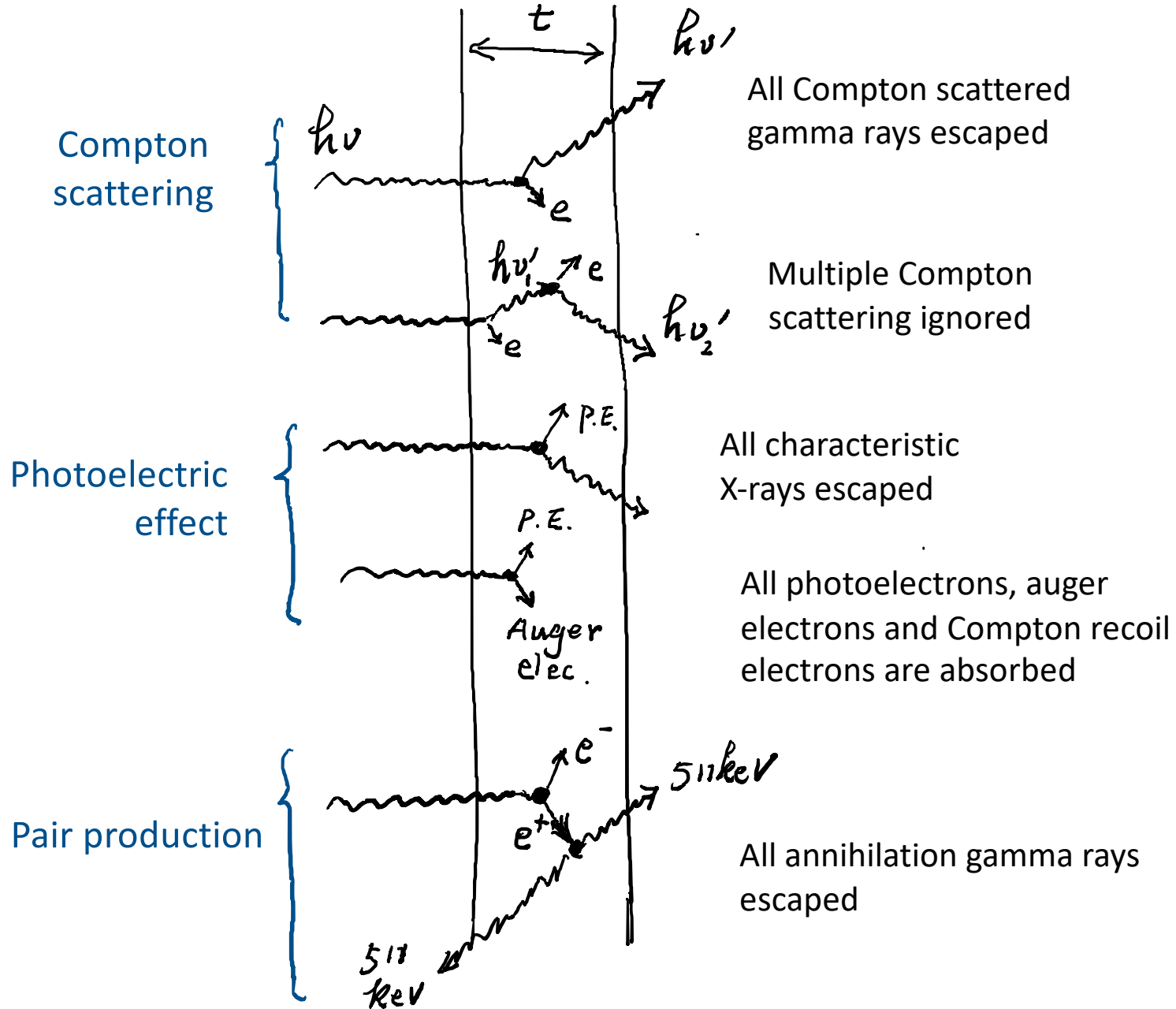


# How is the human dose measured?

## The Bragg-Gray Principle

# Energy Transfer by a Gamma Ray Beam



# Exposure Measurement: The Air Wall Chamber

## Example 6.3

Chamber volume =  $2 \text{ cm}^3$ .

Chamber filled with air at STP.

