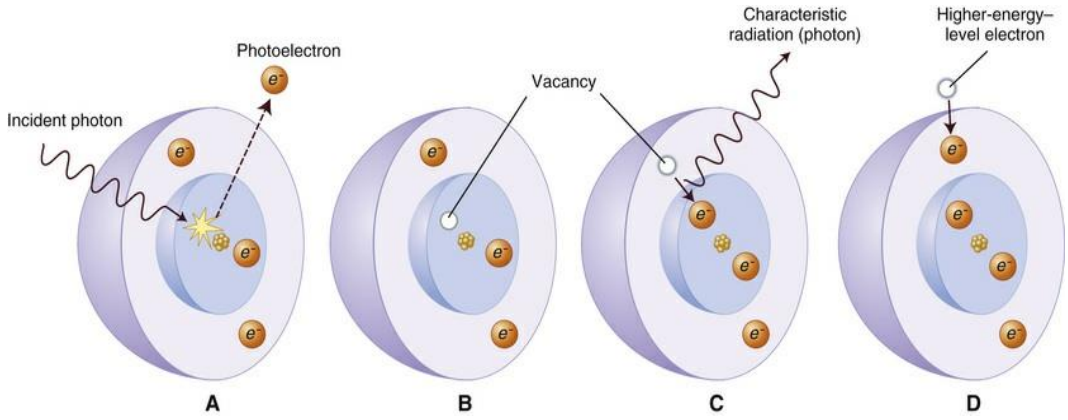


**Fig 13: Photoelectric absorption. (A) Photoelectric absorption occurs when an incident photon gives up all of its energy to an inner electron, which is ejected from the atom (a photoelectron). The incident electron ceases to exist at this point. (B) The ionized atom now has an electron vacancy in the inner orbital. (C) An electron from a higher energy level fills the vacancy and emits characteristic radiation. (D) All orbitals are subsequently filled, completing the energy exchange.**

**2) Compton Scatter (57-62%):**

Compton scatter occurs when a photon interacts with an outer orbital electron. Approximately **(57-62%)** of interactions in a dental x-ray beam exposure involve Compton scatter. The path of the incident photon is deflected by this interaction and is scattered in a new direction. The energy of this scattered photon equals the energy of the

incident photon minus the sum of the kinetic energy gained by the recoil electron and its binding energy. In the diagnostic energy range, most of the energy is retained by the scattered photon which can then cause ionizations, often at tissue sites outside the circumference of the incident beam. As with photoelectric absorption, Compton scatter results in the loss of an electron and ionization of the absorbing atom. When these scattered photons reach the image receptor, they cause *degradation of the image*.

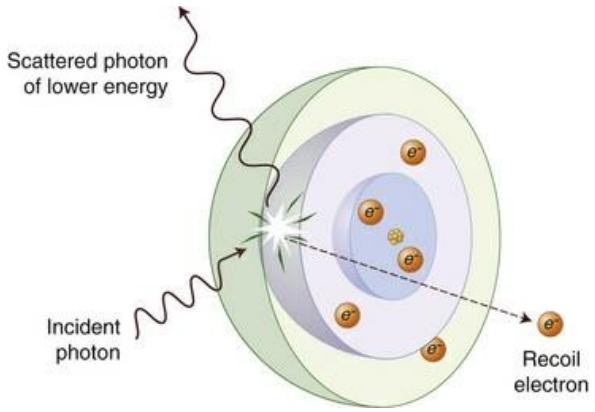


**Fig 14: Compton scattering occurs when an incident photon interacts with an outer electron, producing a scattered photon of lower energy than the incident photon and a recoil electron ejected from the target atom. The new scattered photon travels in a different direction from the incident photon.**

### 3) Coherent Scatter (7-8%):

Coherent scatter (also known as **Rayleigh, classical,** or **elastic scatter**) may occur when a low-energy incident photon (<10 keV) interacts with a whole atom. The incident photon causes it to become momentarily excited then ceases to exist. The excited atom quickly returns to the ground state and generates another x-ray photon with the same energy as the incident photon. Coherent scattering accounts for only approximately **(7-8%)** of the total number of interactions in a dental exposure. Because no energy is transferred to the biologic atom and no ionizations are caused, the biologic effects of coherent scatter are insignificant.

