Chapter 1: Introduction to Medical Imaging

- Overview of Modalities
- Properties of an Image: Limitations on Information Content
  - **Contrast** (both object & image): Brightness difference
  - **Sharpness** (blur): Smallest object visible
  - **Noise**: Structured and Statistical
  - **Distortion**: Spatial error
  - Dynamic or Static
  - Computer manipulation
- **Subject Contrast** (patient)
  - Physical basis for image

Projection (Transmission) vs. Emission Imaging

- **2D Projection**
  - Radiography, Mammography
  - Fluoroscopy
- **1D Projection**
  - X-Ray Computed Tomography
  - [Optical Tomography]
  - [Ultrasound Computed Tomography]
  - [Microwave CT]

Emission Imaging

- **Nuclear Medicine**
  - Distribution of Radioactivity
  - 1D or 2D projection
  - Rate of change
- **MRI**
  - NMR radiowave intensity
  - Many other variables
  - 1D, 2D, 3D projection
- **[Thermal]**
  - [Microwave]
  - [Infrared]

2D Projection X-Ray Images: Relative Transmission Map of image density (relative x-ray attenuation)

1D X-Ray Transmission with Reconstruction
Map of x-ray attenuation coefficient (potentially quantitative)

Computer Image Processing
Selectively filters information
A Perspective on Medical Imaging Modalities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Radiography</th>
<th>Computed Tomography</th>
<th>MRI &amp; MRA</th>
<th>Ultrasound</th>
<th>Fluorescopy Angiography</th>
<th>Nuclear Medicine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution (Sharpness)</td>
<td>Excellent</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Good-Excel</td>
<td>Poor</td>
</tr>
<tr>
<td>Contrast Detectability</td>
<td>Fair</td>
<td>Very Good</td>
<td>Excel</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Tissue Contrast Enhancement</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Fair</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Dynamic Imaging</td>
<td>Poor</td>
<td>Very Good</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Anatomical Information</td>
<td>Excellent</td>
<td>Very Good</td>
<td>Poor</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Physiological Information</td>
<td>Fair</td>
<td>Fair-Good</td>
<td>Good</td>
<td>Fair</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Patient Volume</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Medium-Low</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Cost/Exam</td>
<td>Low</td>
<td>Medium-High</td>
<td>High</td>
<td>Medium-High</td>
<td>Medium</td>
<td>Medium-High</td>
</tr>
<tr>
<td>Radiation Dose</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium-High</td>
<td>Medium-High</td>
</tr>
</tbody>
</table>

Chapter 2: Radiation and the Atom

- Atom composition defines its chemical and physical properties
- Energy transformations in the atom determine the type of radiation produced
- Energy: Definition?
- Radiation: Definition?
- Types encountered in Medicine
• **Energy: Definition?**
  – Ability to do work
  – Work = force $\cdot$ distance
  – Kinetic E: involves motion
    – K.E. = $\frac{1}{2} m \cdot v^2$
  – Potential E: Location, deformation, charge in electric field, etc.
  – Unit of Energy (eV): K.E. gained by electron accelerated across potential of 1 volt

• **Radiation: Definition?**
• Types encountered in Medicine

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**AAPM/ABR Syllabus**

- Module 2: Electromagnetic (EM) Radiation
  - **Fundamental Knowledge:**
    1. Describe the wave and particle characteristics of electromagnetic (EM) radiation.
    2. Within the EM radiation spectrum, identify the properties associated with energy and the ability to cause ionization.
  - **Clinical Application:**
    1. Explain how the relative absorption of electromagnetic radiation in the body varies across the electromagnetic energy spectrum.

