- HW2 WILL BE GRADED BY NEXT TUESDAY
- HW4 WILL BE POSTED TOMORROW MORNING
- FEEDBACK: bangerter.feedback@gmail.com password: feedback
- MIDTERM 10/20 - 10/23
- FINAL PRESENTATION

REVIEW: 2 TYPES OF IONIZING RADIATION WE'RE CONSIDERING:

(1) PARTICULATE RADIATION (ELECTRONS, FOR NOW)

$$- KE = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}} - m_0 c^2 = m_0 c^2 \left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right)$$

- INTERACTIONS W/ MATTER INCLUDE:

[DISCUSSED ON P.7 OF LECTURE 9 NOTES AND BELOW]

  - COLLISIONAL TRANSFER: EXCITATION (LOW LEVEL) W/ RELEASE OF INFRARED PHOTON OR IONIZATION OF ANOTHER ELECTRON ("DELTA RAY")
  - CHARACTERISTIC RADIATION: UNSEAT A K-SHELL ELECTRON, AND FORM AN X-RAY PHOTON (ONLY AT CERTAIN DISCRETE FREQUENCIES).
  - BREMSSTRAHLUNG RADIATION: ELECTRON LOSES ENERGY DUE TO DECELERATION AS IT PASSES NUCLEUS, RELEASING A PHOTON.

(2) EM RADIATION

- $E = h\nu$
- INTERACTIONS W/ MATTER INCLUDE:

[DISCUSSED BELOW.]

  - PHOTOELECTRIC EFFECT
  - COMPTON SCATTERING
  - PAIR PRODUCTION (NEED PHOTON W/ ≥ 1.02 MeV FOR PAIR PRODUCTION. IN MEDICAL IMAGING, WE'RE CONCERNED W/ ENERGIES IN THE 25-500 keV RANGE, SO WE WON'T COVER.)

REVIEW FIGURE 4.5 (p. 116 IN BOOK)

- LINES ARE DIFFERENT POTENTIALS BETWEEN ANODE AND CATHODE (i.e., DIFFERENT ELECTRON ENERGIES) (45 keV, 61 keV, 80 keV, 100 keV, 120 keV)
- CUT-OFF AT ~10 keV IS BECAUSE BREMSSTRAHLUNG RADIATION BELOW THAT IS ABSORBED BY THE ANODE MEDIUM (TUNGSTEN).
- BREMSSTRAHLUNG CONTINUOUS, CHARACTERISTIC RADIATION DISCRETE (AT SPECIFIC FREQUENCIES FOR TUNGSTEN)

"HERTZ EFFECT"
FIRST DISCOVERED IN 1887 BY HEINRICH HERTZ.

PHOTOELECTRIC EFFECT:

- x-ray PHOTON IS COMPLETELY ABSORBED BY ATOM! (UNLIKE COMPTON SCATTERING, WHERE THE PHOTON IS NOT ABSORBED BUT LOSES ENERGY AND CHANGES DIRECTION).

- AN INCIDENT PHOTON WITH ENERGY $\hbar\nu$ INTERACTS WITH THE COULOMB FIELD OF THE NUCLEUS OF AN ATOM, CAUSING EJECTION OF AN ELECTRON (USUALLY FROM K-SHELL).

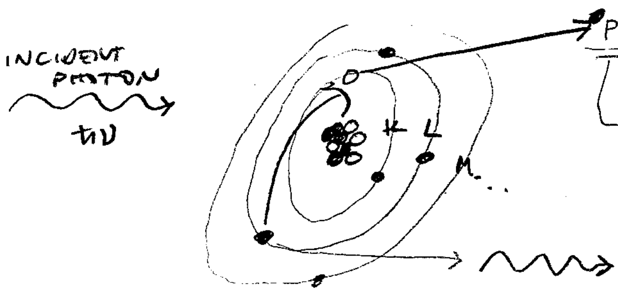


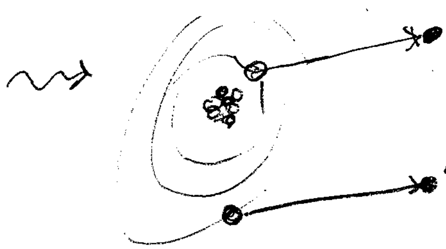
PHOTO ELECTRON

$$E_{e^-} = \hbar\nu - E_B$$

BINDING ENERGY OF EJECTED ELECTRON

CHARACTERISTIC RADIATION (DIFFERENCE IN ENERGY LEVELS)