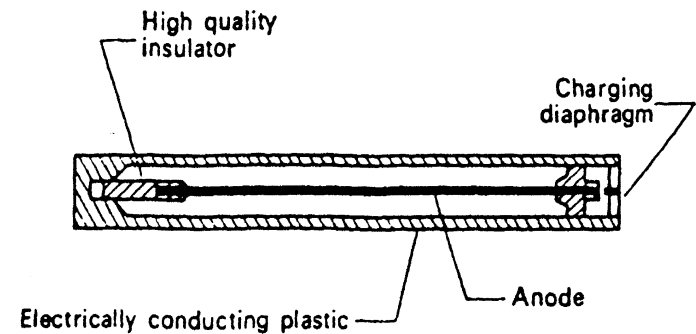
Electrical capacity =  $5 \mu\mu\text{F}$ .

Voltage across chamber before exposure to radiation =  $180 \text{ V}$ .

Voltage across chamber after exposure to radiation =  $160 \text{ V}$ .

Exposure time =  $\frac{1}{2} \text{ h}$ .

Calculate the radiation exposure and the exposure rate.



The exposure is calculated as follows:

$$C \times \Delta V = \Delta Q \quad (6.8)$$

$$5 \times 10^{-12} \text{ farads} \times (180 - 160) \text{ volts} = 1 \times 10^{-10} \text{ coulombs.}$$

## Solution

Since one exposure unit is equal to  $1 \text{ C/kg}$ , the exposure measured by this chamber is

$$\frac{1 \times 10^{-10} \text{ C}}{2 \text{ cm}^3 \times 1.293 \times 10^{-6} \text{ kg/cm}^3} = 3.867 \times 10^{-5} \text{ C/kg,}$$

which corresponds to

$$3.867 \times 10^{-5} \text{ C/kg} \times 3881 \frac{\text{R}}{\text{C/kg}} = 0.150 \text{ R,}$$

## Bragg-Gray Principle

W. H. Bragg (1910) and L. H. Gray (1929, 1936) applied this equation to the problem of relating the absorbed dose in a probe inserted in a medium to that in the medium itself. Gray in particular identified the probe as a gas-filled cavity, whence the name “cavity theory”. The simplest such theory is called the Bragg-Gray (B-G) theory, and its mathematical statement, referred to as the *Bragg-Gray relation*, will be developed next.

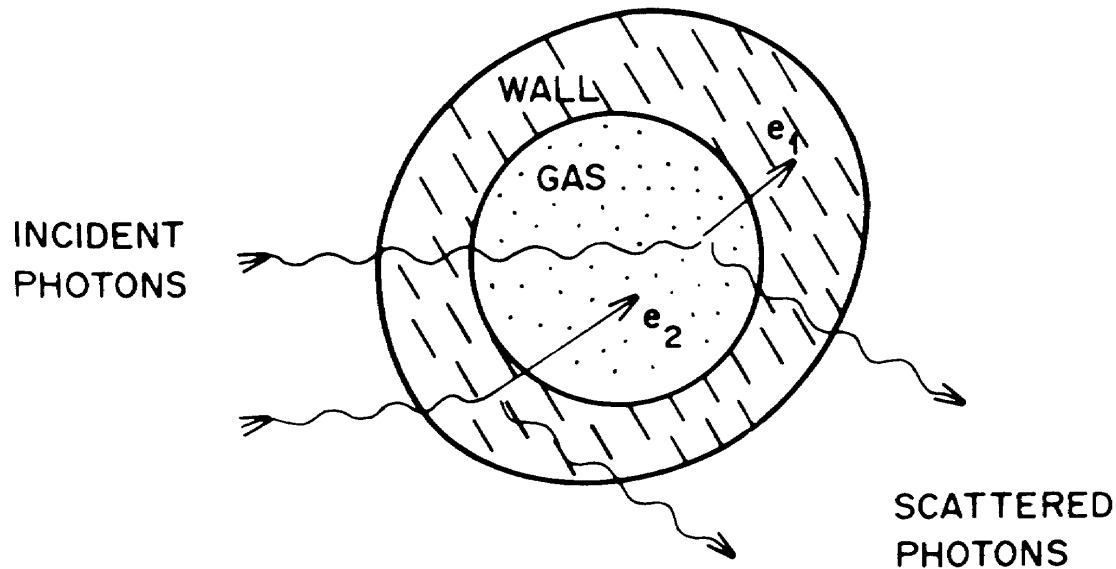
Suppose that a region of otherwise homogeneous medium  $w$ , undergoing irradiation, contains a thin layer or “cavity” filled with another medium  $g$ , as in Fig. 10.1b. The thickness of the  $g$ -layer is assumed to be so small in comparison with the range of the charged particles striking it that its presence does not perturb the charged-particle field. This assumption is often referred to as a “Bragg-Gray condition”. It depends on the scattering properties of  $w$  and  $g$  being sufficiently similar that the mean path length ( $g/\text{cm}^2$ ) followed by particles in traversing the thin  $g$ -layer is practically identical to its value if  $g$  were replaced by a layer of  $w$  having the same mass thickness. Similarity of backscattering at  $w$ - $g$ ,  $g$ - $w$ , and  $w$ - $w$  interfaces is also implied.

