Medical Imaging and Radiation

Turn off all electronic devices

Observations About Medical Imaging and Radiation

- They do their jobs right through your skin
- Imaging involves radiation of various sorts
- Some imaging radiation is itself hazardous
- Radiation can make you well, sick, or neither
- Some radiation involves radioactivity
- Some radiation involves accelerators

5 Questions about Medical Imaging and Radiation

1. How are X-rays produced?
2. Why do X-rays image bones rather than tissue?
3. How does CT scanning create a 3D image?
4. How do gamma-rays kill cancerous tissue?
5. Why does MRI image tissue, not bone?

Question 1

Q: How are X-rays produced?

A: By accelerating electrons or atomic fluorescence

X-rays are high-frequency electromagnetic waves

- An X-ray photon carries a large amount of energy

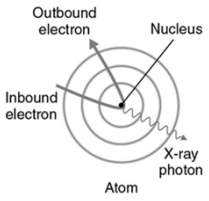
X-rays are produced by very energetic events

- Extremely rapid accelerations of electrons
- Extremely energetic radiative transitions in atoms

Bremsstrahlung X-rays

When a fast-moving electron whips around a massive nucleus

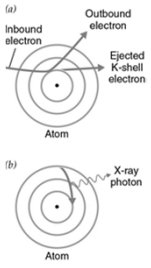
- electron accelerates extremely rapidly
- may emit much of its energy as an X-ray photon



Characteristic X-rays

When a fast-moving electron hits a massive atom

- it may knock an electron out of a tightly bound orbital
- and leave the atom (now an ion) in a highly excited state.
- Atom then undergoes a radiative transition to a less excited state
- and emits an X-ray photon.

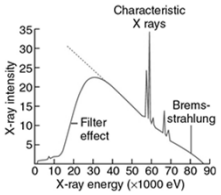


Producing X-rays

X-rays are produced with high-energy electrons

- Accelerate electrons to 10kV - 100kV
- Let electrons hit heavy atoms
- Some X-rays emitted via bremsstrahlung and some as characteristic X-rays

X-ray tube filters away the lowest energy photons, because they're useless and cause skin burns.



Question 2

Q: Why do X-rays image bones rather than tissue?

A: The larger atoms in bone can absorb X-rays.

X-rays interact with atoms in two principal ways

- Rayleigh scattering—absorption and reemission
- Photoelectric effect—absorption and electron ejection

All atoms participate in Rayleigh scattering

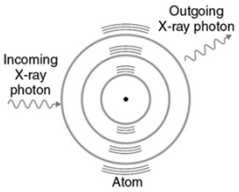
Large atoms participate in the photoelectric effect

X-rays Rayleigh Scattering

Rayleigh scattering is what makes the sky blue

- An atom absorbs a photon and then reemits it
- This "scattered" photon travels in a new direction

All atoms participate in X-ray Rayleigh scattering



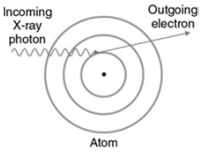
X-ray Photoelectric Effect

Photoelectric effect is a radiative transition

- X-ray photon shifts electron from orbital to free wave
- Free electron carries photon's residual energy

Effect most likely for small free-electron energies

- so effect most likely for atoms with many-electrons



X-ray Imaging

An atom that blocks X-rays casts a shadow

- Many-electron atoms produce strong shadows
- Few-electron atoms cast essentially no shadows

X-ray imaging observes shadows of large atoms

Unfortunately, all atoms Rayleigh scatter X-rays

- Rayleigh scattering causes a distracting haze
- Haze is filtered away by collimating structures

Question 3

Q: How does CT scanning create a 3D image?

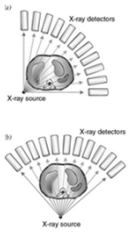
A: Many X-ray images are analyzed by computer

X-rays are taken from different angles

- Shadows overlap differently at each angle

Computer analyzes these X-ray images

- Reconstructs 3D arrangement of parts
- Displays cross sections of the body



Question 4

Q: How do gamma-rays kill cancerous tissue?

A: These high-energy photons destroy molecules.

Gamma-rays are extremely high energy photons
- cause widespread damage to molecules and tissues

Gamma-rays are produce by high-energy events
- radiative transitions within atomic nuclei
- high-energy bremsstrahlung (particle accelerators)

Producing Gamma Rays

Radioactive decay can produce gamma rays
- Decay may leave nucleus in an excited state
- Radiative transition in nucleus emits gamma photon
- Decaying cobalt-60 (Co^{60}) emits two gamma photons

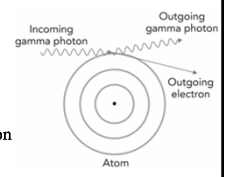
Electron accelerators can produce gamma rays
- Electrons are accelerated to extreme energies
- Near heavy nuclei, emit Bremsstrahlung gamma rays

Gamma-rays and Matter

Gamma rays interact with individual charges

Compton scattering: photon hits electron
- They exchange energy & momentum
- Both particles leave the atom
- Atom, molecule, tissue are damaged

Pair production: photon → electron & positron
- Positron is anti-matter version of electron
- Positron and another electron soon annihilate
- Resulting gammas damage atoms, molecules, tissue



Radiation Therapy

Gamma rays are highly penetrating in tissue
- Little Rayleigh scattering and photoelectric effect
- Much Compton scattering and pair production

Each gamma ray event damages many molecules
- Gamma rays can cause enough damage to kill cells

Approaching tumors from many angles minimizes collateral damage to healthy tissue

Question 5

Q: Why does MRI image tissue, not bone?

A: MRI images hydrogen nuclei, common in tissue.

Magnetic Resonance Imaging images hydrogen
- Hydrogen nuclei are protons
- Protons are magnetic—they are tiny dipole magnets
- Protons tend to orient in an external magnetic field
- Radio waves can influence that orientation

MRI is based on proton-orienting effects

Nuclear Magnetic Resonance

MRI grew out of Nuclear Magnetic Resonance
- Nuclei in a magnetic field interact with radio waves
- Yields information about atoms and their environments

Why NMR works: many nuclei are magnetic dipoles
- In magnetic field, dipole's energy depends on orientation
- Nuclei have quantized orientations (quantum physics)
- In magnetic field, nuclei have quantized energies
- Nuclear orientations can change via radiative transitions

NMR studies atoms via those radiative transitions

Magnetic Resonance Imaging

NMR typically studies hydrogen nuclei (protons)

- Protons have two quantized orientations
- H-NMR flips protons between their two orientations

Magnetic resonance imaging is based on H-NMR

- Person is placed in a carefully designed magnetic field
- That magnetic field varies with location and time
- Protons are probed with sophisticated radio waves
- MRI machine senses where and when protons respond
- MRI machine assembles image a person's hydrogen

MRI images hydrogen and its tissue environment.

Summary about Medical Imaging and Radiation

X-rays and gamma-rays are high energy photons

X-rays scatter from heavy atoms, for imaging.

Gamma-rays disrupt cells, for therapy.

MRI detects and locates hydrogen nuclei.