SOMETIMES THIS DOESN'T MAKE IT OUT OF THE ATOM, AND THE ENERGY KNOCKS AN OUTER-ORBIT ELECTRON LOOSE!



PHOTOELECTRON

NAMED AFTER A FRENCH PHYSICIST... (NOT THE TOOL) :-)

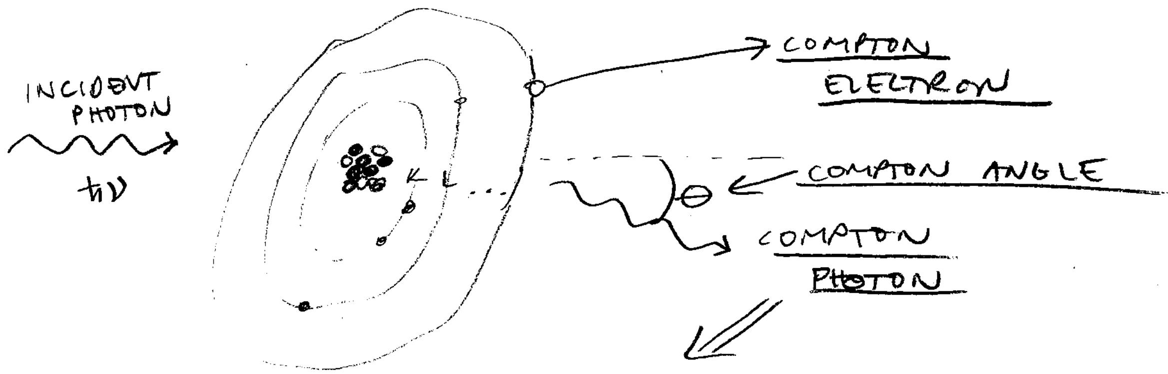
"AUGER" ELECTRON

- PHOTOELECTRONS AND AUGER ELECTRONS ARE NOW ENERGETIC ELECTRONS FREE TO INTERACT W/ MATTER AS DESCRIBED PREVIOUSLY (AND FURTHER DAMAGING TISSUE).

- REMEMBER => INCIDENT PHOTON IS COMPLETELY ABSORBED!

COMPTON SCATTERING:

- INCIDENT PHOTON EJECTS AN OUTER SHELL (OR "VALENCE") ELECTRON, YIELDING ENERGETIC "COMPTON ELECTRON"
- INCIDENT PHOTON LOSES ENERGY (TO THE COMPTON ELECTRON) AND CHANGES DIRECTION (i.e., IS SCATTERED).



ENERGY OF COMPTON PHOTON:

$$E' = \hbar\nu' = \frac{\hbar\nu}{1 + \frac{(1-\cos\theta)\hbar\nu}{m_0 c^2}}$$

ENERGY OF COMPTON ELECTRON?

$$E_{e^-} = \underbrace{\hbar\nu - \hbar\nu'}_{\text{ENERGY LOSS OF INCIDENT PHOTON}}$$

$m_0 c^2 = 511$ keV ⇐ REST ENERGY OF ELECTRON

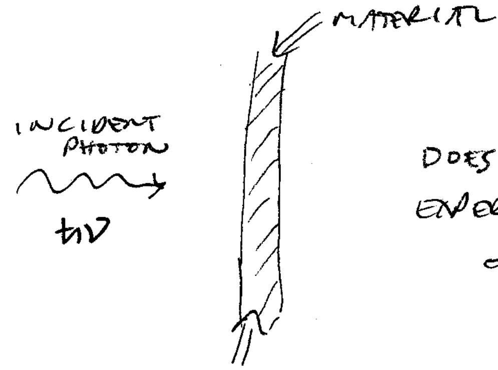
- NOTICE THAT MAXIMUM ENERGY LOSS OCCURS WHEN $\theta = 180°$ ("BACKSCATTER")

- COMPTON SCATTERING IS USUALLY UNDESIRABLE IN MEDICAL IMAGING.

