Therapeutic Radiological Physics

- Books
  - Introduction to Radiological Physics and Radiation Dosimetry by Frank H. Attix
  - The Physics of Radiology, HE Johns and JR Cunningham

Grading and Important Dates

Item	Weight	Date
Homework*	25%	1 week
First Test	25%	Sep 21
Second Test	25%	Oct 19
Last day to	drop class	Nov 21
Final	25%	Nov 30

Homework is due 1 week after assigned. After 1 week grade is 80% of the maximum. After 2 weeks no grade. Homework is mandatory, even with no grade.

Topics to be covered today

- Types and Sources of Ionizing Radiation
- Description of Ionizing Radiation Fields
  - Consequences of the Random Nature of Radiation
  - Simple Description of Radiation Fields by Nonstochastic Quantities
  - An Alternative Definition of Fluence
  - Planar Fluence

Radiological Physics

- RP is the science of ionization radiation and its interaction with matter, with special interested in the energy absorbed by the matter.
- Radiation Dosimetry has to do with the quantification and determination of the this energy.

Ionizing Radiation

- Ability to excite and ionize atoms of matter
- In principle 4-25 eV -> UV (320nm)

Ionization radiation

- Ionization radiations are characterized by their ability to excite and ionize atoms of matter with which they interact.
- Radiological physics – ionizing radiation and its interaction with matter, with special interest in the energy absorbed by the matter
- Radiation dosimetry - quantification of that energy absorbed

Types and sources of ionizing radiations

- Gamma-rays
- X-rays
- Fast electrons
- Heavy charged particles
- Neutrons
- Directly ionizing radiation
- Indirectly ionizing radiation

X-rays

0.1-20 kV	Low energy or soft x-rays or Grenz rays
20-120 kV	Diagnostic range x-rays
120-300 kV	Orthovoltage x-rays
200kV- 1MV	Intermediate x-rays
1 MV upward	Megavoltage x-rays

Heavy Charged Particles

- Proton
- Deuteron (p+n)
- Triton (p+2n)
- Alpha particle (2p+2n)
- Other heavy particles consisting of the nuclei of heavier atoms, with charge
- Pions produced by interaction of fast e or p with nuclei

Ionizing Radiation

- Directly ionization radiation
- Indirectly ionization radiation

- Why is so important?
  - 4 J/kg can kill a person even though this amount of energy only barely elevate the temperature of the person

X-rays

$$E_\gamma = h\nu = \frac{hc}{\lambda} = \frac{12.398 \text{ keV-Å}}{\lambda}$$

$$= \frac{1.2398 \text{ keV-nm}}{\lambda} \qquad (1.1)$$

where 1 Å (Angstrom) = 10^{-10} m, Planck's constant is

$$h = 6.626 \times 10^{-34} \text{ J s}$$

$$= 4.136 \times 10^{-18} \text{ keV s}$$

(note that 1.6022×10^{-16} J = 1 keV), and the velocity of light *in vacuo* is

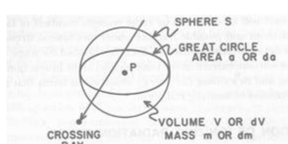
$$c = 2.998 \times 10^{8} \text{ m/s}$$

$$= 2.998 \times 10^{18} \text{ Å/s}$$

$$= 2.998 \times 10^{17} \text{ nm/s}$$

Description of ionizing radiation fields

- Consider a point P in space. How many rays will strike per unit time?



- How large the imaginary sphere has to be?

Description of ionizing radiation fields

- Stochastic
  - Random, can not be predicted. Described by probability distribution
  - Finite domains. Discontinuous in time and space.
  - Its value can be measured with an arbitrarily small error
  - The expectation value N_e is the mean N of its measured values N as the number n of observations approach infinity.
  - Ex: no. of particles striking a sphere of volume V

Description of ionizing radiation fields

- Nonstochastic
  - Can be predicted by calculations.
  - Point function, defined for infinitesimal volumes. We can define spatial gradient and time rate of change.
  - Its value is equal or based upon the expectation value of a related stochastic quantity.

Example

- Assume a random constant radiation field with respect to number of rays at a given point per unit area and interval → Poisson Distribution

$$\sigma = \sqrt{N_e} \cong \sqrt{N}$$

$$\sigma' = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{N_e}{n}} \cong \sqrt{\frac{\overline{N}}{n}}$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(N_i - \overline{N})^2\right]^{1/2}$$

$$\sigma' = \left[\frac{1}{n(n-1)}\sum_{i=1}^{n}(N_i - \overline{N})^2\right]^{1/2}$$

Simple description of radiation fields by nonstochastic quantities

- Fluence

$$\Phi = \frac{dN_e}{da}$$

N_e is the expectation value of number of rays striking a finite sphere surrounding P in time t_0 to t.

