X-ray Production

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Electromagnetic Radiation

Radiation **may be defined as energy in transit from one location to another.**

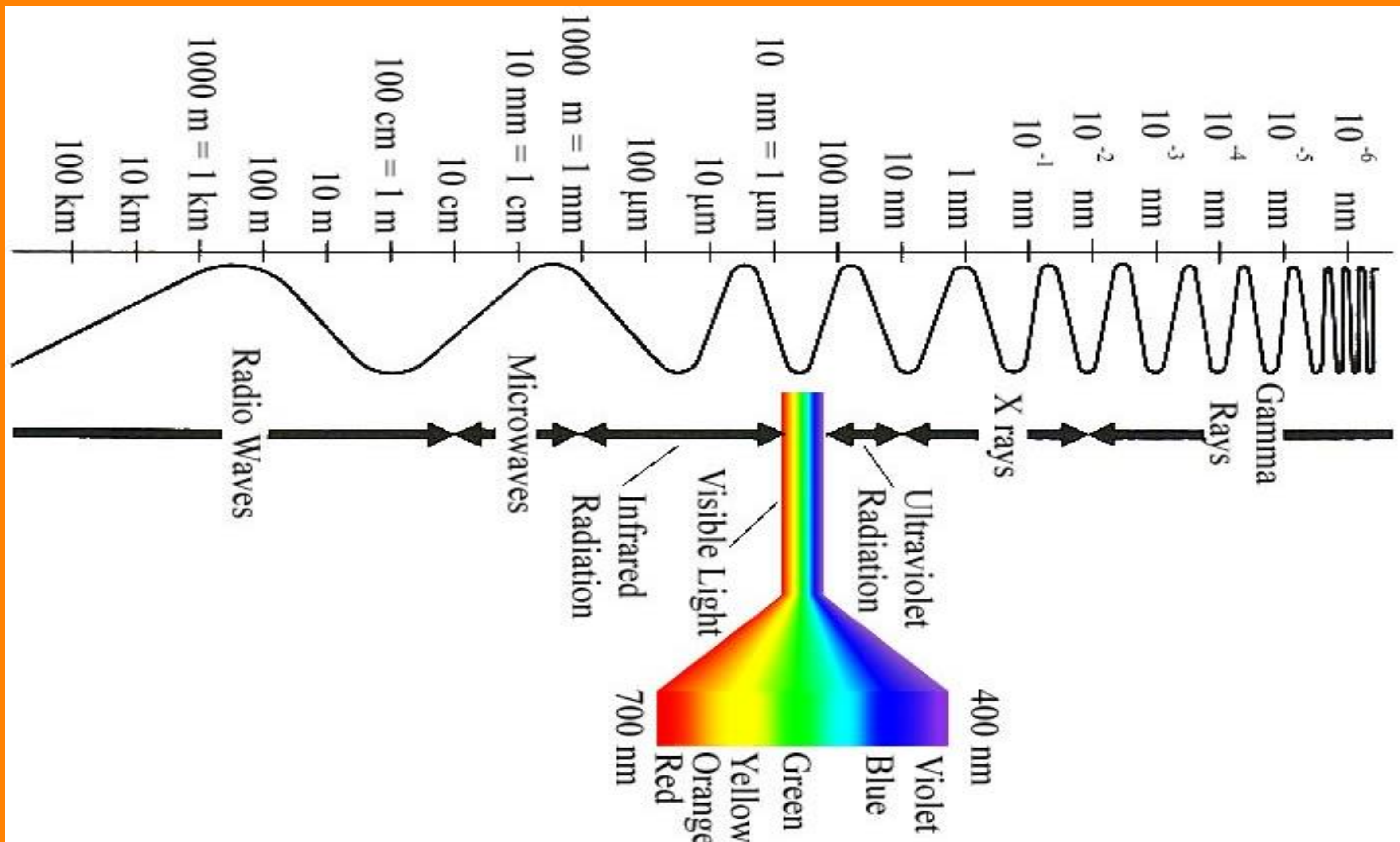
The Nature of X-Rays:

• X-rays, light, radio waves, ultraviolet rays, are electromagnetic radiation;

• electromagnetic Radiation can be produced by accelerating an electric charge;

. It has an associated electric and magnetic field.

Electromagnetic Radiation Spectrum



EM Radiation

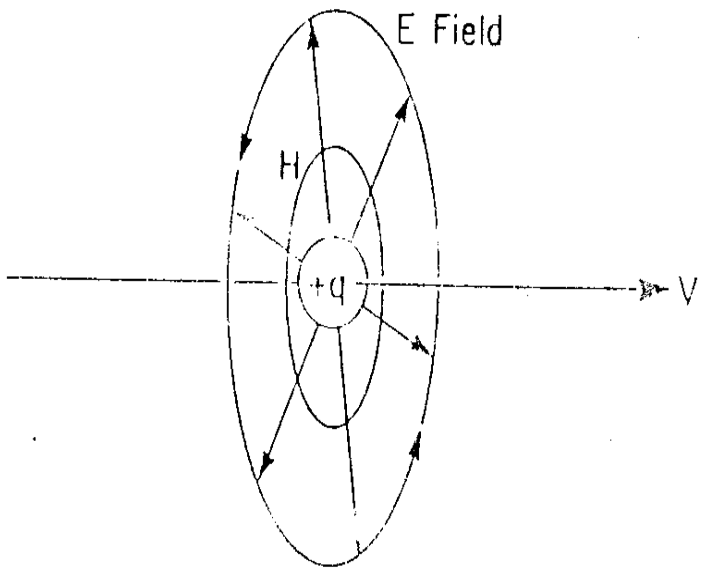


Figure 1–2 Electric and magnetic fields surrounding a positive charge moving with constant velocity

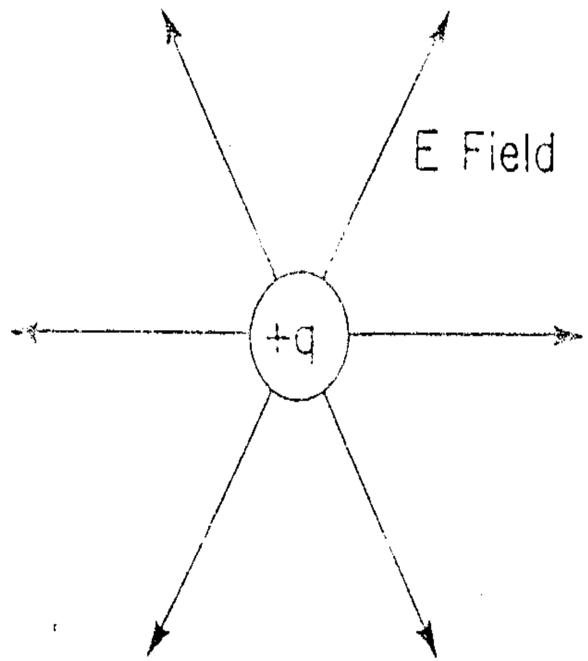


Figure 1–1 Electric field surrounding a positive charge at rest

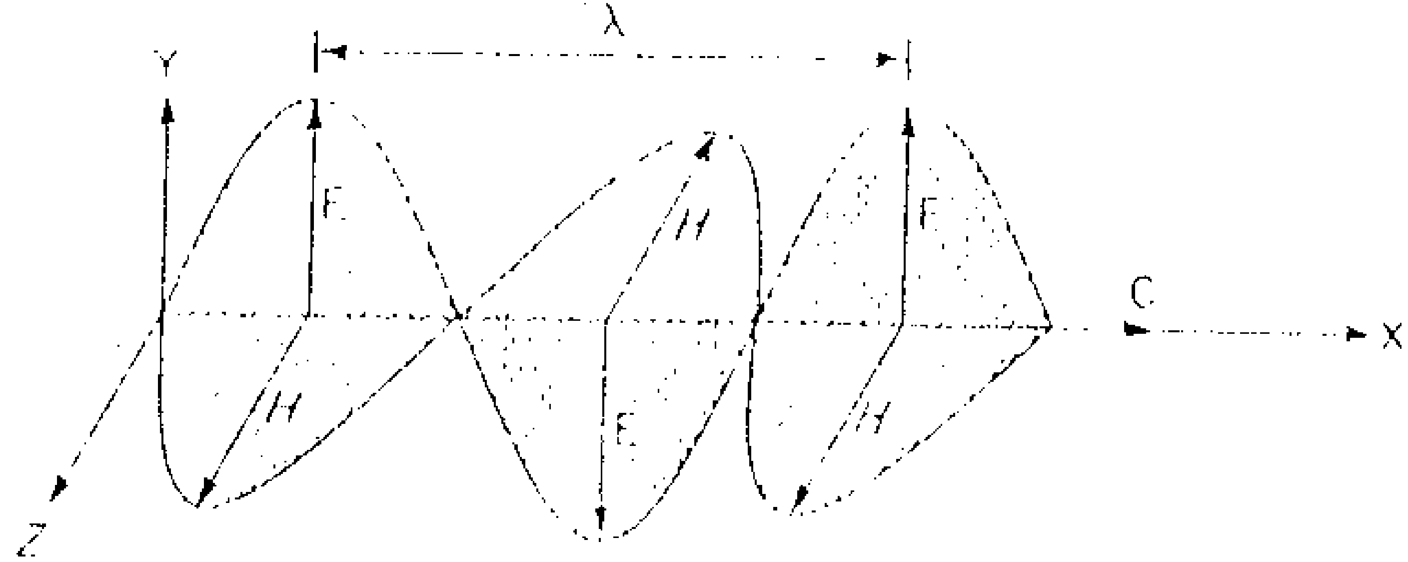
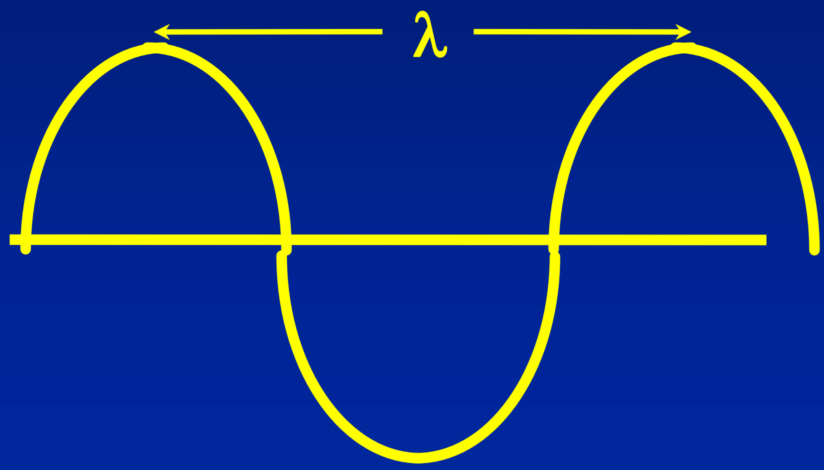


Figure 1–3 Representation of electromagnetic radiation

wave property of x-ray

- X-rays, as well as all other electromagnetic radiation, have the wave-particle duality;

- This wave can be described by its frequency ν (or wavelength λ) and traveling velocity c.
  - c=3 x 10^8 m/sec (velocity in a vacuum)



$$c = \lambda \nu$$

$$\nu = c / \lambda$$

Particle property of x-ray

$E_k = h\,\nu_0$ $\quad \boldsymbol{\nu} = \mathbf{c} / \boldsymbol{\lambda}$ $\quad E_k = hc / \lambda$

$h = 4.15 * 10^{-15}$ ev-Sec

$\longrightarrow \lambda_{(A^0)} = 12.4/E_{(KV)}$

Example: What is frequency of x-ray with 70 Kev energy?

$$E = h\nu \quad , \quad \nu = \frac{E}{h} \quad , \quad \nu = \frac{70 \times 10^3 \text{ ev}}{4.15 \times 10^{-15} \text{ evSec}} = 1.69 \times 10^{19} \text{ Sec}^{-1} \text{ (Hz)}$$

X rays generation

X rays are generated by interactions between the energetic electrons and atoms of the target.