For heavy charged particles (either primary, or secondary to a neutron field), which undergo little scattering, this B-G condition is not seriously challenged so long as the cavity is very small in comparison with the range of the particles. However, for electrons even such a small cavity may be significantly perturbing unless the medium  $g$  is sufficiently close to  $w$  in atomic number.

Bragg-Gray cavity theory can be applied whether the field of charged particles enters from outside the vicinity of the cavity, as in the case of a beam of high-energy charged particles, or is generated in medium  $w$  through interactions by indirectly ionizing radiation. In the latter case it is also assumed that no such interactions occur in  $g$ . All charged particles in the B-G theory must originate elsewhere than in the cavity. Moreover charged particles entering the cavity are assumed not to stop in it.

A second B-G condition, incorporating these ideas, can be written as follows: The absorbed dose in the cavity is assumed to be deposited entirely by the charged particles crossing it.

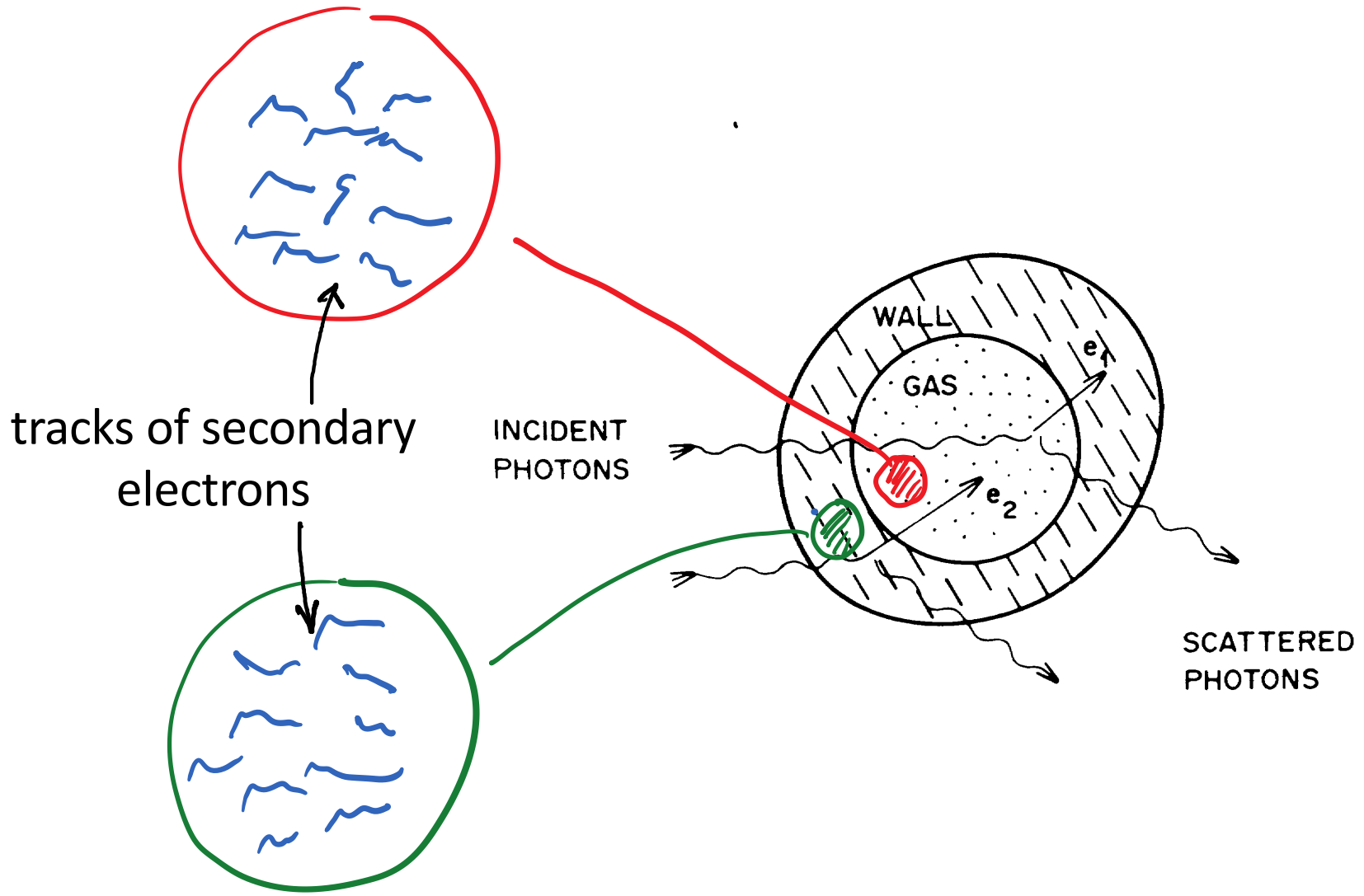
## Absorbed Dose Measurement: Bragg-Gray Principle



