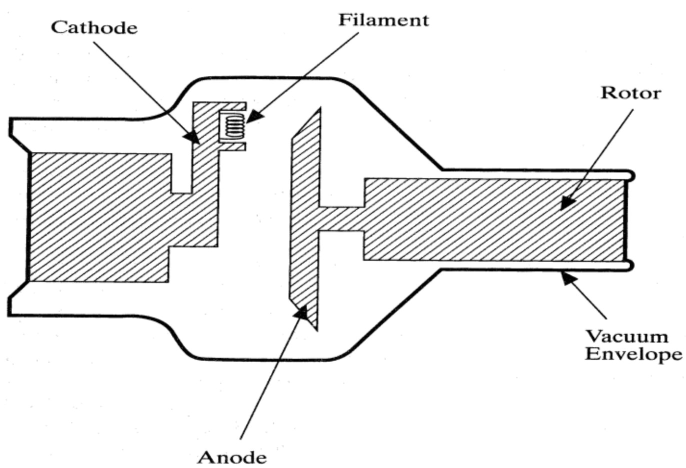
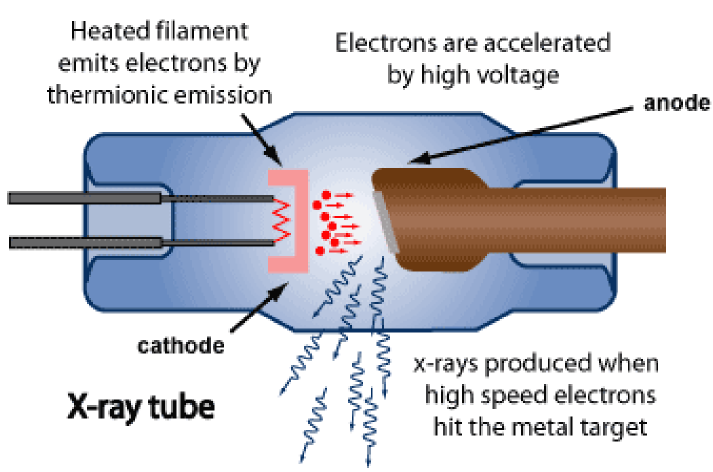
Production of X – rays

The standard device for production of x-rays is the rotating anode x-ray tube, as illustrated in Figure 1. The x-rays are produced from electrons that have been accelerated in vacuum from the cathode to the anode. The electrons are emitted from a filament mounted within a groove in the cathode.

Emission occurs when the filament is heated by passing a current through it. When the filament is hot enough, some electrons obtain a thermal energy sufficient to overcome the energy binding the electron to the metal of the filament. Once the electrons have "boiled off" from the filament, they are accelerated by a voltage difference applied from the cathode to the anode. This voltage is supplied by a generator.





After the electrons have been accelerated to the anode, they will be stopped in a short distance. Most of the electrons' energy is converted into heating of the anode, but a small percentage is converted to x-rays by two main methods:

- One method of x-ray production relies on the fact that deceleration of a charged particle results in emission of electromagnetic radiation, called *bremmstrahlung radiation.as shown in figure 2.* "Bremsstrahlung" means "braking radiation" and is retained from the original German to describe the radiation which is emitted when electrons are decelerated or "braked" when they are fired at a metal target. Accelerated charges give off electromagnetic radiation, and when the energy of the bombarding electrons is high enough, that radiation is in the x-ray region of the electromagnetic spectrum. It is characterized by a *continuous distribution* of radiation which becomes more intense and shifts toward higher frequencies when the energy of the bombarding electrons is increased. The number of x-rays is relatively small at higher energies and increases for lower energies.

