# DAYANANDA SAGAR COLLEGE OF ENGINEERING

Shavige Malleshwara Hills, Kumaraswamy Layout, Bengaluru, Karnataka 560078

## DEPARTMENT OF MEDICAL ELECTRONICS

STUDY MATERIAL

Semester: VII

Subject Code: 18ML7IEMIT

Subject Title: Medical Imaging Techniques

# Syllabus

- **X-RAY MACHINES AND DIGITAL RADIOGRAPHY**: Basics of diagnostic radiology, nature of X-Rays, production of X-Rays, X-Ray machine, visualization of X-Rays, dental X-Ray machines, Portable and mobile X-Ray units, Digital radiography, Fluoroscopy, Angiography, Mammography and Xeroradiography, Image subtraction.
- **COMPUTED TOMOGRAPHY:** Computed tomography, system components, gantry geometry, system electronics, patient dose in CT scanners, Recent developments – Digital radiography, Digital subtraction angiography (DSA), 3D reconstruction, Dynamic Spatial Reconstructor (DSR).
- **RADIONUCLIDE IMAGING**: Radio-isotopes in medical diagnosis, physics of radioactivity, radiation detector, pulse height analyser, uptake monitoring equipment, emission computed tomography, Single – Photon Emission Computed Tomography (SPECT), Positron Computed Tomography (PET) scanner

# Syllabus

**MAGNETIC RESONANACE IMAGING SYSTEM:**

- Basics of Magnetic Resonance Imaging - Fundamentals of nuclear magnetic resonance, Introduction to MRI sub systems, Imaging Methods- Introduction, slice selection, frequency encoding, phase encoding, Spin-Echo imaging- Gradient echo imaging, Blood flow imaging, Characteristics of MRI images- Spatial resolution, image contrast. Biological effects of magnetic fields- Static magnetic fields, Radio-frequency fields, Gradient magnetic fields, Imaging safety, Functional MRI.
- **ULTRASONIC IMAGING SYSTEMS**: Diagnostic ultrasound, physics of ultrasonic waves, medical ultrasound, basic pulse echo apparatus, imaging modes, modern ultrasound imaging systems, portable ultrasound systems, biological effects of ultrasound

# Syllabus

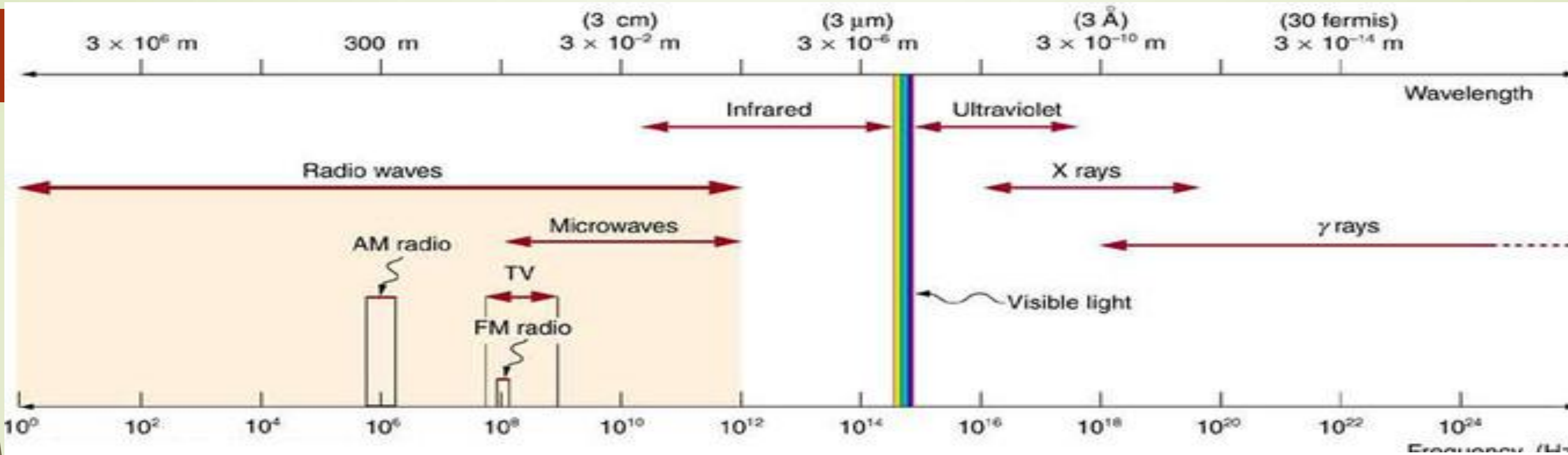
- **THERMAL IMAGING SYSTEMS**: Medical thermography, physics of thermography, infrared detectors, thermographic equipment, quantitative medical thermography, pyroelectric vidicon based thermographic camera, thermal camera based on IR array sensor

# UNIT 1: X-RAY MACHINES AND DIGITAL RADIOGRAPHY

# Unit 1: **X-RAY MACHINES AND DIGITAL RADIOGRAPHY**

- Basics of diagnostic radiology
- Nature of X-Rays, production of X-Rays
- X-Ray machine
- visualization of X-Rays
- dental X-Ray machines
- Portable and mobile X-Ray units
- Digital radiography
- Fluoroscopy
- Angiography
- Mammography and Xeroradiography
- Image subtraction

# EM spectrum


(3 cm)
(3 μm)
(3 Å)
(30 fermis)
3 × 10⁶ m
300 m
3 × 10⁻² m
3 × 10⁻⁶ m
3 × 10⁻¹⁰ m
3 × 10⁻¹⁴ m
Wavelength
Infrared
Ultraviolet
Radio waves
X rays
Microwaves
γ rays
AM radio
TV
FM radio
Visible light
10⁰
10²
10⁴
10⁶
10⁸
10¹⁰
10¹²
10¹⁴
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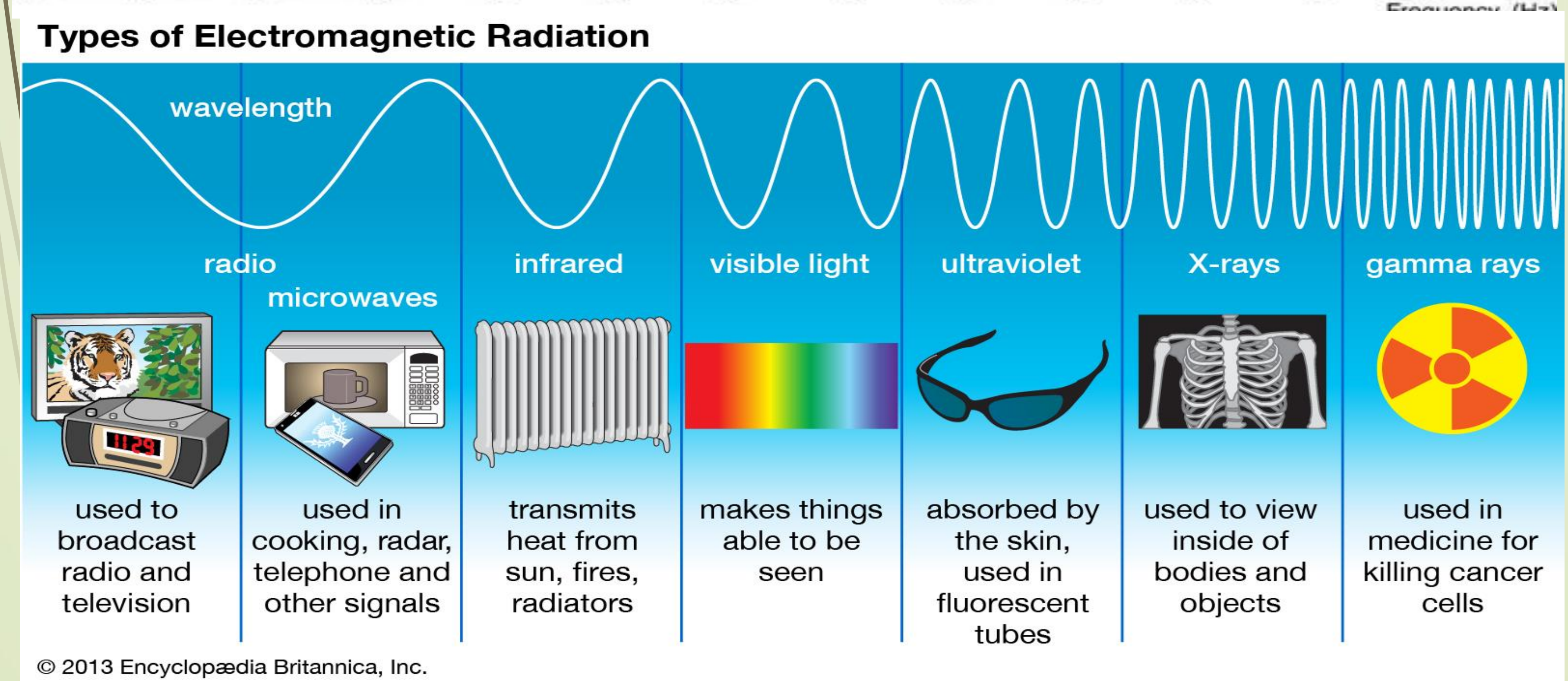
10¹⁸
10²⁰
10²²
10²⁴


Types of Electromagnetic Radiation
wavelength
radio
microwaves
infrared
visible light
ultraviolet
X-rays
gamma rays
used to broadcast radio and television
used in cooking, radar, telephone and other signals
transmits heat from sun, fires, radiators
makes things able to be seen
absorbed by the skin, used in fluorescent tubes
used to view inside of bodies and objects
used in medicine for killing cancer cells
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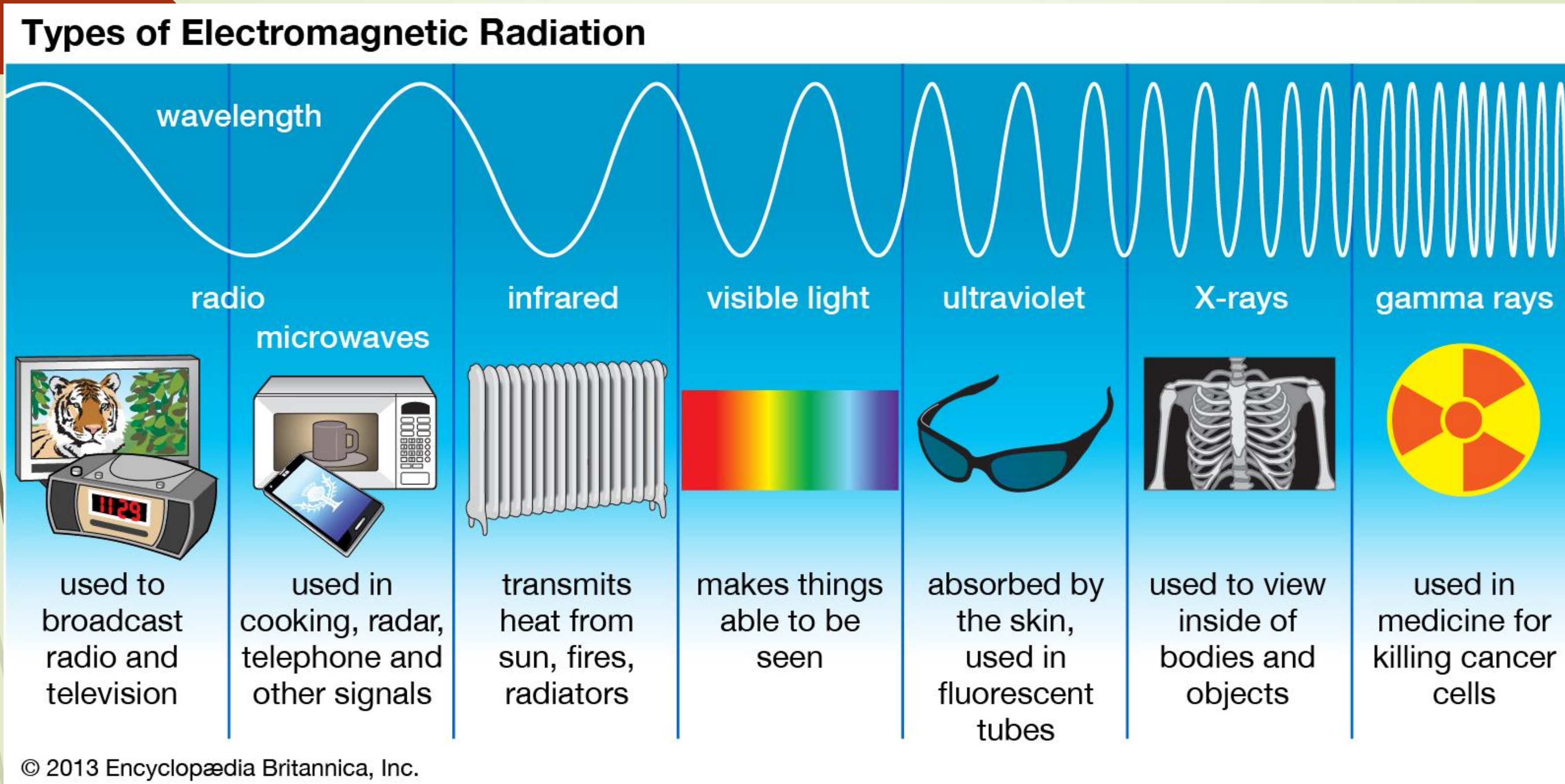
# EM spectrum



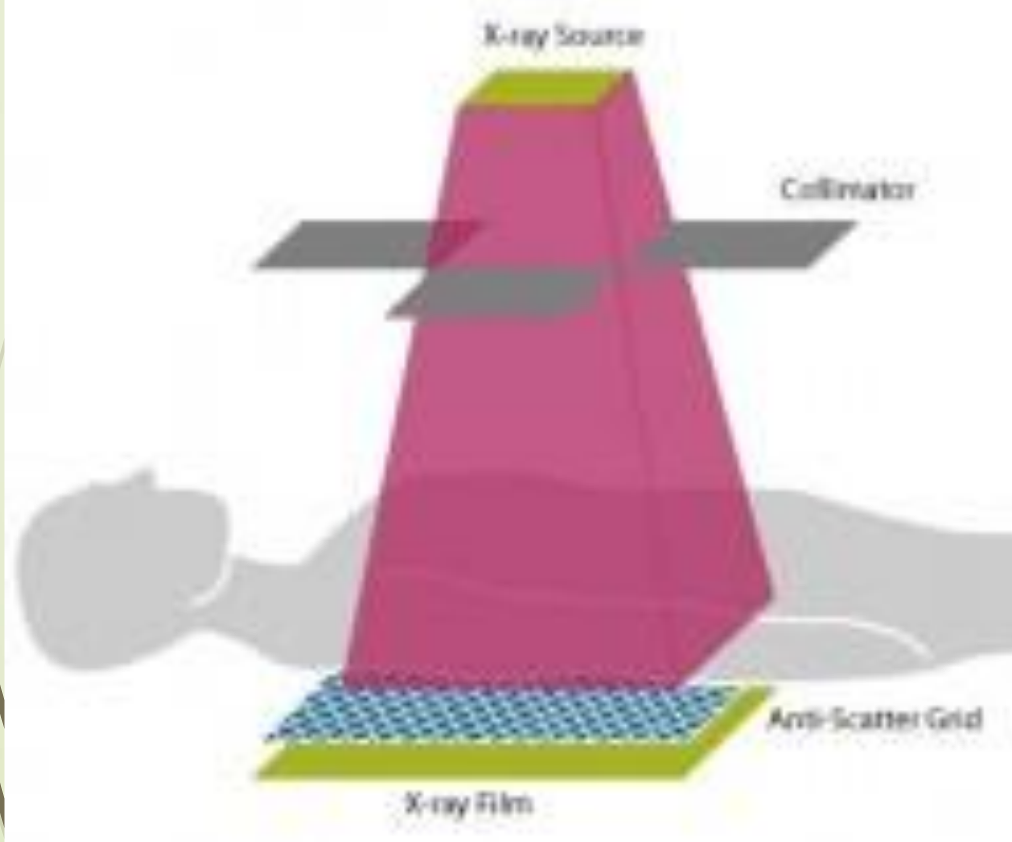

**X-rays** are **electromagnetic waves** with **wavelengths** in the range of 0.01 to 10 nanometers, corresponding to frequencies $3\times10^{16}$ Hz to $3\times10^{19}$ Hz and energies in the range 100 eV to 100 keV.
They are shorter in **wavelength** than UV **rays** and longer than gamma **rays**.

X-rays

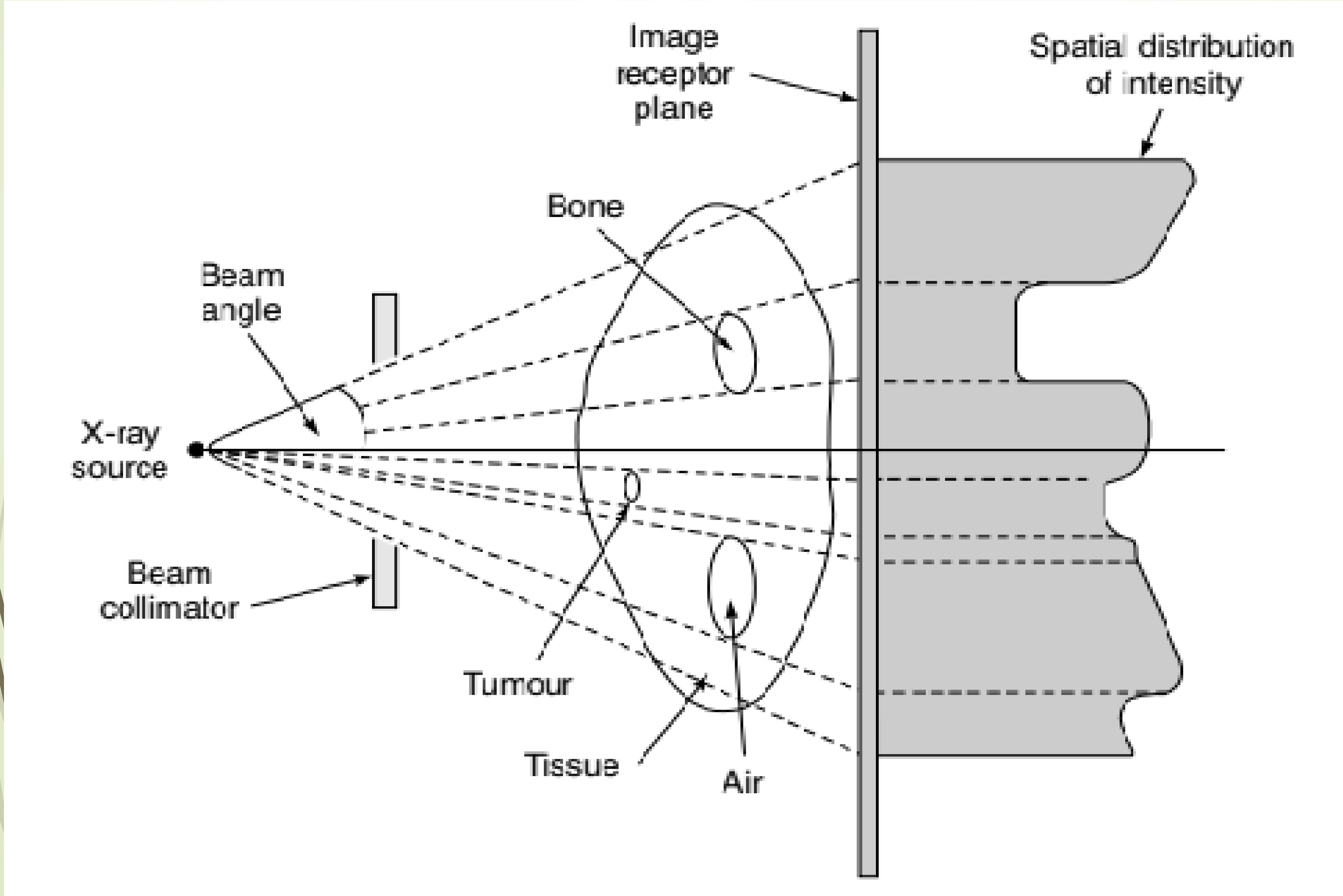
Frau Röntgen's hand

- The X-rays are absorbed by the material they pass through in differing amounts depending on the density and composition of the material.
- X-rays that are not absorbed but they pass through the object and are recorded on X-ray sensitive film

# Basic X-ray set up




# Basic set-up for a diagnostic radiology image formation process



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

Current estimates show that there are approximately 650 medical and dental X-ray examinations per 1000 patients per year.

X-rays are produced when high energetic electrons interact with matter.

$$E = h\nu = h\frac{c}{\lambda}$$

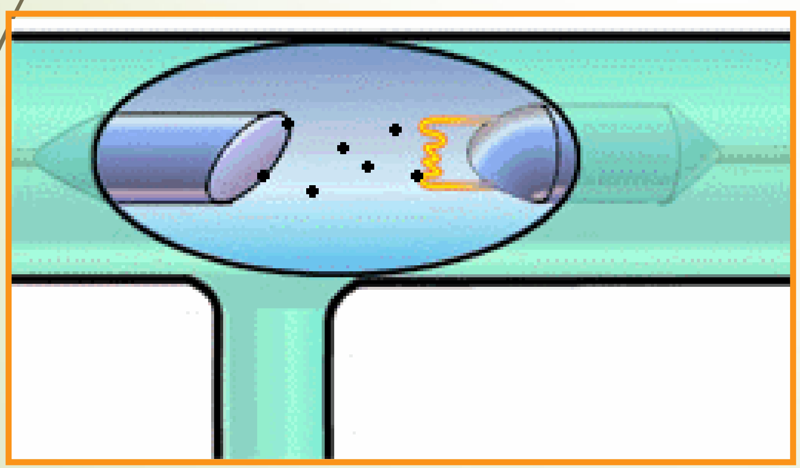
where $h$ = Planck's constant = $6.32 \times 10^{-34}$ J s

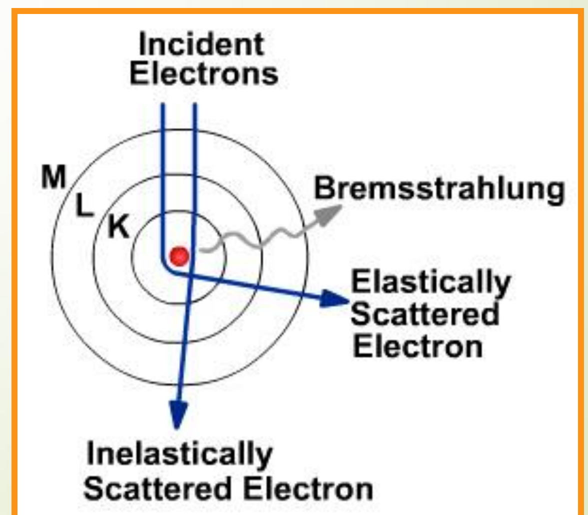
$c$ = velocity of propagation of photons = $3 \times 10^{10}$ cm/s

$\nu$ = frequency of radiation

$\lambda$ = wavelength

The kinetic energy of the electrons is converted into electromagnetic energy by atomic interactions





# Production of X-rays

The quality and the quantity of the x-radiation are controlled by adjusting the

- Electrical parameters - voltage or the potential applied to the tube,
  current that flows through the tube
- Exposure time, usually a fraction of a second

x-rays are produced in a standard way

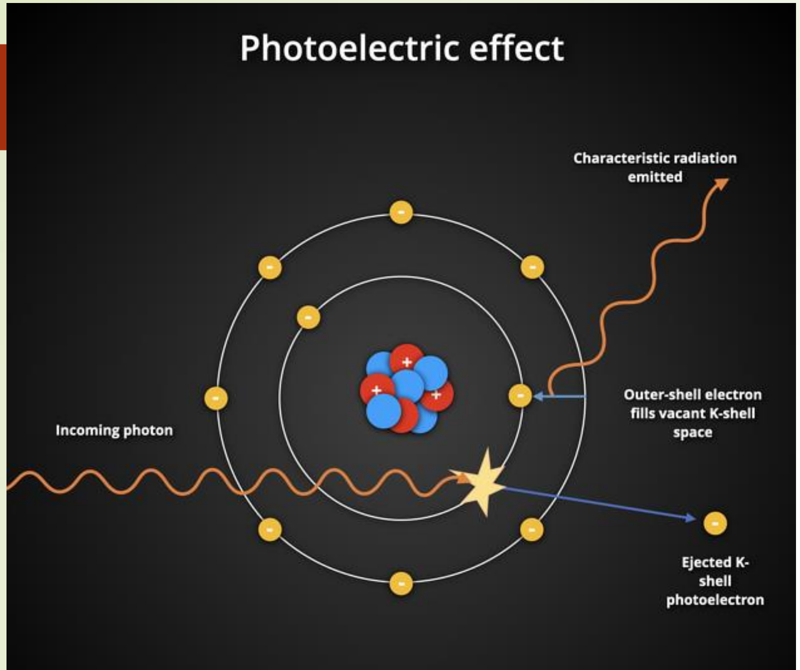
- by accelerating electrons with a high voltage and
- allowing them to collide with the focal spot

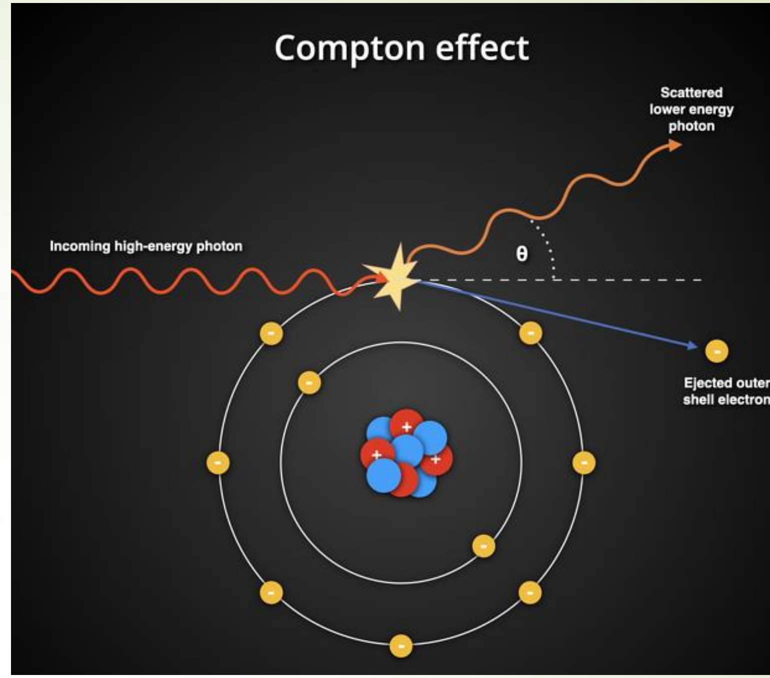
X-rays are produced when the electrons are suddenly decelerated upon collision with the metal target. These x-rays are called "braking radiation" (bremsstrahlung).