### Conditions for Reaching the Electronic Equilibrium

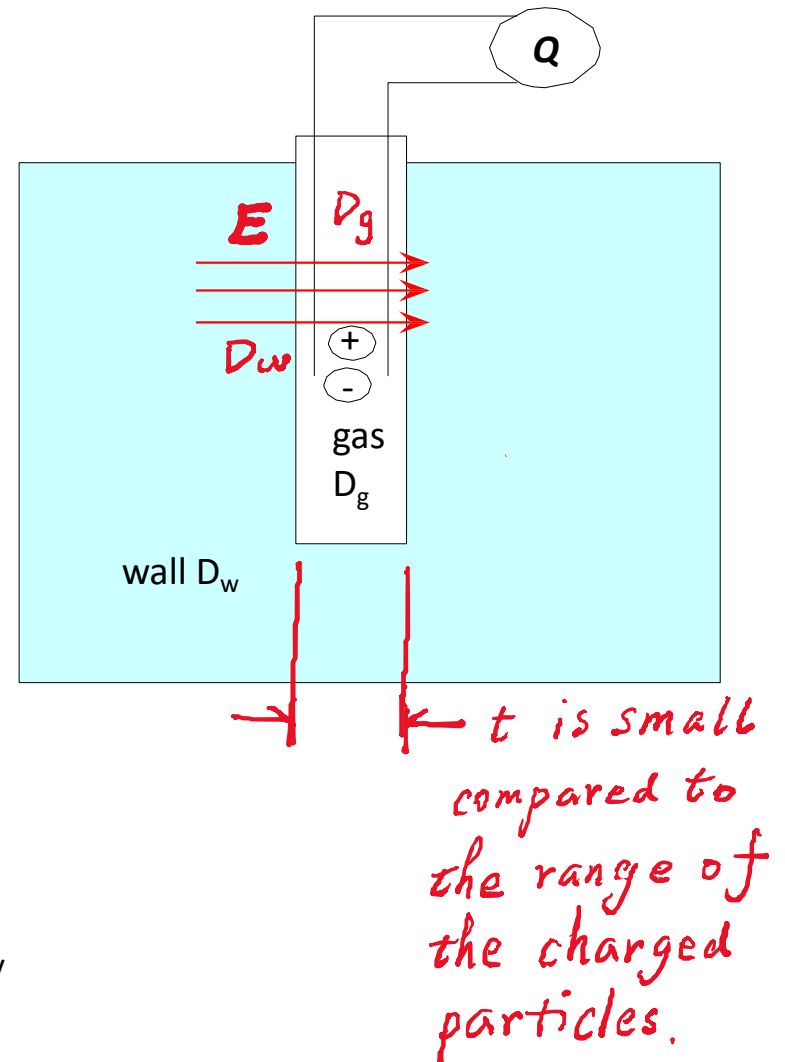
- ➡ Dimension of the gas volume is small compared to the range of the secondary charged particles.
- ➡ Wall thickness  $>$  maximum range of secondary charged particles.
- ➡ Wall thickness is not great enough to significantly attenuate the incident radiation.
- ➡ Wall and gas have similar atomic compositions.

