Department of Medical physics
Second year / 2017-2018

- ***Syllabus of Medical physics/ 2nd semester***

Applications of physics in medicine
Basic concepts of medical imaging
Nuclear medicine
Radiation isotopes
Radiation therapy
Gamma spectroscopy and trace element analysis
Biomedical laser applications

Terminology

- **Medical physics :** refers to two applications of physics namely (the function of the human body in health which is called physiology) and the practice of medicine which include lasers , ultrasound radiation and so on.
- **Physical medicine :** deals with treatment of disease , pain , and injury by massage , exercise , heat and so on .
- **physical therapy :** is the treatment of the body weakness by massage and gymnastics rather than by drags.

Terminology .

❖Biophysics : is involved with biomoleculus and transport of material across cell membrane is deals with next generation .

❖Radiological physics : involved with one of radiation in diagnosis and treatment of disease .

❖Radiation protection : involves protection of patients, workers, and general public from radiation hazard.

❖Medical engineering : involves with the use of medical instrument action .

Modeling .

- To understand a physical phenomenon we simplify it by selecting its main feature by something similar for example the eye by a camera , the film by retina.
- This kind of selection is called modeling.
- The flow of blood is represented by the flow of electricity.
- The relation ship between force (F) , mass (m) and acceleration (a) can be represented by mathematical model that is called equations as : $F = ma$.

Modeling .

- In medical field we can say that the heart rate (R) is a function of the power produced by the body (P) and this fact can be modulated mathematically by the term function as : R= f(p)
- In medical field when calcium in blood drops too lowthe body release some calcium from the bone to increase the level in the blood.
- This kind of increasing in one side and decreasing in another called negative feedback , while positive feedback can occur when the two changed in the same direction like growing in weight means increasing in cell numbers.

Applications of medical physics

- The smallest individual particle carrying the chemical characteristics of the element is the atom
- the atom of each different element have a certain number of positively charged particles are called protons
- The lightest element is hydrogen , which has one proton while uranium the heaviest naturally occurring element has 92 protons.
- The protons are gathered in tiny central core of the atom called the nucleus.
- Another neutral electrically particles accumulated with protons in the nucleus is called neutrons .
- The nucleus revolve very light electrically negative charge particles called electrons.

particles, which identify the element, called protons. The lightest element is hydrogen, which has one proton. Uranium the heaviest naturally occurring element has 92 protons.

The protons are gathered in tiny central core of the atom called the nucleus. Another neutral "electrically" particles accumulated with protons in the nucleus is called the neutrons. Each one of these nucleons "neutrons or protons" has a mass approximately one atomic mass unit.

Faraway from the nucleus revolve very light electrically negative charge particles called electrons. The mass of an electron, approximately, equals one part of two thousands of protons mass. The electrons determine the chemical properties of the atom and chemical reactions involve in the number and energy of these electrons.

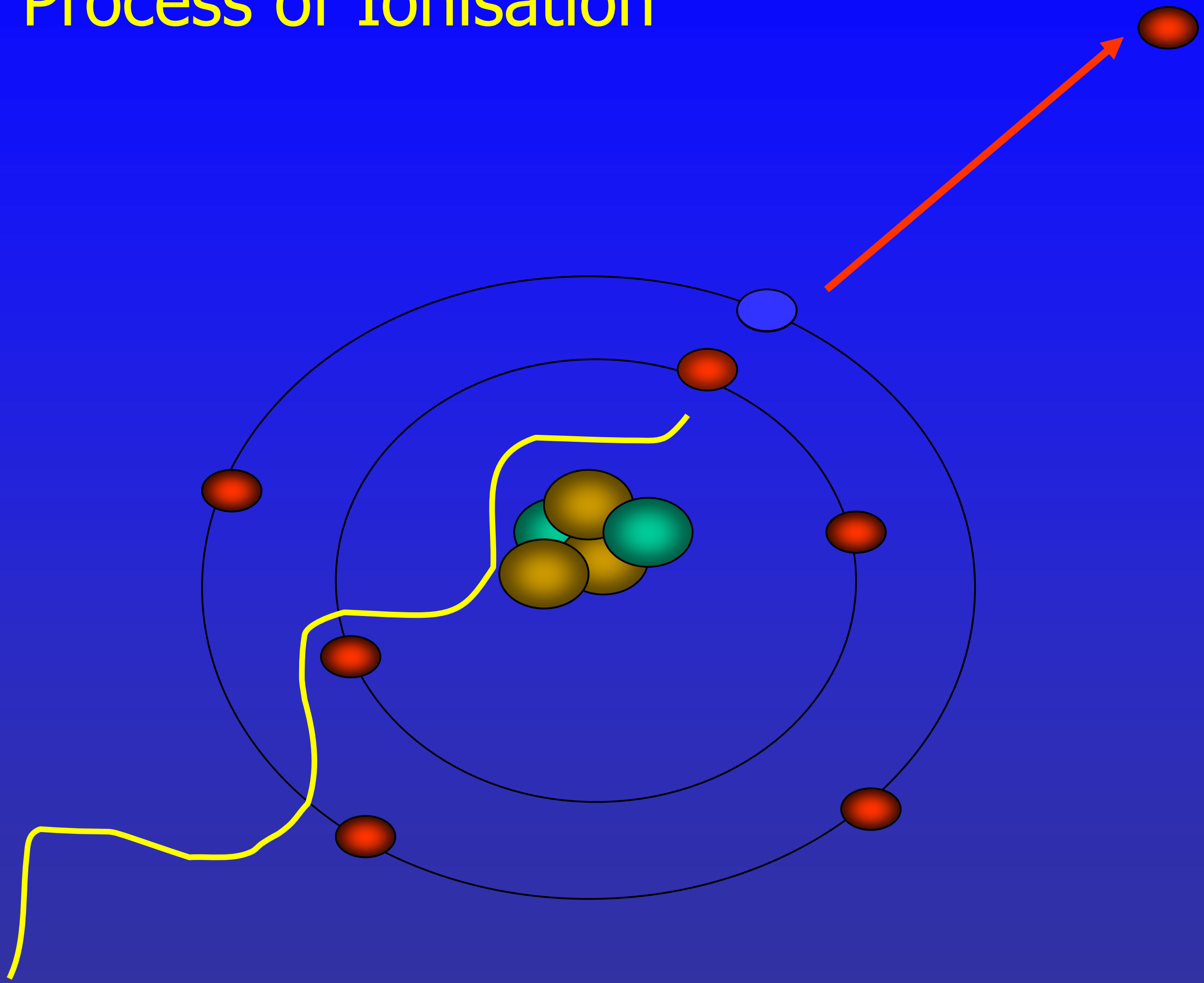
Because the mass of electrons is very small it can be neglected. So mass of an atom is fixed by the sum of the number of protons and the number of neutrons, This sum called the mass number "A", which determined the mass of the nucleus of the atom.

Mass number "A" = No. of protons "Z" + No. of neutrons "N".

$$A=Z+N$$

The number of protons called the atomic number of that element "Z". If this number exceeds the number of electrons in an atom, it means positive charge is exceeded and the atom is call "ionized". The ion pair is the electron that separated from the atom which is the negative ion and the remaining atom which is the positive ion. Hence ionization is that process which the atom loses one or more of its outer electrons.

The Process of Ionisation



An Ion Pair is created

Table .1. Atomic structure of some elements.

Element	Symbol	No. of protons "Z"	No. of neutrons "N"	No. of electron	A mass number
Hydrogen	H	1	0	1	0
Helium	He	2	2	2	4
Carbon	C	6	6	6	12
Nitrogen	N	7	7	7	14
Oxygen	O	8	8	8	16
Sodium	Na	11	10	11	21
Chlorine	Cl	17	20	17	37

The electrons rotate in various orbits around the nucleus. The closest orbit to the nucleus can contain a maximum of 2 electrons, while the second can have up to 8 electrons, and so on for outer orbits 18, 32 respectively, in the from ($2n^2$) where n is the rank of shell. The inner orbit called 'K' orbit (or K shell), the second orbit is called L shell, the third M shell, and so on, as shown in fig.1.

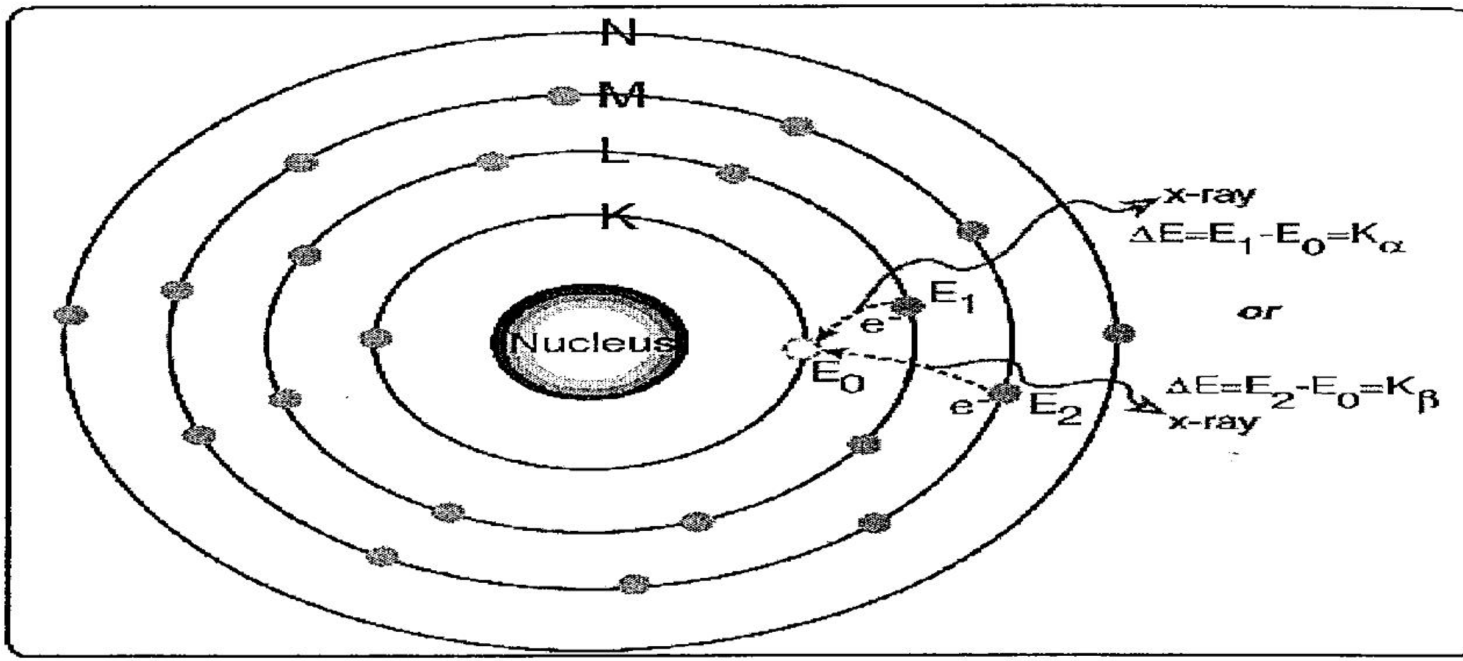


Fig.1: Structure of atom.

