Key Definitions:

- **Radiology**: is the medical science that deals with the study of radiation and its use, radioactive substances and other forms of radiant energy in the diagnosis and treatment of diseases.
- **X-ray:** is a beam of energy that has the power to penetrate substances and record the resultant image on a photographic film.
- **Radiograph:** is a two-dimensional representation of a three-dimensional object
- **Radiography:** is the art and science of making radiographs by the exposure of photographic films to x-rays.
- **A dental radiographer** is any person who positions, exposes, and processes dental x-ray image receptors.
- **Dental Radiograph:** is an image on a film showing the teeth and associated structures when viewed under transillumination.

Composition of Matter: Matter is anything that has mass and occupies space. The atom is the basic unit of all matter and consists of a nucleus containing protons and neutrons, and electrons that are bound to the nucleus by electrostatic forces. The classic view of the atom, the Bohr model, considers the structure of atoms like a solar system, with negatively charged electrons that travel in discrete orbits around a central, positively charged nucleus (Fig1). The contemporary view, the quantum mechanical model, assigns electrons into complex three-dimensional orbitals with energy sublevels.

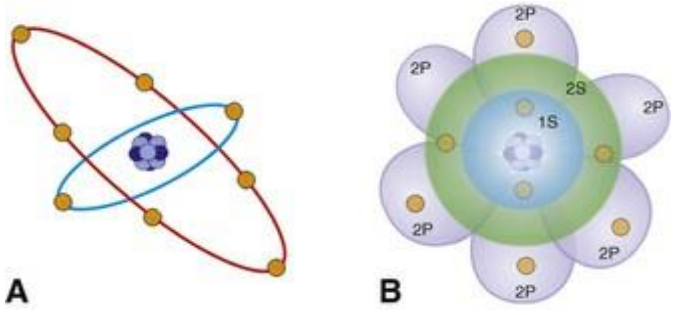


Fig1: (A) Schematic view of the Bohr model of the oxygen atom showing a nucleus with electrons that travel around the nucleus in circular orbits. (B) Schematic view of the quantum mechanical model of the oxygen atom. The central nucleus is surrounded by an electron cloud that represents probability plots of the location of the electron in a complex arrangement.

Ionization:

When the number of electrons in an atom is equal to the number of protons in its nucleus, the atom is electrically neutral. If a neutral atom loses an electron, it becomes a positive ion, and the free electron becomes a negative ion. This process of forming an ion pair is termed ionization. To ionize an atom, sufficient external energy must be provided to overcome the electrostatic forces, and free the electron from the nucleus. High-energy particles, x-rays, and ultraviolet radiation have sufficient energy to displace electrons from their orbitals and ionize atoms. Such radiations are referred to as ionizing radiations.

In contrast, visible light, infrared and microwave radiations, and radio waves do not have sufficient energy to remove bound electrons from their orbitals and are nonionizing radiations.

Electromagnetic Radiation:

Electromagnetic radiation is the movement of energy through space as a combination of electric and magnetic fields. It is generated when the velocity of an electrically charged particle is altered.

γ-Rays, x-rays, ultraviolet rays, visible light, infrared radiation (heat), microwaves, and radio waves all are examples of electromagnetic radiation.

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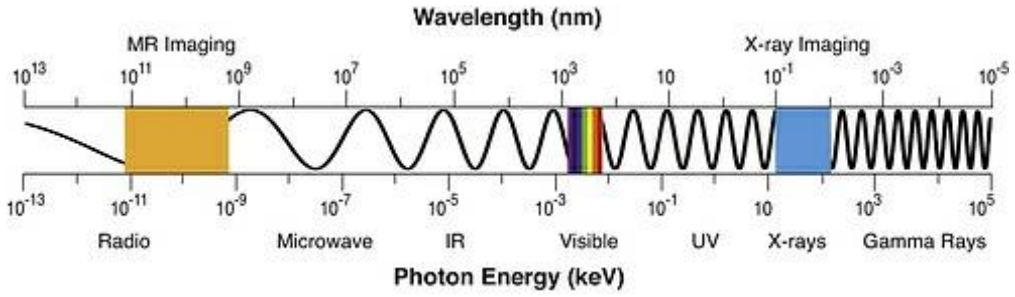


Fig 2: Electromagnetic spectrum showing the relationship between photon wavelength and energy and the physical properties of various portions of the spectrum. Photons with shorter wavelengths have higher energy. Photons used in dental radiography *(blue)* have energies of 10 to 120 keV. Magnetic resonance *(MR)* imaging uses radio waves *(orange)*. *IR,* Infrared radiation; *UV,* ultraviolet radiation.