- Flux density (or fluence rate)

$$\varphi = \frac{d\Phi}{dt} = \frac{d}{dt}\left(\frac{dN_e}{da}\right)$$

Simple description of radiation fields by nonstochastic quantities

- Energy Fluence

$$\Psi = \frac{dR}{da}$$

R is the expectation value of the total energy of N_e rays striking a finite sphere surrounding P in time t_0 to t.

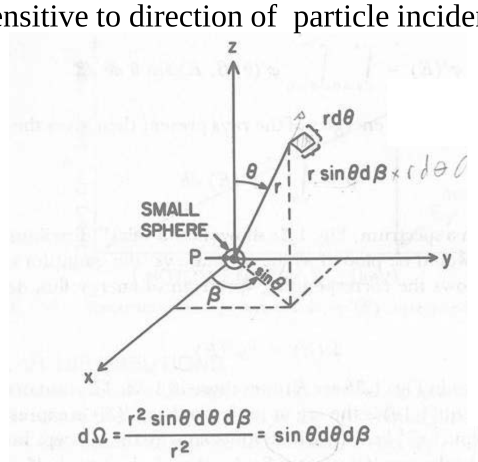
If E is constant then R=EN and $\Psi = E\Phi$

- Energy Flux density (or energy fluence rate)

$$\psi = \frac{d\Psi}{dt} = \frac{d}{dt}\left(\frac{dR}{da}\right)$$

Differential distributions versus energy and angle of incidence

Radiation interaction depends on the energy and type and radiation detectors are sensitive to direction of particle incidence to it



Differential distributions versus energy and angle of incidence

- Differential flux density

$$\varphi'(\theta, \beta, E)$$

$$\varphi'(\theta, \beta, E)\, d\Omega\, dE$$

$$d\Omega = \frac{r^2 \sin\theta\, d\theta\, d\beta}{r^2} = \sin\theta\, d\theta\, d\beta$$

$$\varphi = \int_{\theta=0}^{\pi} \int_{\beta=0}^{2\pi} \int_{E=0}^{E_{\max}} \varphi'(\theta, \beta, E) \sin\theta\, d\theta\, d\beta\, dE$$

Differential distributions versus energy and angle of incidence

- Energy spectra

$$\varphi = \int_{\theta=0}^{\pi} \int_{\beta=0}^{2\pi} \int_{E=0}^{E_{\max}} \varphi'(\theta, \beta, E) \sin\theta\, d\theta\, d\beta\, dE$$

$$\varphi = \int_{0}^{E_{\max}} \varphi'(E)\, dE$$

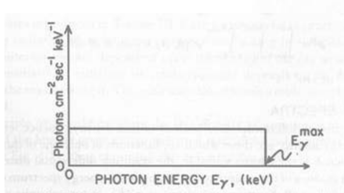


FIGURE 1.3a. A flat spectrum of photon flux density $\varphi'(E)$.

$$\psi'(E) = E\varphi'(E)$$

Differential distributions versus energy and angle of incidence

- Energy flux density spectra

$$\psi = \int_{E=0}^{E_{\max}} \psi'(E)\, dE = \int_{0}^{E_{\max}} E\varphi'(E)\, dE$$

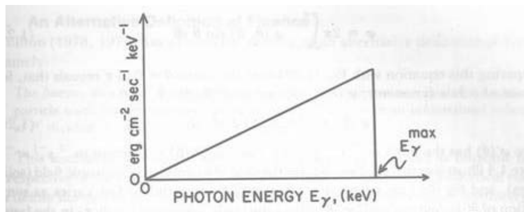


FIGURE 1.3b. Spectrum of energy flux density $\psi'(E)$ corresponding to Fig. 1.3a.

