Medical Equipment II - 2010

Chapter 15: Interaction of Photons and Charged Particles with Matter

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Web: http://ymk.k-space.org/courses.htm

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Photon Interactions

- A number of different ways in which a photon can interact with an atom
- Notation: (γ, *bc)*
  - γ*: incident photon*
  - *b and c* are the results of the interaction
  - Ex1: (γ, γ*)* initial and final photons of same energy
  - Ex2: (γ, *e) photon absorbed and* electron emerges.

Photoelectric Effect

- Photon is absorbed by the atom and a single electron is ejected (γ, *e)*
- Initial photon energy $h\nu_0$ is equal to the final energy

$$h\nu_0 = T_{\rm el} + B.$$

  - T_{el}: Kinetic energy of electron, *B*: binding energy
- Photoelectric cross section is τ .

Compton and Incoherent Scattering

- Original photon disappears and photon of lower energy and electron emerge. (γ, γ' *e)*

$$h\nu_0 = h\nu + T_{\mathrm{el}} + B.$$

- Compton cross section for scattering from a single electron is σ_C.
- Incoherent scattering is Compton scattering from all the electrons in the atom, with cross section σ_{incoh}.

Coherent Scattering

- Photon is elastically scattered from the entire atom.
  - Internal energy of atom does not change
  - Equal energy of incident and scattered photons

$$h\nu_0 = h\nu.$$

- Cross section for coherent scattering is σ_{coh}.

Inelastic Scattering

- Final photon with different energy from the initial photon (γ, γ') without emission of electron.
  - Internal energy of target atom increases or decreases by a corresponding amount.
  - Examples: fluorescence and Raman scattering
  - In fluorescence, (γ, γ' γ''), (γ, 2γ) , (γ, 3γ) possible