# Absorbed Dose Measurement: Bragg-Gray Principle



## Bragg-Gray Principle: Problem Statement

- Homogeneous medium, wall (w)
- Probe - cavity - thin layer of gas (g)
- Charged particles crossing w-g interface
- Objective: find a relation between the dose in a probe to that in the medium
- Basis for dosimetry



# Bragg-Gray Principle

If we look at the very thin layers of wall media immediately adjacent to the interface, then the flux of the charged particles is almost unchanged across the boundary. The dose rate to the wall is given by

$$\dot{D}_w \left( \frac{J}{g \cdot s} \right) = \phi \left( \frac{\text{particles}}{s \cdot \text{cm}^2} \right) \cdot E \left( \frac{J}{\text{particle}} \right) \cdot \mu_w (\text{cm}^{-1}) / \rho_w \left( \frac{g}{\text{cm}^3} \right),$$

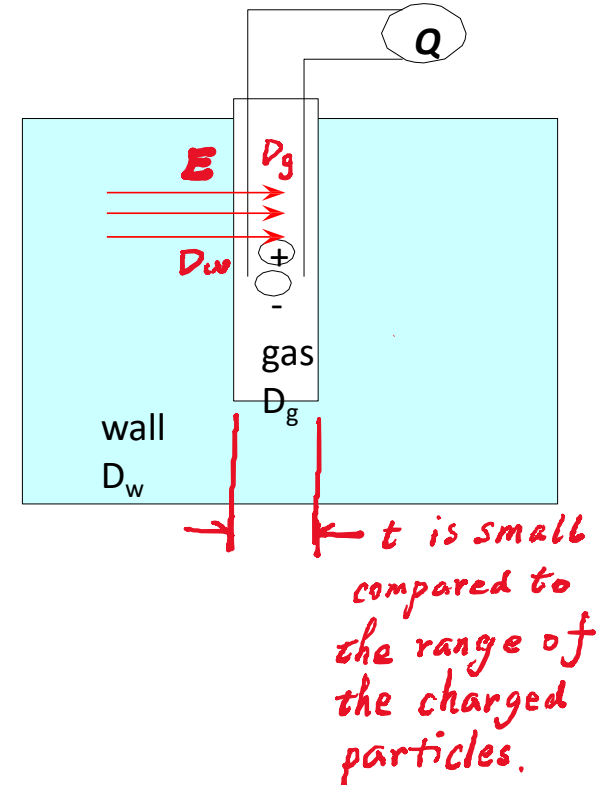
where  $\mu_w$  is the linear energy absorption coefficient.

Then the ratio of dose (rate) in the wall and in the gas is

$$\frac{\dot{D}_w}{\dot{D}_g} = \frac{D_w}{D_g} = \frac{\mu_w / \rho_w}{\mu_g / \rho_g}$$

For charged particles, the linear energy absorption coefficient  $\mu$  is roughly the same as the linear stopping power,  $s = \frac{dE}{dx}$ , therefore

$$\frac{\dot{D}_w}{\dot{D}_g} = \frac{D_w}{D_g} = \frac{\mu_w / \rho_w}{\mu_g / \rho_g} = \frac{s_w / \rho_w}{s_g / \rho_g} .$$



## Absorbed Dose Measurement: Bragg-Gray Principle

- ☞ The Bragg-Gray principle provides a means of relating ionization measurements in a gas volume to the absorbed dose in some convenient materials (such tissue equivalent materials) from which a dosimeter can be fabricated.
- ☞ If the gas cavity is surrounded by a wall medium of proper thickness to establish electronic equilibrium, then the energy absorbed per unit mass of the wall,  $dE_m/dM_m$ , is related to the energy absorbed per unit mass of gas,  $dE_g/dM_g$ , by

$$\frac{dE_m}{dM_m} = \frac{S_m}{S_g} \times \frac{dE_g}{dM_g}$$

where  $S_m$  is the main mass stopping power of the wall medium and  $S_g$  is the mass stopping power of the gas to the secondary electrons.