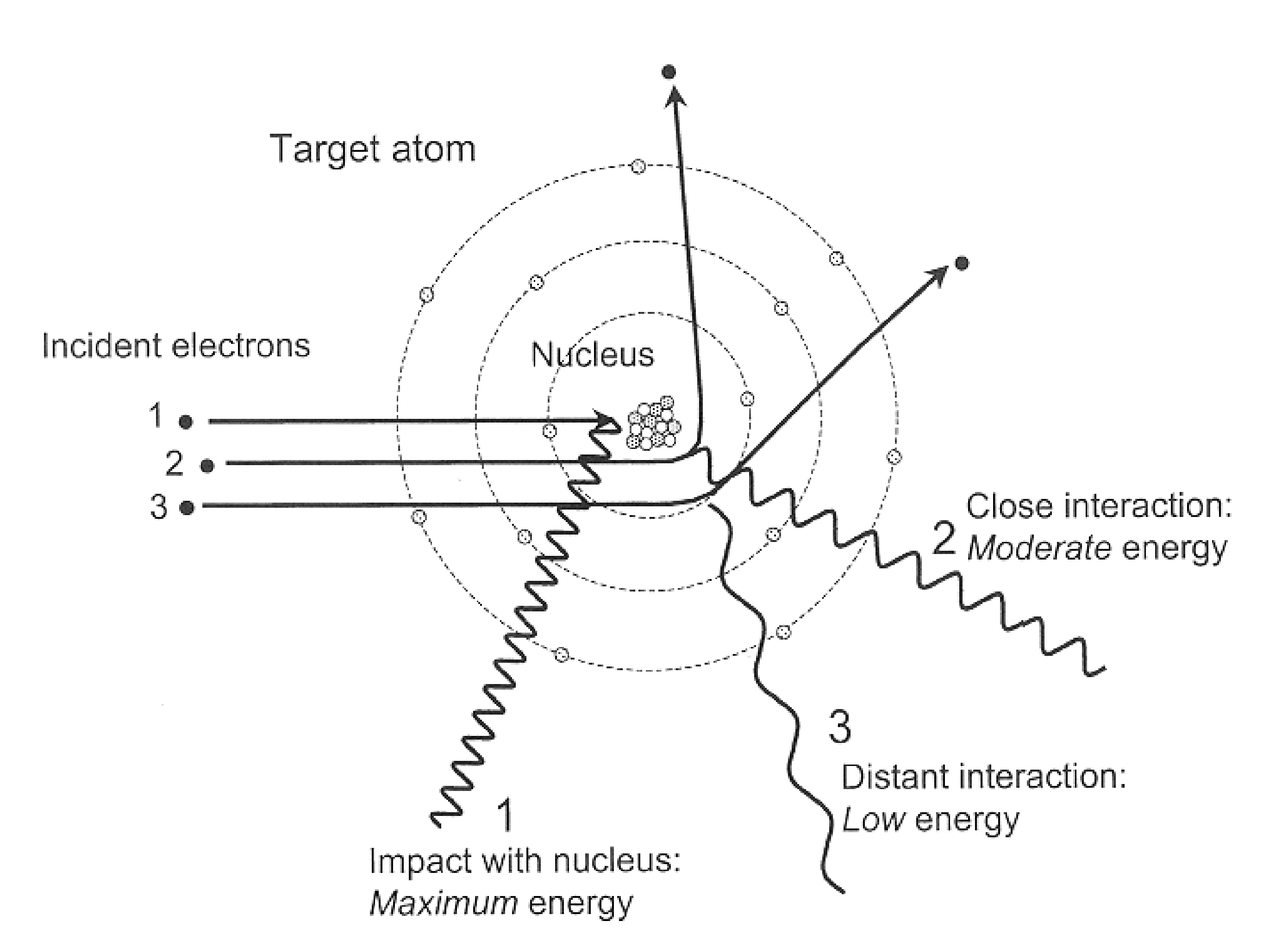
The interactions result x rays in two ways:

(1)Bremsstrahlung (brake radiation, general radiation);

(2) Characteristic radiation

Bremsstrahlung (brake radiation, general radiation)

A charged particle undergoes acceleration or deceleration, it emits photons.



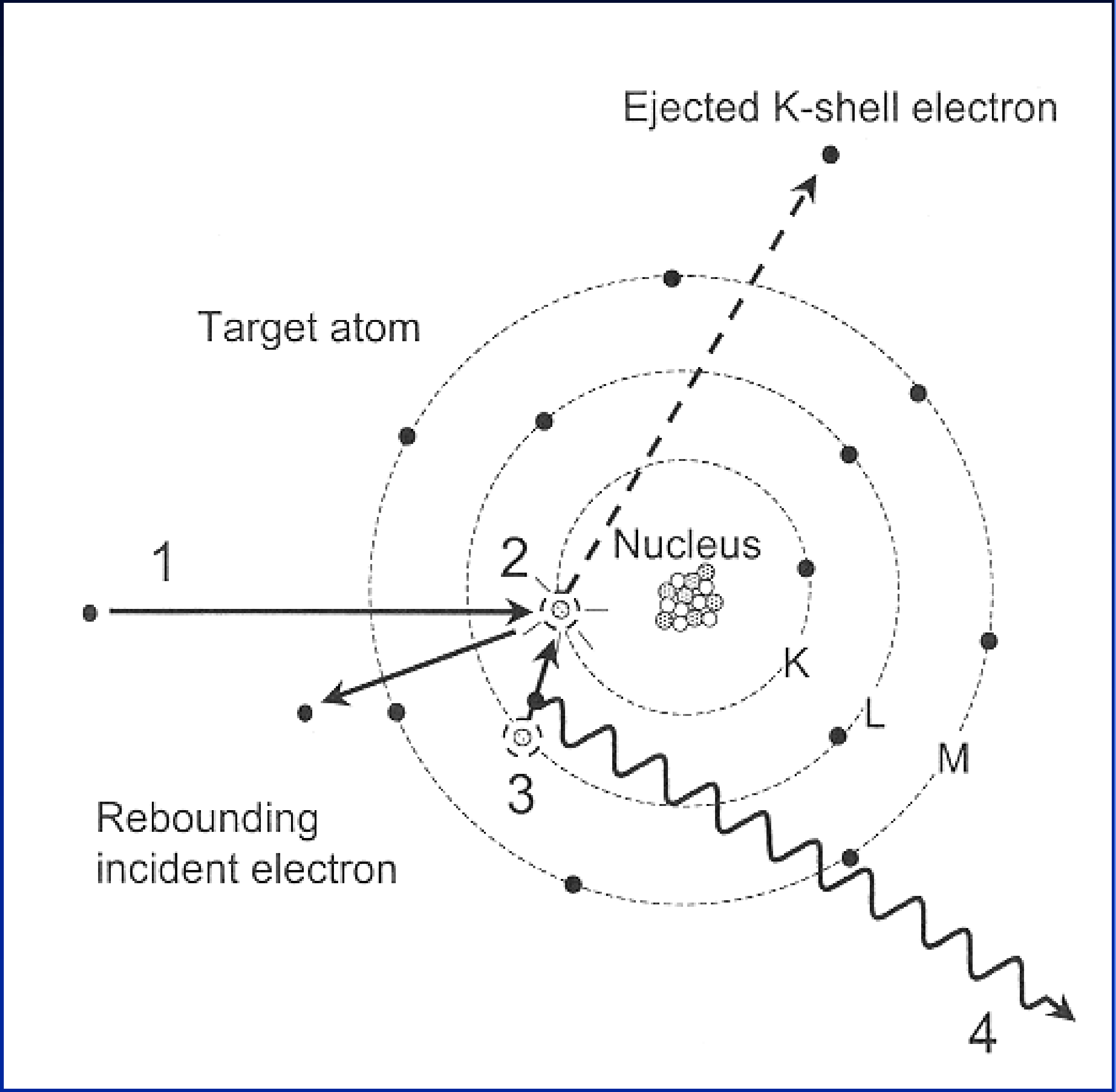
Bremmstrahlung

Most electrons that strike the target give up their energy by interactions with a number of atoms;

Conclusion: The bremsstrahlung produces inherently continuous spectrum of x rays.

99% of the radiation are absorbed by target and the walls of the x-ray tube to produce only heat.

Charactristic x-ray



Characteristic radiation

- The minimum energy required to “knocking out” an electron in a specific orbit depends on binding energy.

- Removal of an electron cause the target atom to a higher energy state with 2 productions:

  1) Positive charged ion
  2) Negative charged ion

Two ways for an ionized atom returning to its normal (lower energy) state:
(1) Characteristic x-ray radiation;
(2) Emission of Auger electrons.

***Characteristic** radiation:*

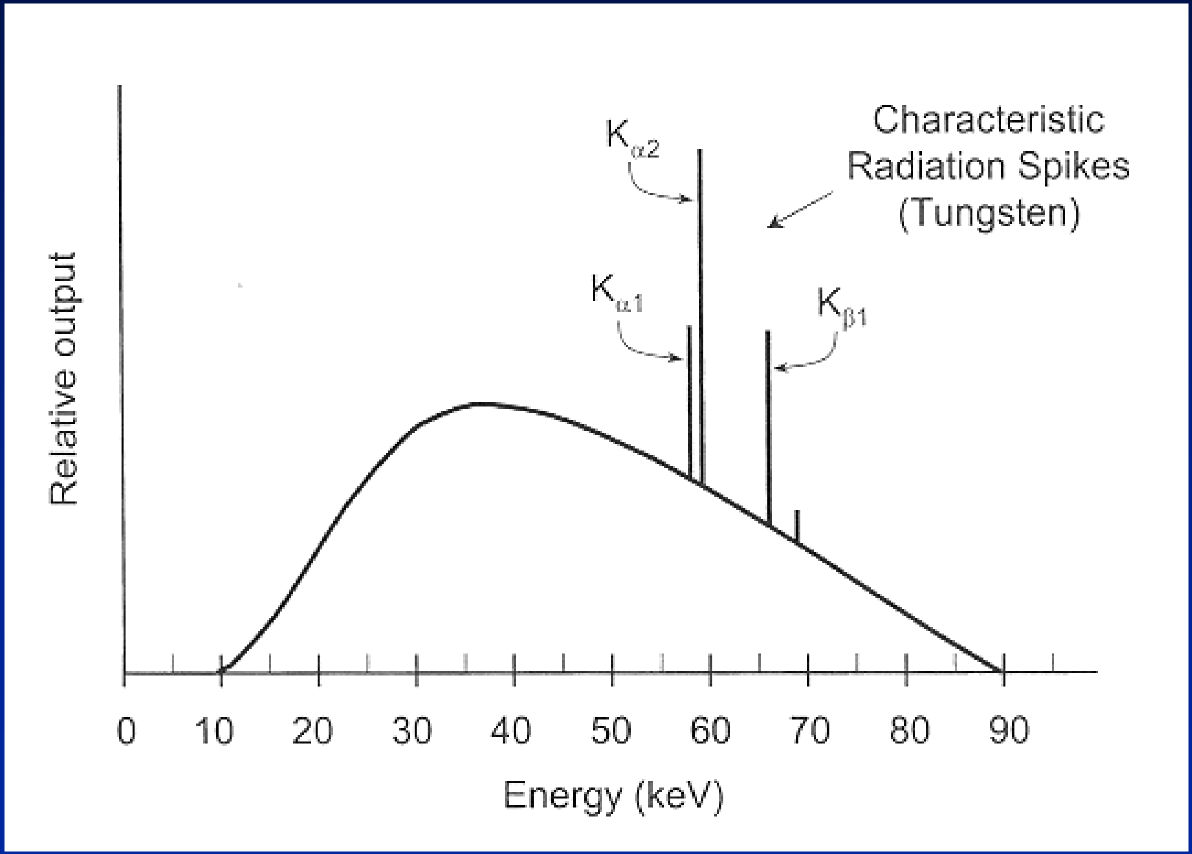
K-shell filling is the most important for diagnostic x rays.
For tungsten:

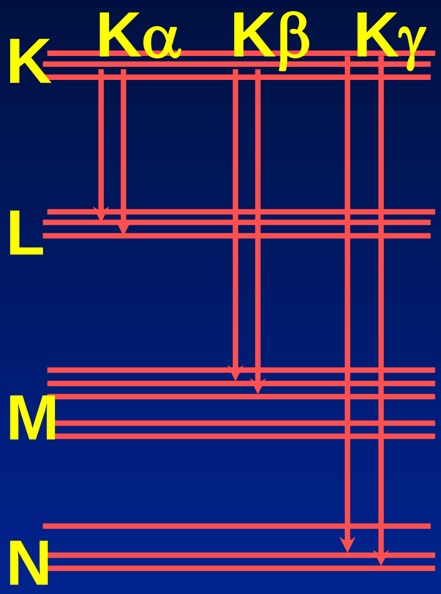
this energy is ~70 keV for K shell.
$E_{k\text{-}L}$= 59 (keV).
L-characteristic x-ray is ~11 keV.

