Seminar

ẢNH HƯỞNG CỦA BỨC XẠ TỚI VẬT LIỆU

(RADIATION EFFECTS IN MATERIALS)

Nguyễn Tiến Hiển, Đào Hải Yến

Bộ môn Vật lý – Khoa Công nghệ thông tin

Contact info: nguyentienhien@vnua.edu.vn

OUTLINE

- 1 – Radiations
- 2 – The particle-material interaction
- 3 – The stopping power
- 4 - Effect due to Nuclear vs. Electronic stopping process;
- 5 – Applications

1 – Radiation

- Radiation = the emission or transmission of energy in the form of waves or particles

1 – Radiation

- Classification

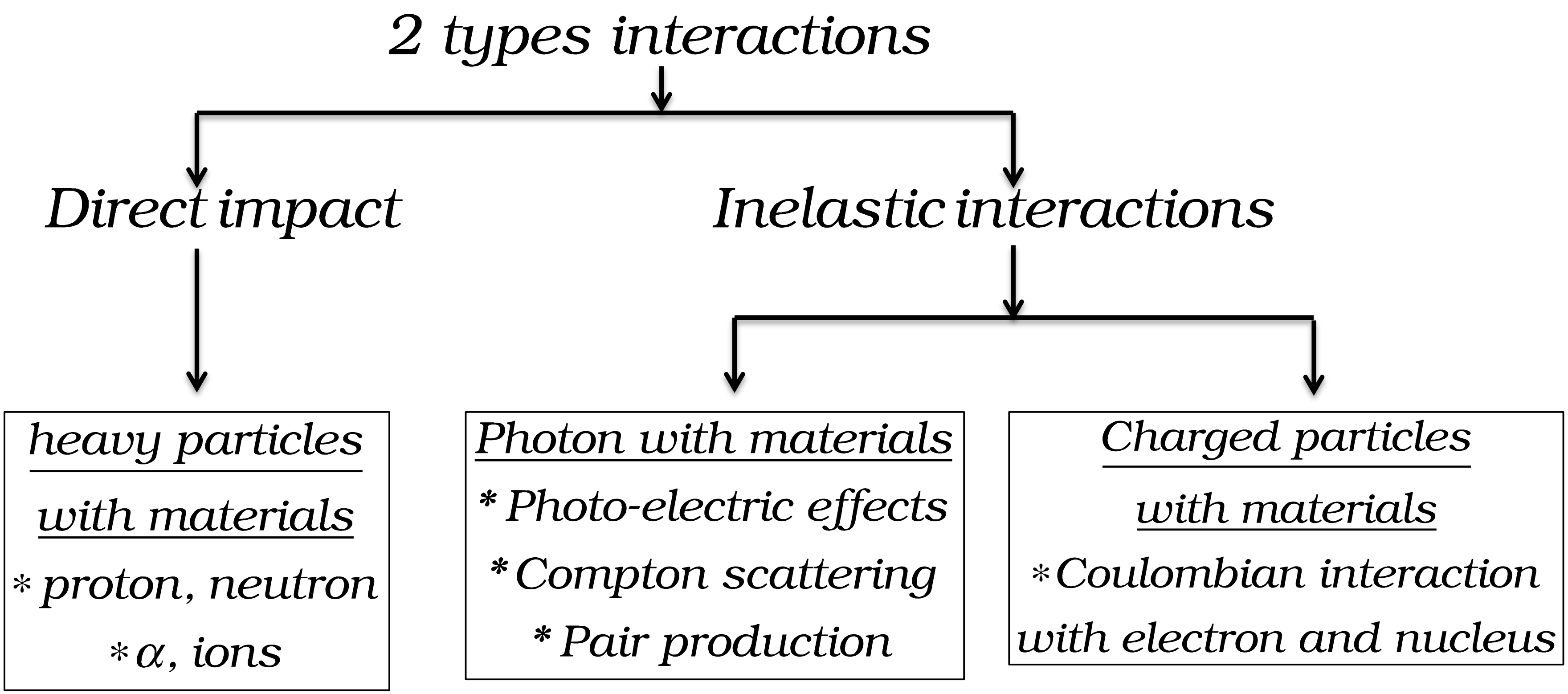
Radiations

- *EM – waves*
  - *Non – ionizing*
    - * *Radar*
    - * *Radio*
    - * *IR (heat)*
    - * *Visible*
    - * *UV*
  - *Indirectly – ionizing*
    - * *X – rays*
    - * γ *– rays*
- *Particles*
  - *Charged*
    - * α *– particles*
    - * β^- *– particles*
    - * β^+ *– particles*
    - * *protons*
    - * *ions*
  - *Un-charged*
    - * *neutron*
    - * *neutrino*

(Indirectly-ionizing, Charged and Un-charged:) **Carry enough energy to produce ions, i.e. ionizing materials (if deposited in matter)**

2 - Radiation-materials interactions

- 2 types of interactions:

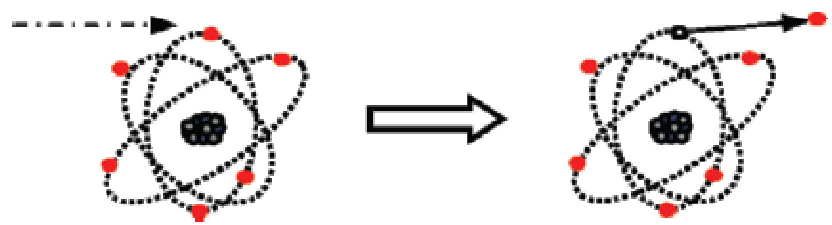


2 - Radiation-materials interactions

- **Photon with mater: 3 modes**

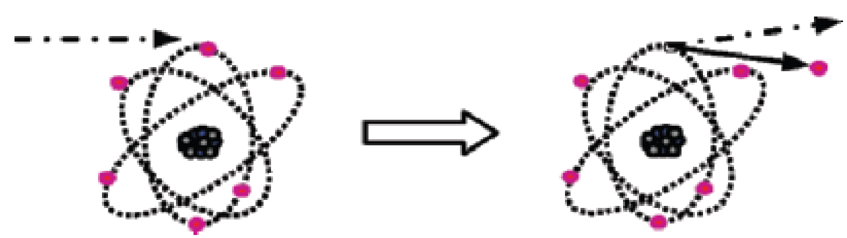
- Photo-electric effect

  Entire energy transfer from photon to an atomic electron



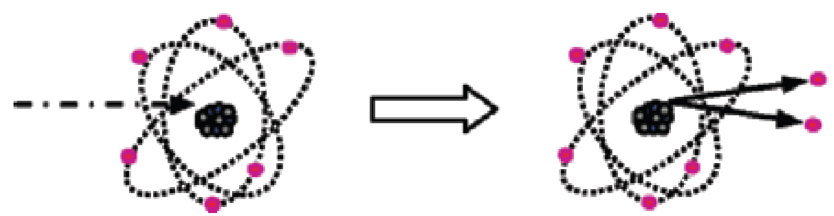
- Compton-scattering effect

  Fraction of energy transferred to Compton electrons.