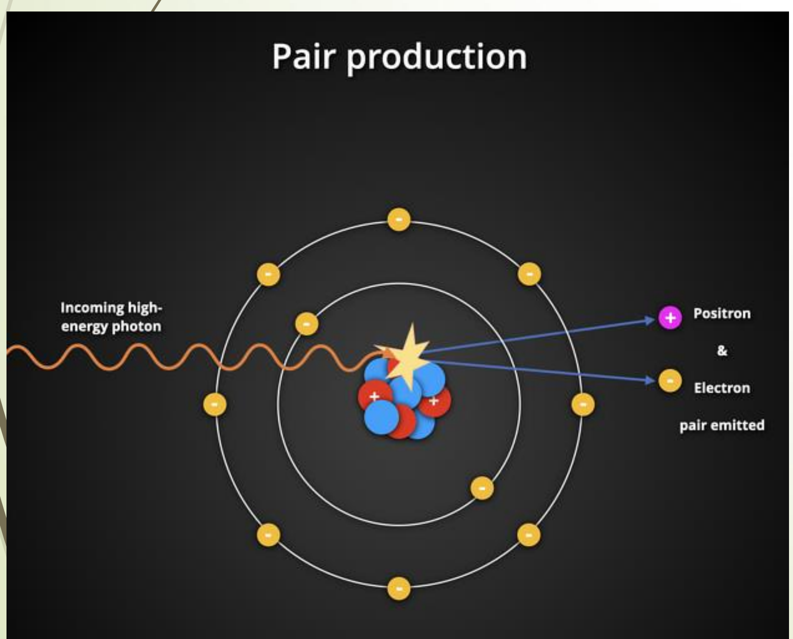
If the electrons have high energy, they can expel an electron out of the atomic shell of the bombarded atom. Electrons from a higher energy level fill the place of the expelled electron, emitting x-ray photons with quantized (precise) energies, determined by the respective electron energy levels.

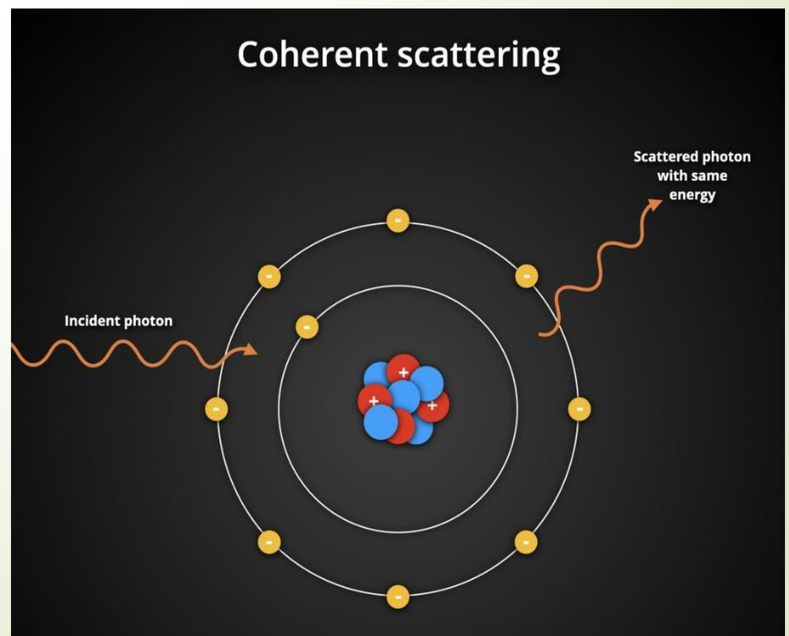
The x-rays produced in this way are called "characteristic x-rays".

# Types of photo-atom interaction



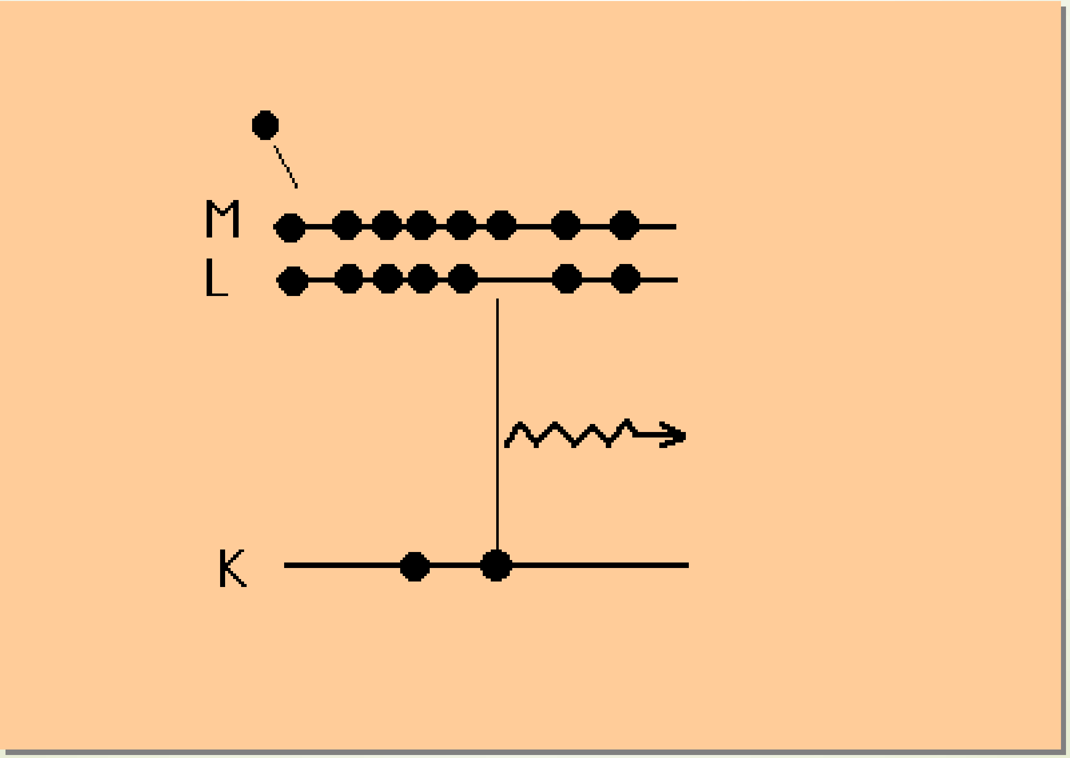



X-rays

## Mechanism

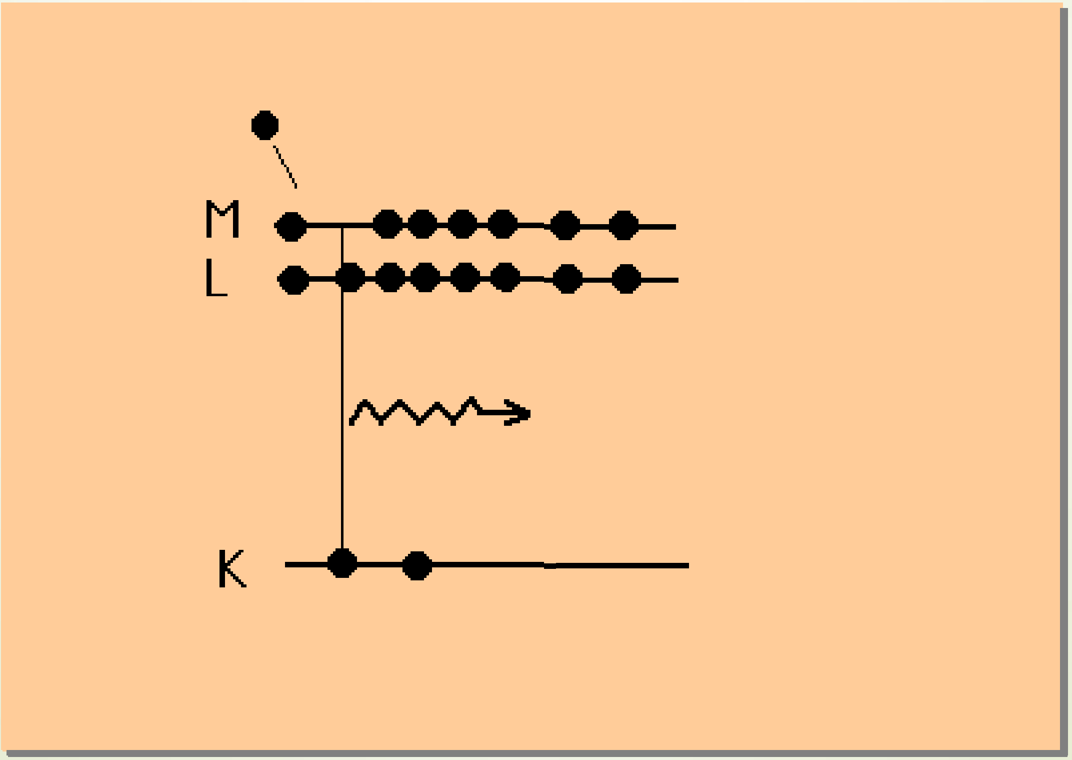
Decelerating charges give off radiation



X-rays

## Mechanism

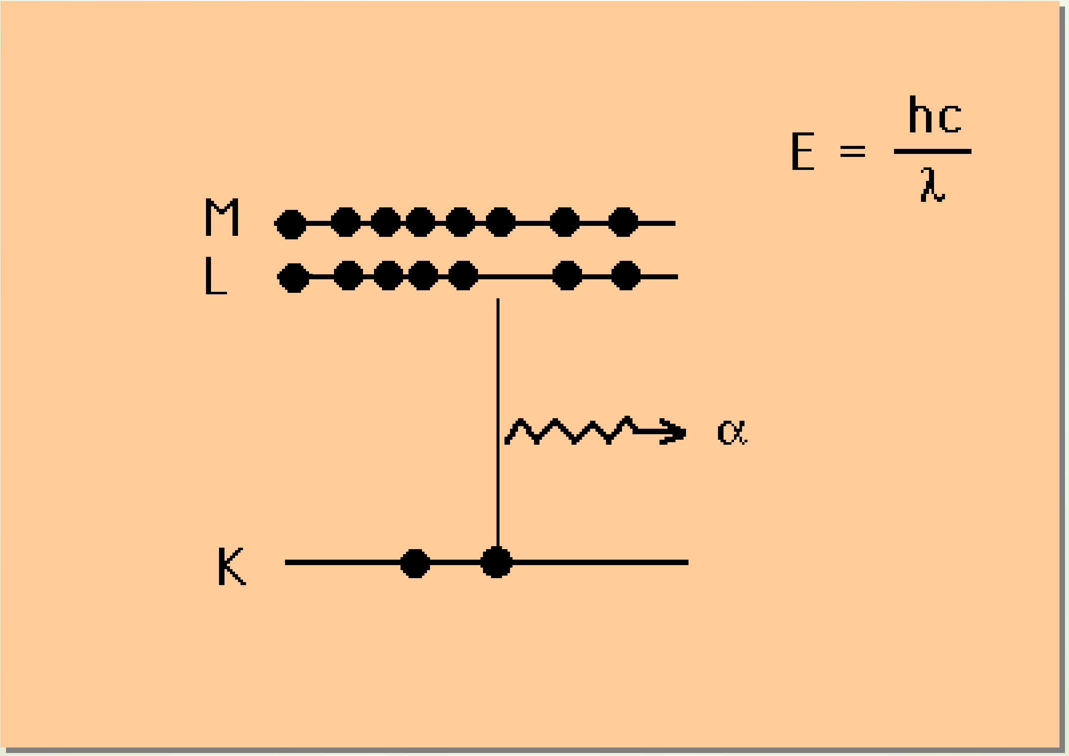
Decelerating charges give off radiation



X-rays

## Mechanism

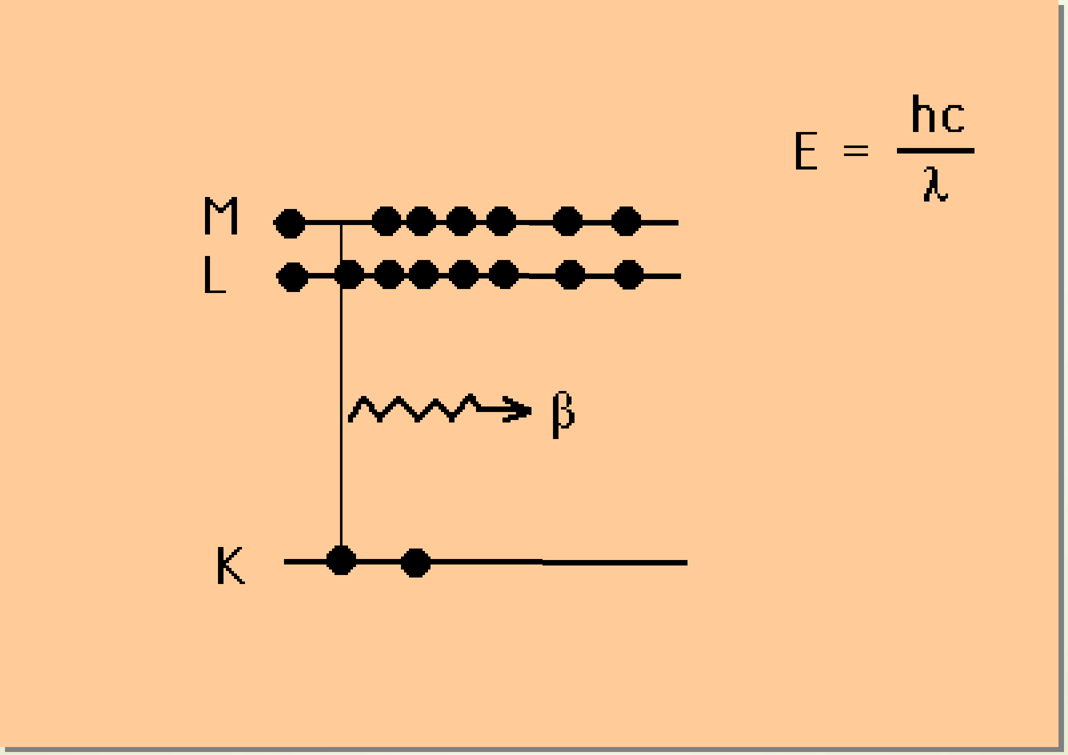
Decelerating charges give off radiation



X-rays

## Mechanism

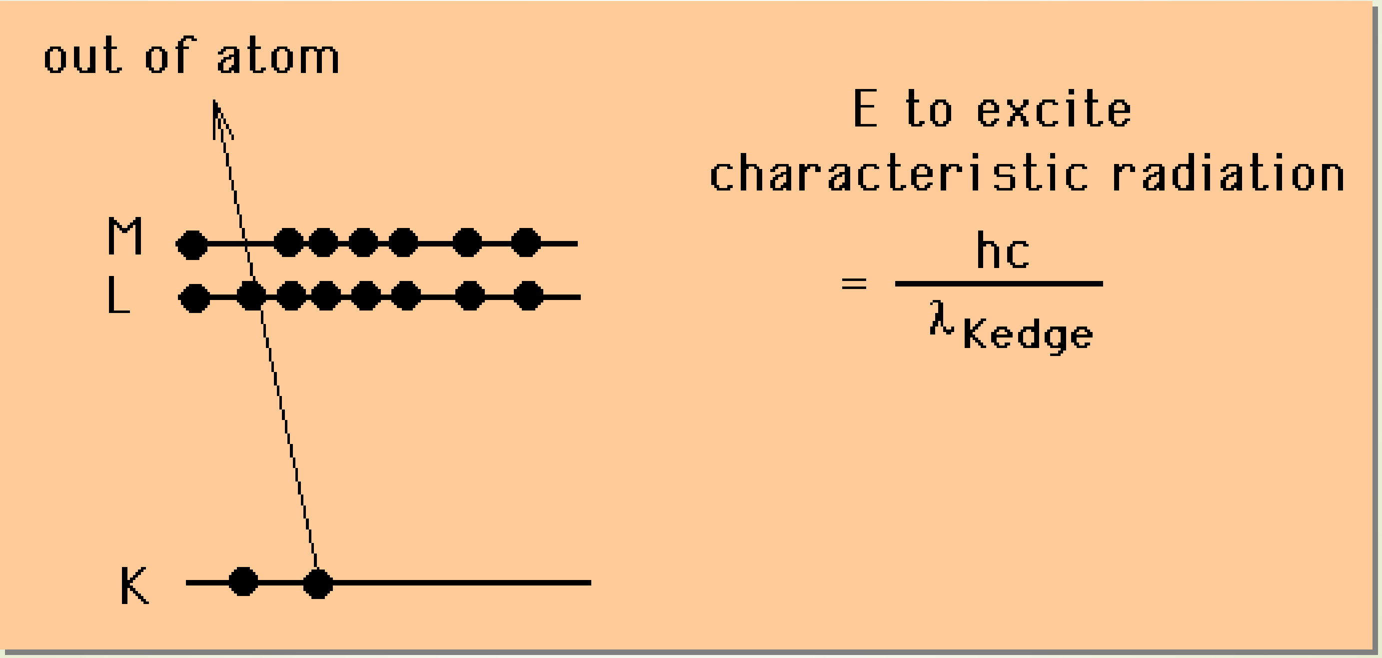
Decelerating charges give off radiation



X-rays

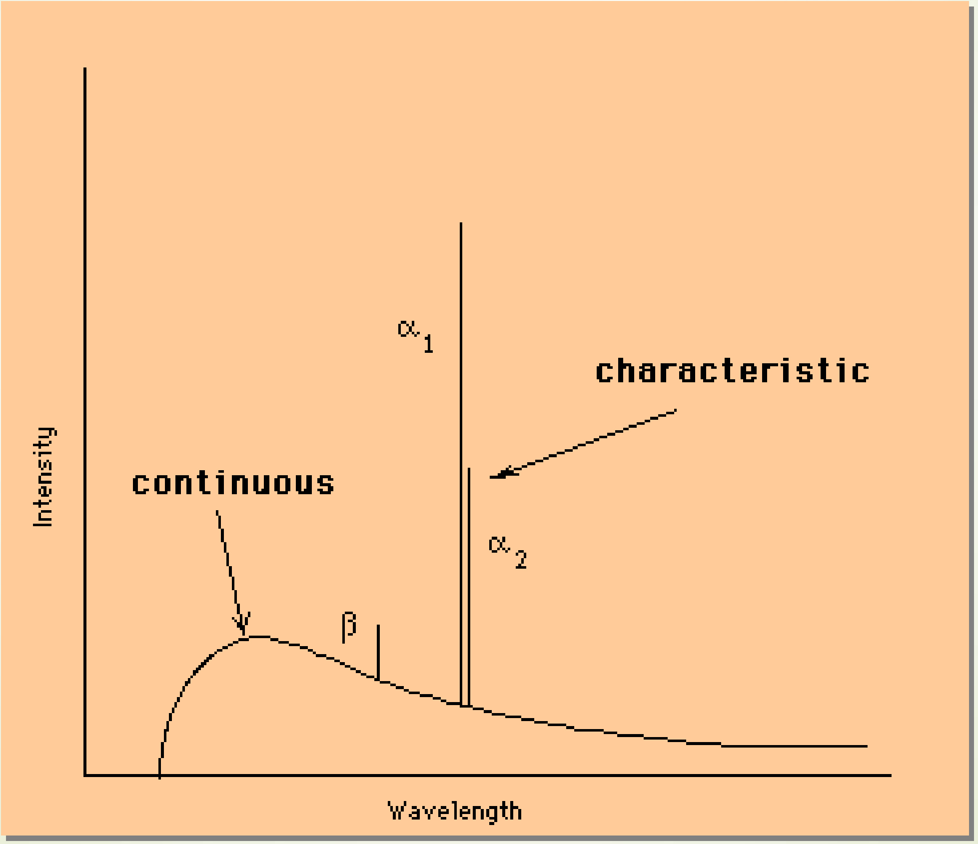
## Mechanism

Decelerating charges give off radiation

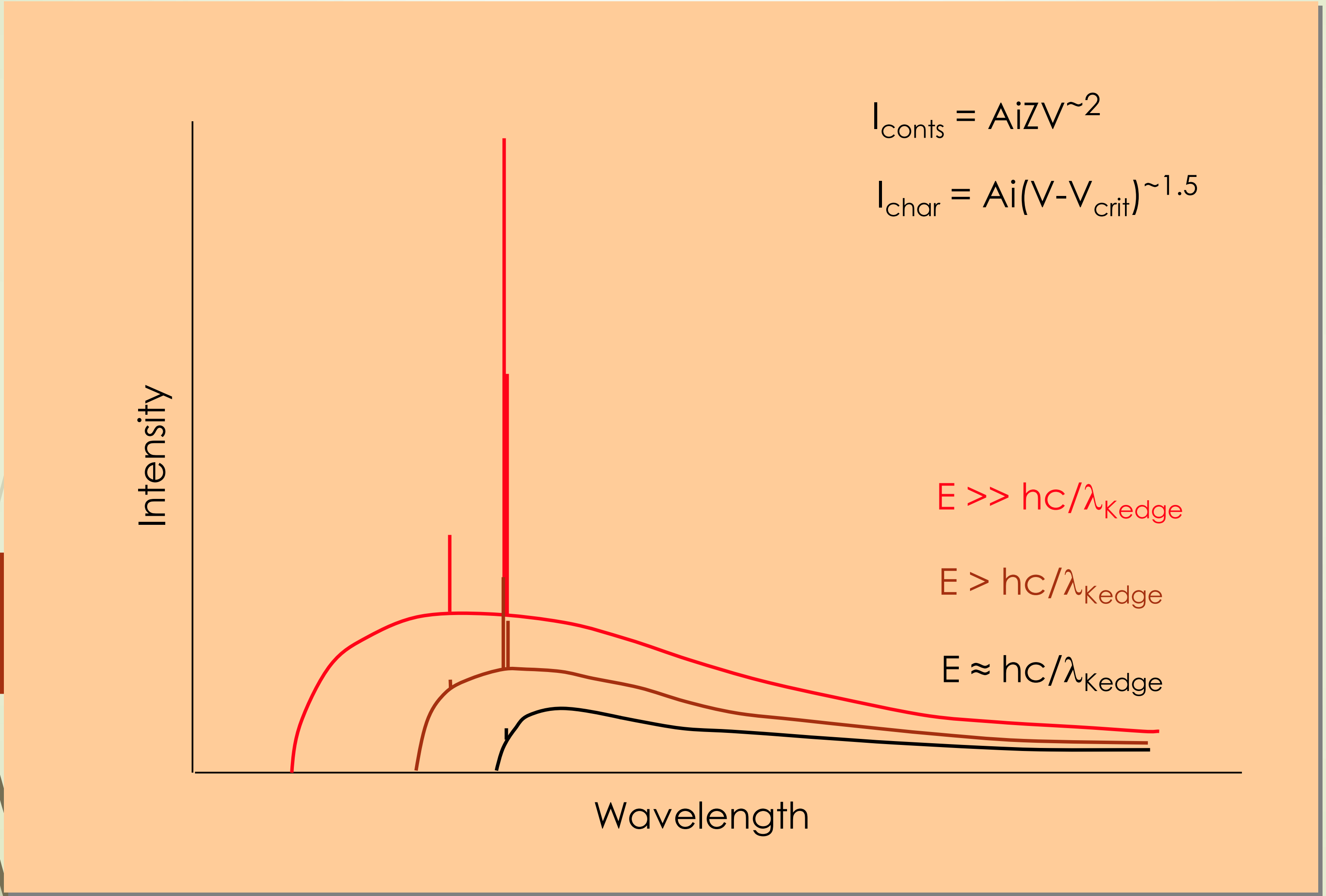


# X-rays

## Typical tube spectrum



# X-rays - vary tube voltage



# Unit of measurement:

- The International Commission on Radiological Units and Measurements has adopted Rontgen as a measure of the quantity of x-radiation.
- This unit is based on the ability of radiation to produce ionization and is abbreviated 'R'.
- One R is the amount of X-radiation which will produce $2.08 * 10^9$ ion pairs per cubic centimetre of air at standard temperature (0°C) and pressure (760 mmHg at sea level and latitude 45°).
- Units derived from the Rontgen are the millirontgen (mR = 1/1000 R) and the microrontgen ($\mu R = 10^{-6}$ R).
- The unit of absorbed dose is rad. One rad is the radiation dose which will result in an energy absorption of $1.0 * 10^{-2}$ J/kg in the irradiated material. It is approximately equal to the dose absorbed by soft tissue exposed to one Rontgen of X-rays
- The Rontgen and the absorbed dose D are related as D = f R where f is a proportionality constant and depends upon both the composition of the irradiated material and quality of the radiation beam.