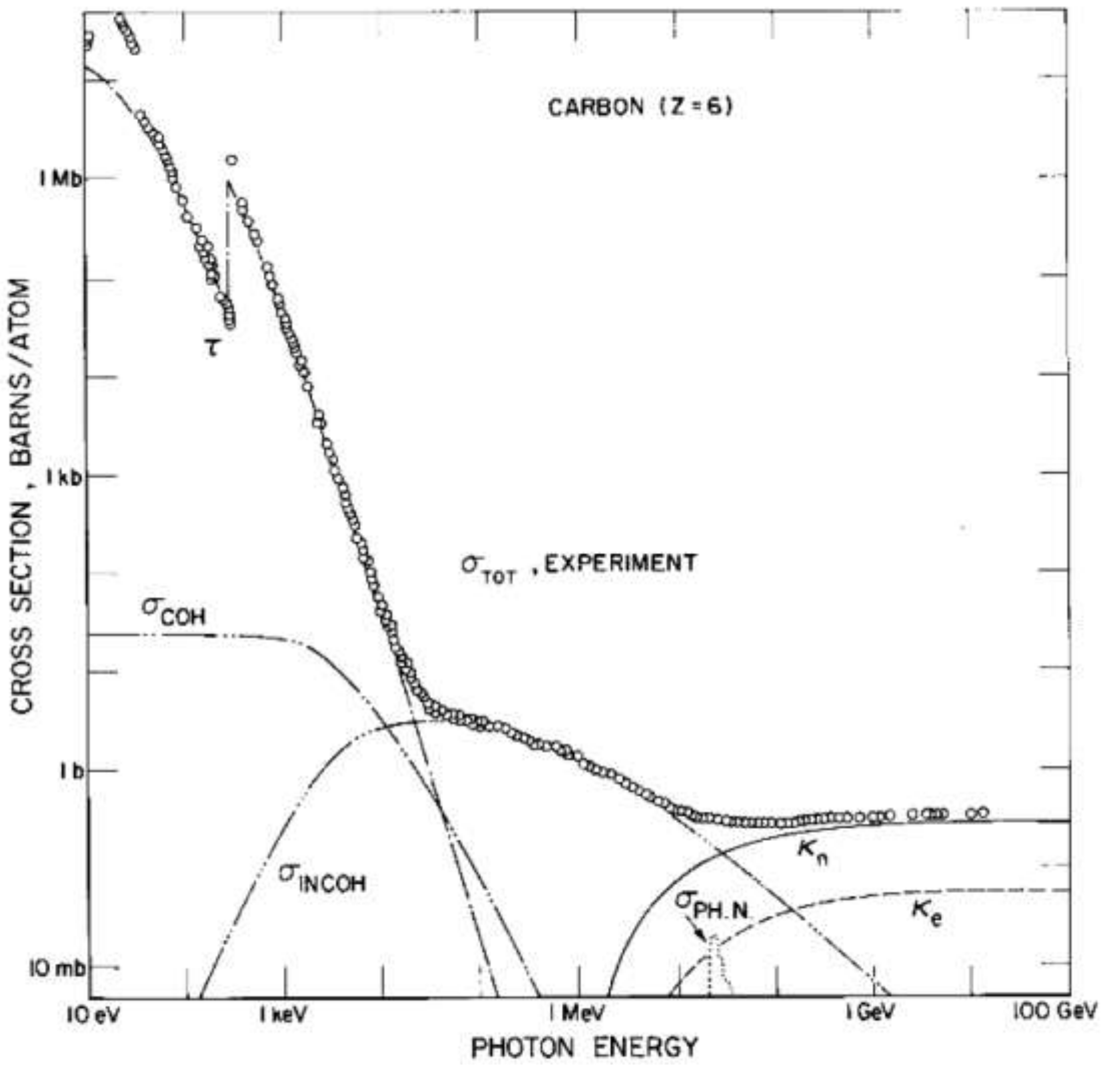
Pair Production

- High energy (γ,e^+ e^-) *interaction*
- Since it takes energy to create negative electron and positive electron or positron, their rest energies must be included in the energy balance

$$h\nu_0 = T_+ + m_e c^2 + T_- + m_e c^2 = T_+ + T_- + 2m_e c^2.$$

- Cross section for pair production is κ.

