PHYS 3313 – Section 001
Lecture #9

Wednesday, Sept. 25, 2013
Dr. Jae Yu

- Compton Effect
- Pair production/Pair annihilation
- Atomic Model of Thomson
- Rutherford Scattering Experiment and Rutherford Atomic Model

Announcements

- Result of Quiz #1
  - Class average: 13.5/65
    - Equivalent to 20.8/100
  - Top score: 54/65
- Reminder of Homework #2
  - CH3 end of the chapter problems: 2, 19, 27, 36, 41, 47 and 57
  - Due Wednesday, Oct. 2
- Quiz #2 coming Monday, Sept. 30
  - Beginning of the class
  - Covers CH1.1 – what we finish today
- Colloquium today
  - Dr. M. Huda of UTA Physics

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Designing novel multi-cation oxide alloys by data mining and DFT calculations

Dr. Muhammad N. Huda

Department of Physics
University of Texas at Arlington

4:00p.m. Wednesday September 25, 2013
Room 101 Science Hall

Abstract:

The discovery of efficient materials is one of the grand challenges for renewable energy conversion and storage. Naturally occurring materials do not fulfill all the required electronic criteria for any given energy conversion process. These electronic requirements in materials are usually targeted by a band-engineering approach, where electronic structures of the materials are modified by selective doping. However, the introduction of impurities would create unwanted defect states in band gap, which would be detrimental to the transport properties of the host due to poor crystallinity. In general, shifting the optical absorption spectrum of a material to the visible region by doping-only process has not been successful in improving the photoconversion efficiency significantly. Here, instead of following a conventional band engineering approach, we will present a novel alloy-design approach by following mineral database search methods and density functional theory (DFT) calculations. Our recent results on some new complex multi-cation oxide materials, predicted in our group, will be presented.

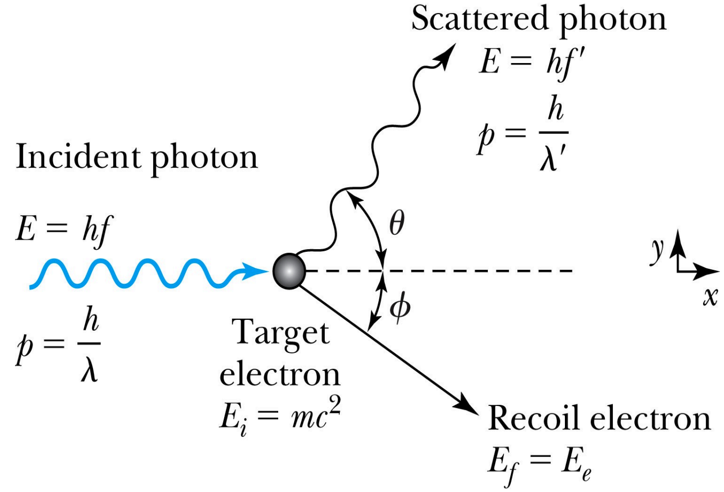
Special Project #3

- A total of N_i incident projectile particle of atomic number Z_1 kinetic energy KE scatter on a target of thickness t and atomic number Z_2 and has n atoms per volume. What is the total number of scattered projectile particles at an angle θ? (20 points)
- Please be sure to clearly define all the variables used in your derivation! Points will be deducted for missing variable definitions.
- This derivation must be done on your own. Please do not copy the book, internet or your friends'.
- Due is Wednesday, Oct. 9.

Compton Effect

- When a photon enters matter, it is likely to interact with one of the atomic electrons.
- The photon is scattered from only one electron
- The laws of conservation of energy and momentum apply as in any elastic collision between two particles. The momentum of a particle moving at the speed of light is

$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$



- The electron energy can be written as

$$E_e^2 = \left(m_e c^2\right)^2 + p_e^2 c^2$$

- Change of the scattered photon wavelength is known as the **Compton effect**:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}\left(1 - \cos\theta\right)$$

Pair Production and Annihilation

- If a photon can create an electron, it must also create a positive charge to balance charge conservation.
- In 1932, C. D. Anderson observed a positively charged electron (e^+) in cosmic radiation. This particle, called a positron, had been predicted to exist several years earlier by P. A. M. Dirac.
- A photon's energy can be converted entirely into an electron and a positron in a process called **pair production**.
  - Can only happen inside a material
  - How much energy do you think is needed?

