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Dosimetry of directly ionizing radiation

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Audun Sanderud

Department of Physics
University of Oslo

Direct ionizing radiation

- Direct ionizing radiation has often small and frequent energy transitions when traversing matter – continues slowing down approximation
- Limited range
- Energy deposit of charged particles is described by *stopping power*
- Electrons give rise to electrons and photon – the radiation field is generally mixed

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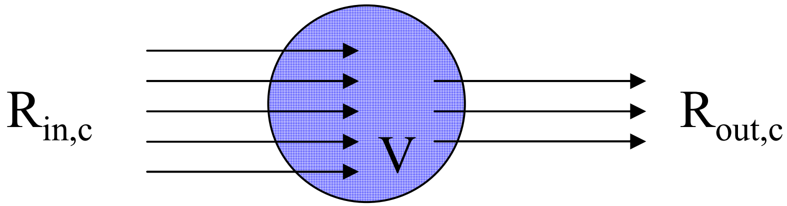
Dose from charged particles 1)

- A pure radiation field of charged particles entering a volume – what is the dose?



- Absorbed energy and dose:

$$\varepsilon = R_{in,u} + R_{in,c} - R_{out,u} - R_{out,c} + \sum Q$$

$$= R_{in,c} - R_{out,c} \qquad (\sum Q \text{ assumed zero})$$

$$= \Delta R_c$$

$$\Rightarrow D = \frac{\Delta R_c}{m}$$

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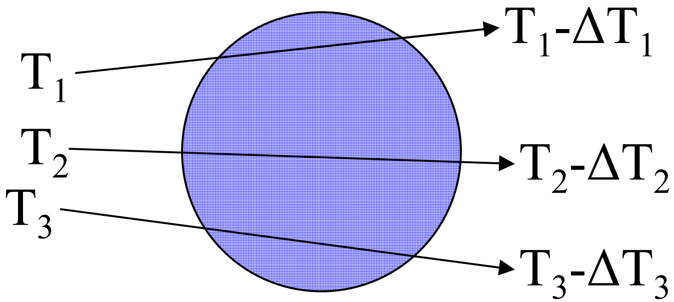
Dose from charged particles 2)

- Problem: establish ΔR_c



- Collision stopping power $(dT/dx)_{col}$ describe the relevant energy deposit

$$\Delta R_c = \sum_{i=1}^{n} \Delta T_n = \sum_{i=1}^{N} \left(\frac{dT}{dx} \right)_{col,i} \Delta x_i$$

(bremsstrahlung shall not med scored – photons will escape a small volume)

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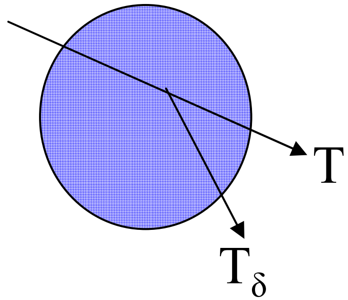
Dose from charged particles 3)

- New problem: what about the secondary electrons with enough energy to escape the volume - will transport energy away and reduce the dose!
- Such secondary electrons are named δ-electrons (remember LET_Δ)



- Absorbed energy from charged particles: $\varepsilon = \Delta R_c + \Delta R_\delta$
- But: δ-electrons is not in a very large number (the cross-section goes as $\sim 1/E^2$, where E is transferred energy)

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δ-electron equilibrium

- Assume that energy from the δ-electrons entering and those leaving the volume is the same, then $\Delta R_\delta = 0$ and:

$$\varepsilon = \Delta R_c$$

$$D = \frac{\varepsilon}{m} = \frac{\Delta R_c}{m} \overset{\delta\text{-equilibrium}}{=} \frac{1}{m}\sum_{i=1}^{N}\left(\frac{dT}{dx}\right)_{col,i}\Delta x_i$$

- Remember: Maximal transferred energy from heavy charged particles to electrons is:

$$E_{max} = 2 m_e c^2 \frac{\beta^2}{1-\beta^2}$$

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δ-electrons

- Since β small (i MeV-region), then E_{max} small
- β = 0.1 (eq. 38 MeV α-particles) give close to E_{max}= 10 keV

- Range to 10 keV electrons in water. 2.5 μm

→ δ-electrons deposit all of there energy very "local" and δ-equilibrium can be present ($\Delta R_{\delta,inn} = \Delta R_{\delta,out} \approx 0$)

