X-Ray Production

The components of an X-ray tube

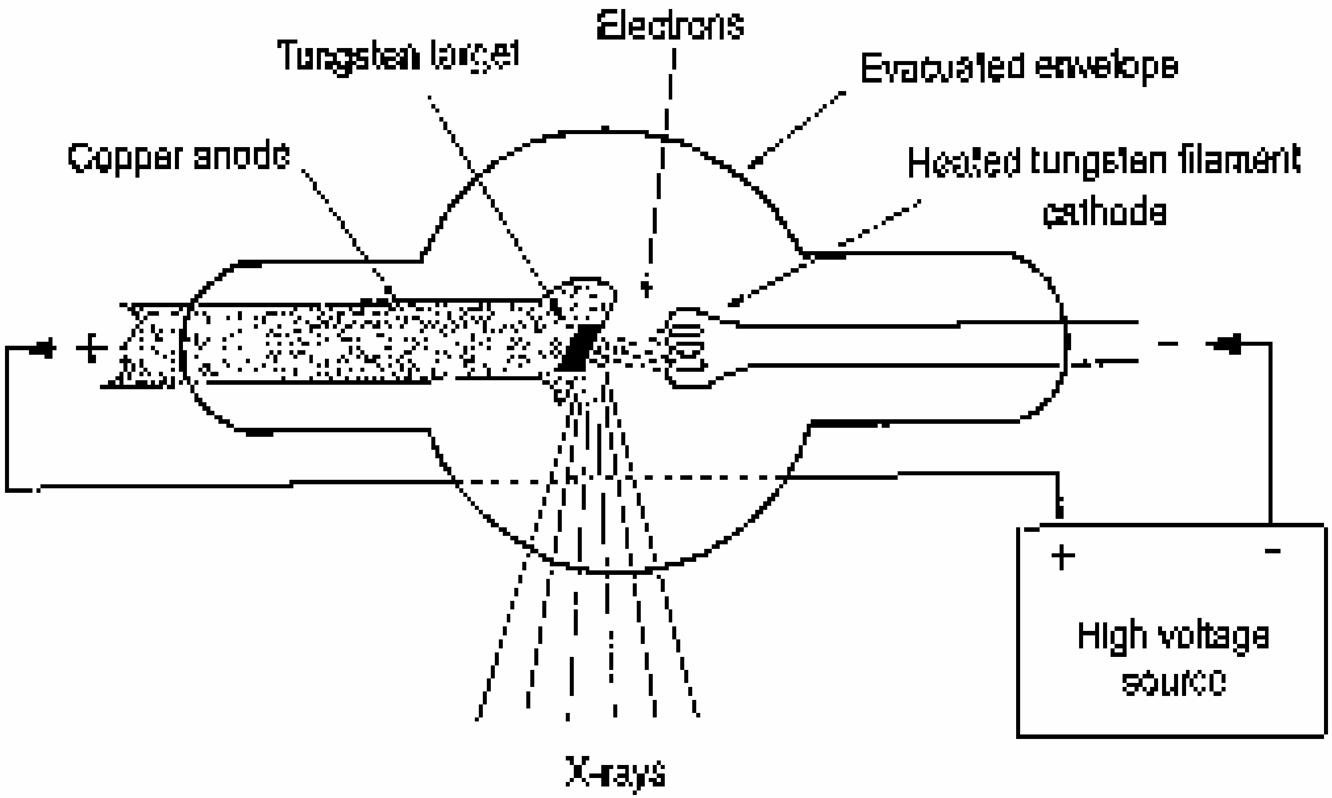
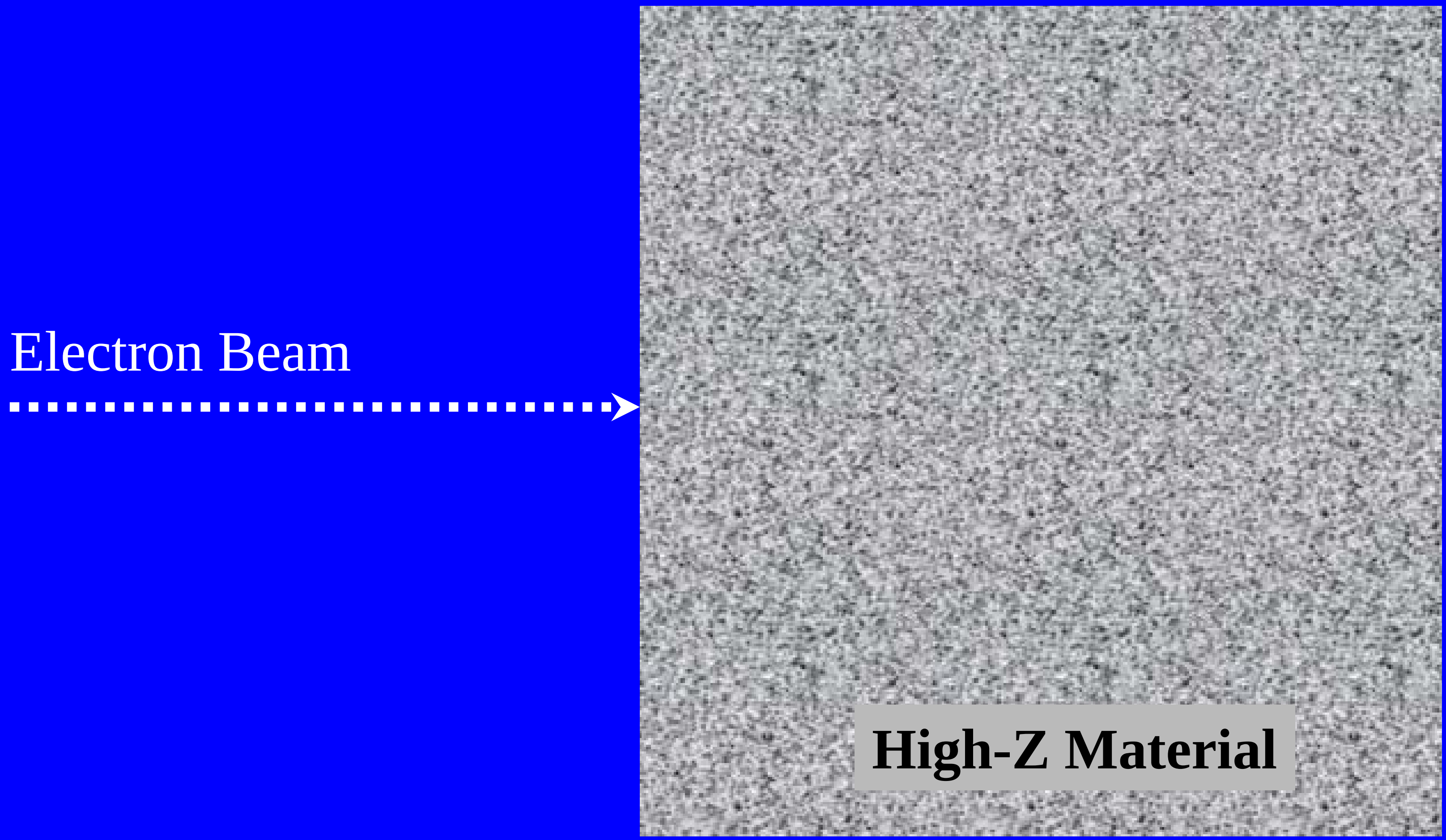
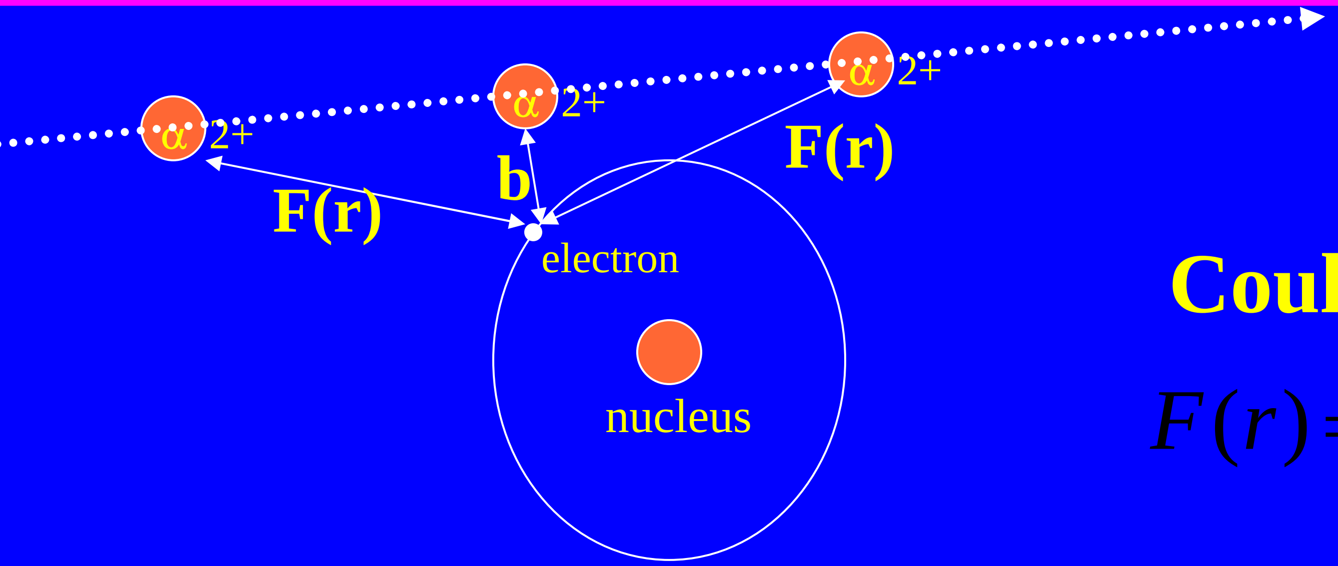


Figure 4.1. X-ray production requirements include a source and target of electrons, evacuated envelope, and high-voltage source.

