PHYS 3313 – Section 001
Lecture #11

Wednesday, Feb. 19, 2014
Dr. Jaehoon Yu

- Pair production/Pair annihilation
- Atomic Model of Thomson
- Rutherford Scattering Experiment and Rutherford Atomic Model
- The Classic Atomic Model
- The Bohr Model of the Hydrogen Atom

Announcements

- Bring your special project after the class
- Mid-term exam
  - In class on Wednesday, Mar. 5
  - Covers CH1.1 – what we finish on Monday, Mar. 3 + appendices
  - Mid-term exam constitutes 20% of the total
  - **Please do NOT miss the exam! You will get an F if you miss it.**
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations or solutions of any problems allowed!
  - No additional formulae or values of constants will be provided!
- Colloquium today: Dr. Kenichi Hatakeyama of Baylor U.

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Beyond the Higgs Boson Discovery

Dr. Kenichi Hatakeyama
Department of Physics
Baylor University

4:00 pm Wednesday February 19, 2014 room 101 SH

Abstract:

The Higgs boson discovery announced by the CMS and ATLAS Collaborations at CERN on July 4th 2012 was a major milestone for particle physics. It filled in the last missing piece of the Standard Model established 40 years ago. However, the Standard Model explains only 5% of the mass of the universe and cannot account for the remaining 95%, which consists of dark matter and dark energy.
The mass of the Higgs boson is also predicted to be very unstable within the Standard Model.
These facts make many physicists believe that the Standard Model is only an effective approximation of a more complete theory that would supersede the Standard Model at a higher energy scale. I will discuss the effort by the CMS experiment at the Large Hadron Collider to search for physics beyond the Standard Model. In particular, I will report on searches for Supersymmetry that can provide a viable dark matter candidate and solve the Higgs mass instability issues.

Refreshments will be served at 3:30p.m in the Physics Lounge

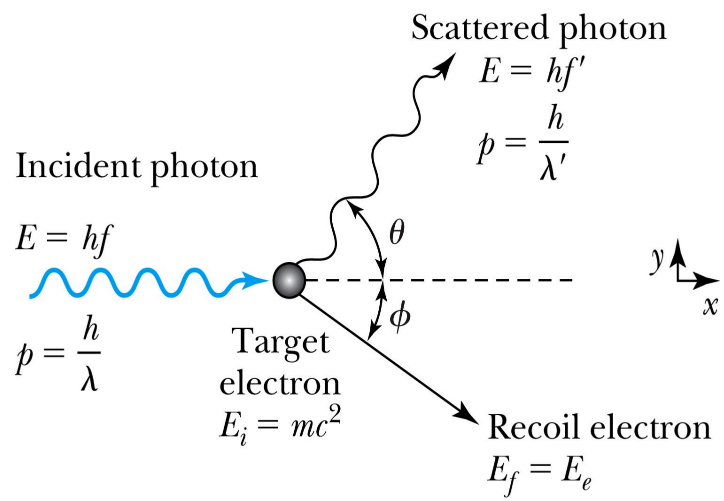
Reminder: Special Project #3

- 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 next Wednesday, Feb.26 .

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**:

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

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?

$$\gamma \to e^- + e^+$$

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

$$hf > 2m_e c^2$$

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 a positronium annihilation will move in the opposite directions with an energy of:

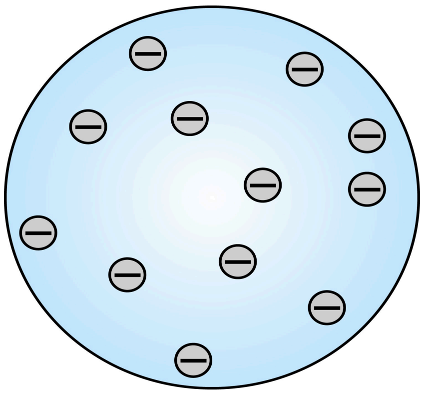
$$hf = m_e c^2 = 0.511\text{MeV}$$

The Atomic Models of Thomson and Rutherford

- Without seeing it, 19th century scientists believed atoms have structure.
- 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.