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Cavity theory – dosimetry of small volume

FYS-KJM 4710

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Cavity theory

- Problem: dose to water (or other substance) is wanted, but dose measured with a detector (*dosimeter*) which have a different composition (atom-number, density)
- Transform dose to detector to dose in water?
- The dose determination is based on both measurements and calculations; dependent of the knowledge of radiation interaction
- Cavity theory: dose of small volume, *or volume of low density* – useful for charged particles

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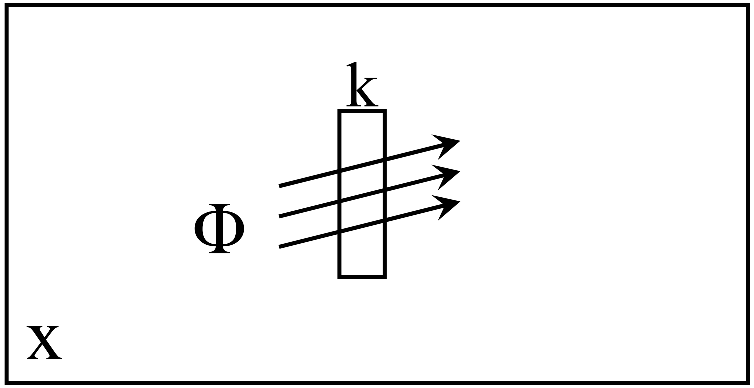
Cavity theory

- Consider a field of charged particles in a medium *x*, with a cavity *k* positioned inside:



- When the fluence is unchanged over the cavity the dose becomes:

$$D_k = \Phi_k \left(\frac{dT}{\rho dx} \right)_{col}$$

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Cavity theory

- When the cavity is absent the dose in the same point in x:

$$D_x = \Phi_x \left(\frac{dT}{\rho dx}\right)_{col}$$

- The dose relation becomes:

$$\frac{D_x}{D_k} = \frac{\Phi_x \left(\frac{dT}{\rho dx}\right)_{col}}{\Phi_k \left(\frac{dT}{\rho dx}\right)_{col}} = {}_k^x\left(\frac{dT}{\rho dx}\right)_{col}$$

→*Bragg-Gray relation*

Bragg-Gray cavity theory

- The B-G relation give that the dose relation between the cavity and the medium where the dose are to be determent is given by the stopping power relation
- Assumption (B-G conditions):
  - Deposited dose are only due to charged particles
  - The particle fluence does not change over the cavity

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Example: B–G theory

- The cavity is filled with air. The number of gas ionizations (measurable value) are proportional with dose to the air volume. The cavity is placed in water and radiated with 1 MeV electrons and the dose in the air cavity is measured to 1 Gy. What is the dose to water?
- Dose relation:

$$\frac{D_{water}}{D_{air}} = {}^{water}_{air}\left(\frac{dT}{\rho dx}\right)_{col} \quad \Rightarrow \quad D_{water} = {}^{water}_{air}\left(\frac{dT}{\rho dx}\right)_{col} D_{air}$$

- The relation between (water/air) are tabulated or the theoretical expressions can be used.

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Example: B–G theory

- Relation:

$$ {}^{water}_{air}\left(\frac{dT}{\rho dx}\right)_{col} = \frac{1.85\ \mathrm{MeV\ cm^2/g}}{1.66\ \mathrm{MeV\ cm^2/g}} = 1.11 $$

- Dose to water is then:

$D_{water} = 1.11\ D_{air} = 1.11$ Gy

- Cavity theory attach the dose in the sensitive volume (the measurable value) to the actual volume
- If only the dose to the cavity can be determinate, then it is just *relative dosimetry*

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Spectrum of charged particles

- Spectrum can be given as differential fluence, Φ_T
- Have to add together the dose contributions for all kinetic energies:

$$D = \int_0^{T_{max}} \Phi_T \left(\frac{dT}{\rho dx}\right)_{col} dT = \frac{\Phi}{\Phi} \int_0^{T_{max}} \Phi_T \left(\frac{dT}{\rho dx}\right)_{col} dT = \Phi \overline{\left(\frac{dT}{\rho dx}\right)}_{col}$$

- The dose relation is then given by the *average* stopping power:

$$\frac{D_x}{D_k} = {}_k^x\overline{\left(\frac{dT}{\rho dx}\right)}_{col}$$

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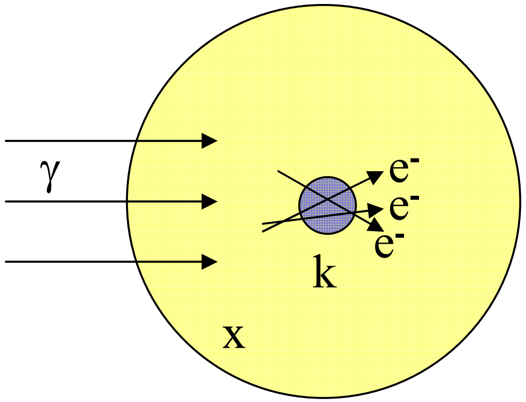
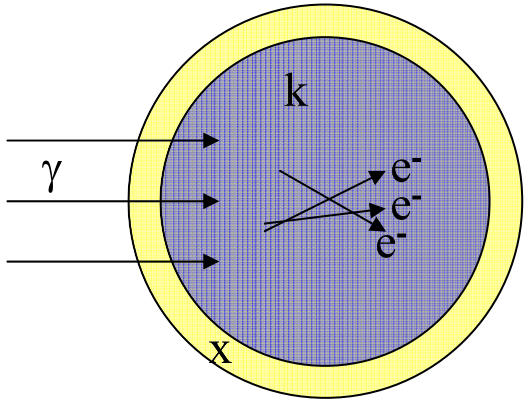
Theory of electrons and photons

- What happen when the cavity increase in volume or density; and the photons also are absorbed?
- Have two extreme cases:



No photon absorption in the cavity: B-G theory

$$\frac{D_x}{D_k} = {}_k^x\left(\frac{dT}{\rho dx}\right)_{col}$$



Photon absorption in the cavity: CPE theory

$$\frac{D_x}{D_k} = = \left(\frac{\mu_{en}}{\rho}\right)_k^x$$

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Burlin cavity theory

- Burlin derived a theory where both electron and photon absorption in the cavity are accounted for:

$$\frac{D_x}{D_k} = d \, {}^{x}_{k}\!\left(\frac{dT}{\rho dx}\right)_{col} + (1\text{-}d)\left(\frac{\mu_{en}}{\rho}\right)^{x}_{k} \qquad 0 \leq d \leq 1$$

- d = 1 : no photon absorption → B-G theory
- The range of electrons important – if kinetic energy high enough electrons traverse the cavity and d > 0