# X-rays

White radiation

- Produced upon "collisions" with electrons in target
- Any amount of energy can be lost up to a max. amount
- Continuous variation of wavelength

Characteristic radiation

- Specific energies absorbed
- Specific x-ray wavelengths emitted
- Wavelengths characteristic of target atom type

# X-ray sources

Sealed tubes - Coolidge type

- common - Cu, Mo, Fe, Cr, W, Ag
- intensity limited by cooling requirements (2-2.5kW)
  - (~99% of energy input converted to heat)

# Production of X-rays

The X-rays in the medical diagnostic region have wavelength of the order of $10^{-10}$m. They propagate with a speed of 3 x$10^{10}$ cm/s and are unaffected by electric and magnetic fields.
The X-ray tube provides an environment for X-ray production via Bremsstrahlung x ray and characteristic radiation mechanisms.

- X-rays are produced in a specially constructed glass tube, which basically comprises.

  (i) a source for the production of electrons,

  (ii) a energy source to accelerate the electrons

  (iii) a free electron path

  (iv) a means of focusing the electron beam and

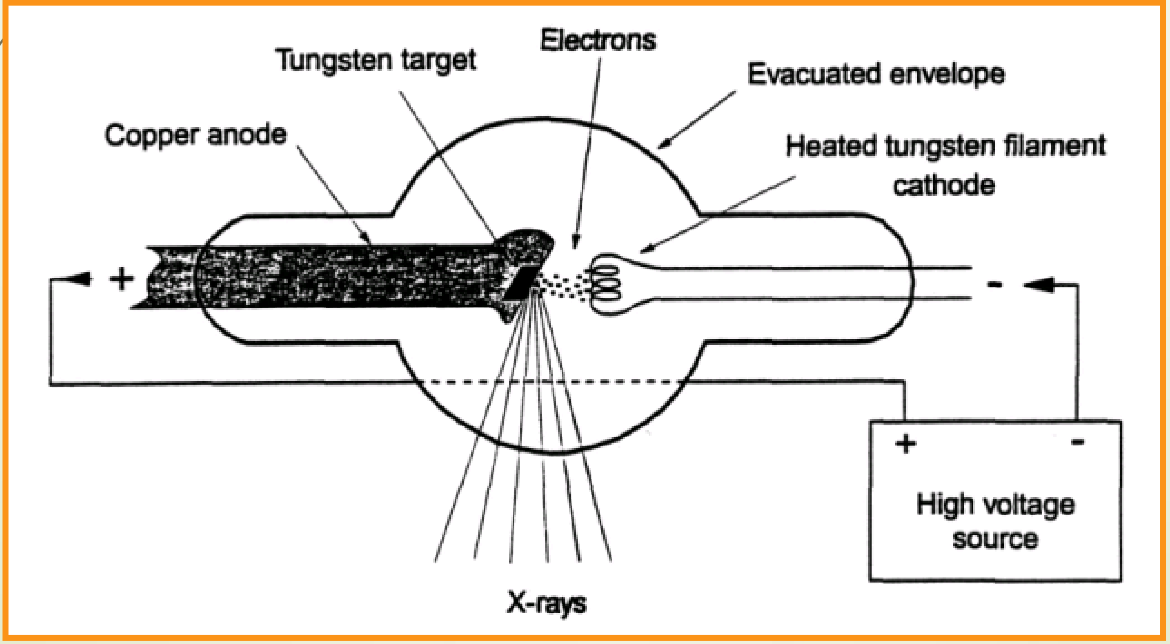
  (v) a device to stop the electrons

- Stationary mode tubes and rotating anode tubes are the two main types of X-ray tubes

# Production of X-rays

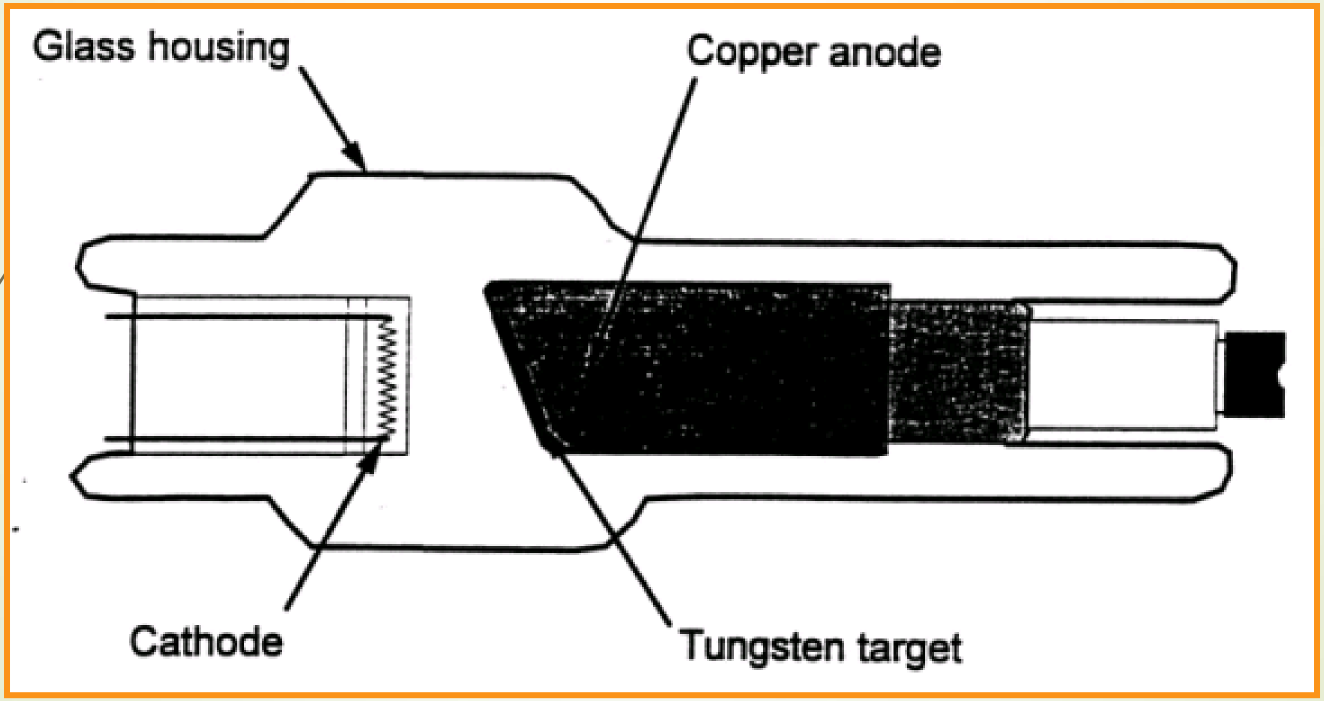
The classical X-ray tube requires:

- electron source
- electron acceleration potential
- target for X-ray production

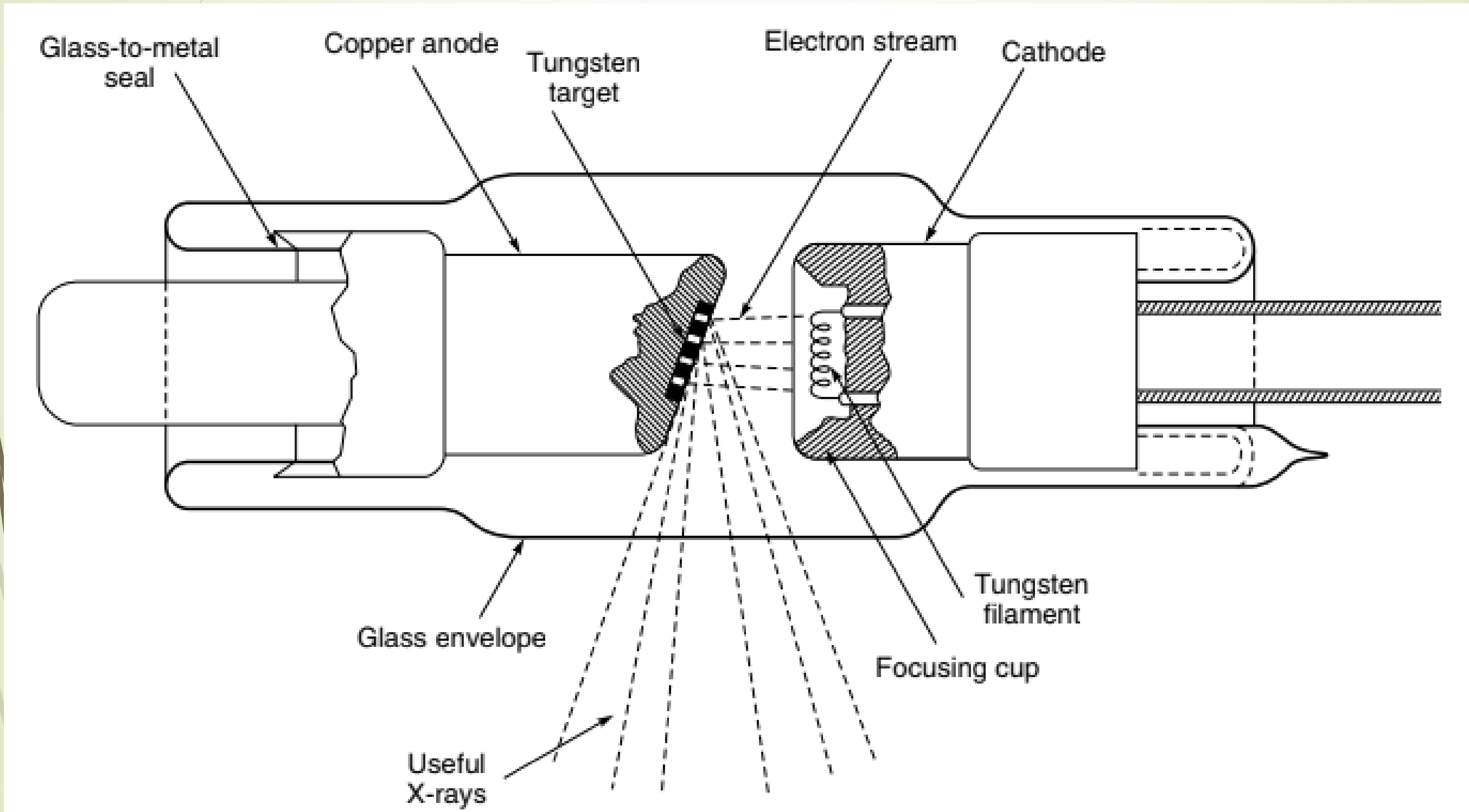


## The two major **anode** configurations are:

The stationary anode is the classical configuration, tungsten target for X-ray production and copper block as heat sink



# Construction of stationary anode X-ray tube



# Construction of stationary anode X-ray tube

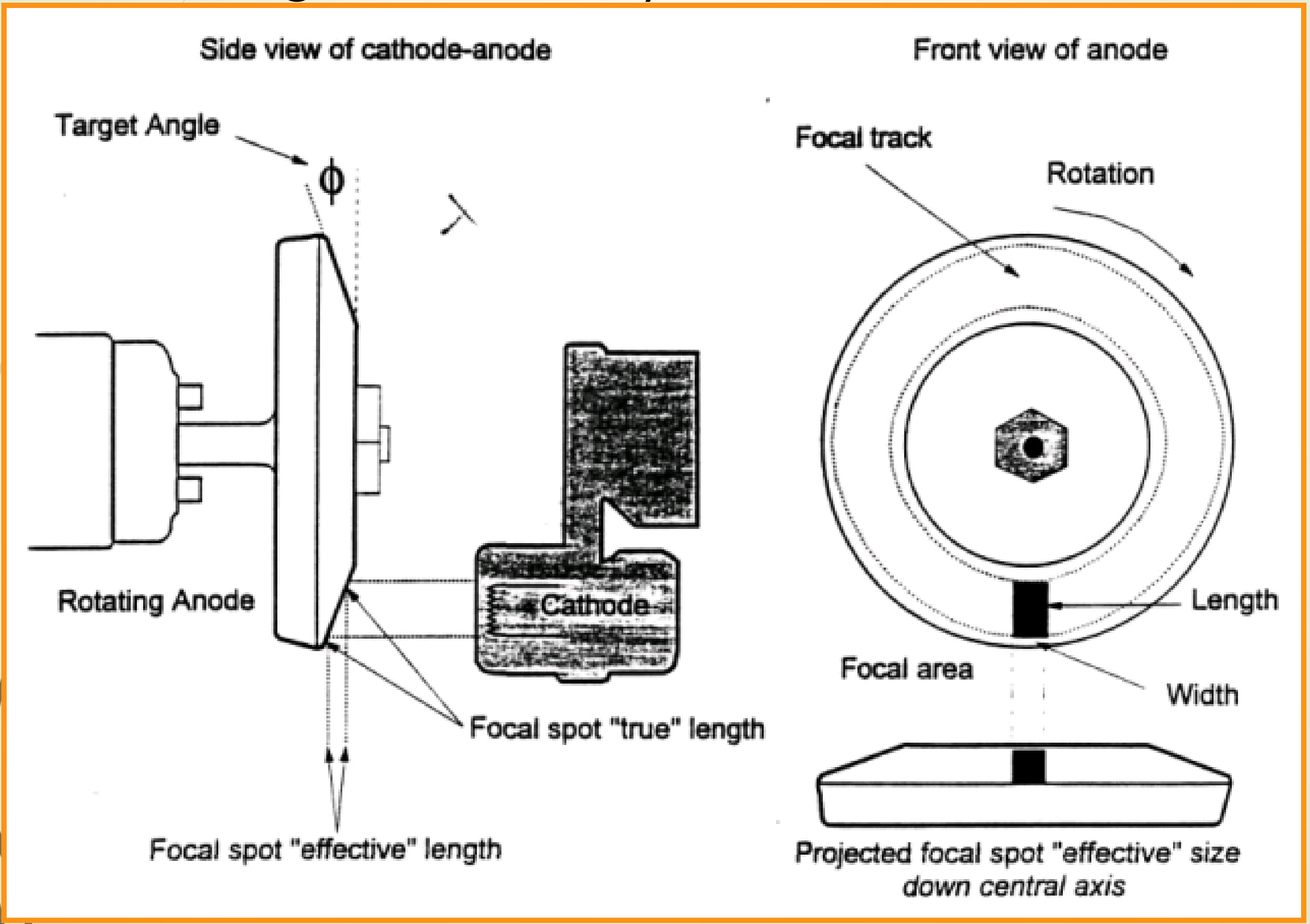
- The normal tube is a vacuum diode in which electrons are generated by thermionic emission from the filament of the tube.
- The electron stream is electrostatically focused on a target on the anode by means of a suitably shaped cathode cup.
- The kinetic energy of the electrons impinging on the target is converted into X-rays.
- Most electrons emitted by the hot filament become current carriers across the tube.
- It is possible to independently set (i) Tube current by adjusting the filament temperature, and (ii) Tube voltage by adjusting primary voltage.

# Construction of stationary anode X-ray tube

Some X-ray tubes function as a triode with a bias voltage applied between the filament and the cathode cup.

- The bias voltage can be used to control the size and shape of the focal spot by focusing on the electron beam in the tube.
- The cathode block, which contains the filament, is usually made from nickel or from a form of stainless steel.
- The filament is a closely wound helix of tungsten wire, about 0.2 mm thick, the helix diameter being about 1.0–1.5 mm. The target is normally comprised of a small tablet of tungsten about 15 mm wide, 20 mm long and 3 mm thick soldered into a block of copper.
- Tungsten is chosen since it combines a high atomic number (74)—making it comparatively efficient in the production of X-rays. It has a high melting point (3400o C) enabling it to withstand the heavy thermal loads.
- In special cases, molybdenum targets are also used, as in the case of mammography, where in improved subject contrast in the breast is desirable.
- The lower efficiency of X-ray production and the lower melting point make molybdenum unsuitable for general radiography.

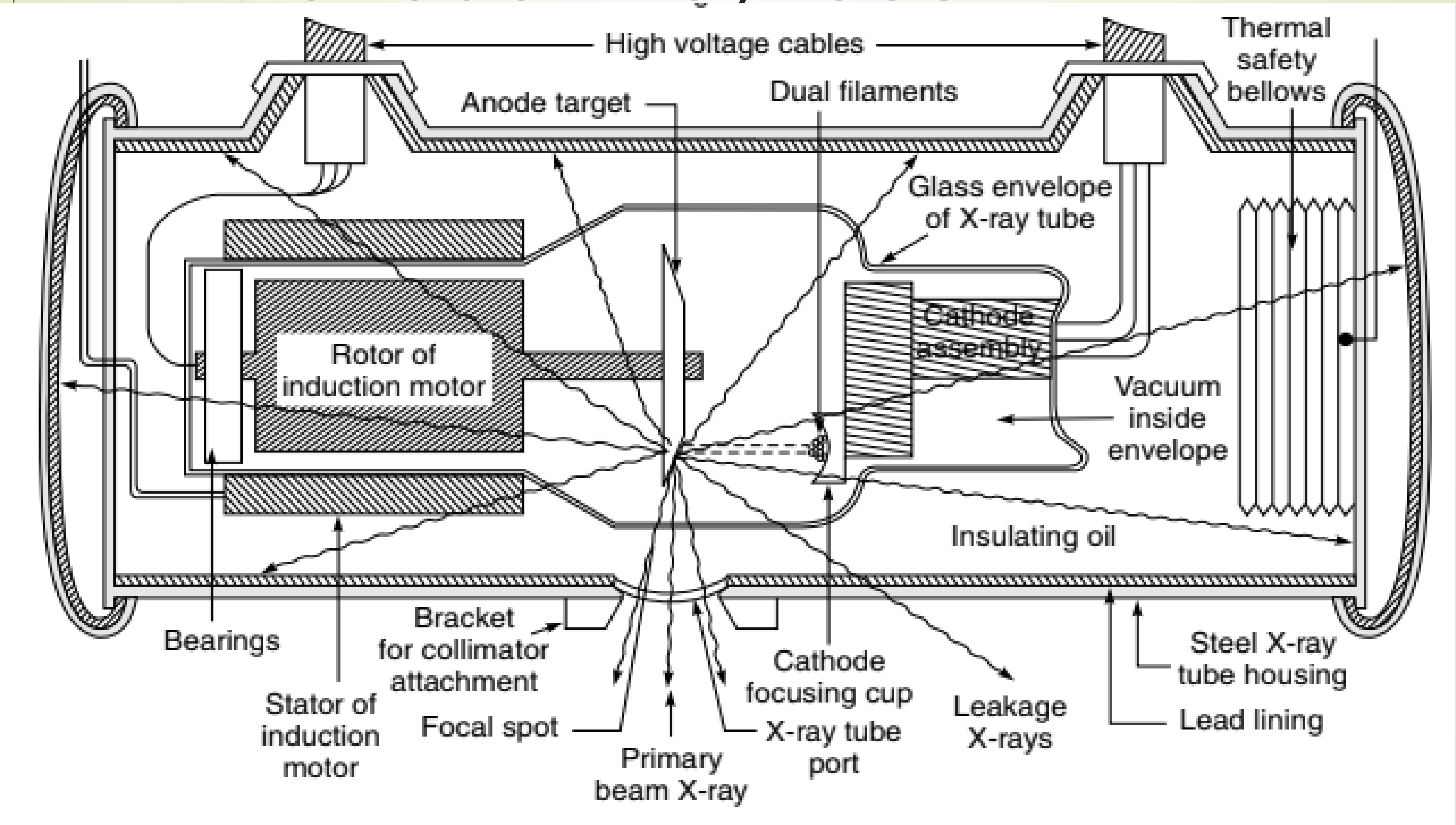
The rotating anode is a tungsten disc, large rotating surface area warrants heat distribution, radiative heat loss (thermally decoupled from motor to avoid overheating of the shaft)



# Rotating anode X-ray tube

- With an increasing need in radiology for more penetrating X-rays, requiring higher tube voltages and current, the X-ray tube itself becomes a limiting factor in the output of the system
- This is primarily due to the heat generated at the anode. The heat capacity of the anode is a function of the focal spot area.
- Therefore, the absorbed power can be increased if the effective area of the focal spot can be increased.
- This is accomplished by the rotating anode type of X-ray tubes. The tubes with rotating anode are based on the removal of the target from the electron beam before it reaches too high a temperature under the electron bombardment and the rapid replacement of it by another cooler target

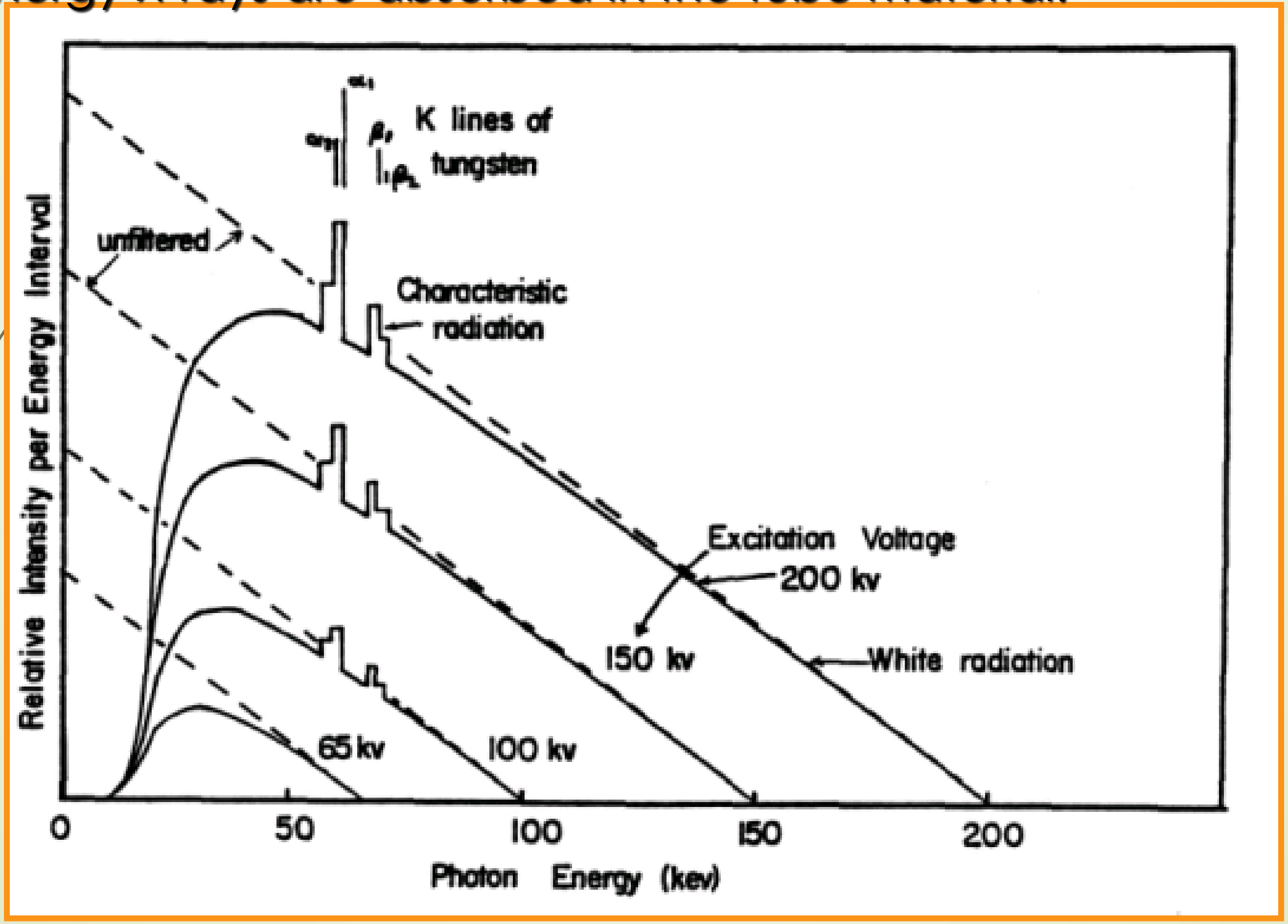
# Construction of rotating anode X-ray tube



The intensity of the electron beam determines the intensity of the X-ray radiation.