The energy position of the electrons is determined by the distant of that electron from the nucleus. The lower the orbit of an electron the higher it's binding energy. when an electron jumps from high level to a low one, the atom emits a discrete amount of energy, equal to the difference between the two particular energy levels .

X- Ray radition

- X-rays are one of the main diagnostical tools in medicine since its discovery by Wilhelm Roentgen in 1895.

- X-radiation (composed of X-rays) is a form of electromagnetic radiation.
-
- Most X-rays have a wavelength ranging from 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz(3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 100 eV to 100 keV.

X -Ray

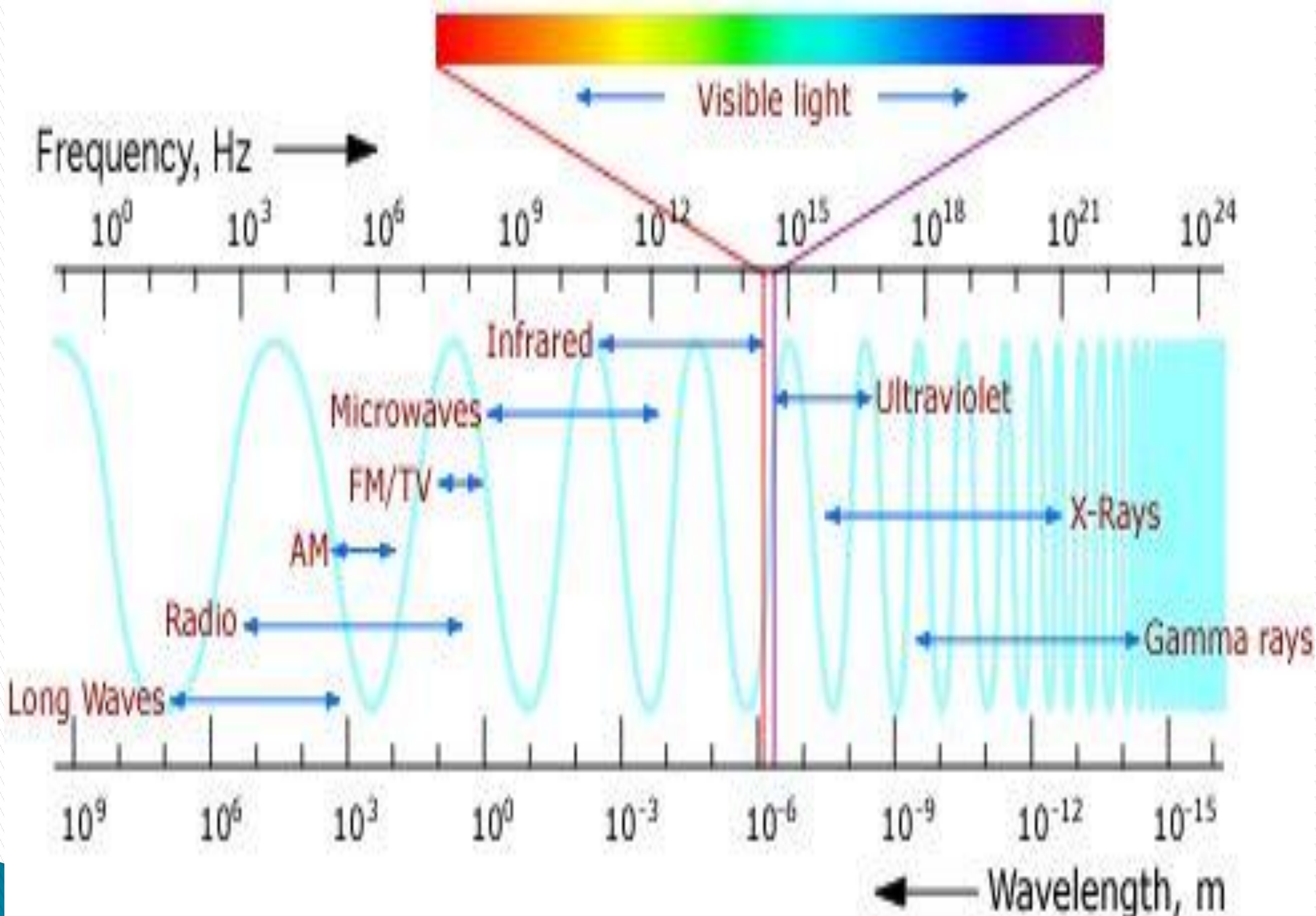
- X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays. In many languages, X radiation is referred to with terms meaning **Röntgen radiation**, after the German scientist Wilhelm Röntgen.

Discovery of X- ray radiation

- William Roentgen, an X-ray discoverer, has shed an electronic beam inside a glass tube with high electrical tension between the ends.

- This tube was discharged from the air and released electrons from a negative electrode to a positive electrode. This tube is surrounded by light colored paper to protect the user from the emitted electromagnetic field.

- A phosphoric screen was placed at the end of the tube. When the electronic beam collided with it, this screen began to glow. When Roentgen accidentally put his hand between the tube and the phosphoric screen, he saw a picture of his hand on the screen. This was the first X-ray operation


Visible light
Frequency, Hz
10^0
10^3
10^6
10^9
10^12
10^15
10^18
10^21
10^24
Infrared
Ultraviolet
Microwaves
FM/TV
X-Rays
AM
Radio
Gamma rays
Long Waves
10^9
10^6
10^3
10^0
10^-3
10^-6
10^-9
10^-12
10^-15
Wavelength, m

Properties of x - Ray

- X-ray photons carry enough energy to ionize atoms and disrupt molecular bonds. This makes it a type of ionizing radiation, and therefore harmful to living tissue.

- A very high radiation dose over a short period of time causes radiation sickness, while lower doses can give an increased risk of radiation-induced cancer.

- The ionizing capability of X-rays can be used in cancer treatment to kill malignant cells using radiation therapy.

11.3 X-ray production.

1- Characteristic x-ray.

When the projectile electron ionizes a target atom by removing a K-shell electron, an electron hole is produced in this shell. This unnatural state for the atom is corrected by filling an outer shell electron into the hole. Tungsten, for example, when a K-shell electron is ionized, its position can be filled from any out shells "L, M, N, O, or P" (fig.3).The transition of an orbital electron from an outer shell to an inner shell is accompanied by the emission of an x-ray photon. The x-ray has energy equal to the difference in the building energies of the orbital electron involved, (table 2).

Similar characteristic x-rays are produced when the target atom is ionized by removal of electrons from shell other than K-shell. The vacancy in the L-shell would be filled by an electron from any of the farther shells. X-ray resulting from electron transitions to the L-shell are called L x-rays but are much less energetic than K – x-rays, because the binding energy of an L shell electron is much lower than that of a K shell.

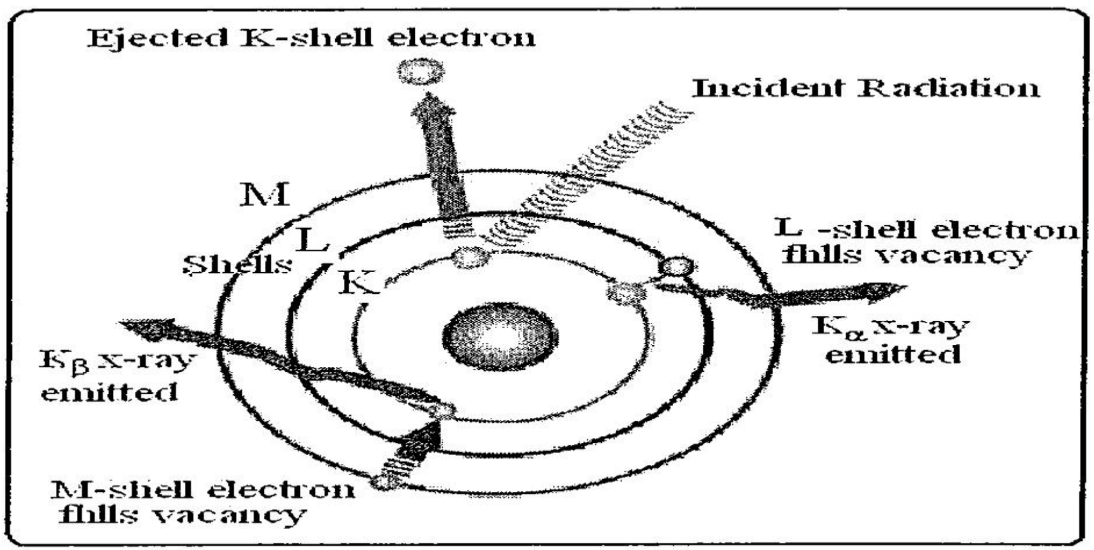


Fig3: Characteristic x-ray.

Production of Characteristic X-rays

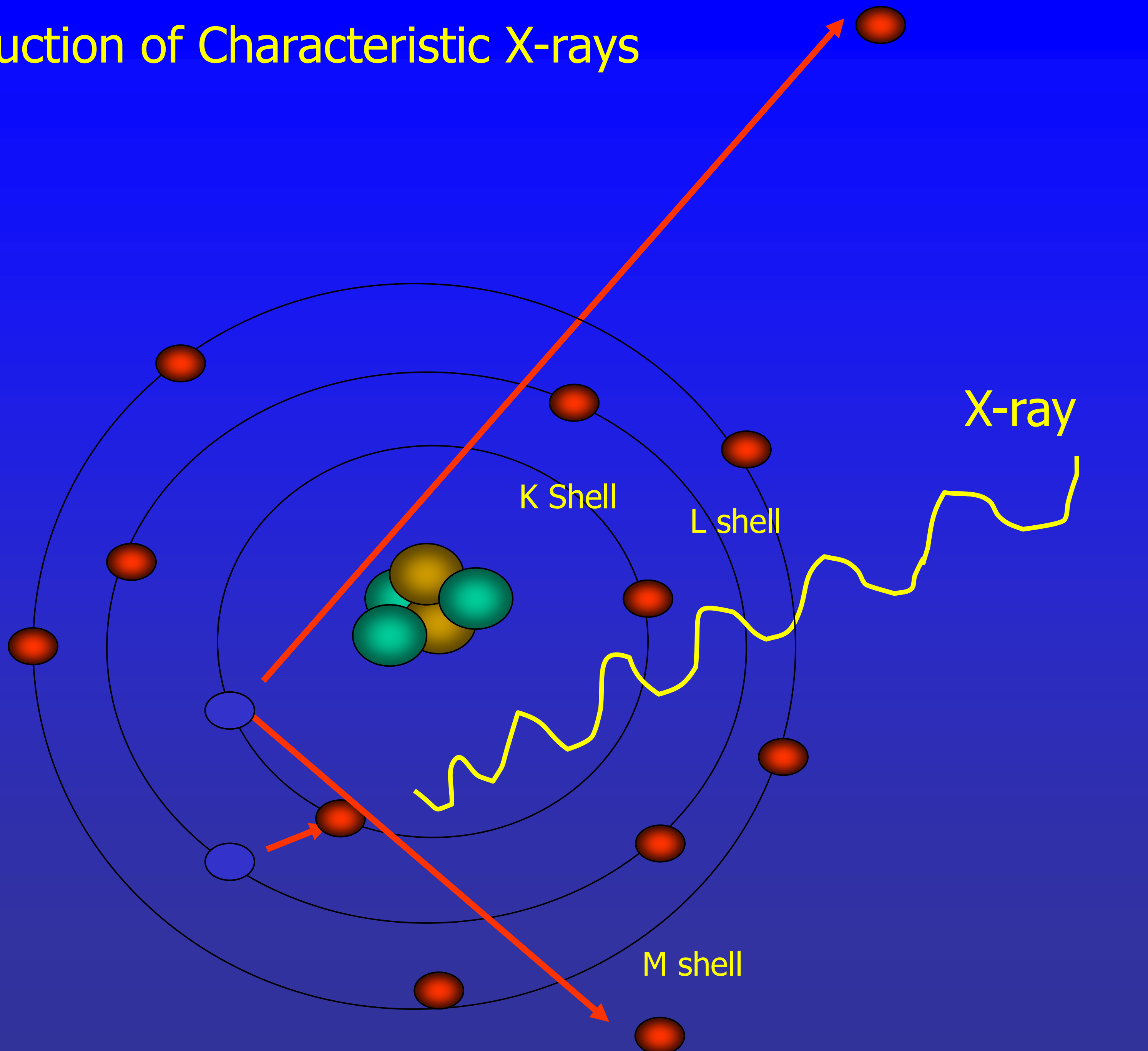


Table.2. Characteristic x-ray of tungsten in KeV.