# Absorbed Dose Measurement: Bragg-Gray Principle

**TABLE 6.2. Mean Mass Stopping Power Ratios,  $S_m/S_{\text{air}}$  for Equilibrium Electron Spectra Generated by  $^{198}\text{Au}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$ , on the Assumption That the Electrons Slow Down in a Continuous Manner**

Energy, MeV	Medium		
	Graphite	Water	Tissue
0.411 ( $^{198}\text{Au}$ )	1.032		
0.670 ( $^{137}\text{Cs}$ )	1.027	1.162	1.145
1.25 ( $^{60}\text{Co}$ )	1.017	1.155	1.137

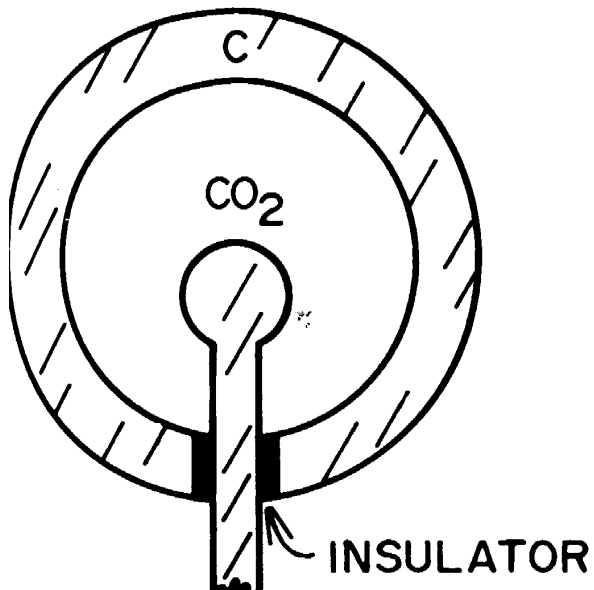
Source: N.B.S. Handbook 78, *Report of the International Commission on Radiological Units and Measurements*, National Bureau of Standards, U.S. Govt. Printing Office, Washington, D.C., 1959.