The electron energy determines the shape of the bremsstrahlungs spectrum, in particular the endpoint of the spectrum.

Low energy X-rays are absorbed in the tube material.



The X-ray energy determines also the emission of characteristic lines from the target material.

**Electron Binding Energies in keV of Common X-ray Tube Target Materials**

| Electron Shell | Tungsten | Molybdenum | Rhodium |
|---|---|---|---|
| K | 69.5 | 20.0 | 23.2 |
| L | 12.1/11.5/10.2 | 2.8/2.6/2.5 | 3.4/3.1/3.0 |
| M | 2.8–1.9 | 0.5–0.4 | 0.6–0.2 |

**K-shell Characteristic X-ray Energies (keV)[a]**

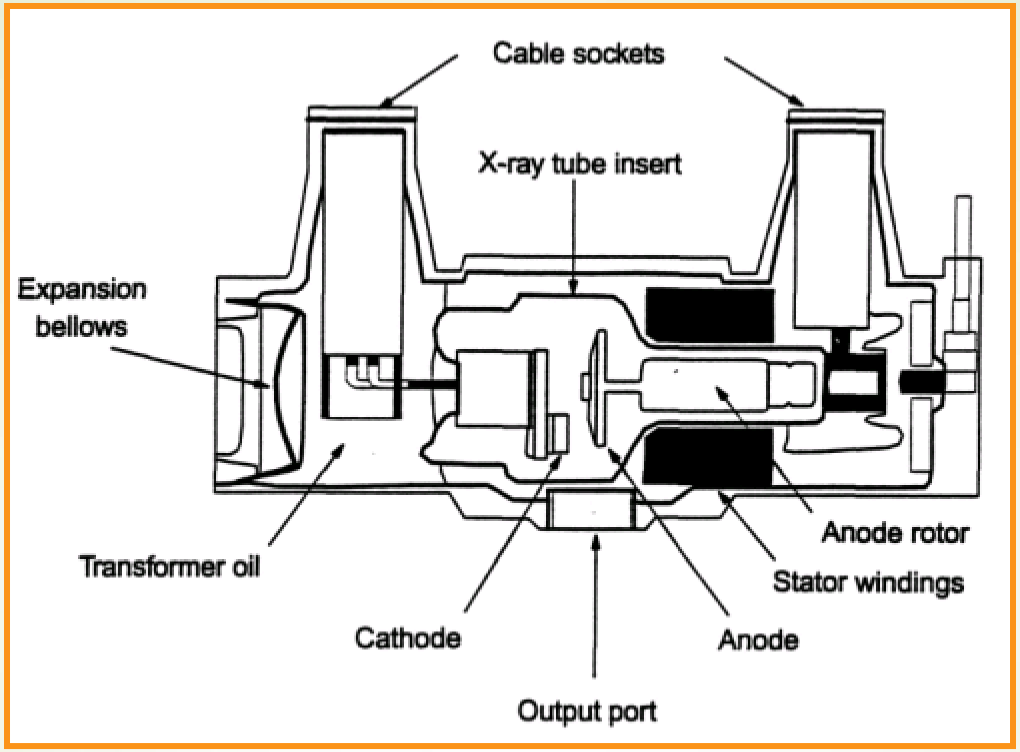
| Shell transition | Tungsten | Molybdenum | Rhodium |
|---|---|---|---|
| $K_{\alpha 1}$ | 59.32 | 17.48 | 20.22 |
| $K_{\alpha 2}$ | 57.98 | 17.37 | 20.07 |
| $K_{\beta 1}$ | 67.24 | 19.61 | 22.72 |

[a]Only prominent transitions listed.

## The major components of the modern X-ray tube are:

- *cathode* (electron source)
- *anode* (acceleration potential)
- *rotor/stator* (target device)
- *glass/metal envelope* (vacuum tube)

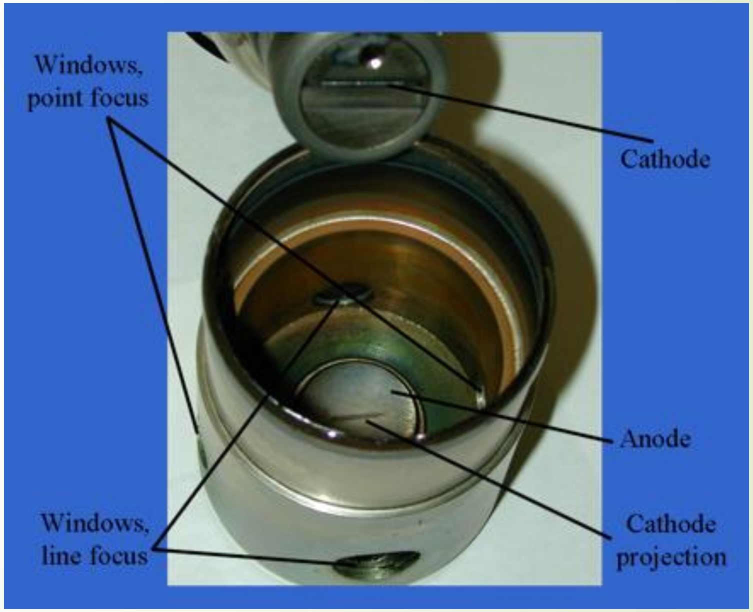
The figure shows a modern X-ray tube and housing assembly.




Typical operation conditions are:

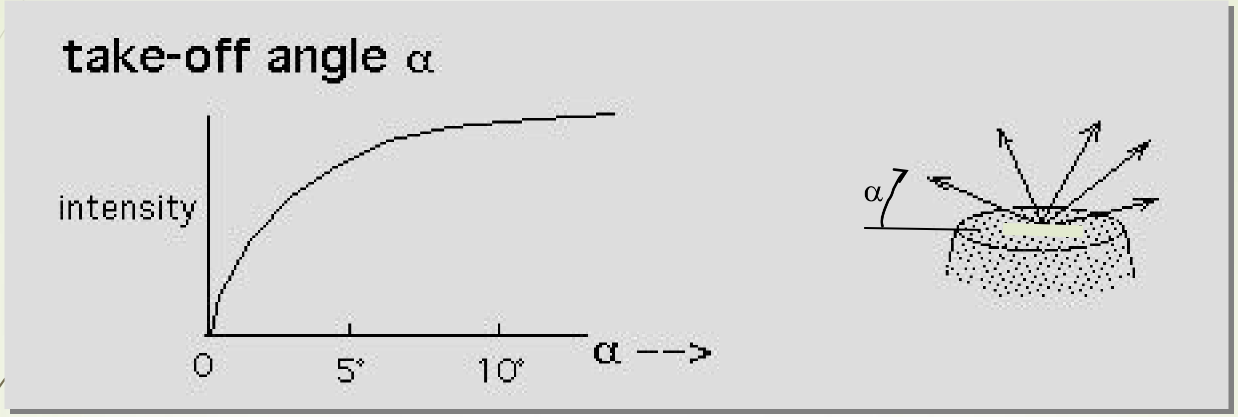
- Acceleration Voltage: 20 to 150 kV
- Electron Current: 1 to 5 mA (for continuous operation)
- Electron Current: 0.1 to 1.0 A (for short exposures)

# X-rays


Windows,
point focus
Cathode
Anode
Windows,
line focus
Cathode
projection

# X-ray sources

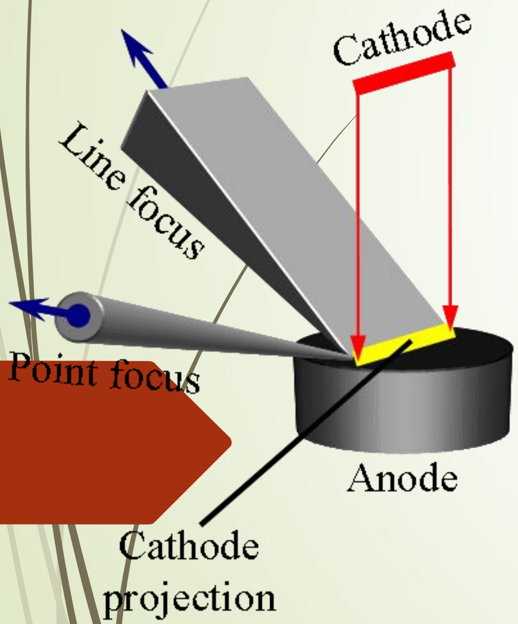
Intensity changes with take-off angle

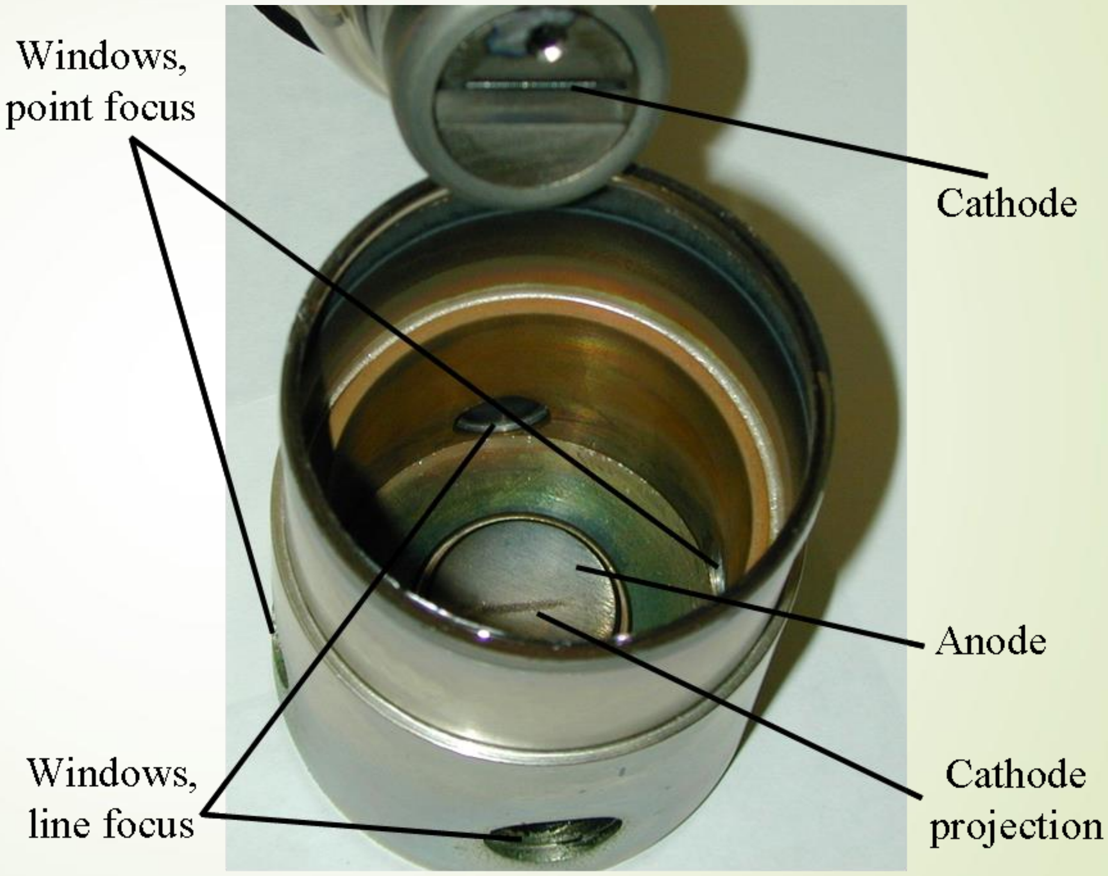



But resolution decreases with take-off angle

focal spot - normal focus 1x10 mm --> 0.1x1mm (line) $\alpha = 6°$
1x1mm (spot)
fine focus 0.4 x 0.8 mm --> 0.04 x 0.8 mm (line)
0.4 x 0.8 mm (spot)

# X-ray sources

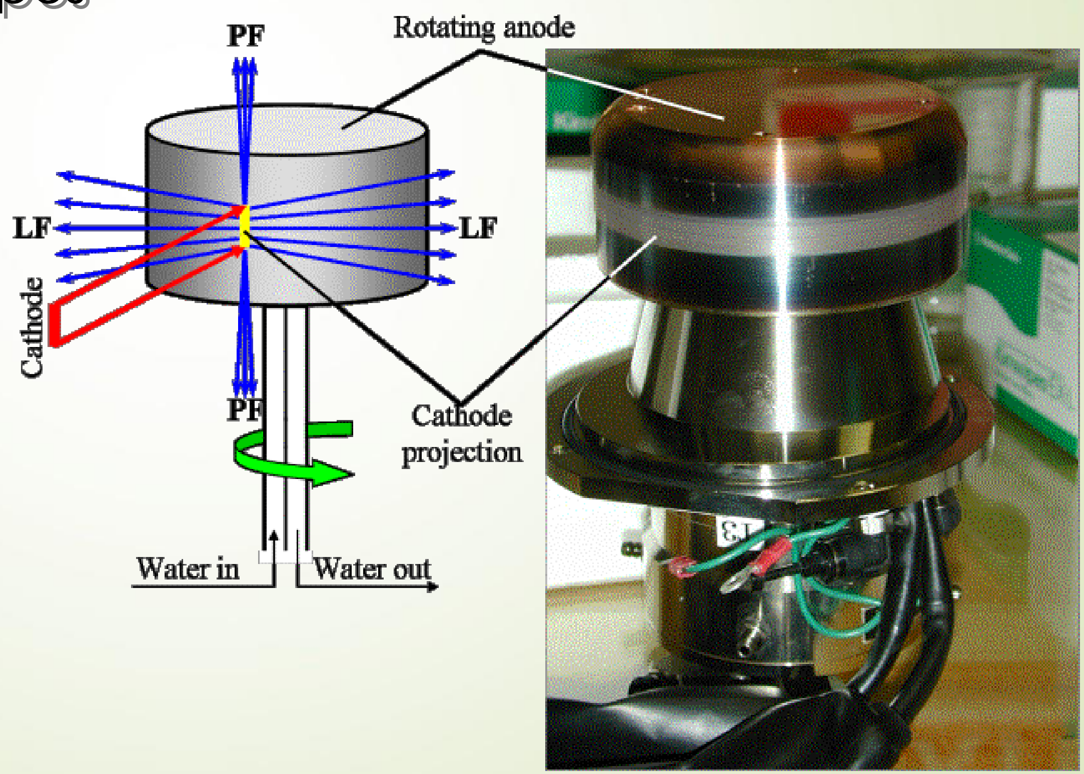


Other X-ray sources

## Rotating anode

High power - 40 kW
Demountable
Various anode types



Other X-ray sources

Synchrotron

need electron or positron beam orbiting in a ring
beam is bent by magnetic field

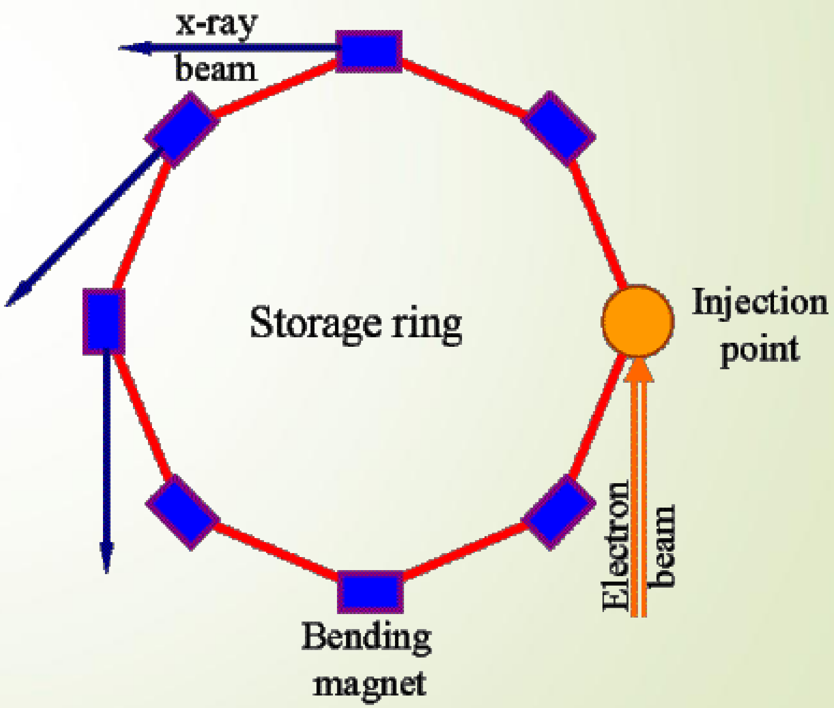
x-ray emission at bend

Advantages

$10^{-4}$ - $10^{-5}$ rad divergence
(3-5 mm @ 4 m)

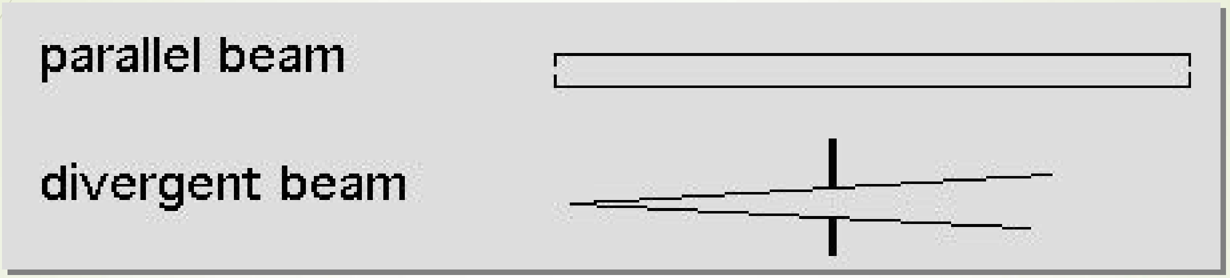
high brilliance
wavelength tunable

high signal/noise ratio



Beam conditioning

Collimation



Beam conditioning

Monochromatization

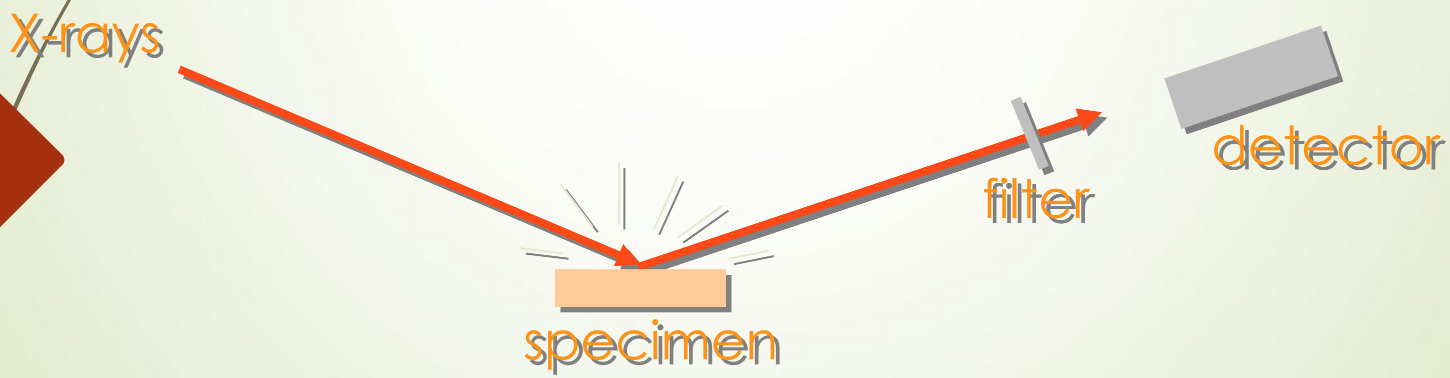
β-filters – materials have atomic nos. 1 or 2 less than anode

50-60% beam attenuation

placing after specimen/before detector

filters most of specimen fluorescence

allows passage of high intensity & long wavelength white radiation



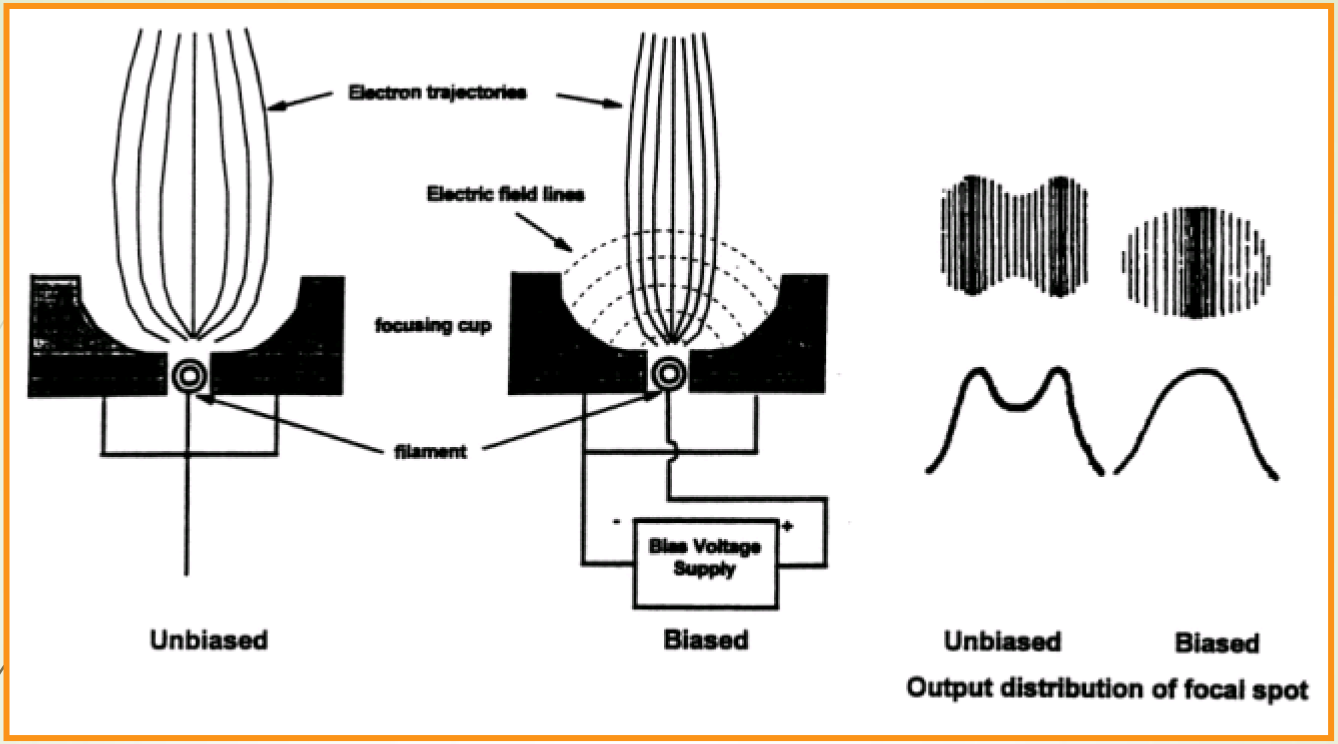
The **cathode** consists of:

a. a spiral of heated low resistance R tungsten wire (filament) for electron emission. Wire is heated by filament current $I = U / R$.

$$( U \approx 10 \text{ V}, I \approx 3\text{-}6 \text{ A} )$$

Electrons are released by thermionic emission, the electron current is determined by the temperature which depends on the wire current. The electron current is approximately 5 to 10 times less than the wire current.

b. a focusing cup with a negative bias voltage applied to focus the electron distribution.




The anode is the target electrode and is maintained at a positive potential difference $V_a$ with respect to the cathode. Electrons are therefore accelerated towards the anode: $E = w \cdot V_a$

Upon impact, energy loss of electrons takes place by scattering and excitation processes, producing heat, electromagnetic radiation and X-rays.

