PHYS12 CH:22.5 When Radiation Heals

Medical Applications of Radioactivity

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Outline

How can radiation both
cause and cure cancer?

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The same nuclear physics that powers weapons also heals millions.

The Paradox of Radiation

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cause and cure cancer?

The same nuclear physics that powers weapons also heals millions.

Understanding this paradox requires understanding cells, DNA, and targeted destruction.

Learning Objectives

By the end of this lesson, you will be able to:

- **22.5:** Describe how nuclear imaging works (radioisotope imaging, PET)

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- **22.5:** Describe the ionizing effects of radiation and how they can be used for medical treatment

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22.5 Seeing the Invisible

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2. **Radiation depends on the nucleus, not the molecule** - we can tag compounds with radioactive isotopes

The Universal Tool

Put a radioactive isotope in a drug. Track where the drug goes. See what's happening inside the body.

Radiopharmaceutical

A compound tagged with a radioactive isotope and used for medical purposes.

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- Computer creates an image showing function, not just structure

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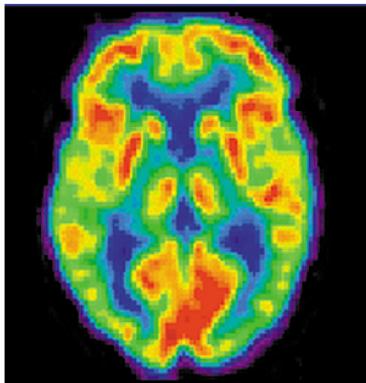- **Bone-seeking compounds:** Detect tumors and healing points

The Mental Model
Each isotope is like a specialized spy, reporting from specific locations in the body.
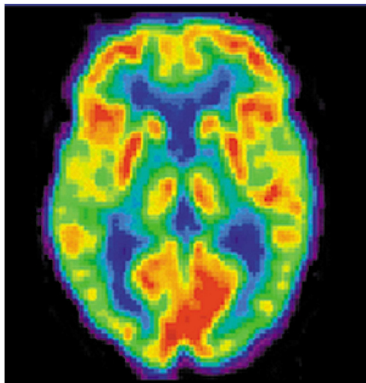
Brain scan of patient with Alzheimer's disease using a
radiopharmaceutical.

22.5 The Anger Camera

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Components:

- Lead collimator narrows gamma ray beams
- Scintillator converts gamma rays to visible light
- Photomultipliers convert light to electrical signals
- Computer creates image from detector array

Single-Photon-Emission Computer Tomography

Rotating gamma camera creates 3D image with better contrast than Anger camera alone.

22.5 SPECT: Adding the Third Dimension

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- Creates cross-sectional slices (like CT scan)
- Trade-off: Better 3D detail, but lower spatial resolution

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Positron Emission Tomography (PET):
Uses isotopes that emit positrons (β^+ particles).

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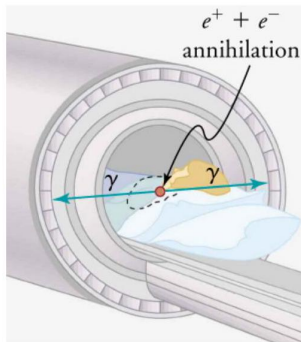5. Gamma rays travel in **exactly opposite directions**
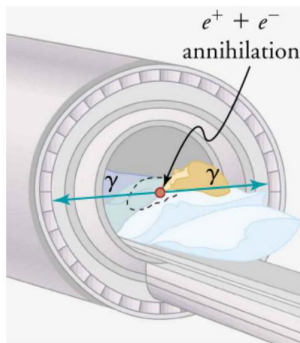
The Universal Law

$$E = mc^2$$

Mass converts to energy: electron mass = 0.511 MeV per gamma ray.

Detectors on opposite sides detect simultaneous 0.511 MeV photons, pinpointing annihilation location.

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Real-World: Mapping Thought

PET can show which parts of brain activate when you speak, close your eyes, or solve math problems.

22.5 The Double-Edged Sword

The Paradox

Ionizing radiation:

- Can cause cancer, burns, and hair loss
- Can treat and cure cancer

How do we understand this?

The Paradox

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The Universal Truth

All effects of ionizing radiation come from one source:
Damage to DNA molecules inside cells.

22.5 DNA: The Code of Life

DNA structure:

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The Mental Model

DNA is like the source code for your body. Radiation introduces bugs. The cell tries to debug.

A cell with damaged DNA repair ability can:

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22.5 When Repair Fails

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Civilian View vs. Reality

Civilian: "Radiation always causes cancer."
Physicist: "Radiation damages DNA. Outcome depends on dose, cell type, and repair ability."

22.5 Why Radiation Kills Cancer

The Vulnerability

Cancer cells reproduce rapidly. Radiation damages DNA most during cell division.

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Cancer cells are MORE sensitive to radiation than normal cells.

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Target rapidly dividing cancer cells while minimizing damage to slowly dividing normal cells.

This is why radiation can both cause and cure cancer.