Characteristic x-ray	L shell	M shell	N shell	O shell	P shell	Effective energy
K	57.4	66.7	68.9	69.4	69.5	69
L		9.3	11.5	12.0	12.1	12
M			2.2	2.7	2.8	2
N				0.52	0.6	0.6
O					0.08	0.08

The binding energy is the strength of attachment of an electron to the nucleus and the closer electron is to the nucleus, the more tightly it is bonded. So K-shell electrons have higher binding energies than L-shell electrons, L-shell electrons are more tightly than M-shell electrons and so on. ,(table 3).

Table .3. Electron binding energy for three atoms.

Name of atom	Symbol	Shell No.	No. electrons	B.E (KeV)
Carbon	$^{12}_{6}C$	K	2	0.28
		L	4	0.01
Barium	$^{137}_{56}Ba$	K	2	37.44
		L	8	5.99
		M	18	1.29
		N	18	0.25
		O	8	0.04
		P	2	
Tungsten	$^{184}_{74}W$	K	2	69.53
		L	8	12.1
		M	18	2.82
		N	32	0.60
		O	12	0.08
		P	2	

2- Bremsstrahlung Radiation.

Another type of x ray production is due to interaction of an electron with the nucleus of the atom. The electron avoids the orbital electrons and been influenced by the nucleus by the electrostatic force of attraction.

As the electron passes by the nucleus, it is slowed down, a cause to the very strong field of the nucleus, and changes its direction leaving the atom with reduced kinetic energy. This loss in kinetic energy reappears as an x-ray photon. Those types of x-rays are called bremsstrahlung or stopping x- ray.

A projectile electron can lose any amount of its kinetic energy; consequently bremsstrahlung radiation can take any value. (fig. 4).

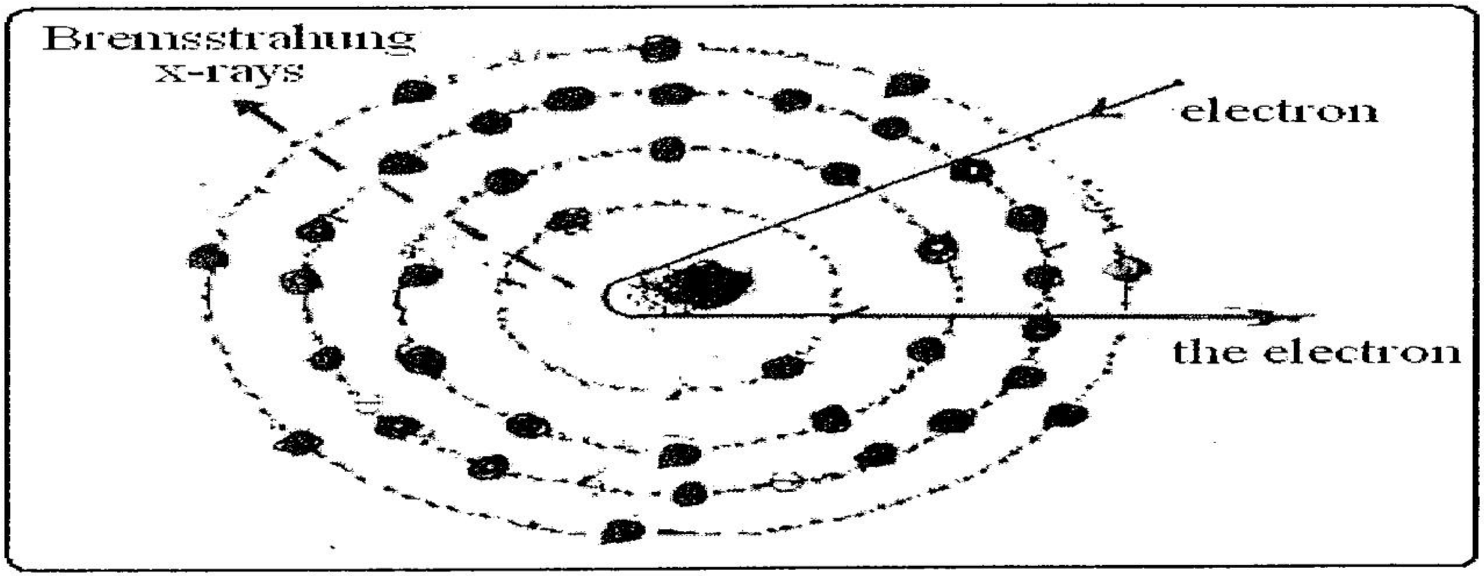
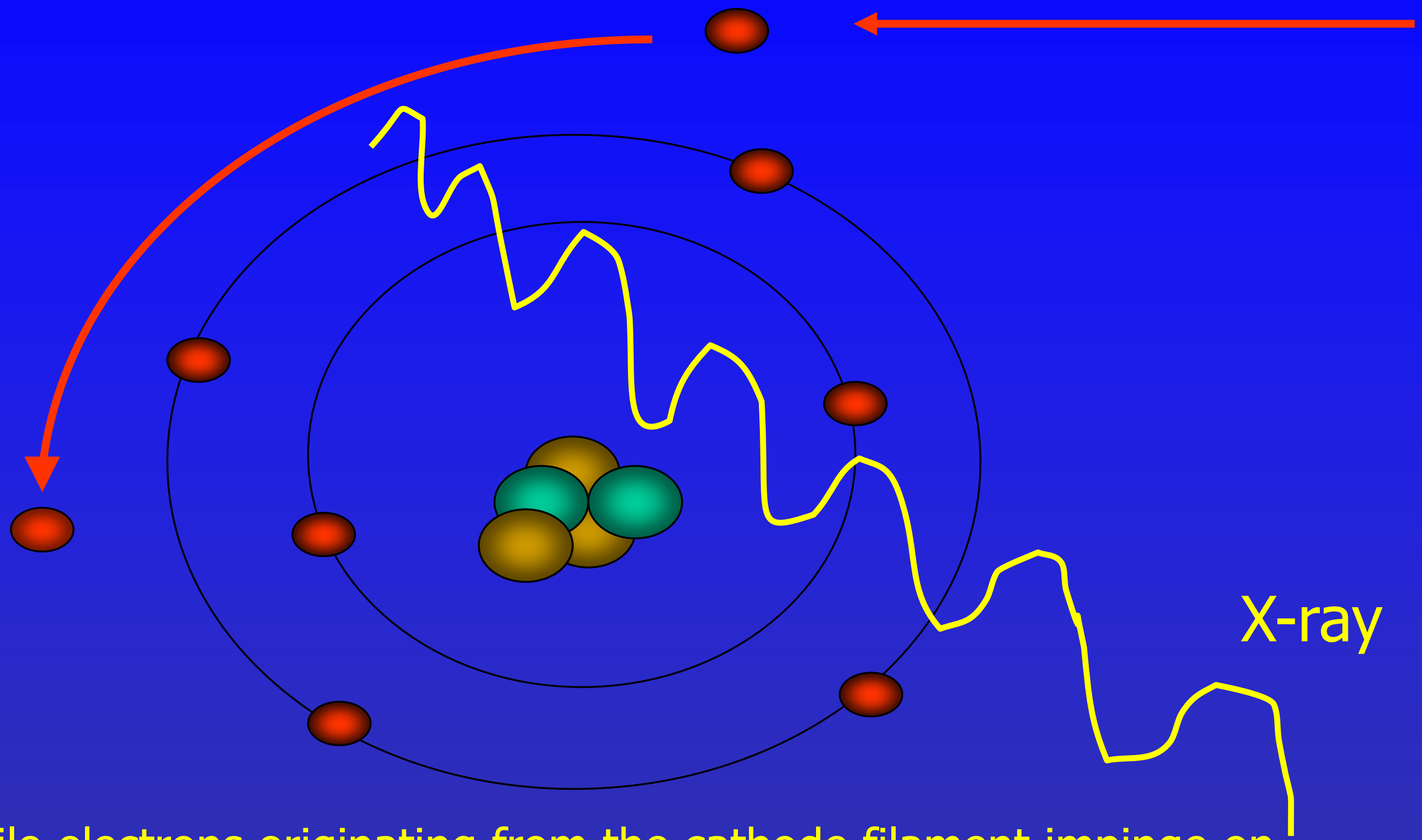


Fig. 4: Bremsstrahlung x-rays

Bremsstrahlung radiation



Projectile electrons originating from the cathode filament impinge on atoms in the anode and will often pass close by the nucleus of these atoms.

As the electrons pass through the target atom they slow down, with a loss in kinetic energy. This energy is emitted as x-rays. The process is known as *bremsstrahlung* or "braking energy".

To describe the output of an x-ray machine from the two types of spectra in one form is called the general spectrum, (fig. 5)

The output intensity of an x-ray machine or the radiation exposure is measured in roentgen (R) or mile roentgen (mR). The roentgen (c/ kg) is a measure of the number of ion pairs produced in air by a quantity of x-rays. 1R = 2.08 x 10 خطأ! خطأ! يتعذر إنشاء كائنات من تحرير رموز الحقول. ion /cm يتعذر إنشاء كائنات من تحرير رموز الحقول. of air . 1 C = 1 ampere.