Energy Dependence



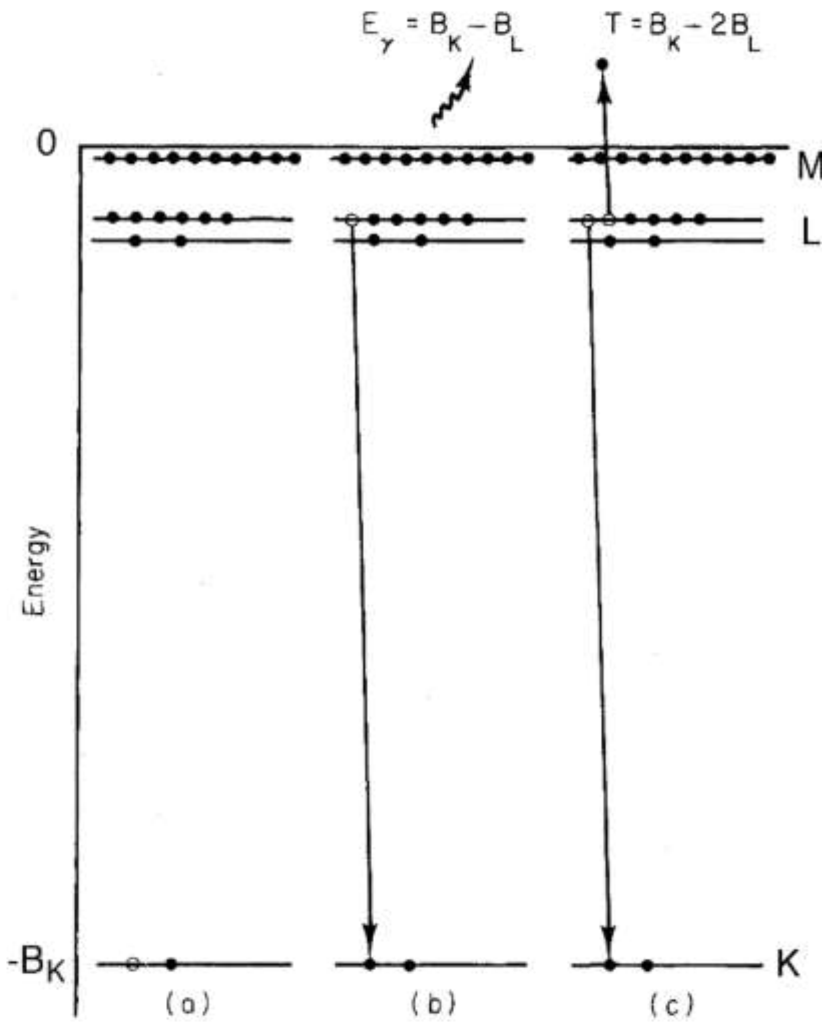
Deexcitation of Atoms

- Excited atom is left with a hole in some electron shell.
  - Similar state when an electron is knocked out by a passing charged particle or by certain transformations in the atomic nucleus
- Two competing processes:
  - Radiative transition: photon is emitted as an electron falls into the hole from a higher level,
  - Nonradiative or radiationless transition: emission of an Auger electron

Deexcitation of Atoms

Process	Total photon energy	Total electron energy	Atom excitation energy	Sum
Before photon strikes atom	$h\nu$	0	0	$h\nu$
After photoelectron is ejected [Fig. 15.12(a)]	0	$h\nu - B_K$	B_K	$h\nu$
Case 1: Deexcitation by the emission of a K and an L photon				
Emission of K fluorescence photon [Fig. 15.12(b)]	$B_K - B_L$	$h\nu - B_K$	B_L	$h\nu$
Emission of L fluorescence photon	$B_K - B_L$, B_L	$h\nu - B_K$	0	$h\nu$
Case 2: Deexcitation by emission of an Auger electron from the L shell				
Emission of Auger electron [Fig. 15.12(c)]	0	$h\nu - B_K$, $B_K - 2B_L$	$2B_L$	$h\nu$
First L-shell hole filled by fluorescence	B_L	$h\nu - B_K$, $B_K - 2B_L$	B_L	$h\nu$
Second L-shell hole filled by fluorescence	B_L, B_L	$h\nu - B_K$, $B_K - 2B_L$	0	$h\nu$