. Characteristic ~ 10% of total spectrum

-The low-energy photons are absorbed by the target and the walls of the x-ray tube to produce heat.

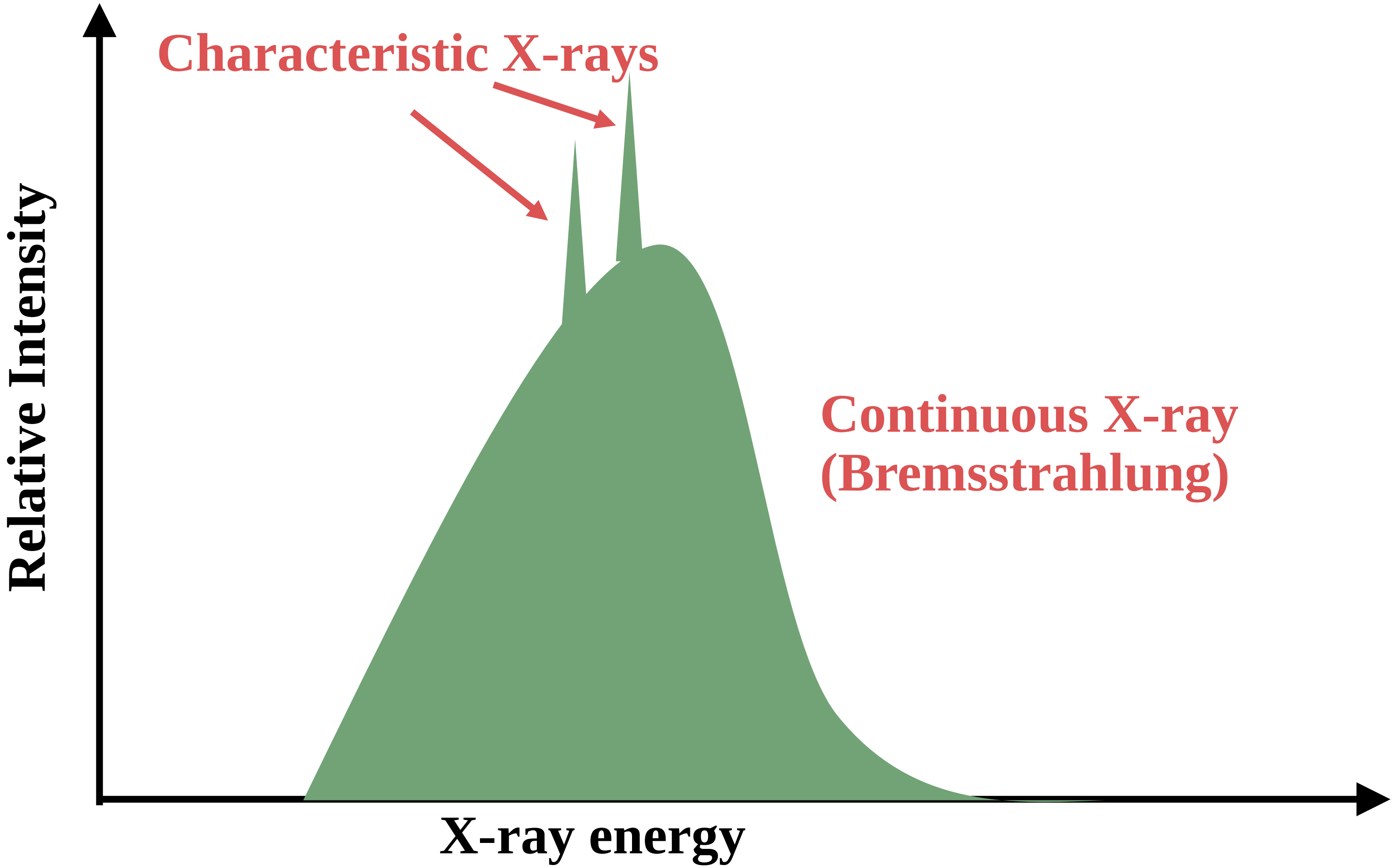
K-Characteristic Radiation





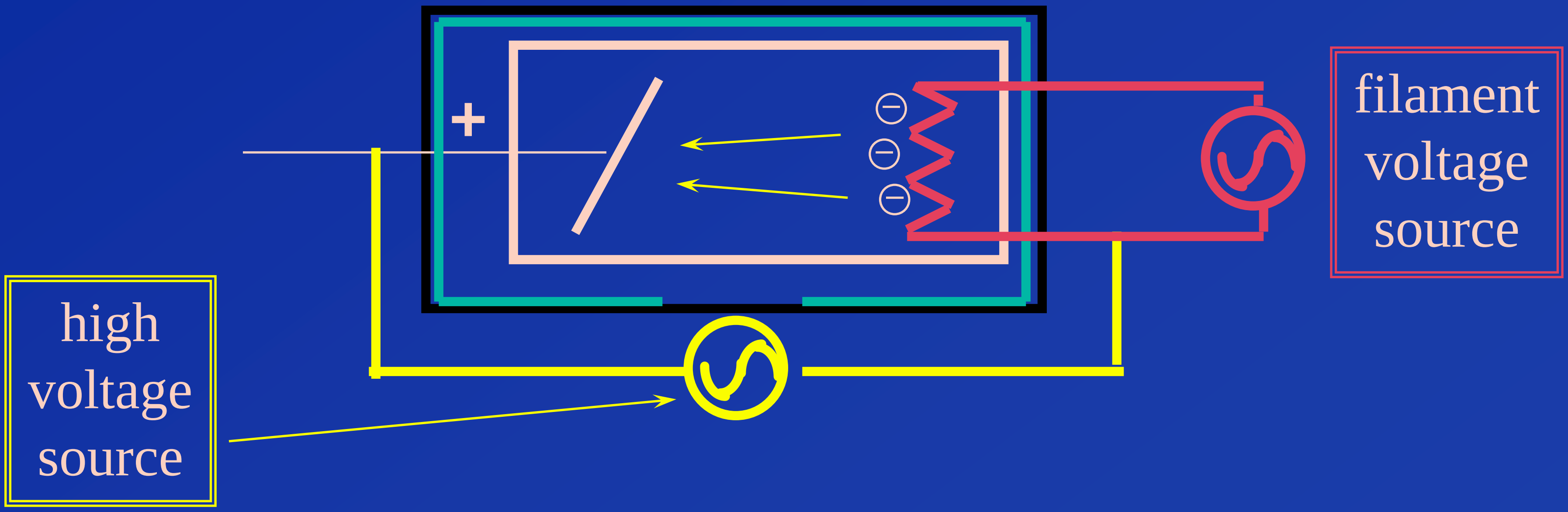
X-ray spectrum

– Example of energy distribution.



Intensity & Technique

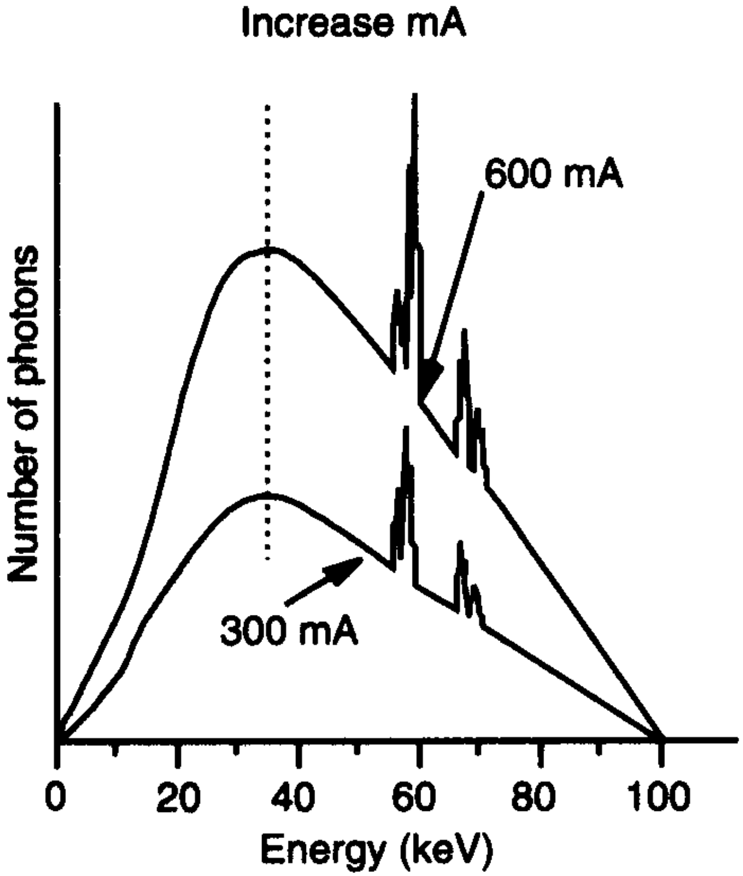
- beam intensity proportional to mA
- beam Intensity ~ proportional to kVp^2