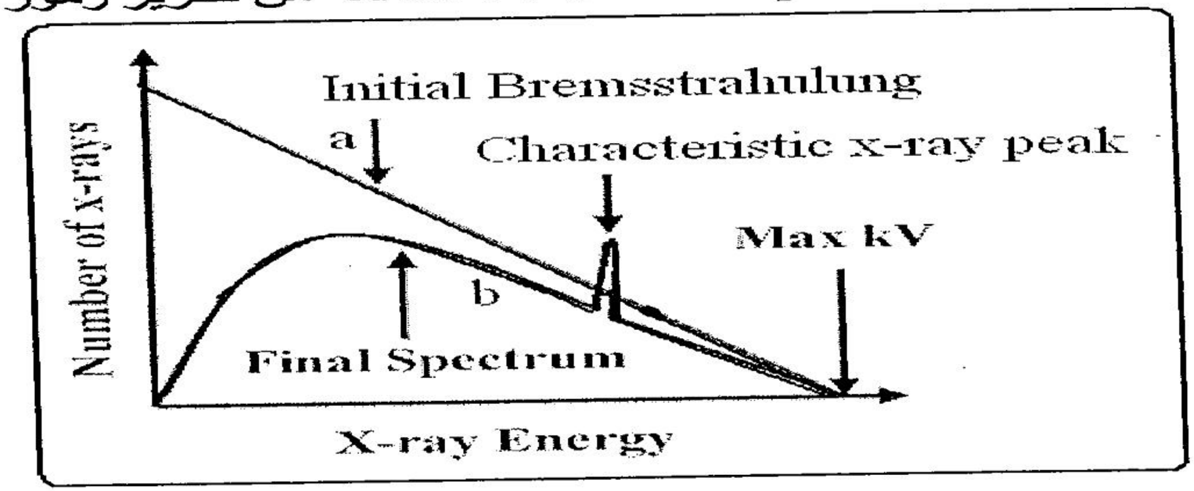


Fig. 5:a- Bremsstrahlung x-ray spectrum.
6-General x-ray spectrum.

11.4 X-ray absorption

1- Differential absorption in tissue.

If an X-rays penetrate the body and are transmitted with no interaction whatever, then they affect the film and make a dark region on the radiograph .But those x-rays which absorbed inside the body will not reach the film and do nothing to it. Hence, an x-ray image results from the **difference** between those x-ray absorbed and those not absorbed at all. This called the differential absorption fig.(6).

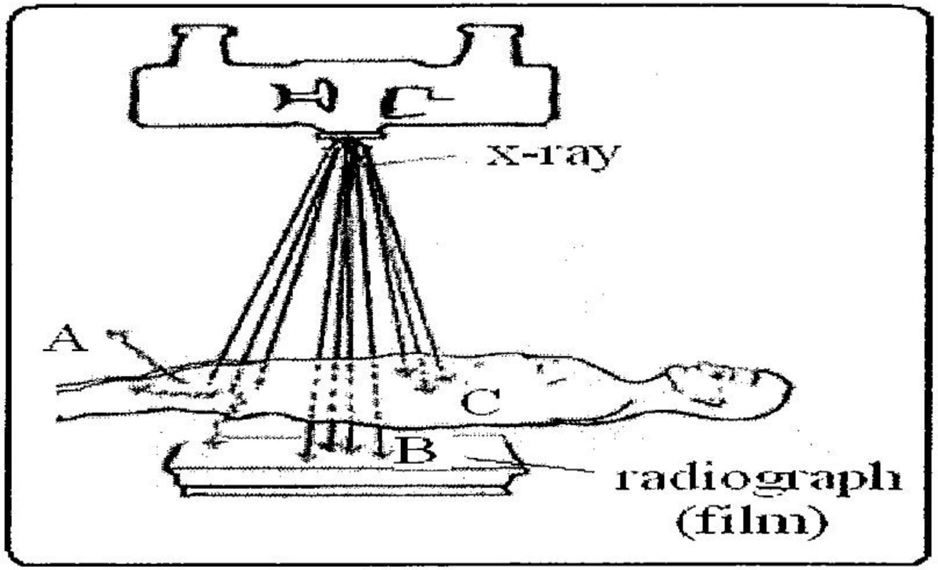


Fig.6: A-Scattered x-ray, B- X-rays that penetrate the body, and C-X-rays do not reach the film.

2- X-ray absorption in body.

X-ray absorption in the human body, depends on two factors; atomic number of the tissue and it's mass density.

I) Dependence on atomic number:

The probability of an x-ray undergoing photoelectric absorption is proportional to the third power of the atomic number of absorbing material.

Table (4) shows effective atomic number of various materials important to diagnostic radiology. From this table bone has an atomic number of 13.8, where soft tissue has 7.4.The probability that an x-ray will undergo a photoelectric interaction is approximately seven times greater in bone than in soft tissue.

II)) Dependence on mass density:

Mass density shows how tightly the atoms of a substance are packed. It is the quantity of matter per unit volume. The interaction of x-rays with tissue is proportional to the mass density of the tissue, even without the atomic number related photoelectric effect. Table (4) shows also mass densities of several radio logically important materials.

Table.4. Effective atomic number & density of some materials.

Type of substance	Effective atomic No.	Density $kg/m^3 * 10^3$
Human Tissue:		
Muscle	7.4	1.00
Fat	6.9	0.91
Bone	13.8	1.85
Lung	7.4	0.32
Contrast material:		
Barium	56	3.5
Iodine	53	4.93
Air	7.6	0.001293
Other:		
Concrete	17	2.35
Tungsten	74	19.3
Lead	82	11.3
Molybdium	42	

13-1. X-RAY MACHINE.

Every x-ray machine has three principal parts: the x-ray tube, the control console, and the high-voltage section. In dental and portable machines, these components are housed compactly.

13-1 -1 X-ray tube.

There are two primary parts usually seen in x-ray tube; the cathode and the anode. Each of these is called an electrode encased in a protective housing and therefore, the tube is inaccessible, (fig. 1).

I) Protective housing: The x-ray tube is always mounted inside a lead protective housing designed to control two serious hazards that; excessive radiation exposure and shock. It also provides mechanical support for the x-ray tube from damage. Some housing have cooling fan to cool the tube. The tube window is a segment of a 5 cm square thin glass through which the useful beam is emitted. Other x-rays that escape through the protective housing are leakage radiation.

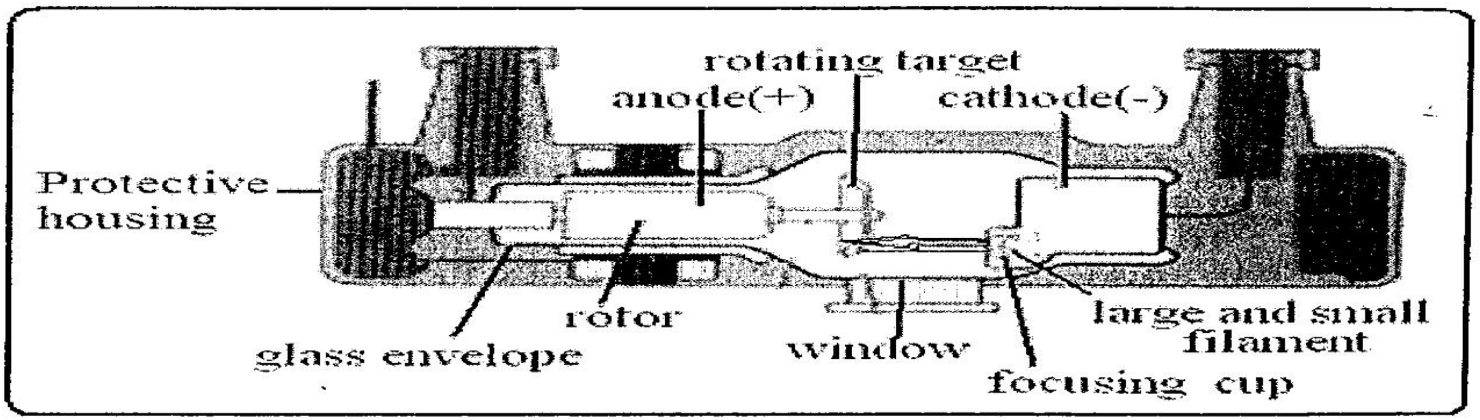


Fig. 1: X-ray tube.

II) Cathode: The cathode is the negative side of the x-ray tube. It contents the filament. Filament: is a coil of wire about 2 mm in diameter and 1 to 2 cm long. When the current through the filament is 4 A and above, the outer-shell electrons of the filament atoms are literally boiled off and ejected from the filament.

III) Anode: The anode is the target. It is the positive side of the x-ray tube which receives electrons from the cathode. The anode is an electrical conductor. It also provides thermal conductor, since 99 % of the electrons kinetic energy is converted into heat which must be conducted away before it melts the anode. Rotating-anode allows the electron beam to interact with a much larger target area, and therefore, the heating of the anode is not confirmed to one small spot as in stationary anode.

Tungsten is the material of choice as a target due to;
i) Its high atomic number (Z = 74) results in high-efficiency x-ray production.
ii) Its good thermal conductivity results as efficient metal for dissipating the heat generation at the anode.
iii) Its high melting point (3410 C^0) results in standing up under high current without melting.

13-1-2 Shapes and sizes:

The types of x-ray machines are usually identified according to either the energy of the x-ray they produce or the purpose for which those x-ray are intended. Diagnostic x-ray machines usually operated at maximum voltages ranging from 25 to 150 KV_p and at tube current from 25 to 1200 mA. Therapeutic x-ray machines, operated at higher or lower voltage but at tube current not exceeding 20 mA.

The modern general purpose x-ray examination room usually contains a radiographic unit and a fluoroscopic unit with an electronic image intensifier. The fluoroscopic x-ray tube is usually located under the examining table. The head of radiographic tube is attached to an overhead movable camera that permits easy positioning of the tube and aiming of the x-ray beam. This type of equipment can be used for nearly all radiographic table and many overhead radiographic tubes are employed for a special vascular and neurological exams.

Every x-ray machine has three principal parts: the x-ray tube, the control console, and the high-voltage section. In dental and portable machines, these components are housed compactly. The protective barrier might have a window for viewing the patient. The high-voltage generator may be housed in a container located in the corner or in a cabinet rack against a wall. Hence an X-ray imaging system consists of an X-ray source, an X-ray tube, a detector system and an imaging system. When a classical photographic film is used, the detector system is at the same the imaging system, e.g. in mammography this is an X-ray photograph of the breasts.

Nowadays, the imaging system is a PC. First, an electron beam is emitted from a heated cathode filament. This beam is focused and accelerated towards an angled anode target, called the focal spot. Only around 1% of the kinetic energy of the electrons is converted into X-ray photons and the excess heat is dissipated via a heat sink. At the focal spot, X-ray photons are emitted in all directions from the target surface with the highest intensity between 60 ° and 90° due to the angle of the anode target. There is a small window in the X-ray tube directly above the angled target, allowing the X-ray beam to exit the tube with little attenuation. The beam is projected on a target, in medicine a part of the body. The object absorbs part of the beam and a part passes through the object. The latter part will produce the image. The more photons pass the blacker the image on a classical transparent cassette film, the X-ray photograph or radiograph. Areas where radiation is absorbed show up as lighter shades of grey.

Factors controlling the x-ray beam

- The x-ray beam emitted from an x-ray tube may be modified to suit the needs of the application by altering the beam exposure length (timer), exposure rate (mA), beam energy (KVp and filtration), beam shape (collimation), and target-patient distance (long or short cone).
- ***1. Exposure Time***
- Portrays the changes in the x-ray spectrum that result when the exposure time is increased while the tube current (mA) and voltage (KVp) remain constant. When the exposure time is doubled, the number of photons generated is doubled, but the range intensity of photons energies is unchanged. Therefore changing the time simply controls the "quantity" of the exposure, the number of photons generated. The amount of radiation that a patient receives is determined by the mAs (mA x time).