X-ray was discovered by (**Roentgen**) in **1895**, it travels in a form of pure energy and the basic unit is x-ray photon or (quantum).

X-ray photons travel with a wave motion called (sine – wave) and the distance between the crests of these waves called (wave – length) which measured by a unit (A° Angstrom). The X-ray photons wave length used in diagnostic radiography is ranged between (0.1 - 0.5 A°) and the amount of energy contained in each photon called (photon energy) which depend on **Wave length and Frequency** of x – ray.

Photon energy = Frequency X Wave length
Short W. L === High Frequency === more energy
Long W. L === Low Frequency === less energy

Similarities between X-ray and light:

1- Both belong to the same electro-magnetic radiation family.
2- Both travel in straight lines at the same speed which is 186,000 miles per seconds.
3- Both affected the photograph films and made them black.
4- Both not affected by magnetic fields.
5- X-ray and light cast the shadows of objects in the same manner.

Differences between X-ray and light:

1- Due to the short-wave length of x-ray, it can penetrate some opaque materials, while the visible light can't, because it has long wave length.
2- X- ray has the ability to ionize atoms while the light can't.
3- X- ray has the ability to produce light (blue light) when it hits some objects and this phenomenon called (fluorescence).
4- X- ray is invisible.

X- ray machine:

X-ray machines produce x-rays that pass through a patient's tissues and strike a digital receptor or film to make a radiographic image. The primary components of an x-ray machine are **the x-ray tube** *and* **its power supply**, *positioned within* **the tube head**. For intraoral x-ray units, the tube head is typically supported by **an arm** that is usually mounted on a wall.

A control panel allows the operator to adjust the duration of the exposure, and often the energy and exposure rate of the x-ray beam. An electrical insulating material, usually oil, surrounds the tube and transformers. Often, the tube is recessed within the tube head to increase the source-to-object distance and minimize distortion

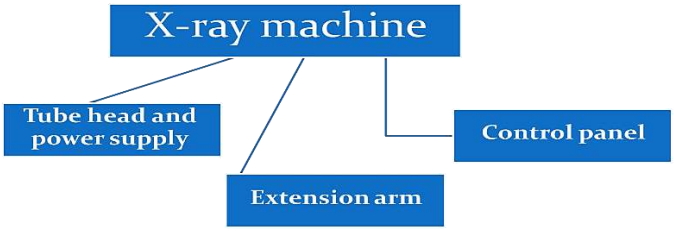




Fig 3: Example of an intraoral wall-mounted x-ray unit, the Planmeca ProX.

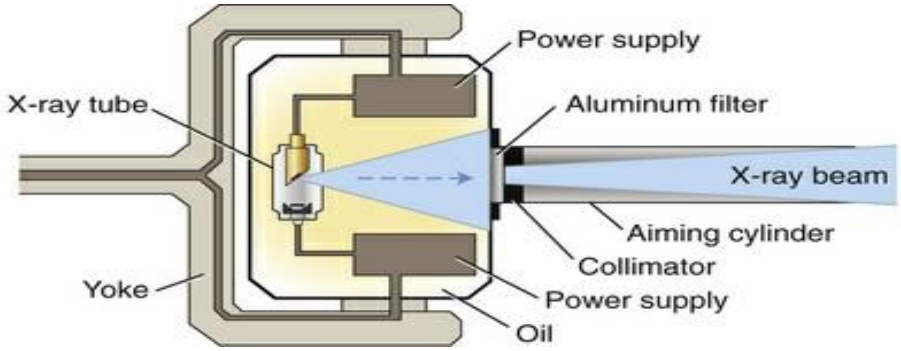


Fig 4: Tube head showing a recessed x-ray tube, components of the power supply, and oil that conducts heat away from the x-ray tube. Path of useful x-ray beam *(blue)* from the anode, through the glass wall of the x-ray tube, oil, and finally an aluminum filter. The beam size is restricted by the metal tube housing and collimator. Low-energy photons are preferentially removed by the aluminum filter.

