CHAPTER 1

Introduction and Basic Radiation Physics

It has always been a debatable issue as to how much physics a dental student/practitioner should know. It is felt that for the sake of better understanding and application of radiology and radiography, certain basic principles have to be known.

Radiology: It is defined as study and use of radiant energy including Roentgen rays, radium and radioactive isotopes as applied to medicine and dentistry.

Roentgenology: It is the study and use of Roentgen rays as applied to medicine and dentistry.

Radiography: It is the production of a photographic image of an object through the use of X-rays.

Radiation: It is the process of transfer of energy from one point to another in the form of electromagnetic waves, e.g. light, radiowaves, X-rays, etc.

Matter: It is the substance of which all physical things are composed, it is anything that occupies space and has inertia, it has mass and can exert force and can be acted upon by a force. Matter can exist in three states, viz. solid, liquid and gaseous.

Atom: It is the fundamental unit of any particular element. Historically, atom was considered to be indivisible (*a* means *cannot*, *tomi* means *to cut*). However, each atom has central nucleus of protons and neutrons and negatively charged electrons orbiting around it.

It is now clear that even the individual protons and neutrons are made up of smaller fundamental particles termed **Quarks**. Quarks are considered as fundamental because they cannot be further split or divided. There can be either Up Quark or Down Quark

Charge of Quarks: Up Quark + 2/3 Down Quark –1/3

A proton has 2 Up Quarks and 1 Down Quark, so its charge is 2/3 + 2/3 = 4/3 – 1/3 = 3/3 = +1, i.e. single positive charge

A neutron has 1 Up Quark and 2 Down Quarks, so its charge is $+2/3 -1/3 - 1/3 = 2/3 - 2/3 = 0$, i.e. neutral charge.

Electrons exist in three-dimensional orbitals around the nucleus currently designated by letters s, p, d, f, g and h (previously designated by K, L, M, N, O, P).

Atomic number: The distinguishing number of protons in the nucleus of an atom is referred to as atomic number, and is designated by the symbol Z.

At rest position, number of electrons is equal to the number of protons.

Atomic mass number: Denotes the total number of protons and neutrons in the nucleus, and is designated by the symbol A.

Discovery of X-rays

On the night of 8th November 1895, Prof. Wilhelm Conrad Roentgen, who was a professor of physics at the University of Wurtzberg, Germany, accidentally, discovered X-rays. He was experimenting with Hittorf Crooke's tube for cathode rays, when he observed a greenish glow emanating from barium platinocyanide screen kept at a distance. When he interposed his hand, unintentionally, between the tube and the screen, he could detect the image of his bones in the shadow. He at once realized the significance of this finding and established the property of penetration. He then covered the tube with black paper and fluorescence persisted, which further confirmed the property of penetration. He also realized that this new kind of a ray must be responsible for fogging of photographic plates observed by him, and reported by others (photographic property).

Roentgen had discovered these new rays and as anything unknown in mathematics is designated by symbol 'x', he called them X-rays. His colleagues described this as an un-American modesty, and they later insisted on calling X-rays as Roentgen rays.

The first radiograph was made immediately afterwards and was of his wife Bertha's hand. The exposure time required was 15 minutes!

The first dental X-ray was made by **Otto Walkhoff.** Exp time 25 mins!

The first intraoral X-ray was made by **Dr Edmund Kells** in 1896**.**

Unfortunately, early workers failed to realize the harmful effects of X-rays, worked without protection and suffered from skin ulcerations, necrosis and even malignancies and underwent mutilating surgeries.

Only **Sir Rollins** had realized the possibility of radiation hazards and had advised certain precautions to be taken to prevent them and hence he is known as the "Father of radiation protection".

Radiation is the transfer of energy from one point to another through space and matter.

It can be:

i. *Electromagnetic radiation:* Transfer of energy in the form of waves.

ii. *Particulate radiation:* Transfer of energy in the form of movement of particles.

ELECTROMAGNETIC SPECTRUM

Electromagnetic radiation includes various forms of radiant energy rays right from visible light to X-rays and radiowaves, electric waves, etc. mentioned in Table 1.1. The properties of electromagnetic radiation can be explained on the basis of two theories:

1. Wave theory
2. Quantum theory

Properties of Electromagnetic Radiation

1. It travels in a straight line by wave motion.
2. While passing through matter EM radiation gives rise to 2 fields, a magnetic field at right angles to pathway of propagation, and an electric field at right angles to magnetic field, hence termed electromagnetic.

TABLE 1.1: The electromagnetic spectrum

Type of rays	*Wavelength in angstrom units/km*	*Required potential difference in kVp*
Electric waves	10^{18}Å (50000–100,000 km)	
Hertzian waves	10^{13}–10^{18}Å (1000 km)	
Radio/wireless/TV	10^{10} A–10^{12}Å (1–100 km)	
Infrared	10^{5} Å	
Visible light red	7700 Å	
Violet	4000 Å	
Ultraviolet	10^{3} Å/1000 Å	
Grenz rays	1–2 Å	10–20 kV
Soft X-rays	0.5A–1Å	20–50 kV
Diagnostic X-rays	0.1–0.5Å	50–100 kV
Therapeutic X-rays		
Hard X-rays	0.01Å–0.05Å	200–500 kV
Supervoltage/megavoltage	0.001Å	2–20 MeV
Cosmic X-rays	0.0001Å	

3. The basic difference between various electromagnetic radiations is their wavelengths.
4. All EM radiations travel at the speed of 3×10^8 m/s or 1,86,000 miles per second (speed of light)
5. They can travel through vacuum.
6. Exhibit phenomena of diffraction and interference.
7. Follow the inverse square law; (Intensity $\propto$ 1/Distance^2)

Visible light has wavelength between 4000–7000 Å, violet has a shorter wavelength, λ (4000Å)

UV light has shorter wavelength than violet light. It produces following effects on skin

1. Photoerythema (sunburn)
2. Photopigmentation (sun-tan)
3. Photochemical production of vitamin D

It can also be used for sterilization of eatables and other substances and treatment of skin lesions such as psoriasis (PUVA therapy).

Electromagnetic waves which have still shorter wavelength (0.1–0.5Å) make them more penetrating and these are the X-rays used for diagnostic purpose.

EM radiations used for radiotherapy has to have still shorter wavelength (0.01–0.001Å) and greater penetration and capacity to kill malignant cells.

Electromagnetic radiations having longer wavelengths than red are called infrared rays and are that part of sunlight manifested as heat. They are also used to relieve painful muscle spasm.

Radiowaves having wavelengths (1–200 km) are used in magnetic resonance imaging (MRI). The radiowaves are also used in the field of telecommunication. Electric waves have the longest wavelength in the spectrum.

Particulate Radiation

This type of radiation is released by the process of radioactivity. Unlike smaller atoms which have equal number of protons and neutrons large atoms have more number of neutrons than protons which makes them unstable. Such large unstable atoms breakdown releasing α and β particles and γ rays by the process of radioactivity after which the atom is converted to another element.

α particles are positively charged and are heavy. They are made up of 2 protons (He nuclei) which densely ionize the matter through which they pass, rapidly give up their energy and become neutral helium atoms. α particles cannot penetrate deep and can even be absorbed by sheet of paper.

An unstable atom with excess number of neutrons decays by converting neutron into a proton, a β particle and a neutrino. β particles are similar to electrons. High speed β particles are smaller, lighter and carry a single negative charge and are not densely ionizing and penetrate matter deeper than α particles up to 1.5 cm. β particles from radioactive iodine^{131} are used in the treatment of CA thyroid.

An unstable atom with excess proton decays by converting a proton into a neutron a β^+ particle (positron) and a neutrino. Positron is highly reactive and quickly combines with electron to form two γ rays by annihilation reaction. This reaction is the basis of positron emission tomography.

Gamma rays (γ) are emitted by nuclei of radioactive atoms and have greater energy than X-rays. X-rays are produced outside the nucleus by interaction between electrons and the nuclei of target material (tungsten) used in the X-ray machine.

Natural radioactivity and radiotherapy involves both particulate and electromagnetic radiations. Diagnostic radiography mainly involves electromagnetic radiation (X-rays in radiography and gamma rays (γ) in radionuclide scanning).

Uses of X-rays

1. Diagnostic
2. Therapeutic—X-rays have capacity to damage the living cells which are rapidly multiplying and therefore cancer cells are more prone to damage by X-rays
3. In metallurgy—crystallography
4. Spectroscopy—identification of certain substances
5. Sterilization of tinned foods
6. Detection of casting defects in metallic objects.

CONSTRUCTION AND WORKING OF X-RAY MACHINE

Principle

Electrical energy can be converted into kinetic energy (potential difference can be used to give speed to electrons) kinetic energy of electrons can be converted into heat and X-rays.

