Illinois Institute of Technology

PHYS 561
Radiation Biophysics

Andrew Howard

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PHYSICS 561
RADIATION BIOPHYSICS

ANDREW HOWARD

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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/.

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

Radiation and Medicine: 1895

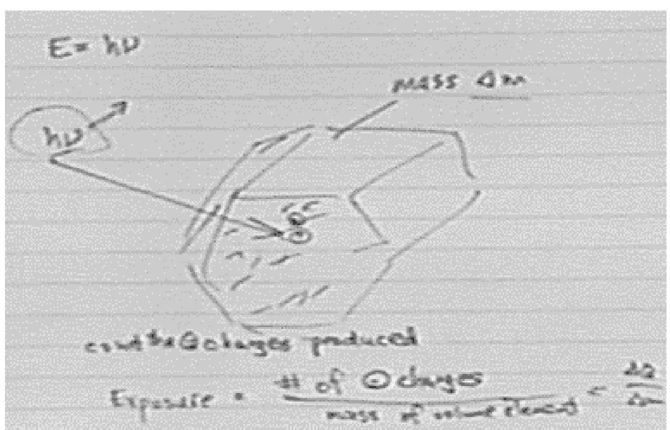
First medically observable deleterious effect from X-rays was recorded less than six months after Roentgen's discovery of X-rays. So the history of radiation biophysics goes back almost as far as the history of X-rays

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.

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 $\cdot 10^{-4}$ C/kg	1 Gy=100 Rad	1 J = 10^7 erg



$$\Delta E_D = \Delta E_E - \Delta E_L - \Delta E_R.$$

The unit for energy imparted, ΔE_D, is the gray. Joul

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Equivalent Dose: unit: Sievert

significance depends on energy and how influential that energy is.

$$H_{T,R} = D_R W_R$$

for { Tissue T, Radiation Type R. If R is (^{60}Co photons) $W_R = 1$

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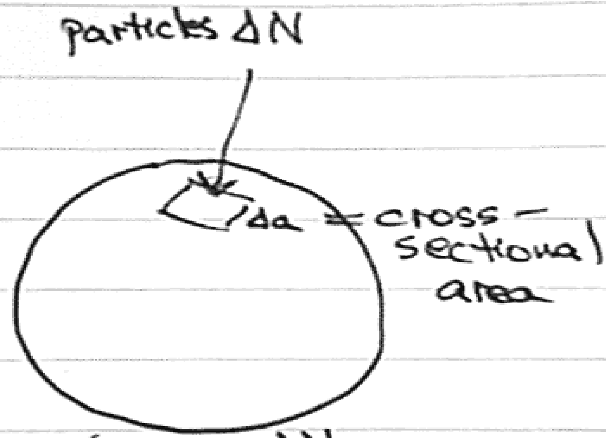

$$\Phi = \frac{\Delta N}{\Delta a}$$

units : L^{-2}, e.g.

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Particle Flux Density ϕ

time rate of particle fluence: $\phi = \frac{\Delta \Phi}{\Delta t}$: $m^{-2}\,sec^{-1}$

Energy fluence:

measure energy, not number.

$$\Psi = \frac{\Delta E_f}{\Delta a} \Rightarrow \text{units } E/A, \text{ e.g. } J/m^2$$

Energy flux density

$$\psi = \frac{\Delta \Psi}{\Delta t} \Rightarrow \frac{J}{m^2\text{-}sec}$$

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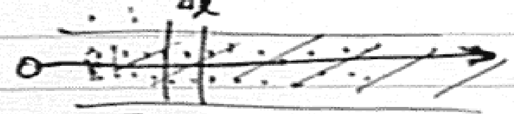
Kerma :

Kinetic Energy Released to the Medium

KERMA

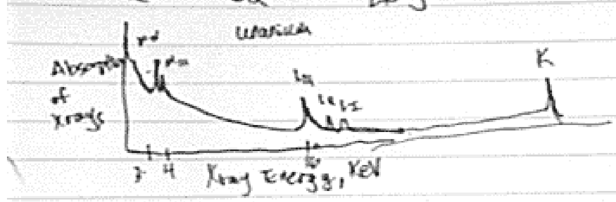
$\left(\frac{\Delta E_K}{\Delta m}\right)$ Gy.