Angular distributions

- For a field symmetrical with respect to the z axis, it will be convenient to describe it in terms of the differential distribution of the flux density as function of the polar angle θ only.

$$\varphi = \int_{\theta=0}^{\pi} \int_{\beta=0}^{2\pi} \int_{E=0}^{E_{\max}} \varphi'(\theta, \beta, E) \sin\theta\, d\theta\, d\beta\, dE$$

$$\varphi'(\theta) = \int_{\beta=0}^{2\pi} \int_{E=0}^{E_{\max}} \varphi'(\theta, \beta, E) \sin\theta\, d\beta\, dE$$

Angular distributions

$$\varphi(\theta_1, \theta_2) = \int_{\theta_1}^{\theta_2} \varphi'(\theta)\, d\theta$$

Flux density thru polar angles Φ_1 and Φ_2

$$\varphi'(\theta, \beta) = \int_{E=0}^{E_{\max}} \varphi'(\theta, \beta, E)\, dE$$

Flux density per unit solid angle $d\Omega$

$$\varphi = \int_{\theta=0}^{\pi} \int_{\beta=0}^{2\pi} \varphi'(\theta, \beta) \sin\theta\, d\theta\, d\beta$$

Angular distributions

Symmetrical about z-axis then $\varphi(\theta,\beta)$ can be integrate over all β

$$\varphi = 2\pi \int_{\theta=0}^{\pi} \varphi'(\theta, \beta) \sin\theta\, d\theta$$

$$\varphi(\theta_1, \theta_2) = \int_{\theta_1}^{\theta_2} \varphi'(\theta)\, d\theta$$

$$\varphi'(\theta) = (2\pi \sin\theta)\, \varphi'(\theta, \beta),$$

Angular distributions

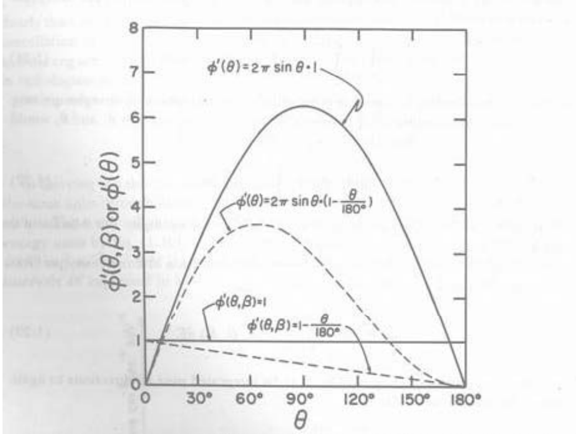


FIGURE 1.4. Isotropic radiation field expressed in terms of its flux-density distribution per unit solid angle, $\varphi'(\theta, \beta)$ = constant = 1 m^{-2} s^{-1} sr^{-1} (lower solid curve). The same field is also shown in terms of its distribution per unit polar angle, $\varphi'(\theta)$, in m^{-2} s^{-1} $radian^{-1}$ (upper solid curve). These two curves are related by the factor $2\pi \sin \theta$, which is also true if $\varphi'(\theta, \beta)$ is a function of θ only [e.g., see dashed curves for $\varphi'(\theta, \beta) = 1 - (\theta/180°)$].

Alternative definition of fluence

- Chilton (1978, 1979)

  The fluence at a point P is numerically equal to the expectation value of the sum of the particle track lengths (assumed to be straight) that occur in an infinitesimal volume dV at point P, divided by dV.

Planar fluence

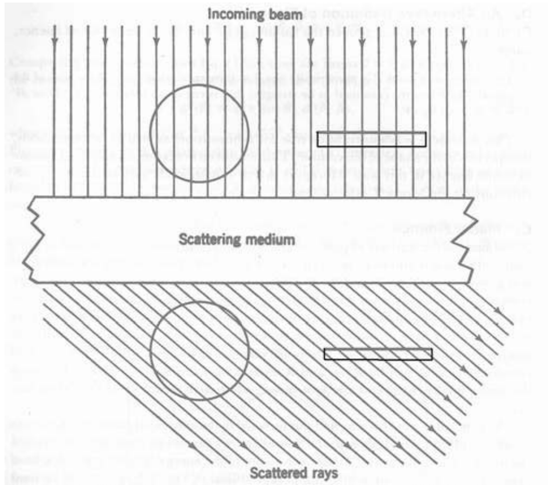


FIGURE 1.5. Particles scattered through an angle θ in a nonabsorbing foil, illustrating effect on fluence vs. planar fluence. (After Whyte, 1959.)

Planar fluence

- The radiation penetrates straight thru both detectors
- The radiation is stopped and absorbed in both detectors
- The energy deposited is always related to the fluence. Only in the case of nonpenetrating rays striking a flat detector, the energy deposited is related to the planar fluence.

Homework

- Chapter 1 problems.
- If delivered within 1 week after deadline. Maximum is 80% of the total.
- After 2 weeks, grade for the homework=0.
- Homework is mandatory, even with grade=0.