High energy electron beam striking high-Z material



STOPPING POWER

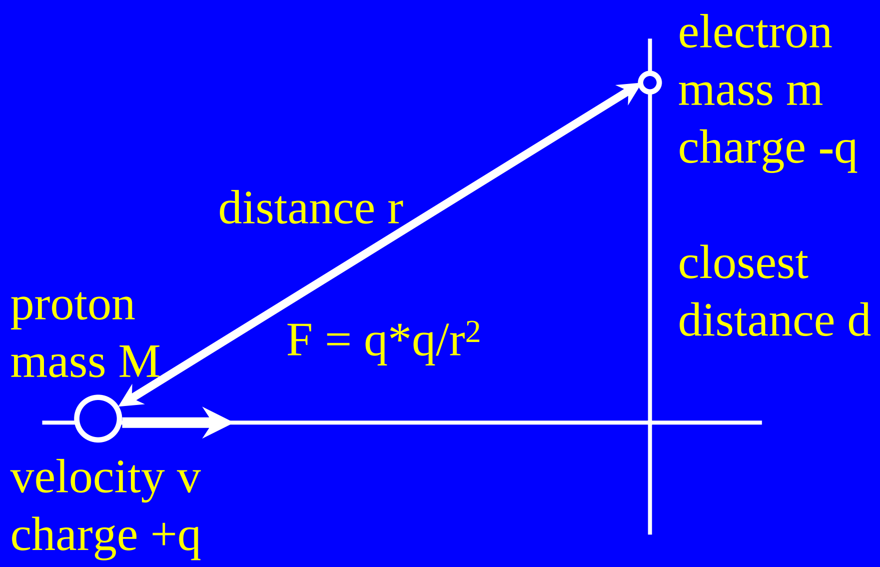


Coulomb force

$$F(r) = \frac{q*Q}{r*r}$$

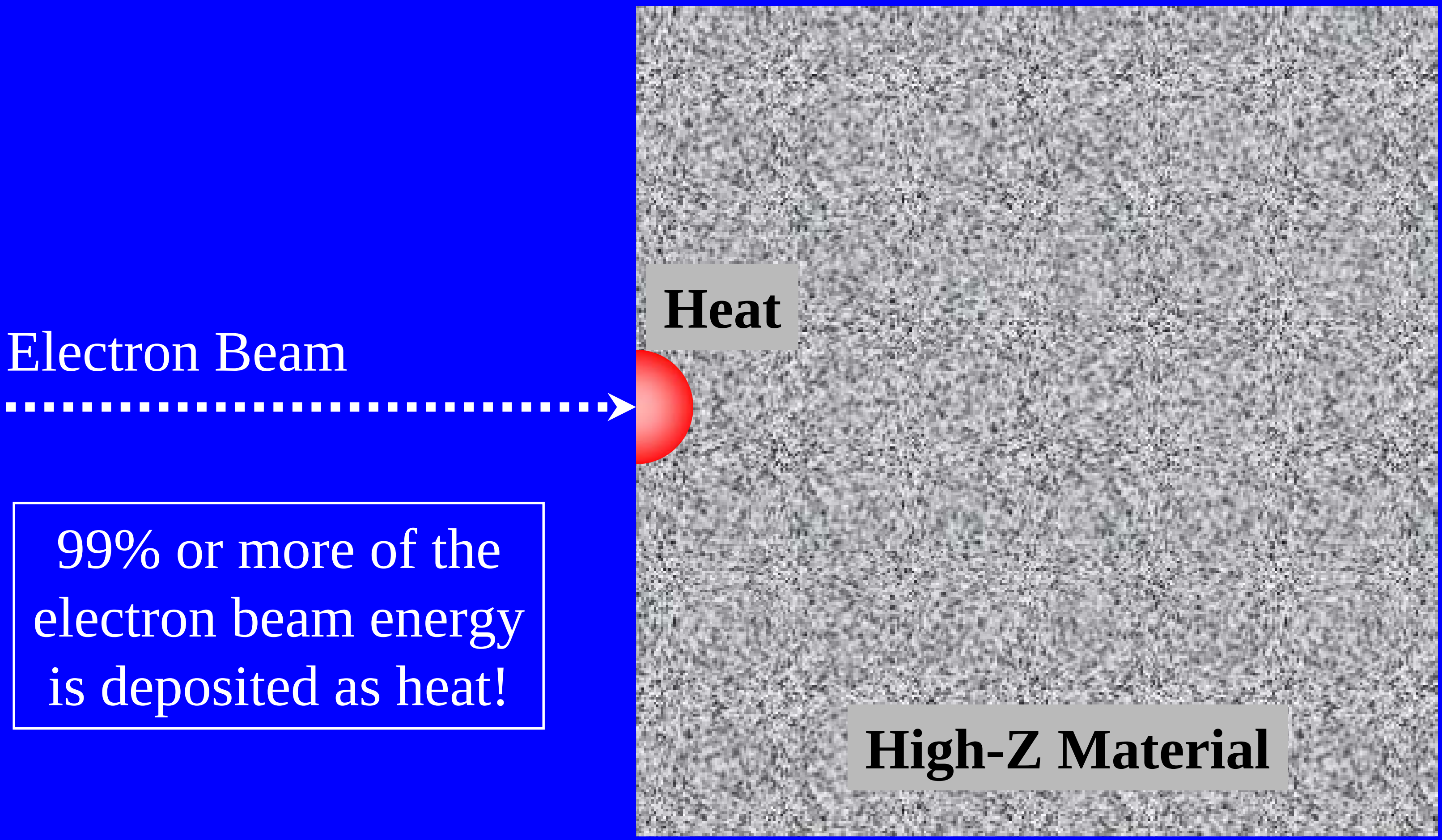
$$Momentum = \int F\,dt = \frac{2ze^2}{bv}$$

$$Energy = \frac{2ze^4}{mb^2v^2}$$



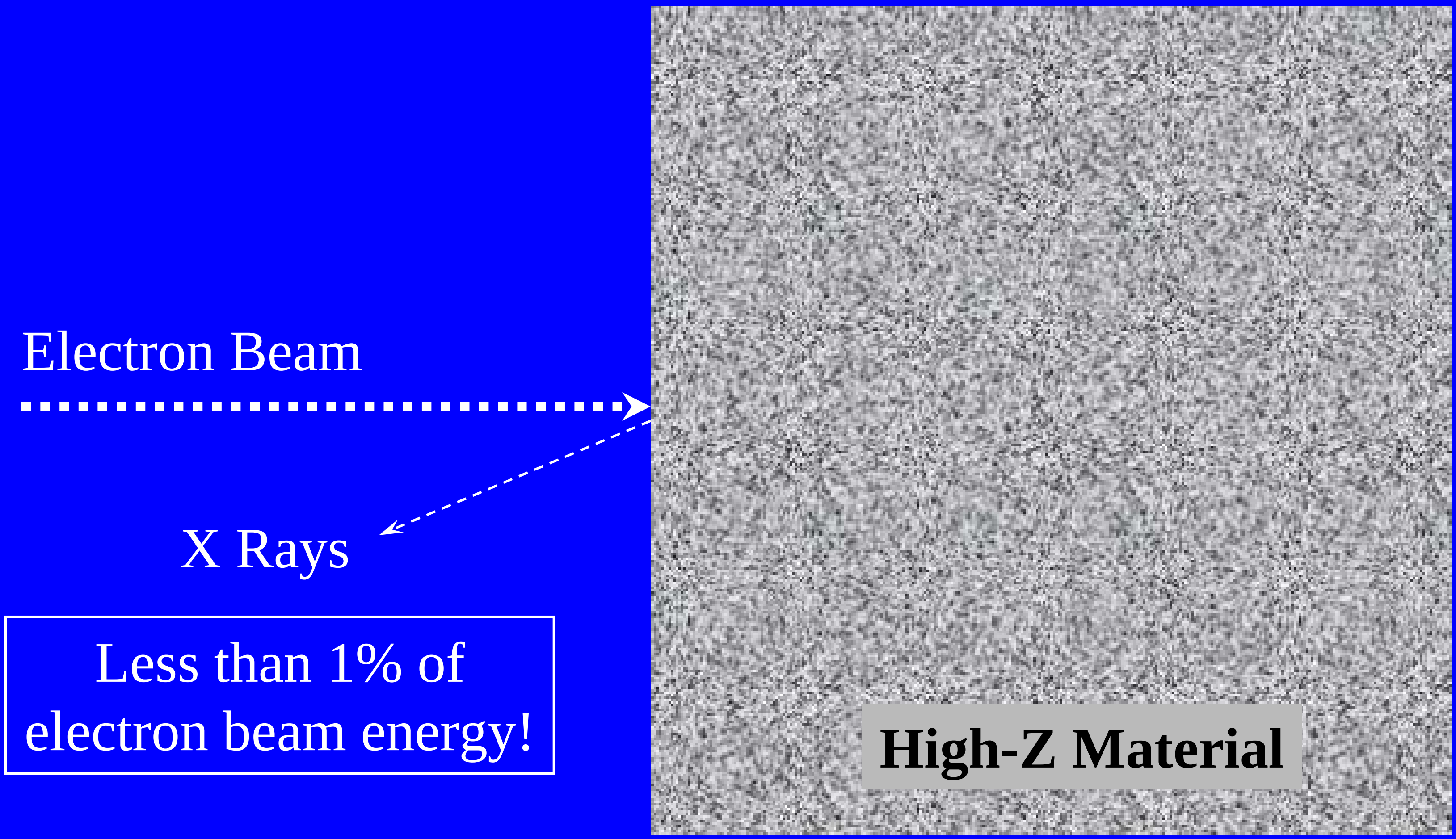
High energy electron beam striking high-Z material produces Heat

Electron Beam

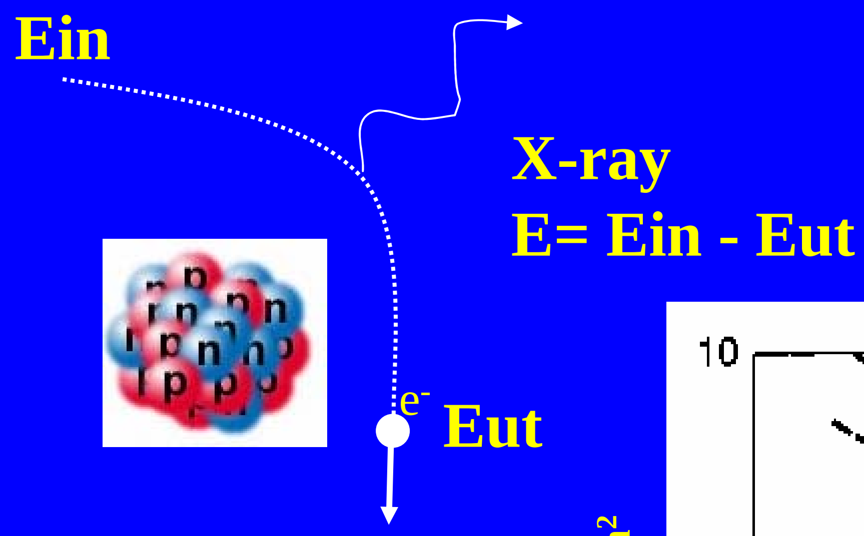


99% or more of the electron beam energy is deposited as heat!