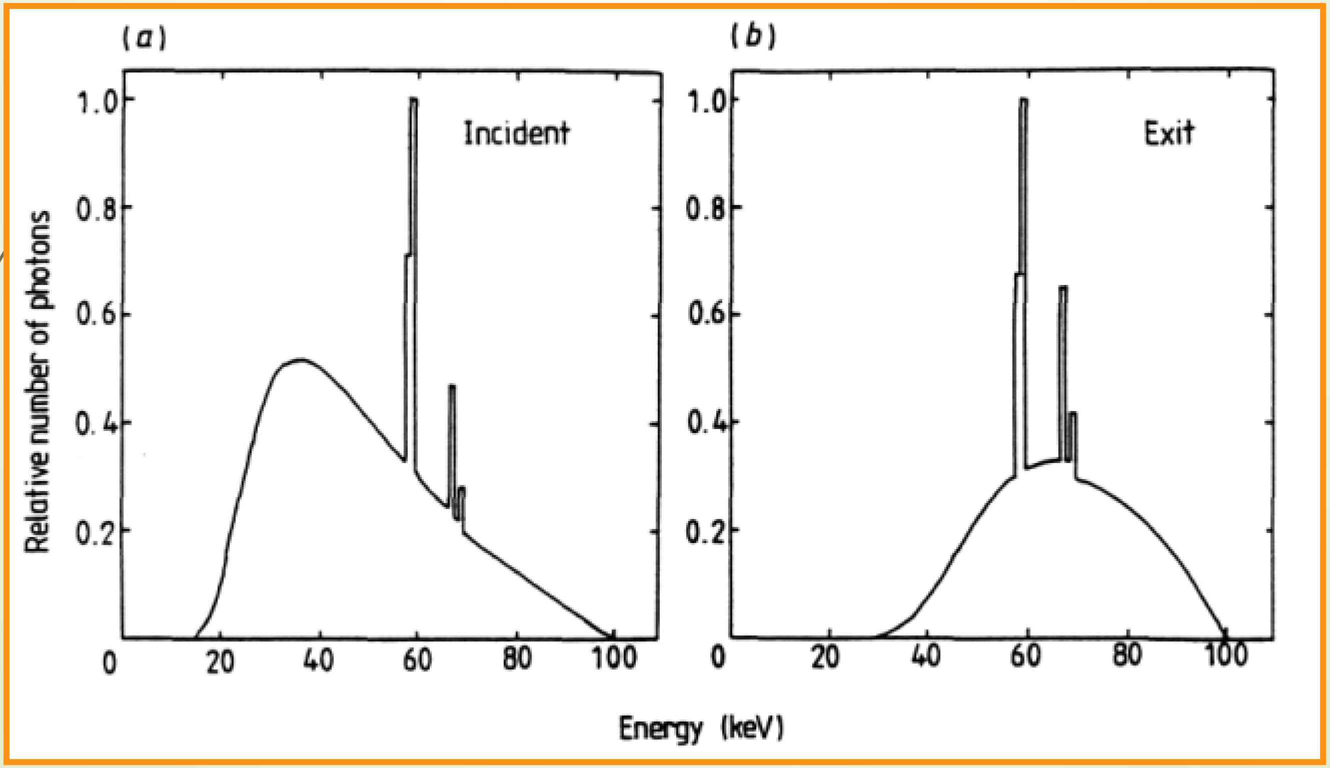
$\approx$ 0.5% of the electron energy is converted into X-rays.

Because of the relatively low X-ray production efficiency, most of the released energy comes in form of heat:

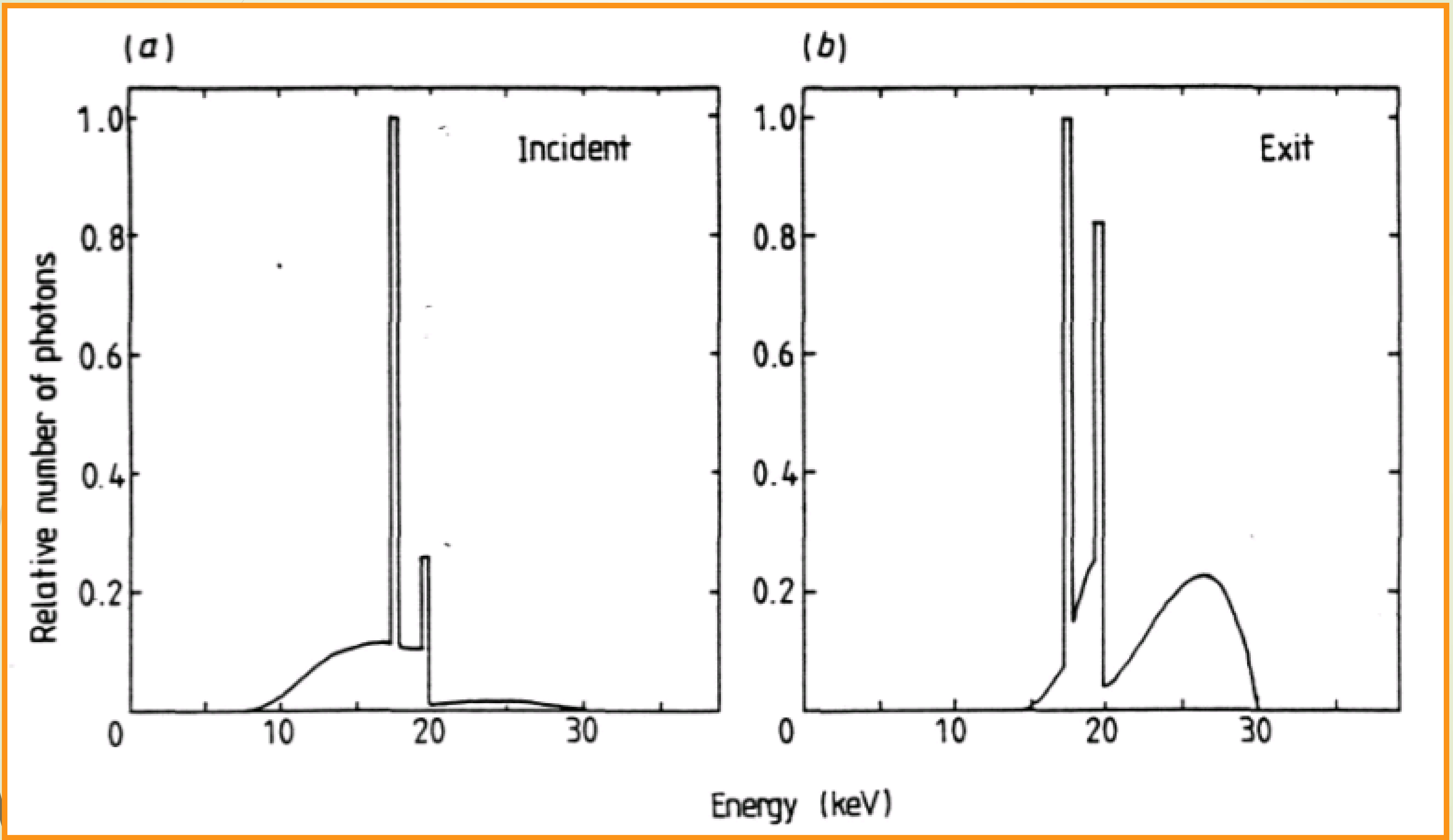
➡ heat generation is a major limitation for X-ray machines

➡ high melting point material with high X-ray output

- tungsten (high melting point) good overall radiative emission



- molybdenum (high melting points) high emission of characteristic X-rays



The **anode angle** is defined as the angle of the target surface to the central axis of the X-ray tube.

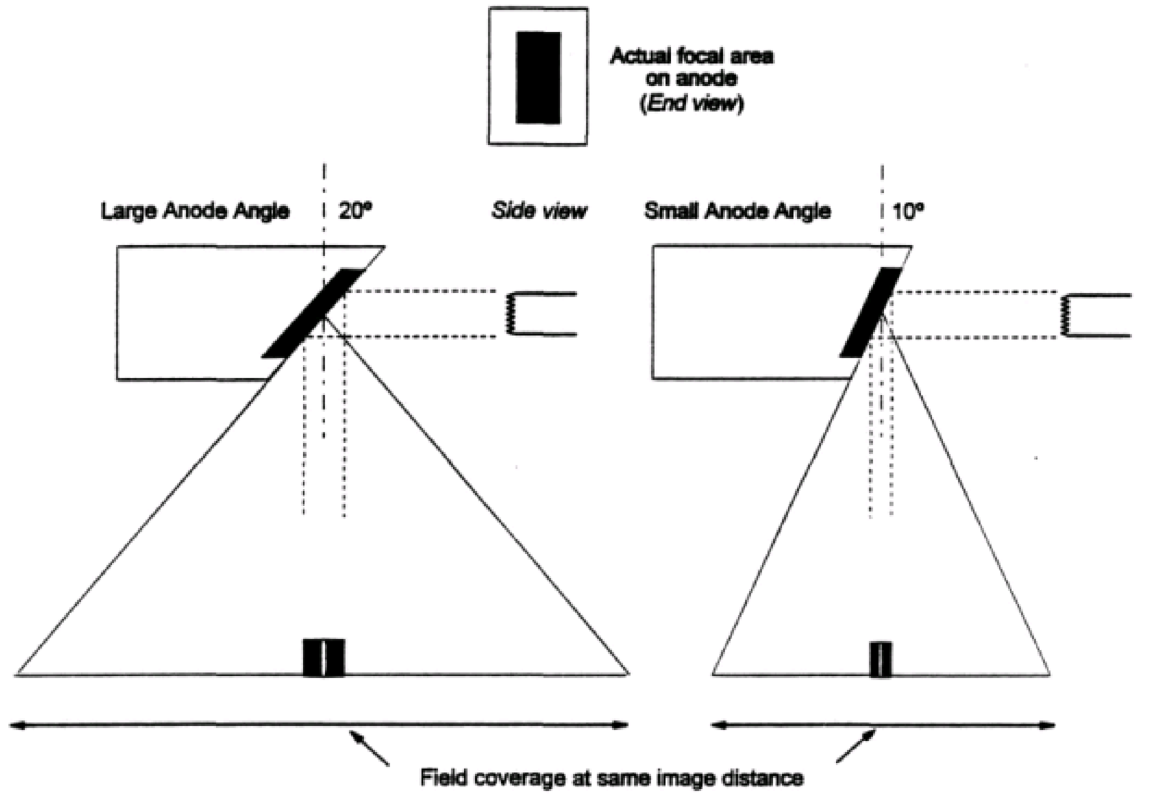
The **focal spot size** is the anode area that is hit by the electrons.

The anode angle $\theta$ determines the effective focal spot size:

$$\boxed{\text{effective focal length} = \text{focal length}} \bullet \sin\theta$$

The angle $\theta$ also determines the X-ray field size coverage. For small angles the X-ray field extension is limited due to absorption and attenuation effects of X-ray photons parallel to the anode surface.

Typical angles are: θ = T to 20°.




The effective focal spot size varies with anode angle. For the same *actual* size, the projected *effective* size is smaller for a smaller anode angle. Field size coverage, however, is also reduced at the same image distance for a smaller anode angle.

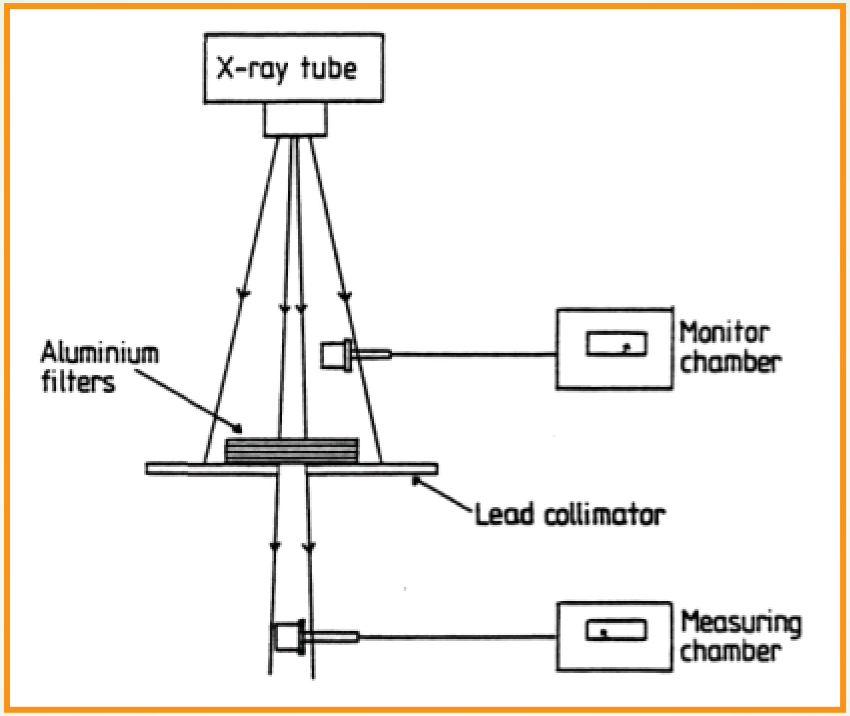
A small angle in close distance is recommended for small spot coverage, a large angle is necessary for large area coverage.

The X-rays pass through a tube window (with low X-ray absorption) perpendicular to the electron beam.

Usually the low energy component of the X-ray spectrum does not provide any information because it is completely absorbed in the body tissue of the patient. It does however contribute significantly to the absorbed dose of the patient which excess the acceptable dose limit.

These lower energies are therefore filtered out by aluminum or copper absorbers of various thickness.

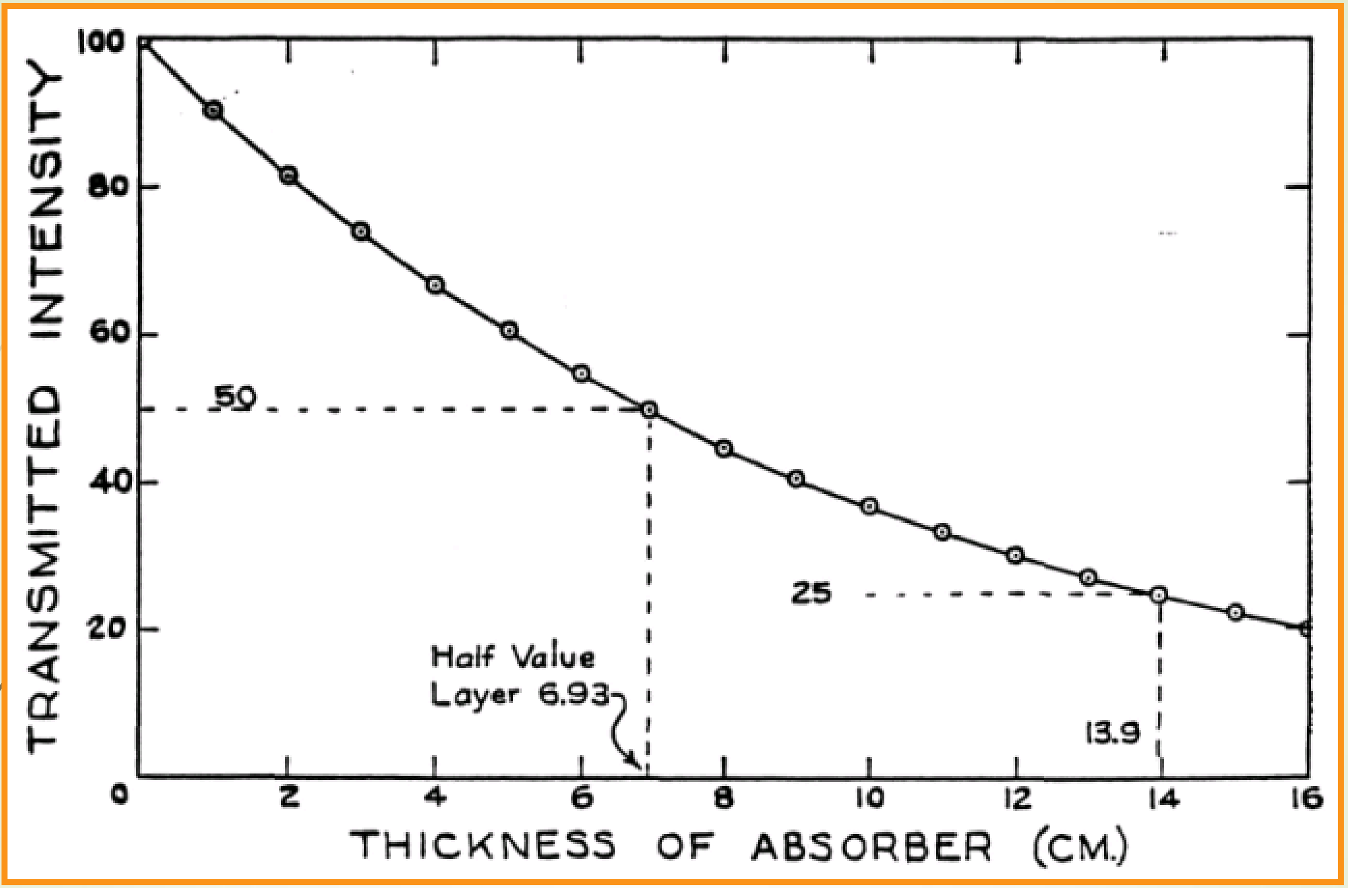
The minimum thickness d depends on the maximum operating potential of the X-ray tube but is typically d ≈ 2.5 mm for $V_a \geq 100$ kV




The intensity drops exponentially with the thickness d:

$$\boxed{I(d) = I_0 \cdot e^{\mu_{eff} d}}$$

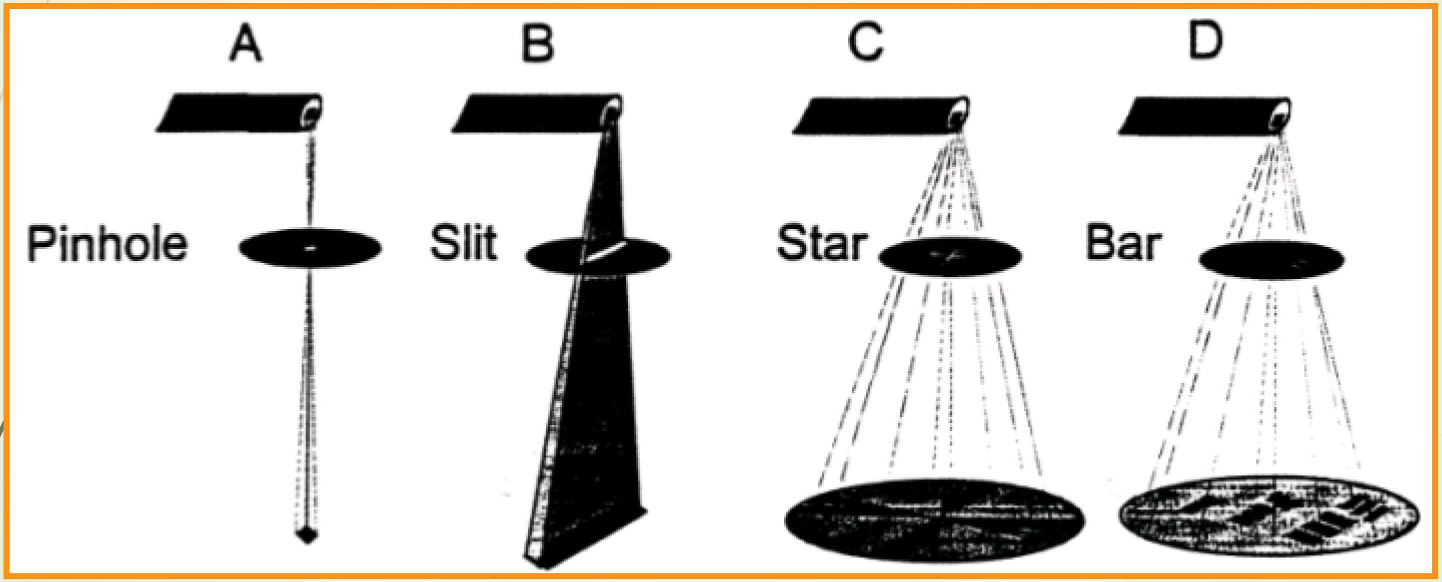
with $\mu_{eff}$ as material dependent absorption coefficient.



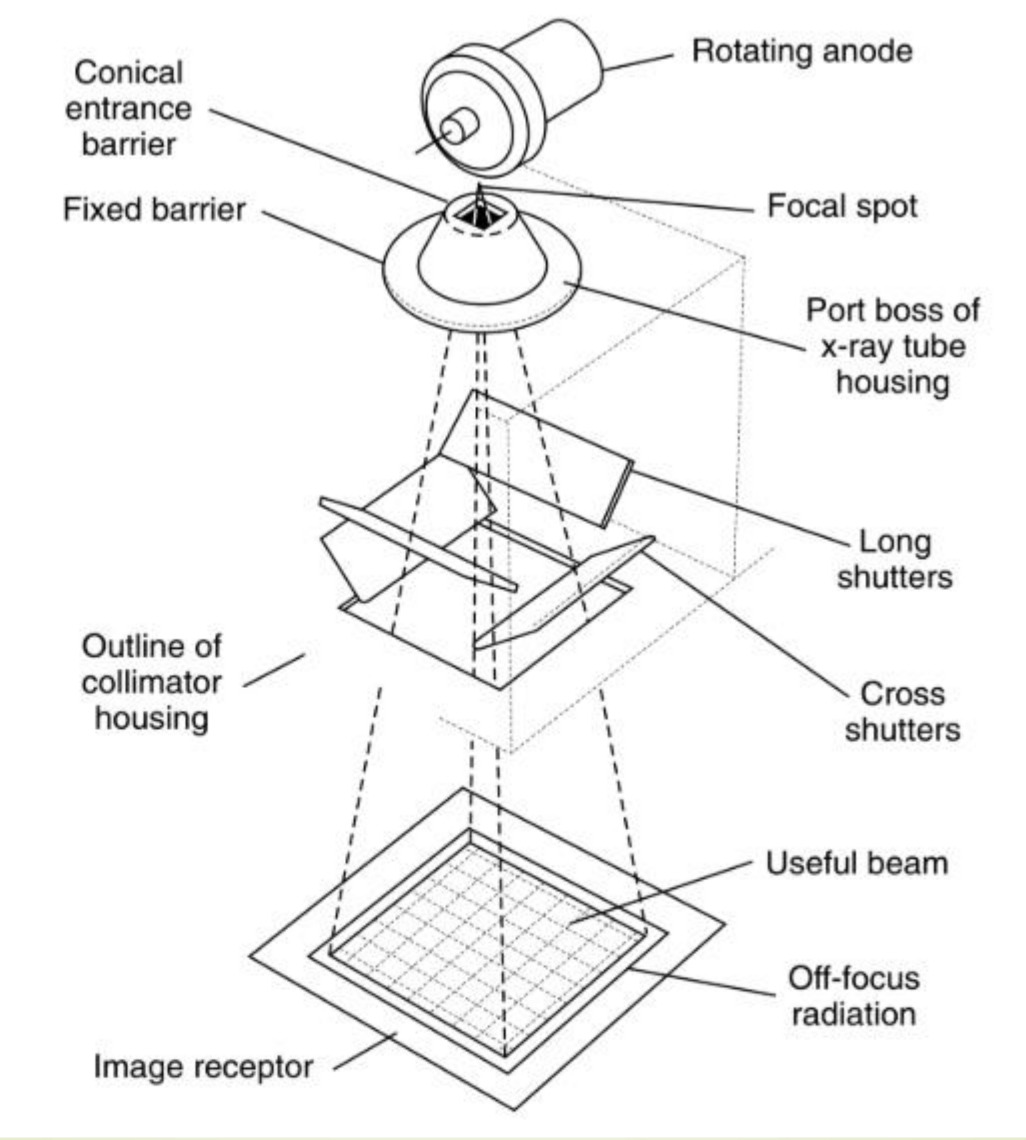

**Graph showing how the intensity of an x-ray beam is reduced by an absorber whose linear absorption coefficient is $\mu = 0.10\ cm^{-1}$.**

# Collimator design

Collimator design allows to optimize the point exposure!



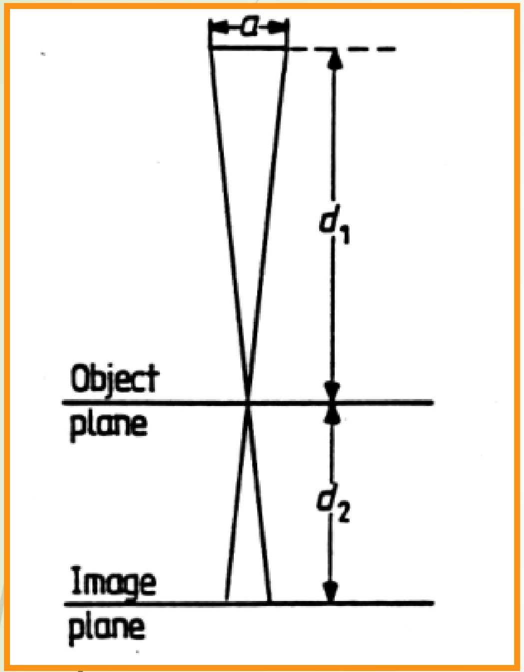
# Layout of a collimator



# Collimator

- The collimator is placed between the X-ray tube and the patient. It consists of a sheet of lead with a circular or rectangular hole of suitable size. Alternatively, it may consist of four adjustable lead strips which can be moved relative to each other
- This results in a low dose to the patient and simultaneously increases the image contrast, because less scattered radiation reaches the image plane
- The scattered radiation produces diffuse illumination and fogging of the image without increasing its information content, and therefore, by choosing the smallest possible field size and using a collimator, the loss of contrast due to scattered radiation is reduced

The size of the collimator (object size) determines the geometric "unsharpness" (blurring) of the image.