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**Electromagnetic Radiation**

- Duality of properties
  - Waves (refraction, interference, etc.)
  - Quanta or photons (scattering, ionization, etc.)
- Constant velocity
  - $c = 3.0 \times 10^8 \text{ m/sec}$ in vacuum
- Waves
  - $v = \lambda \cdot f$, $v$ = velocity, $\lambda$ = wavelength, $f$ = frequency
- EM Particles (photons)
  - Ionizing radiation

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**Particles and Waves have Distinctly Different Properties**

- **Wave Source**
- **Wave**
- **Particles**
- **Barrier**
- **Detector**

![](image1)

**Light behaves like a particle (photons)**

$$E_{\text{photon}} = h \cdot f$$

$h$ = Planck’s constant

$$f = \text{frequency}$$

![](image2)
Particles can behave like Waves

Electromagnetic Radiation

- **Duality**
  - Waves
  - Quanta or photons
- **Constant velocity**
  - \( c = 3.0 \times 10^8 \text{ m/sec} \) in vacuum
- **Waves**
  - \( v = \lambda \cdot f \), \( v \) = velocity, \( \lambda \) = wavelength, \( f \) = frequency
- **EM Particles (photons)**
  - \( E (J) = h \cdot f \), \( E = \text{energy}, h = \text{Planck's const} = 6.62 \times 10^{-23} \text{ J sec} \)
  - \( E (J) = h \cdot c \), \( E \text{(keV)} = \frac{12.4}{\lambda (\text{Å})} \)
- **Ionizing EM**
  - E above near-ultraviolet is sufficient to remove bound electrons
  - 12.6 eV required to ionize \( \text{H}_2\text{O} \)

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**Question 1**

1. The wavelength of a photon is 1.24 x 10^{-1} Å. What is its energy in keV?
   - A. 124 keV
   - B. 1 keV
   - C. 10 keV
   - D. 100 keV
   - E. 12.4 keV

   - **Solution**
     - \( E \text{(keV)} = \frac{12.4}{\lambda (\text{Å})} = \frac{12.4}{0.124} = 100 \text{ keV} \)

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AAPM/ABR Syllabus

Module 3: Particulate Radiation

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Identify the different categories and properties of particulate radiation.

Radioactive Decay

Particulate Radiation

Energy equivalence of rest mass

\[ E = mc^2 \]

For electron:

\[ m = 9.109 \times 10^{-31} \text{ kg}, \quad c = 2.998 \times 10^8 \text{ m/sec} \]

\[ E = 8.187 \times 10^{-14} \text{ J} \]

\[ E = 0.511 \text{ MeV or } 511 \text{ keV} \]

Fortunately we don’t expect you to memorize conversion factors, but you should know the energy equivalent of an electron/positron. You will see it so often this won’t be a problem.

Particles in Medicine

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Relative Charge</th>
<th>Mass (amu)</th>
<th>Energy Equivalent (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>α, He²⁺</td>
<td>+2</td>
<td>4.0028</td>
<td>3727</td>
</tr>
<tr>
<td>Proton</td>
<td>p, H¹⁺</td>
<td>+1</td>
<td>1.007593</td>
<td>938</td>
</tr>
<tr>
<td>Electron</td>
<td>e⁻, β⁻</td>
<td>-1</td>
<td>0.000548</td>
<td>0.511</td>
</tr>
<tr>
<td>Positron</td>
<td>e⁺, β⁺</td>
<td>+1</td>
<td>0.000548</td>
<td>0.511</td>
</tr>
<tr>
<td>Neutron</td>
<td>n⁰</td>
<td>0</td>
<td>1.008982</td>
<td>940</td>
</tr>
</tbody>
</table>

1 amu = 1/12 mass of Carbon-12 atom = 931 MeV

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Module 1: Structure of the Atom

After completing this module, the resident should be able to apply the “Fundamental Knowledge” and “Clinical Applications” learned from the module to example tasks, such as those found in “Clinical Problem-Solving.”

Fundamental Knowledge:

1. Describe the components of the atom.

2. Explain the energy levels, binding energy and electron transitions in an atom.

3. For the nucleus of an atom, describe its properties, how these properties determine its energy characteristics and how changes within the nucleus define its radioactive nature.