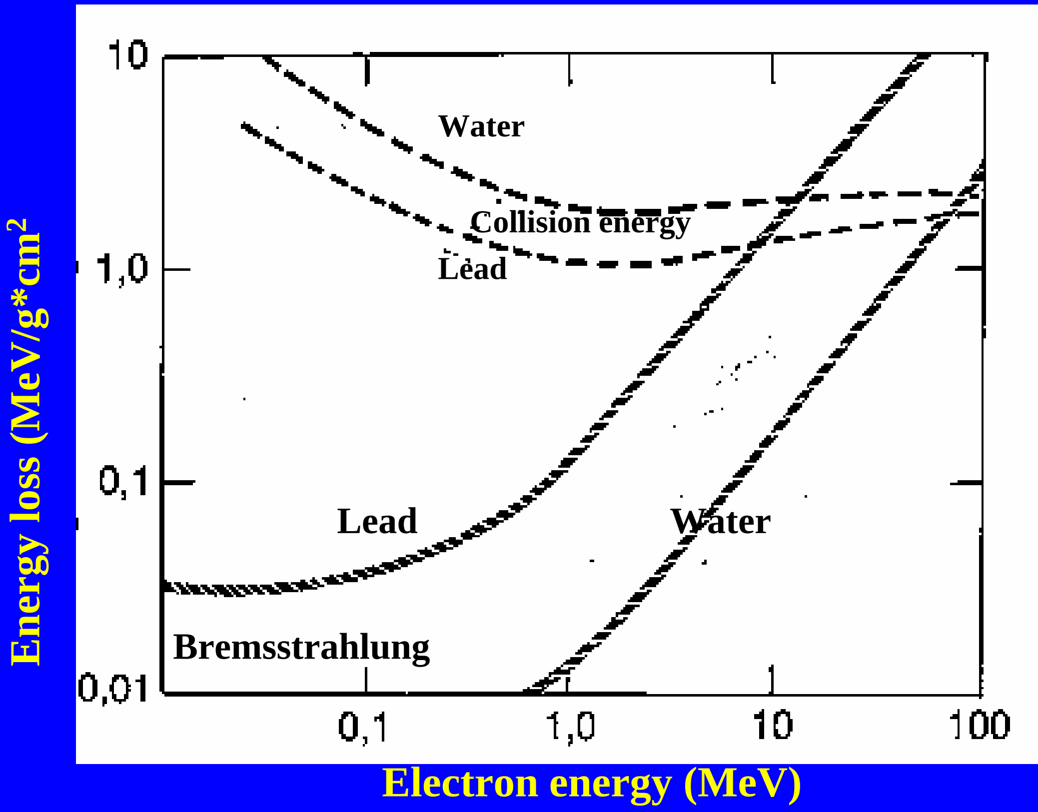
High energy electron beam striking high-Z material produces Heat and X Rays.