- Pair production

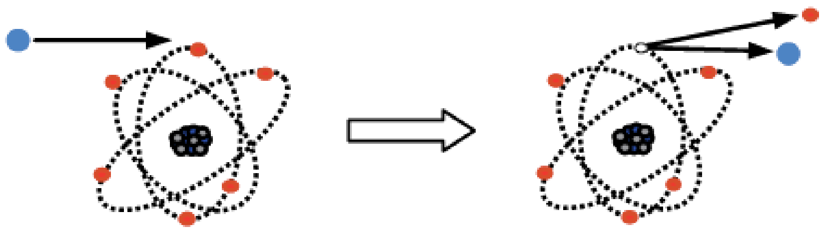
$$\gamma \rightarrow e^{+} + e^{-}$$



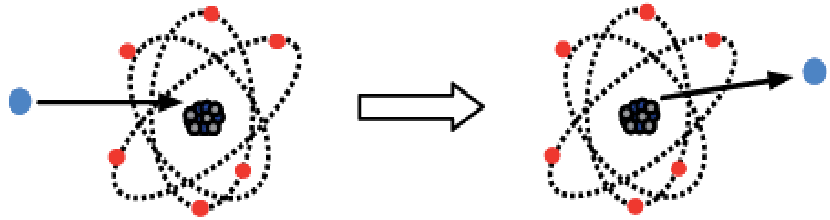
2 - Radiation-materials interactions

- **Coulombian interaction**

- Coulomb interactions with atomic electrons.
  (ionization, excitation)



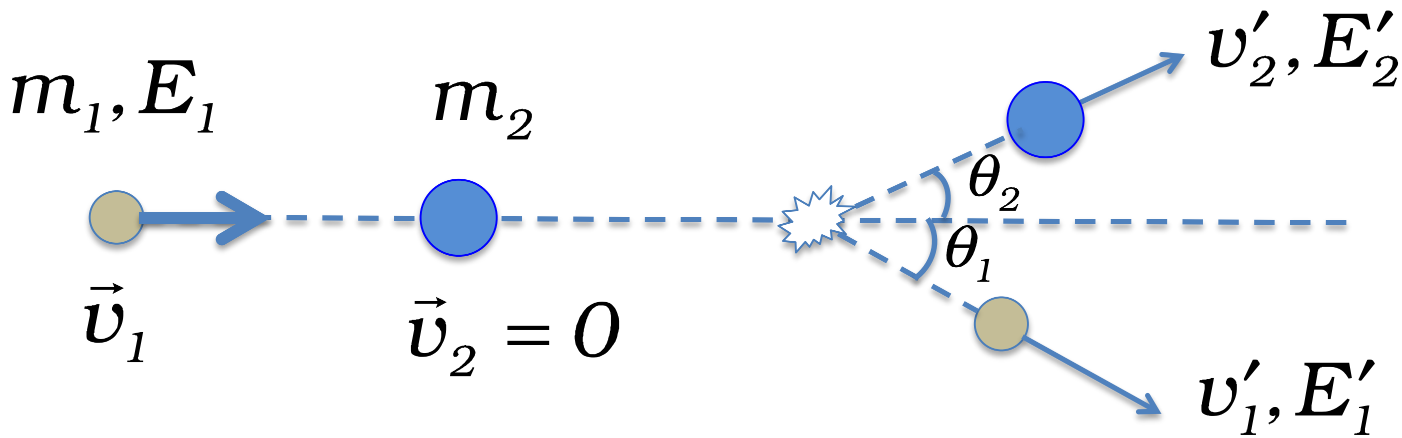
- Coulomb interactions with atomic nuclei.
  (multiple Coulomb scattering)



“Inelastic nuclear collision!”

Severely breaking chemical bond at high speed (energy)

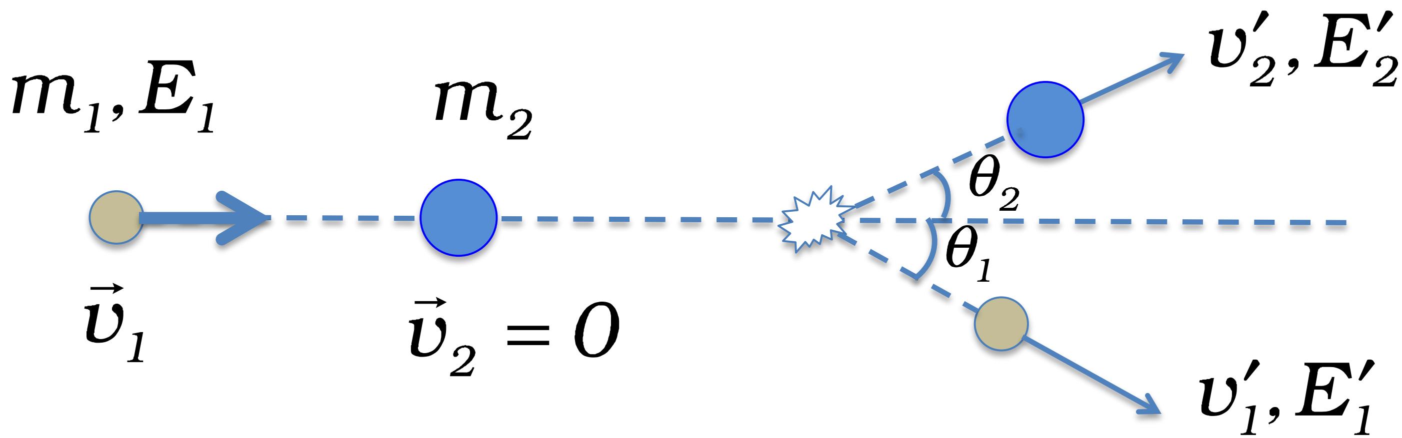
- **The "direct impact"**



- Hypothesis
  - Thermal vibration of atoms is negligible
  - Atoms are supposed to be "immobile"
  - Interaction with electron is too small to be able to affect the elastic collision

2 - Radiation-materials interactions

- **The "direct impact"**



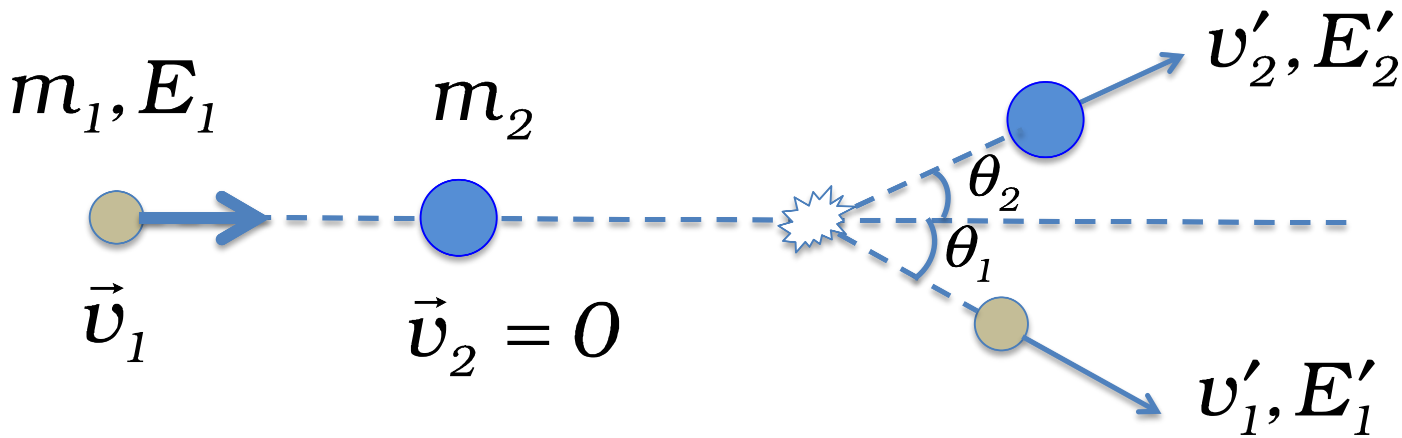
- Elastic scattering: internal state of colliding partners unchanged