Factors controlling the x-ray beam

- ***2. Tube Current (mA)***
- Illustrates the changes in the spectrum of photons that result from increasing tube current (mA) while maintaining constant tube voltage (kVp) and exposure time. 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 ration. A linear relationship exists between mA and radiation output. The quantity of radiation produced (mAs) is expressed as the product of time and tube current. The quantity of radiation remains constant regardless of variations in mA and time as long as their product remains constant. For instance, a machine operating at 10mA for 1 second (10mAs) produces the same quantity of radiation when operated at 20 mA for 0.5 second (10 mAs).

Factors controlling the x-ray beam

- ***3. Tube Voltage (KVp).***
- Increasing the KVp increases the potential difference between the cathode and anode, thus increasing the energy of each electron when it strikes the target. The greater the potential difference the faster the electrons travel from the cathode to the anode. This results in an increased efficiency of conversion of electron energy into x-ray photons, and thus an increase in :-
- ***a- The number of photons generated***
- ***b- Their mean energy .***
- ***c- Their maximal energy .***
- The increased number of high-energy photons produced per unit time by use of higher KVp results from the greater efficiency in the production of Bremsstrahlung photons that occurs when increased number of higher-energy electrons interact with the target .

Factors controlling the x-ray beam

- The ability of x-ray photons to penetrate matter depends on their energy. High-energy x-ray photons have a greater probability of penetrating matter, whereas relatively low-energy photons have a greater probability of being absorbed. Therefore the higher the KVp and mean energy of the x-ray beam, the greater the penetrability of the beam through matter. The radiation that does damage to a patient is the radiation that is absorbed by the patient .

Half Value Layer

- A useful way to characterize the penetrating quality of an x-ray beam by its half-value layer (HVL). The HVL is the thickness of an absorber, such as aluminum, required to reduce by one half the number of x-ray photons passing through it. As the average energy of an x-ray beam increases, so does it HVL. The term quality refers to the mean energy of an x-ray beam .Half value layer measures the intensity of a beam .

Factors controlling the x-ray beam

- ***4. Filtration***
- An x-ray beam consists of a spectrum of x-ray photons of different energies, but only photons with sufficient energy to penetrate through anatomic structures and reach the image receptor (usually film) are useful for diagnostic radiology. Those that are of low-energy (long wavelength) contribute to patient exposure but do not have enough energy to reach the film .
- The higher the KVp, the less radiation is absorbed by the patient. Consequently, to reduce patient dose, the less-penetrating photons should be removed. This can be accomplished by placing an aluminum filter in the path of the beam. The aluminum preferentially removes many of the lower-energy (long waves) photons with lesser effect on the higher-energy photons that are able to penetrate to the film .

Factors controlling the x-ray beam

- ***5. Collimation***
- A collimator is a metallic barrier with an aperture in the middle used to reduce the size and shape of the x-ray beam and therefore the volume of irradiated tissue within the patient .
- The round collimator is a thick plate of radiopaque material (usually lead) with a circular opening centered over the port in the x-ray through which the x-ray beam emerges .Typically, round collimators are built into open-ended aiming cylinders. Rectangular collimators further limit the beam to a size just larger than that of the x-ray film. The size of the beam should be reduced to the size of the film being exposed to reduce further unnecessary patient exposure. Some types of film-holding instruments also provide rectangular collimation of the x-ray beam .Use of collimation also improves image quality.

Factors controlling the x-ray beam

- When an x-ray beam is directed as a patient about 90% of the x-ray photons are absorbed by the tissues and 10% of the photons pass through the patient and reach the film. Many of the absorbed photons generate scattered radiation within the exposed tissues by a process called Compton scattering. These scattered photons travel in all directions. Many for the film and thereby degrade image quality. The detrimental effect of scattered radiation of the images can be minimized by collimating the beam to reduce the number of scattered photons reaching the film .

- ***6- Distance :*** radiation intensity from an x-ray tube varies intensity

with the square of the distance from the target.

Interaction of X-Rays with Matter

- X-rays possess intrinsic energy that may be imparted to the matter they interact with that interaction takes place as either absorption (transfer of energy from the X-ray photon to the absorbing material) or scattering (in which the X-ray photon is "redirected" by interaction with the scattering material). The process of scattering is the primary process responsible for diffraction, but both processes (that are, in many ways interdependent) result in the production of potentially damaging secondary radiation, that radiation is capable of producing significant short- and long-term health effects in the event of exposure to human tissue .The X-rays produced for diffraction analysis by an X-ray source consist of the characteristic radiation (dependent on the anode target) plus the continuous spectrum.

Interaction of X-Rays with Matter

- The energy of X-rays and their wavelength are inversely proportional (higher energy = lower wavelength), and the continuous spectrum minimum wavelength decreases as the accelerating voltage (kV) of the X-ray source increases. It is important to understand that an increase in filament current (mA) and kV (beyond the minimum value required to produce characteristic radiation for the target) will result in an increase in the intensity of the generated X-rays, but will not change their energy.

Interaction of X-Rays with Matter

- ***Energy Transfer***

- There are two basic types of energy transfer that may occur when X-rays interact with matter :

- ***Ionization,*** *in which the incoming radiation causes the removal of an electron from an atom or molecule leaving the material with a net positive charge.*

- ***Excitation,*** *in which some of the X-ray's energy is transferred to the target material leaving it in an excited (or more energetic) state*

Interaction of X-Rays with Matter

❖Theoretically there are five basic mechanisms by which x-rays interact with matter but only two of these processes are important to diagnostic radiology the Compton effect and photoelectric effect . These processes are:

1- The photoelectric effect

2- The Compton effect

3- Classical scattering.

4- photo-disintegration effect.

5- Pair Production

Interaction of X-Rays with Matter

1- The Photoelectric Effect

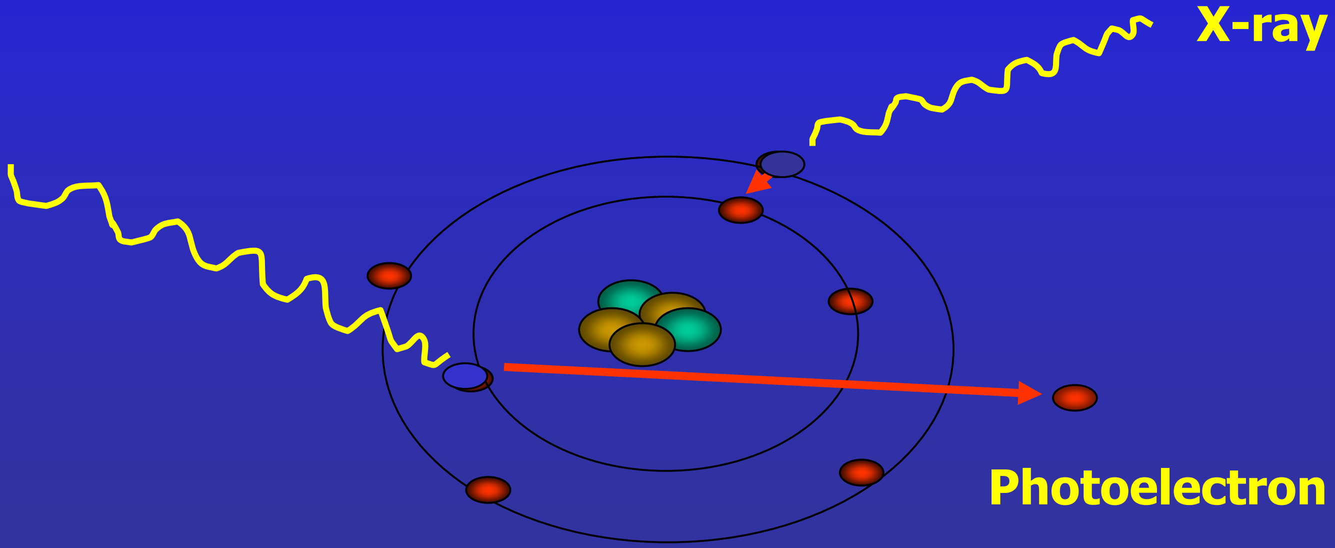
Simply stated, the photoelectric effect occurs when photons interact with matter with resulting ejection of electrons from the matter. Photoelectric (PE) absorption of x-rays occurs when the x-ray photon is absorbed resulting in the ejection of electrons from the atom. This leaves the atom in an ionized (i.e., charged) state.

Interaction of X-Rays with Matter

- The ionized atom then returns to the neutral state with the emission of an x-ray characteristic of the atom. PE absorption is the dominant process for x-ray absorption up to energies of about 500 KeV. PE absorption is also dominant for atoms of high atomic numbers.
- The photoelectric effect is responsible for the production of characteristic x-rays in the x- ray tube, but the process is also important as a secondary process that occurs when x-rays interact with matter. An x-ray photon transfers its energy to an orbital electron, which is then dislodged and exits the atom at high speed with a kinetic energy equal to :
- $KE = Ex - P$

Photoelectric effect

- X-ray transfers energy to an inner shell electron which then ejected.
- Filling the inner shell electron results in a characteristic x-ray.
- Characteristic x-rays from nitrogen, carbon and oxygen have very low energies.
- The final result is absorption of the x-ray (i.e. there is no exit radiation)



Interaction of X-Rays with Matter

- KE = Ex - P

Where :

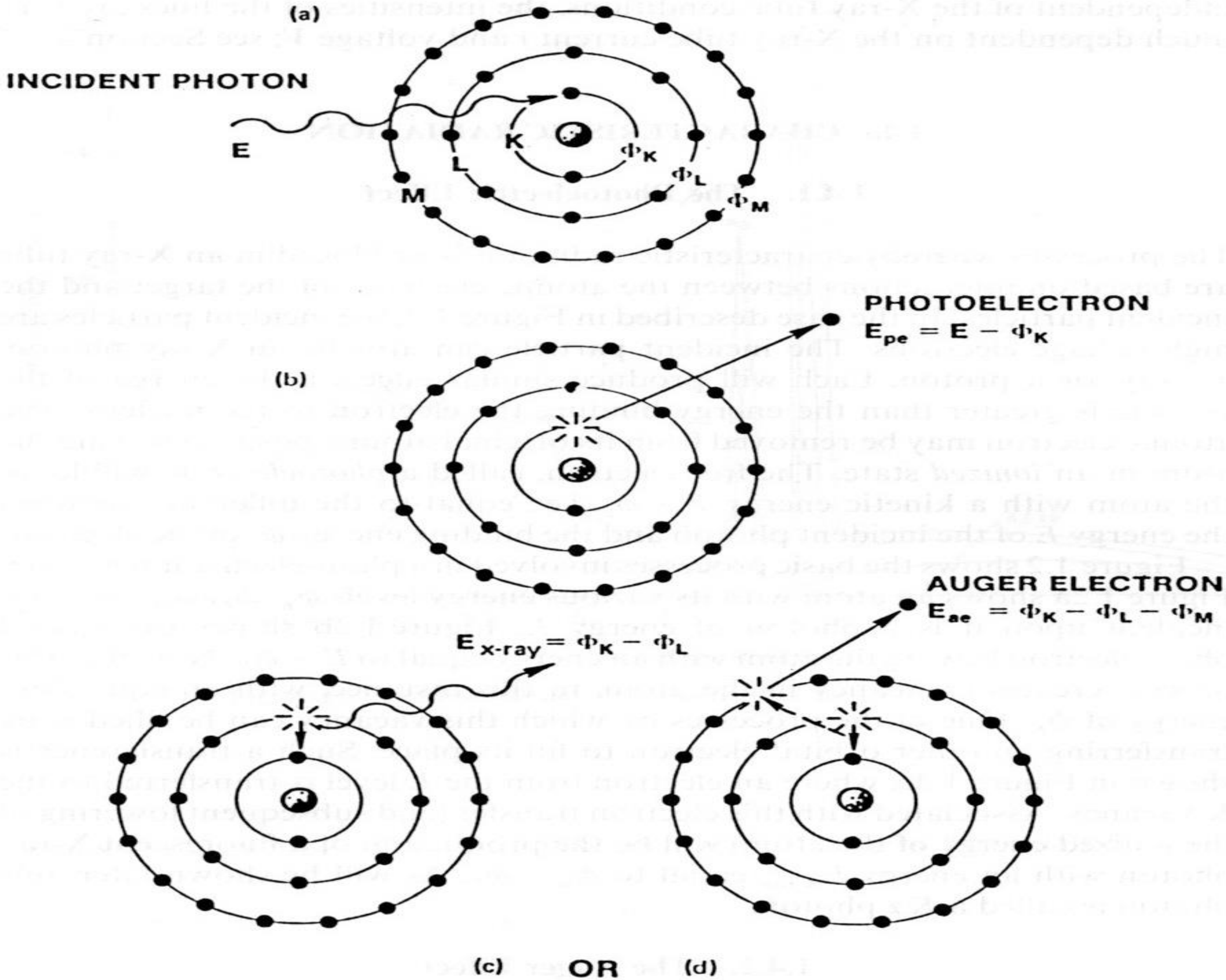
- KE is the kinetic energy of the photoelectron
- Ex is the energy of the incident X-ray photon
- P is the energy required to remove the electron. This is equivalent to its binding energy in the atom.