Linear Energy Transfer



$$LET = \frac{\Delta E_L}{\Delta l} = \frac{dE_L}{dl}$$

$$ET = \frac{\Delta E_L}{\Delta l} = \frac{dE_L}{dl}$$ units: $\frac{\text{Energy}}{\text{Length}}$ eg. $\frac{J}{m}$.



Radioactivity

nuclei are composed of protons & neutrons

nucleus

change form

+ fragment

fragment : e^-, e^+, α particle, n

(p+2n)

1) Decay constant:

Probability of decay per unit time

$\lambda = \frac{dP}{dt}$ units: T^{-1}, e.g. $\underline{sec^{-1}}$.

more common: describe radioactivity in terms of half-life or half-time

defined $T_{1/2} \ni N(t) = \frac{1}{2}N(0)$

$\therefore T_{1/2} = \frac{\ln 2}{\lambda}$

$T_{1/2} = \ln \frac{2}{\lambda}$. should be $\frac{\ln 2}{\lambda}$ (1.12)

in terms of half-life
or half-time

defined $T_{1/2} \ni N(t) = \frac{1}{2}N(0)$

$\therefore T_{1/2} = \frac{\ln 2}{\lambda}$

Activity: $\frac{dN}{dt} = A = -\lambda N$
important

units $\frac{\text{disintegrations}}{\text{unit time}} \Rightarrow Bq = 1 \frac{\text{disintegration}}{\text{sec}}$

old unit: Curie : $3.7 \cdot 10^{10} s^{-1} = 3.7 \cdot 10^{10}$ Bq.

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Electromagnetic Radiation

Maxwell's ~~radiation~~ equations :

Coulomb's law

Biot - Savart law

Faraday's law

Charge conservation

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Maxwell's ~~radiation~~ :

Coulomb's law

Biot - Savart law

Faraday's law

Charge conservation

Properties of light were closely related to electrodynamics:

$$\text{speed of light} = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

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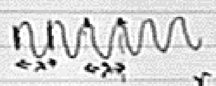
Properties of light:

- wave behavior (19th c) → (20th century)
- particle behavior (20th c)



$$e^{i\underline{k}\cdot\underline{r}} = \cos \underline{k}\cdot\underline{r} + i \sin \underline{k}\cdot\underline{r}$$

$\underline{r}$: position

$\underline{k}$: spatial frequency .

$c = \lambda \nu$

velocity   wavelength   temporal frequency

$L/T \quad = \quad L \quad \cdot \quad$ inverse time T^{-1}

$m/sec \quad\quad m \quad\quad sec^{-1}$

inverse sec : Hertz

$780 \text{ KHz} = 78 \cdot 10^5 \sec^{-1} \Rightarrow \text{time} = \frac{1}{78 \cdot 10^5} \sim 1.2 \cdot 10^{-6} \sec$

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780 KHz

$\Rightarrow \lambda = \frac{c}{\nu} = \frac{3.0 \cdot 10^8 \, m/sec}{7.8 \cdot 10^5 \, sec^{-1}}$

$= \frac{3.0 \cdot 10^3}{7.8} \approx \underline{3.84 \cdot 10^2 \, m}$

so wavelength at WBBM is $\underline{384 \, m}$

visible light : $\lambda \sim 500 \text{ nm} = 5 \cdot 10^2 \cdot 10^{-9} \, m$

$= \underline{5 \cdot 10^{-7} \, m}$

Xrays : $\lambda \sim 0.1 \text{ nm} = \underline{1 \cdot 10^{-10} \, m}$

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visible light : $\lambda \sim 500 \text{ nm} = 5 \cdot 10^2 \cdot 10^{-9} \, m$

$= \underline{5 \cdot 10^{-7} \, m}$

Xrays : $\lambda \sim 0.1 \text{ nm} = \underline{1 \cdot 10^{-10} \, m}$

Energy of an oscillator must be

$E = nh\nu$

$n \downarrow$ integer (1, 2, ... large)