Creation of bremsstrahlung

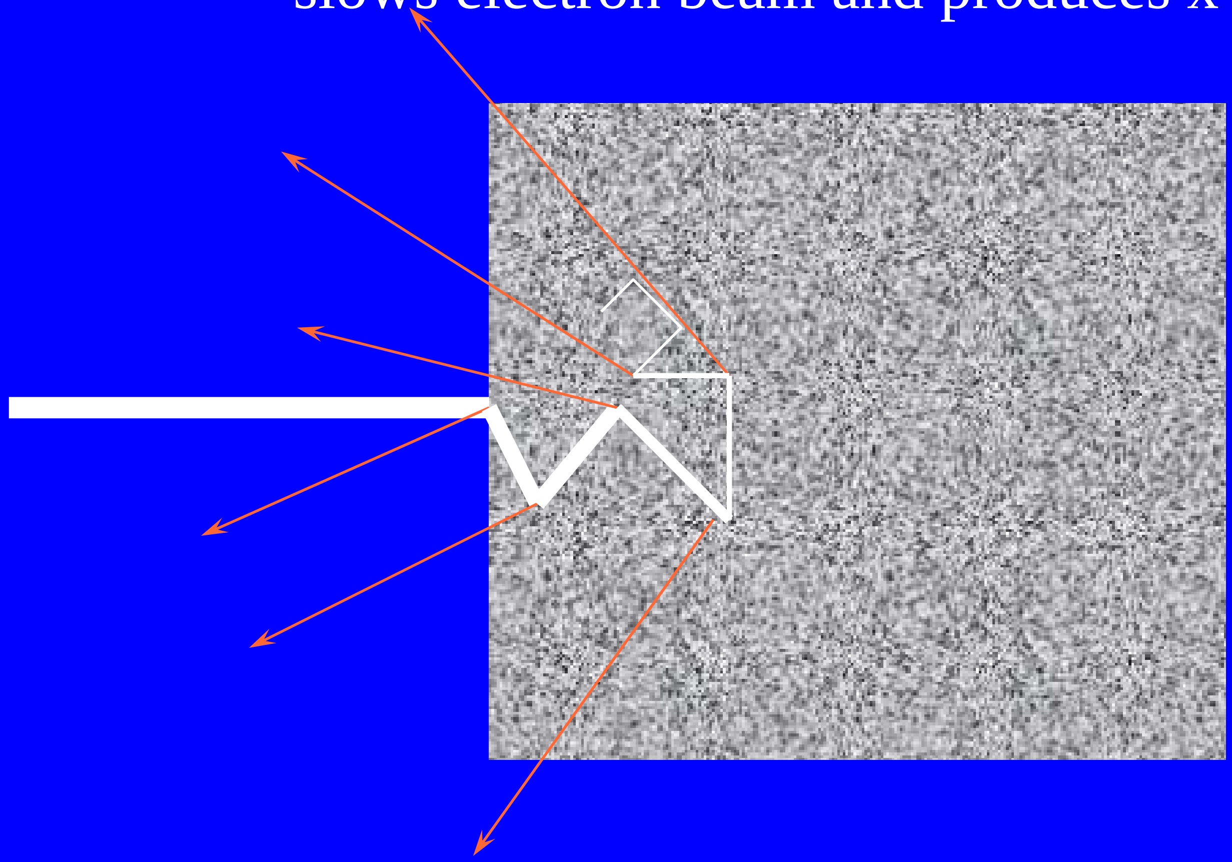


Bremsstrahlung

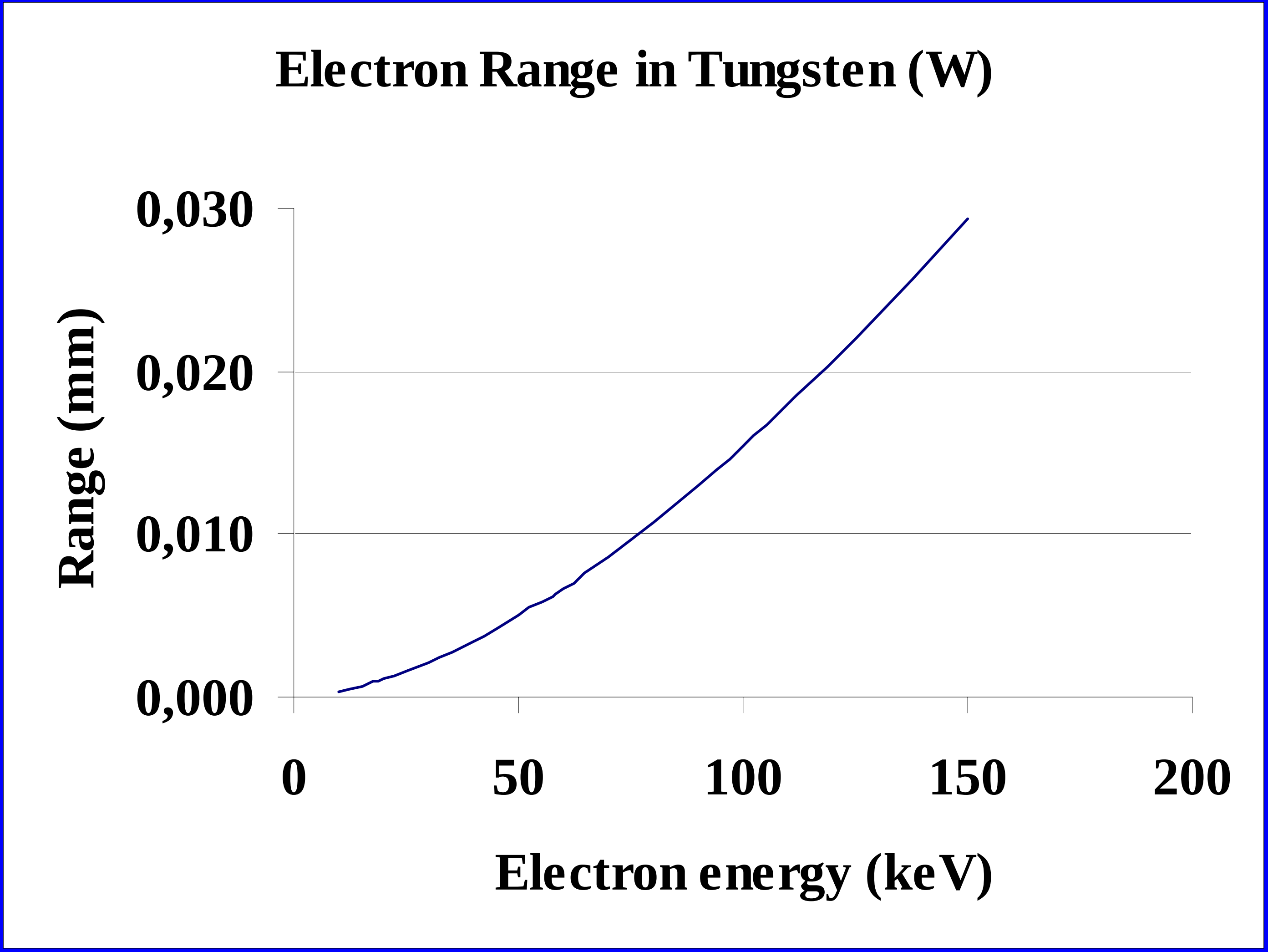


Bremsstrahlung “braking” radiation

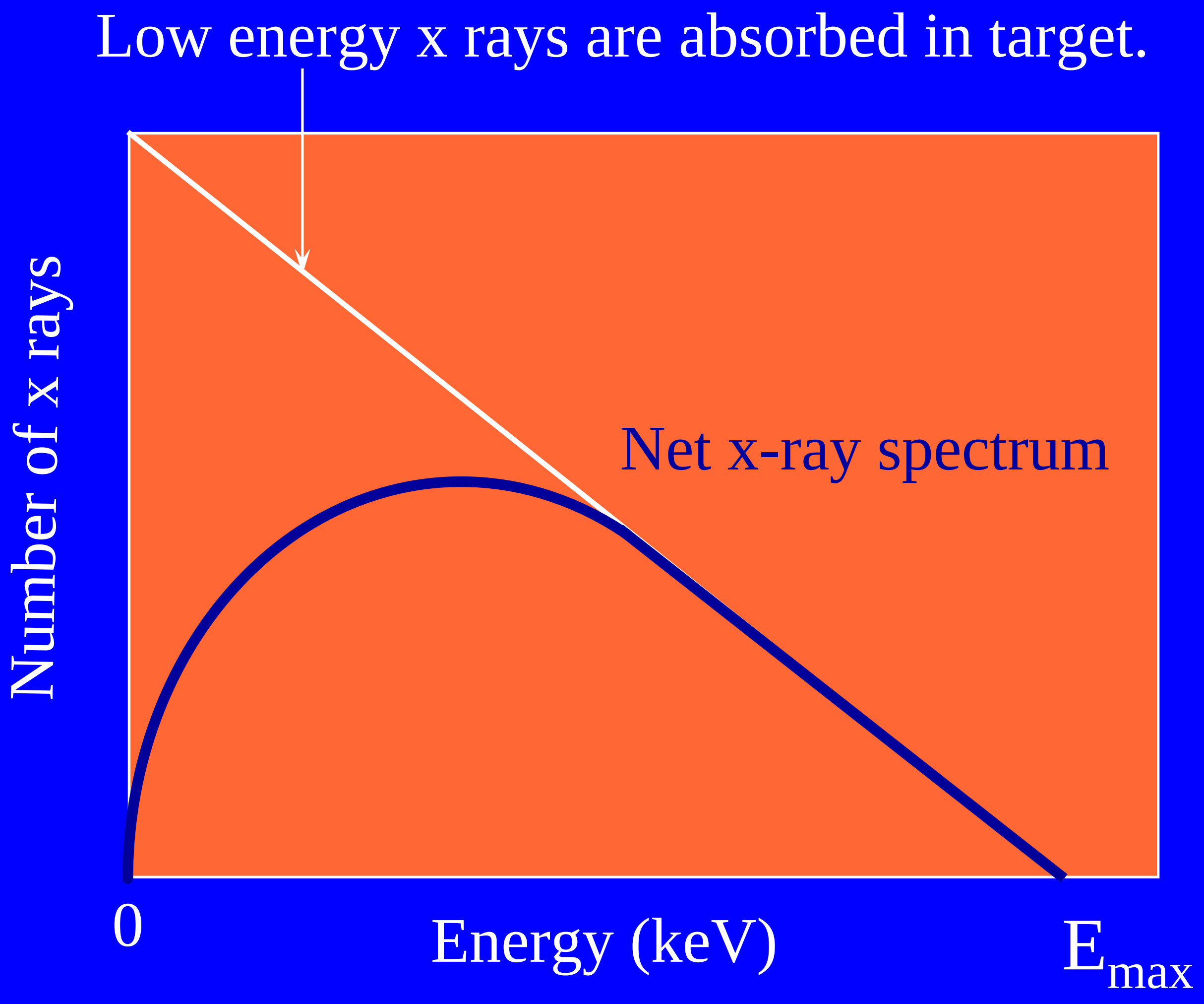
Collision with weakly-bound electrons slows electron beam and produces x rays.



Electron range in a Tungsten anode



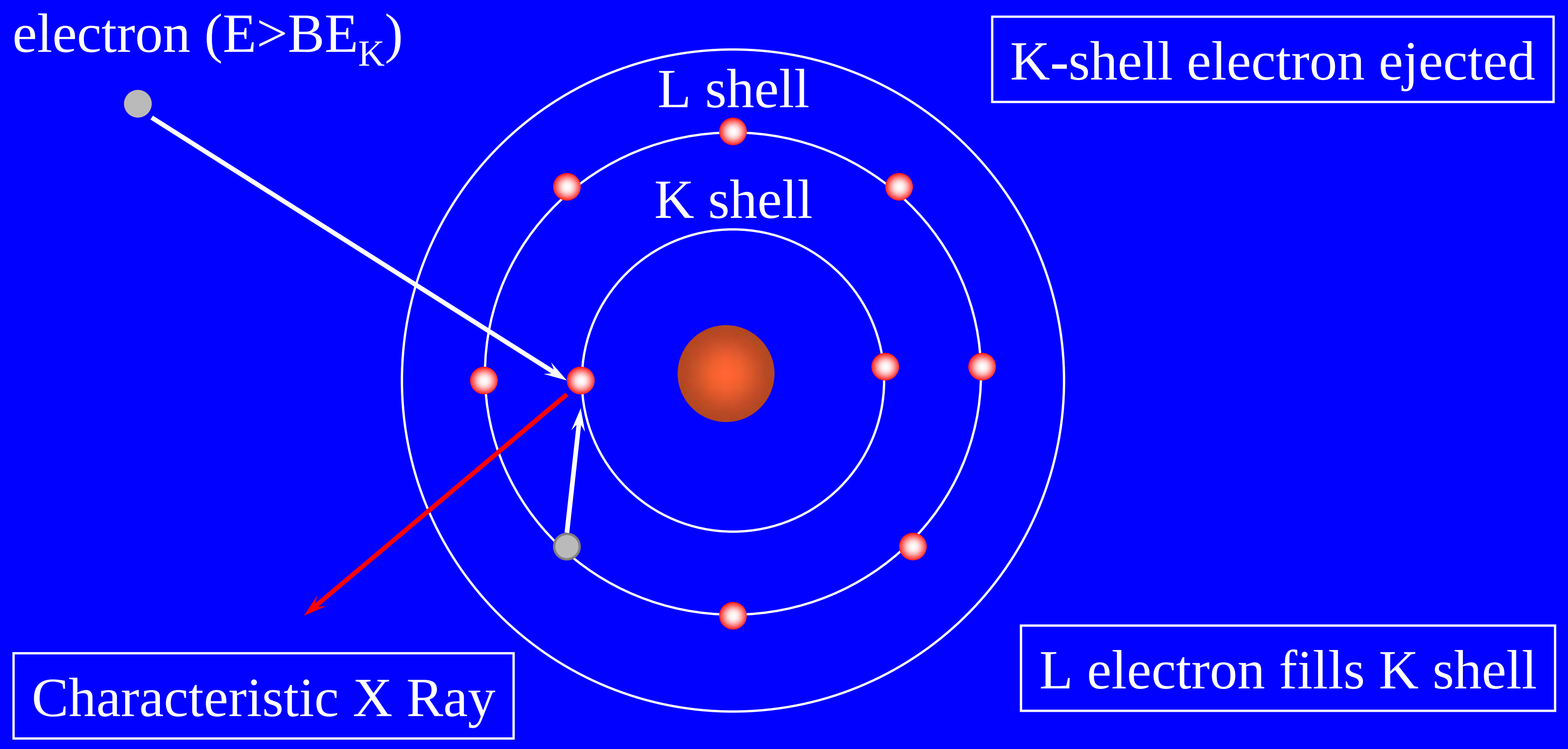
Energy of x rays is function of electron beam energy, E_{max}



Bremsstrahlung x-ray properties

- electron beam interaction with loosely-bound electrons
- electron looses energy with successive e^- collisions
- continuous spectrum of x-ray energies
- highest x-ray energy = $E_{electron}$
- Interaction proportional to Z
- Interaction proportional to $E^2_{electron}$

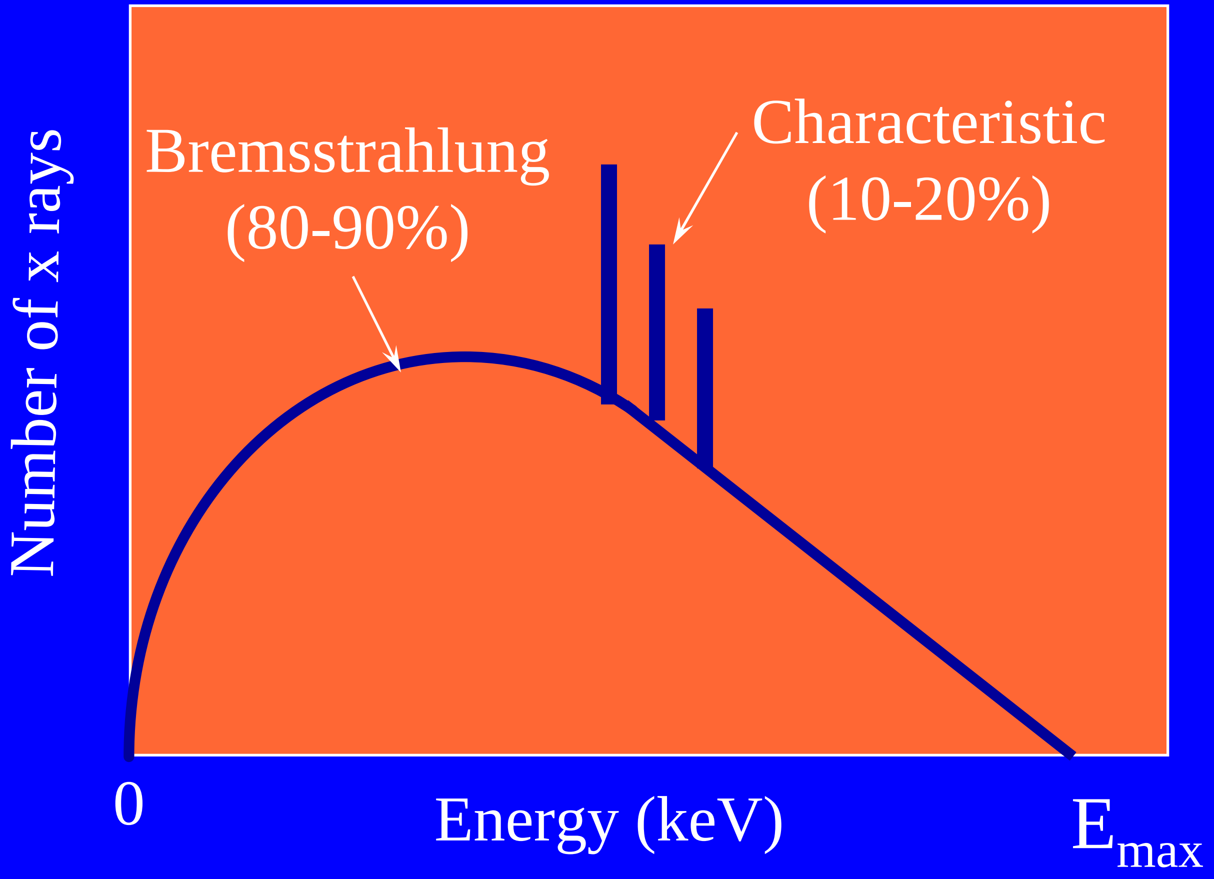
Characteristic x rays produced by photo-electric absorption of tightly-bound electrons



Characteristic x-ray energies

- electron beam interaction with tightly-bound electrons
- K shell most important
- $E_{electron} > BE_K$
- discrete x-ray energies emitted
- x-ray energies = difference in BE
- maximum x-ray energy = $BE_K - BE_L < BE_K$
- BE_K proportional to Z^2

Typical x-ray spectrum



Fixed contra rotating anode

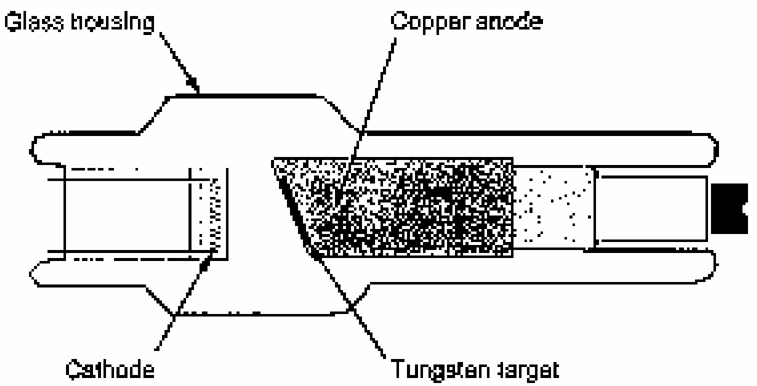


Figure 4.10. The fixed anode x-ray tube is comprised of a tungsten insert placed in a copper block. Heat is removed (dissipated) from the target area by conduction into the copper block.