Interaction of X-Rays with Matter

- The energy equivalent of the rest mass of an electron is moc2, and is equal to about 0.51 MeV (mo is the rest mass of an electron and c is the speed of light). When Ex is much lower than this value, the electron will exit at a high angle to the incident beam; when Ex is closer to this value, the electron will exit at close to parallel with the beam .When the photoelectron is ejected, it has the capability, depending on its energy, to interact with subsequent electrons in other molecules or atoms in a chain reaction until all its energy is lost. If that interaction results in the ejection of an outer orbital electron, this is known as the Auger (au-jay) effect, and the electron called an Auger electron.

Interaction of X-Rays with Matter

- The probability of producing a secondary photoelectron vs. an Auger electron is directly proportional to the KE of the photoelectron. The production of photoelectric and Auger electrons is shown diagrammatically in the following figure from Jenkins and Snyder (1996). In the diagram (a) shows the incident X-ray photon, (b) shows the production of a high-energy primary photoelectron. In (c) a lower energy electron moves into the vacated K-shell resulting in the production of an X- ray photon that leaves the atom, and in (d) the X-ray photon is absorbed by an outer shell electron resulting in the emission of a Auger electron.
- It is easy to see how the photoelectric (and Auger) effect can significantly damage the molecular structure of soft tissues encountered by an X-ray beam.



(a)
INCIDENT PHOTON
E
K
L
M
Φ_K
Φ_L
Φ_M
PHOTOELECTRON
$E_{pe} = E - \Phi_K$
(b)
AUGER ELECTRON
$E_{ae} = \Phi_K - \Phi_L - \Phi_M$
$E_{x\text{-}ray} = \Phi_K - \Phi_L$
(c)
OR
(d)

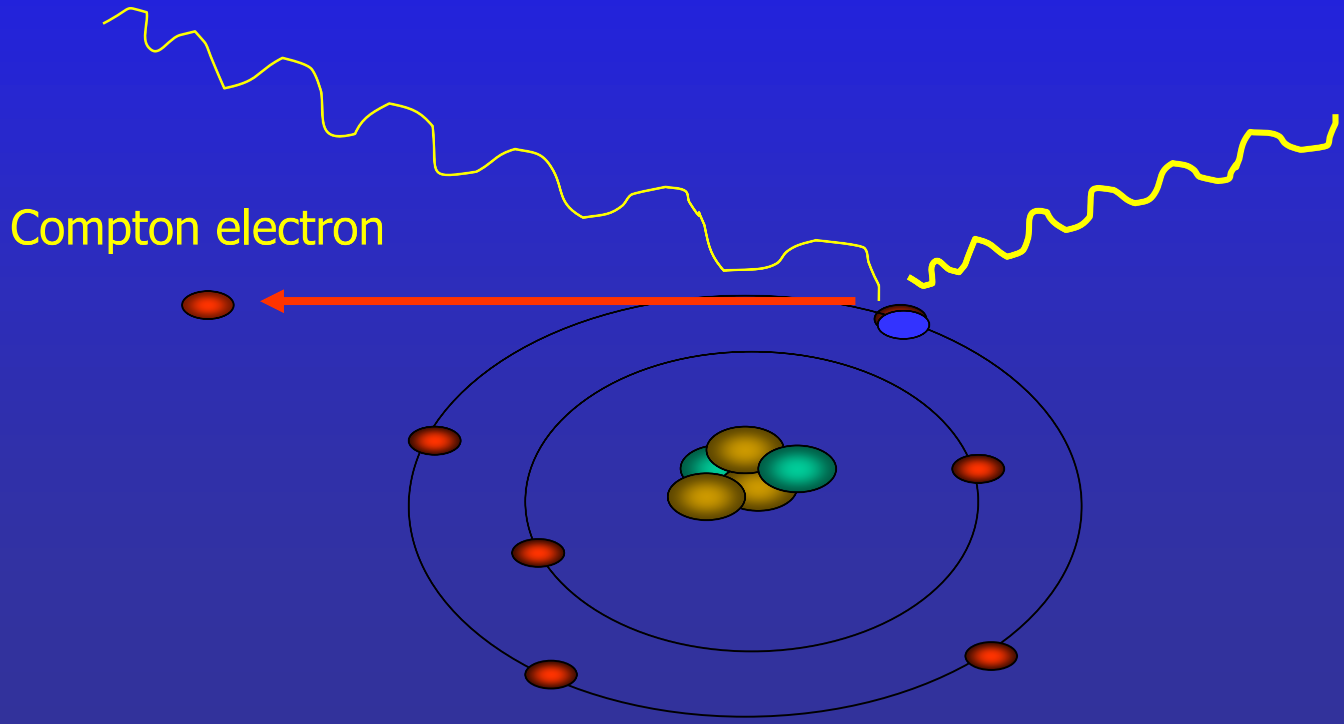
Interaction of X-Rays with Matter

2- The Compton Effect

- Moderate energy x-rays throughout the diagnostic range, can undergo an interaction with outer shell electrons that not only scatters the photon but reduces its energy an ionizes the atom as well. This interaction is called the Compton effect or Compton scattering and is shown schematically in fig. in this process the incident x-ray interacts with an outer shell electron and ejects its from the atom, thereby ionizing the atom . the x-ray continues in an altered direction with decreased energy . The energy of the Compton scattered x-ray is equal to the difference between the energy of the incident x-ray and the energy imparted to the electron.

Compton Scattering

- The incident x-ray is scattered by an outer shell electron which is also ejected (Compton electron)
- The X-ray is scattered at angle depending on amount of energy transferred
- The energy of the incident x-ray is shared between the scattered x-ray and the Compton electron
- The scattered X ray has lower energy and longer wavelength



Interaction of X-Rays with Matter

- The energy imparted to the electron is equal to its binding energy plus the kinetic energy with which it leaves the atom. Mathematically this energy transfer is represented as :
- $E_i = E_s + (E_b + E_{kE})$
- Where :
- Ei is the energy of the incident x-ray.
- Es is the energy of the scattered x-ray .
- Eb is the electron binding energy.
- EkE the kinetic energy of the electron

Interaction of X-Rays with Matter

- During a Compton interaction most of the energy is divided between the scattered photon and the secondary electron , also called the Compton electron. Usually the scattered photon retains most of the energy. Both the scattered photon and the secondary electron may have sufficient energy to undergo many more ionizing interaction before losing all their energy . ultimately the scattered photon will be absorbed photoelectrically , and the secondary electron will drop into an atomic shell hole previously created by some other ionizing event.

- Compton scattered photons can be deflected in any direction including 180 degree from the incident photon. At a deflection of 0 degree no energy is transferred . as the angle of deflection increase to 180 degree , more energy is transferred to the secondary electron , but even at 180 degree deflection the scattered x-ray retain at least about two thirds of its original energy.
- Photons scattered back in the direction of the incident x-ray beam are called backscatter radiation . this type of radiation is of considerable importance to radiotherapy.

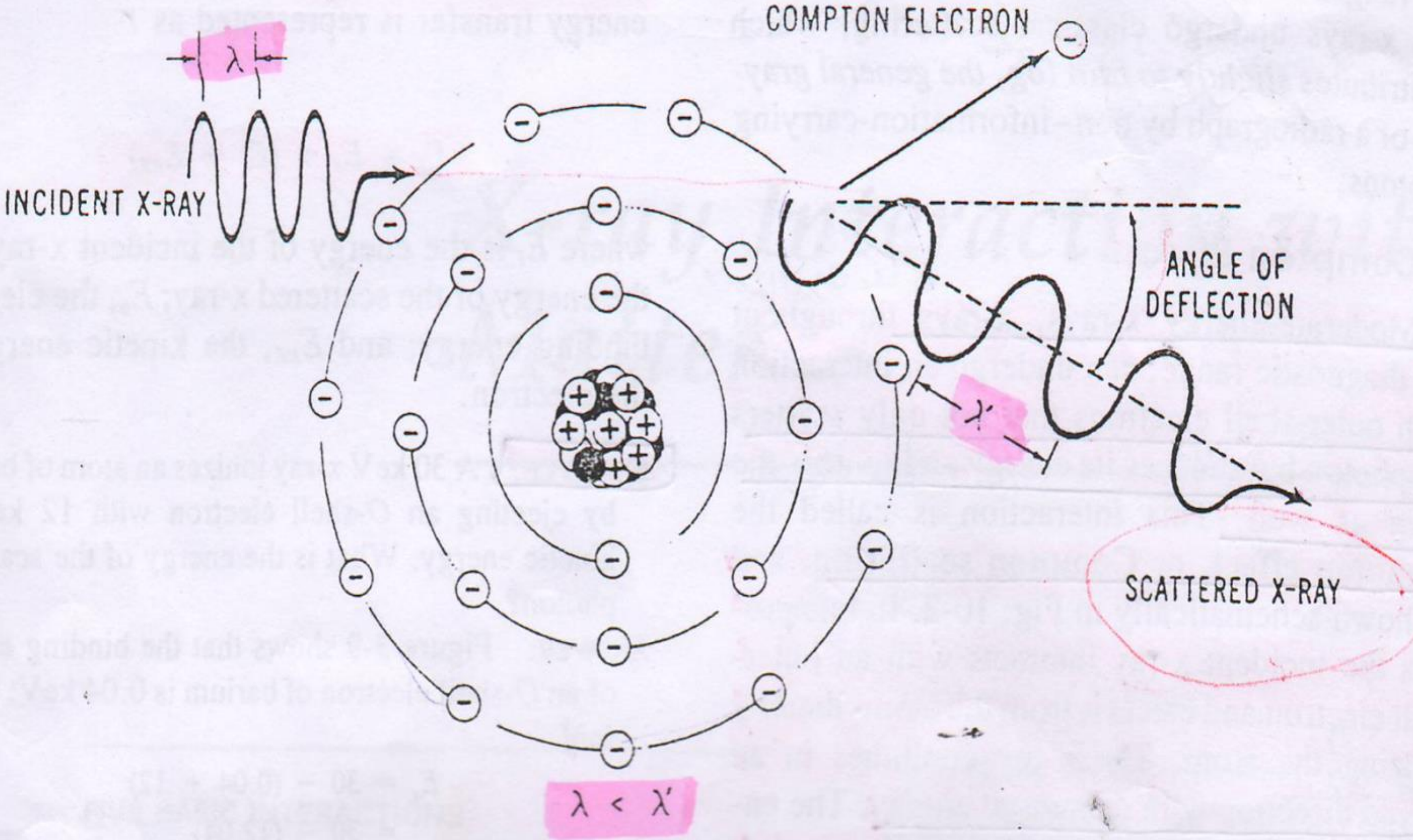


Fig. 10-2. Compton effect occurs between moderate-energy x-rays and outer-shell electrons. It results in ionization of the target atom, change in photon direction, and reduction of photon energy. The wavelength of the scattered x-ray is greater than that of the incident x-ray.