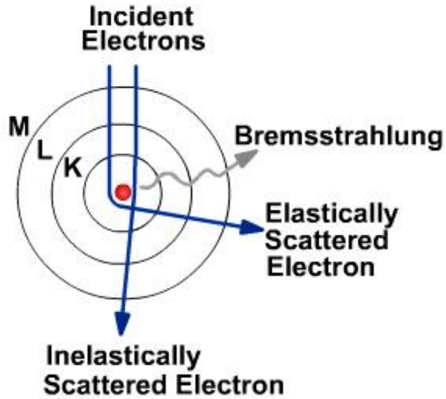
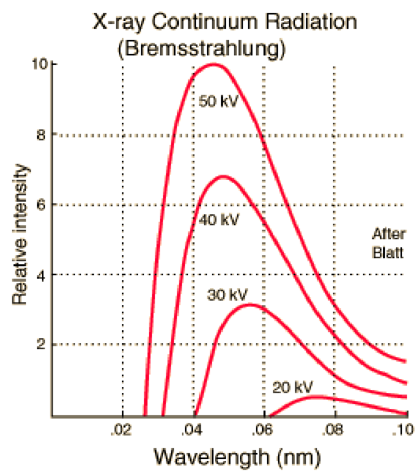
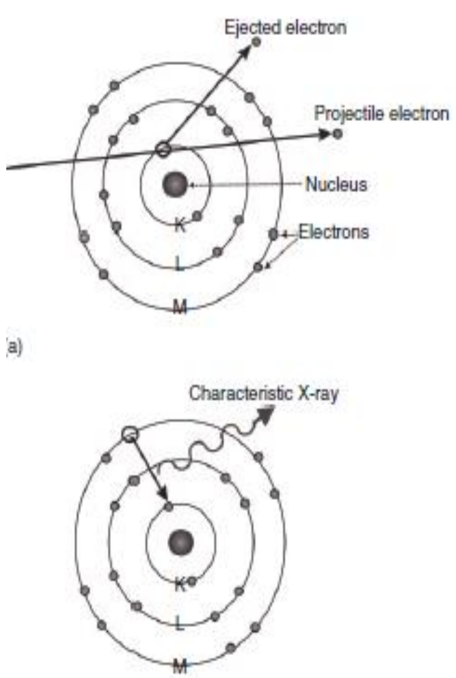


Figure (2) *bremmstrahlung radiation*



The curves above are from the 1918 data of Ulrey, who bombarded tungsten targets with electrons of four different energies.

❖ A second method of x-ray production occurs when an *accelerated electron strikes an atom* in the anode and removes an inner electron from this atom. The vacant electron orbital will be filled by a neighboring electron, and an x-ray may be emitted whose energy matches the energy change of the electron. The result is production of large numbers of x-rays at a few *discrete energies*. Since the energy of these characteristic x-rays depends on the material on the surface of the anode, materials are chosen partially to produce x-rays with desired energies. For example, molybdenum is frequently used in anodes of mammography x-ray tubes because of its 20-keV characteristic x-rays.



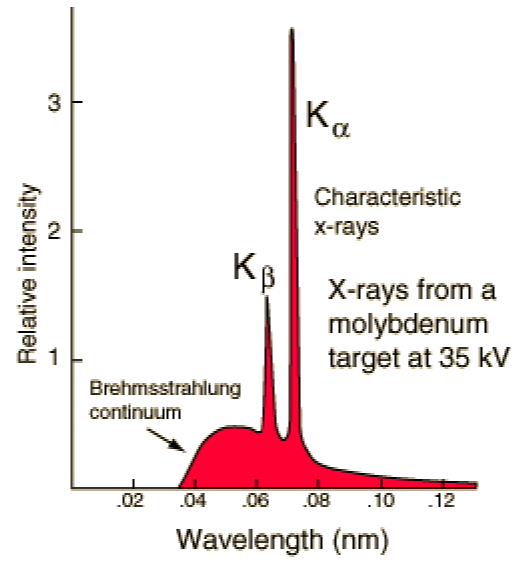


Figure 3 (a) An atom being ionised when a K – shell electron is ejected by an energetic projectile electron. (b) The vacancy in the K -shell, resulting from ionization of the atom, is fi lled by an M -shell electron. A characteristic X -ray is given off.