$$E_1 = E'_1 + E'_2 = (E_1 - T) + T$$

- Inelastic scattering: excitation and ionization of colliding partners

$$E_1 = E'_1 + E'_2 + Q = E'_1 + T + Q$$

- **The "direct impact"**

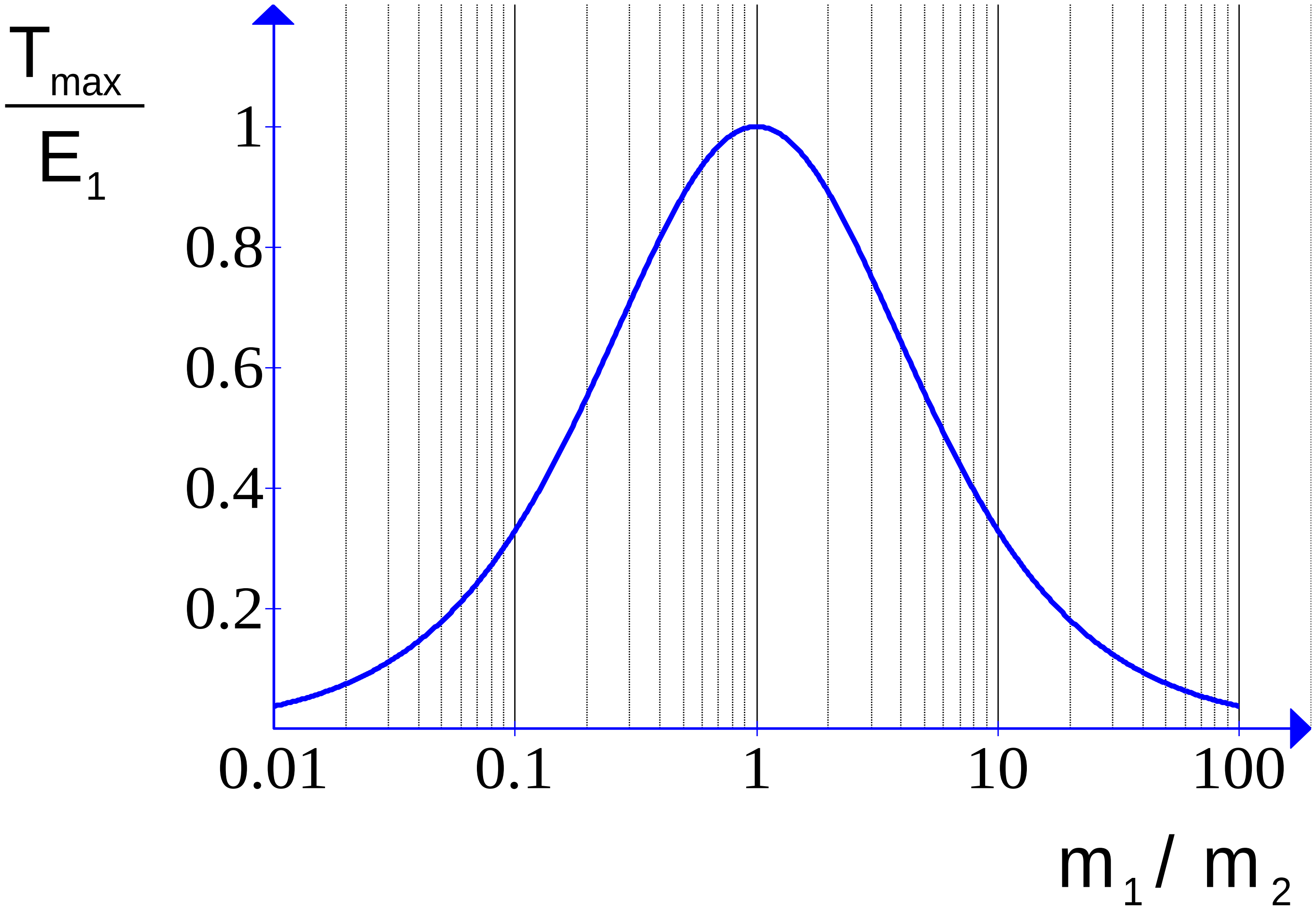


  - Energy transfer

$$\begin{cases} T = T_{max} \cos^2 \theta_2 \\ T_{max} = \dfrac{4 m_1 m_2}{(m_1 + m_2)^2} E_1 \end{cases}$$

2 - Radiation-materials interactions

- **The "direct impact"** / Energy transfer



2 - Radiation-materials interactions

- **The "direct impact"**/Characteristics
  - Direct impact = 1-to-1 collision
  - Energy transfer is often superior to the "displacement threshold" of atom (minimum energy needed to permanently displace an atom from its regular lattice site) → easily create a defect in mater
  - Collision probability becomes important when the energy of radiation is low (< 1 MeV)
  - Energy transfer in discrete amount

3 – The stopping power

- Energy loss (Energy deposed to materials)

$$\Delta E(\Delta x) = \sum_{i=1}^{N(\Delta x)} T_i \quad \begin{cases} \Delta x: \ \ thickness\ of\ target \\ N(\Delta x): \ \ total\ number\ of\ collisions \\ T_i: \ \ energy\ lost\ in\ collision\ i \end{cases}$$

- Elastic and inelastic processed

$$\langle \Delta E(\Delta x) \rangle = \langle \Delta E_\nu(\Delta x) \rangle + \langle \Delta E_\varepsilon(\Delta x) \rangle$$

- Stopping power (stopping force)

$$S = \left(-\frac{dE}{dx} \right) = \lim_{\Delta x \to 0} \frac{\langle \Delta E \rangle}{\Delta x} = \left(-\frac{dE}{dx} \right)_\nu + \left(-\frac{dE}{dx} \right)_\varepsilon$$

3 – The stopping power

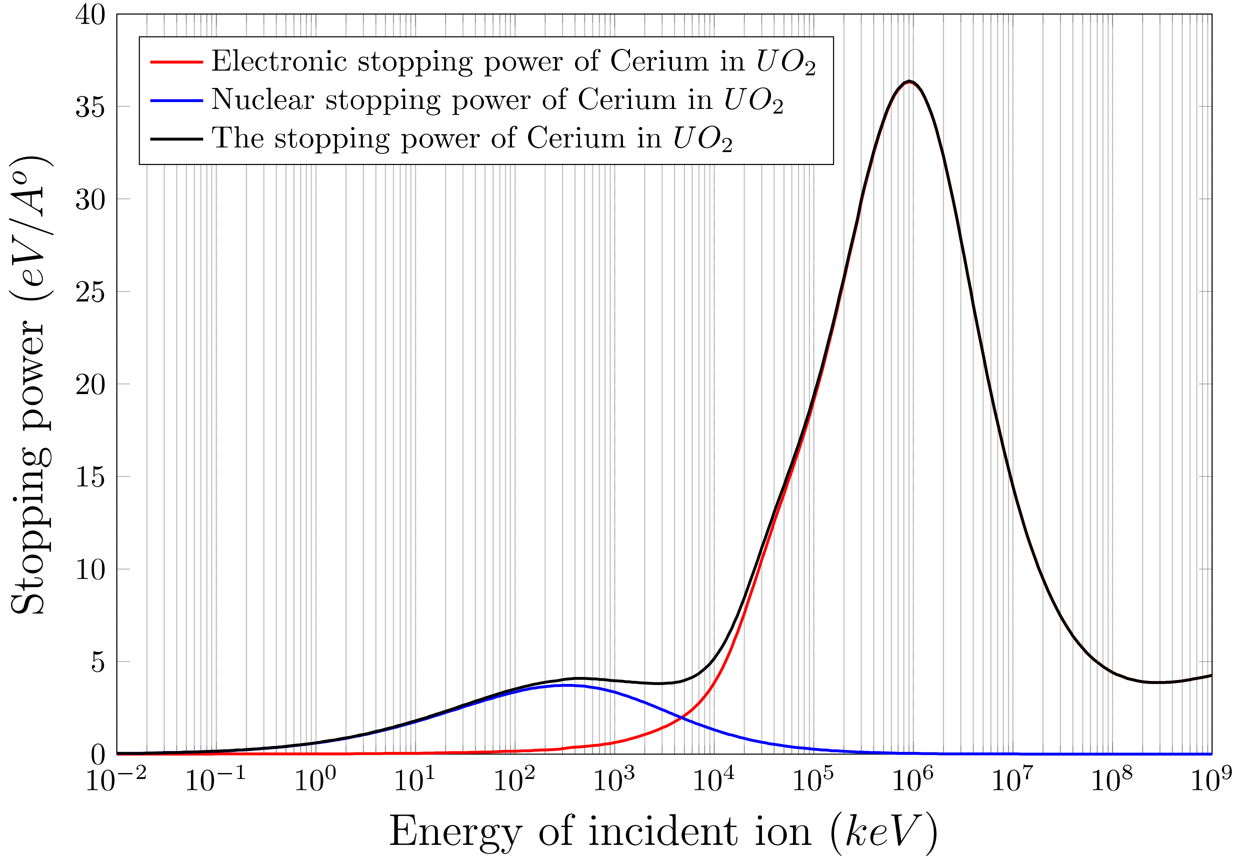
- Characteristics
  - Depends on the energy of radiation

$$S = -\frac{dE}{dx} = -\frac{dE}{dx}(E)$$

  - Depends on the materials (target) through which it passes
  - Depends on types of interactions (dominant by electronic interaction at high energy and dominant by nuclear interaction at low energy, i.e. at the end of its path)
  - Usually considered as a properties of materials (even though it depends on type and energy of radiation)