3- Classical scattering

- Low energy x-ray those with energies be low about 10 KeV can interact with matter by classical scattering sometimes called coherent or thompson scattering fig .

- In classical scattering the incident photon interact with a target atom causing it to become excited . The target atom immediately releases this excess energy as a secondary or scattered photons with wavelength equal to that of the incident atom ($\lambda = \lambda$) and therefore of equal energy . The direction of the secondary photon is different from that of the incident photon.

- The net result of classical scattering is a change in direction of the x-ray without a change in its energy. There is no energy transfer and therefore no ionization .

- Classical scattering is of little importance to diagnostic radiology because it primarily involves low energy x-ray which contribute little to the radiograph anyway . some classical scattering however occurs throughout the diagnostic range. At 70 KVp perhaps a few percent of the x-rays undergo classical scattering which contributes slightly to film fog , the general graying of a radiograph by non information carrying photons.

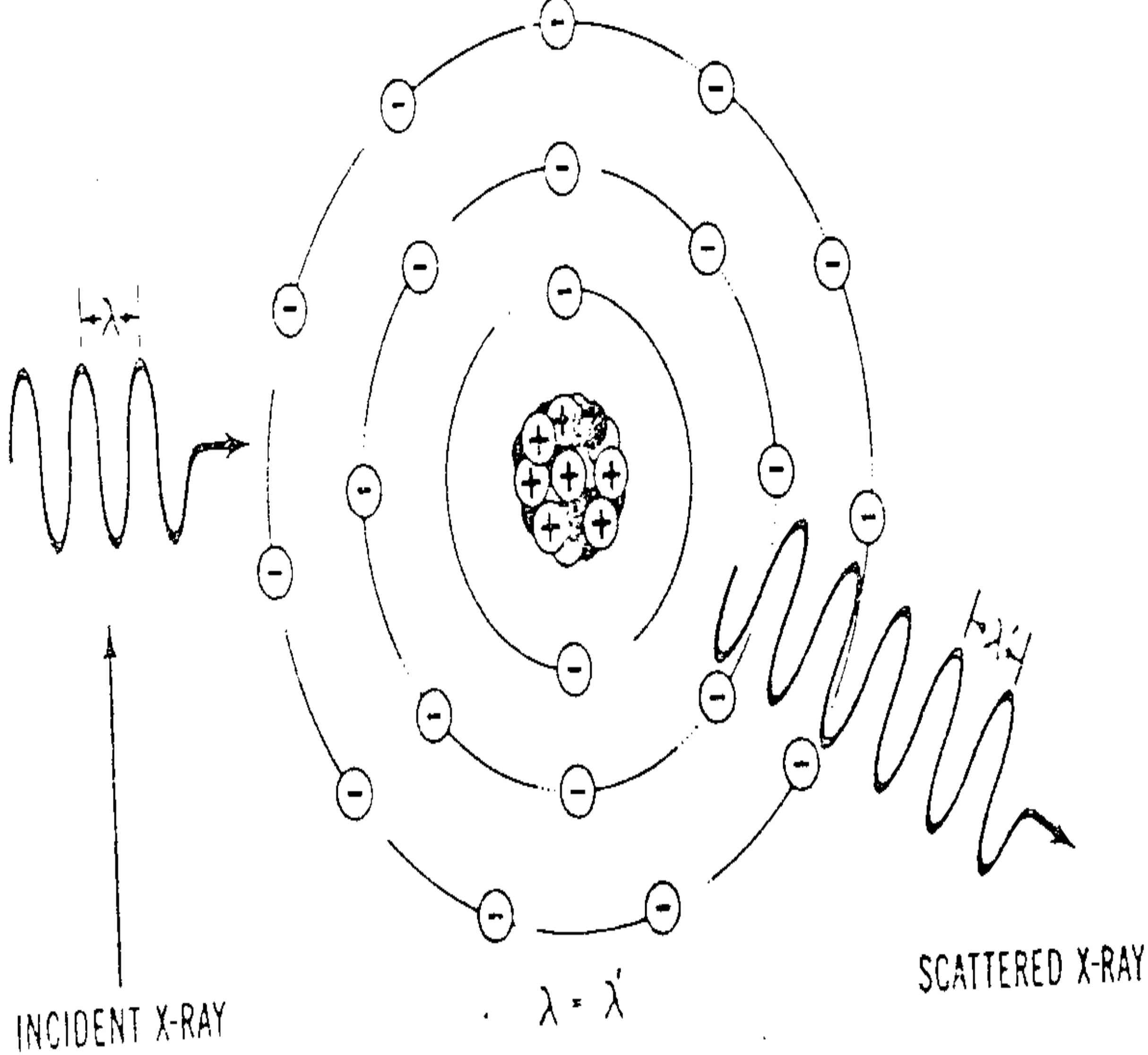
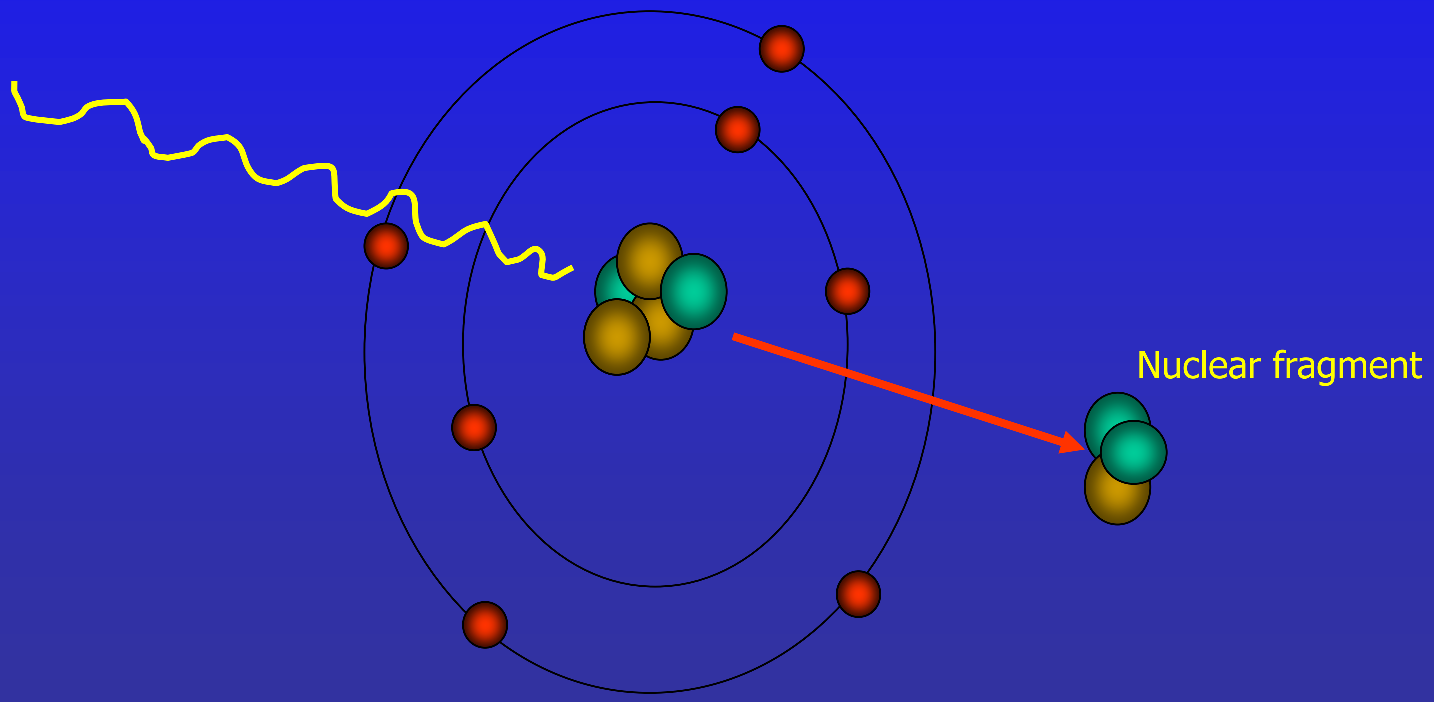


Fig. 10-1. Classical scattering is an interaction between low-energy x-rays and atoms. The x-ray loses no energy but changes direction slightly. The wavelength of the incident x-ray is equal to the wavelength of the scattered x-ray.

- ***4- Photodisintegration***
- High energy x-ray photons those with energies above 10 MeV can escape interaction with electrons and the nuclear electrostatic field and be absorbed directly by the nucleus . when this happens the nucleus is raised to an excited state and instantaneously emits a nucleon or other nuclear fragment. This process is called photo-disintegration and is shown schematically in fig. because it involves only x-rays with energies greater than approximately 10 MeV , photo-disintegration like pair production is unimportant to diagnostic radiology.