The X-ray tube is a highly evacuated glass tube (lead beryllium glass) in which are mounted cathode and anode assembly (Figs 1.1 and 1.2). The X-ray tube is evacuated because:

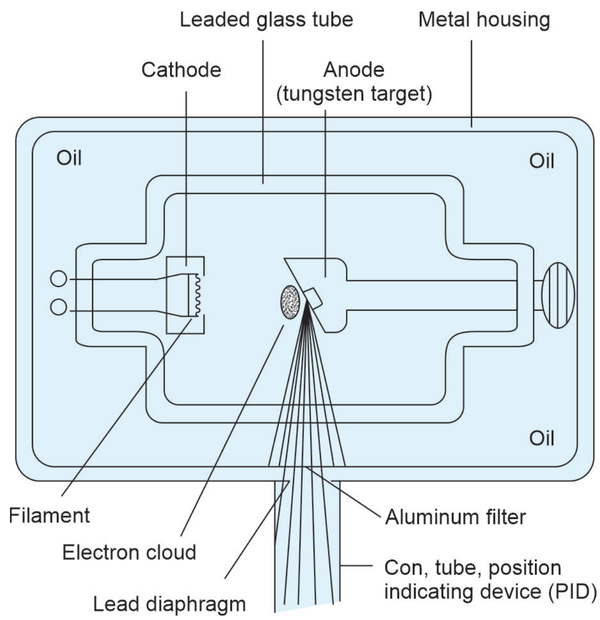

Fig. 1.1: Construction of X-ray tube (*Source:* Internet)

i. Presence of air will obstruct flow of electrons and reduce their kinetic energy.
ii. Presence of oxygen will oxidize tungsten filament.

The lead beryllium glass is surrounded by lead (Pb) shield except in the area of the port. Pb shield is used because:

i. It absorbs all the radiations except the useful beam.
ii. It provides earthing to the X-ray tube to prevent chances of electric shock.
iii. Prevents physical damage to the tube.

Cathode is made up of tungsten (W) filament mounted in concavity of molybdenum focusing cup.

Tungsten is preferred as a filament material because it has:

1. High atomic number (74) therefore more number of electrons are given out, i.e. high thermionic emission.
2. High melting point (3380°C) so that filament should not melt.
3. Low vapor pressure at high temperature so that it will not vaporize.

Tungsten filament is in the form of a coil 1 cm in length and 0.2 cm in width, mounted on 2 stiff wires. Tungsten filaments also have thorium 1% which increases the thermionic emission.

The function of molybdenum focusing cup is to restrict the size of electron cloud and also serve as a cathode and helps in repelling electrons (because of negative charge).

The anode is made up of tungsten button (focal spot or target) mounted in a copper stem. Tungsten is preferred as a target material because it satisfies the requirements of ideal target material, i.e.

1. High atomic no. (Z = 74); which gives rise to increased interactions cbetween incoming electrons and W atoms thereby generating more number of X-ray photons.
2. High melting point (3380°C) so that anode does not melt, despite the heat produced there.
3. High thermal conductivity which transmits the heat generated to the copper stem.
4. Low vapor pressure at high temperature, so that tungsten does not evaporate.

Such vapors, if present, are likely to line the tube and give rise to excessive filtration and also act as a source of radiation giving rise to stray radiations.

The heat generated at the anode is dissipated by:

1. Conduction—through the copper stem.
2. Convection—through the oil surrounding tube called insulating oil/transformer oil.
3. Radiation—through the radiator device attached to copper stem.

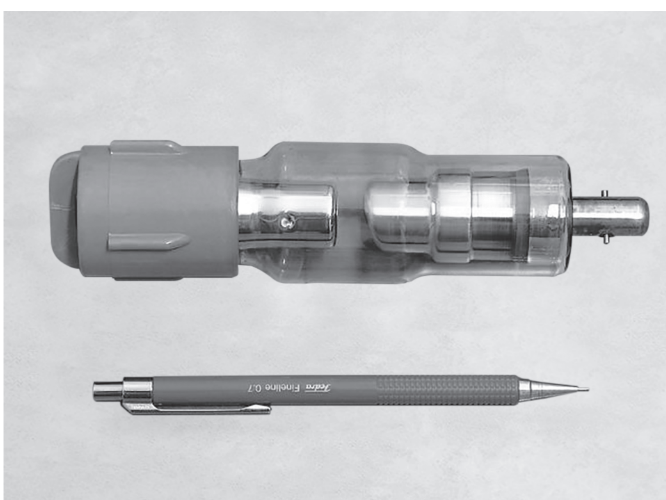

Fig. 1.2: The X-ray tube (*Source:* Internet)

THE WORKING OF X-RAY MACHINE

When electrons traveling at a high speed are suddenly stopped by an impact against a solid object, X-rays are produced. In an X-ray machine, electrons are produced, by heating the filament electrically. An electron cloud is produced at the cathode by thermionic emission. Size of electron cloud is restricted by molybdenum focusing cup. These electrons will travel at high speed only when anode is made positive. This is done by applying a potential difference of 65,000 volts between anode and cathode. As the anode is made positive with respect to the cathode the electrons present around the filament are strongly repelled from cathode and they are bombarded against the focal spot where X-rays are produced along with heat. 99.8% of the KE is converted into heat which is dissipated as stated above and only 0.2% is converted into X-rays. X-rays so produced are allowed to come out through the port of the X-ray tube.

Interaction between Incident Electrons and Atoms of the Focal Spot

Characteristic radiation: When electrons approach the tungsten anode, if kVp is more than 70 then K-shell electron is knocked off and L-shell electron falls in its place. In doing so, L-shell electron gives out energy which is equivalent to difference of energy level between K and L shells. This energy is in the form of X-radiation and since energy level of a particular element at each shell is characteristic, the radiation given out is called ***characteristic radiation*** (Fig. 1.3).

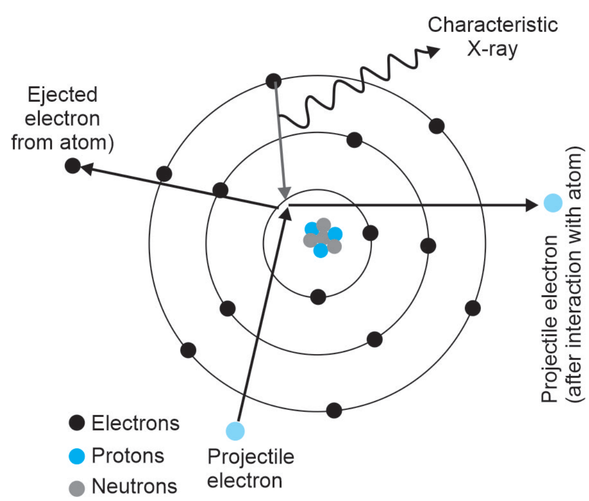

Fig. 1.3: Production of characteristic radiation (*Source:* Internet)

Braking radiation or Bremsstrahlung: When kVp is less than 70, incoming electrons undergo a sudden change in direction and sudden reduction of speed, i.e. they decelerate (because they are repelled by electrons of tungsten atom). Due to this change in speed of the electrons, the radiation which is given out is known as braking radiation or Bremsstrahlung which means braking in German and also called white radiation. Mostly, the radiations generated in a dental X-ray machine are of this type (Fig. 1.4).

Circuit of X-ray tube (Fig. 1.5): It is divided into two parts:

1. Filament circuit (to produce electrons by heating filament)
2. Cathode-anode circuit (to provide the potential difference of 65,000 volts)

Filament circuit uses a step-down transformer (sdt), because, only 10 V is required to heat the filament, whereas supply is 220 V.

Cathode-anode circuit has a step-up transformer (sut) because the voltage has to be stepped up from 220 V to 65,000 V.

Autotransformer has a single coil which is divided by means of a pointer. kVp can be adjusted by the operator by using kVp selector which is actually an autotransformer which converts the primary input voltage to a desired secondary voltage which in turn is transformed into the high voltage (65000 volts or more).

A step-down transformer has less turns of coil in the secondary compared to the primary.

In the step-up transformer, the no. of turns of coil in the secondary are more compared to primary.