1. X-Ray Tube

An x-ray tube is **the heart of the X-ray generating system** and it is composed of a cathode and an anode situated within an evacuated glass envelope or tube because air or gas molecule will prevent the electron from reaching the anode. To produce x-rays, electrons stream from the filament in the cathode to the target in the anode, where the energy from some of the electrons is converted into x-rays.

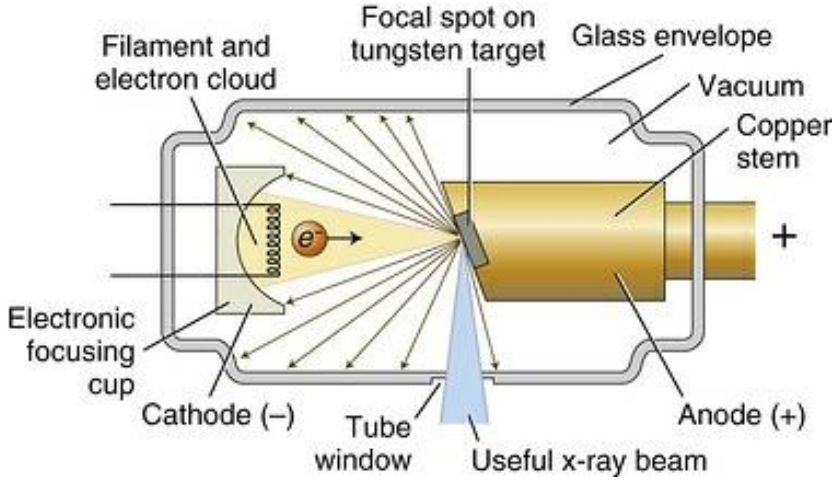


Fig 5: X-ray tube with the major components labeled. The path of the electron beam is shown in *yellow*. X-rays produced at the target travel in all directions. The useful x-ray beam is shown in *blue*.

<u>The component parts of the X-ray tube consist of:</u>

a. A leaded glass housing
b. A negative cathode
c. A positive anode.

a. *A leaded glass housing*: It is a leaded glass vacuum tube that prevents X- rays from escaping in all directions (radiation leakage). One central area of the leaded glass tube has a "window" that permits the X-ray beam to exit the tube.

***b. A negative cathode*:** It is principally composed of two parts:

- filament.
- focusing cup.

• **<u>The filament</u>** is the source of electrons in the tube, it is made up of a coil of tungsten wire. It is a coil of tungsten wire approximately 2 mm in diameter and 1 cm or less in length, and typically contains approximately

1% thorium, which greatly increases the release of electrons from the heated wire. The filament is heated by a low-voltage source and emits electrons at a rate proportional to the temperature of the filament.