3 – The stopping power

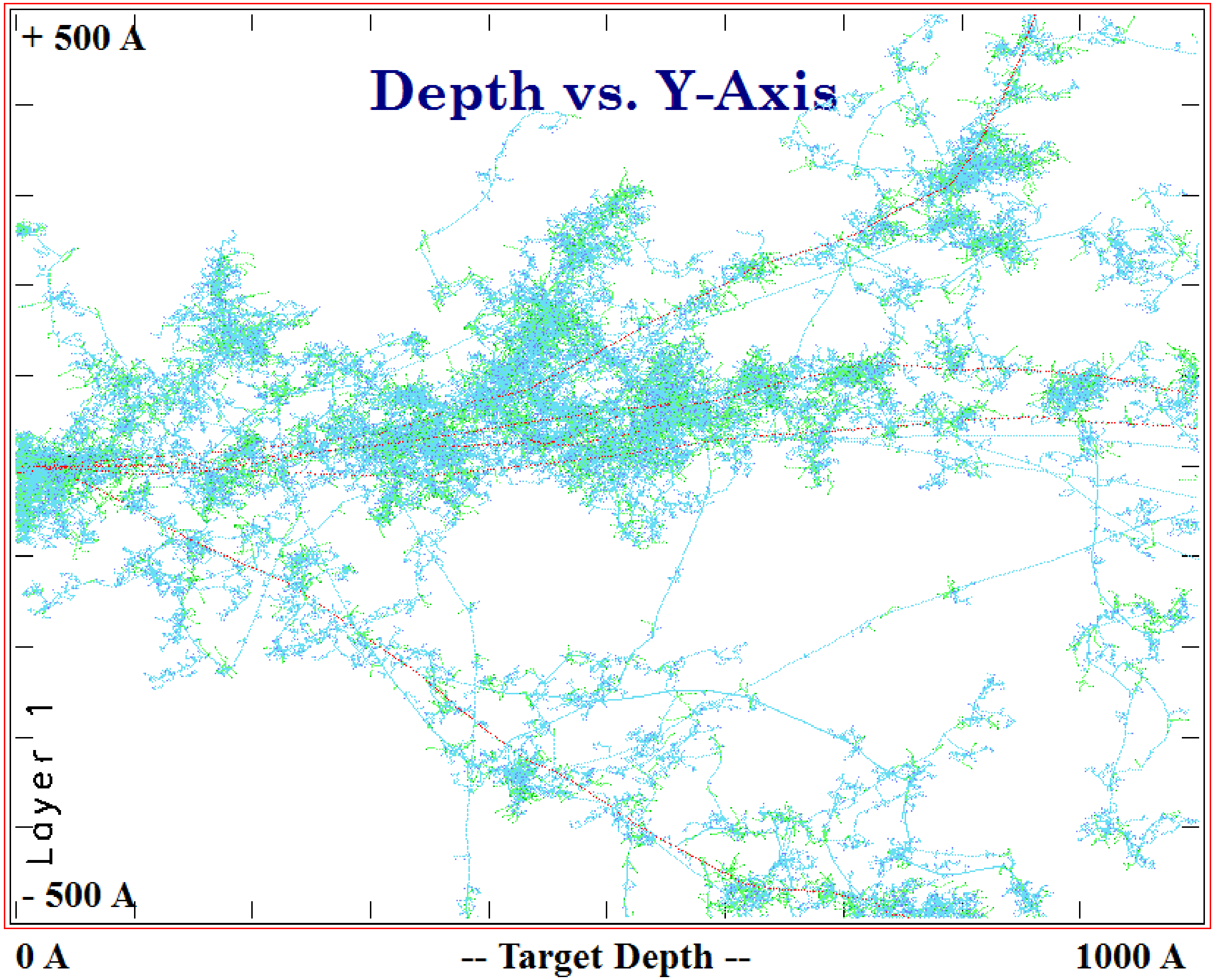
- Electronic vs. nuclear stopping power



1. H. A. Bethe. Ann. Phys. (Leipz.), 5, page 325, 1930
2. F. Bloch. Ann. Phys. (Leipz.), 16, page 285, 1933
3. V. E. Anderson, R. H. Ritchie, C. C. Sung, and P. B. Eby. Relativistic corrections to stopping powers. Phys. Rev. A, 31:2244–2247, Apr 1985
4. N. Bohr. Scattering and stopping of fission fragments. Phys. Rev., 58:654 – 655, Oct 1940. 21
5. N. Bohr. Velocity-range relation for fission fragments. Phys. Rev., 59:270 – 275, Feb 1941.

4 – Effects due to stopping process

- Effects of nuclear stopping process/Collision cascade



4 – Effects due to stopping process

- Number of defect created/ "Kinchin and Peace's model"

$$\begin{cases} N(T) = 0 & \text{if } T < E_d \\ N(T) = 1 & \text{if } E_d \le T < 2E_d \\ N(T) = (T/2)E_d & \text{if } T \ge 2E_d \end{cases}$$

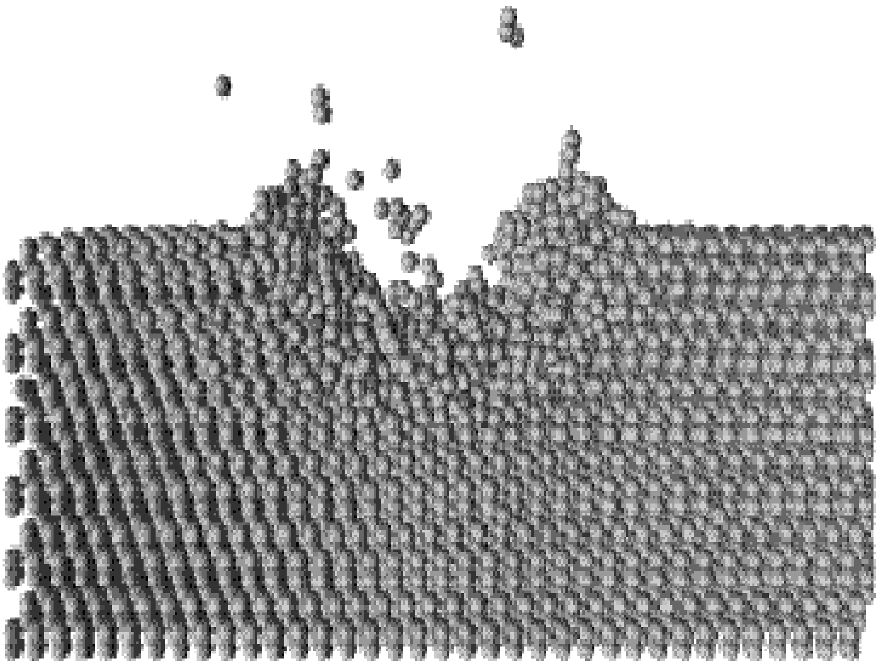
$$\langle N(T) \rangle = k \frac{T - E_1}{2E_d}; \; k \approx 0.8$$