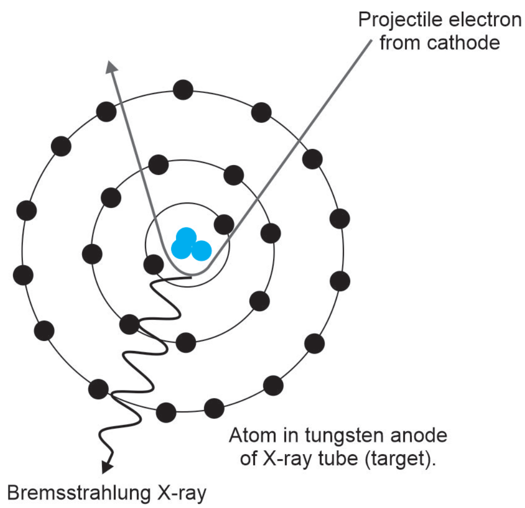

Fig. 1.4: Production of Bremsstrahlung radiation (*Source:* Internet)

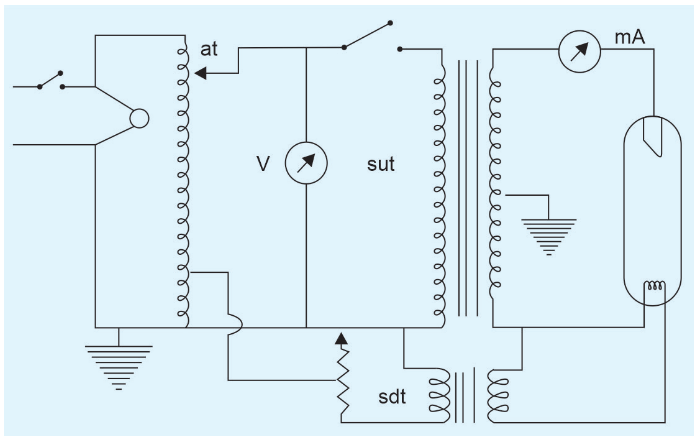

Fig. 1.5: Circuit diagram of X-ray tube. V—voltmeter; At—autotransformer; sut—set-up transformer; sdt—step-down transformer

Line Focus Principle (Angle of Truncation)

The actual size of focal spot is 1 mm × 3 mm. However, the anode is angled at 20 degrees to central ray, as a result of which the rectangular focal spot appears as a square (Fig. 1.6). This is done to facilitate:

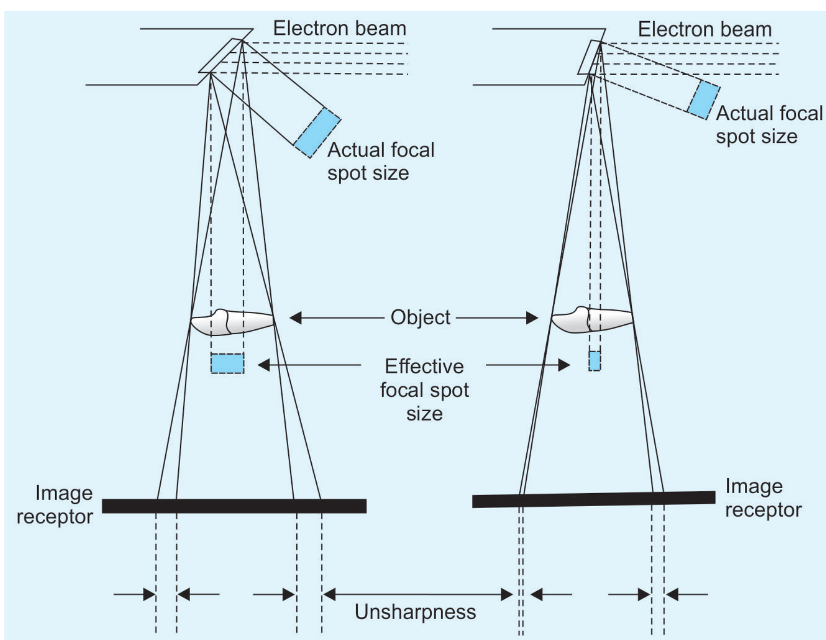

Fig. 1.6: Explaining the line focus principle (*Source:* White and Pharoah 5th edition)

i. Heat distribution across larger surface [less heat per unit area] at the anode, at the same time.
ii. Sharp image because rectangular focal spot appears as a square when viewed in the direction of the central ray (smaller the focal spot sharper the image).

Heel effect: The intensity of the emergent beam is not uniform as seen from the diagram. This is because part of the X-ray beam is absorbed by the focal spot itself. If the anode was not angulated and was flat, the 'Heel' of the target would have absorbed most of the X-ray photons. The cathode side of the beam is more intense as it does not have to travel through the target as much as the anode side of the beam which gets absorbed in the target itself and this contributes to 'heel effect'. Uneven density on the radiograph caused by heel effect is seen on extra-oral films as they are of a larger size than the IOPA film.

Rotating anode: In certain OPG, cephalometric and CBCT machines, anode is in the form of a bevelled Cu disc 7.5–10 cm in diameter. Focal spot is in the form of 0.6 mm tungsten ring incorporated in Cu disc. During exposure, the Cu disc is rotated so that at each moment a different part of focal spot gets bombarded by electrons (Fig. 1.7). This

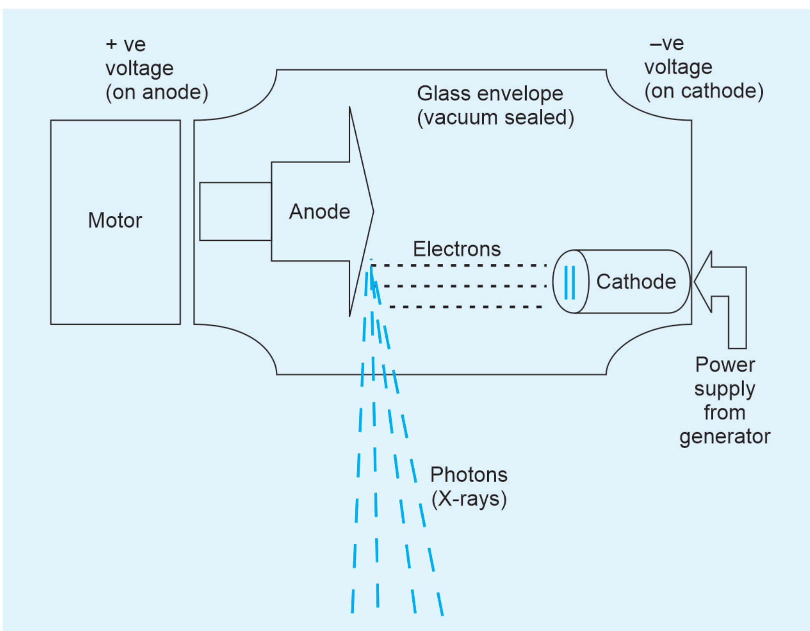

Fig. 1.7: Diagram of an X-ray tube with a rotating anode (*Source:* Internet)

gives rise to less heat per unit area. Such anodes can be used with tube currents of 100 to 500 mA and rotate at about 3000 revolutions per minute.

Tube current: **Milliamperage (mA)** denotes the tube current that is the flow of electrons from the cathode to anode. It is not the same as the current used to heat the filament. If the filament current (indicated by mA selector) is increased, the temperature of the filament increases, thereby increasing thermionic emission and the tube current. This gives rise to greater number of electrons striking against anode and as a result more number of X-ray photons. Thus mA controls the quantity of X-rays. The number of X-ray photons will also increase, if the exposure time is increased.

mAs factor (milliamperes × seconds) denotes product of mA and exposure time in seconds. If mAs is increased, more no. of X-ray photons are produced. In other words, mAs factor, denotes total photon production and mAS controls quantity of X-rays.

Tube voltage: **kVp** denotes potential difference between cathode and anode. If kVp is increased, the electrons travel at greater speed and have greater KE. As a result, more interactions take place within the focal spot hence more X-ray photons of short wavelength are given out. The energy of the X-ray photons is related to the kinetic energy of incoming electrons and therefore if kVp is increased the penetration power of X-rays increases. kVp can be adjusted by the operator by using kVp selector which is actually an auto-transformer that converts the primary input voltage to a desired secondary voltage which in turn is transformed into the high voltage (65000 volts or more).

Rectification is the conversion of alternating current (AC) to direct current (DC). During the first phase, the cathode is negatively charged and anode is positively charged. The electrons hit against the anode and X-rays are produced. But when current changes its direction during the second phase, cathode becomes positively charged. Therefore, electrons present at anode (because of the thermionic emission secondary to the heat produced), travel backwards and hit against the filament, thereby causing burnout of the filament. Such a phenomenon takes place in a general X-ray machine where high kVp and mAs is required to be used for good radiographic density and optimum contrast. Hence in such machines rectifying devices are used to convert AC to DC.

In a dental X-ray machine, however, the amount of heat produced at the anode does not give rise to excess electrons. As a result, when current changes its direction, there are no electrons at the anode to travel back to the cathode and hence dental X-ray tube is called ***self rectified*** or ***half wave rectified***

Some dental X-ray machines are provided with full wave rectified, high frequency power supply instead of conventional half wave rectified AC power supply. This provides constant potential between cathode and anode so that the mean energy of the resultant X-ray beam is higher. The radiographic images generated by such constant potential X-ray machines provide longer contrast scale and the patient receives lower radiation dose compared to conventional machines.

Primary radiation is the radiation emitted by the focal spot of the target.

Stray radiation is the radiation emitted by any part of the X-ray tube other than the focal spot.

Useful beam is that part of primary radiation which is allowed to emerge out through the collimating device.

Scattered radiation is the radiation which has undergone a change in direction during passage through a substance.

Secondary radiation is the radiation emitted by a substance through which X-rays are passing.