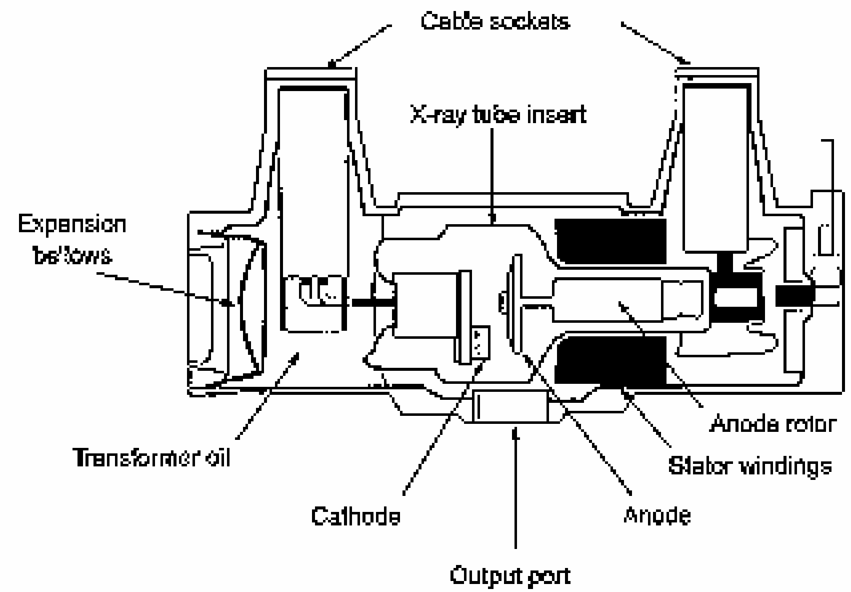
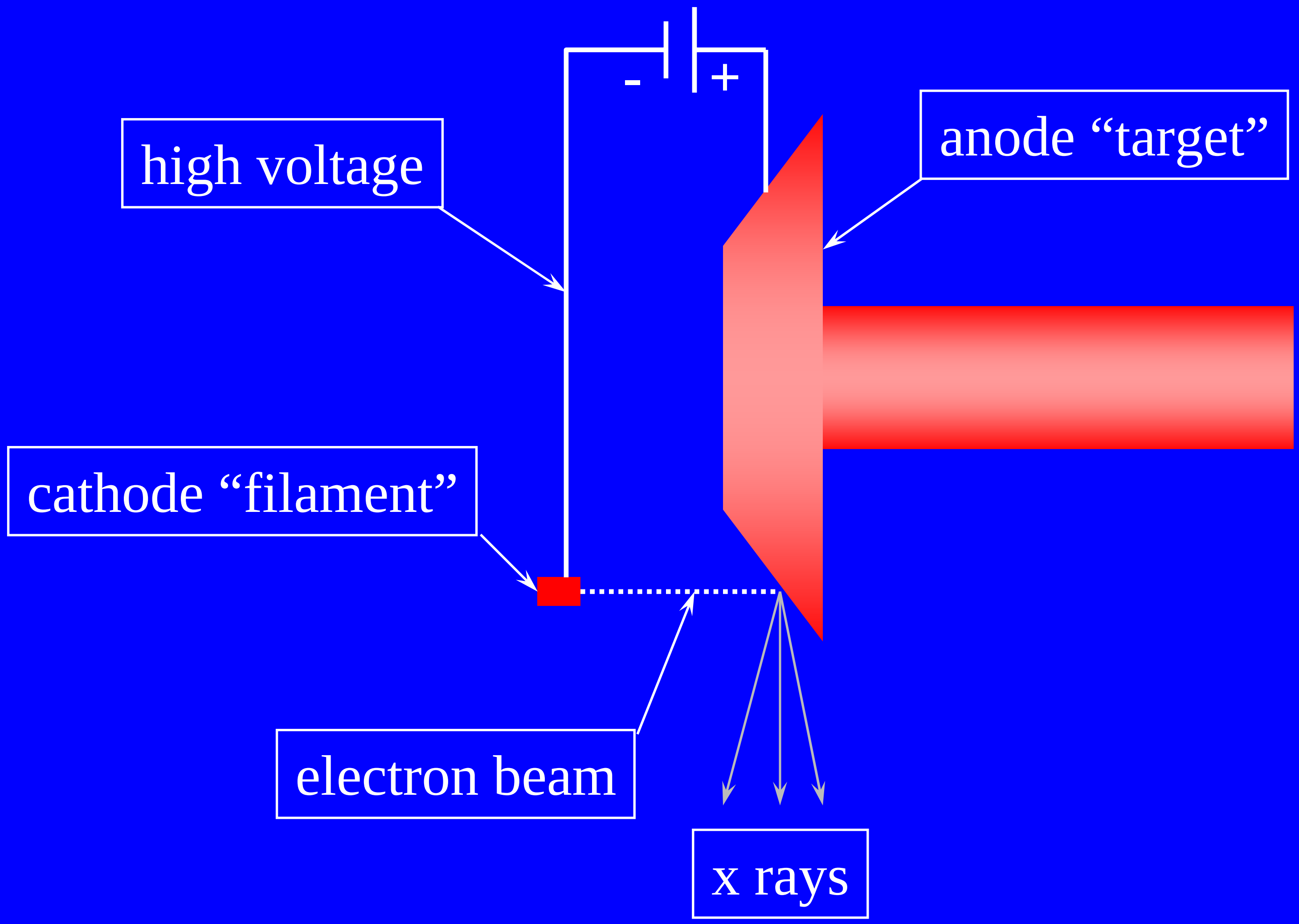
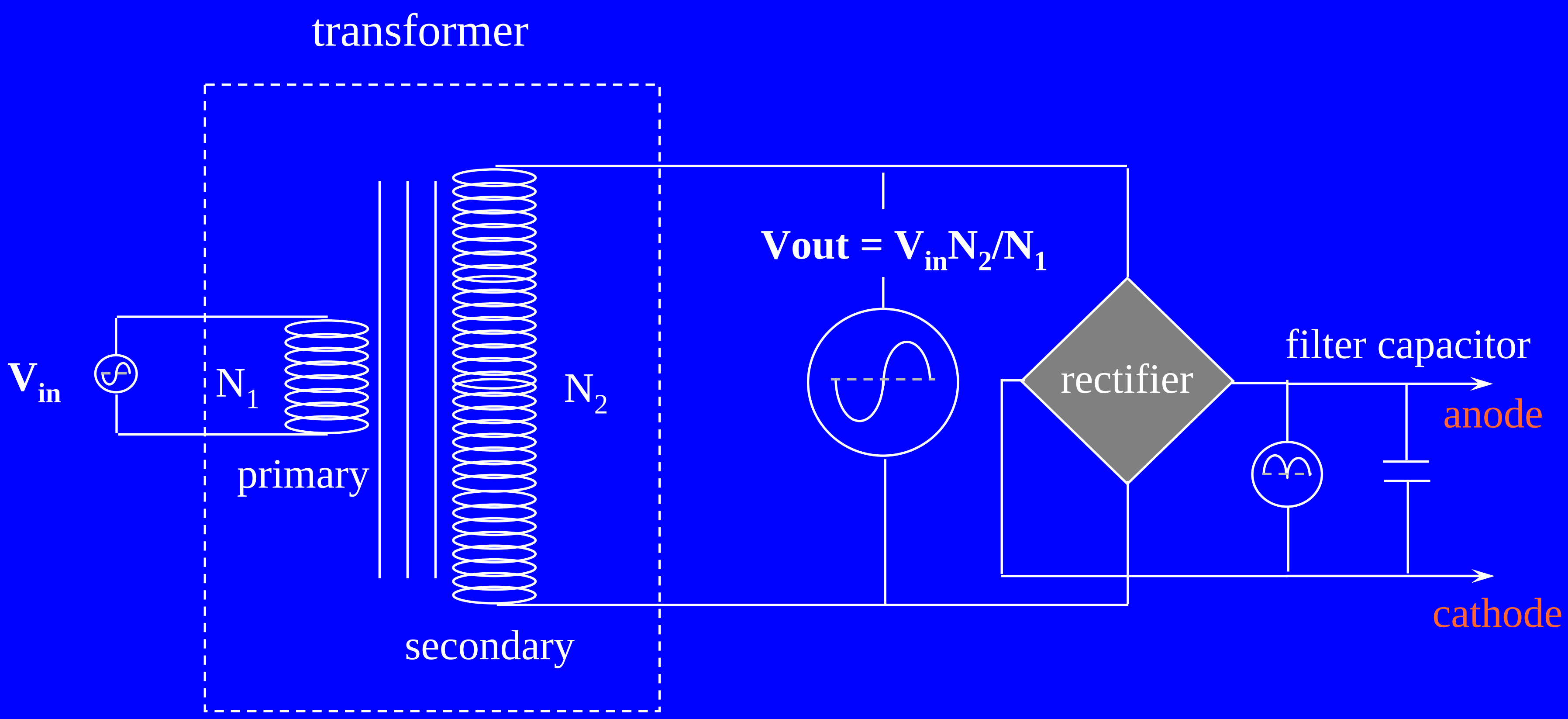


Figure 4.6. A modern x-ray tube and housing assembly.