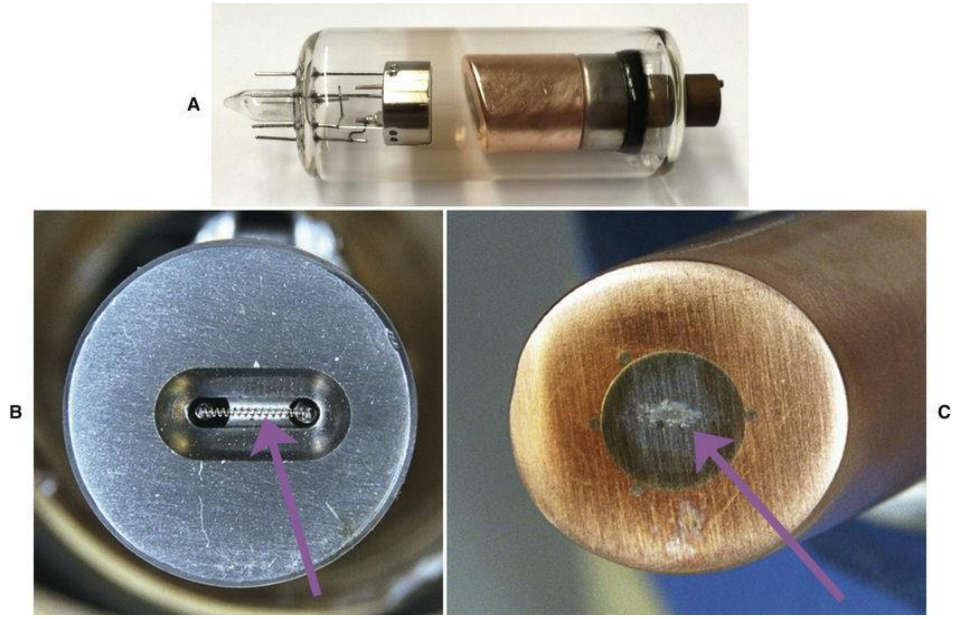


Fig 6: (A) Dental stationary x-ray tube with cathode on left and copper anode on right. (B) Focusing cup containing a filament *(arrow)* in the cathode. (C) Copper anode with tungsten inset. Note the elongated actual focal spot area *(arrow)* on the tungsten target of the anode. ([B] and [C], Courtesy John DeArmond, Tellico Plains, Tennessee.)

• **<u>The focusing cup</u>** is a negatively charged concave reflector cup of molybdenum and houses the filament. The electrons emitted by the filament into a narrow beam directed at a small rectangular area on the anode called the **focal spot**. The x-ray tube is evacuated to prevent oxidation and collision of the fast-moving electrons with gas molecules, which would significantly reduce their speed. The vacuum also prevents, or "burnout," of the filament.

c. *A positive anode or the positive electrode*: It consists of thin tungsten button (target) embedded in a solid copper stem. The purpose of the **target** in an x-ray tube is to convert the kinetic energy of the colliding electrons into x-ray photons. The conversion of the kinetic energy of the electrons into x-ray photons is an inefficient process, with more than 99% of the electron kinetic energy converted to heat so the target surrounded by an oil bath which used to absorb heat that created during generation of X- ray.

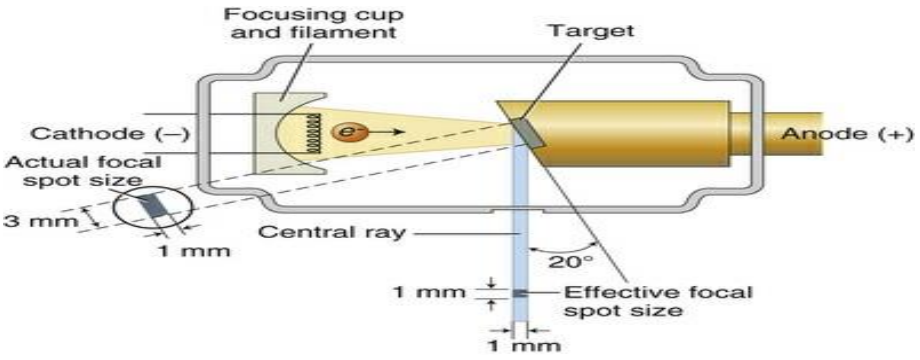


Fig 7: The angle of the target to the central ray of the x-ray beam has a strong influence on the apparent size of the focal spot. The projected effective focal spot (seen below the target) is much smaller than the actual focal spot size (projected to the left). This provides a beam that has a small effective focal spot size to produce images with high resolution, while allowing for heat generated at the anode to be dissipated over the larger area.

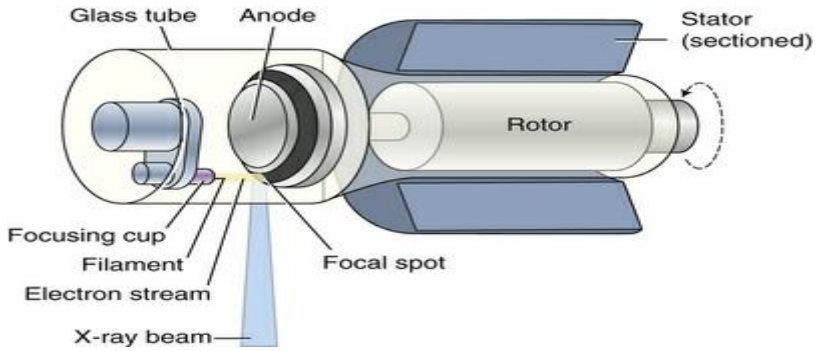


Fig 8: X-ray tube with a rotating anode allows heat at the focal spot to spread out over a large surface area *(dark band).* Current applied to the stator induces rapid rotation of the rotor and the anode. The path of the electron beam is shown in *yellow*, and the useful x-ray beam is shown in *blue*.