PLANAR SCINTIGRAPHY (EXAMPLE 4.3 IN BOOK, p. 118)

PROBABILITY OF EM INTERACTIONS:

- IMPORTANT FOR x-ray AND CT ⇒ ATTENUATION
- SHIELDING (PHOTOELECTRIC EFFECT ABSORBS INCIDENT PHOTON)
- COMPTON SCATTERING ⇒ PATH IS NO LONGER A STRAIGHT LINE! (USE ENERGIES TO MINIMIZE COMPTON SCATTERING?)



DOES IT PASS THROUGH OR EXPERIENCE A PHOTOELECTRIC OR COMPTON EVENT?

ATOMIC # Z, (OR Z_{eff} IN A MIXED MATERIAL)

MORE Z_{eff}, HARDER TO AVOID!

IN HUMAN TISSUE (IN HIGHER Z MATERIALS, CLOSER TO Z_{eff}^3)

PHOTOELECTRIC:

$$\text{PROB}[\text{PHOTOELECTRIC EVENT}] \propto \frac{Z_{eff}^4}{(h\nu)^3}$$

MORE ENERGY, MORE "PENETRATING"

- WHEN PHOTON ENERGY RISES ABOVE L-SHELL OR K-SHELL BINDING ENERGIES, PROBABILITY OF PHOTOELECTRIC EVENT INCREASES ABRUPTLY, ⇐ IMPORTANT FOR CONTRAST AGENTS. THEN BEGINS TO DECREASE.

COMPTON:

- OCCUR W/ LOOSELY BOUND ELECTRONS, SO ELECTRON DENSITY (ED) MATTERS.
$$ED = \frac{N_A Z}{W_m}$$
N_A = AVOGADRO'S #
W_m ← MOLECULAR WEIGHT (GRAMS/mole)
- IGNORING KLEIN-NISHINA DECREASE W/ ENERGY, WE HAVE:

$$\text{PROB}[\text{COMPTON EVENT}] \propto ED = \frac{N_A Z}{W_m}$$

- RELATIVE FREQUENCY OF INTERACTIONS IMPORTANT (TABLE 4.5, p. 121)

ATTENUATION OF EM RADIATION:

- ACTUALLY A STATISTICAL PROCESS, BUT WE TREAT AS DETERMINISTIC AND ADD NOISE. :)

MEASURING x-ray BEAM STRENGTH:

PHOTON FLUENCE:

$$\Phi = \frac{N}{A}$$

N ← # PHOTONS

A ← AREA (PERPENDICULAR TO DIRECTION OF PROPAGATION)

PHOTON FLUENCE RATE:

$$\phi = \frac{N}{A\Delta t}$$

Δt ← FIXED INTERVAL OF TIME

ENERGY FLUENCE:

MONOENERGETIC SOURCES

$$\Psi = \frac{Nh\nu}{A}$$

RATE: ⇒

$$\psi = \frac{Nh\nu}{A\Delta t}$$

⇐ ENERGY FLUENCE RATE ALSO KNOWN AS "INTENSITY" OF AN x-ray BEAM "I".

$$I = E\phi = h\nu\phi$$

↑ ENERGY PER UNIT AREA PER UNIT TIME.

POLYENERGETIC SOURCES:

PLOT N AS FUNCTION OF E ⇒ LINE SPECTRUM.

x-ray SPECTRUM $S(E)$ ⇐ # PHOTONS PER UNIT ENERGY PER UNIT TIME.

$$\phi = \int_0^\infty S(E')\,dE'$$

$$I = \int_0^\infty E'\,S(E')\,dE'$$