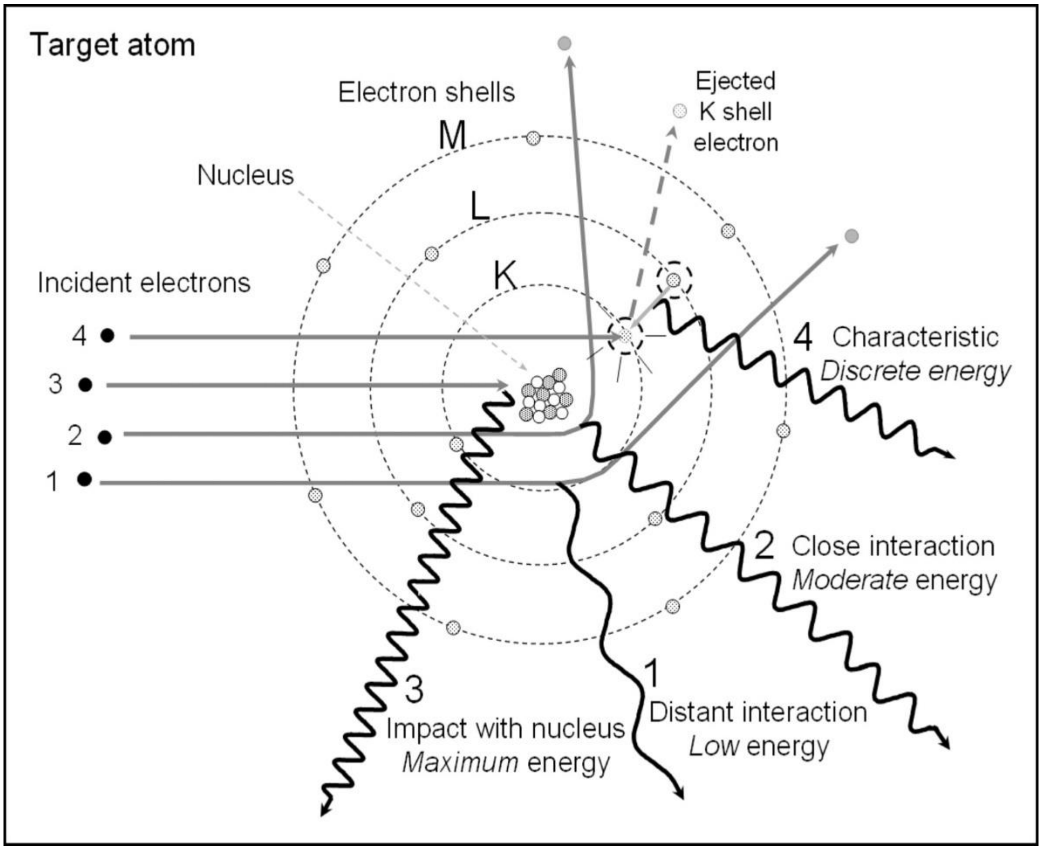


Figure4: X-ray production by energy conversion. Events 1, 2, and 3 depict incident electrons interacting in the vicinity of the target nucleus, resulting in bremsstrahlung production caused by the deceleration and change of momentum, with the emission of a continuous energy spectrum of x-ray photons. Event 4 demonstrates characteristic radiation emission, where an incident electron with energy greater than the K-shell binding energy collides with and ejects the inner electron creating an unstable vacancy. An outer shell electron transitions to the inner shell and emits an x-ray with energy equal to the difference in binding energies of the outer electron shell and K shell that are "characteristic" of tungsten.

<u>Low-energy x-rays are undesirable because:</u>

- They increase dose to the patient but do not contribute to the final image *because* they are almost totally absorbed.

Therefore, the number of low-energy x-rays is usually reduced by use of a layer of absorber that preferentially absorbs them.

The extent to which low energy x-rays have been removed can be quantified by the half-value layer of the x-ray beam. It is ideal to create x-rays from a point source because any increase in source size will result in blurring of the final image.

The blurring has its main effect on *edges* and *small objects*, which correspond to the higher frequencies. The effect of this blurring **depends on** the geometry of the imaging and is worse for larger distances between the object and the image receptor (which corresponds to larger geometric magnifications).

To avoid this blurring, the electrons must be focused to strike a small spot of the anode. The focusing is achieved by electric fields determined by the exact shape of the cathode. However, there is a limit to the size of this focal spot *because* the anode material will melt if too much power is deposited into too small an area. This limit is improved by use of a rotating anode, where the anode target material is rotated about a central axis and new (cooler) anode material is constantly being rotated into place at the focal spot.