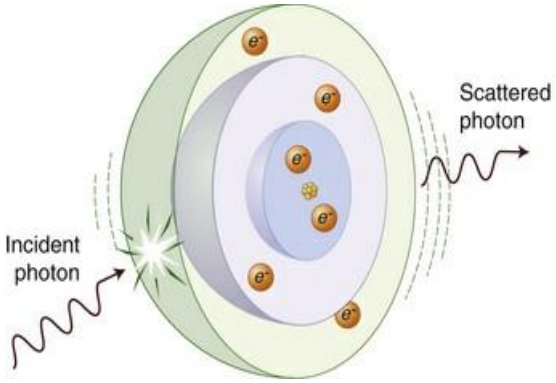


**Fig 15: Coherent scattering results from the interaction of a low energy incident photon with a whole atom, causing it to be momentarily excited. After this interaction, the atom quickly returns to the ground state and emits a scattered photon of the same energy but at a different angle from the path of the incident photon.**

**4) No interaction (8-9 %):**

(No interaction=transmission): X – Ray photons can pass through the atom without any change occurred to both of them.

## ➢ Half Value Layer:

As an x-ray beam travels through matter, its intensity is reduced primarily. The higher the kVp setting, the greater the penetrability of the resulting beam through matter. A useful way to characterize the penetrating quality of an X-ray beam is by its half-value layer (HVL). The HVL is the thickness of an absorber, such as aluminum, that reduces the number of X-ray photons to (one half). In oral diagnosis the acceptable value is approximately **2 mm** of aluminum.

As an x-ray beam passes through this material, the intensity of the beam decreases from preferential removal of low energy photons. Because the transmitted photons are predominantly higher energy, the mean energy of the residual beam increases. The term **beam hardening** is used to describe this increase in the mean energy of the beam.

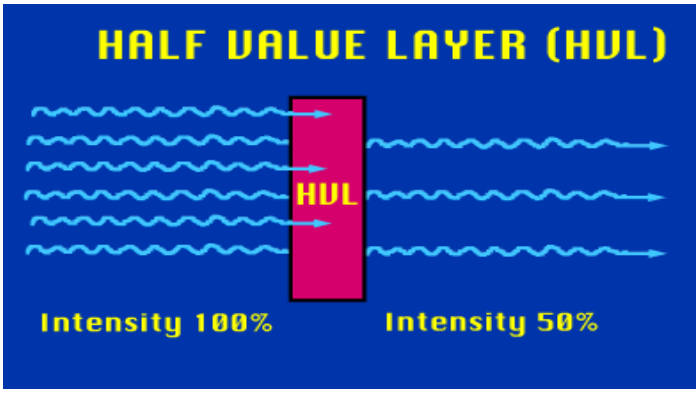


**Fig 13: diagram explain halve value layer.**

## X- ray measuring unites:

### 1. Traditional Units

- **Roentgen:** is the amount of X- radiation or gamma radiation which will produce in one cc of air ions carrying one electrostatic unit of either sign.
- **Rad:** (roentgens absorbed dose) representing the amount of radiation energy absorbed by an organ or tissue.
- **Rem:** (roentgens equivalent man dose) is a measure of the degree of damage caused to different organs or tissues.
- **Curie (Ci):** is the unit of quantity of radioactive material and not the radiation emitted by that material.

### 2. International system of units SI Units

- Coulomb per kilogram (C\kg): 1 C\kg = 3876 R
- Gray (Gy): 1Gy = 100 rad
- Sievert (Sv): 1Sv = 100 rem
- Becquerel (Bq): 1Bq= 2.7 $x$ 10*$^{11}$ Ci