FACTORS AFFECTING X Ray BEAM

- TUBE CURRENT
- TUBE POTENTIAL
- FILTRATION
- HIGH OR LOW Z TARGET MATERIAL
- TYPE OF WAVEFORM

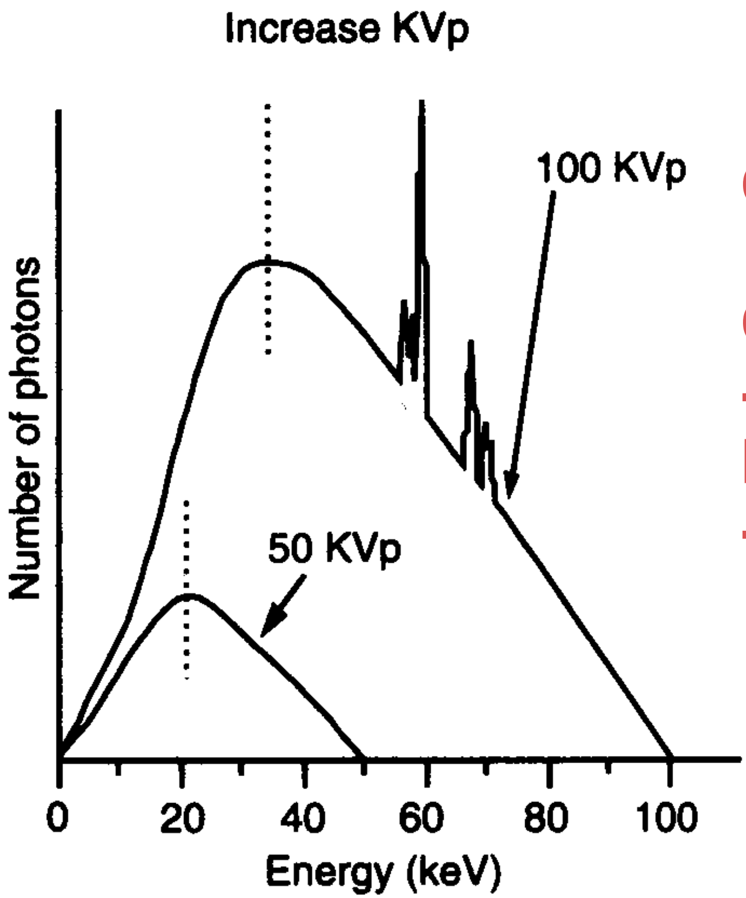
X Ray spectrum: tube current



Change of QUANTITY
NO change of quality

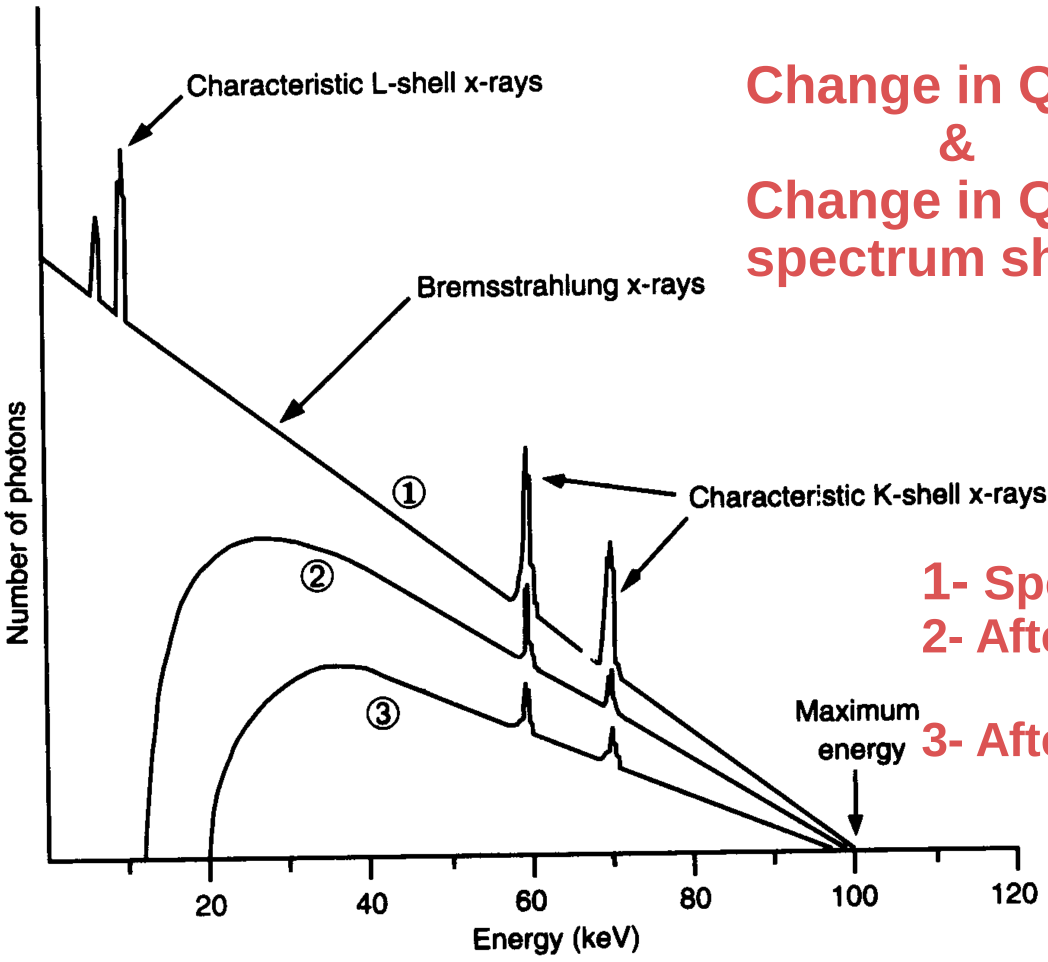
Effective kV not changed

X Ray spectrum: tube potential



Change in QUANTITY
&
Change in QUALITY
- spectrum shifts to higher Energy
- characteristic lines appear

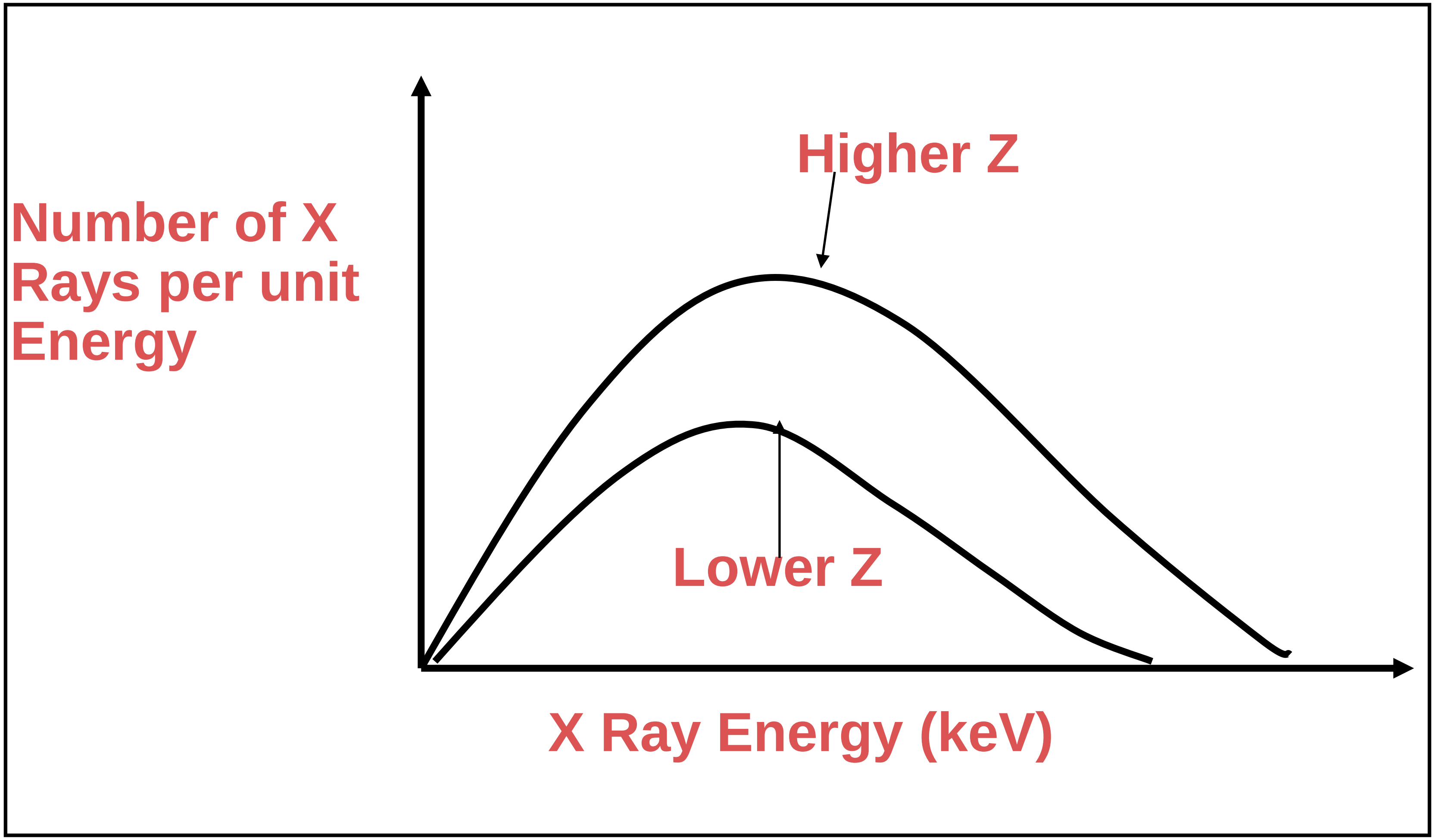
X Ray spectrum: filtration



Change in QUANTITY
&
Change in QUALITY
spectrum shifts to higher energy

1- Spectrum out of anode
2- After window tube housing (INHERENT filtration)
3- After ADDITIONAL filtration

X Ray spectrum: Target Z



Factors affecting X-Ray

Quantity

- TUBE CURRENT (mA)
- EXPOSURE TIME (s)
- TUBE POTENTIAL (kVp)
- WAVEFORM
- DISTANCE (FSD)
- FILTRATION

Quality

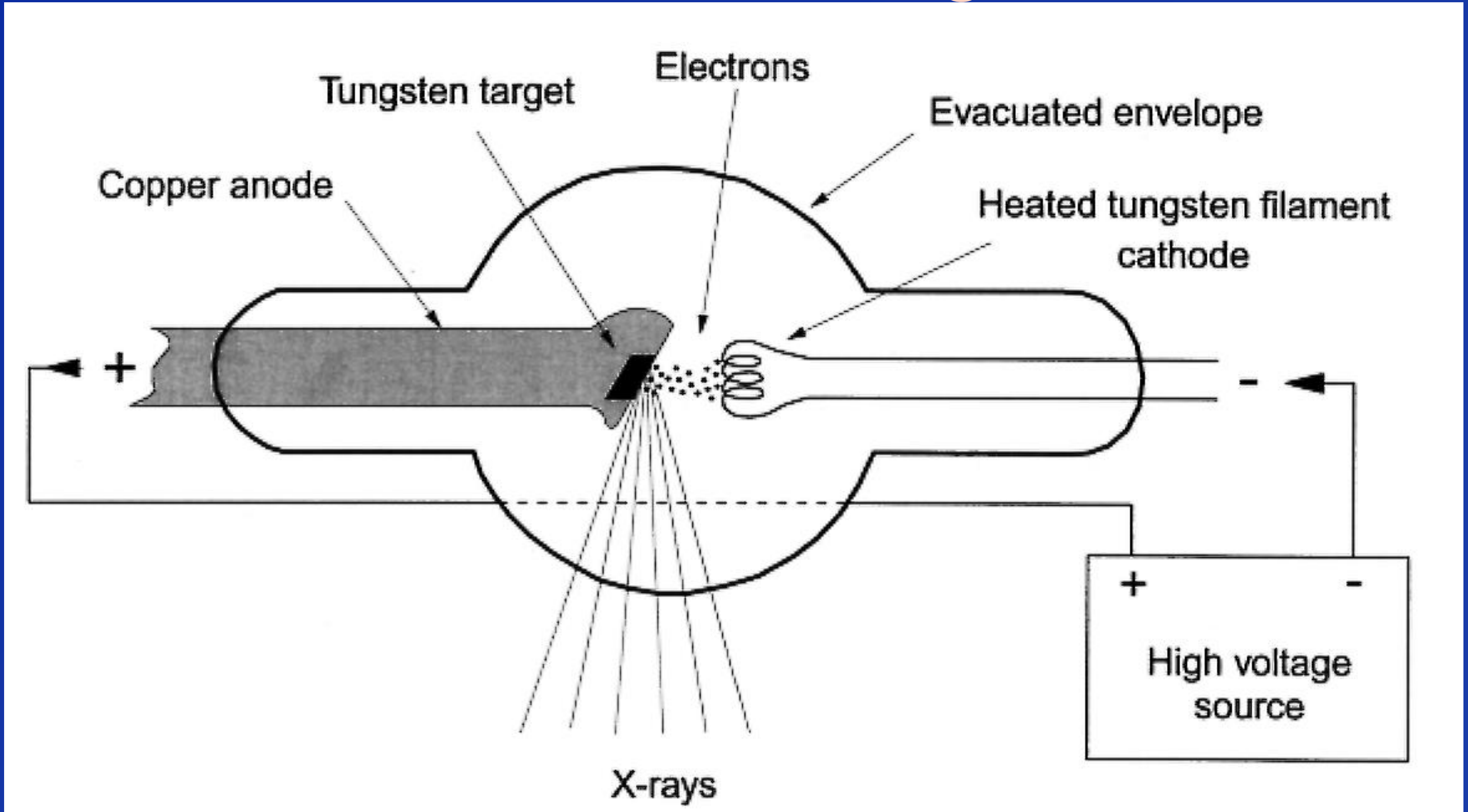
- TUBE POTENTIAL (kVp)
- FILTRATION
- WAVE FORM