Features of selection an ideal target material:

1. High atomic number (74), allows for efficient x-ray production.
2. High melting point (3422°C), to withstand heat produced during x-ray production.
3. High thermal conductivity (173 W m^{-1} K^{-1}), to dissipate the heat produced away from the target.
4. Low vapor pressure at the working temperatures of an x-ray tube, to help maintain vacuum in the tube at high operating temperatures.

❖ The tungsten target has low thermal conductivity so embedded in **a large block of copper** which functions as a thermal conductor to remove heat from the tungsten, reducing the risk of the target melting.

Focal Spot:

it is an area on the tungsten target (anode) from which x- ray photons are emerged. The x- ray tube with rectangular focal spot is described as **Line focus type, or actual focal spot.** The projection of this spot when viewed from any point with the x- ray beam appears more or less like a square, this square projection called **Effective focal spot.** The smaller the focal spot, the sharper the radiographic image, so the sharpness of the radiograph is inversely proportional with the size of the focal spot.

Focal spot size depends upon the following factors:

1- The size and shape of the filament

2- The dimension of the focusing cup and the depth of filament in it

3- Electric field associated with the focusing cup

4- The spacing between cathode and anode

Power Supply:

The x-ray tube and two transformers lie within an electrically grounded metal housing called the **head** of the x-ray machine. The primary functions of the supply transformers of an x-ray machine are to:

• Provide a low-voltage current to heat the x-ray tube filament.

• Generate a high potential difference to accelerate electrons from the cathode to the focal spot on the anode.

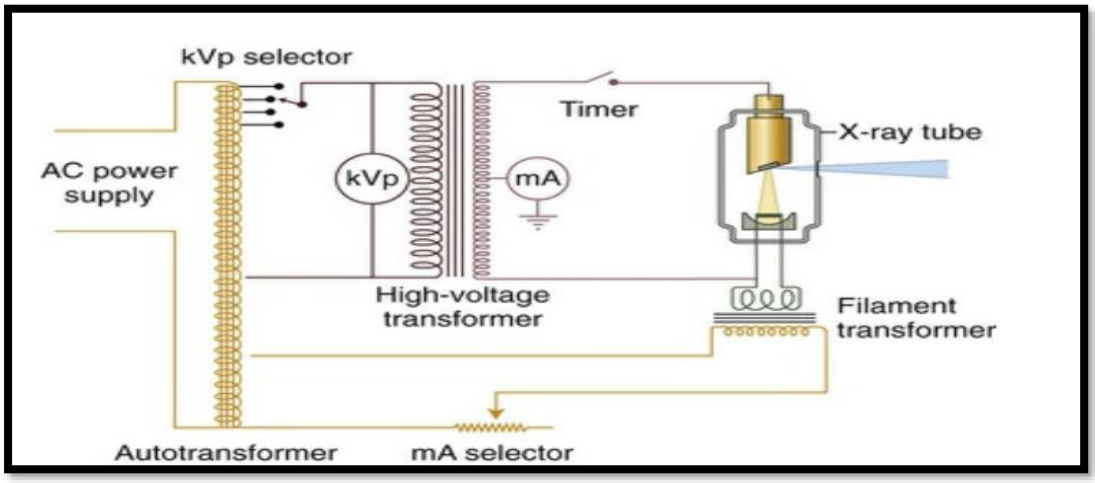


Fig 9: Schematic of dental x-ray machine circuitry and x- ray tube with the major components labeled. The operator selects the desired kVp from the

autotransformer. The voltage is greatly increased by the high-voltage step-up transformer and applied to the x-ray tube. The kVp dial measures the voltage on the low-voltage side of the transformer but is scaled to display the corresponding voltage in the tube circuit. The timer closes the tube circuit for the desired exposure time interval. The mA dial measures the current flowing through the tube circuit. The filament circuit heats the cathode filament and is regulated by the mA selector. *AC*, Alternate current.

X-Ray Tube Controls

1. Tube Current (Milliamperes, mA)

During x-ray production, electrons produced at the filament are attracted to the anode. This flow of electrons from the cathode to the anode generates a current across the x-ray tube and is called the tube current. The magnitude of this current is regulated by the milliampere control, which adjusts the resistance and the current flow through the filament, thereby regulating the number of electrons produced. For many intraoral dental x-ray units, the mA setting is fixed, typically at 7 to 10 mA. Some units offer the flexibility of a selection of mA settings, ranging from 2 to 10 mA.