$ML^2T^{-2} = \left(\underset{\text{unitless}}{n}\right)\left(\underset{\text{constant}}{h}\right) T^{-1}$

units of h: $\underline{ML^2T^{-1}}$

units of angular momentum

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n oscillator must be

$\cancel{E_n} = (n+\frac{1}{2})h\nu$

n integer (1, 2, ... large)

n (unitless) (h constant) J^{-1}

$h: ML^{2}T^{-1}$

oscillator can emit packets of radiation

$\Delta E = \Delta n \cdot h\nu$

$h = 6.63 \cdot 10^{-34}$ Jsec

~~3.3#~~

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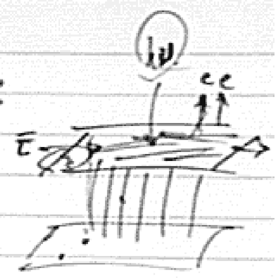
Photoelectric Effect:



$E_{light} = h\nu = E_0 + K_{max}$

work function

energy imparted to electrons

light can behave as a particle as well as a wave

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mass energy:

relativity says:

an object with mass m
carries around an energy

$$E = \frac{mc^2}{\sqrt{1-v^2/c^2}} \quad (27)$$

e.g. proton with same velocity
electron

then $\dfrac{\text{mass energy of proton}}{\text{mass energy of}}$

an object with mass m
carries around an energy

$$E = \frac{mc^2}{\sqrt{1-v^2/c^2}} \quad (27)$$

e.g. proton with same velocity
electron

then $\dfrac{\text{mass energy of proton}}{\text{mass energy of electron}} = \dfrac{E_p}{E_e} = \dfrac{m_p c^2/\sqrt{1-v^2/c^2}}{m_e c^2/\sqrt{1-v^2/c^2}}$

but we said velocities are equal so $\dfrac{E_p}{E_e} = \dfrac{m_p}{m_e}$

Homework:

electrons at APS:

$$\text{Energy} = 7\,\text{GeV} = 7\cdot 10^9\,\text{eV} = \frac{m_e c^2}{\sqrt{1-v^2/c^2}}$$

now $\underline{m_e c^2} = 0.511\cdot 10^6\,\text{eV}$

$$E = 7\cdot 10^9\,\text{eV} = \frac{0.511\cdot 10^6\,\text{eV}}{\sqrt{1-v^2/c^2}} \quad : \text{find } c-v$$

What's going on?

We describe mass energy as

$$E = \frac{m_o c^2}{\sqrt{1-v^2/c^2}} = \underline{\gamma m_o c^2}$$

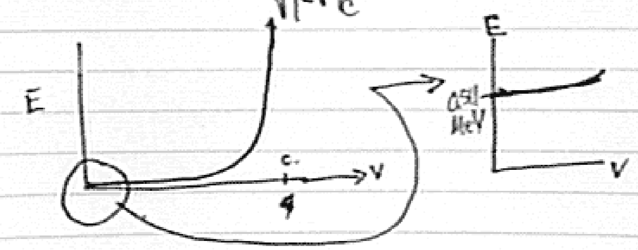
m_o = rest mass of object.

Define relativistic mass as $\dfrac{m_o}{\sqrt{1-v^2/c^2}} = \gamma m_o = m_r$

Then $E = m_r c^2$ ..

thus we have Einstein's famous equation for energy.

at $v=0$, $m_r = \frac{m_o}{\sqrt{1-v^2/c^2}} = \frac{m_o}{\sqrt{1-0}} = \underline{\underline{m_o}}$



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If $v = 0.1c$

then $\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{1}{\sqrt{1-(.1)^2}}$

$= \frac{1}{\sqrt{.99}} = \underline{1.05}$

at $V = 0.98c$: $\gamma \sim 5$.

APS: $\frac{7 \cdot 10^9 \text{ eV}}{0.511 \cdot 10^6 \text{ eV}} = 13000 = \gamma$

electrons

$m_r = \gamma m_o$ so $m_r \sim 13000\, m_o$

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PROBLEMS

1. Assume an oscillating spring that has a spring constant, k, of 20 N m^{-1}, as mass of 1 kg, and an amplitude of 1.0 cm. If Planck's radiation formula describes the behavior of this system, what is the quantum number, n. What is ΔE if n changes by 1? The frequency of a simple oscillator is given by

$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{m}}.$$

2. An atom is shown to absorb light at a wavelength of 375 nm. It emits light at 580 nm. What is the energy absorbed by the atom from one incoming photon?

$$E = (n + \tfrac{1}{2})h\nu.$$