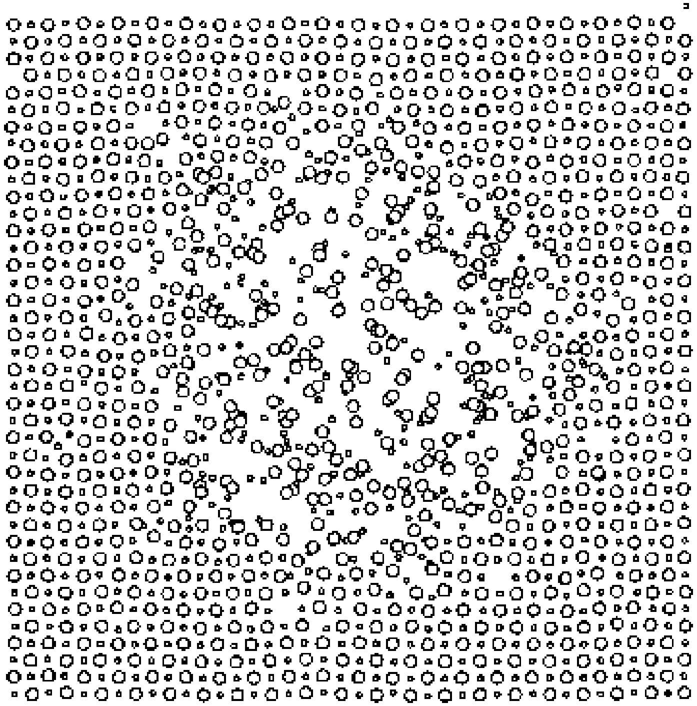
$$\langle N_{tol} \rangle = \frac{E_1}{2E_d}$$

1. G. H. Kinchin and R. S. Pease. The displacement of atoms in solids by radiation. Reports on Progress in Physics, 18(1):1, 1955

4 – Effects due to stopping process

- Effects of electronic stopping process/ "Ion explosion model"

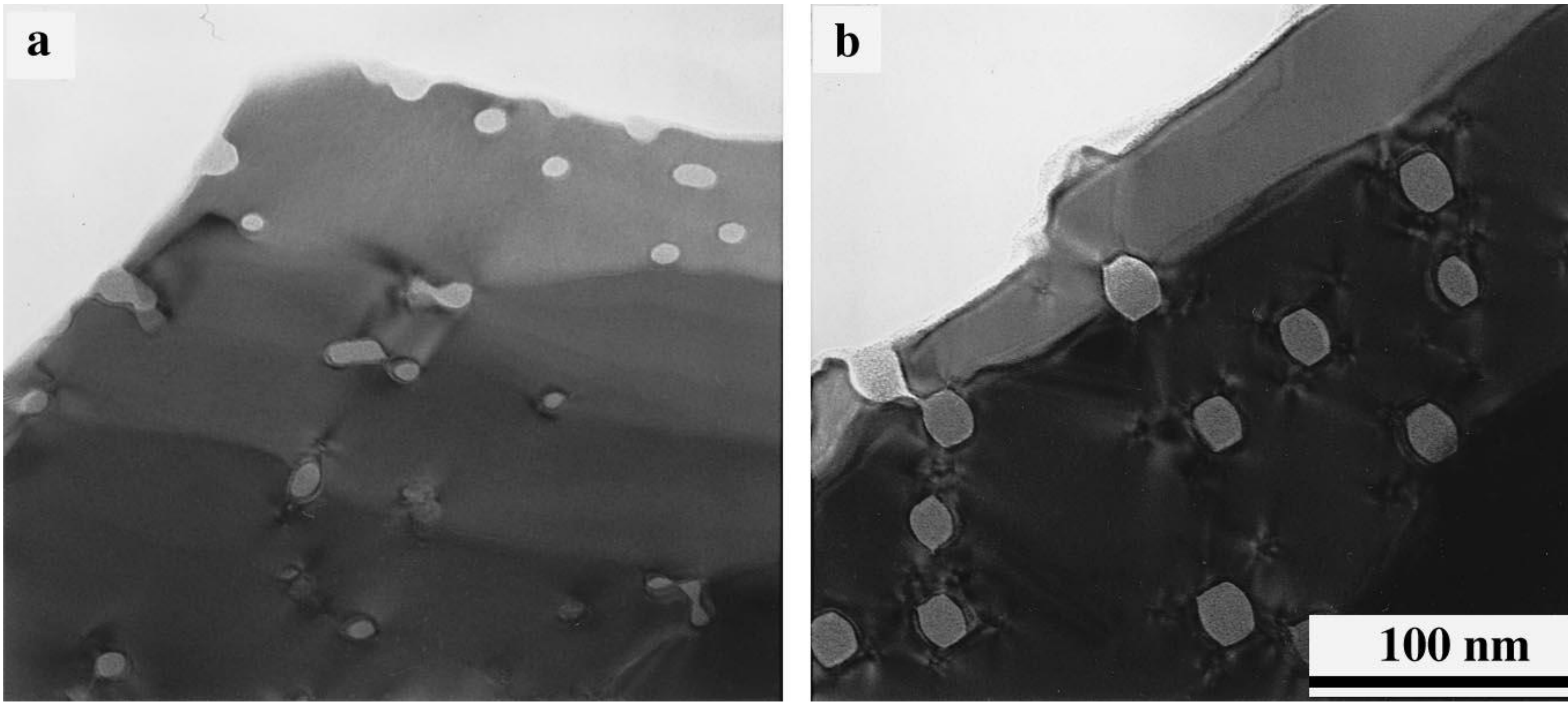




1. Fleischer, R. L.; Price, P. B. & Walker, R. M. Ion explosion spike mechanism for formation of charged-particle tracks in solids. *J. Appl. Phys., American Institute of Physics,* **1965**, *36*, 3645
2. D. A. Young, Evolution of a model ion explosion spike in potassium chloride by molecular dynamics, Europhys. Lett. **2002,** 59, 540

4 – Effects due to stopping process

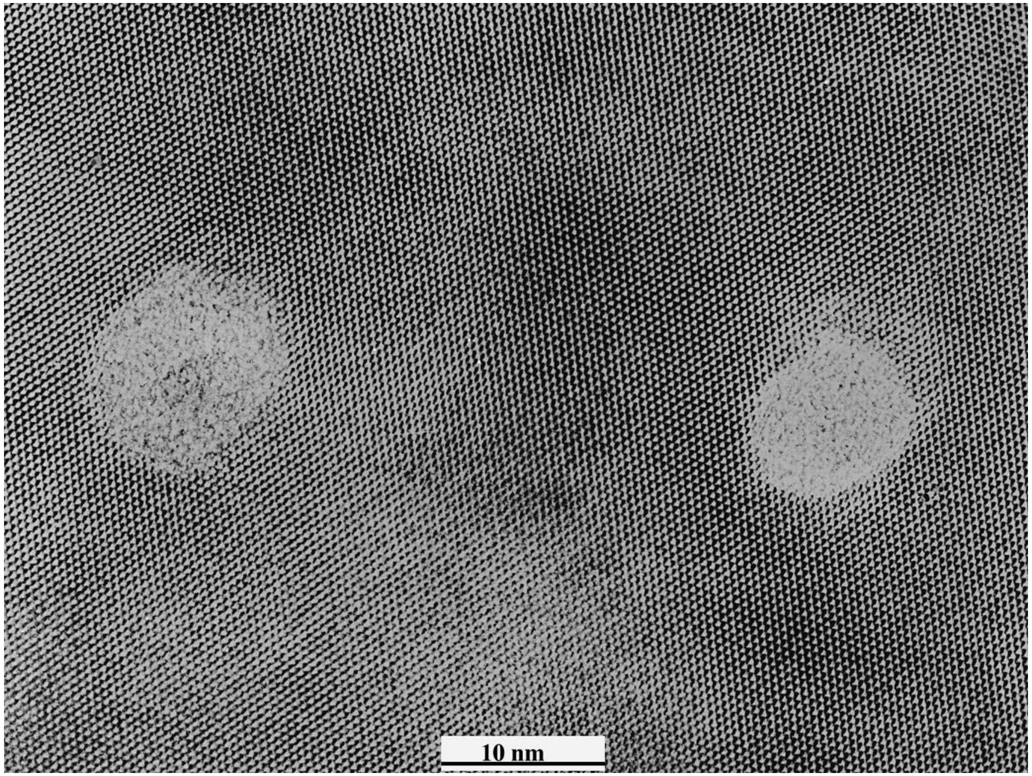
- Effects of electronic stopping process/ "Latent track"