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

Pair Production in Empty Space?

- Energy conservation for pair production in empty space

$$hf = E_+ + E_- + K.E.$$

- Momentum conservation yields

$$hf = p_- c\cos\theta + p_+ c\cos\theta$$

- Thus max momentum exchange $hf_{\max} = p_- c + p_+ c$

- Recall that the total energy for a particle can be written as

$$E_{\pm}^2 = p_{\pm}^2 c^2 + m_e^2 c^4$$

However this yields a contradiction: $hf > p_- c + p_+ c$

and hence the conversion of energy in empty space is impossible and thus pair production cannot happen in empty space

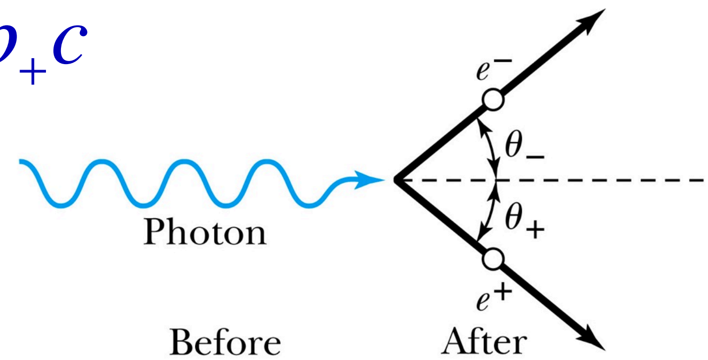
Pair Production in Matter

- Since the relations $hf_{\max} = p_{-}c + p_{+}c$ and $hf > p_{-}c + p_{+}c$ contradict each other, a photon can not produce an electron and a positron in empty space.
- In the presence of matter, the nucleus absorbs some energy and momentum.

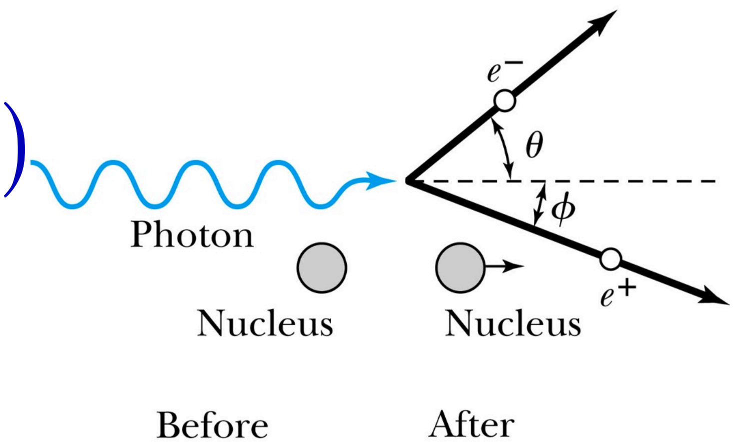
$$hf = E_{-} + E_{+} + K.E.(\text{nucleus})$$

- The photon energy required for pair production in the presence of matter is

$$hf > 2m_e c^2$$



(a) Free space (**cannot occur**)



(b) Beside nucleus

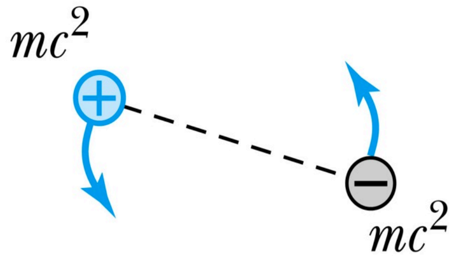
Pair Annihilation

- A positron going through matter will likely **annihilate** with an electron.
- A positron is drawn to an electron and form an atom-like configuration called **positronium**.
- Pair annihilation in empty space will produce two photons to conserve momentum. Annihilation near a nucleus can result in a single photon.
- Conservation of energy: $2m_e c^2 \approx hf_1 + hf_2$
- Conservation of momentum: $0 = \frac{hf_1}{c} - \frac{hf_2}{c}$
- The two photons will be almost identical, so that