4. For an atom, describe how its electron structure and associated energy levels define its chemical and radiation-associated properties.

5. Explain how different transformation (“decay”) processes within the nucleus of an atom determine the type of radiation produced and the classification of the nuclide.

Structure of the Atom

radius of atom ≈ 0.5 \times 10^{-10} \text{ m}, so diameter ≈ 1.0 \times 10^{-10} = 1 \text{ Å}
• Electron Binding Energy
  Decreases with distance from nucleus
  Increases rapidly with Z

2. The energy of characteristic radiation produced by an “L to K” transition will be ______ that produced by an “M to K” transition.
   - A. Greater than
   - B. The same as
   - C. Less than

3. Tungsten has a K-shell binding energy of ___ keV.
   6.90, 6.95, 69.0, 69.5, 695

4. Which of the following is/are true?
   - The L-shell has a higher binding energy than K.
   - Carbon has a higher K-shell binding energy.
   - Two successive 35 keV photons could remove an electron from the K-shell.
   - A 69 keV photon could not remove a K-shell electron, but could remove an L-shell electron.
Nuclide Families

<table>
<thead>
<tr>
<th>Family</th>
<th>Nuclides with Same</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotopes</td>
<td>Atomic number (Z)</td>
<td>I(^{131}), I(^{125}): Z=53</td>
</tr>
<tr>
<td>Isobars</td>
<td>Mass number (A)</td>
<td>Mo(^{99}), Tc(^{99}): A=99</td>
</tr>
<tr>
<td>Isotones</td>
<td>Neutron number (A-Z)</td>
<td>(_{\text{i}}^{131}) 131-53=78</td>
</tr>
<tr>
<td>Isomers</td>
<td>A and Z same but different energy state</td>
<td>Tc(^{99m}) and Tc(^{99}): Z=43, A=99, (\Delta E=142) keV</td>
</tr>
</tbody>
</table>

\(X = \text{element symbol}\)
\(Z = \text{number of protons}\)
\(A = \text{number of protons + neutrons}\)

5. The pairs of nuclides listed below are:
- A. Isobars
- B. Isomers
- C. Isotones
- D. Isotopes
- E. Isodoses

\(\text{isobars} : 26\text{Fe}^{57} \text{ and } 27\text{Co}^{57}\)
\(\text{isotopes} : 54\text{Xe}^{131} \text{ and } 54\text{Xe}^{133}\)
\(\text{isobars} : 15\text{P}^{32} \text{ and } 16\text{S}^{32}\)
\(\text{isomers} : 43\text{Tc}^{99m} \text{ and } 43\text{Tc}^{99}\)
\(\text{none} : 1\text{H}^{1}\text{ and } 2\text{He}^{4}\)

Nuclear Binding Energy or Mass Defect

- Difference between the mass of an atom and the rest mass of all its constituent components
- Difference due to nuclear binding energy
- Example: \(\text{N}^{14}\)
  - Mass of 7 p\(^{+}\), 7 n, 7 e\(^{-}\) = 14.11536 amu
  - Mass of \(\text{N}^{14}\) = 14.00307 amu
  - Difference = 0.11229 amu \* 931 MeV/amu
  - \(= 104.5\text{ MeV}\)
- That’s a lot of energy and “splitting” an atom releases it.

6. The energy of a photon is:
- A. Proportional to its wavelength
- B. Proportional to its frequency
- C. Inversely proportional to the exposure time
- D. Inversely proportional to its wavelength
- E. Can be expressed in terms of potential difference (volts)
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   – C. Inversely proportional to the exposure time
   – D. Inversely proportional to its wavelength
   – E. Can be expressed in terms of potential difference (volts)

\[
E = h \cdot f = h \cdot c / \lambda
\]

\[
E \text{ (keV)} = 12.4 / \lambda \text{ (Å)}
\]