$$\frac{dE_m}{dM_m} = \frac{S_m}{S_g} \times \frac{dE_g}{dM_g}$$

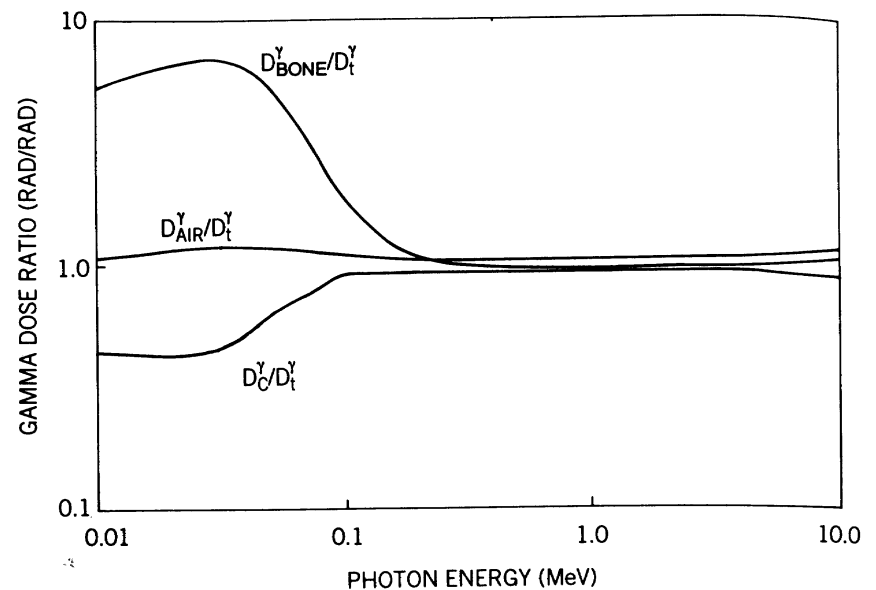
# Measurement of X- and Gamma Ray Dose

☞ For gamma rays with different energies

$$\frac{dE_m}{dM_m} = \frac{S_m}{S_g} \times \frac{dE_g}{dM_g}$$



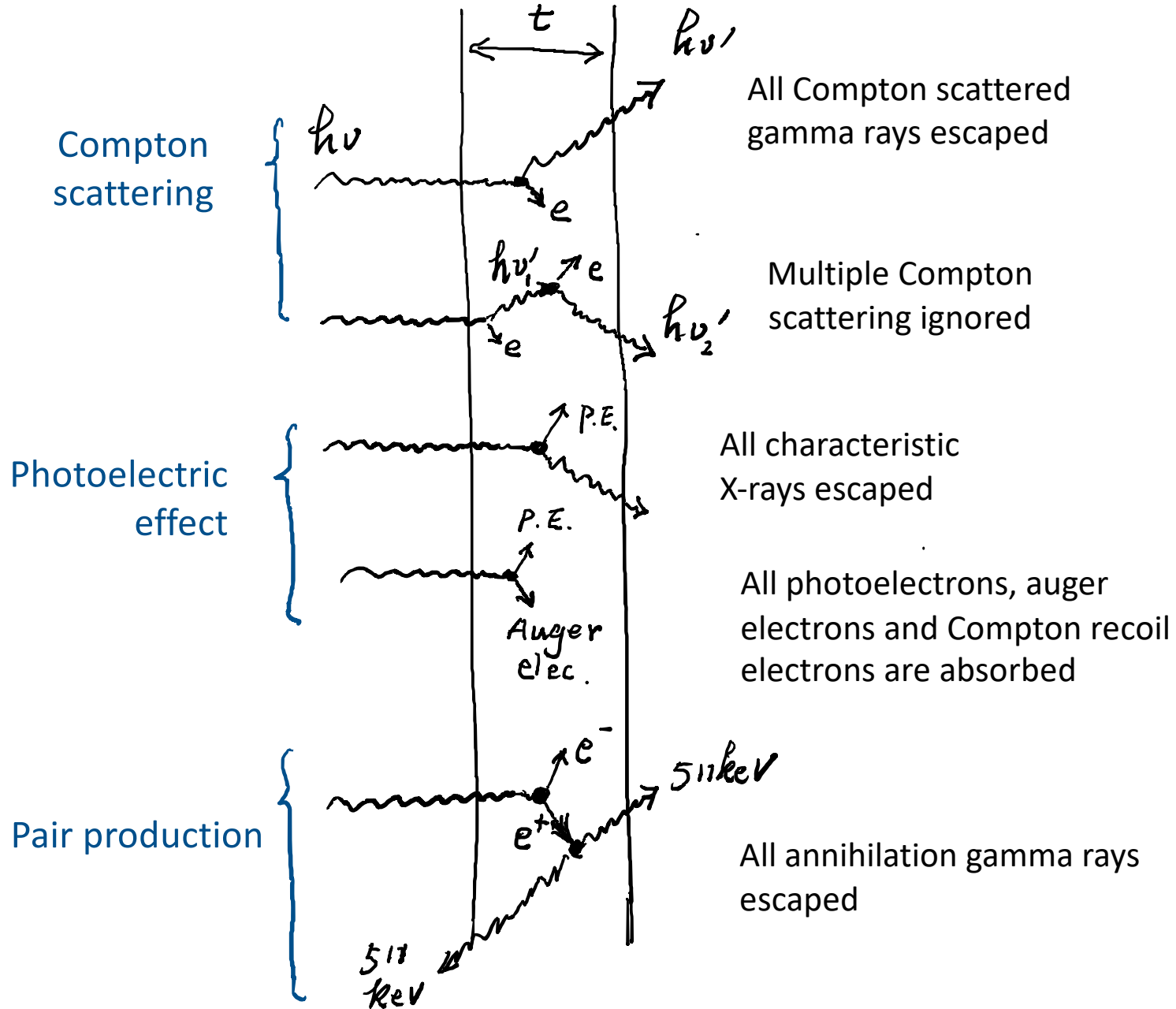
**FIGURE 12.4.** Cross section of graphite-walled CO<sub>2</sub> chamber for measuring photon dose.