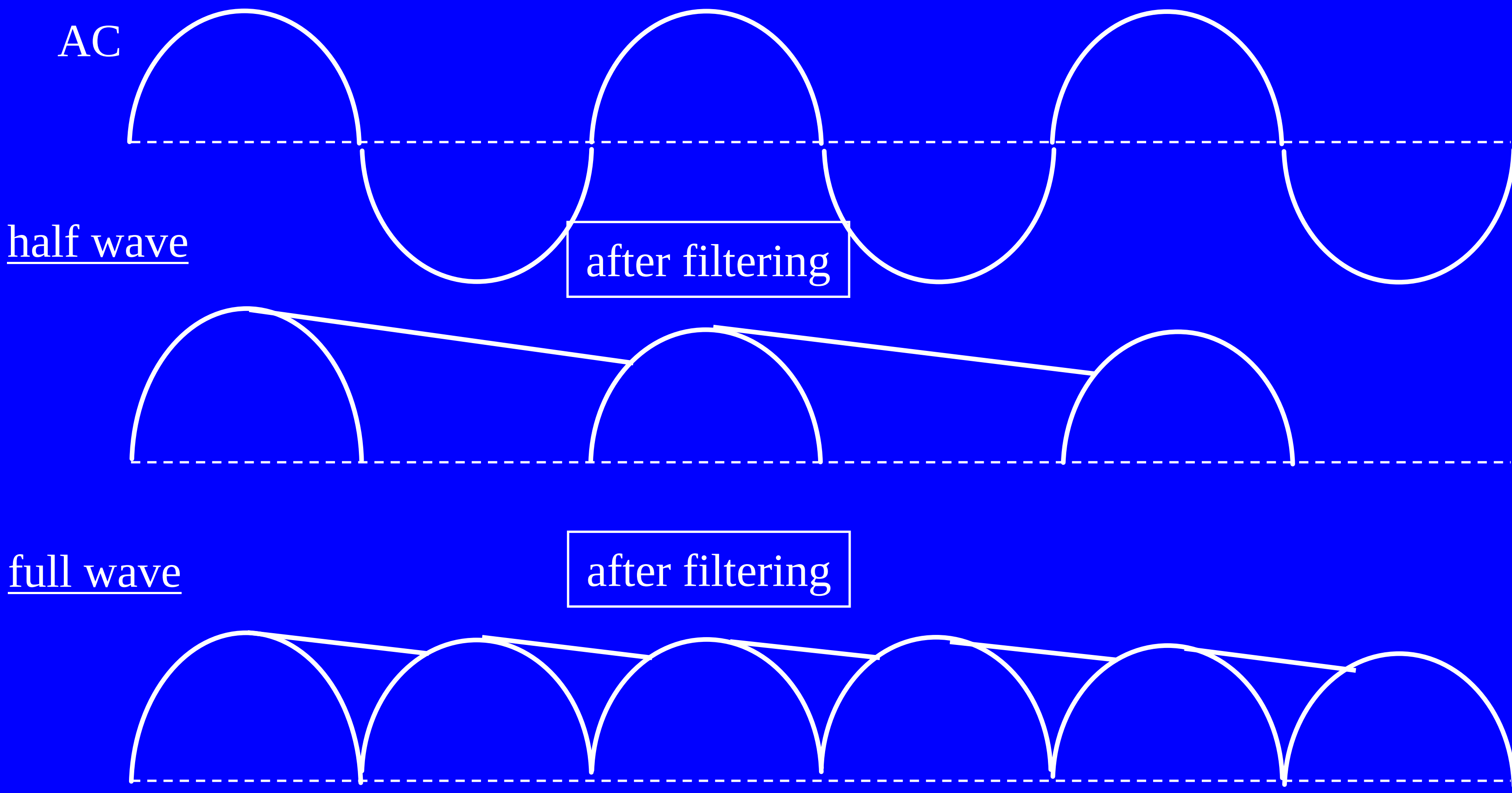
X ray tube design



High voltage generation

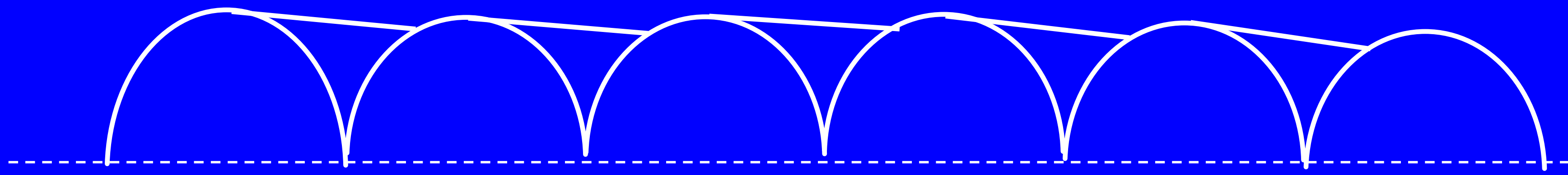


Types of rectification



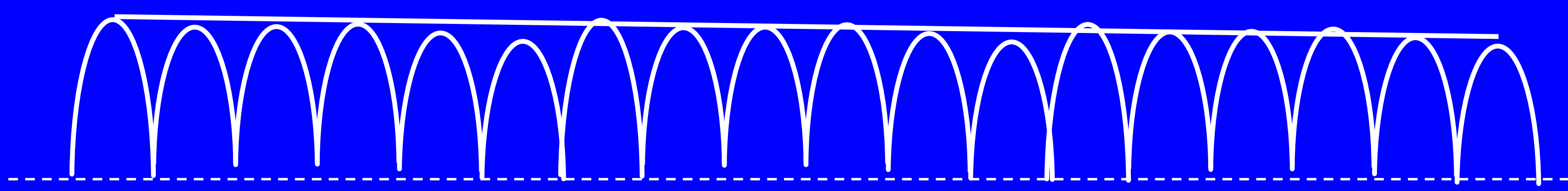
Three phase versus single phase

single phase



after filtration

three phase



High voltage ripple decreases spectrum energy

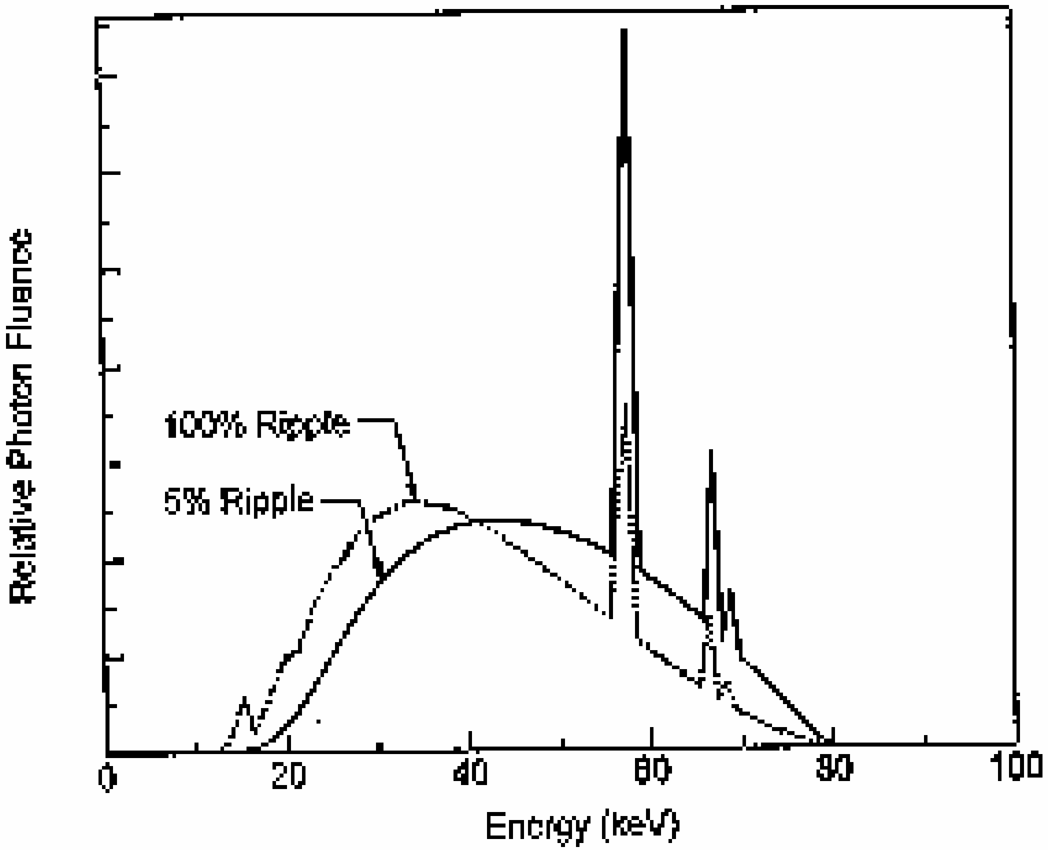


Figure 4.29. Output intensity (bremsstrahlung) spectra of a single-phase (100% ripple) versus a 3-phase generator (5% ripple at 80 kVp) for a given kVp and mAs demonstrate the higher effective energy and greater output of the low-voltage ripple 3-phase generator.