X-Ray Tube Construction

- DIAGNOSTIC X-RAY TUBES
- Glass Enclosure
- Cathode
- Line Focus Principle
- Anode
- Rotating Anode
- Grid-Controlled X-Ray Tubes
- Saturation Voltage
- Heel Effect
- TUBE RATING CHARTS

X- rays Tube

The x-ray tube is made of pyrex glass that encloses a vacuum containing 2 electrodes



(1) Tungsten **target**

Several reasons for chosen of Tungsten as

the target material

1. high atomic number (74)

2. high melting point

3. tungsten melts at 3370" C

(2) Tungsten **filament**

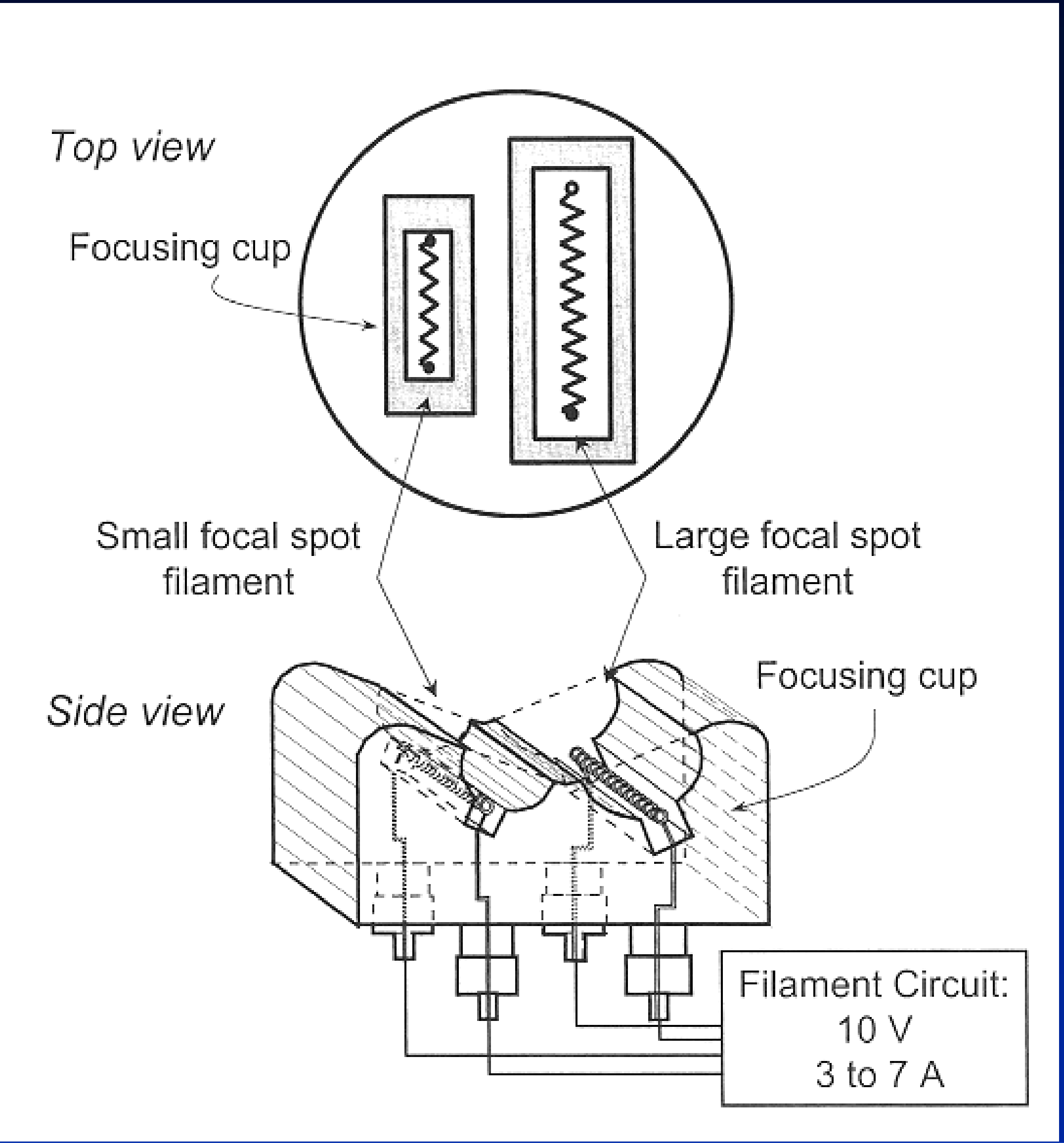
Filament is made of tungsten wire with high melting point (3370^{0} C), low vaporization, and lasting strength.

(3) Electric circuit to provide the heating currents. This is filament circuit which is different from the x-ray tube current.

(4) Electrons are accelerated towards the anode.
The x-ray tube current, measured in mA , refers to the number of electrons flowing per second from the filament to anode.

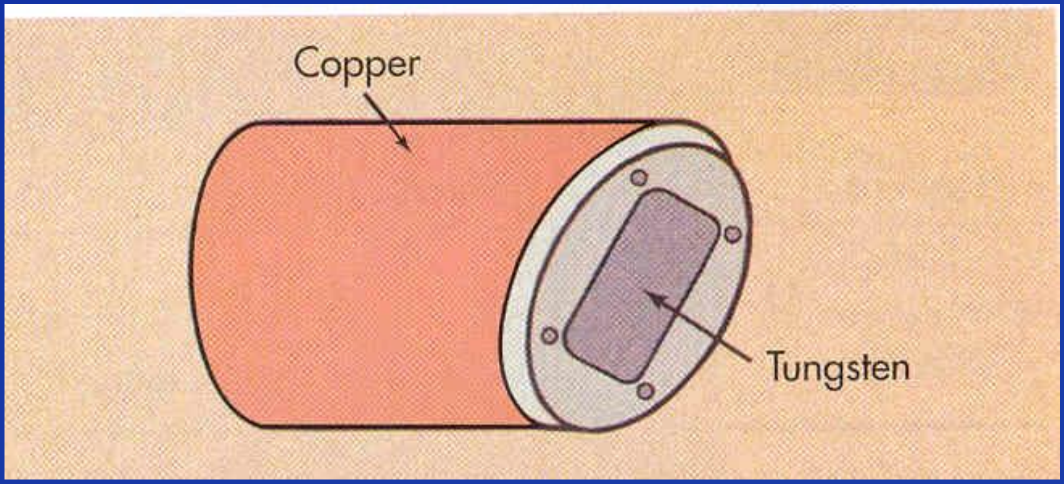
2 filaments
+
Focusing cup

Focal spot construction



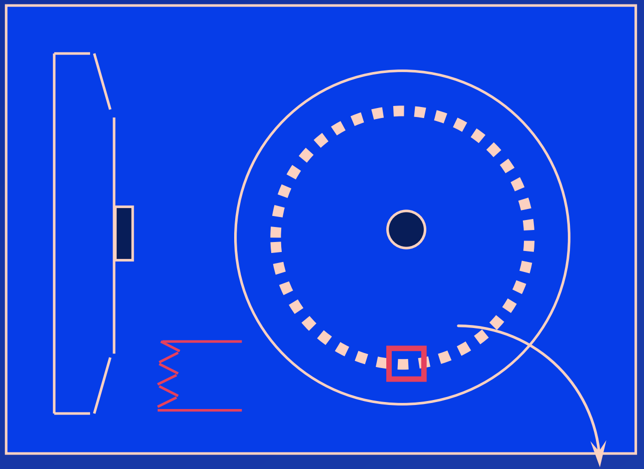
Stationary Anode

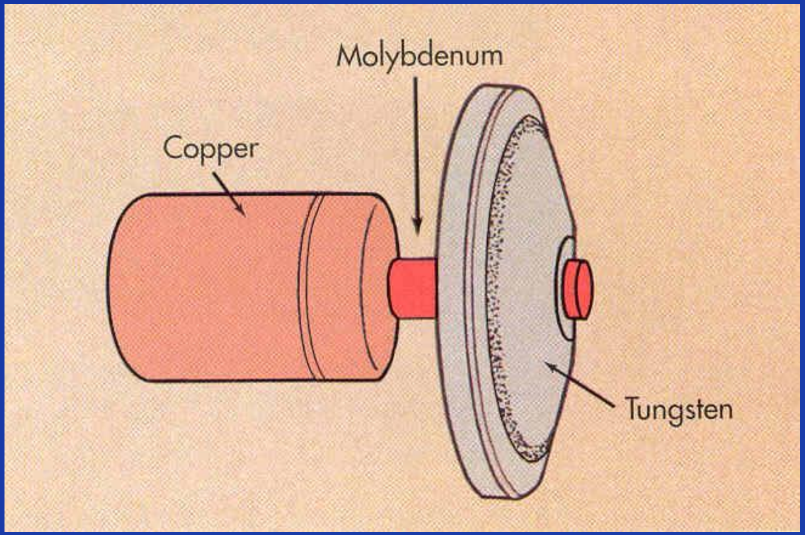
- Made of tungsten target embedded in a large copper bar.
- Usually used in dental x-ray machine.



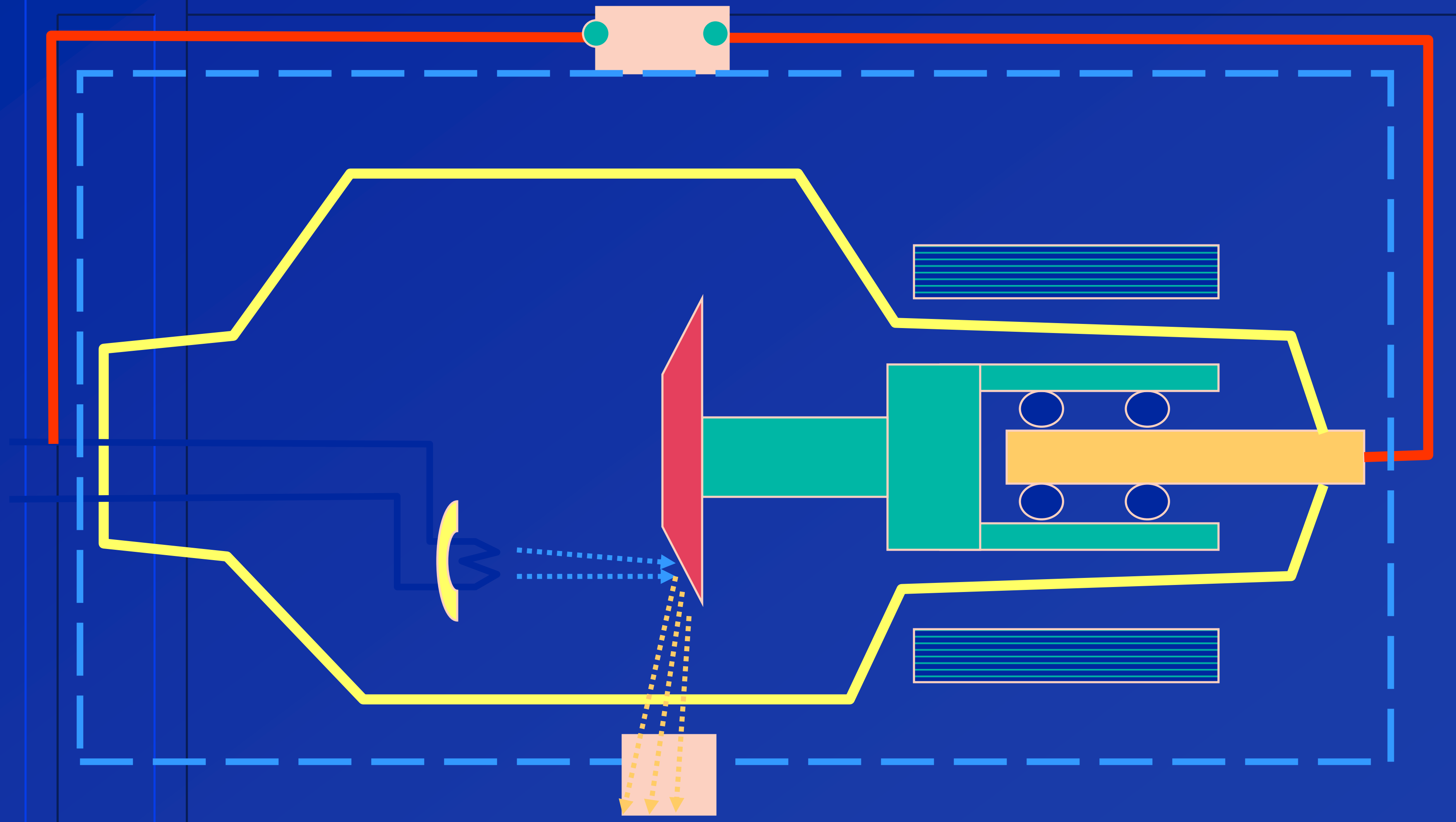
Rotating Anode

- Advantages
  - better heat ratings
- Disadvantages
  - More complex ($)
    - Rotor drive circuitry
    - motor windings in housing
    - bearings in insert