2. Tube Voltage (Kilovoltage, kV)

A high voltage is required between the anode and cathode to ***give electrons sufficient energy to generate x-rays***. The kilovolt peak (kVp) selector adjusts the high-voltage transformer to boost the peak voltage of the incoming line current (110 or 220 V). Typically, intraoral, panoramic, and cephalometric machines operate between 50 and 90 kVp (50,000 to 90,000 V), whereas computed tomographic machines operate at 90 to 120 kVp, and higher.

3. Alternating Current X-ray Generators:

For an incoming line with alternating current (AC), the polarity of the line current alternates (60 cycles per second), and the polarity of the x-ray tube alternates at the same frequency. When the polarity of the voltage applied across the tube causes the target anode to be positive and the filament to be negative, the electrons around the filament accelerate toward the positive target, and x-rays are produced. When the voltage across the cathode and anode is highest, the efficiency of x-ray production is highest, and thus the intensity of x-ray pulses peaks at the center of each cycle.

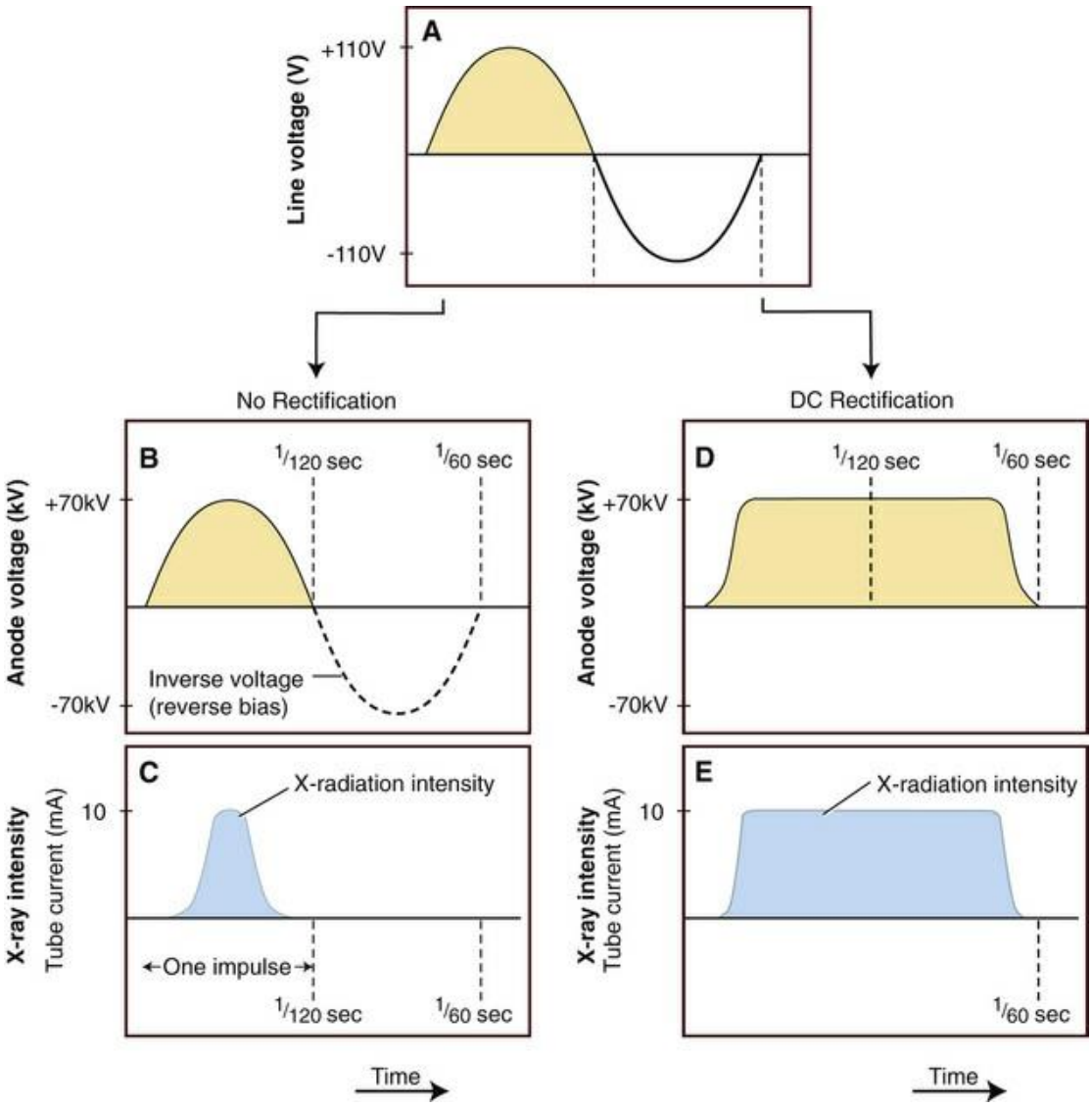


Fig10: (A) Incoming alternate current line voltage (110 V, 60 cycles per second in this case). (B) Voltage at the anode varies from zero up to the kVp setting (70 kVp in this case). (C) The intensity of radiation produced at the anode *(blue)* is strongly dependent on the anode voltage and is highest when the tube voltage is at its peak. (D) Incoming constant potential (110 V in this case) that is maintained through the operation cycle. (E) Voltage at the anode varies from zero up to the kVp setting (70 kVp in this case). Note that the increase and decrease of the potential difference at the start and end of the cycle is rapid. The intensity of radiation produced at the anode *(blue)* is higher with considerably less heterogeneity of photon energy.