Photonuclear Disintegration

Only occurs with very high energy x-ray (> 10 MeV)



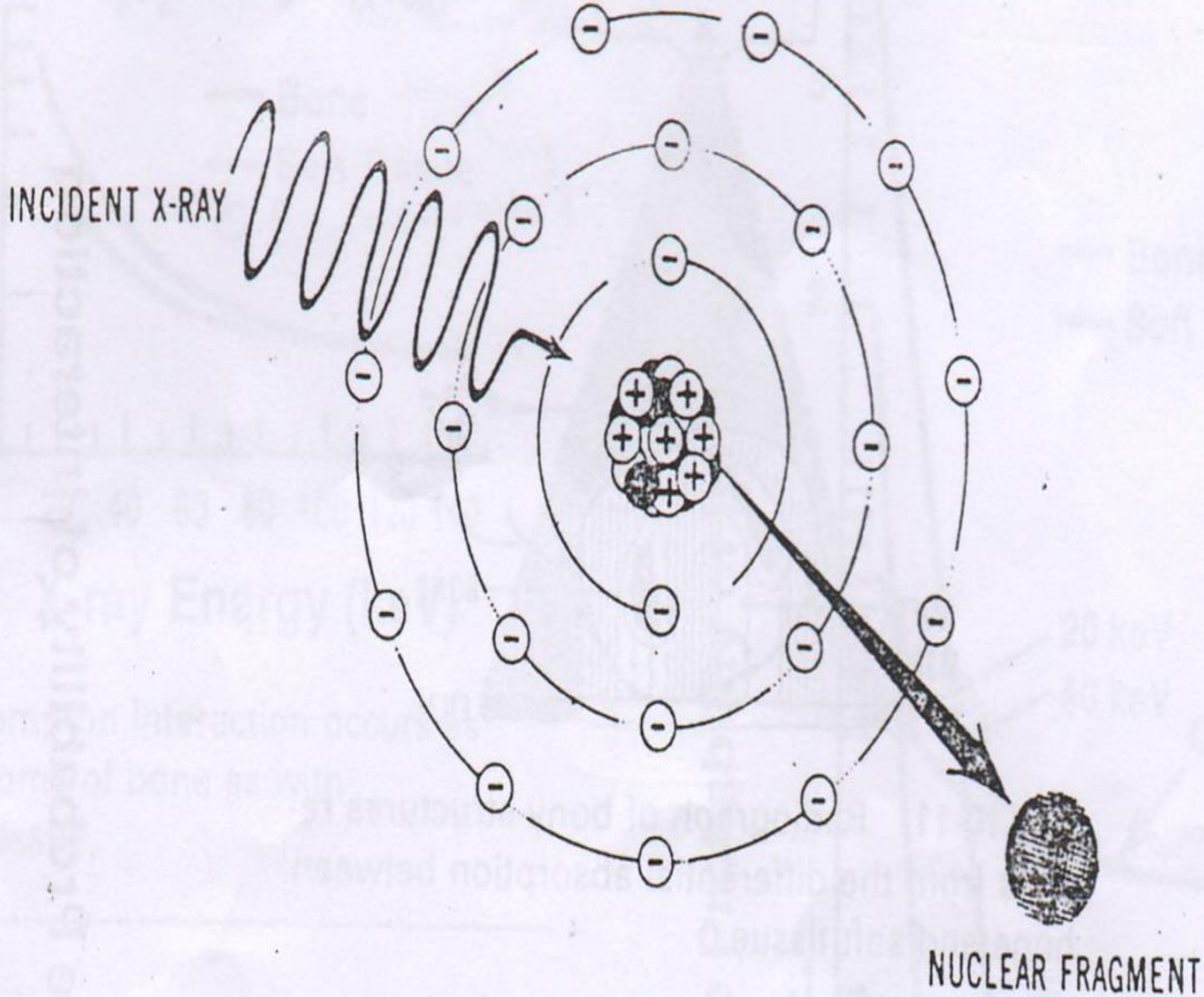


Fig. 10-9. Photodisintegration is an interaction between high-energy photons and the nucleus. The photon is absorbed by the nucleus, and a nuclear fragment is emitted.

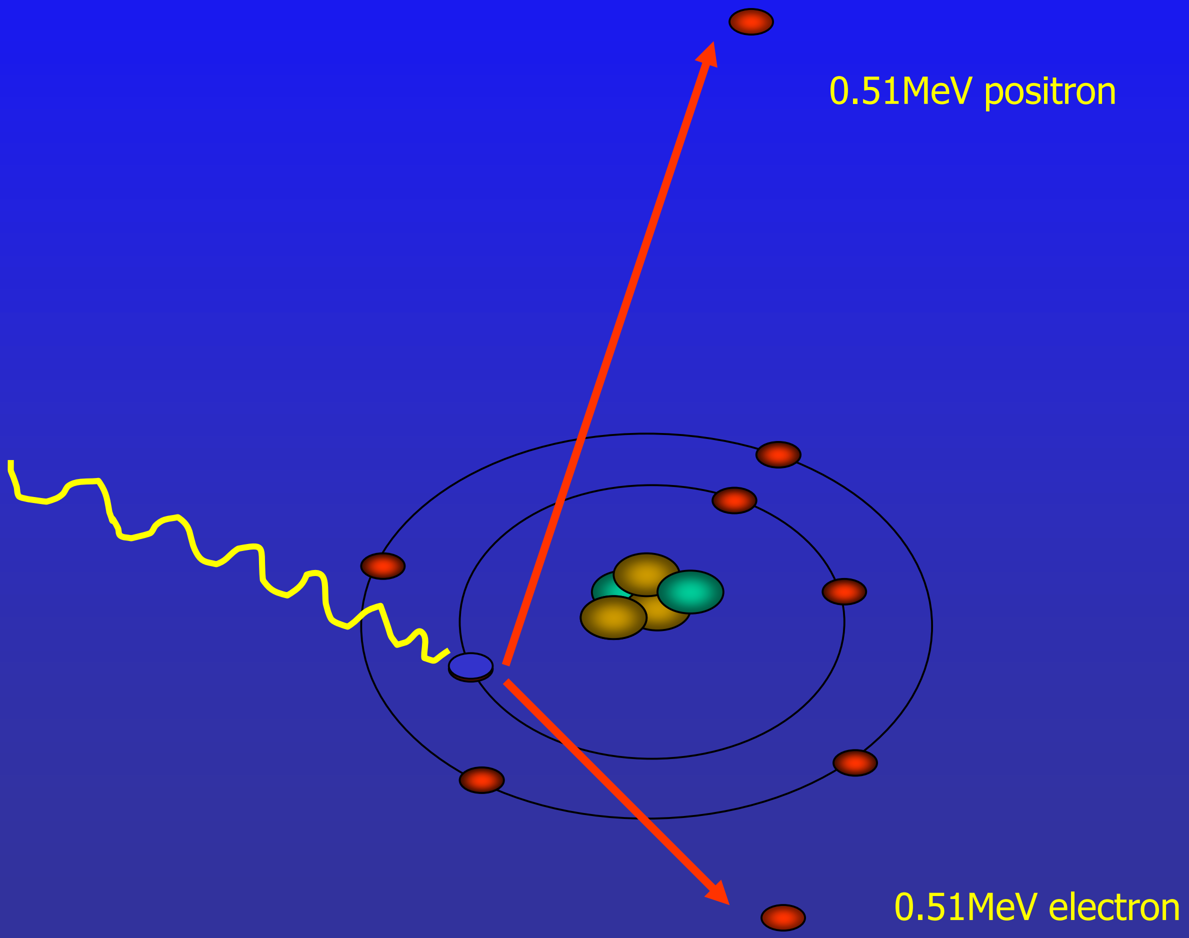
Interaction of X-Rays with Matter

5- Pair Production

- Pair Production (PP) can occur when the x-ray photon energy is greater than 1.02 MeV, when an electron and positron are created with the annihilation of the x-ray photon . Positrons are very short lived and disappear (positron annihilation) with the formation of two photons of 0.51 MeV energy. Pair production is of particular importance when high- energy photons pass through materials of a high atomic number. Pair production is a rare process and only occurs at high X-ray photon energies with high atomic weight targets. It is virtually nonexistent at the low-energies involved in X-ray diffraction work. Pair production is impossible unless the incident X-rays exceed 1.02 MeV. Pair production is not a significant process at the X-ray energies involved in X-ray diffraction.

Pair Production

Occurs with high energy x-ray (> 1.02MeV)



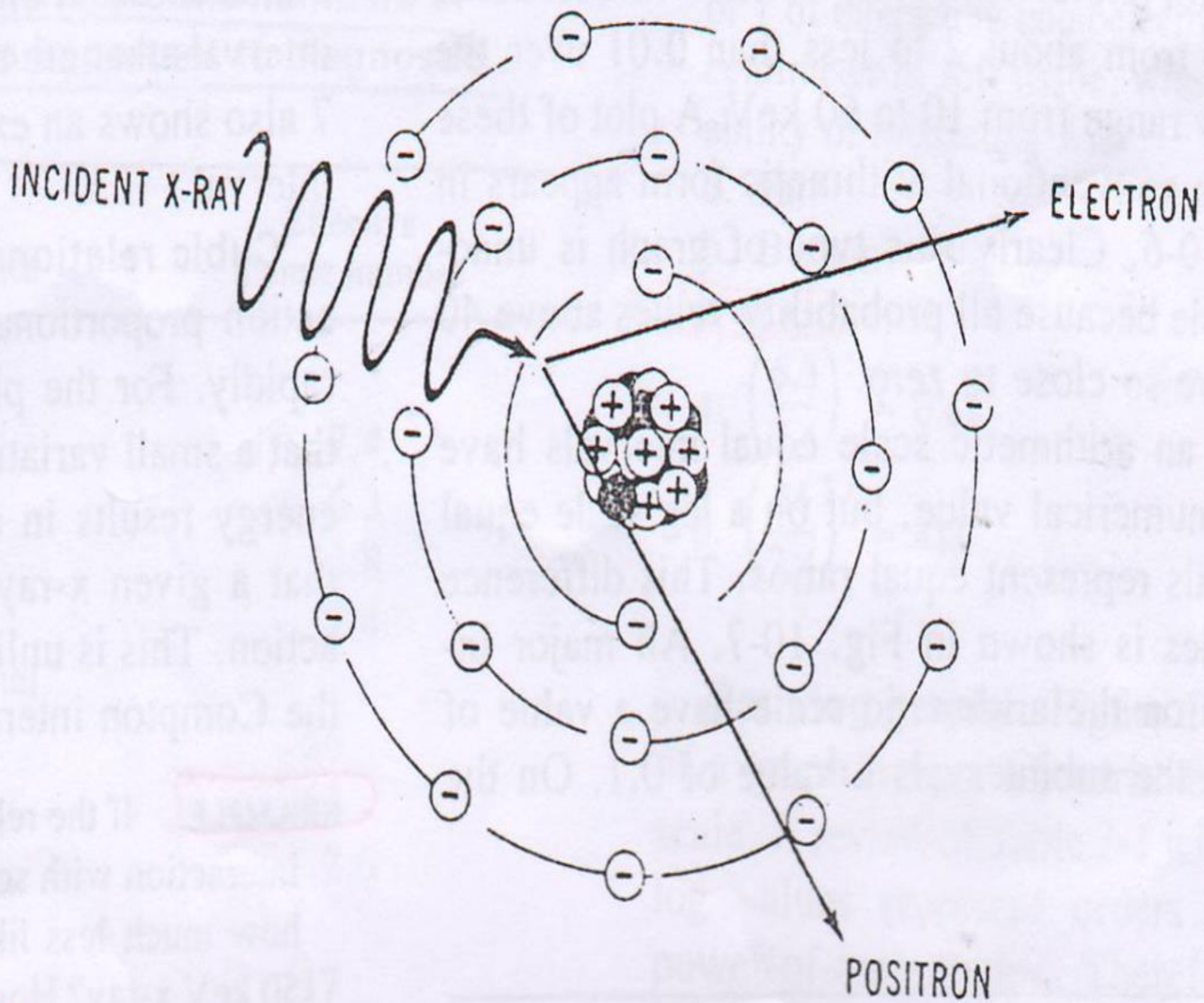


Fig. 10-8. Pair production occurs with x-rays that have energies greater than 1.02 MeV. The photon interacts with the nuclear force field, and two electrons that have opposite electrostatic charges are created.