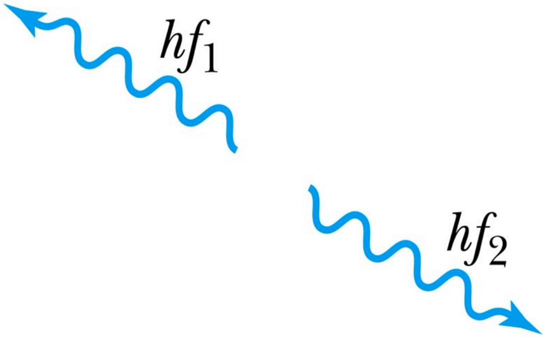
$$f_1 = f_2 = f$$

- The two photons from positronium annihilation will move in the opposite directions with an energy of:

$$hf = m_e c^2 = 0.511\text{MeV}$$



(a) Positronium, before decay (schematic only)



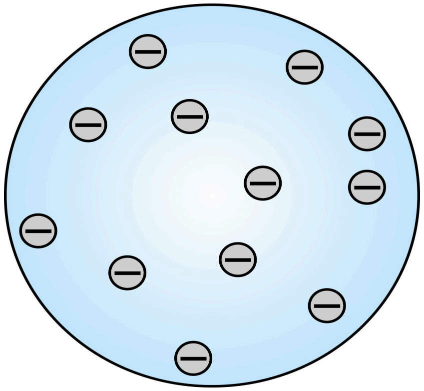
(b) After annihilation

The Atomic Models of Thomson and Rutherford

- Pieces of evidence that scientists had in 1900 to indicate that the atom was not a fundamental unit
- There are simply too many kinds of atoms (~70 known at that time), belonging to a distinct chemical element
  - Too many to be fundamental!!
- Atoms and electromagnetic phenomena seem to be intimately related
- The issue of **valence** ➔ Why certain elements combine with some elements but not with others?
  - Is there a characteristic internal atomic structure?
- The discoveries of radioactivity, x rays, and the electron

Thomson's Atomic Model

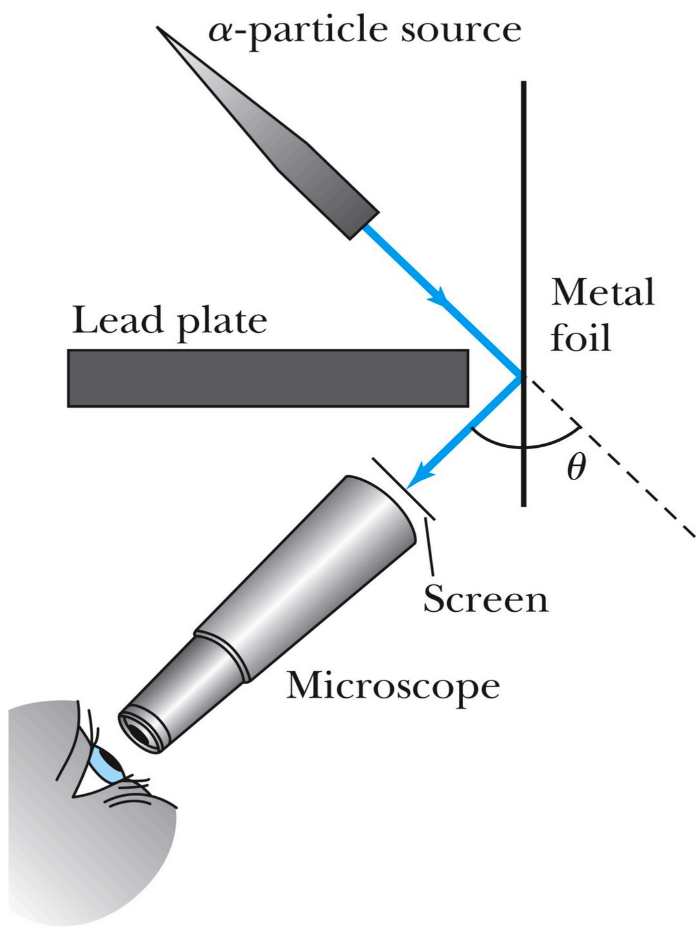
- Thomson's "plum-pudding" model
  - Atoms are electrically neutral and have electrons in them
  - Atoms must have an equal amount of positive charges in it to balance electron negative charges
  - So how about positive charges spread uniformly throughout a sphere the size of the atom with, the newly discovered "negative" electrons embedded in a uniform background.