Properties of X-rays

1. *Diagnostic properties:*

A. *Penetration*

a. X-rays can penetrate through matter in a differential manner. Degree of penetration of X-rays depends on kVp. It varies inversely as wavelength and directly as kVp. For diagnostic radiography wavelength used is 0.1–0.3Å.

b. Penetration of X-rays also varies according to density of material through which they are passing, e.g. penetration is more through pulp, less through dentin and lesser through enamel and filling material because the density of enamel is more (inorganic content, i.e. Ca 96%).

c. Penetration also depends on the thickness of material through which they are passing.

B. *Photographic properties:* X-rays can produce photochemical reaction of sensitized surface of the film. When X-rays pass through a film at a particular point, certain changes occur in AgBr crystals at that point which when developed appear as dark shadows known as a radiolucent shadow (e.g. pulp). Whereas enamel does not permit more X-rays to pass through and hence appears as white this is called radiopaque.

C. *Fluorescence:* When X-rays fall on certain crystalline substances they emit visible light, e.g. barium platinocyanide gives rise to green light. Ca tungstate gives blue light and the recently used (rare earth materials) gadolinium and lanthanum give rise to greenish fluorescence. This property is used in the functioning of intensifying screens.

2. ***Biological properties:*** X-rays can have harmful effect on living cells, as X-rays can directly damage the DNA, chromosomes and also other cellular components. Such genetic changes can have a cytocidal effect on the cells and this is termed the **direct effect** of radiation. Sometimes repeated exposure to X-rays may cause formation of a 'mutant gene' which may lead to carcinogenesis.

   Indirect effect of radiation is associated with formation of unstable compounds, alteration of the cellular enzymes, etc. with which the body cells are incompatible.

3. ***Thermal properties:*** When X-rays pass through matter they give rise to heat, however, it is very neglible.

4. ***Chemical properties:*** Because X-rays are ionizing radiations, they can cause alteration in the chemicals through which they pass. For example, $FeCI_2$ to $FeCI_3$, H_2O to H^+ and OH^-.

5. ***Properties of physics:***
   a. X-rays are invisible electromagnetic radiations.
   b. They travel at the speed of light, i.e. 1,86,000 miles/sec or 3×10^8 meters/sec.
   c. They cannot be focused.
   d. They obey the laws of polarization and interference.
   e. They satisfy the inverse square law, i.e. intensity of X-ray beam varies inversely as square of the distance of that point from the source of radiation.

In order to generate a radiographic image, we must have three basic essentials: The X-ray source, the patient and the film or other image recording receptors along with digital software and hardware. Any variation in these can alter the radiograph and hence the factors are divided as follows:

FACTORS AFFECTING THE RADIOGRAPHS

I. Radiation beam factors (X-ray source)
II. Object factors (patient/object)
III. Image recording factors (film, digital sensor)

I. *Radiation beam factors*

1. Focal spot size
2. TFD
3. Milliamperage
4. kVp
5. Filtration
6. Collimation
7. Exposure time
8. Tube rating
9. Duty cycle

II. *Object factors*

1. Object thickness
2. Object density

III. *Image recording factors*

1. Reduction of secondary radiation
   - Pb foil
   - Pb backing
   - Grids
2. Films and film storage
3. Intensifying screens
4. Film processing

I. Radiation Beam Factors

1. *Focal spot size:* If the size of the focal spot is large, each point on the focal spot acts as source of X-rays and the rays incident on the object cast the shadow at different spots giving rise to unsharpness or penumbra formation (e.g. your shadow under a tube light appears to be unsharp). If the source is small, the shadow becomes sharper (e.g. your shadow under a light bulb appears to be sharp). Therefore it is said that the focal spot should be as small as possible to obtain a very sharp image (Fig. 1.8). Ideally, a point source should be used but it is not practically possible and hence we use a focal spot which is 1 mm × 3 mm rectangular projected as a square (line focus principle).
2. *Target film distance:* It should be as long as possible. As X-rays coming from a distance are more parallel and less divergent, there is less magnification and penumbra formation (Fig. 1.9). However, TFD cannot be increased indefinitely because of the inverse square law.

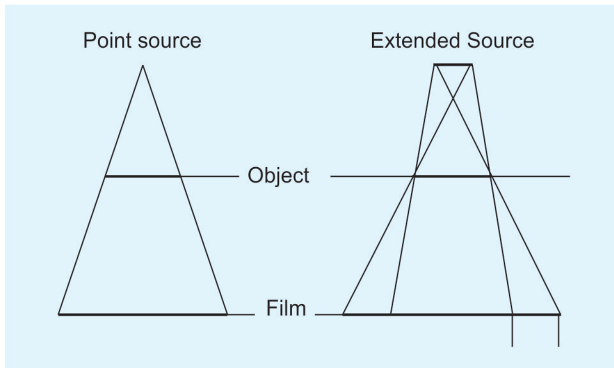

Fig. 1.8: Importance of a point source

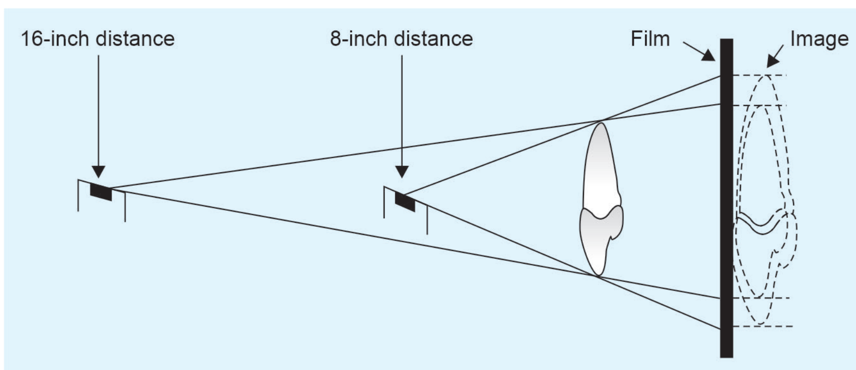

Fig. 1.9: Importance of large target film distance. (*Source:* Internet)

Thus each technique has its own ideal TFD, e.g. for periapical radiographs, the desirable TFD is 6–8 inches, for cephalometric projection, the TFD is 5 ft for other extraoral views, it is 3 ft.

3. ***Milliamperage:*** It denotes the tube current that is the flow of electrons from cathode to anode and is not the same as the current used to heat the filament. If the current to filament is increased, the temperature of the filament increases thereby increasing the thermionic emission, i.e. number of e-produced at the cathode resulting in increased tube current (mA) and thus, the number of X-ray photons is also increased. Thus mA controls the quantity of radiation. If mA is increased, radiograph becomes darker.
4. ***kVp:*** It denotes the potential difference between the anode and cathode. If kVp is increased, the KE of the electrons increases and this gives rise to more penetrating X-ray photons, i.e. kVp controls

the quality of radiation. Increased kVp also increases the mean energy of the photons, maximum energy of the photons and also increases the number of photons as a result of increased number of interactions between incident electrons and target atoms. Increased kVp also rapidly repels the electrons from the cathode and helps in generating more number of electrons which in turn increases the number of photons. It may hence be stated that kVp controls both the quality and quantity of X-rays.

However, kVp cannot be increased indefinitely because all X-rays might pass through the object without being absorbed, giving rise to a very poor contrast. On the other hand, if kVp is too less, the resultant beam of X-rays will have a very less penetrating power and will be entirely absorbed by the object. Hence, each technique requires an optimum kVp.

For example, IOPA, OPG , cephalometric, skull views–60 kVp to 90 kVp

CBCT 90 to 120 kVp

5. ***Filtration:*** Since the kVp across the tube varies from 0–65,000 V, the X-ray photons which come out are not of uniform wavelength. Therefore, the X-ray beam is made up of long wave photons or soft X-rays and short wave photons or hard X-rays. The soft X-rays do not penetrate the hard tissue structures and they are fully absorbed in the tissues, causing harm. Short wave photons, i.e. hard X-rays on the other hand have the capacity to penetrate the tissues and cast a shadow and are hence of use in diagnostic radiography. The purpose of filtration is to eliminate or to cut off long wave photons and this is achieved by the following means:

   a. Inherent
      - Glass wall of X-ray tube
      - Oil surrounding the X-ray tube
      - Cone of the tube.

   b. Added: 1.5–2.5 mm thickness aluminum disc is an added filter.

   c. Total filtration. Sum total of inherent and added is known as total filtration.

   Government regulations require total filtration of 1.5 mm of aluminum equivalent for dental machines operating at 70 kV and 2.5 mm of aluminum for machines operating at higher kV.

6. ***Collimation:*** It is the restriction or controlling the size and shape of the X-ray beam so as to avoid damage caused by radiation. The collimating device helps us to expose only the area to be imaged as

it restricts the size and shape of the X-ray beam and protects the adjacent structures from unwarranted radiation exposure.

