Illinois Institute of Technology

PHYSICS 561
RADIATION BIOPHYSICS

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2/16/2001

Radiation Biophysics: Introduction

- What we're trying to do:
  provide you with an understanding of what happens when ionizing radiation interacts with biological tissue.
- Most of you are in the Health Physics curriculum: there, you're learning about ionizing radiation
  - how it is produced
  - what it is used for
  - how to deliver it
  - how to quantitatite it
  - how to minimize exposure of people and things to it.

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Introduction (continued)

- You have also learned about the biological effects of radiation in other courses.
- In this course the emphasis is on the *biological* effects, both harmful and beneficial, of radiation.
- But to put those biological issues in context:
  - We'll discuss radiation physics and radiation chemistry.
  - We won't spend a lot of time on those subjects: you've dealt with those subjects in other courses.

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Who is your instructor?

- I am in the biology faculty within the Biological, Chemical, and Physical Sciences Department at IIT.
- But my graduate degree is in physics, so I'm reasonably familiar with physics and chemistry as well as biology.

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Am I qualified to teach this?

- I'm a protein crystallographer:
  - I use X-ray diffraction to study the 3-D structures of large biomolecules
  - I am not a health physicist by specialization
  - My research is often affected by concerns for the radiation safety of my experiments.
  - I'm a *consumer* of rad. biophysics knowledge.
- I postdoc'd in toxicology in a DOE lab: mechanistic studies stuck with me

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How will this course work?

- Live meetings: Wednesday evenings at IIT through May, with one week off in March.
- Internet: roughly one week behind.
- Primarily lectures, but with discussion
- Internet students: I want you to communicate extensively with me by e-mail; it's the only way I'm going to get to know you. Be brazen! Be daring!

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Homework

- We will start every class except this one by going over the homework assignment.
- The homework is due at 11:59 p.m. on the Friday two days after class, so we won't answer the homework questions in class, but we will discuss how the problems work, and if there are items that require clarification we'll provide them then.

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Course Plans (continued)

- 2 midterms and a final
  - Open-book and open-notes
  - Only forbidden item: other books (so I can steal problems from other books if I want!)
- the detailed schedule is on the web at http://icarus.csrri.iit.edu/radbio/.

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Course Sources

- Edward L. Alpen, *Radiation Biophysics*,
  - 2nd Ed.: San Diego: Academic Press, 1998. 520 pp..., cloth. ISBN 0-12-053085-6. $69.95.
  - We'll work closely from textbook except in our discussion of radiation chemistry (chapter 6) and a lecture (I hope) at the end of the course on organismal biology and biochemistry
- Supplemental readings (HTML, books)

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A history of radiation biophysics

- Early characterizers of the properties of X-rays and radioactivity:
  - Röntgen: X-rays, 1895
  - Becquerel: radioactivity
  - Rutherford: radioactive chain decay
  - The Curies: radium, polonium
- Edison's fluoroscope: 1896

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Radiation and Medicine: 1895

First medically observable deleterious effect from X-rays was recorded less than six months after Roentgen's discovery of X-rays. So the history of radiation biophysics goes back almost as far as the history of X-rays

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Quantities, Units, and Definitions

The world of radiation research has gone through a major change in the units that it uses to express quantities. As recently as the 1970's when I was learning radiation quantitation, the traditional units for activity, dose, energy imparted, and equivalent dose were still in common use. In this course we will use the more modern units except in dealing with older research papers.