4. Timer:

A timer is built into the high-voltage circuit ***to control the duration of the x-ray exposure***. The electronic timer controls the length of time that

high voltage is applied to the tube and thus the time during which x-rays are produced.

Some x-ray machine timers display the exposure time in fractions of a second. In some intraoral units, the exposure times are preset for different anatomic areas of the jaws. In some units, the exposure time is expressed as number of pulses in an exposure (e.g., 3, 6, 9, 15). The number of pulses divided by 60 (the frequency of the power source) gives the exposure time in seconds. A setting of 30 pulses means that there will be 30 pulses of radiation, equivalent to a 0.5-second exposure

Generation of X-ray:

- X- ray photons generate at the surface and within the anode target (tungsten button) by bombardment of anode with electrons coming from cathode when the filament is heated electrically.
- The speed of these electrons depends on the potential difference between cathode and anode of the tube (kV).
- Electrons impact on (a rectangular area) at the surface of tungsten button on the anode called (focal spot).
- Now the kinetic energy of these electrons will be converted to X-radiation and heat.

In fact, there is only 0.2% of this energy will converted to X- ray while the remaining energy goes in form of heat. This heat will dissipate with the aid of radiator that attach to the anode.

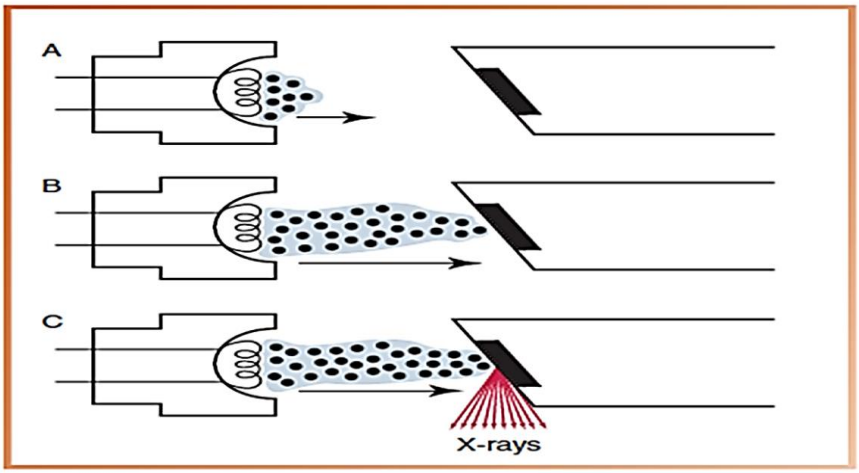


FIGURE 2-19 The production of dental x-rays occurs in the x-ray tube. **A**, When the filament circuit is activated, the filament heats up, and thermionic emission occurs. **B**, When the exposure button is activated, the electrons are accelerated from the cathode to the anode. **C**, The electrons strike the tungsten target, and their kinetic energy is converted to x-rays and heat.