Collimation can be achieved by:

i. *Lead (Pb) diaphragm*, which is 2 mm thick, in which there are number of apertures. The Pb diaphragm is adjusted for obtaining a suitable beam size. If the aperture is round, the resultant beam is cone shaped. If the aperture is rectangular the resultant beam is pyramidal. The diameter of the circular beam at the skin level should be 2 ¾th of an inch and dimension of the rectangular beam should be 1½ × 2 inches for periapical radiographs. For orthopantomography a slit beam collimation is utilized of dimension 2 mm × 30 mm which substantially reduces the radiation exposure to the patient.

ii. *Pb lined cylinders:* Nowadays open ended lead lined cylinders are preferred. Such cylinders further restrict the size of the X-ray beam as the walls of the Pb lined cylinders absorb the divergent rays and allow a small beam to emerge from the open end.

Collimation of the X-ray beam decreases the exposed volume and hence also decreases the scattered radiation which in turn improves the image quality.

7. ***Exposure time:*** It indicates the time interval in which X-rays are produced. Along with mA, exposure time [S] determines the total photon production [mAs factor] and increased exposure time will give rise to a darker film. Exposure time can be increased or decreased to obtain a desirable picture, e.g. to study salivary calculus in Wharton's duct, less exposure time is used. Similarly buccal expansion caused by a cyst can be better visualized with less exposure time. The exposure time is also related to TFD because of the inverse square law, i.e. if the TFD increases; the exposure time has to be increased as the intensity [no. of photons per unit area] of the beam will be less.

$$\text{E.T.} \propto 1/\text{intensity}$$
$$\text{E.T.} \propto D^2$$

The inverse square law states that the intensity of radiation at a given point is inversely proportional to the square of the distance of the point from the source (Fig. 1.10).

Timer provided with the X-ray machine is used to control the exposure time. To minimize the damage to the filament, the timing device sends a current to the filament only for half a second before the actual exposure to bring it to correct temperature. In certain machines, a continuous low current is used to preheat the filament

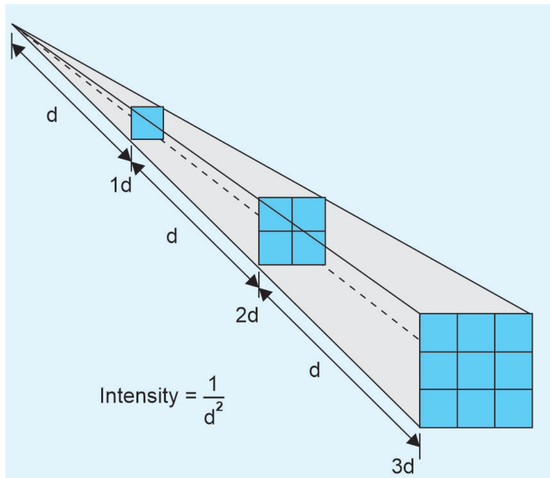

Fig. 1.10: Inverse square law (*Source:* Internet)

without any damage. In such cases the machine may be left on continuously during working hours specifically in busy radiology departments. However X-ray machines in private dental clinics should be switched on just before the exposure to prolong tube life.

8. ***Tube rating*** charts show the operating limits of the X-ray tube—maximum exposure time the tube may be energized without damage to the target from overheating at a particular kVp and mA.
9. ***Duty cycle*** relates to how frequently successive exposures can be made without damage to the tube, and depends on the heat build up → kVp × mA × sec.
   Certain electronic timers are provided with the mechanism which allows successive exposures only after adequate cooling intervals between two exposures.

II. Object Factors

1. ***Object density:*** A dense structure has the capacity to absorb more number of X-ray photons than a relatively less dense structure. As a result of this, dense structures appear radiopaque or white (enamel or silver filling, etc.) whereas, less dense structure (dentine, cementum, etc.) appear comparatively less radiopaque, while the pulp or periodontal ligament space allows maximum number of X-ray photons to pass through and hence will appear darkest (radiolucent). Thus, the density of an object plays an important role in diagnostic

radiography and at times exposure factors have to be modified to obtain an optimum X-ray picture.

2. ***Object thickness:*** If the object to be radiographed is thicker, then kVp or penetration power of the X-ray is to be increased along with exposure time to obtain a good radiograph. Thicker objects also have a greater disadvantage because they may generate more scattered radiation which in turn gets absorbed by the object thereby increasing radiation damage.

III. Image Recording Factors

1. Reduction of Secondary and Scattered Radiation

a. ***Pb foil:*** It is used in intraoral film packet for the following reasons: X-rays which have passed through the film are of no further use in diagnostic radiography. On the contrary, they can irradiate the tissues behind the film and this can also result in scattered or secondary radiation capable of travelling backwards (back scatter) thus cause fogging of the film.

The lead foil used in the X-ray film packet:

i. Absorbs the X-rays which have passed through the film and reduces the patient exposure.
ii. Absorbs the back scatter and prevents fogging of the film.
iii. Gives the stiffness to the film packet.

The lead foil has a typical pattern to it, e.g. tyre track, herring bone, etc. Whenever the film is placed wrongly this pattern appears on the film and this reverses the side identification as the embossed dot does not face the tube.

b. ***Pb backing of the cassette:*** Similar functions are served by it because it absorbs the back scattered X-rays as well as those that have passed through the film.

c. ***Grids:*** When a beam of X- rays passes through an object it gets split into two types of photons:

- Forward moving primary photons, which are carrying the message to the film.
- Obliquely moving scattered photons, which are likely to cause fogging of the film as they have changed their direction.

The purpose of the grid is to cut off the obliquely moving scattered photons (Fig. 1.11). Grid is a sheet of radiolucent material in which are incorporated strips of lead (Pb). As the Pb strips are parallel the scattered photons, moving obliquely strike the lead strips at an angle and are absorbed by them and only the forward moving primary

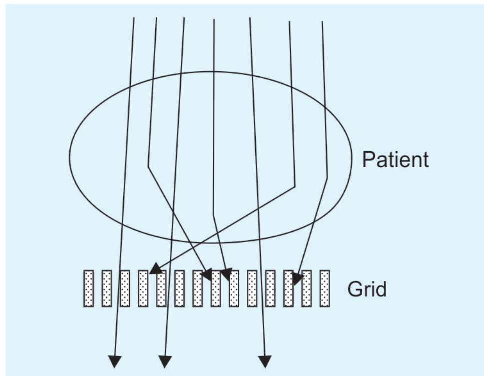

Fig. 1.11: The principle of a grid. (*Source:* Basic Radiation Physics—Meredith)

photons which are relatively straight are allowed to pass. The grid is used in extraoral radiography and is placed between the object and the film.

Types of grids:

a. *Stationary grids*
   i. Linear/parallel grid: Pb strips are placed parallel to each other. In this type at the periphery the divergent primary photons may get cut-off and therefore the grid has to be modified.
   ii. Focused grid: In this type, to eliminate primary photons being cut-off at the periphery, Pb strips are focused towards the X-ray source (Fig. 1.12).

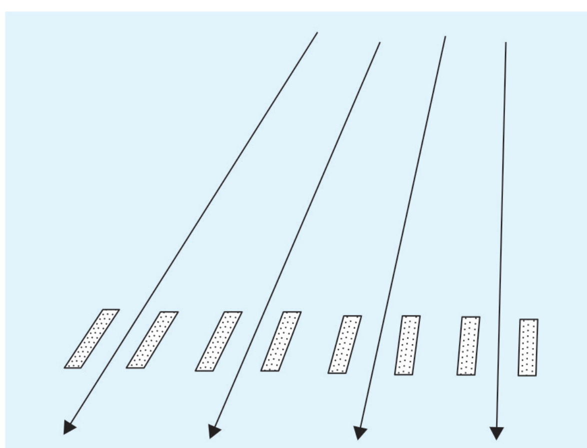

Fig. 1.12: Arrangement of lead strips in a focused grids. (*Source:* Basic Radiation Physics—Meredith)

iii. Pseudofocused: In this type, there is a progressive diminution in the height of the Pb strips from the center to the periphery. As the strips are shorter at the periphery the primary photons are allowed to pass (Fig. 1.13).

iv. Crossed grid: To eliminate the X-ray photons which are scattered in the plane of Pb strips, 2 grids are placed at right angles to each other, known as crossed grid.

b. *Moveable grid/Potter-Bucky diaphragm:* If a stationary grid is used the rays are absorbed by the Pb strips and white lines appear on the film. This can be eliminated if the grid is moved at a regular speed during the exposure. Such movable grids are called Potter-Bucky diaphragm.

Grid ratio is given by the formula

$$r = h/D,$$

where r = grid ratio, h = height of Pb strips, D = distance between two adjacent Pb strips (Fig. 1.14).

