APPH 226: Electron Binding Energies and Interactions

Objective: 1.4

MRT Program

Review: Atoms

- What is an atom?
  - The smallest particle that has all the properties of an atom
- Models:
  - Greek atom
  - Dalton atom
  - Thomson atom
  - Bohr's atom

Why does this matter?

- For our purposes, we need to understand what is happening at the atomic level because:
  - Interactions in the x-ray tube
  - Interactions between the patient and x-ray photons
  - Interactions between the exiting x-ray photons and the image receptor form the image

Atomic Structure

- Three fundamental particles:
  - Proton – positive charge
  - Electron – negative charge
  - Neutron – no charge

Atomic Structure

- Nucleus
  - Center of the atom
  - Contains protons and neutrons
    - Contributes to mass of the atom
- Electrons
  - Surround the nucleus in various orbits (shells)
  - Small particle (~2000 times smaller than a proton/neutron)

Atomic Number

- Also known as the Z number
- Comes from the number of protons
- Every element has a specific number of protons

Atomic Particles

- When the number of electrons or neutrons changes
- Isotope
  - Atoms that have the same # of protons, but different # of neutrons
  - Results in a different atomic mass
- Ion
  - Atom that has a different number of electrons
  - Gains or loses an electron
    - Results in a positive or negative charge on the ion

Atomic Charge

- Neutral
  - If an atom has: # of protons = # of electrons
  - The positives and negatives cancel each other out
- Ionization
  - When the balance is disrupted
  - Caused by electrons being added/removed

Ionization

- An ionized atom is not electrically neutral
  - Carries charge that is equal to the difference between the number of electrons and protons
- Adding or subtracting protons does not result in ionization
  - Very strongly bound together
  - If the number of protons changes, so does the type of atom
- How about neutrons
  - No, they are electrically neutral

Anode Heat

- Most of the kinetic energy from the incoming filament electrons is converted into heat
- Outer shell electrons dropping back to normal energy levels repeatedly are responsible for more of the heat generation in the anode
- 99% of incoming electrons results in heat

Shells

- Electrons orbit the nucleus at very high speeds
- The attraction between the positive nucleus and the negatively charged electrons is what keeps the electrons in orbit
- Electrons are held in their orbits by electron binding energy

Shells

- Each electron shells is named by a letter, starting from the closest to the nucleus and moving outwards
- The innermost shell is K, then moving outward with L, M, N, O…
- Electrons fill the innermost shells first then outward
- Each shell can only hold a certain number of electrons
  - Max # of electrons per shells is given by: $2(n)^2$
  - E.g. K shell: $2(1)^2 = 2$ electrons
  - E.g. N shell: $2(4)^2 = 32$ electrons

Forces

- What prevents the electrons from flying away from the nucleus or crashing into it?

Electron Binding Energy

- Defined as: the strength of the attachment of an electron to the nucleus
- Which has a stronger attachment, a K-shell electron or an M-shell electron?
  - It is closer to the nucleus
- The binding energy is the strongest for the K-shell and gets weaker the further away the electron is from the nucleus
  - The closer an electron is to the nucleus, the higher the binding energy
  - More energy required to remove a k-shell electron vs an m-shell electron

Characteristic Radiation

- Involves the filament electron and an orbital electron of a target atom
  - The filament electron enters a target atom, striking an orbital electron
  - If the energy of the filament electron is greater than the binding energy of the orbital electron, it is removed from the shell

Characteristic Radiation

- When an inner shell electron is lost, the atom is unstable, so an outer shell electron will drop into fill the vacancies
- When the electron drops into an inner shell:
  - Gives off potential energy (heat)
  - Characteristic x-ray photon

Characteristic Radiation

- The energy (kinetic) of the incoming projectile electron must be ≥ the binding energy
- X-ray photon created has energy equal to the difference in the binding energies of the orbital electrons involved
  - K-characteristic x-rays
    - Not the only type, the xrays are names for the shell being filled
  - Specific energies – characteristic to the atom

Characteristic Radiation

K-shell: 69 keV

L-shell:12 keV

M-shell:3 keV

N-shell:1 keV

O-shell:0.1 keV

Bremsstrahlung Radiation

- This is the other type of interaction that produces x-rays used in diagnostic imaging
- Projectile electron (filament) completely misses the orbital electrons as it passes through a target atom… but it comes close enough to the nucleus to be influenced

Bremsstrahlung Radiation

- When the incident electron comes close to the nucleus, there is a force of attraction
  - Electron (negative), Nucleus (positive)
  - Electron slows down and change direction
    - Losing kinetic energy, releasing it in the form of an x-ray

Bremsstrahlung Radiation

- The closer the electron gets to the nucleus, the more it is influenced
- The greater the direction change, the more kinetic energy is lost (released as an x-ray)
  - Can lose any amount of energy (all or some)
  - Slight direction change
    - Lower energy x-ray
  - Large direction change
    - Higher energy x-ray

Summary of Interactions

- Product = Heat
  - Excitation
  - Ionization (outer shell electrons)
- Product = Radiation
  - Characteristic
  - Bremsstrahlung

Readings

- Bushong: Radiologic Science for Technologists, 11th Ed.
  - Pg 27-34
  - Pg 123- 127 (Finish Bremsstrahlung Radiation)