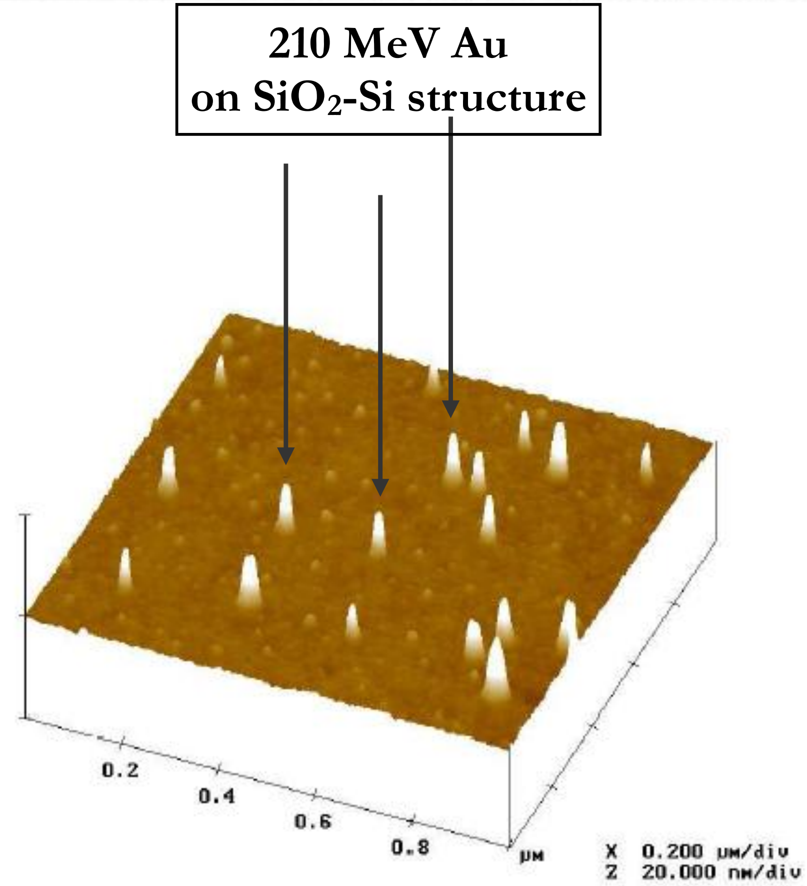


1. J. Vetter et al. / Nucl. Instr. and Meth. in Phys. Res. B 141 (**1998**) 747

4 – Effects due to stopping process

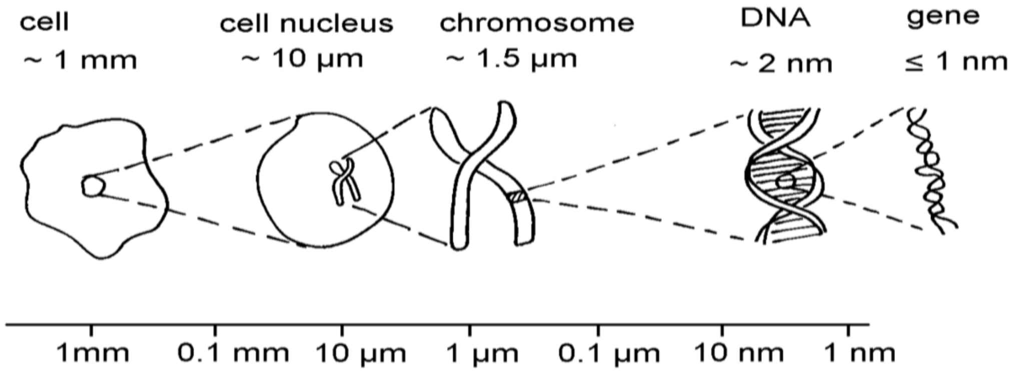
- Effects of electronic stopping process/ “Latent track”





1. J. Vetter et al. / Nucl. Instr. and Meth. in Phys. Res. B 141 (**1998**) 747
2. Appl. Phys. Lett., vol 88, 041906-1 (**2006**)

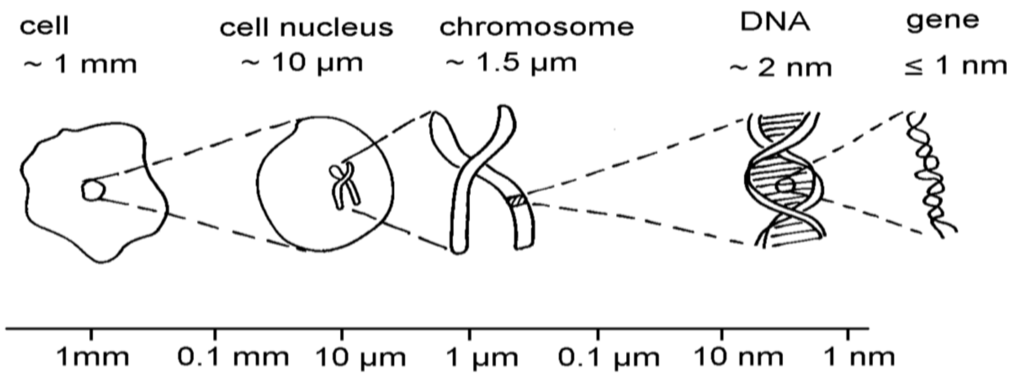
Application/Proton therapy



- **Idea**: "Selective cell destruction (cancer)"
- **How it can be done?**

  By destroying the cell using Energy
- Why is this possible?

Application/Proton therapy



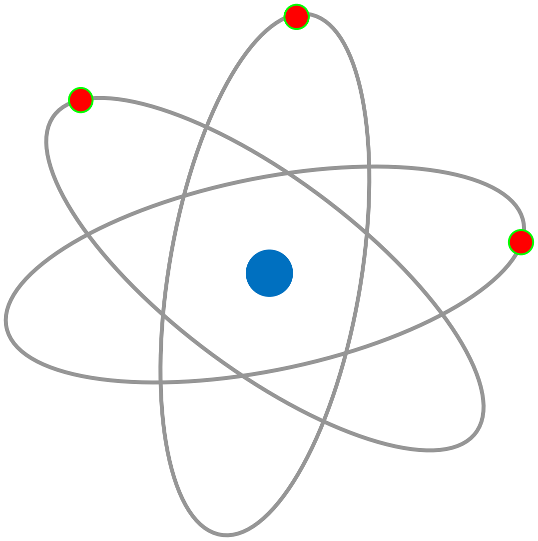
- Radiations damage a cell by altering it's atom causing the atom's electron to become excited and then ionized
- Enzymes repair this damage but cancer cell slower than healthy cell
- Results (during radiation exposure): More cancer cells end up dying than healthy cells

Application/Proton therapy

- In order to treat cancer: The main goal is to delivers a defined dose distribution within the target volume and none <u>out side it.</u>
- **Choice of radiation: what type of radiation would be the best?**
  - Protons can be used clinically.
  - Maximum radiation dose can be placed into the tumor.
  - Proton therapy provides sparing of healthy tissues.