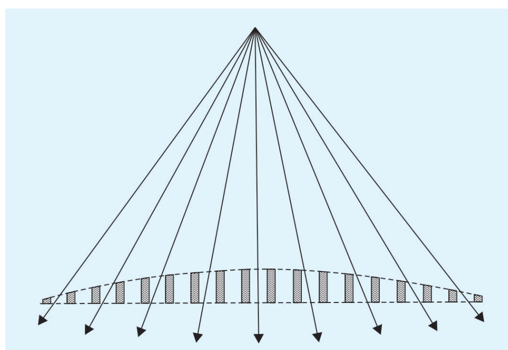

Fig. 1.13: Arrangement of lead strips in a pseudofocused grids. (*Source:* Basic Radiation Physics—Meredith)

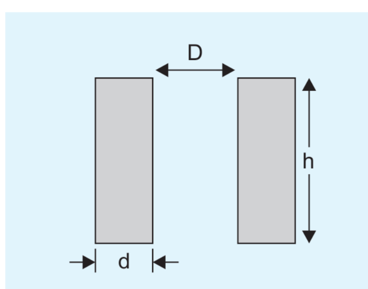

Fig. 1.14: Measurements for the calculation of grid ratio. (*Source:* Basic Radiation Physics—Meredith)

It indicates the efficiency with which the scattered photons are absorbed. The disadvantage of using a grid or Potter-Bucky diaphragm is that the exposure time has to be increased as the Pb strips absorb the X-ray photons and reduce the number of incident photons.

2. Films and Film Storage

In olden days the films were made of glass plates wrapped in black paper and rubber dam material to prevent leakage of saliva. After that cellulose nitrate base were used, but this had two main disadvantages:

- Cellulose nitrate base is highly inflammable.
- Films used to curl.

This was overcome by the use of cellulose triacetate. Recently, polyester base and polyethylene terephthalate is used.

Construction: Film is made up of two components:

a. *A base*: Which is 0.2 mm thick and is made up of polyethylene terephthalate or cellulose triacetate.
   - It has transparent bluish tint.
   - Its function is to provide uniform support to the emulsion.

b. *Emulsion*: It consists of Ag halide (bromide and iodide) crystals suspended in a gelatinous/non-gelatinous matrix which acts as a vehicle. This vehicle keeps the Ag halide crystals evenly or uniformly dispersed. During film processing, the vehicle absorbs the processing solutions thereby allowing the chemicals to react with the Ag halide crystals. The Ag iodide crystal has a larger diameter and disrupts the regularity of the AgBr crystal and increases the sensitivity of the AgBr.
   - Thickness of the emulsion is 0.01 mm and the emulsion is present on both the sides of the transparent base thereby increasing the radiosensitive material and reducing the exposure time.
   - It is sensitive to light and X-rays.
   - It is the active component of the film.

   In between the emulsion and the base there is an adhesive layer. The emulsion is covered with protective super coat, (a dense layer of gelatin). This coat protects the film during handling and during the automatic processing (roller system) (Fig. 1.15).

   The dental X-ray film has an embossed dot in one corner. The film is placed in such a way that the dot is towards occlusal surface that is away from the periapical region. The film is placed with the convex dot towards the tube as after processing the embossed dot is used to correctly orient the film for side identification.

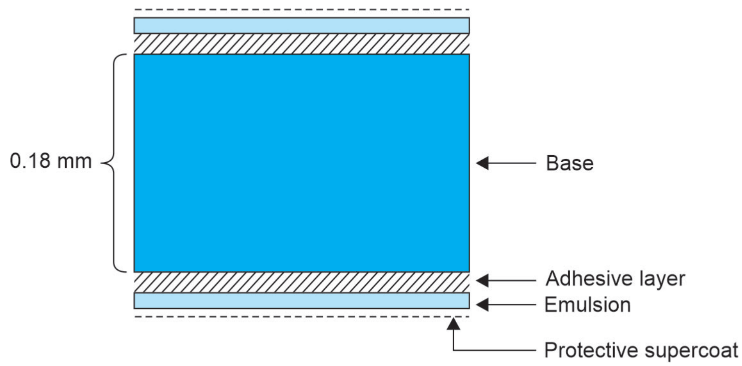

Fig. 1.15: Cross-section of an X-ray film

The film packet contains:

- Outer packet made up of a sealed plastic cover to prevent ingress of light and saliva. The side of the film packet which is to touch the teeth and face the X-ray tube is usually white and has a pebbled (older films) or smooth surface. The reverse side of the film packet has usually two colors, e.g. blue and white or black and white to help prevent wrong placement of the film and has a triangular flap to help strip the film.
- Inside the film packet there is a black envelope covering the film which protects the film from light and damage during removal from the packet. A lead or tin foil is incorporated in the packet and is placed outside the black envelope towards the reverse side of the packet.

I. Films are classified as:

1. Screen
2. Non-screen

1. *Screen films* are more sensitive to visible light because color dyes are added to the emulsion, which makes it more sensitive to particular light given out by the intensifying screens. The green sensitive dyes added to the surface of tabular grains increase their light gathering capacity. The absorbing dye in the emulsion also prevents crossover of light from one screen to the other side emulsion. This helps to prevent unsharpness of the image. It is essential to use a certain film and screen combination. Mostly all the films used in extraoral radiography are of screen type and they are used along with intensifying screens provided in specialized containers called *cassettes*.

2. *Non-screen films* do not have special dyes added to their emulsion and they are sensitive to X-rays. Mostly all the intraoral films are of non-screen type. (*Exception:* Upper true occlusal wherein intraoral cassette with correct screen film combination is used) non-screen films are of the following types:
   a. Periapical film: Size 32 × 41 mm
   b. Occlusal film: Size 57 × 76 mm
   c. Bitewing film

II. According to speed: If exposure time required to produce a radiograph of useful density is less then it is called a fast speed film. The speed of film depends on:

a. *Grain size:* The size of Ag halide grains. The larger the size of the crystal the faster is the speed.
b. *Thickness of emulsion:* Thicker the emulsion more is the radiosensitive material available and faster is its speed.

But larger the grain size lesser is the sharpness of the film, which affects the details of the film. To overcome this T-mat G films were introduced wherein the grain is flat or broad at the film surface and narrow towards base (like letter T) so that film speed can be increased without compromising the sharpness of the image.

Insight film utilizes tabular grains of mean diameter 1.8 μm and ultra speed film 1 μm. The tabular grains are oriented parallel with film surface and offer large cross-sectional area to the X-ray beam hence 'Insight film' requires half as much exposure as an ultra speed film. According to speed the films are of the following types:

1. Speed A
2. Speed B
3. Speed C
4. Speed D
5. Speed E/Ekta speed.

III. According to their size:

1. Periapical 32 × 41 mm Pedo film (size 0) 22 mm × 35 mm
2. Occlusal 57 × 76 mm
3. Orthopantomograph 6″ × 12″/(15 cm × 30 cm)
4. Lateral oblique 5 × 7″
5. PA waters/mandible 10″ × 12″ or 8″ × 10″

Properties of films

1. **Density** is defined as the degree of blackness present on the film measured in terms of light transmission on a logarithmic scale, e.g. if a beam of light is filtered to its 1/10th by a film then density is 1 and if a beam of light is filtered to its 1/100th then its density is 2. The density of the diagnostic film is 0.1 to 0.2. Density of the film depends upon the exposure time and mA and it is directly proportional to these factors. The relation of density to the log of exposure is given by the H-D curve.
2. **Contrast** is the difference in the various gradations of density in the different areas of a radiograph. If between total white and total black there are very few areas of varying densities then it is called a *high contrast* or *short scale* contrast gradation. If between the total white and black areas there are more number of areas of varying densities than is called *low contrast* or *long scale contrast* gradation.

   Contrast is related to kilovoltage peak (kVp) of the beam. If kVp is increased, the contrast decreases and vice versa. However, for each radiographic technique, one must employ adequate kVp and obtain optimum contrast to make the relevant details fully apparent.

   Factors influencing the contrast:

   a. Milliamperage and exposure time
   b. kVp
   c. Filtration
   d. Object thickness and density

   Contrast is also considered as: (a) Subject contrast and, (b) Film contrast

   a. *Subject contrast:* Depends upon the subject density, thickness and atomic number, as these factors modify the degree of absorption of the X-ray beam. For instance, teeth and bone absorb X-rays to a greater extent than soft tissue.

      Subject contrast is also affected by beam energy and intensity which in turn depends on the kVp.

   b. *Film contrast:* Describes the inherent capacity of the film to display contrast. A high contrast film displays area of small difference in subject contrast more clearly than a low contrast film.

      Film contrast also depends on film processing which should be optimal to enhance the contrast.

      Fogging of the film which is due to undesirable density adversely affects the contrast.

3. **Detail** is the ability of the radiograph to reproduce the sharp outlines. This depends on:
   - The size of Ag-Br crystals, smaller the size of the crystal, better and sharper are the details.
   - Focal spot size.
   - Movement of the patient.
4. **Latitude** is a measure of range of exposures that can be recorded as series of distinguishable densities on the film. Wide latitude means long scale contrast gradation. By increasing the kVp, the latitude increases.
5. **Radiographic noise:** Appearance of uneven density on a uniformly exposed radiographic film. The cause of radiographic noise is radiographic mottle and radiographic artifact. Mottle appears as areas of uneven density on exposed radiograph visualized as darker and lighter areas on the film.

