Introduction – The Nature of Electromagnetic Radiation

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Purpose

• To identify and describe some of the basic properties common to all forms of electromagnetic radiation
• To recognize x-rays and gamma rays as a form of electromagnetic radiation
• To differentiate between waves and particles
• To identify analogous properties among waves and particles

Introduction – Patient Case

• 62 yr old woman with Stage IIIB (T1N3M0) NSCLC rt lower lobe
• Dose prescription
  – 6 MV x-rays
  – 1.8 Gy/fraction x 35 fractions
  – IMRT
Introduction – Patient Case

- 100% of the CTV gets 63 Gy
- 93% of the PTV gets 63 Gy
- V20 for total lung is 37%
- Max cord dose is 44.9 Gy

Help! – I’m lost

- Why are we treating the patient with x-rays?
- What do we mean by “6 MV”?
- What is a “Gy”?
- What is IMRT?
- What is a dose distribution and what do the lines mean?
- What is a DVH?
- What is a CTV? PTV?
- What do we mean by V20?
Basic premise

• We transfer energy
  – Power mains to electrons
  – Electrons to x-rays
  – X-rays to atoms in patient
• Energy causes things to happen
  – Electrons removed from atoms
  – Chemical reaction
  – Cellular changes
  – Clinical changes

Basic premise

• Follow the energy!
• Transfer energy through space by means of waves – radiation
• Transfer energy through space by means of electric and magnetic waves – electromagnetic radiation
• If the energy of the electromagnetic radiation is sufficient to remove electrons from atoms – ionizing radiation

Waves and particles

• Electromagnetic radiation can be looked on either as waves or as particles.
• To understand the properties of electromagnetic radiation and how electromagnetic radiation can be used to transfer energy, we must understand properties of both waves and particles.
Properties of waves

- Definition – a periodic disturbance that can be propagated

Two types of waves

- Compare direction of disturbance with direction of propagation
  - Longitudinal – disturbance moves along direction of propagation
  - Transverse – disturbance moves perpendicular to direction of propagation

Example of transverse waves
How waves are characterized

- Amplitude – magnitude of disturbance
- Frequency – number of peaks per unit time
  - Frequency denoted by \( \nu \)
  - Units are 1 Hertz (Hz) = 1 cycle/sec

How waves are characterized

- Wavelength – distance between successive peaks
  - Wavelength denoted by \( \lambda \)
  - Units are units of length

Relation between wavelength and frequency

\[ \lambda \nu = c \]

\( c \) is speed of propagation of wave
Nature of electromagnetic waves

- Periodic fluctuations in electric and magnetic fields
- Caused by interactions of charges
- Electromagnetic waves are transverse waves

Speed of propagation

- All electromagnetic waves travel at same propagation speed $c = 3.00 \times 10^8$ m/sec in vacuum

Problem

- KUHF radio broadcasts at a frequency of 88.7 MHz. What is its wavelength?

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/sec}}{88.7 \times 10^6 \text{ sec}^{-1}} = 3.38 \text{ m}$$
### Spectrum of Electromagnetic Radiation

<table>
<thead>
<tr>
<th>Wave Category</th>
<th>Specific Kind</th>
<th>Typical Wavelength</th>
<th>Corresponding Photon Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radio</strong></td>
<td>Broadcast (1000 kHz)</td>
<td>30,000 cm</td>
<td>0.000 000 004 eV</td>
</tr>
<tr>
<td></td>
<td>TV (10 MHz)</td>
<td>300 cm</td>
<td>0.000 000 4 eV</td>
</tr>
<tr>
<td></td>
<td>Radar (3,000 MHz)</td>
<td>10 cm</td>
<td>0.000 012 eV</td>
</tr>
</tbody>
</table>

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<tr>
<th>Wave Category</th>
<th>Specific Kind</th>
<th>Typical Wavelength</th>
<th>Corresponding Photon Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light</strong></td>
<td>Infrared</td>
<td>12,000 Å</td>
<td>1 eV</td>
</tr>
<tr>
<td></td>
<td>Visible</td>
<td>6,000 Å</td>
<td>2 eV</td>
</tr>
<tr>
<td></td>
<td>Ultraviolet</td>
<td>3,000 Å</td>
<td>4 eV</td>
</tr>
</tbody>
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<th>Typical Wavelength</th>
<th>Corresponding Photon Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-rays and γ rays</strong></td>
<td>Diagnostic</td>
<td>0.4 Å</td>
<td>30 keV</td>
</tr>
<tr>
<td></td>
<td>Orthovoltage</td>
<td>0.1 Å</td>
<td>120 keV</td>
</tr>
<tr>
<td></td>
<td>60Co</td>
<td>0.01 Å</td>
<td>1200 keV</td>
</tr>
<tr>
<td></td>
<td>Linear Accel</td>
<td>0.06 Å</td>
<td>2000 keV</td>
</tr>
<tr>
<td></td>
<td>High-energy</td>
<td>0.0015 Å</td>
<td>8000 keV</td>
</tr>
<tr>
<td></td>
<td>Linac</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Spectrum of electromagnetic radiation

<table>
<thead>
<tr>
<th>Wave Category</th>
<th>Specific Kind</th>
<th>Typical Wavelength</th>
<th>Approximate Corresponding Photon Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic Ray-Produced Waves</td>
<td>Photons produced by cosmic particles</td>
<td>0.000012 Å</td>
<td>&gt; 1,000,000 keV</td>
</tr>
</tbody>
</table>

Wave properties

- Electromagnetic waves can exhibit both wave properties and particle properties:
  - Wave properties
    - Diffraction – bending of waves around corners
    - Interference – constructive or destructive adding of wave amplitudes

Interference

constructive  destructive
Particle properties

- Electromagnetic waves can exhibit both wave properties and particle properties:
- Particle properties
  - View electromagnetic waves as discrete clumps of energy
  - Massless particles called photons – quantum theory
  - Energy of photon given by
  \[ E(\text{keV}) = \frac{12.4}{\lambda (\text{Å})} \]

Waves vs particles

- Photons travel only at \( 3.00 \times 10^8 \) m/sec
- Photons have no mass
- Electromagnetic waves exhibit either wave properties or particle properties, but never both simultaneously

<table>
<thead>
<tr>
<th>Waves</th>
<th>Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>Intensity</td>
</tr>
<tr>
<td>Frequency</td>
<td>Energy</td>
</tr>
</tbody>
</table>