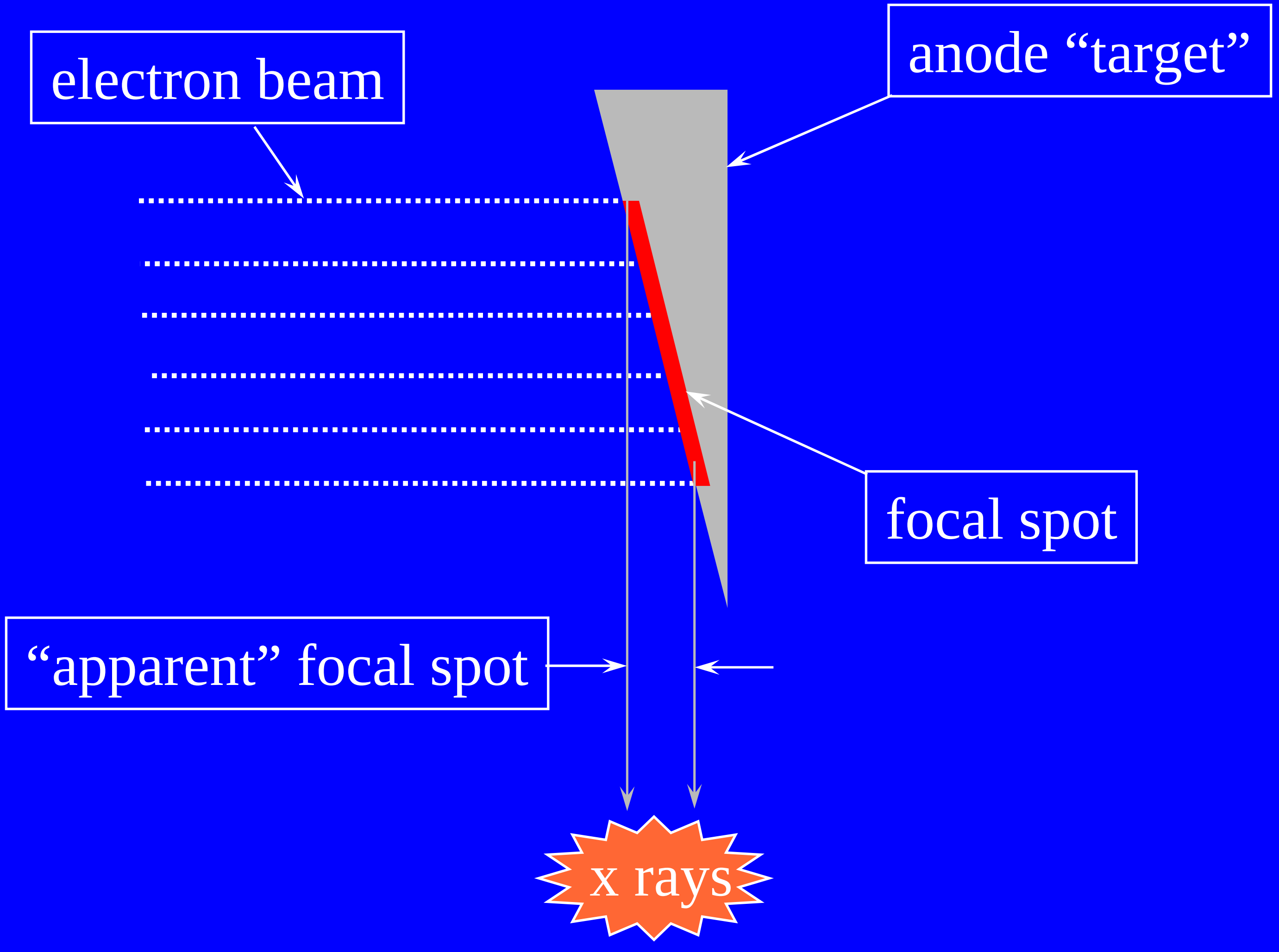
High voltage generator properties

- full-wave rectification better than half-wave
- three phase better than single phase
- twelve-pulse, full-wave better than six-pulse, full wave

HV generator controls

- peak kilovoltage (kVp)
- tube current (mA)
- exposure time (s)
- total energy delivered to tube:
  Energy = kVp * mA * s = kVp * mAs
- instantaneous power delivered to tube:
  Power = kVp * mA
- x-ray tube limited in both power and energy

Focal spot geometry



Focusing the electron beam increase resolution

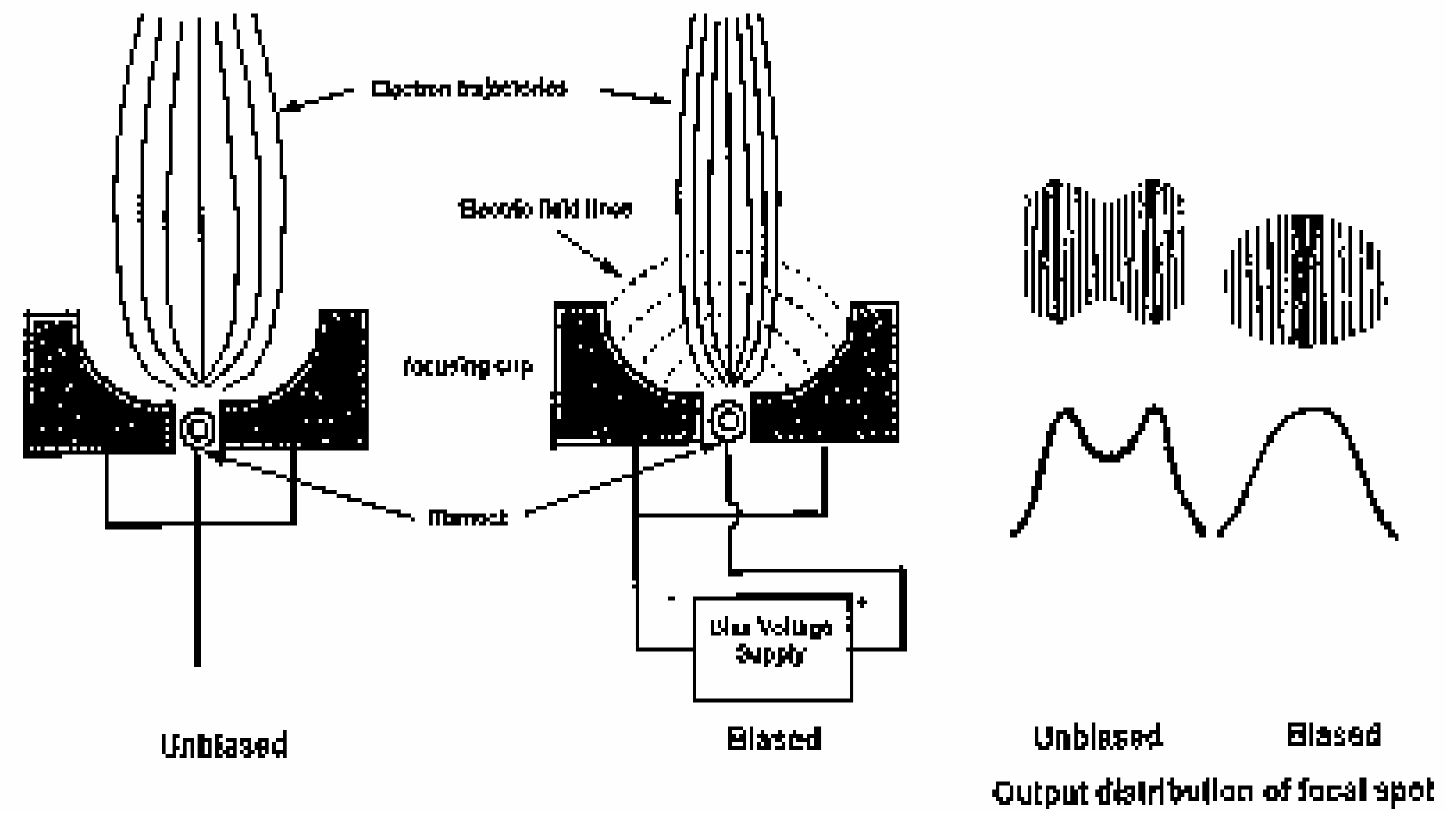


Figure 4.8. Output distribution of focal spot with unbiased and biased focusing cup. The focusing cup shapes the electron distribution leaving the cathode filament. A negative bias voltage further restricts the electron distribution to achieve a smaller focal spot size.

Anode angle relates to beam width

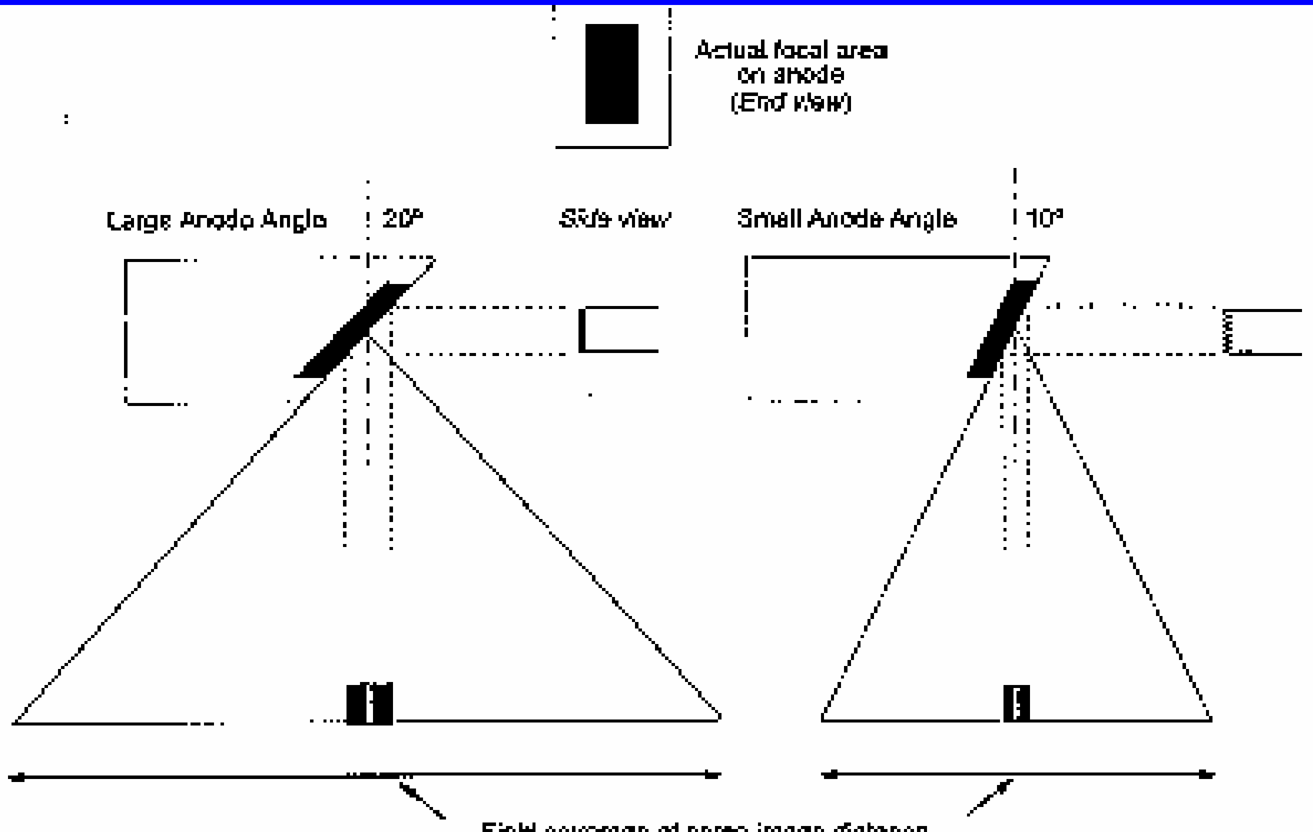


Figure 4.13. The effective focal spot size varies with anode angle. For the same *actual* size, the projected effective size is smaller for a smaller anode angle. Field size coverage, however, is also reduced at the same image distance for a smaller anode angle.