Application/Proton therapy

- Characteristics of proton
  - Subatomic particle
  - Non-poisonous
  - Stable, positively charged
  - Heavy particle with mass 1800 that of electron.
  - Very little scattered as they travel through tissue → travel in straight lines.
  - Interacts via different modes with matter

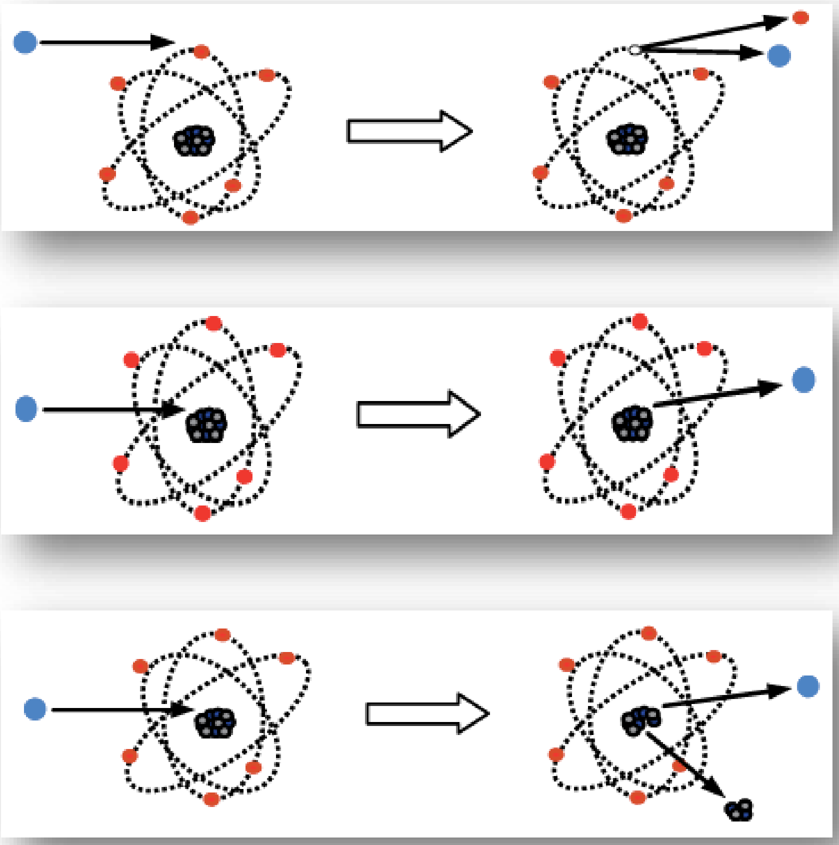


$$m_p = 1.67(26) \cdot 10^{-27} \ kg$$

$$m_e = 9.10(94) \cdot 10^{-31} \ kg$$

Application/Proton therapy

- Characteristics of proton



- Coulomb interactions with atomic electrons.

Electronic (ionization, excitation)

- Coulomb interactions with atomic nuclei.

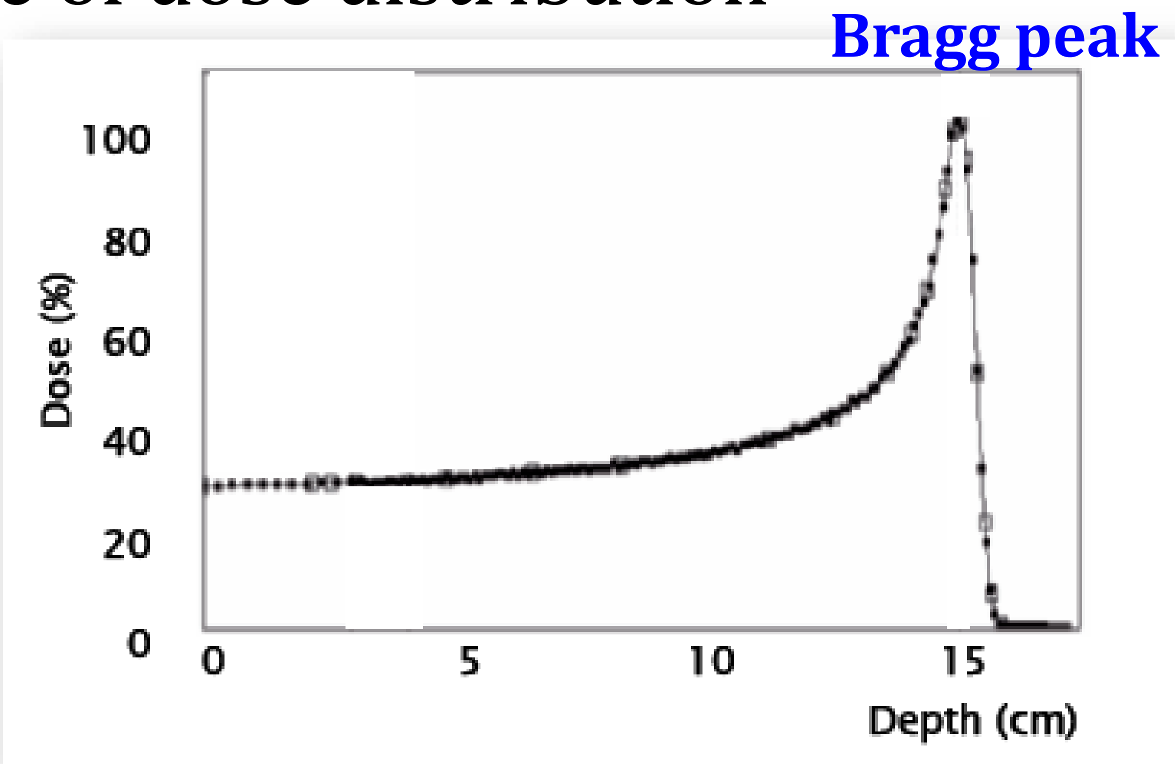
"multiple Coulomb scattering."

- Nuclear interactions with atomic nuclei.

Interacts with materials via both Elastic nuclear collision and Inelastic nuclear collision!

Application/Proton therapy

- Shape of dose distribution



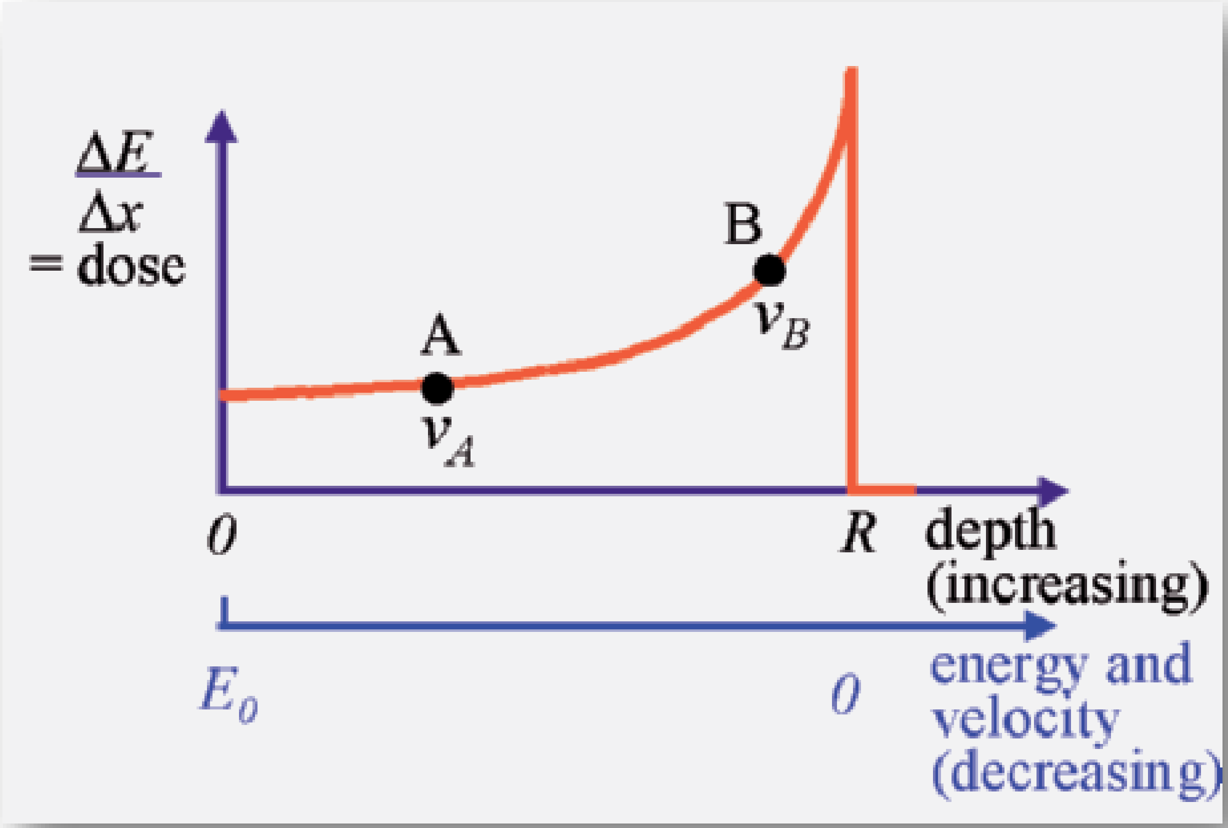
- Low entrance dose (plateau)
- Maximum dose at depth (Bragg peak)
- Rapid distal dose fall-off

