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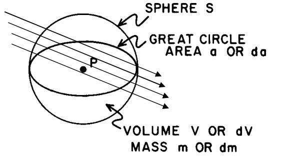
Description of radiation fields

Eirik Malinen

Ionizing radiation field

- Field of ionizing particles, where the particles may have a directional- and energy distribution
- Radiation field striking a small sphere:



- Number of particles N striking the sphere is proportional to dose

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Fluence

- Fluence *F*: number of particles *dN* striking the sphere per unit area *da:*

$$\Phi = \frac{dN}{da}$$ (*da* is the great circle area)

- The small sphere defines a point in space
- Fluence is as an expectation value; *N* is in reality a stochastic quantity
- For a radiation field through a medium, the fluence varies due to absorption, scattering and creation of new particles → $\Phi = \Phi(\vec{r})$

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Fluence 2

- The fluence may vary in time – the fluence rate is defined as:

$$\Phi_t = \frac{d\Phi}{dt} = \frac{d^2N}{dtda}$$

- Thus

$$\Phi = \int_0^{t_0} \Phi_t dt$$

- For a time-independent field:

$$\Phi = \Phi_t \Delta t$$

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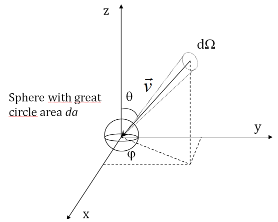
Fluence 3

- The radiation field may have a an energy and directional dependence. The differential fluence is:

$$\Phi_T = \frac{d\Phi}{dT} \;,\; \Phi_\Omega = \frac{d\Phi}{d\Omega} \quad (d\Omega = \sin\theta d\theta d\varphi)$$

- Φ_T is the number of particles per energy and area in the energy interval [T, T+dT] striking the sphere



Energy fluence

- How much energy 'strikes' the sphere?
- The energy fluence is defined as:

$$\Psi = \int_0^{T_{max}} T\Phi_T dT$$

- For a monoenergetic field:

$$\Psi = T\Phi = T\frac{dN}{da}$$

- Differentiated:

$$\Psi_T = \frac{d\Psi}{dT} = T\Phi_T \;,\; \Psi_\Omega = \frac{d\Psi}{d\Omega} = \int_0^{T_{max}} T\frac{d\Phi_T}{d\Omega} dT$$

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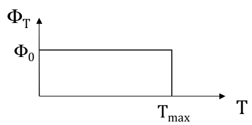
Fluence *vs* energy fluence

- Differential fluence with respect to energy is constant up to T_{max}:

$$\Phi_T = \Phi_0 \;\Rightarrow\; \Phi = \int_0^{T_{max}} \Phi_T dT$$

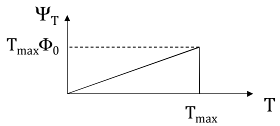
$$\Rightarrow \underline{\underline{\Phi = T_{max}\Phi_0}}$$



- Differential energy fluence is:

$$\Psi_T = T\Phi_T \;\Rightarrow\; \Psi = \int_0^{T_{max}} \Psi_T dT = \int_0^{T_{max}} T\Phi_T dT$$

$$\Rightarrow \underline{\underline{\Psi = \frac{1}{2}T_{max}^2\Phi_0}}$$



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Average particle energy in field

- Differential fluence and energy fluence are distribution functions
- Average energy defined as:

$$\langle T \rangle_\Phi = \frac{\int_0^{T_{max}} T\Phi_T dT}{\int_0^{T_{max}} \Phi_T dT} = \frac{\Psi}{\Phi}$$

$$\langle T \rangle_\Psi = \frac{\int_0^{T_{max}} T\Psi_T dT}{\int_0^{T_{max}} \Psi_T dT} = \frac{\int_0^{T_{max}} T^2\Phi_T dT}{\int_0^{T_{max}} \Psi_T dT} \neq \langle T \rangle_\Phi$$

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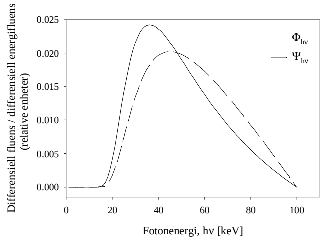
Fluence *vs* energy fluence 2

- X-ray spectrum is either differential fluence or differential energy fluence
- Problem: is often given as ”intensity”



Fluence *vs* energy fluence 3

- In our example:

$< T >_{\Phi} \approx 48$ keV

$< T >_{\Psi} \approx 54$ keV

- Always ask what the unit of the ordinate is in X-ray (or e.g. e^-) spectra!