22.5 The Central Challenge

Therapeutic Ratio

$$\text{Therapeutic Ratio} = \frac{\text{Abnormal cells killed}}{\text{Normal cells killed}}$$

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Therapeutic Ratio

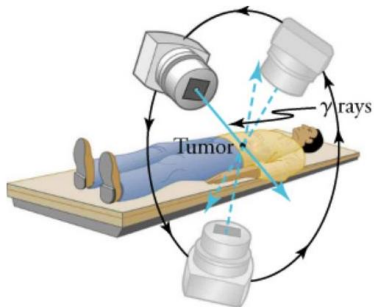$$\text{Therapeutic Ratio} = \frac{\text{Abnormal cells killed}}{\text{Normal cells killed}}$$

Goal of radiotherapy:

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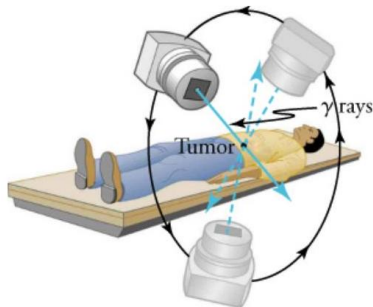- Achieve highest possible therapeutic ratio

The Trade-off

Radiation doesn't distinguish cancer from normal cells - only rapidly dividing from slowly dividing.

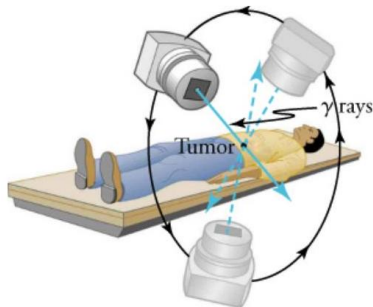**Strategy:** Rotate ^{60}Co gamma source around patient. All beams intersect at tumor.

22.5 Geometric Targeting

Strategy: Rotate ^{60}Co gamma source around patient. All beams intersect at tumor.

- Tumor receives high dose from all directions
- Surrounding tissue receives low dose from each beam

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5. Antibodies concentrate in abnormal tissue they were designed to fight
6. Radiation destroys cancer cells locally

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The Limit

Technique is limited by tolerable damage to organs that process and eliminate the radiopharmaceutical.

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Key point: Must specify which tissue received the dose.

- Whole-body dose
- Localized dose (e.g., forearm)

Attempt: Radiation Dose Calculation

The Challenge (3 min, silent)

A 60.0-kg person is exposed to ionizing radiation over their entire body and absorbs 1.80 J of energy.

Given:

- Mass = 60.0 kg
- Energy absorbed = 1.80 J

Find: Whole-body radiation dose in rads

Can you calculate the dose? Work silently.

Turn and talk (2 min):

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2. How do you convert J/kg to rads?
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Name wheel: One pair share your approach (not your answer).

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Reveal: The Dose

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Check: 1.80 J over 60 kg is small energy per mass, so low rad dose. Reasonable!

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Number expressing relative damage from a given type of radiation.

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Relative Biological Effectiveness (RBE)

Number expressing relative damage from a given type of radiation.

- X-rays, γ rays: RBE ≈ 1
- Beta particles: RBE $\approx$ 1-2
- Alpha particles: RBE $\approx$ 10-20
- Neutrons: RBE $\approx$ 3-10

Alpha particles:

- Short range (stopped by skin)

22.5 Why Alpha Is Deadly Inside

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Civilian View vs. Reality

Civilian: "Alpha is safe - can't penetrate skin."
Physicist: "Alpha is safe OUTSIDE. Deadly INSIDE."

22.5 The Rem: Dose Equivalent

Roentgen Equivalent Man (rem)

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The Mental Model

Rads measure energy deposited. Rems measure biological damage.

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Dose Levels

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Key Point

Dose spread over time allows repair. Same total dose over weeks causes less damage than in one day.

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Context

Average background radiation: $\sim$0.3 rem/year
Chest X-ray: $\sim$0.01 rem
CT scan: $\sim$1 rem

The Revelations

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What You Now Know

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4. Radiation damages DNA - effects depend on dose and repair ability
5. Cancer cells are more sensitive to radiation than normal cells
6. Radiotherapy maximizes therapeutic ratio through targeting
7. Dose units: rad (energy), RBE (effectiveness), rem (biological damage)

Key Equations

$$1 \text{ rad} = 0.01 \text{ J/kg} \qquad (1)$$

$$\text{rem} = \text{rad} \times \text{RBE} \qquad (2)$$

$$\text{Therapeutic Ratio} = \frac{\text{Abnormal cells killed}}{\text{Normal cells killed}} \qquad (3)$$

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Physics doesn't just explain the universe - it saves lives.

Complete the assigned problems

posted on the LMS

Temporary page!

LATEX was unable to guess the total number of pages correctly. A was some unprocessed data that should have been added to the this extra page has been added to receive it.

If you rerun the document (without altering it) this surplus page away, because LATEX now knows how many pages to expect for t document.