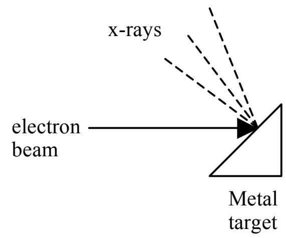
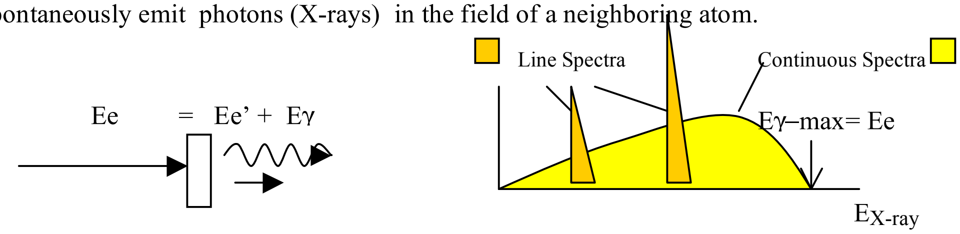
X-rays Production by Electrons

X-rays were first observed by Wilhelm Roentgen in 1895, a German scientist who found them by accident when experimenting with electron beams and vacuum tubes. The wavelength of a 10KeV X-ray is quite small, λ =1240eVnm/10000eV= 0.124 nm (1 Angsrom=10^{-10} m), allowing it readily to penetrate matter.

Roentgen found that X-rays were copiously produced by stopping electrons in a heavy metal target of high-*Z* material. The generated x-ray spectra is composed of two components.



(a) Continuous bremsstrahlung portion. When charged particles are accelerated (de-accelerated) they can spontaneously emit photons (X-rays) in the field of a neighboring atom.



When Ee' = 0, $E\gamma$ is a maximum. When Ee' = Ee, $E\gamma = 0$ a minuimum. So the X-ray spectra ranges , from 0 to Ee.

(b) an **X-ray Line Spectra** described by the Bohr model. For a many electron atom the inner electrons shield the nucleus and a *Zeff* must be substituted for *Z*.

$$E_n \simeq Z_{eff}{}^2 \times \frac{13.6eV}{n^2} \qquad \textit{Energy levels of a hydrogen-like atom of charge Z}$$

$$\Delta E_{L\alpha} \simeq Z_{eff}{}^2 \times 13.6eV \left(\frac{1}{n_1{}^2} - \frac{1}{n_2{}^2}\right)$$

Zeff takes in to account the effective shielding of the nucleus by inner oribital electrons and other spin-orbit and spin-spin effects.

In a typical electron x-ray tube, electrons are accelerated to the target by Vacc = 10's of KVolts of potential. A 100KV x-ray tube will produce at best 10 KeV X-rays !

K,L,M x-rays are produced in materials when inner atomic electrons are dislodged or ionized. Following the Bohr model, Mosely predicted x-rays would follow the pattern:

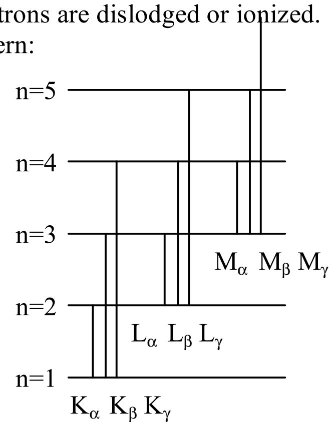
$$E_{K\alpha} \simeq (Z-1)^2 \times 13.6eV \left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

$$E_{K\beta} \simeq (Z-6)^2 \times 13.6eV \left(\frac{1}{1^2} - \frac{1}{3^2}\right)$$

$$E_{L\alpha} \simeq (Z-6)^2 \times 13.6eV \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$E_{L\beta} \simeq (Z-6)^2 \times 13.6eV \left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

etc.



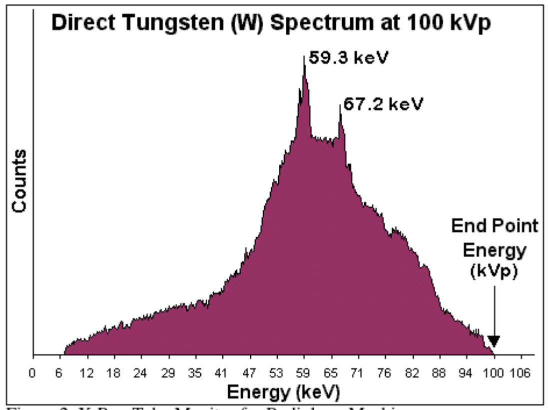


Figure 2. X-Ray Tube Monitor for Radiology Machines

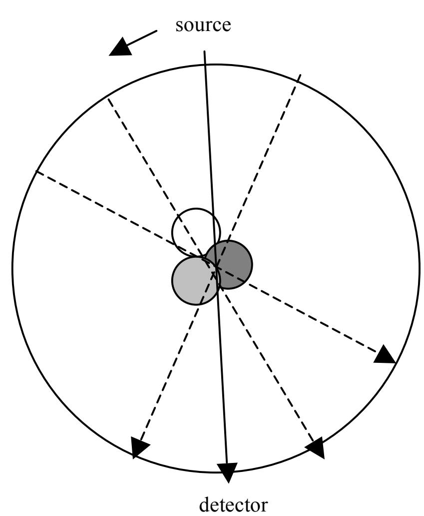
Figure 1: The bremsstrahlung is caused by the de-acceleration of the electron in the metal. The x-ray lines are from the filling of inner core electrons that have been displaced.

Computed Tomography (CT)
The attenuation of X-rays passing through an object can be used for imaging – computed tomography. For a monoenergetic x-ray beam and a variable density absorber we can integrate over the line of sight of the beam and obtain the image after many measurements are made. A typical scenario of a CT scan is shown below.

$$I_{x,y} = I_0 \; e^{-\int \mu(x,y)\, s}$$

$$\ln(I_0 / I_{x,y}) = \int \mu(x,y) ds$$

$$\mu(x,y) = \left[\ln(I_0 / I_{x,y})\right]^{-1} \equiv \text{x-ray image}$$



Questions to Answer:

1) Estimate the energy of the Kα X-ray in Pb.

2) A technique of identifying trace elements in a sample such as blood serum is to expose it to protons of a few MeV in energy. The protons excite X-ray transitions in the heavy metals in the serum. Estimate the the energy of the Kα X-ray emission from Cu and Zn and compare to their accepted values. 8.04 keV and 8.64keV respectively