Rotating-anode X-ray tube



Rotating-anode X-ray tube

•large disc of tungsten, or an alloy of tungsten

•Rotates 3600 (rpm)

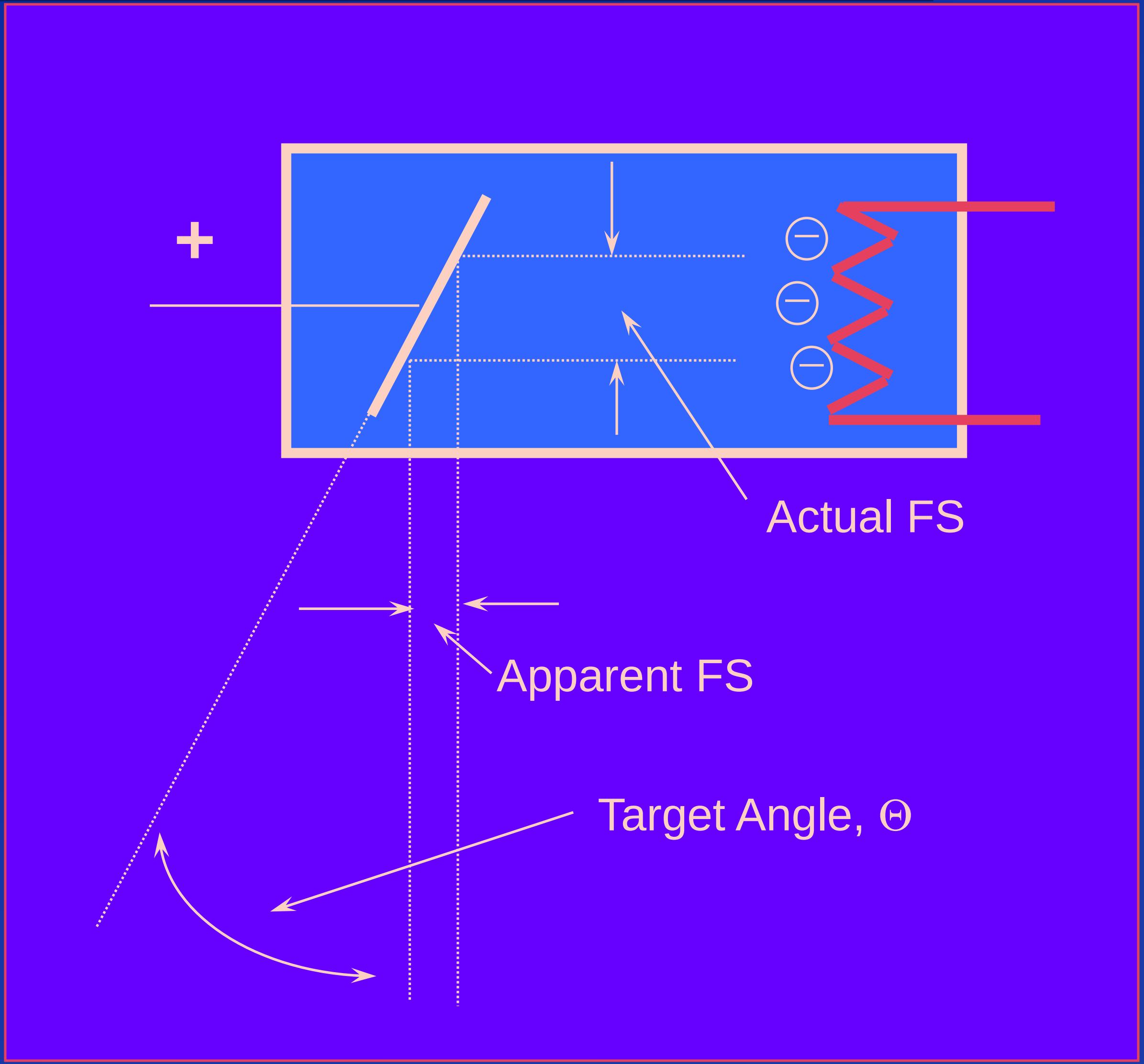
•The purpose of the rotating anode is to spread the heat a large area of the anode.

Line Focus

Focal spot
looks small from
patient's perspective

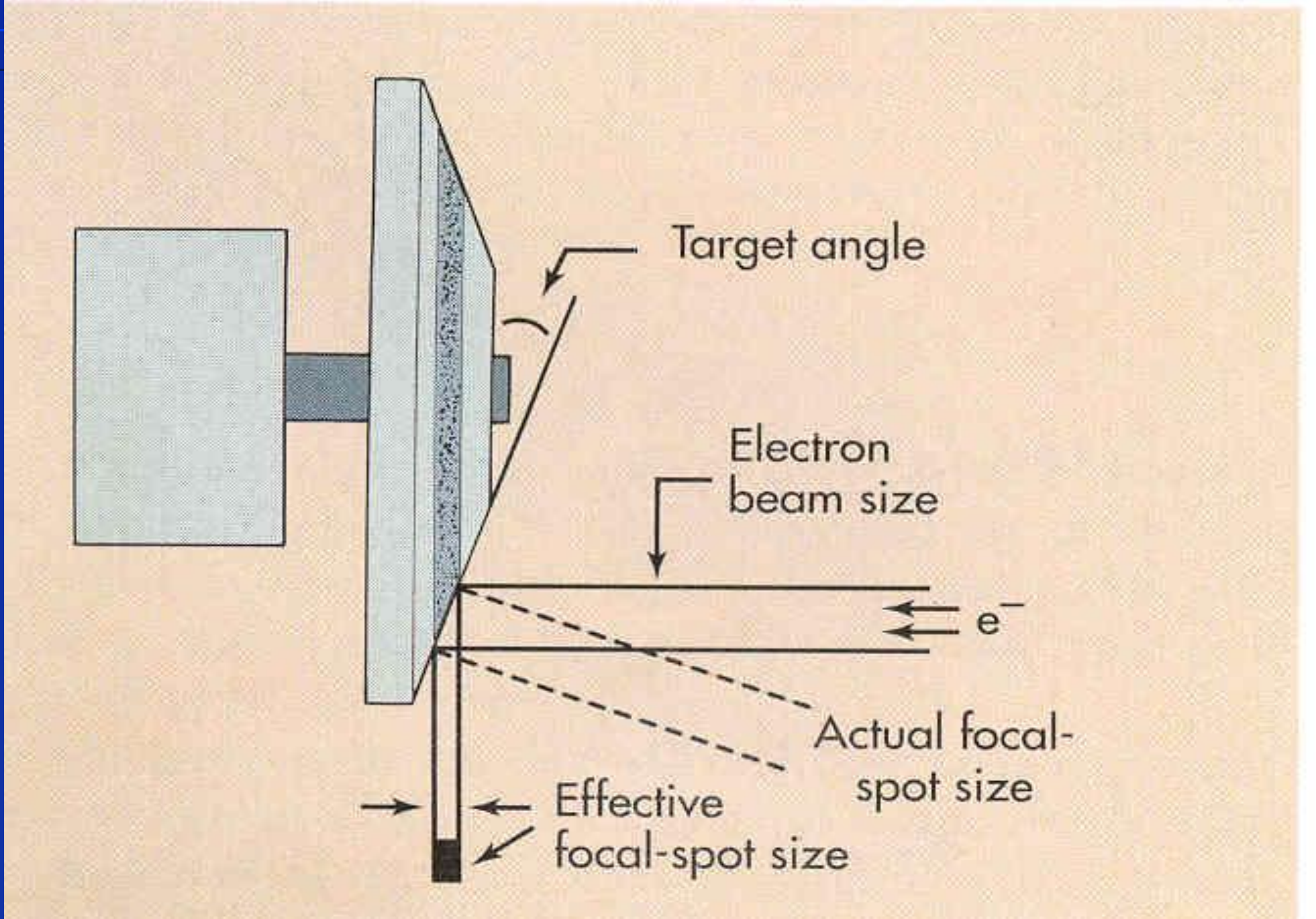
Imaging size
Looks large from
filament

better heat capacity



Apparent FS = Actual FS X sin Θ

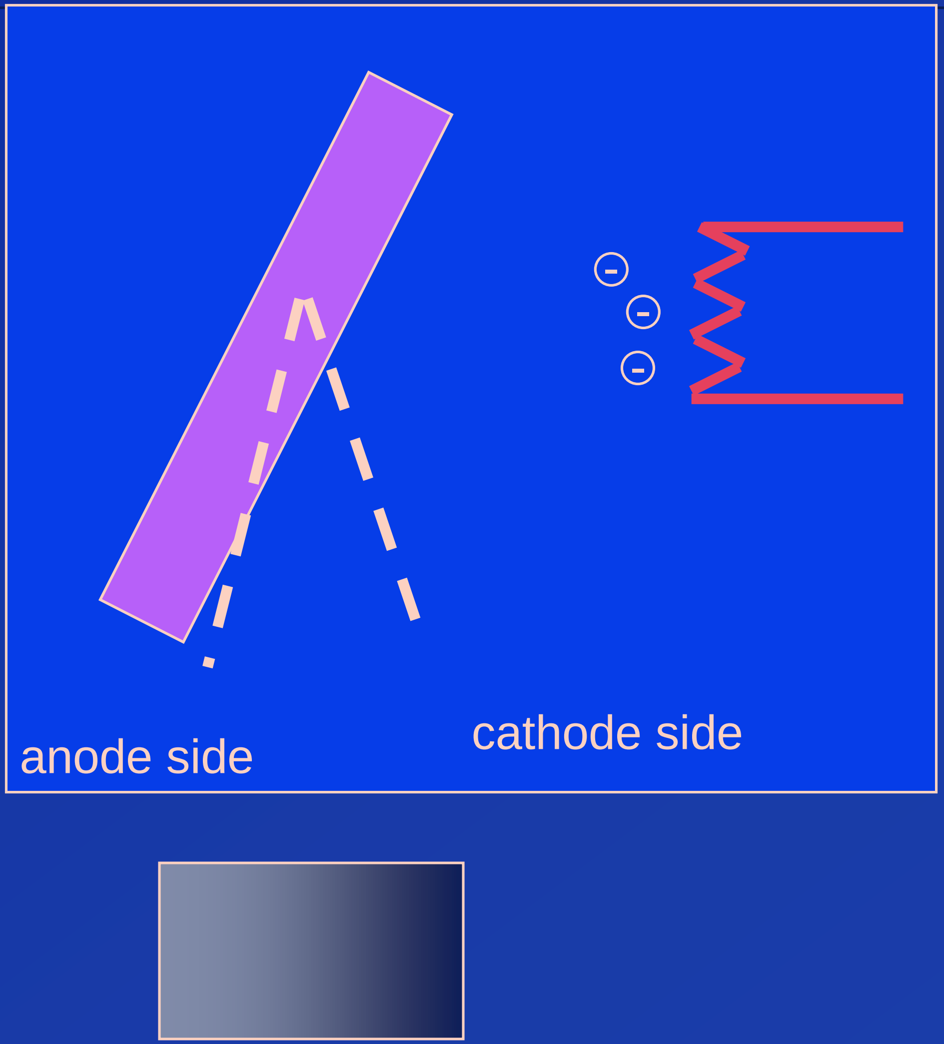
Line focus principle in Rotation Anode



- The unfortunate bi-product of the line-focus principle is the “anode heel effect”