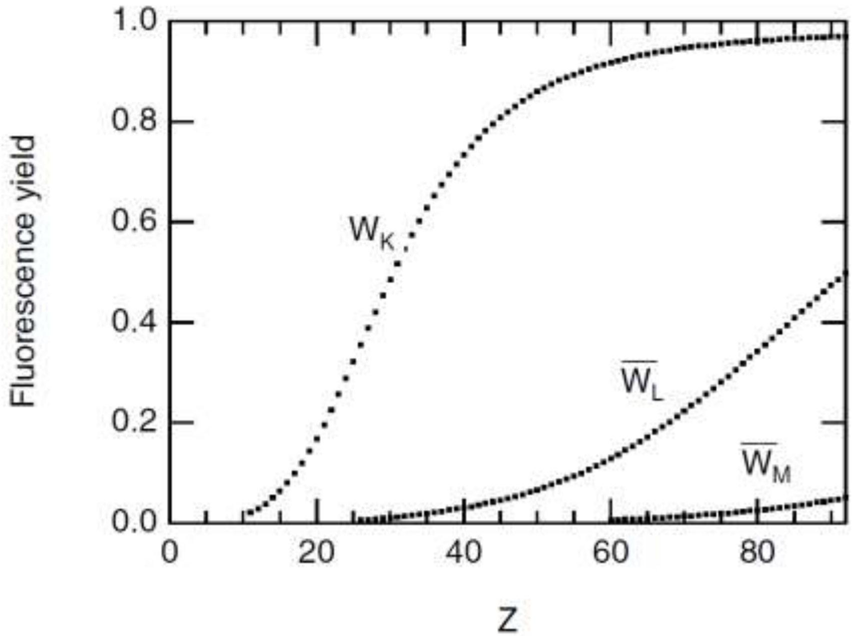
Deexcitation of Atoms



$$\Delta l = \pm 1, \qquad \Delta j = 0, \pm 1.$$

Deexcitation of Atoms

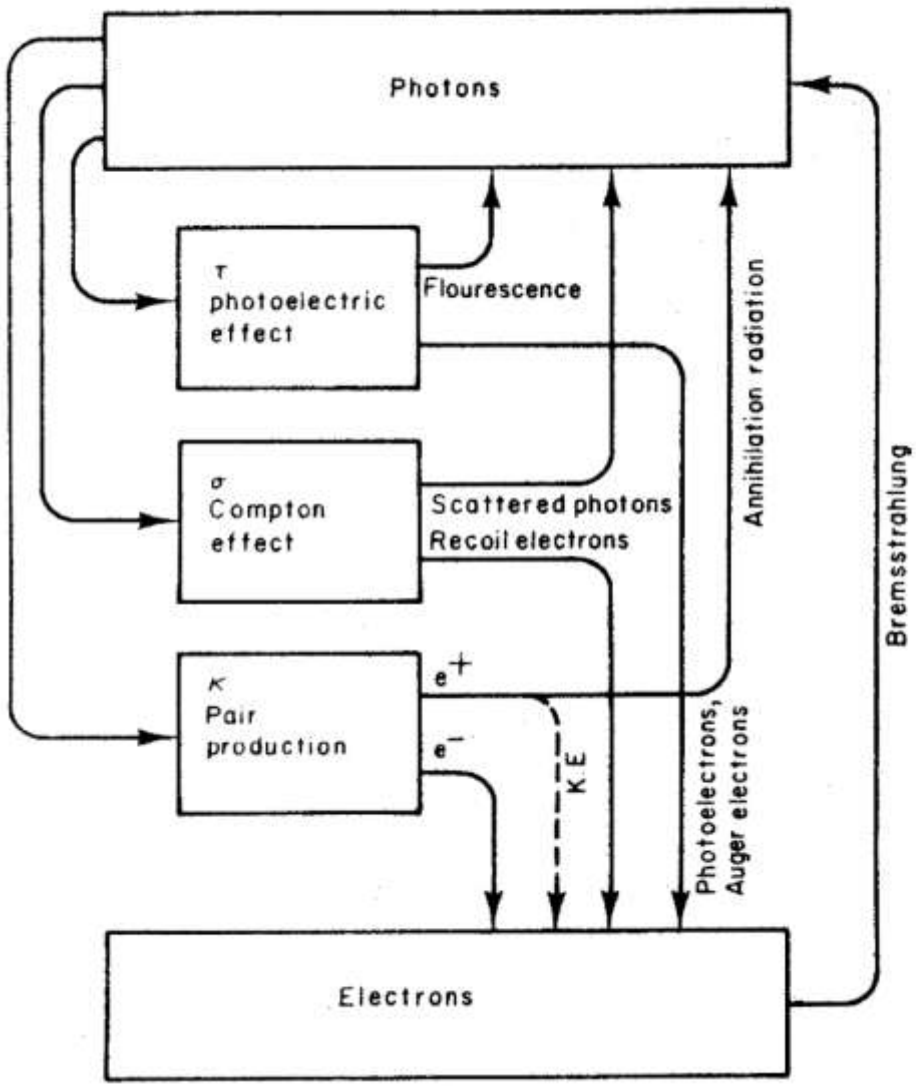
- Probability of photon emission is called the fluorescence yield, W_K.
  - *Auger yield is* $A_K = 1 - W_K$.
  - *L* or higher shells: consider yield for each subshell



Deexcitation of Atoms

- Coster–Kronig transitions
  - Radiationless transitions within the subshell
  - Hole in L_I-shell can be filled by an electron from the L_{III}-shell with the ejection of an M-shell electron
- Super-Coster–Kronig transitions
  - Involves electrons all within same shell (e.g., all M)
- Auger cascade
  - Bond breaking – important for radioactive isotopes

Energy Transfer from Photons to Electrons



Problem Assignments

- Information posted on web site