   The factors influencing mottle are:

   a. Film graininess, becomes obvious with magnification.

   b. Use of intensifying screens increases mottle.
6. **Resolution:** It is the ability of the radiograph to record separate structures that are close to each other. It is measured by calculating the line pairs per mm. For OPG it is 5 line pairs per mm and for IOPA it is 10 lines per mm. Factors such as focal spot size, film grain size, patient movement which affect 'detail' also affect the resolution.

   Parallax error: As the films used routinely are double emulsion films and the X-ray beam is divergent, there is a certain degree of unsharpness. This happens because the shadow of a point on the object is recorded at different spots by the 2 sides of the emulsions. This is normally not discernible. But if the film is wet and hence the emulsion swollen, the image may appear unsharp.

Storage of X-ray films: While storing films one must avoid light, heat, electricity, moisture and sources of radiation. In other words, X-ray films are to be stored in a cool, dry place away from sources of radiation in lightproof containers.

3. Intensifying Screens

These are used in extraoral radiography to reduce exposure time. Intensifying screens intensify the action of X-rays (on the film) by converting the X-ray photons into visible light by the property of fluorescence. It is made up of 4 layers:

a. Plastic base or polyester base.

b. Reflecting layer (titanium dioxide).

c. Active phosphor layer, which contains fluorescent material.
d. Protective super coat.

Active phosphor layer is made up of Ca tungstate which emits blue light, or rare earth materials such as terbium activated gadolinium oxysulphide (Gd_2O_2S: Tb) emits green light and thulium activated lanthanum oxybromide (LaOBr: Tm) emits blue light and niobium activated yttrium tantalate emits blue and UV light. Rare earth screens can convert a single X-ray photon into 4000 photons of visible light. The resultant light photons expose the film placed between two screens. The construction of a cassette having intensifying screens is shown in Fig. 1.16.

Functions: By utilizing the property of fluorescence, the intensifying screen converts X-rays into visible light. As a result, the X-ray film placed between the 2 intensifying screens in the cassette gets exposed not only to X-rays but also to visible light produced by both the screens. Intensifying screens thus intensify the action of X-rays and reduce the exposure time. The front screen is thin to provide adequate penetration to X-ray photons. The back screen is thick to capture majority of the X-ray photons.

Speed of the intensifying screens: If exposure time required to produce a radiograph of useful density with a particular screen is less, then the speed is said to be fast. The speed of the intensifying screen depends upon:

- The size of the fluorescent crystals, i.e. larger the size, faster the speed.
- Thickness of the phosphor layer, i.e. thicker the layer, faster the speed.

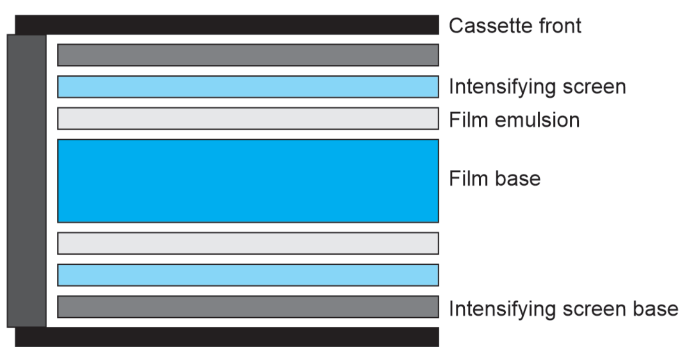

Fig. 1.16: Cross-section of a cassette with intensifying screens. (*Source:* Internet)

However, if the speed of the intensifying is more, then the sharpness decreases, because of larger crystal size. For example, OPG film appears unsharp compared to IOPA because hi-speed film and screen is used in OPG.

Sharpness is defined as the ability of the film to define an edge precisely, e.g. DE junction, trabecular pattern, etc.

Radiographic blur or unsharpness is because of:

a. Image receptor blurring
b. Motion blurring
c. Geometric blurring

Image receptor blurring can be because of:

i. Double emulsion film causing parallax error, more apparent when film is wet
ii. Large grain size of fast speed film
iii. Large grain size of the intensifying screen: Visible light and ultraviolet radiation emitted by the screen spreads out beyond the point of origin and expose the film area larger than the phosphor crystal causing unsharpness. Thicker phosphor layer causes dispersion of light and hence blurring. It is important to maintain a very close contact between screen and film to minimize unsharpness caused by dispersion of light and to maximize image sharpness.

When intensifying screens are used, parallax distortion contributes to image unsharpness. This happens because light from one screen may cross the film base to reach the emulsion on the opposite side. This problem can be solved by incorporating dyes in the emulsion to absorb the emitted light.

Motion unsharpness results when the patient or the receptor or the tube moves during exposure.

Geometric unsharpness results from large focal spot size, decreased source film distance, increased object film distance. (Ref Chapter on Ideal Radiograph).

Interactions of X radiation with matter: When an X-ray photons pass through matter, one of the following four things can happen:

1. **No interaction:** X-ray photons pass through matter without any change in the photon or in the matter (9% of total interactions)
2. **Coherent or elastic scattering:** X-ray photons may cause vibrations of the electrons in the atoms of the matter, which return to their

own shell. This phenomenon is called excitation. After the excitation the atom comes back to its ground state and releases a photon with the same energy as the incident photon. This is termed coherent or elastic scattering (7% of total interactions).

3. **Compton scatter:** Greater number of photons may displace a peripherally placed electron (57% of interactions). In doing so, it may lose a little of its energy and will emerge out as a scattered photon (with change in its direction). This is called compton effect/ scatter. The chances of Compton scattering is greater in bone than in soft tissue as bone is more dense and has more electron density than soft tissues. As the photon is absorbed and undergoes scatter, it does not reach the film. Hence Compton effect plays a role in image formation.

   However the resultant scattered photons travel in all directions and may exit the patient and strike the film but carry no diagnostic information and degrade the image by reducing contrast.

4. **Photoelectric effect:** Sometimes, photons may displace centrally located K(s) or L(p) shell electrons. The electron in the adjacent shell falls immediately in the vacant shell. In doing so, it liberates energy equivalent to the energy difference between the two orbits/shells. Since the energy level at each shell for a particular element is characteristic, the energy given out in the form of radiation is called characteristic radiation. Because complete energy of the X-ray photon is utilized to displace the inner shell electron and because the photon displaces an electron, this is called photoelectric effect (27% of interactions).

   Photoelectric interaction is more likely to occur in bone which is denser than the soft tissue, as a result more X-ray photons are absorbed by the bone. This differential photoelectric absorption is readily appreciable on the dental radiographs as different densities, e.g. enamel will appear more radiopaque compared to dentine or pulp and bone will be more radiopaque than soft tissues.

5. At times X-ray photons produced at very high kVp travel very close to the nucleus and just ceases to exist (annihilation reaction) as it splits into an electron and positron (highly reactive positively charged electron). This positron immediately combines with an electron and this gives rise to two photons of high energy travelling in the opposite direction. This phenomenon is called pair production. On their way out these photons can give rise to various changes stated above.

To summarize, when X-ray photons pass through matter they change the electronic configuration of the matter or cause disturbances in the electric charge of the atom and hence X-rays are called ionizing radiations.

Attenuation of X-ray beam: As a beam of X-rays passes through an object it is partly and differentially absorbed by various interactions stated above. This is called beam attenuation. The exiting beam of X-rays carry a message to the film, but part of the beam also has scattered photons which degrades the image by fogging. Differential beam attenuation plays a fundamental role in image formation and it depends on the penetrating power of the X-ray beam and the differential densities of the object through which the X-rays are passing.

Half value layer: This term is used to describe the penetrating power of the X-ray beam. It denotes the thickness of an absorbing material such as aluminium required to reduce number of X-ray photons passing through it to its half. X-ray beam with photons having higher mean energy will require a greater thickness of absorber to reduce its intensity by half and hence its HVL will be greater.

Beam hardening: As the heterogenous X-ray beam passes through an absorber, lower energy X-ray photons (soft X-rays) are absorbed and the resultant beam has photons with greater mean energy and the beam is said to be hardened. The hardened X-ray beam has photons with greater mean energy that pass through the object but do not contribute to image formation. These photons degrade the image quality.

Rare earth filters such as gadolinium are sometimes used to eliminate these high energy photons and improve the resultant image quality.

4. Film Processing

At the microscopic level the silver halide crystal shows distribution of the Ag^+, Br^-, I^- and relatively free interstitial Ag^+ ions. An unexposed film contains Ag, Br, I in ionic (charged) form. There is an important site present at the periphery termed latent image site (LIS) containing sulfur impurity (triallyl carbamide), which can capture the electrons and help in precipitation of Ag (Fig. 1.17).