Heal effect

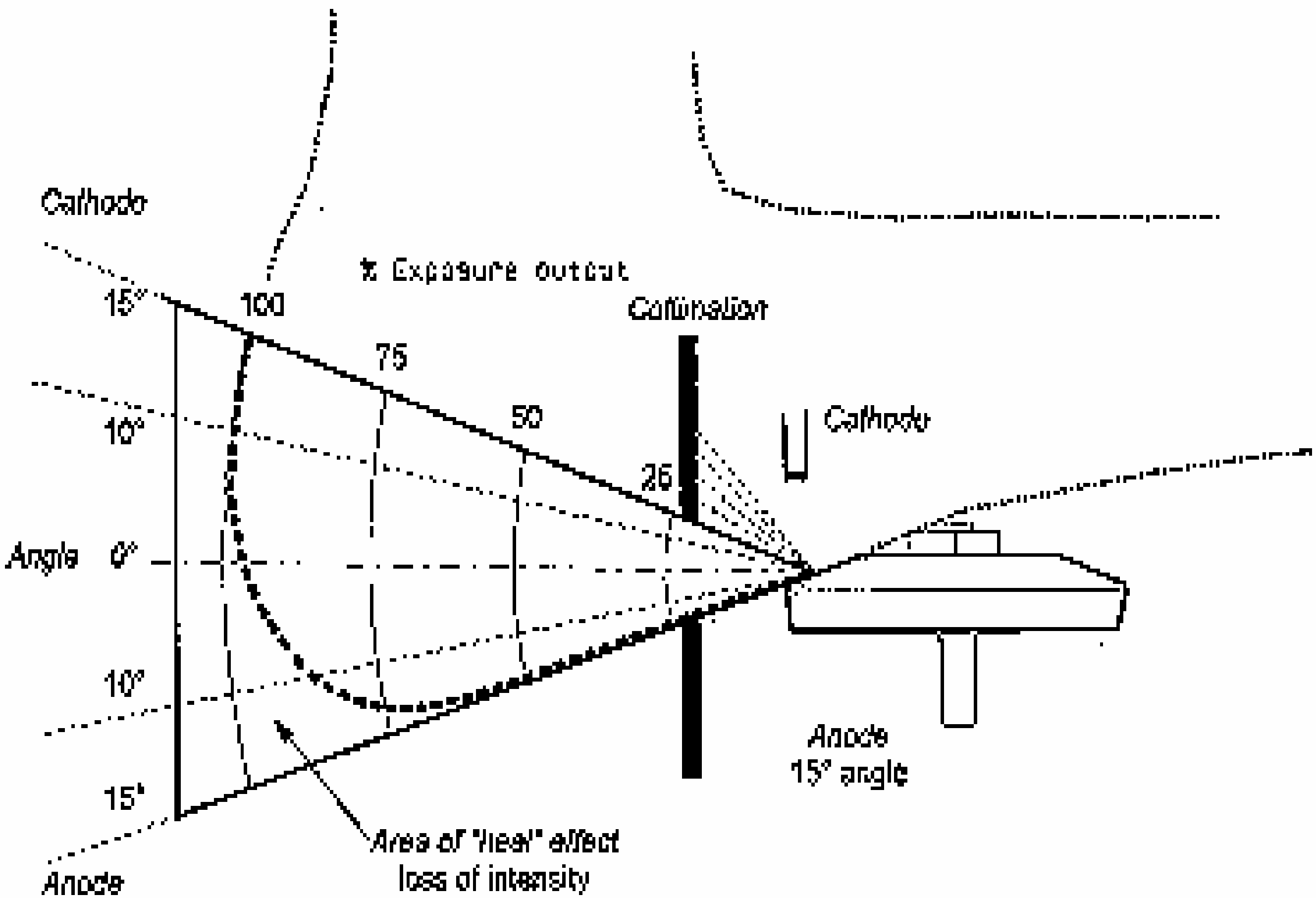
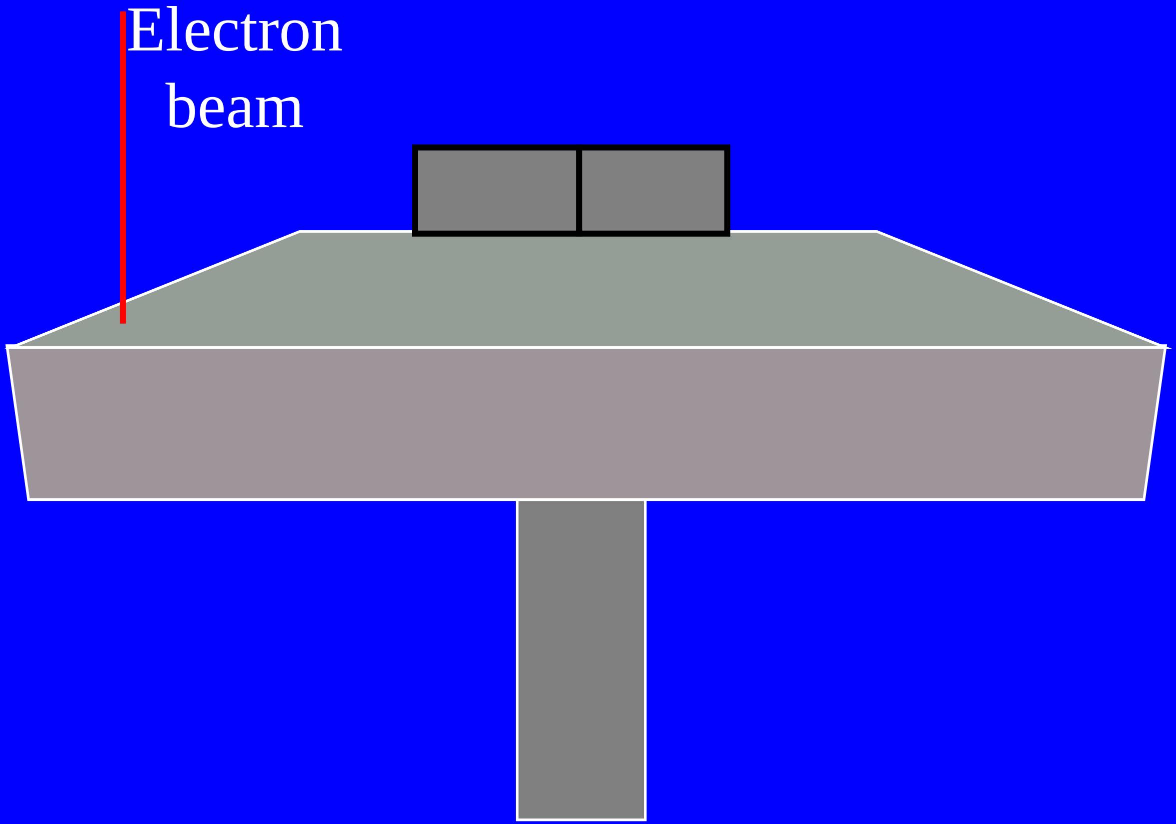
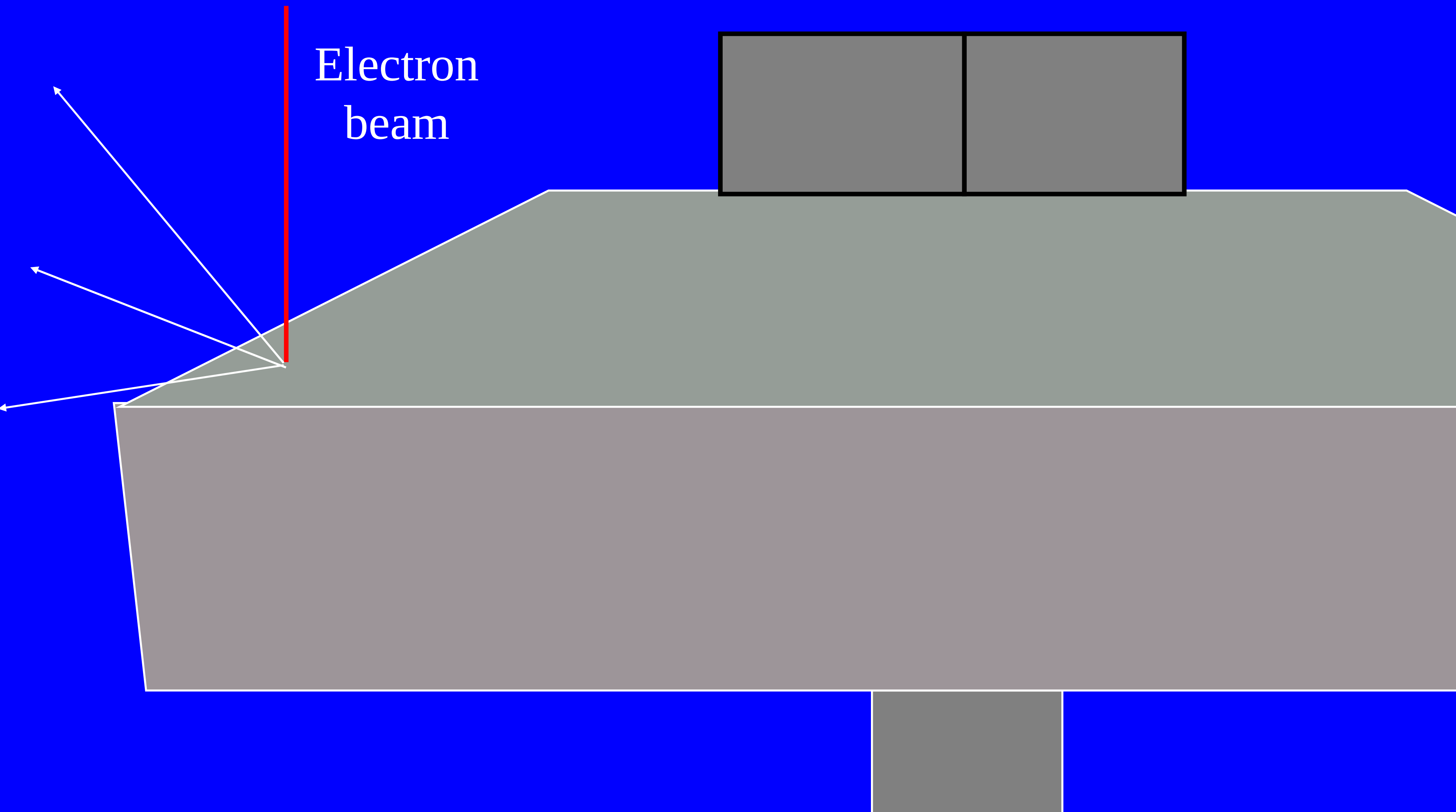


Figure 4.15. The "heel" effect is a loss of intensity on the anode side of the x-ray tube. This figure illustrates the origin of its name.

Heal effect



Heal effect



Angulated focal spot properties

- “target” angulated 10^0-20^0
- “apparent’ focal spot foreshortened
- heat spread out over larger anode area
- “apparent” focal spot increases in size toward cathode
- “apparent” focal spot decreases in intensity toward anode - “heel” effect