The blurring *B* in the image is given by:

$$B = a \cdot \frac{d_2}{d_1} = a \cdot (m - 1)$$

where *a* is the effective size of the collimator of the X-ray tube and m is the image magnification:

$$m = \frac{d_2 + d_1}{d_1}$$

The resulting geometric unsharpeness $U_g$ is defined:

$$U_g = \frac{B}{m} = a \cdot (1 - \frac{1}{m})$$

Additional unsharpeness can be caused by the image receptor (grain size, resolution of the film, etc) and by movement of the object (restless person).

For general radiography purposes the geometric unsharpeness dominates the other components

Therefore the unsharpeness will increase with increasing magnification. To keep magnification small (close to m=1) requires the image receptor to be as close as possible to the patient and the focus patient distance to be large.

Typical conditions are:

- a ≈ 1mm
- $d_1 \approx 1$ m
- $d_2 \approx 10$ cm

$$\boxed{m=\frac{110\text{cm}}{100\text{cm}}=1.1}$$

$$\boxed{U_g=1\text{mm}\cdot\left(1-\frac{1}{1.1}\right)=0.091\text{mm}}$$

For a close dental X-ray shot the conditions are:

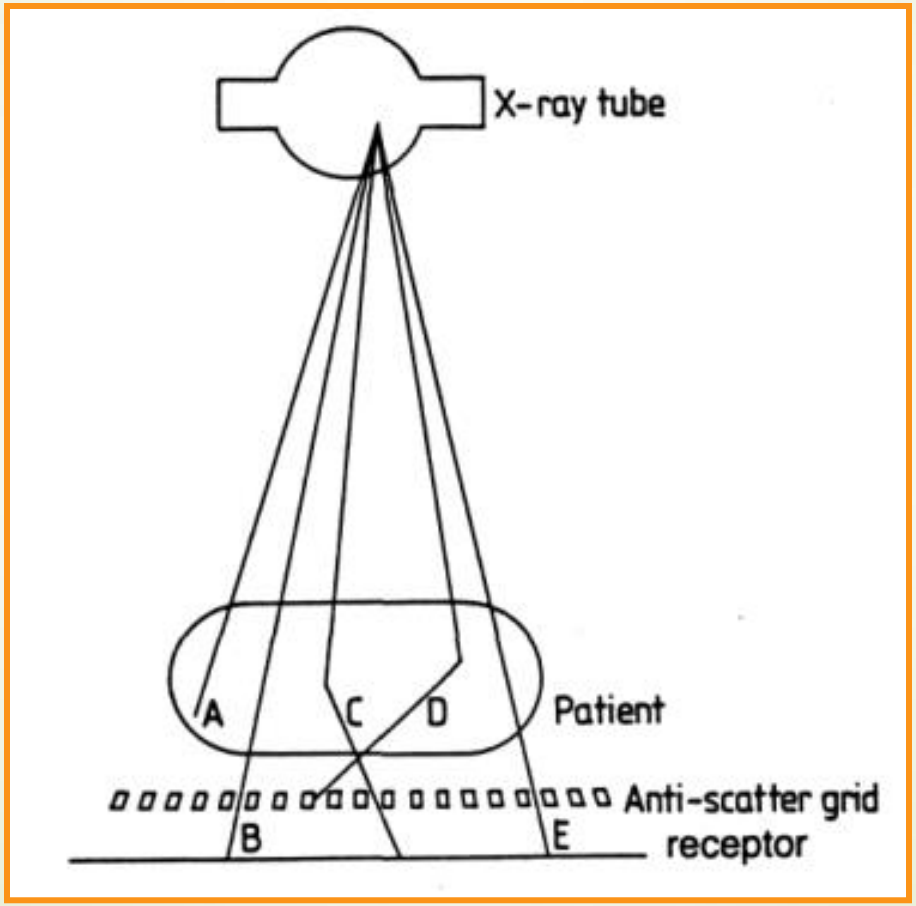
- a ≈ 1mm
- $d_1$ ≈ 5 cm
- $d_2$ ≈ 1 cm

$$m = \frac{6\text{cm}}{5\text{cm}} = 1.2$$

$$U_g = 1\text{mm} \cdot \left(1 - \frac{1}{1.2}\right) = 0.167\text{mm}$$

GRIDS

The radiographic image of the X-ray exposure is determined by the interaction of the X-rays which are transmitted through the patient with a photon detector (film, camera etc.)



# GRIDS

Primary X-ray photons have passed through the patient without interaction, they carry useful information.

They give a measure for the probability that a photon pass through the patient without interaction which is a function of the body tissue attenuation coefficients.

Secondary photons result from interaction inside the patient, they are usually deflected from their original direction and carry therefore only little information. They create background noise which degrades the contrast of the image.

Scattered photons are often absorbed in grids between the patient and the image receptor.

# GRIDS

- Grids are inserted between the patient and the film cassette in order to reduce the loss of contrast due to scattered radiation.
- A grid consists of thin lead strips separated by spacers of a low attenuation material.
- The lead strips are so designed that the primary radiation from the X-ray focus, which carries the information, can pass between them while the scattered radiation from the object is largely attenuated.
- Because of the shadow cast by the lead strips, the final image is striped.
- These grid lines do not usually interfere with the interpretation of the image. However, final details in the image may be concealed.
- In order to avoid this, the grid can be displaced during the exposure so that the lead strips are not reproduced in the image. Such moving grids are known as 'Bucky Grids'.

The two dimensional image $I(x, y)$ of the three dimensional distribution of the X-ray attenuating body tissue of the patient can be described as a function of the initial photon intensity $N$ of energy $E$, the energy absorption efficiency of the image receptor $\varepsilon(E)$ (film) and the attenuation coefficients $\mu$ which have to be considered along the photon path in z-direction.

$$\boxed{I(x,y) = \int (N(E) \cdot \epsilon(E) \cdot E \cdot e^{(-\int \mu(x,y,z)dz)} + S(E) \cdot \epsilon(E) \cdot E)dE}$$

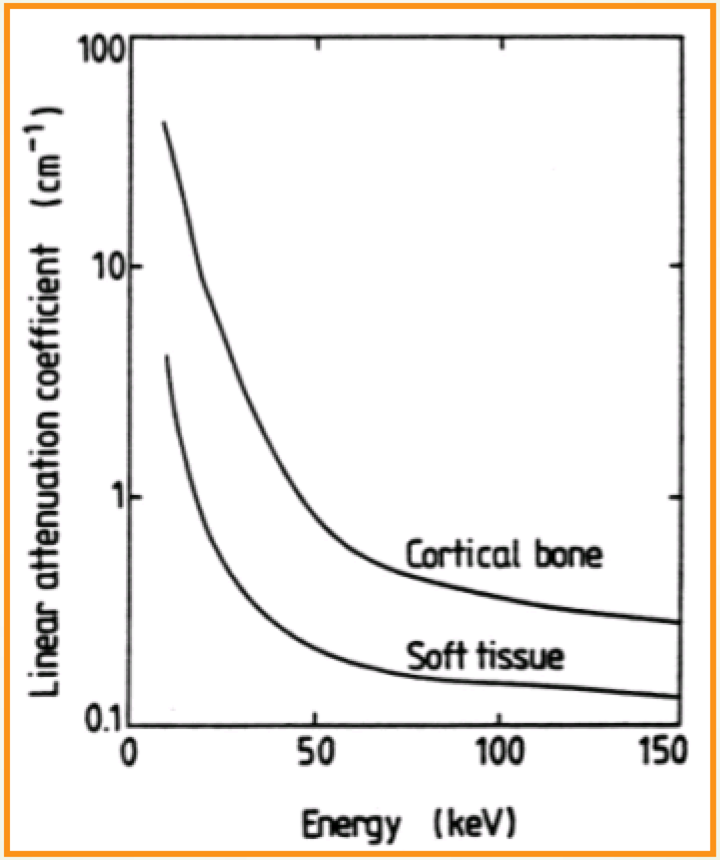
with $S(E)$ as distribution of the scattered secondary X-ray photons.

The expression can be simplified to:

$$\boxed{I(x,y) = \int N(E) \cdot \epsilon(E) \cdot E \cdot e^{(-\int \mu(x,y,z)dz)}(1 + R)dE}$$

with $R$ as the ratio of secondary to primary radiation.

As higher the attenuation coefficient, as larger absorption, as lower the final intensity of the image.



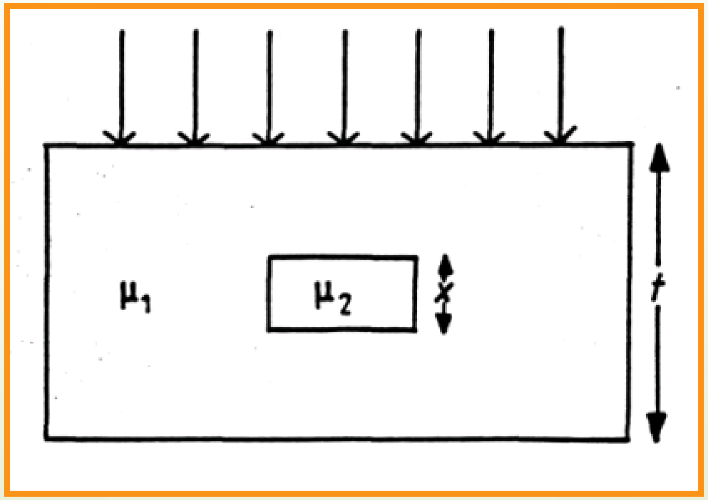

For bone tissue the attenuation coefficient is considerably larger than for soft body tissue, therefore increased absorption.

The quality of the image can be assessed by a few physical parameters:

- radiographic contrast
- noise and dose

## CONTRAST OF THE IMAGE

Consider that you want to image clearly a target tissue of thickness x with an attenuation coefficient $\mu_2$ inside the body of thickness *t* with a lower soft body tissue attenuation coefficient $\mu_1$



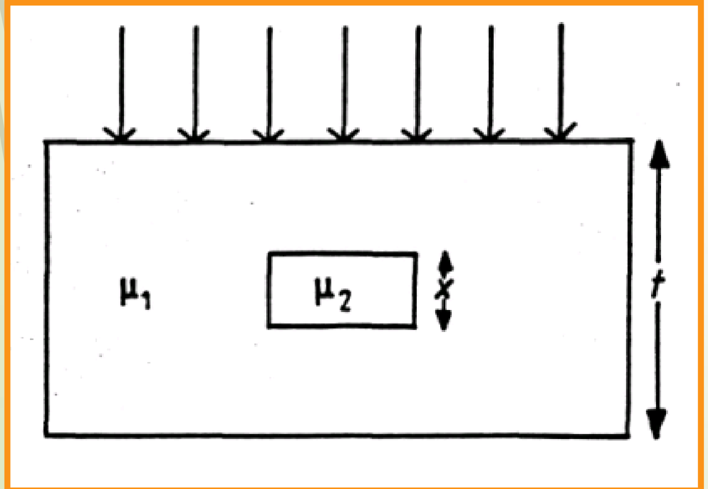
The **contrast** C of the target tissue volume is defined in terms of the image distribution function $I_1$ and $I_2$:

$$\boxed{C = \frac{I_1 - I_2}{I_1}}$$

$I_1$ gives the energy absorbed outside the target tissue

$I_2$ gives the energy absorbed inside the target volume.

Approximating for an X-ray energy *E*:




$$I_1 = N \cdot \epsilon(E) \cdot E \cdot e^{(-\mu_1 t)} + S \cdot \epsilon(E)E$$

$$I_2 = N \cdot \epsilon(E) \cdot E \cdot e^{(-\mu_1(t-x)-\mu_2 x)} + S \cdot \epsilon(E)E$$

This yields for the contrast $C$:

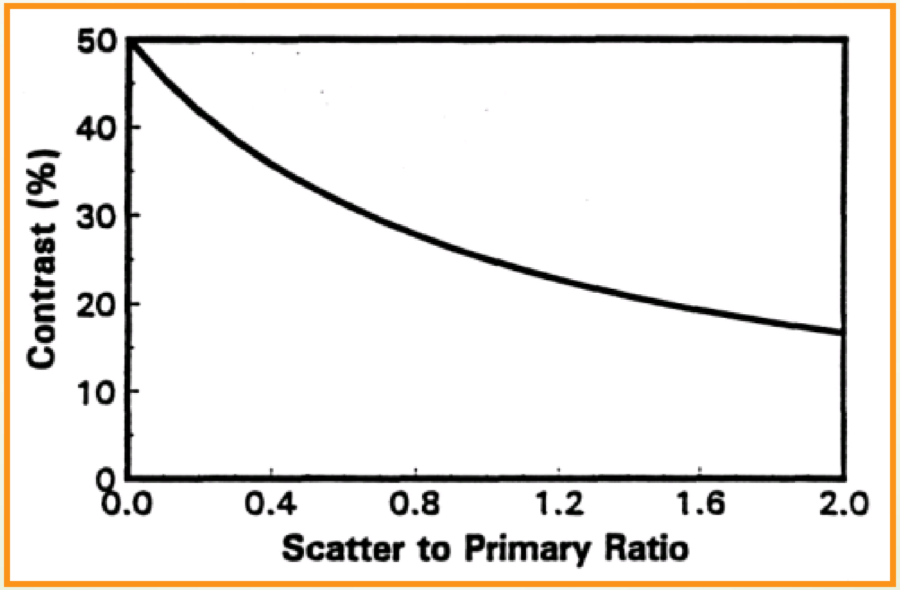
$$C = N \cdot \epsilon(E) \cdot E \cdot e^{-\mu_1 t} \cdot (1 - e^{[-(\mu_2-\mu_1)x]})/I_1$$

The expression can be simplified to:

$$C = \frac{(1 - e^{(\mu_1 - \mu_2)x})}{(1 + R)}$$

The contrast depends mainly on the difference of attenuation coefficients $\mu_1$ and $\mu_2$ as well as on the ratio of scattered to primary X-ray photons.

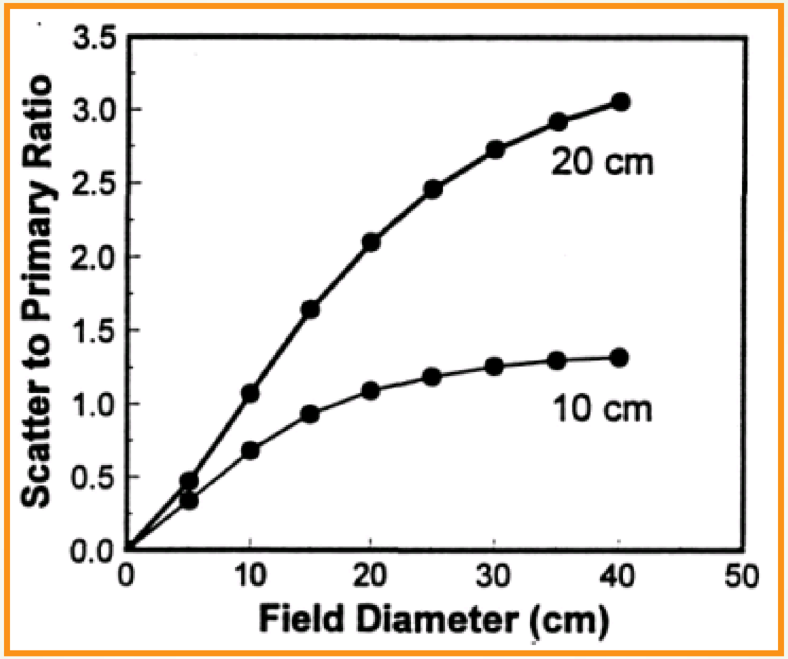
As higher the ratio R (the number of scattered photons), as lower the contrast.




Therefore it is important to understand and to reduce secondary scattered photon intensity to minimize *R*.

The number of scattered photons depends on several parameters:

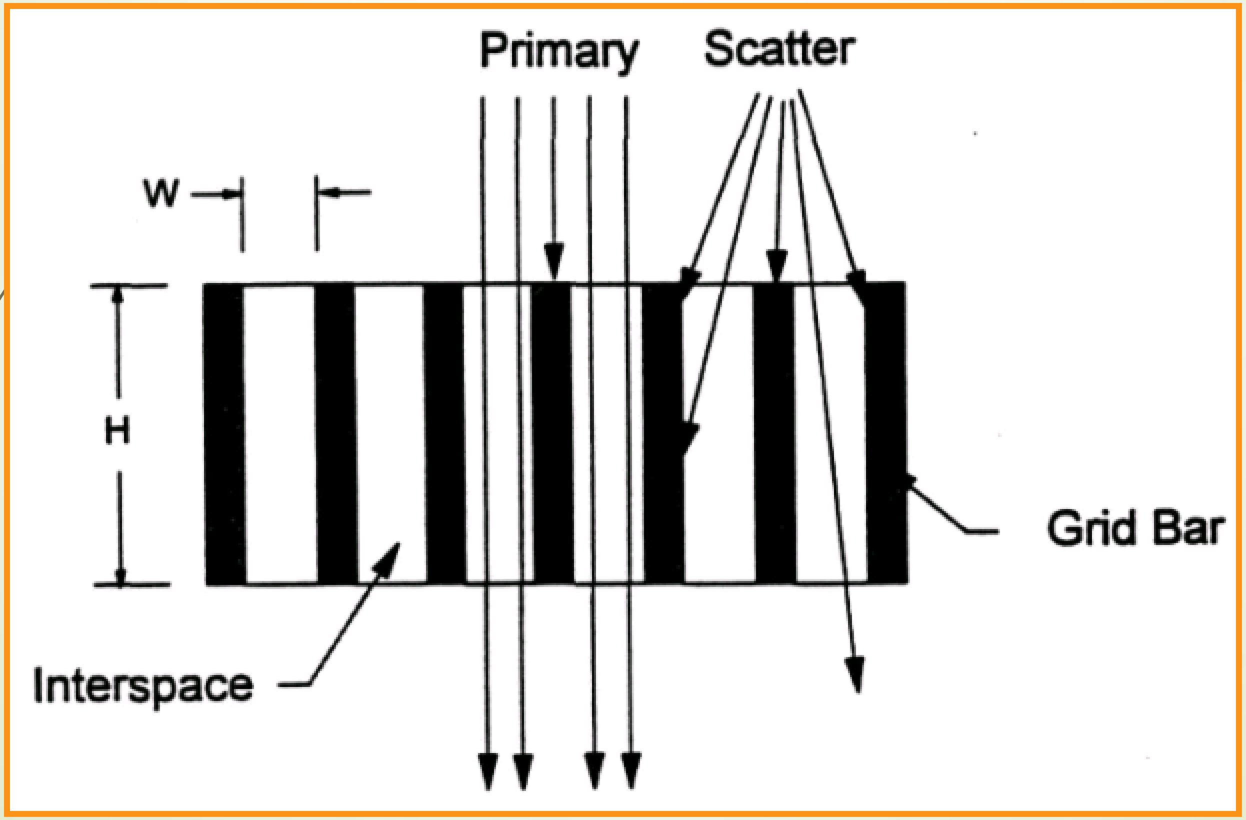
- X-ray field size; an increase in field size increases *R* 3.5



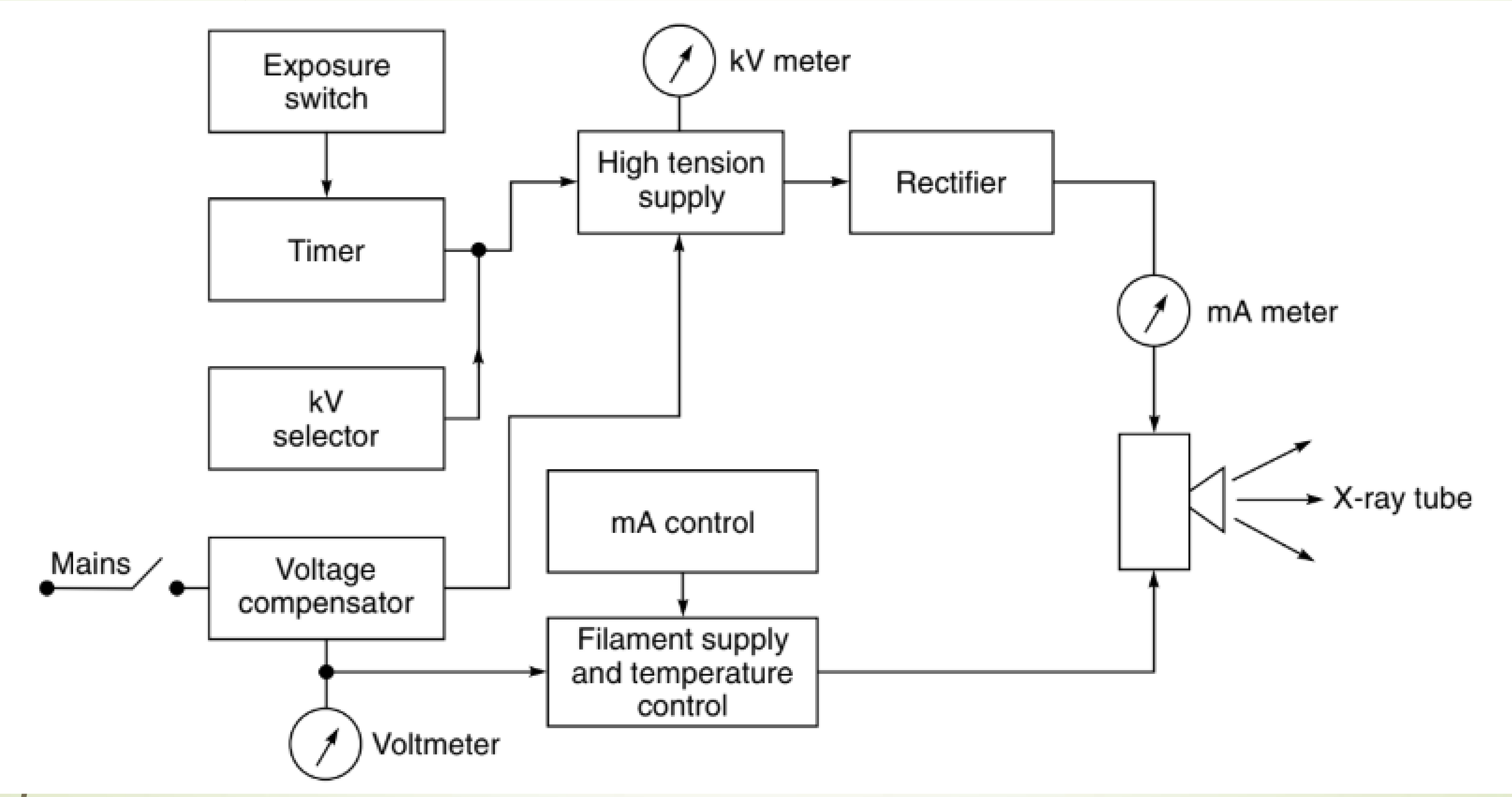

- Thickness of radiated volume (increase is roughly proportional with thickness due to increase in scattering events)

- X-ray energy dependence - decrease of scatter with increasing ene

To reduce the number of secondary scattered photons a led grid is typically between object and image receptor. Because scattered photons will not meet the grid at normal incidence, they will be absorbed by the grid stripes.