Heel Effect

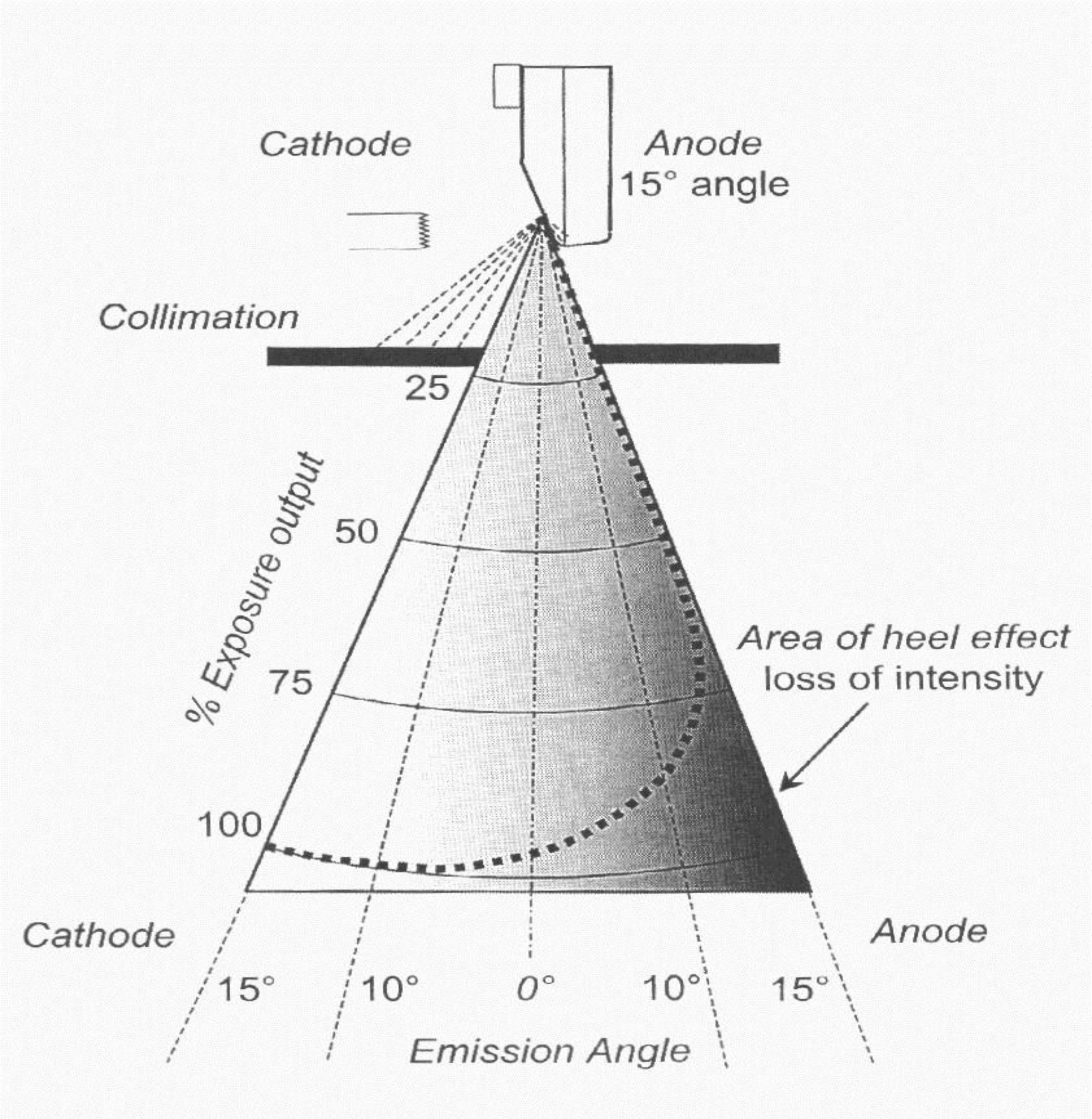
- Intensity of x-ray beam significantly reduced on anode body (anode side)
- beam goes through more target material exiting the anode



Heel effect

Intensity is not constant over the entire field of coverage.

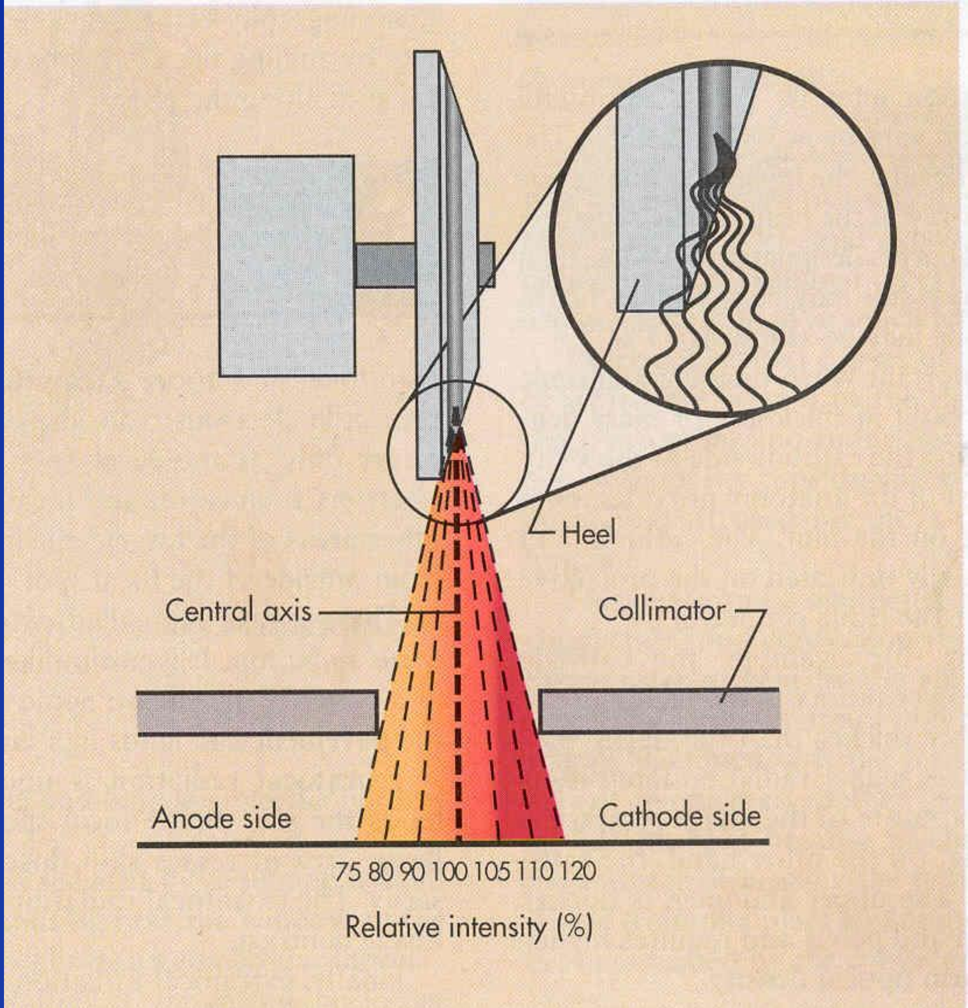
The shape of field is like a Heel.



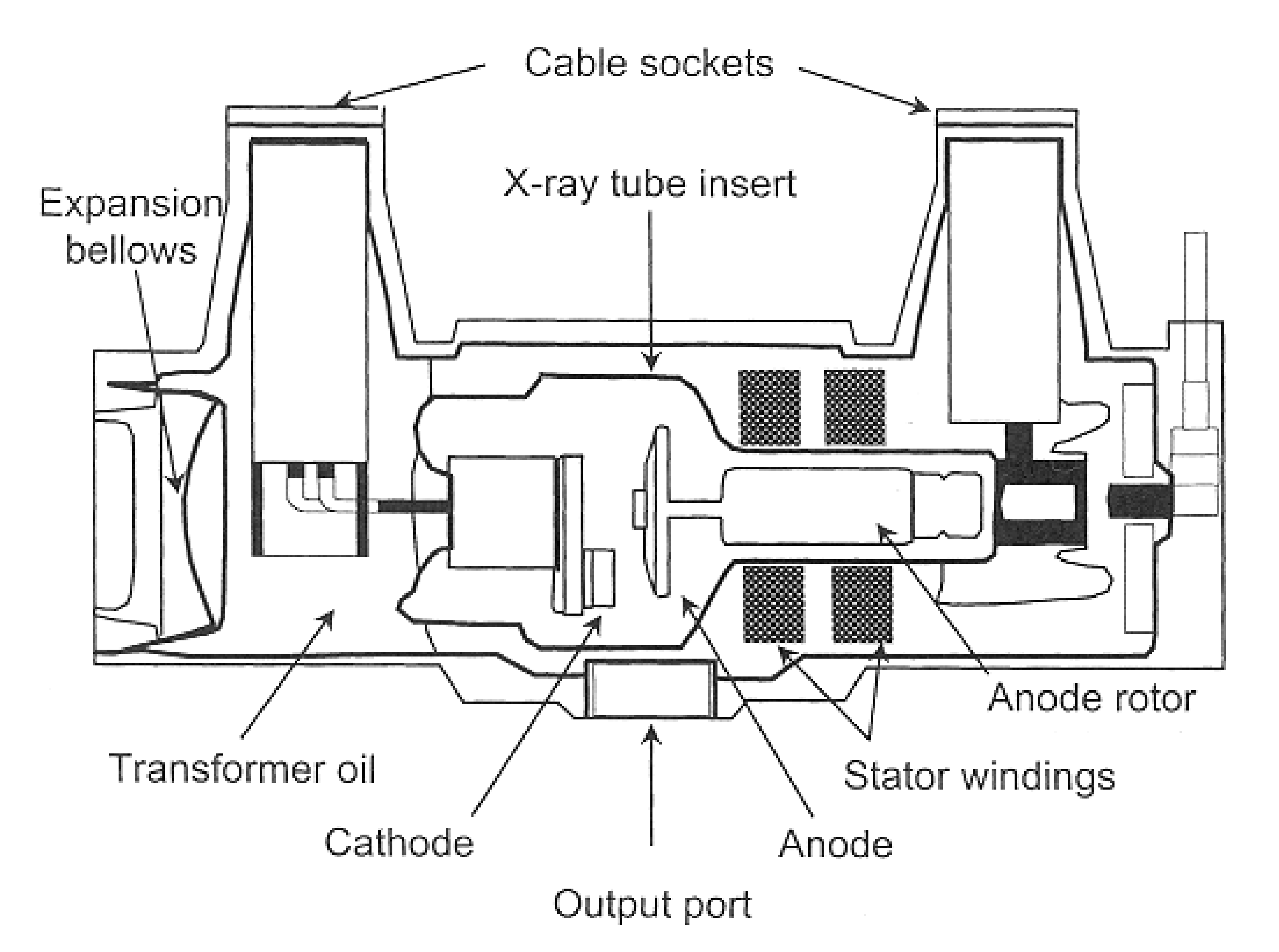
Anode heel effect

- Heel effect can be problematic.