To further increase the power limit, the anode is made with an angle surface. This allows the heat to be deposited in a relatively large spot while the apparent spot size at the detector will be smaller by a factor of the sine of the anode angle. Unfortunately, this angle cannot be made too small *because* it limits the area that can be covered with x-rays. In practice, tubes are usually supplied with two (or more) focal spots of differing sizes, allowing choice of a smaller (sharper, lower-power) spot or a larger (more blurry, higher-power) spot.

The x-ray tube also limits the total number of x-rays that can be used in an exposure because the anode will melt if too much total energy is deposited in it. This limit can be increased by using a more massive anode.

BASICX-RAYCIRCUIT

The **main circuit** and **filament circuit** are combined to form the complete basic x-ray circuit that is composed of sequence of devices to produce x-rays.

X-RAYCIRCUITS

MainCircuit

1. **PRIMARY CIRCUIT**–Control Panel
    - **Main Switch**: The switch that generates the power to the x-ray tube.
    - **Exposure Switch**: A remote control device that permits current to flow through the circuit.
    - **Timer**: Device used to end the exposure at an accurately measured preset time.

2. **SECONDARY CIRCUIT**–high voltage transformers, rectification & x-ray tube.

Filament Circuit

- **FILAMENT CIRCUIT** varies current sent to the filament in order to provide the required mA value.

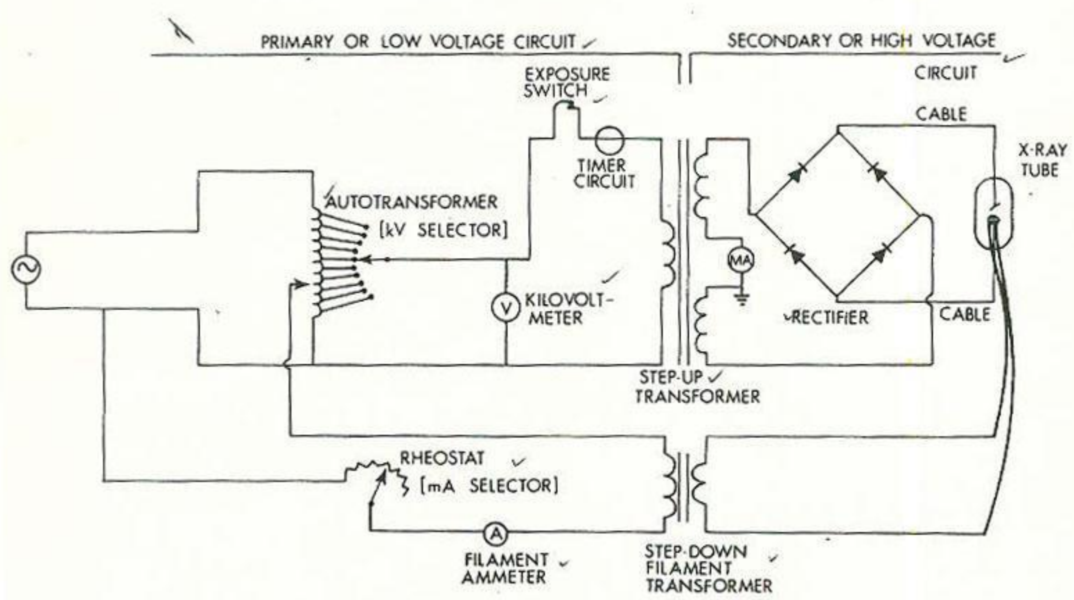


Figure 14.12. Simplified wiring of a single phase x-ray unit, with full-wave rectification.

MAINCIRCUIT

- Supplies power to the x-ray tube so that x-rays are produced.
- Modifies incoming current to produce x-rays.
- Boost the voltage to the necessary range of x-ray production.
- Permit the radiographer to adjust technical factors.
- Incorporate appropriate circuitry to increase x-ray production efficiency.

FILAMENTCIRCUIT

- Supplies power to the filament of the x-ray tube so that the filament supplies enough electrons by thermionic emission.
- Modifies incoming line power to produce thermionic emission from the filament wire.