# X-RAY MACHINE



# X-RAY MACHINE SUB SYSTEM

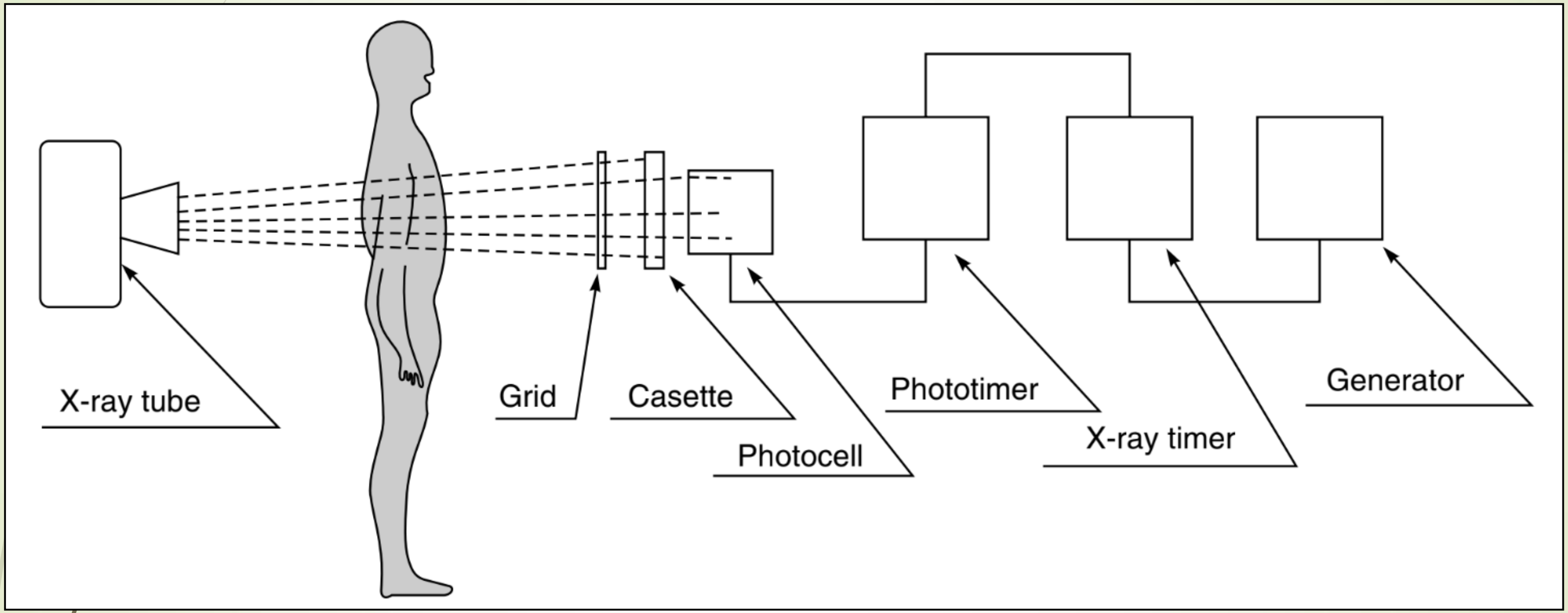
Two parts in a circuit

1) One of them producing high voltage, which is applied to tube's anode and comprises a high voltage step up transformer followed by rectification
   - A kv selector switch facilitates change in voltage between exposures
   - Voltage is measured with the help of kV meter
   - Exposure switch controls the timer and thus the duration of application of kV
   - To compensate for mains supply voltage(230V) variations, a voltage compensator is included in the circuit
2) Second part of the circuit concerns the control of heating X-ray tube filament
   - The filament is heated with 6-12V of AC supply at a current 3-5amps
   - Filament temperature determines the tube current or mA
   - Filament temperature control has an attached mA selector
   - Filament current is controlled by primary side of filament transformer, a variable choke or a rheostat
   - Rheostat provides a stepwise control of mA and most commonly used in modern machines

# X-RAY MACHINE SUB SYSTEM

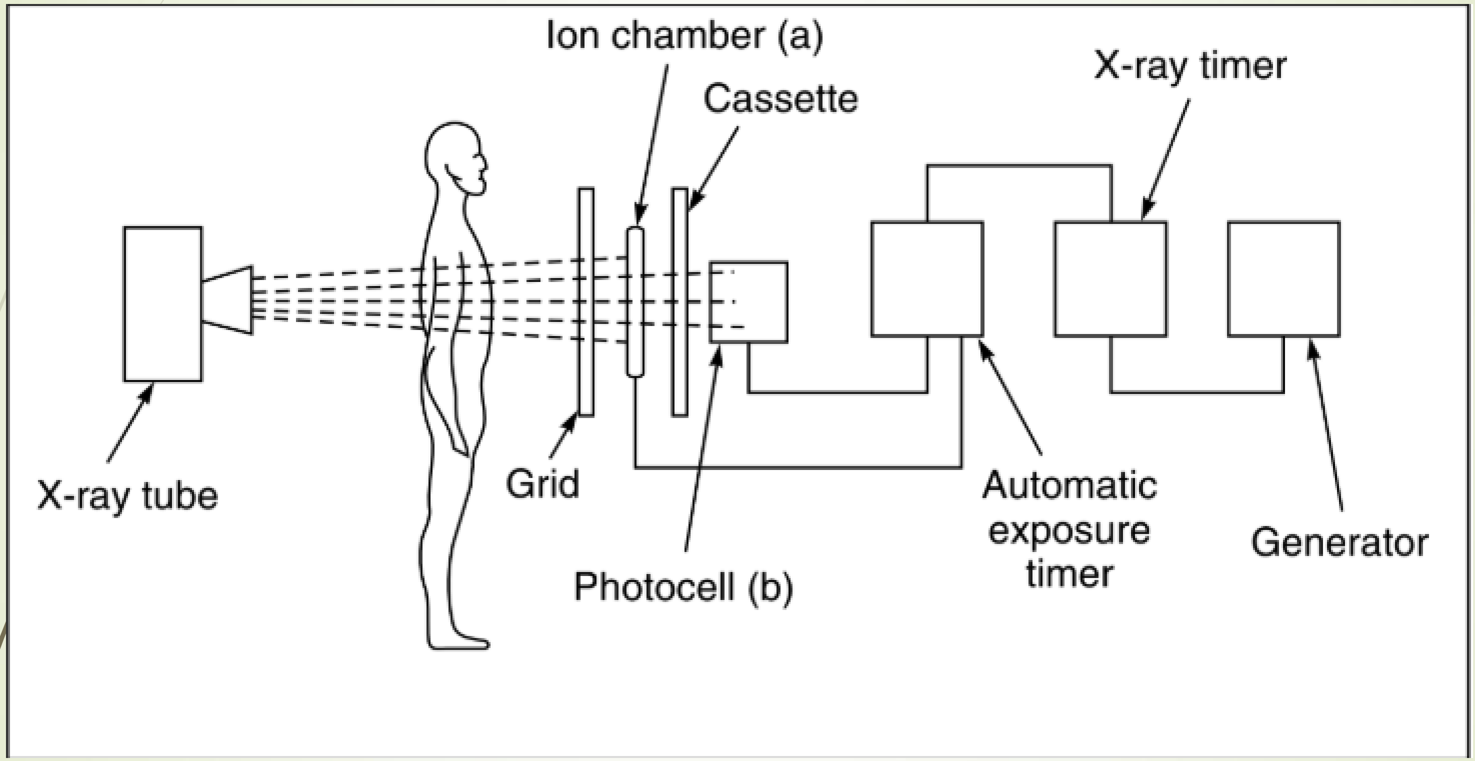
- Preferred method of providing high voltage DC to anode of X-ray tube is by a bridge rectifier using four valve tubes or solid state rectifiers
- kV meter is connected across primary of HT transformer
- Considerable developments is seen in control elements to increase accuracy, better information display and greater flexibility of selection of factors

# Automatic exposure control: Photocell method




- A flourescent detector is placed on exit side of patient and behind the radiographic cassette which monitors X-ray intensity transmitted through the film screen system
- Circuit controls the X-ray exposure switch and turns the x-ray radiation off when a radiation flux sufficient to properly expose the

# Automatic exposure control: Ionization method




- Ion chamber is placed between patient and cassette
- Signal from chamber is amplified and used tocontrol a high speed relay which terminates the the exposure, when a pre-set density level has been reached

# Visualization of X-rays

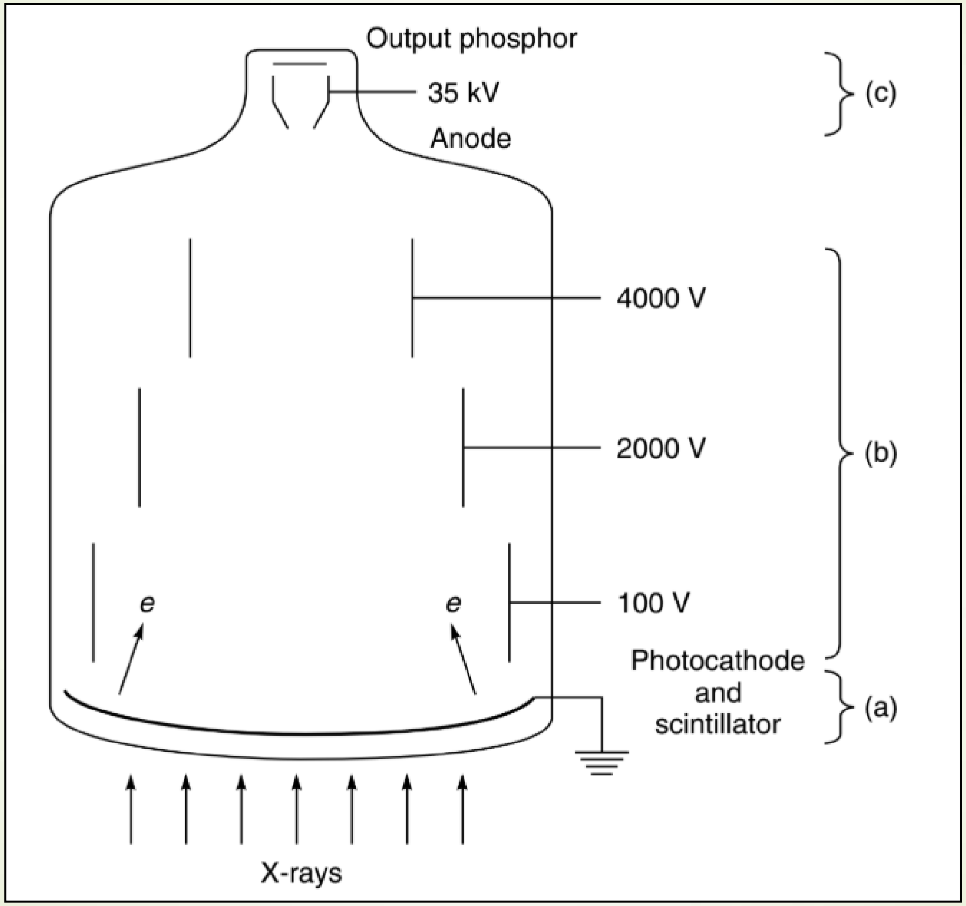
X-ray films:

- X-rays are of much shorter wavelength than visible light, react with photographic emulsions in a similar fashion as that of light
- After having been processed in developing solution, a film that has been exposed to X-rays shows an image of X-ray intensity
- Film is sandwiched between two screens and held in a light tight cassette. Film is exposed to X-rays as well as to the light from fluorescence of screen. Such screens are called intensifying screens.

Fluorescent Screens:

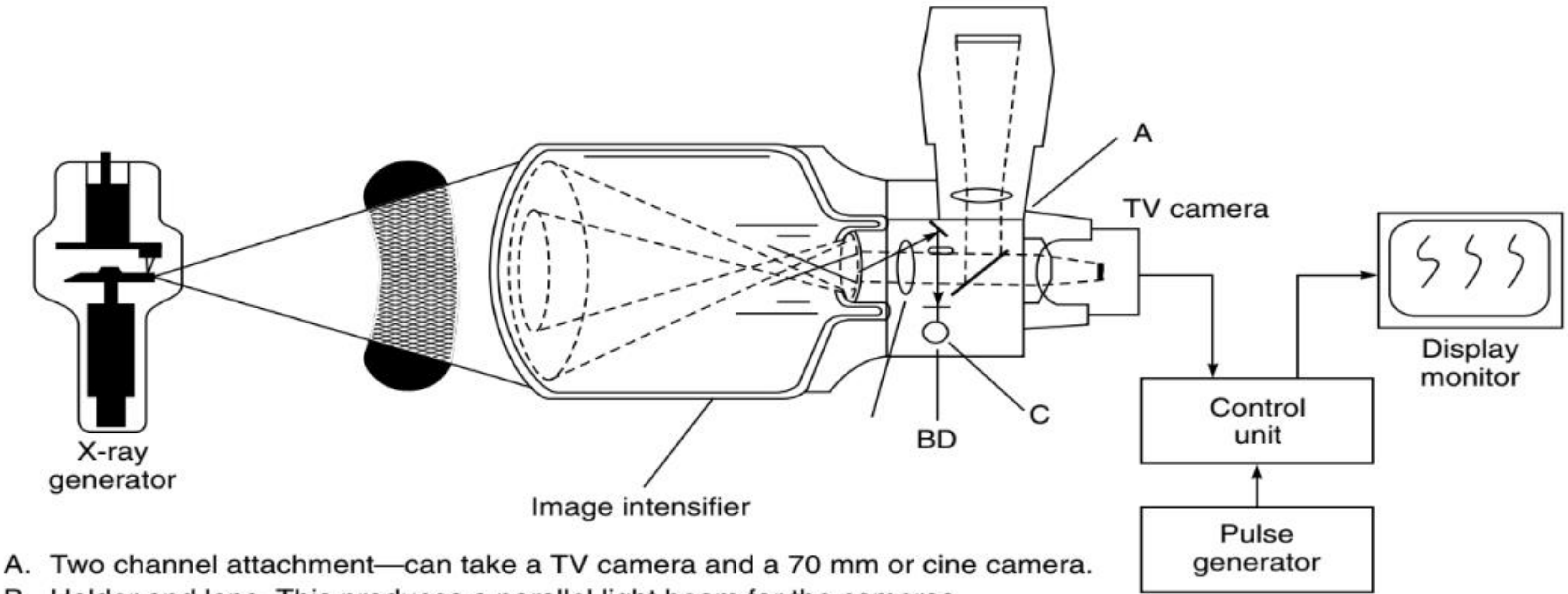
- In Fluoroscopy, X-rays are converted into a visual image on a fluorescent screen which can be viewed directly.
- It facilitates a dynamic radiological study of human anatomy.
- The fluorescent screen consists of a plastic base coated with a thin layer of fluorescent material, Zinc cadmium sulphide, which is bonded to a lead-glass plate.
- Image is viewed through the glass plate which provides radiation protection but allows optical image to be viewed.

# X-ray image intensifier tube




(a) Input surface consists of scintillation layer and photocathode
(b) Three focusing electrodes with typical bias voltages
(c) Electrode and output phosphor

# X-ray image intensifier




A. Two channel attachment—can take a TV camera and a 70 mm or cine camera.
B. Holder and lens. This produces a parallel light beam for the cameras.
C. Photo pick-up.
D. Electrical signal from photo pick-up. It provides the control for 70 mm and cinefluorography.

# Dental X-ray mach

- X-rays are the only media available to detect location of teeth, their internal condition and degree of decay at an early stage
- Since object- film distance is rather low, and the tissue and bone thickness are limited, X-ray machine of low power is adequate to get good contrast
- Dental units have fixed tube voltage- 50kV and fixed current of 7mA

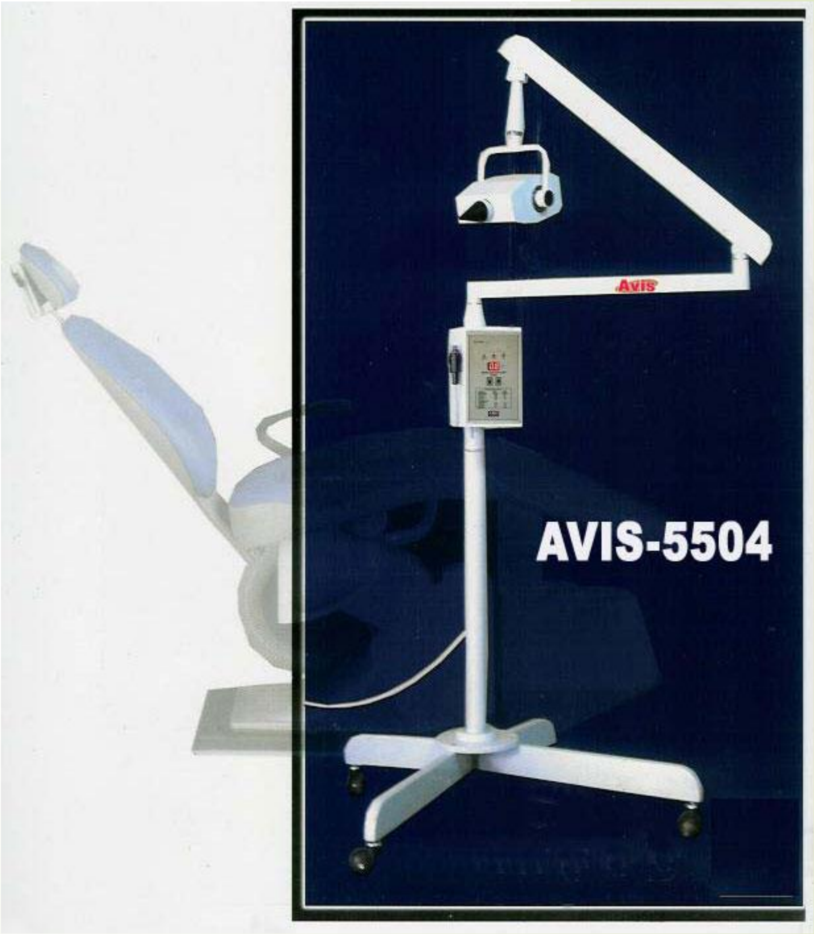
Wall mounted

Portable

# DENTAL X-RAY UNIT

**Product Code:** AVI-5504 **Category:** Dental Instruments
**Specification**

| | |
|---|---|
| X-Ray Output | 70Kv-10mA |
| X-Ray Tube | 0.5mm focus imported tube |
| Radiation Leakage | =<0.25 mG/hr. from focal spot |
| Voltage Compensation | 190V to 250V built in digital controlled voltage stabilizer |
| Power Requirement | 230V,50Hz, 5Amp. |
| Radiography Cones | Short Cone / Long Cone (Optional) |




**Stands are available in two different models**

1.Mobile Floor mounted– model which caster wheels enabling smooth movements.

2.Wall Mounted – for cramped working conditions. The timer box can be mounted on wall or any other remote place.

# PORTABLE X-RAY UNITS

- A portable unit is designed that it can be dismantled, packed into a small case and conveniently carried to site
- X-ray tube and high voltage generator are enclosed in one earthed metal tank filled with oil.
- X-ray is usually a small stationary anode type, operating in self rectifying mode
- Includes mains voltage compensator, combined kV and current switch and time selector
- Current must be limited to 15A
- Maximum radiographic output commonly found on portable units is in the range of 15-20mA at 90-95kV

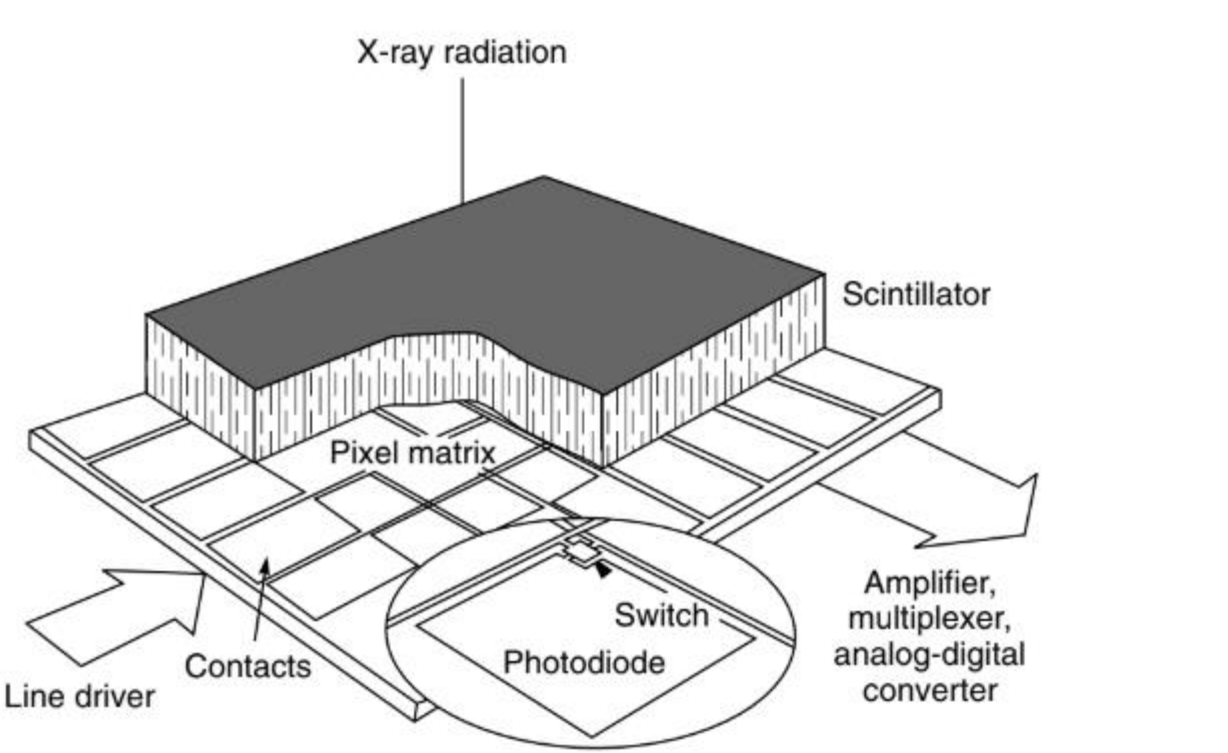
# MOBILE X-RAY UNITS

- Mobile unit carries the control table and column supporting X-ray tube permanently mounted on the mobile base.
- Mobile units are heavier than portable units and are capable of providing higher outputs.
- Mobile units provide greater selection of mA and kV values
- Most mobile units have radiographic output of 300mA and max of 125kV
- Requires supply current of 30A
- Mobile units make use of stored energy if there are any limitations on electrical supply

# PHYSICAL PARAMETERS OF X-RAY DETECTORS

- Detector Quantum Efficiency (DQE) : Describes efficiency of detector
- Function of dose and spatial frequency, effected by various components of system
- Dynamic Range: Range from minimum to maximum radiation intensity that can be displayed in terms of either differences in signal intensity or density differences in conventional film
- Modulation Transfer Function(MTF): MTF describes how the contrast of image component is transmitted as a function of its size or its spatial frequency. Expressed in line pairs per mm(lp/mm)
- Contrast Resolution:  It is the smallest detectable contrast for a given detail size that can be shown by imaging system with different intensity(density) or the whole dynamic range.
- Threshold contrast is a measure for imaging of low contrast structures and is largely determined by DQE of detector

# Digital Radiography

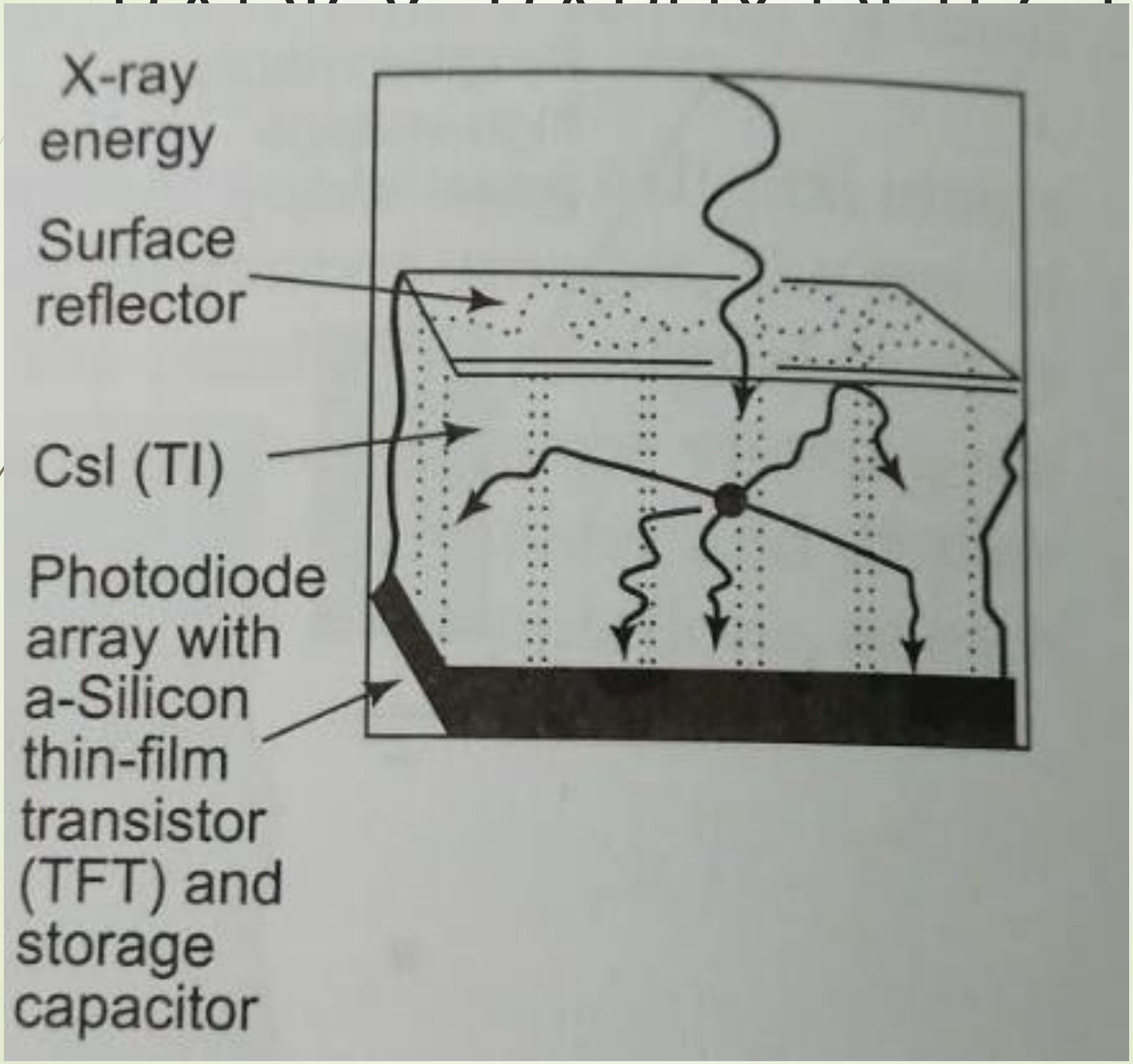



*Flat X-ray solid state detector with an amorphous silicon active readout matrix*