Application/Proton therapy

- <u>**Why?**</u>
- Protons have the ability of loosing <u>little</u> energy when entering tissue (dominant by electronic interaction)
- But depositing more and more as they slow down…
- Finally, depositing a heavy dose of radiation just before they stop, giving rise to the so-called Bragg peak (dominant by nuclear elastic collision)

Application/Proton therapy

- **<u>Stopping power?</u>**

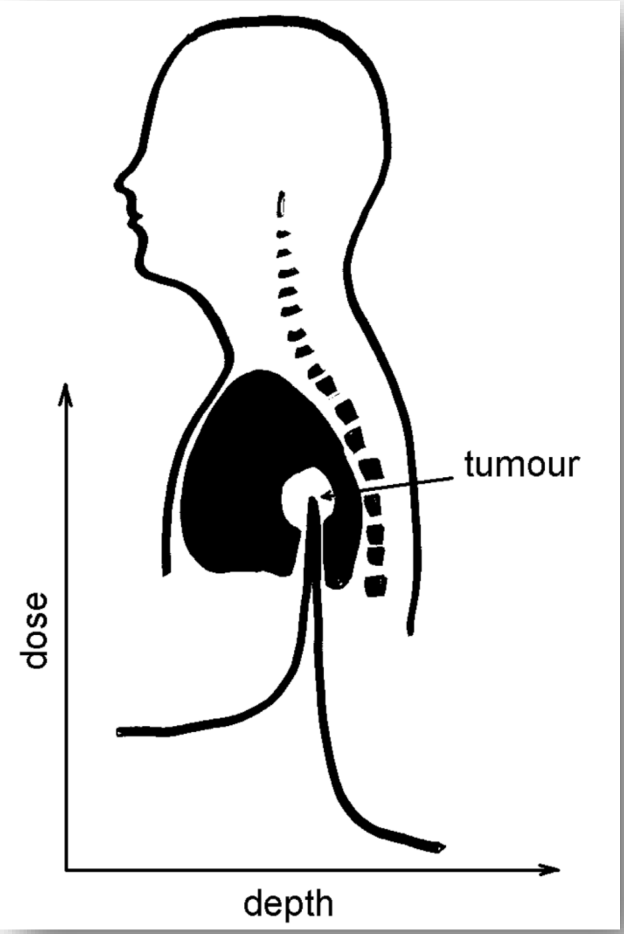


The Bethe-Block formula: $\frac{dE}{dx} \propto \frac{1}{v^2}\left(\frac{Z}{A}\right)z^2$

Application/Proton therapy

- Could the Bragg peak provide the tumor with uniform dose?
- **No, it cannot**. Because The Bragg peak is too narrow to fit the shape & depth of the tumor

Problem!!!



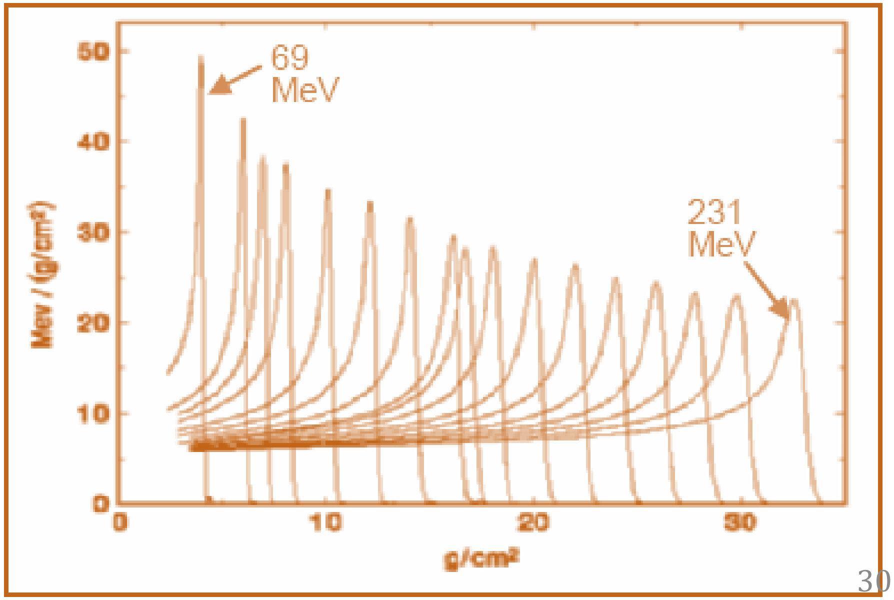
Application/Proton therapy

- Bragg peak dependence on energy

- The *range is* (the depth of penetration from the front surface *to* the distal point on the Bragg peak)

energy (MeV)	*range in water (cm)*
70	4.0
100	7.6
150	15.5
200	25.6
250	37.4

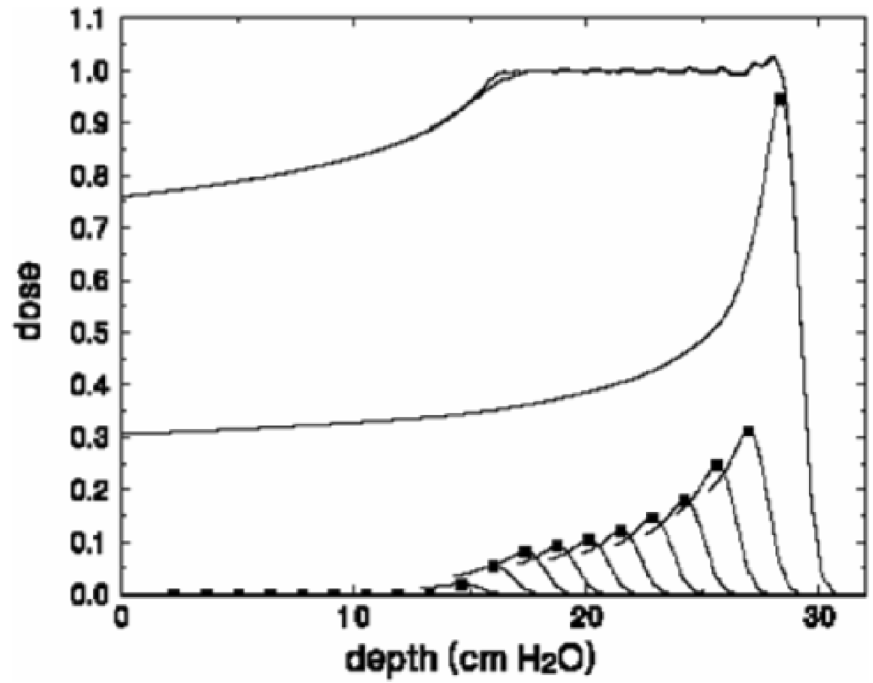
- Bragg peak depends on the initial energy of the protons so the greater the energy, the greater the range



Application/Proton therapy

- Solution: Superposition of Bragg-peaks by energy variation

- An extension in depth can be achieved by proton beams of successively
- Delivering not just one, but many Bragg peaks each with different range (energy)



Summary

- **Proton therapy**
- They are deterministic events.
- They easier to control.
- It receive very small dose.
- A sharp burst of energy released
- At tumor and none beyond it.
- Ideal for tumors in or near
- Critical structures (brain, heart, eye) pediatric cancers.

QUESTION?

Nguyễn Tiến Hiển, Đào Hải Yến
Bộ môn Vật lý – Khoa Công nghệ thông tin
Contact info: nguyentienhien@vnua.edu.vn