- Filament circuit adjusts to mA ratings (50,100,200,etc.)
- After mA selection, current sent to step down transformer to modify amps that reach.

1. Main breaker: this is where the alternating current comes from to power the circuit.
2. Exposure switch: when you push the button to start an exposure this switch closes to start the exposure.
3. Autotransformer: this is where you adjust the kVp for the exposure.
4. Timer circuit: this part of the circuit stops the exposure.
5. High -voltage step-up transformer: this transformer bumps the voltage up so that the x-ray tube has very high voltage to make the electrons have enough energy to form x-rays.
6. Four-diode rectification circuit : this makes the current only go in one direction through the x-ray tube.
7. Filament circuit variable resistor: this variable resistor adjusts the current going to the filament.
8. Filament step-down transformer: this transformer steps the voltage down and therefore the current up.
9. X-ray tube -this is where the x-rays are created.
10. rotor stator -this rotates the anode

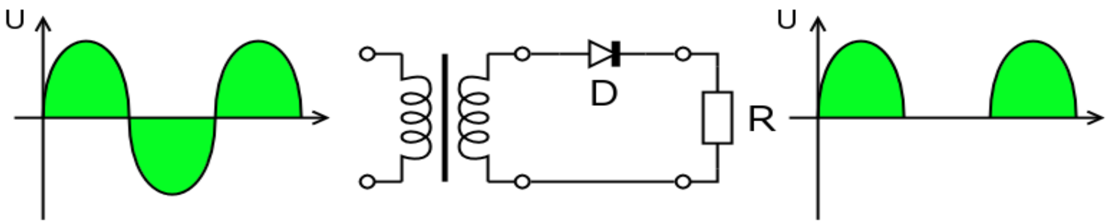
TRANSFORMERS

- Autotransformer: That contains an iron core and a single winding or wire; is used in the x-ray circuit to provide a small increase in voltage before the step up transformer.
- Step-uptransformer: that increases voltage from primary to the secondary coil and decreases current in the same proportion. Has more turns in secondary than in primary coil. Is used to increase voltage to the kilovoltage level for x-ray production.
- Step-down transformer: that decreases voltage from primary to the secondary coil and increases current in the same proportion. Has more turns in the primary than in the secondary coil. Is used in the filament portion to increase current flow to the cathode.

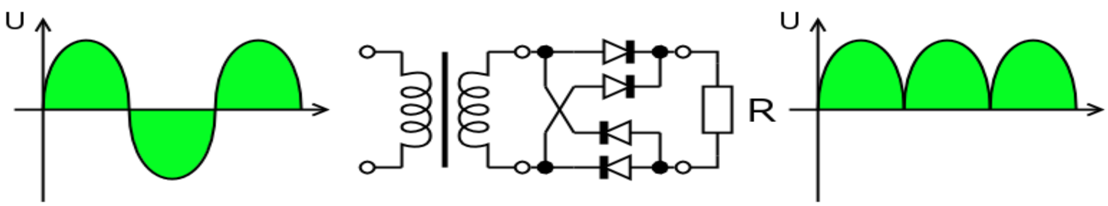
RECTIFIERS

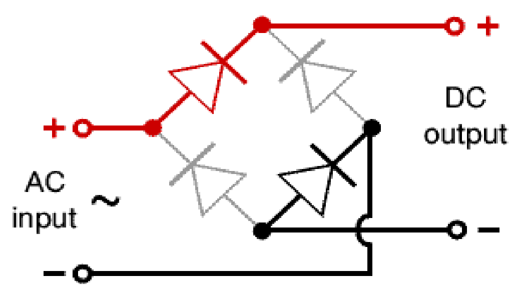
- A rectifier is an electrical device that converts alternating current (AC) to direct pulsating current (DC).
- Two Types of Rectifiers:

1. Half Wave Rectifiers: pass half of the alternating electrical current through one or more diodes



2. Full Wave Rectifiers: generally use four diodes to function, changing the entire current into a direct current.





TIMER

- Used to regulate the duration of the x-ray exposure.
- Electronic timers are the most common timers used.
- They operate by charging a silicon- controlled rectifier which triggers the exposure.
- The exposure times are calculated within 0.001 seconds with only a 1 msec delay.