Latent image production: When an X-ray photon passes through Ag halide crystal it knocks off an electron from the Br ion and liberates an

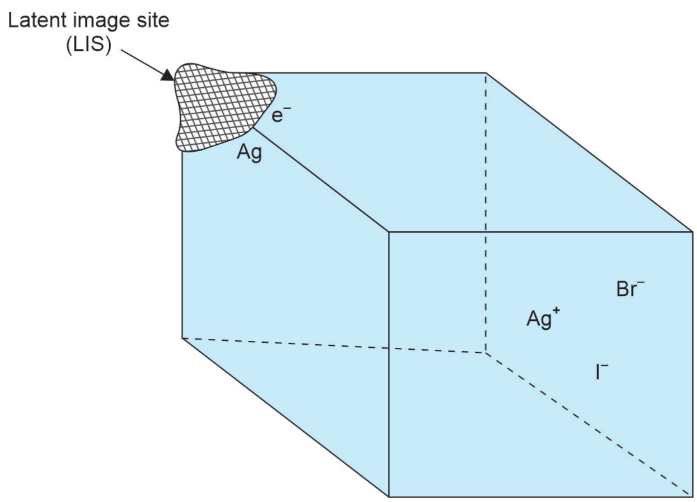

Fig. 1.17: AgBr crystal and latent image site

electron. (Two such neutral Br atoms joint together to form Br gas which is liberated in the emulsion.)

$$Br + X\text{-ray} = Br^{+} + e^{-}$$

Electrons liberated by Br ion are captured at the site known as LIS (latent image site) which is sulfur impurity within the crystal (triallyl carbamide).

Interstitial Ag ions which are positively charged and relatively free traverse through the crystal and accumulate in these latent image sites to form a neutral silver atom. Thus millions of specks of silver are formed at the multiple sites of X-ray exposure in the entire film and are collectively called latent image. The formation of latent image disturbs the ionic status of the crystal and makes it vulnerable to the electrons donated by the developer. When the film is immersed in the developer, metallic silver gets deposited at the site and within the entire crystal of latent image formation. During fixing, the unexposed Ag^{+} and Br^{-} ions/atoms are dissolved by the fixing agent.

Developer: The developer contains the following constituents:

1. **Developing agent:**
   a. Elon/metol or phenidone, which produces the details by donating electron to the silver ions and causing them to precipitate.
   b. Hydroquinone, which provides the contrast.
2. **Restrainer:** Potassium bromide (KBr) or benzotriazole. It acts as an antifog agent and prevents the developing of the unexposed crystals.

3. **Activator:** Sodium bicarbonate. It provides the alkaline medium which is required for the emulsion to swell up and open the pores so that the developing solutions can pass into the emulsion and can bring about the precipitation of silver.
4. **Preservatives:** Sodium bisulphite. It prevents the oxidation of the developing agent because it has comparatively a greater affinity for oxygen. It forms a colorless soluble compound with the oxidized developer, thereby preventing yellowish brown stains on the film.
5. **Vehicle:** Water in which all the constituents are mixed.

Fixer: The fixer contains the following constituents:

1. **Fixing agent:** Sodium thiosulfate. It dissolves the unexposed and undeveloped AgBr and AgI that exist in the ionic form.
2. **Hardener:** Potash alum. It hardens the gelatin which was softened by the activator in the developer.
3. **Acetic acid:** Provides the acidic medium for dissolution of the AgBr and also hardens the gelatin.
4. **Preservative:** Sodium bisulphite. It forms a colorless soluble compound with the oxidized developer carried to the fixer, thereby preventing the yellowish brown stains.
5. **Vehicle:** Water in which all the constituents are mixed.

Processing: It is a collective title given to a series of procedures carried out in the dark room, namely:

- Developing
- Rinsing
- Fixing
- Washing
- Drying

Methods of processing

1. ***Time temperature method:*** In this method, the temperature of the developer is controlled at 68°F and the films are developed for 4.5 minutes. A special timer is provided which will give out a signal at the end of 4.5 minutes.

Advantages:

i. If at 68°F, the films are dark, it implies that the films are over-exposed. Thus, this method maintains a direct check on the exposure time.

ii. It is the most standardized procedure and does not require expertise as opposed to the visual method.

Disadvantage: Unlike the visual method, the films cannot be overdeveloped or underdeveloped to obtain the desirable contrast.

2. ***Visual method:*** In this method, the films are held against the safe light from time to time during development. The moment the pulp chamber becomes evident or the roots are seen separate from the bone, developing is said to have completed.

   Advantages:

   i. If the X-ray film is over exposed, it can be underdeveloped and vice versa.

   ii. X-ray film can be developed to obtain the desirable contrast, e.g. films can be underdeveloped to see the hypocalcified salivary calculus and buccal/lingual expansion of cyst or tumors.

   Disadvantages:

   i. It is not a standardized procedure.

   ii. It requires expertise and experience.

3. ***Modified time temperature method:*** A special chart can be pre-pared mentioning the developing time at a particular temperature, taking into account the age of the developing solution in number of days.
4. ***Daylight processing:*** This is carried out in a special device having safe light filters and two glove-like compartments through which the operator can put his hands and develop the films. The process obviates the need for a darkroom.
5. ***Automatic processing:*** A special roller system is provided to which the film is fed. Developing, fixing and drying takes place as the film passes through the roller system. A fully processed and dry film is made available within the shortest possible time. Such a unit is ideal for urgent radiographs. Certain automatic processors have a web system instead of a roller. The processing chemicals of these systems are maintained at a suitable higher temperature to ensure rapid developing and effective hardening materials such as glutaraldehyde is added in the developer itself.
6. ***Monobath:*** The film packet is itself provided with a developer and fixer and the X-ray films can be developed on the spot. A darkroom is not required. It is ideal for root canal treatment where urgent radiographs are required or in places where darkroom facilities are not available.

Importance of rinsing

- If the film is not rinsed prior to fixing, the developer is carried onto the fixer and neutralization reaction takes place. Sodium bicarbonate reacts with the acetic acid in the fixer to liberate carbon dioxide gas which gives rise to blister formation. These blisters then rupture giving rise to a pitted radiograph.
- **Dichroic fog:** If the developer is carried to the fixer, it reacts with the Ag thiosulfate present in the fixer and causes precipitation of silver on the film. This results in fogging which appears as pink in transmitted light and green in reflected light. Hence this is called dichroic fog.

Importance of fixing: If the films are not fixed adequately, the unexposed AgBr crystals remain on the film which when exposed to light can turn brown/black thereby making the film useless. The ideal fixing time is 15–20 minutes. To confirm that the fixing is adequate, the film is viewed in bright light and it is ascertained whether the light transmission is complete in the most radiopaque region.

Importance of washing: During fixing, the AgBr crystals are dissolved in the fixer and two types of silver thiosulfates are formed, the soluble and insoluble form. The soluble form dissolves in the fixing tank. This insoluble form remains adherent to the film and if not washed out in running water, it gets exposed to light and atmosphere giving rise to yellowish brown stains on the film. The adherent Ag thiosulfate can only be removed by washing the film under running water for at least 15 minutes.

The Darkroom

The darkroom for processing the films must have the following requirements.

1. Processing tanks for the developer, fixer and running water, an inlet and outlet for water.
2. A dry working table for handling the films prior to developing.
3. Cupboard for storage of the films.
4. The entrance to the darkroom may be in the form of a maze or a labyrinth or must have a door which can be bolted from inside.
5. Illumination: The darkroom must be fitted with a bright tube light for use during non working hours. Safe lights illumination must be

provided for use during film developing. Red bulbs of 10–40 watts with ruby red filter can be used with one bulb fitted above the developing tanks, one above the working table and one on the ceiling. The minimum distance between the table and the red light must be 3 feet. The Kodak GBX2 filter bulbs can also be used safely in the darkroom.

6. Ventilation: The room should be air conditioned and should have two fans, one for inlet for fresh air and one exhaust fan located at a higher level to drive out the foul air.
7. Cleanliness and tidiness are very important in the darkroom and everything should be kept in its proper place.

Coin test is carried out to ascertain that there is no entry of light and the darkroom is completely dark. It also helps to test the safety of the safe light. This test is carried out in the darkroom with only the safe light on. In this test a metallic coin is placed on an unexposed IOPA X-ray film (after stripping it from its packet) which is kept on the working table below the safe light. After about 3–4 minutes the film is processed by routine method. If the film shows a radiopaque shadow of the coin, it means that either the safe light is not safe or there is entry of light in the darkroom. Coin test can be repeated with the safe light switched off, if the radiopaque shadow of the coin still persists, it means that there is entry of light in the darkroom. If coin test is positivse it can explain the fogging of the films and necessary steps have to be taken to rectify the darkroom or the safe light.

References and Suggested Reading

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7. Dental Radiology Blackman and Peyton.