# Announcements

- HW3: 13, 17, 23, 25, 28, 31, 37, 38

*** Course Web Page **
http://highenergy.phys.ttu.edu/~slee/2402/
Lecture Notes, HW Assignments,
Schedule for thePhysics Colloquium, etc..

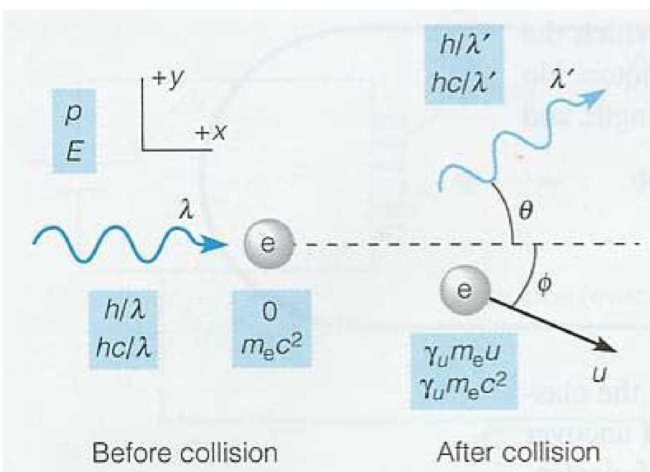
# Lecture 8 – Chapter. 3
# Wave & Particles I

## EM-“Waves” behaving like “Particles”

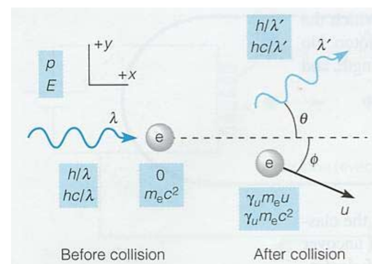
***Outline:***

- Blackbody Radiation (Plank; 1900; 1918*)
- The Photoelectric Effect (Einstein; 1905; 1921*)
- The Production of X-Rays (Rontgen;1901; 1901*)
- **The Compton Effect (Compton; 1927; 1927*)**
- **Pair Production (Anderson; 1932; 1936*)**
- **Is It a Wave or a Particle? → Duality?**

**Momentum & Energy when a photon strike a free electron**




**Energy and Momentum Conservation**




Momentum conserved:

$$x\text{-component:} \quad \frac{h}{\lambda} = \frac{h}{\lambda'}\cos\theta + \gamma_u m_e u \cos\phi$$

$$y\text{-component:} \quad 0 = \frac{h}{\lambda'}\sin\theta - \gamma_u m_e u \sin\phi$$

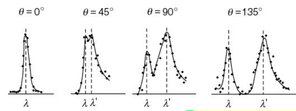
Energy conserved:

$$h\frac{c}{\lambda} + m_e c^2 = h\frac{c}{\lambda'} + \gamma_u m_e c^2$$

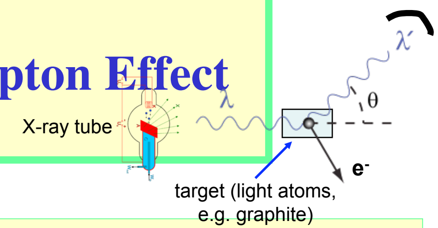
The photoelectric effect and the Compton effect are two important ways in which EM radiation interacts as a particle with matter.

We now discuss a third!