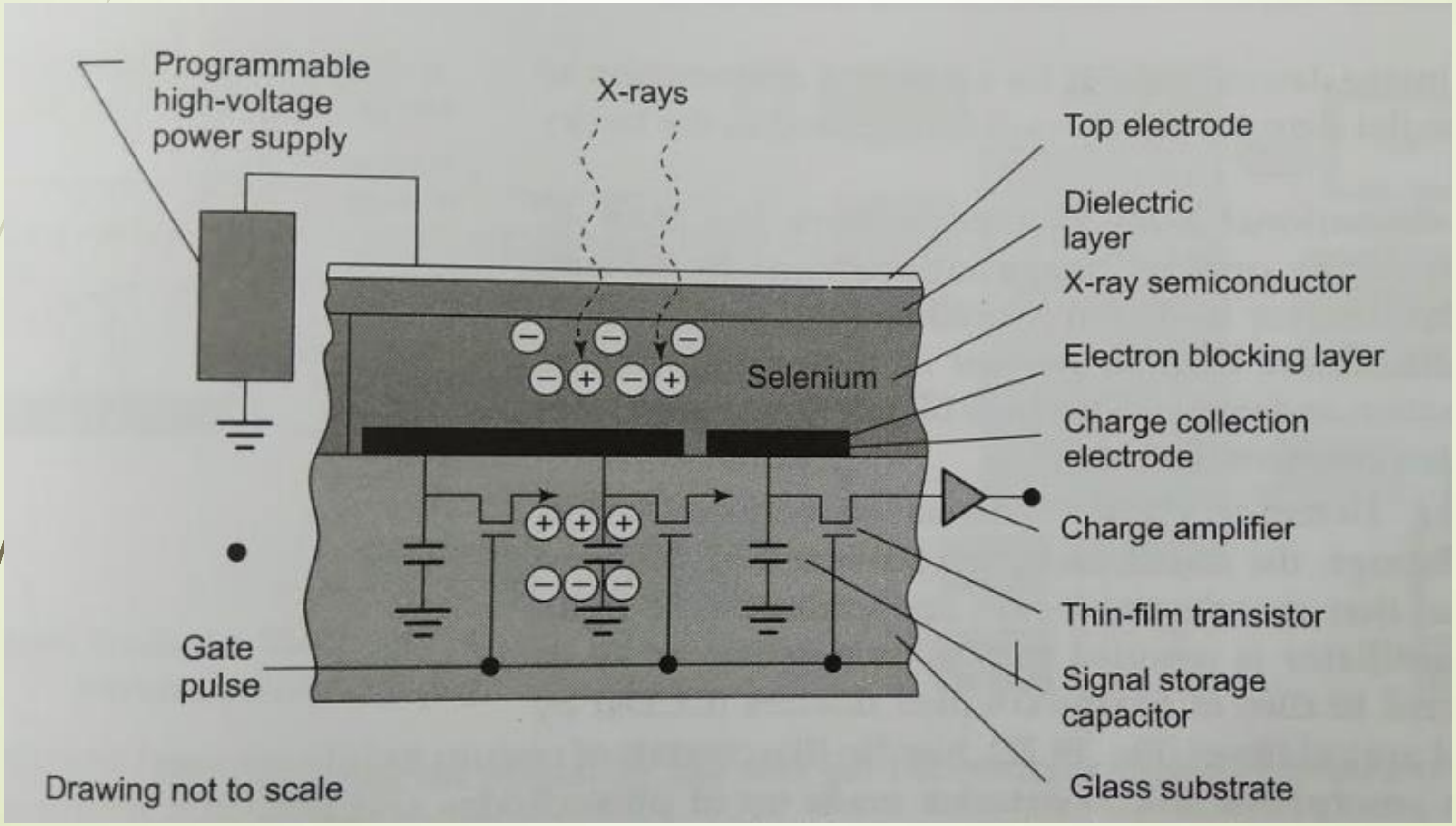
# A flat panel detector

- A flat panel detector has the potential to close the gap between digital systems already in use (CT, MR etc.) and radiography, and thus represents one more important step towards the fully digital hospital.
- Amorphous (non-crystalline) silicon (a-silicon) is used in place of the classic microchip with mono-crystalline silicon, as this is necessary for achieving the large detector area.
- The a-Si layer is brought onto a glass carrier as a thin layer and structured into an array of sensors (photo-diodes) using conventional photo-lithographic methods.
- A switching element (a diode or a transistor) is allocated to each individual sensor so that the sensor can be connected to a read-out line in the column direction.

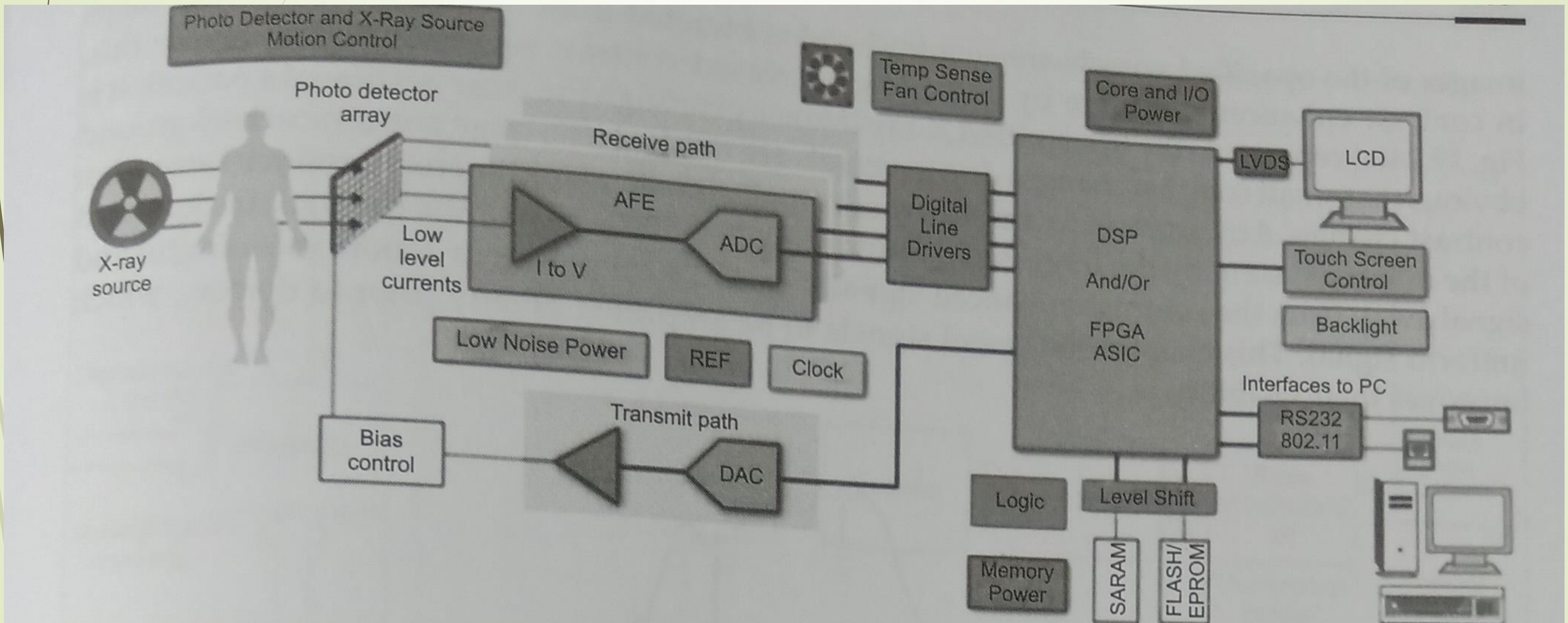
# INDIRECT DIGITAL RADIOGRAPHY DETECTOR



# DIRECT CONVERSION RADIOGRAPHY DETECTOR



# Digital radiography



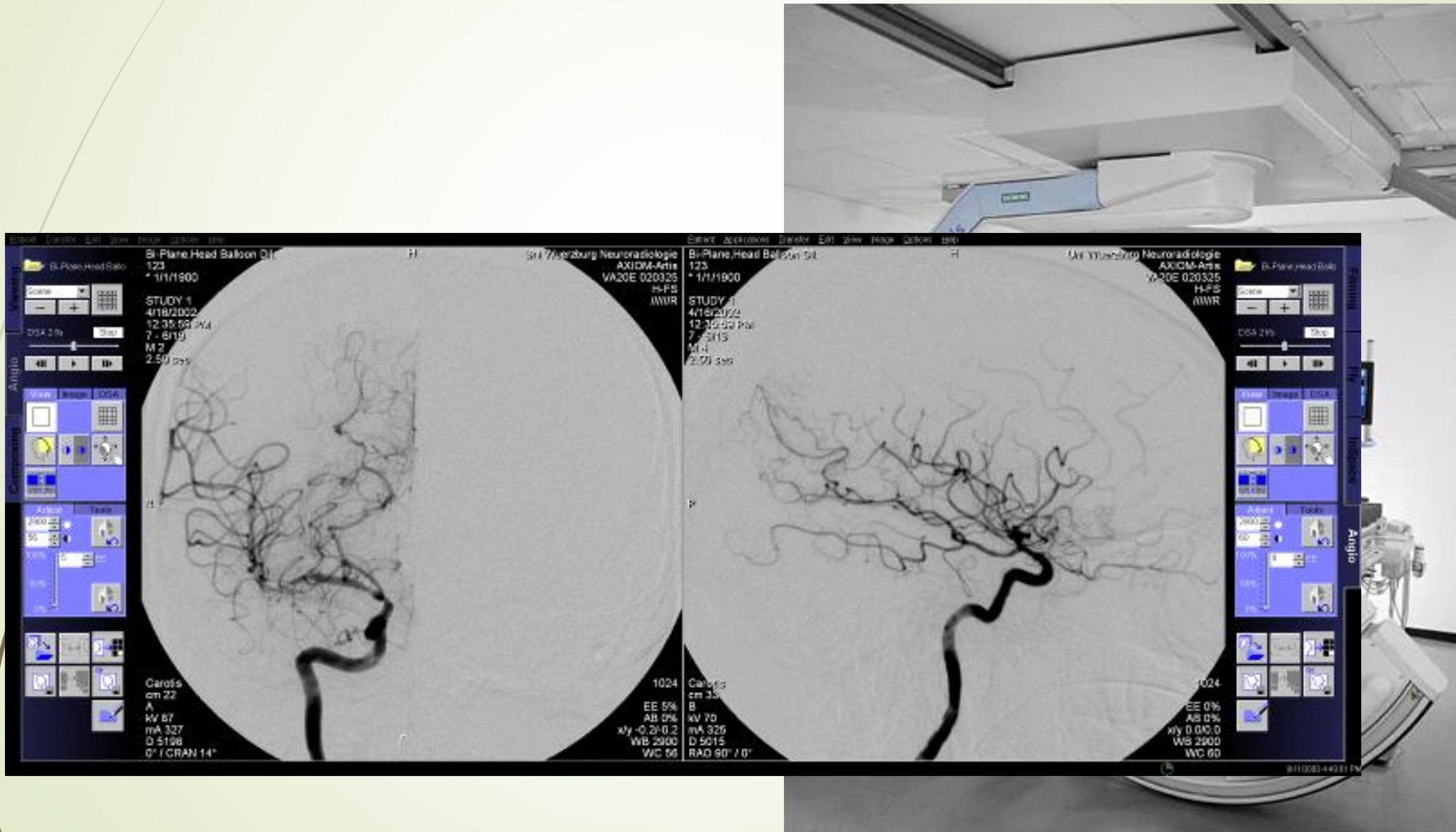

➤ Fig. 19.23 *Block diagram for processing and read out electronics in digital radiography (Adapted from Texas Instruments, 2010)*

# Digital radiography

Advantages

- The most important application of digital technology is the development of digital subtraction angiogrphy (DSA). In this technique, a pre-injection image (mask) is acquired, the injection of contrast agent is then performed, then images of the opacified vessels are acquired and subtracted from the mask. This greatly helps in contrast enhancement there by providing increased contrast sensitivity.
- The image is displayed on the monitor immediately after acquisitions, so that the image quality can be checked while the patient is still in the examination room. Any changes in the patient position or the equipment settings can be made immediately, without having to wait until a film has been developed.
- The digital images can be automatically combined with the patient and the exposure data in the system and transferred online to the laser camera or the diagnostic workstation.

# Angiography and XRay - AX



# Angiography

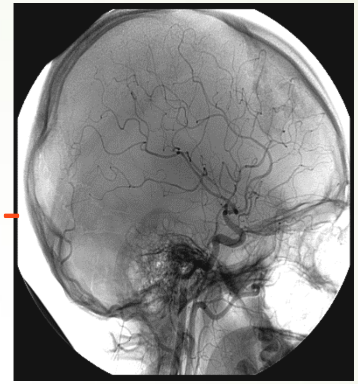
- Angiography is a special x-ray examination that allows blood vessels to be visualized.  Its typical clinical applications range from the visualization of coronary, cranial and cervical arteries and veins, to the peripherals in pelvis and extremities.
- This method facilitates the diagnosis of stenoses and thromboses and even the treatment of these conditions using special invasive techniques.
- Angiography uses contrast media to visualize blood vessels. The contrast media is administered through a catheter that is placed as close as possible to the vessel to be visualized. A C-arm x-ray system is needed to perform vascular radiography. It is equipped with a mobile C shaped arm with an x-ray at one end and a flat panel detector at the other end.

# Image subtraction

Examinations *DSA*

Mask image

−

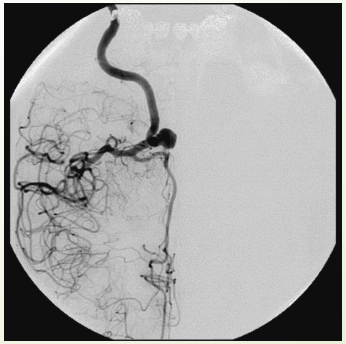


Filled image

=

Subtraction image

Acquisitions without contrast medium = Mask images
Acquisitions with contrast medium = Filled images
Immediate subtraction on the monitor



Examinations *Aneurysms*

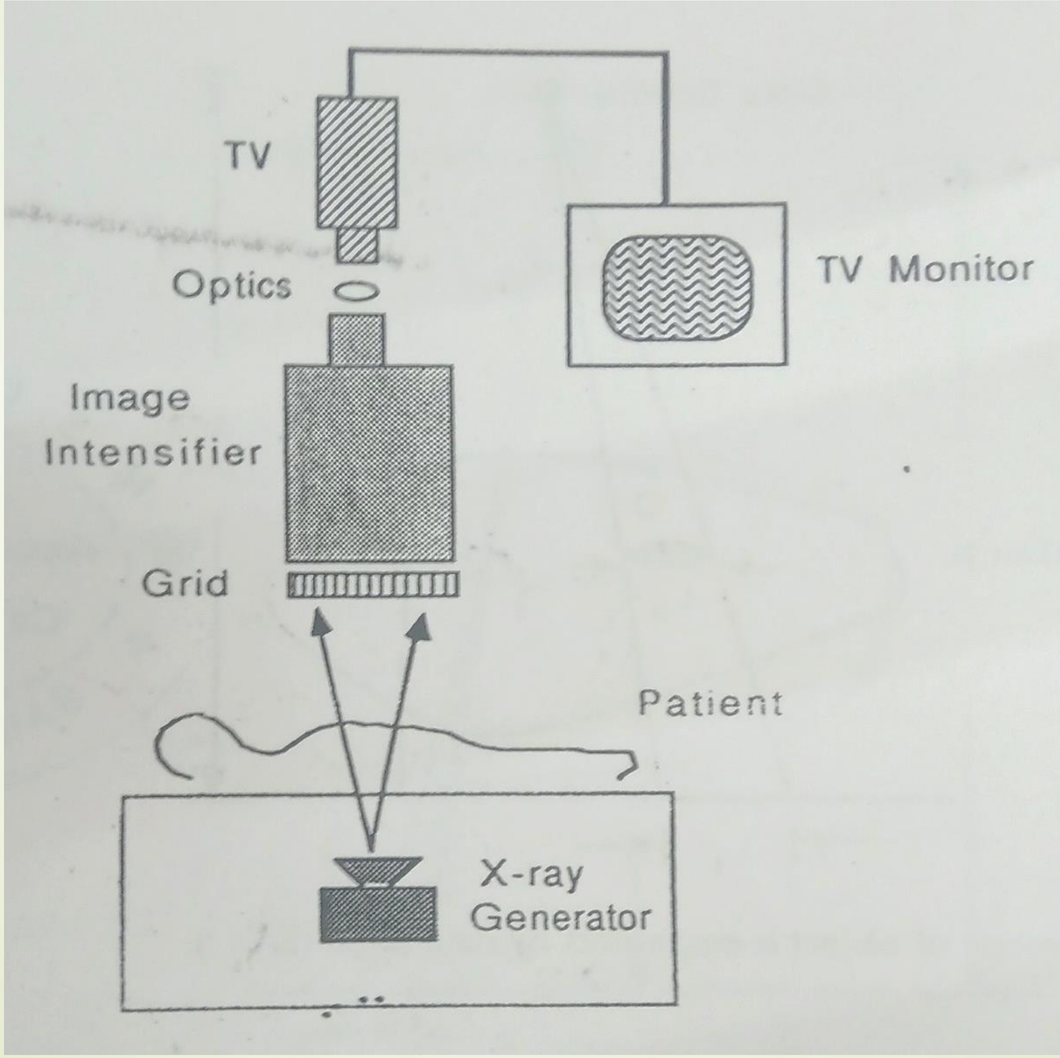
# Fluoroscopy

- The X-ray images can be recorded on a film for examination as was discussed or can be visualized directly on a fluorescent screen in motion of the object of interest, such as a contrast medium like barium sulfate in the digestive tract, must be studied.
- A conventional fluoroscope except that the image intensifier is replaced with a fluorescent screen assembly.
- The screen assembly consists of a grid, a slot for inserting the film if necessary, the fluorescent screen, and a lead glass layer to absorb radiation passing through the screen.
- The problem with the conventional fluoroscope is that the image produced is very weak. So the room has to be darkened for examining the image. Even so, the quality of the fluoroscopic image is very poor compared to an average radiograph on film. Therefore, an image intensifier that amplifies the light signal is always used in the modern version of a fluoroscope.

# Fluoroscopy

- In a typical fluoroscopic procedure for examining the digestive tract, a contrast medium like barium sulfate that is nontoxic is either taken orally by the patient or by enema depending on which part of the GI tract is being examined
- Common GI tract problems (cig.. ulcers, tumors, or obstructions) can be diagnosed by fluoroscopy. Figure shows a colon radiograph where colon containing the contrast medium appears much darker than the surrounding tissues
- In this procedure the patient is being continuously exposed to X-ray radiation
- The radiation dose received by the patient can be very high It is therefore important to take this into consideration during an examination

# Fluoroscopy



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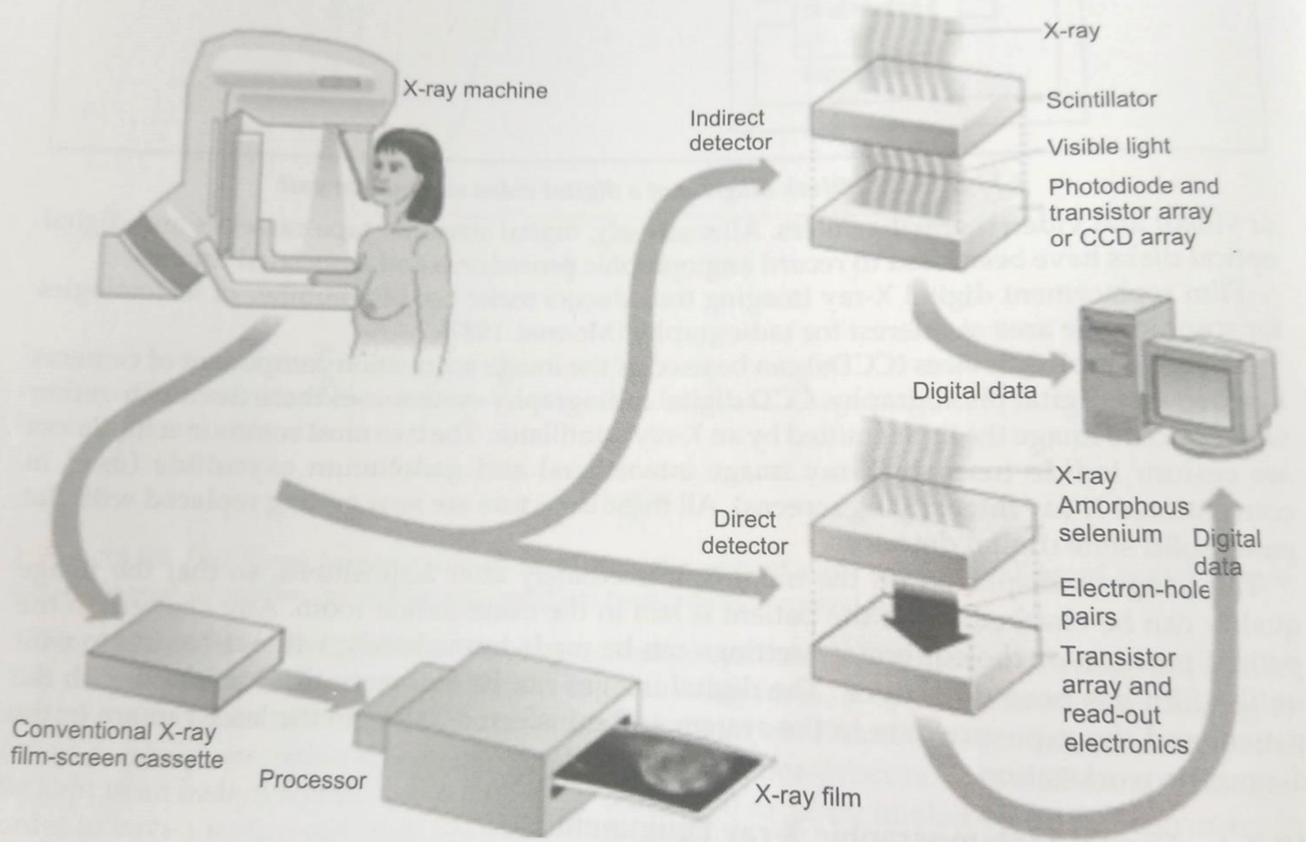
# DIGITAL MAMMOGRAPHY




➤ Fig. 19.26 *Principle of digital mammography. There are two methods of X-ray detection: indirect, in which a scintillator converts X-rays into visible light that is picked up by a solid state detector; and direct, which employs a coding of amorphous selenium to convert X-rays into electron-hole pairs for sensing by a transistor array (Moore, 2001)*

# DIGITAL MAMMOGRAPHY

- Mammography is an X-ray imaging procedure used for examination of the female breast.
- It is primarily used for diagnosis of breast cancer and in the guidance of needle biopsies.
- The female breast is highly radiation-sensitive. Therefore, the radiation dosage during mammography should be kept as low as possible.
- Also, it is required to achieve better spatial resolution than other types of film/screen radiographs.
- In order to achieve these goals, an X-ray tube with a small focal spot size is used to minimize the possibility of geometric blur.
- The film/screen cassette has a single emulsion film and a single screen, and is designed to provide excellent film/screen contact.

# DIGITAL MAMMOGRAPHY

- Mammographic X-ray equipment can either be used with special film/screen cassette or as xero-radiographic units.
- The units intended for film/screen use have a molybdenum target X-ray tubes with a beryllium window and a 0.03 mm molybdenum filter.
- Radiographs are usually taken at 28–35 kV.
- Xero-radiographic systems use X-ray tubes with tungsten targets and about 1 mm aluminum filter.
- Radiographs with this technique are taken at 40–50 kV. Hence, both types of mammographic units operate at low peak voltages

# Xeroradiography

- Xeroradiography is an X-ray technique developed by the Xerox Corporation that uses an X-ray energy level between 35 and 45 keV and an electrostatic technique to record the X-ray image instead of film.
- In this technique, a selenium coated plate, which is positively charged, is exposed to X-rays coming through the patient
- The X ray photons cause the selenium to release electrons, neutralizing part of the positive charge.
- The areas of the plate under thick body parts will retain most of the positive charge, whereas on the areas of the plate under thin parts of the body, most of the charge will be neutralized.
- The plate is then sprayed with negatively charged blue powder. The amount of powder retained by a certain area of the plate will be an indicator of the X-ray intensity over that area. The powder pattern is transferred by heat to a sheet of paper coated with plastic for viewing and storage.

# Xeroradiography

- During the spraying process, the powder near an area that has little remaining charge is attracted to the edge of the nearest arca with more remaining charge, producing a well defined image of that edge.
- The edge enhancement effect is the main reason that the Xeroradiography shows detail in thick body parts better than a conventional X-ray.
- However, Xeroradiography is less sensitive than conventional X-ray.
- To obtain a Xeroradiography of similar quality, patient dose may have to be increased.
- In new models in which a liquid toner is used the patient dose is cut to half (less than 0.3 rad for a 5 cm breast in a two-view study).

# Xeroradiography