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Radiation Measurement Units

Quantity	Exposure (e.m. only)	Dose	Energy Imparted
Definition	$\Delta Q/\Delta m$	$\Delta E_D/\Delta m$	E_D
SI Unit	C/kg	Gray	Joule
Definition		Joule/kg	kg-m^2/sec^2
Old Unit	Roentgen	Rad	Erg
Definition	1 esu/cm^3	100 erg/g	g-cm^2/sec^2
Conversion	1 R = 2.58 á10^{-4}C/kg	1 Gy=100 Rad	1 J = 10^7 erg

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Additional Quantities: Equivalent Dose

- Effects of a dose depend on how much energy is deposited per unit mass and on how influential that energy is in the medium:
- $H_{T,R} = D_R W_R$ (D_R=dose, W_R= weight factor) for tissue T, radiation type R.
- If R is ^{60}Co photons, W_R=1 (reference type)
- Unit: Sievert (1 J/kg)

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RBE and Kerma

- RBE (relative biological effectiveness):
  - describes weight factors for specific biological endpoints (e.g. carcinogenesis) as well as specific radiation types.
  - Often used in context of radiation-induced tumors and other long-term problems.
- Kerma: Kinetic Energy Released to the Medium
  - Let ΔE_K =initial kinetic energy of all charged particles liberated. Then Kerma $K = \Delta E_K / \Delta m$
  - Dimensions of dose (book says energy—that's wrong)
  - Units: Gy or rad.

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Fluences and Flux Densities

- Let ΔN = # particles entering a sphere with cross sectional area Δa (total area $a = 4\pi r^2$)
- Particles enter during time interval dt
  —Then—
- Particle fluence = $\Phi = \Delta N / \Delta a$
- Particle flux density = $\phi = \Delta \Phi / \Delta t$

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Energy Fluence, Flux Density

- Let ΔE_f = sum of energy (exclusive of rest energy) of all particles entering sphere of cross-sectional area Δa
- Energy fluence: $\Psi = \Delta E_f / \Delta a$
- Energy flux density: $\psi = \Delta\Psi / \Delta t$

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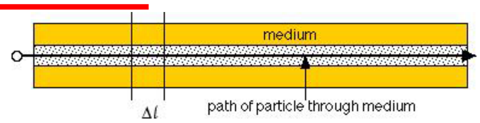
Linear Energy Transfer (LET)



- LET defined as dE_L/dl, where dE_L is the energy locally imparted to the medium over the length interval dl.
- Dimensions: Energy / length; units: J/m
- *restricted range stopping power*: don't look for energy deposited far from path.

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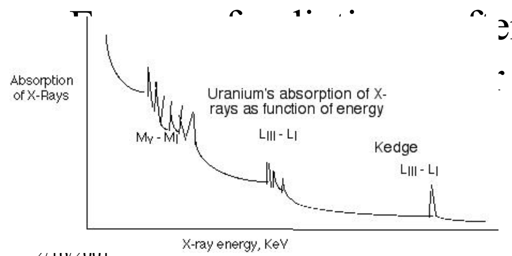
What does LET depend on?

- Nature of radiation
  - Alpha particles can be stopped by paper
  - Betas can be stopped by aluminum
  - Photons can get through almost anything
- Nature of medium (density, chemistry)
- … en in subtle ways:
  … absorption edges.



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Charged Particle Equilibrium

CPE exists at a point *p* centered in a volume *V* if each charged particle carrying a certain energy out of *V* is replaced by another identical charged particle carrying the same energy into *V*. If CPE exists, then dose = kerma.

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Radioactivity Measurements

- Let dP be the probability that a specific nucleus will undergo decay during time dt.
- Decay constant of a nuclide in a particular energy state is $\lambda = dP/dt$.
- Half-time or half-life: time required for half of starting particles to undergone transitions.
  $T_{1/2}$=ln $2/\lambda$
  (not ln $(2/\lambda)$, as the book claims)

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Activity

- Let dN = expectation value (most likely number) of nuclear transitions in time dt.
- Then activity $A = dN/dt = -\lambda N$
  (note that the minus sign is just keeping track of disappearance rather than appearance)
- Dimensions: time^{-1}
- Units: 1 becquerel = 1 disintegration /sec
- Old unit: Curie: $3.7 \bullet 10^{10}$ s^{-1}

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