- Thomson thought when the atom was heated the electrons could vibrate about their equilibrium positions and thus produce electromagnetic radiation.

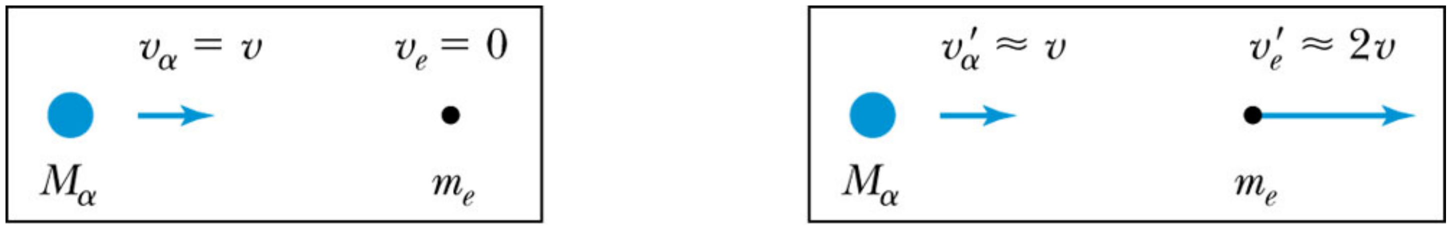
Experiments of Geiger and Marsden

- Rutherford, Geiger, and Marsden conceived a new technique for investigating the structure of matter by scattering a particles from atoms.
- Geiger showed that many a particles were scattered from thin gold-leaf targets at backward angles greater than 90°.



Ex 4.1: Maximum Scattering Angle

Geiger and Marsden (1909) observed backward-scattered (θ>=90^o) α particles when a beam of energetic α particles was directed at a piece of gold foil as thin as 6.0x10^{-7}m. Assuming an α particle scatters from an electron in the foil, what is the maximum scattering angle?



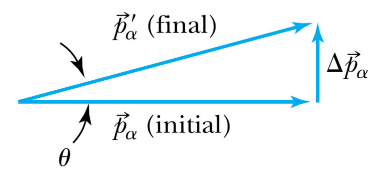
Before After

- The maximum scattering angle corresponds to the maximum momentum change
- Using the momentum conservation and the KE conservation for an elastic collision, the maximum momentum change of the α particle is

$$M_\alpha \vec{v}_\alpha = M_\alpha \vec{v}'_\alpha + m_e \vec{v}'_e$$
$$\frac{1}{2} M_\alpha v_\alpha^2 = \frac{1}{2} M_\alpha v_\alpha'^2 + \frac{1}{2} m_2 v_e^2$$

$$\Rightarrow \Delta \vec{p}_\alpha = M_\alpha \vec{v}_\alpha - M_\alpha \vec{v}'_\alpha = m_e \vec{v}'_e \Rightarrow \Delta p_{\alpha-\max} = 2 m_e v_\alpha$$

- Determine θ by letting Δp_{max} be perpendicular to the direction of motion.



$$\theta_{\max} = \frac{\Delta p_{\alpha-\max}}{p_\alpha} = \frac{2 m_e v_\alpha}{m_\alpha v_\alpha} = \frac{2 m_e}{m_\alpha} = 2.7\times 10^{-4}\,rad = 0.016^\circ$$