- Range will 1 MeV electrons: 0.5 cm

→ δ-equilibrium usually not the case with a high energetic electron field

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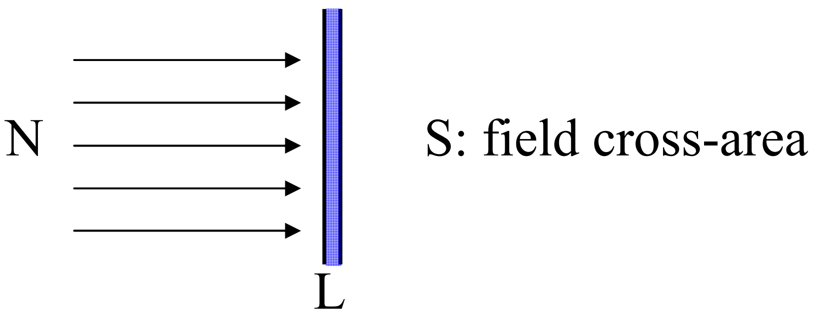
Dose from heavy charged particles 1)

- A parallel stream of N heavy charged particles against a thin foil:



- Particle fluence: $\Phi = N/S$
- Total stopping power approximately collision stopping power (no bremsstrahlung):

$$\left(\frac{dT}{dx}\right)^{\text{heavy charged particles}} = \left(\frac{dT}{dx}\right)_{\text{col}}$$

Dose from heavy charged particles 2)

- Dose:

$$D = \frac{1}{m}\sum_{i=1}^{N}\left(\frac{dT}{dx}\right)_i \Delta x_i \overset{\text{parallell}}{=} \frac{1}{m} N \left(\frac{dT}{dx}\right) L$$

$$= \frac{1}{\rho S L} N \left(\frac{dT}{dx}\right) L = \frac{N}{S}\left(\frac{dT}{\rho dx}\right)$$

$$= \Phi \left(\frac{dT}{\rho dx}\right)$$

- Dose proportional with field intensity and energy losses per length unit
- Important assumption: (dT/dx) constant trough the foil

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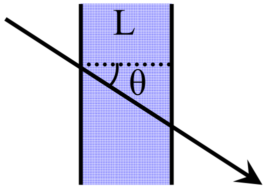
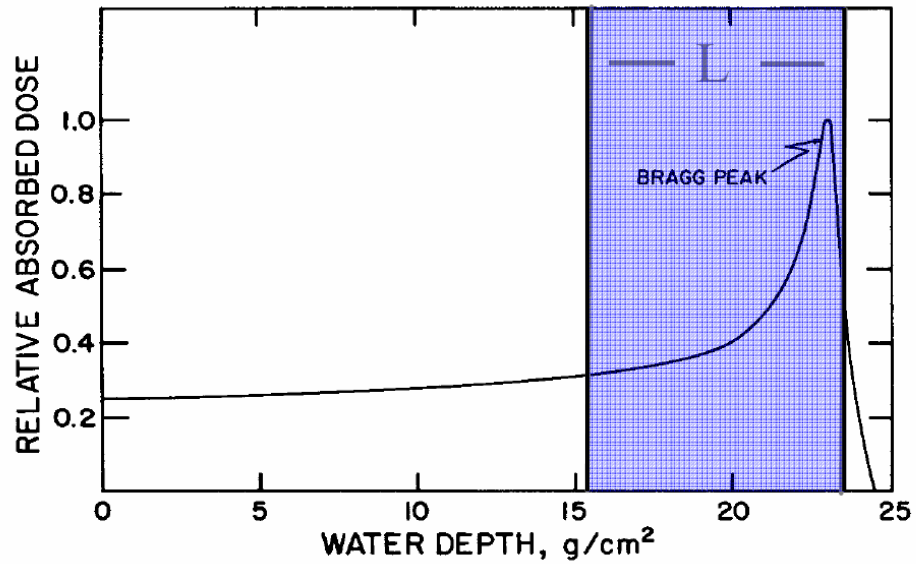
Dose from heavy charged particles 3)

- If the beam is not normal to the foil, the path gets longer $\rightarrow \Delta x = L/\cos\theta$, have then:

$$D = \Phi \left(\frac{dT}{\rho dx} \right) \frac{1}{\cos\theta}$$



- If the foil is thick enough, the (dT/dx) diversify dramatically; consider Bragg peak:



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Dose from heavy charged particles 4)

- Thick foil give then a heterogenic dose distribution
- To find *mean dose* can the following be done:
  - Calculated residual range: $\Re_{res} = \Re_{in} - L$
  - Find energy T_{out} correspond to $\Re_{res}$ (from table)
  - Deposit energy from one particle: $\Delta T = T_{in} - T_{out}$
  - The dose becomes:

$$D = \frac{N\Delta T}{m} = \Phi \frac{\Delta T}{\rho L}$$

Dose from electrons

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- Problem with electrons:
  1. Much scattering – increased pathlength
  2. Bremsstrahlung
  3. Many δ-electrons
- For relatively high energetic electrons in tick foils of low-Z materials point 1.–3. becomes less important
- Tools to estimate dose:
  1. Mean scattering angel
  2. Radiation yield
  3. LET_{Δ}