- Heel effect should be consider during patient positioning and can be beneficial



ساختمان لامپ کامل اشعه x با آند دوار



X-ray Generator

- Electric power is needed in a x-ray tube for three objectives:
  (1) To boil off the electrons from the filament;
  (2) To accelerate electrons;
  (3) To control the exposure time.

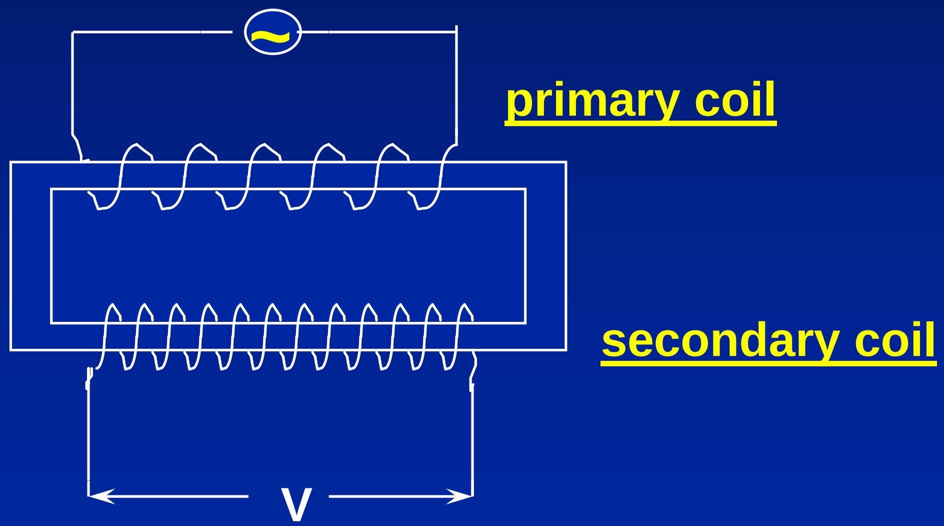
- The x-ray generator has a circuit for each of these objectives:
  (1) Filament circuit;
  (2) High-voltage circuit;
  (3) Time circuit

- Two compartments
  Control panel : Exposure switching, Exposure timer.
  Transformer assembly : Voltage transformers, Current rectifiers.

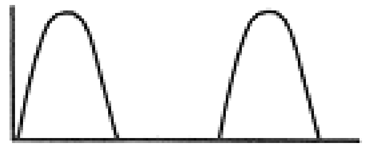
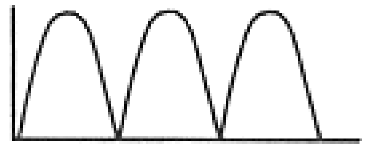
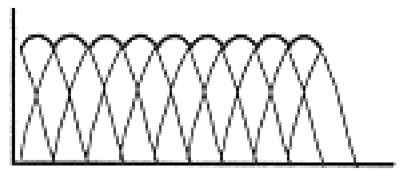
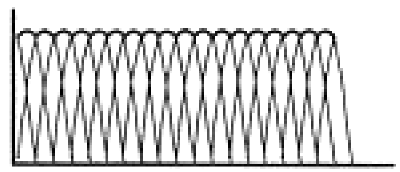
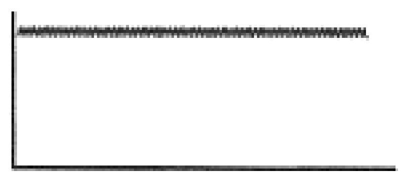
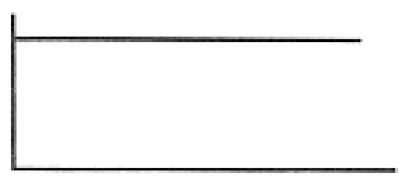
X-ray generator

- Voltage transformers provide low-voltage (~ 10 V) for the filament current
- and high-voltage (~ 150, 000 V) for the cathode-anode tube.

$$V_p/V_s=N_p/N_s$$



Principle of transformer: Changing magnetic field induces electric currents

Generator type	Typical voltage waveform	kV ripple
Single-phase 1-pulse (self rectified)		100%
Single-phase 2-pulse (full wave rectified)		100%
3-phase 6-pulse		13% - 25%
3-phase 12-pulse		3% - 10%
Medium--high frequency inverter		4% - 15%
Constant Potential		<2%

Xray Tube Rating Chart

Power=Heat Unit (HU) = kV.mA.S

35-kW X-ray tube can accept 500 mA for 0.1 sec exposure at 70 kVp.

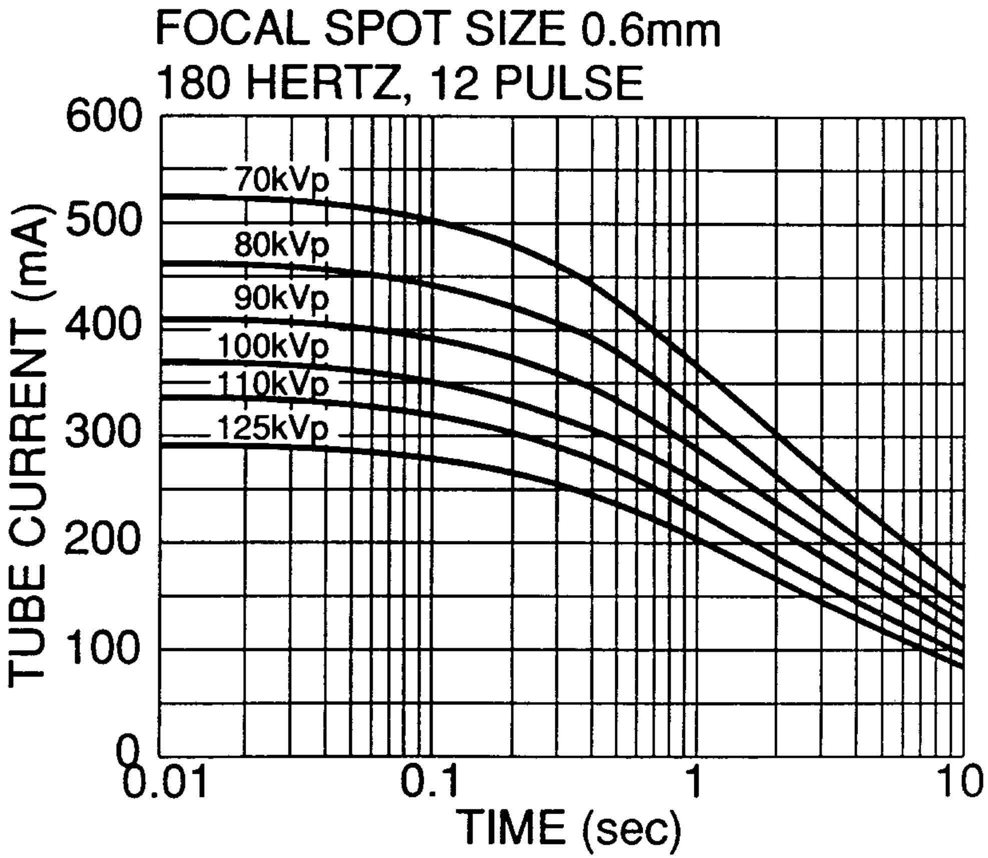
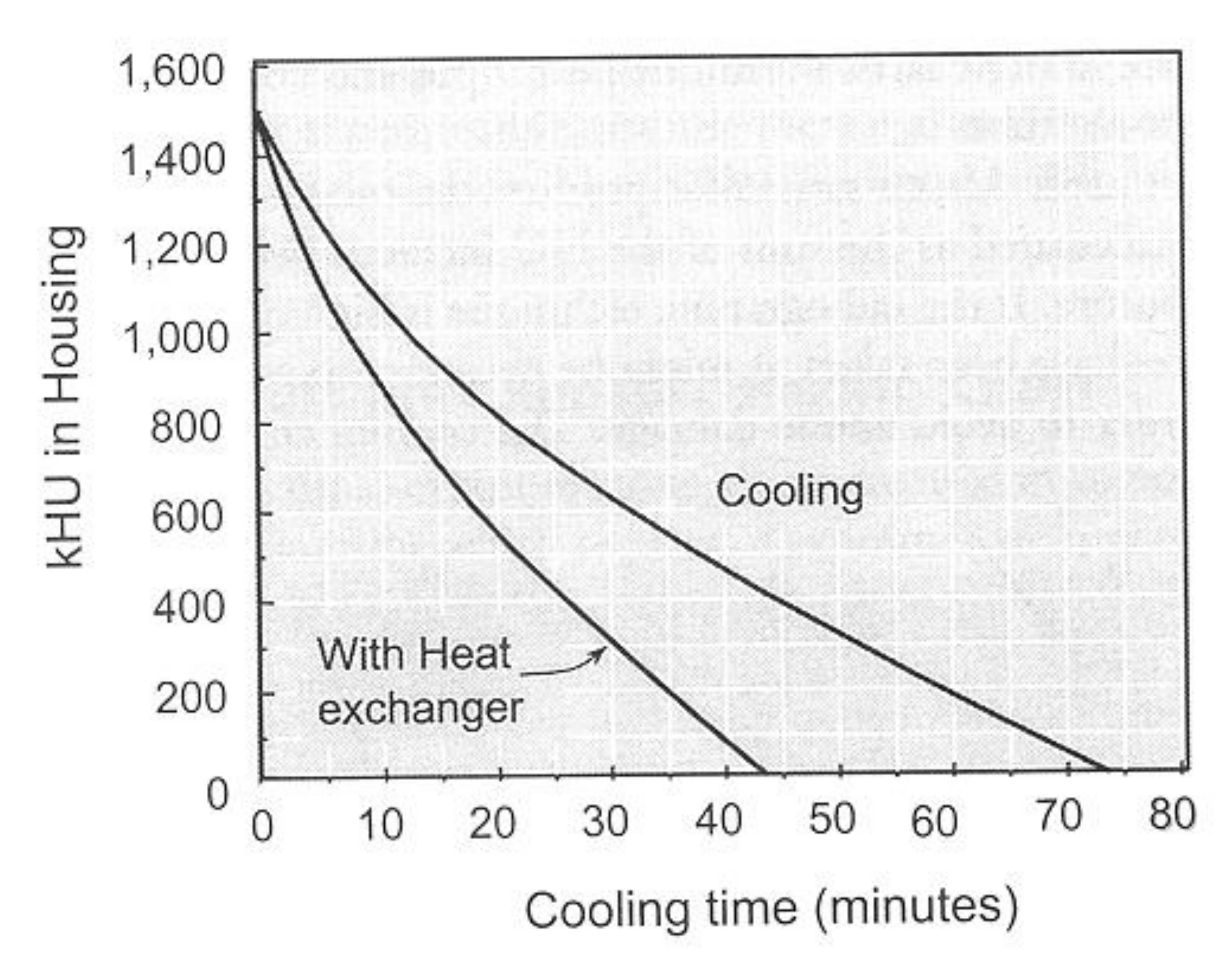


Figure 2–9 An x-ray tube rating chart



1,600
1,400
1,200
1,000
800
600
400
200
0
kHU in Housing
Cooling
With Heat
exchanger
0
10
20
30
40
50
60
70
80
Cooling time (minutes)

Useful Formulas

keV, kV_P , S (sec), and mA are the units particularly suited to x-ray physics.

E(keV) = 12.4/λ (angstrom)
1 angstrom =10^{-10} m
1 eV = 1.6 X 10-19 joules
1 e = 1.6 X 10-19 coulombs
1 joule = 1 coulomb X 1V
1 cal = 4.184 joule
1 ampere = 1 coulomb/sec