**FIGURE 12.5.** Ratio of absorbed doses in bone, air, and carbon to that in soft tissue, D<sub>t</sub><sup>Y</sup>.

# Kinetic Energy Released per Unit Mass (Kerma)

# Energy Transfer by a Gamma Ray Beam



## Kinetic Energy Released per Unit Mass (Kerma)

- ☞ Kerma: Initial kinetic energy of the “primary” ionizing particles (including the photoelectrons, positron-electron pairs, recoil electrons and the scattered nuclei in case of fast neutrons) produced by the interaction of incident radiation per unit mass of the interacting medium.
- ☞ Measured in Gy (Joules per kilogram).
- ☞ An example (Cember, p183)

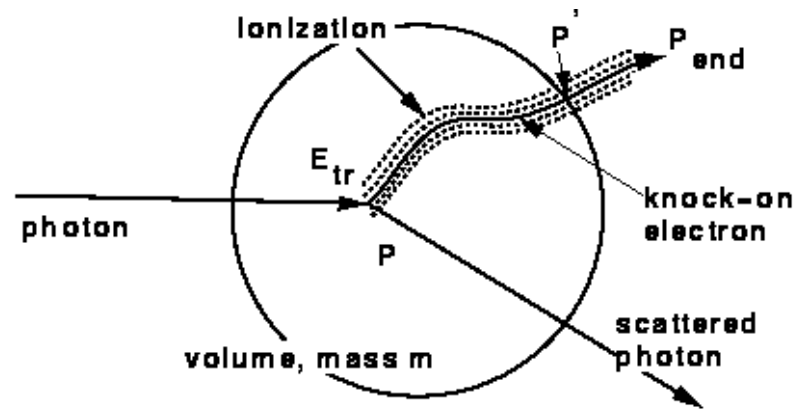


Figure 1: The exposure, air kerma and absorbed dose for a single photon which Compton scatters and transfers an energy  $E_{tr}$  to an electron at point  $P$ . The volume of interest is shown as a circle and the mass of this volume is  $m$ . The energetic electron set in motion at  $P$  slows down and stops at  $P_{end}$ . As it slows down it loses energy which results in 30 ion pairs being created near the track, per keV of energy lost.

## Kinetic Energy Released per Unit Mass (Kerma)

### *Example 6.6*

A 10-MeV photon penetrates into a 100-g mass, and a pair-production interaction leads to a positron and an electron of 4.5 MeV each. Both charged particles dissipate all their kinetic energy within the mass through ionization and bremsstrahlung production. Three bremsstrahlung photons of 1.6, 1.4, and 2 MeV each are produced and escape from the mass before they interact. The positron, after expending all its kinetic energy, interacts with an ambient electron as they mutually annihilate one another to produce two photons of 0.51 MeV each. Calculate

- (a) The kerma
- (b) The absorbed dose.

## Kinetic Energy Released per Unit Mass (Kerma)

(a) Kerma is defined as the *sum of the initial kinetic energies per unit mass of all charged particles produced by the radiation*. In this case, a positron-negatron pair of 4.5 MeV each ( $2 \times 4.5$  MeV) represents all the initial kinetic energy:

$$K = \frac{2 \times 4.5 \text{ MeV} \times 1.6 \times 10^{-13} \frac{\text{J}}{\text{MeV}}}{0.1 \text{ kg} \times 1 \frac{\text{J}}{\text{kg}}/\text{Gy}} = 1.44 \times 10^{-11} \text{ Gy}.$$

(b) Dose is defined as the *energy absorbed per unit mass*. Here we have the 9 MeV of initial kinetic energy, of which (1.6 + 1.4 + 2) MeV was converted to bremsstrahlung and escaped from the mass. The absorbed dose, therefore is

$$D = \frac{(4.5 + 4.5) \text{ MeV} - (1.6 + 1.4 + 2) \text{ MeV}}{0.1 \text{ kg} \times 1 \frac{\text{J}}{\text{kg}}/\text{Gy}} \times 1.6 \times 10^{-13} \frac{\text{J}}{\text{MeV}} = 6.4 \times 10^{-12} \text{ Gy}.$$

## Kinetic Energy Released per Unit Mass (Kerma)

- ☞ Kerma: decreases continuously with increasing depth in an absorbing medium.
- ☞ The absorbed dose is relatively less at the surface. It increases as electronic equilibrium is approached and the ionization density increases due to the increasing number of secondary ions produced by the primary ionizing particles. The maximum occurs approximately at a depth equal to the maximum range of the primary ionizing particles.