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



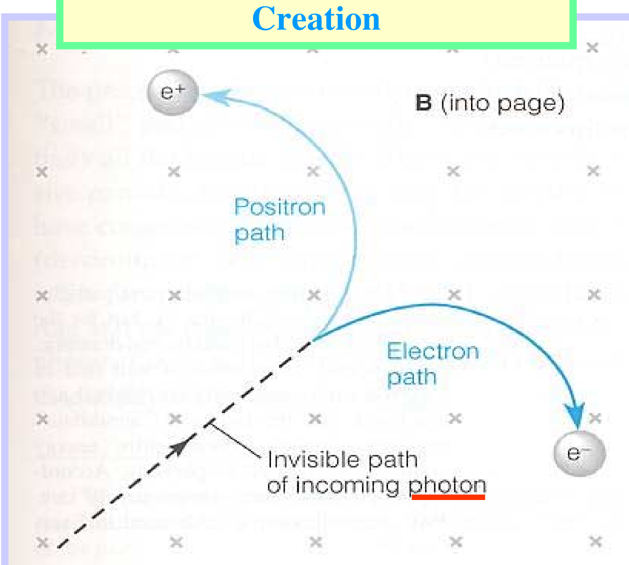

## The Compton Effect



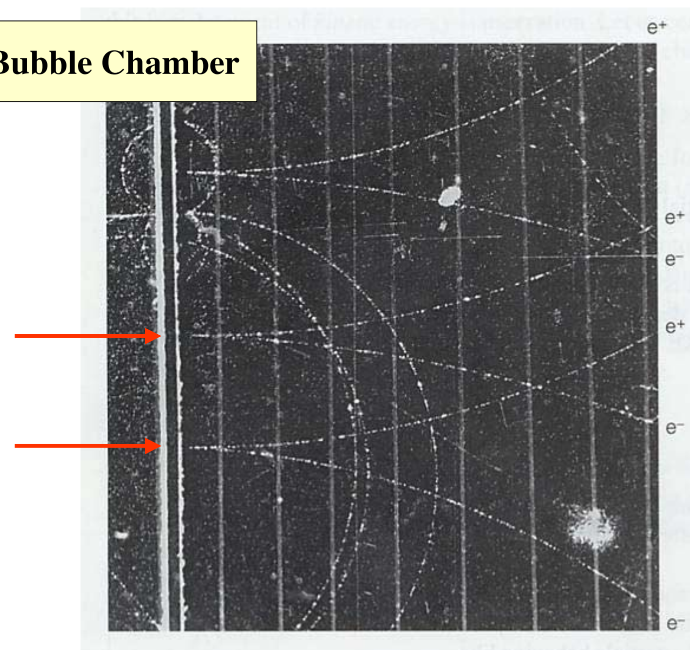

**Photons carry momentum like particles and scatter individually with other particles**

**indeed, the wavelength shift is independent of the target material and the initial photon wavelength.**

## Particle-Antiparticle Pair Creation




## Bubble Chamber



**Example 2.5**

Calculate the energy and wavelength of the least-energetic photon capable of producing an electron-positron pair.

**Solution**

The energy in the photon becomes the energy of the massive particles, internal/mass energy plus any kinetic energy. The minimum energy required is that which is barely able to produce the pair, with *no* kinetic energy. In this case, the photon energy equals just the internal energy of the pair:

$$2 \cdot m_e c^2 = 2(9.11 \times 10^{-31}\ \text{kg})(3 \times 10^8\ \text{m/s})^2$$

$$= 1.64 \times 10^{-13}\ \text{J} \quad (\cong 1\ \text{MeV})$$

Thus,

$$h\frac{c}{\lambda} = 2m_e c^2 \Rightarrow \lambda = \frac{hc}{2m_e c^2}$$

$$= \frac{(6.63 \times 10^{-34}\ \text{J}\cdot\text{s})(3 \times 10^8\ \text{m/s})}{1.64 \times 10^{-13}\ \text{J}}$$

$$= 1.21 \times 10^{-12}\ \text{m}$$

***Electromagnetic Waves***
behaving like
***Particles*** **"PHOTONS"**
(Chapter 2)

**Black Body Radiation**
**The Photoelectric Effect**
**The Production of X-Rays**

**PHOTONS**
$E = hf$

**The Compton Effect**

**PHOTONS**
$p = hf/c = h/\lambda$

**Particle-Antiparticle Pair Production**

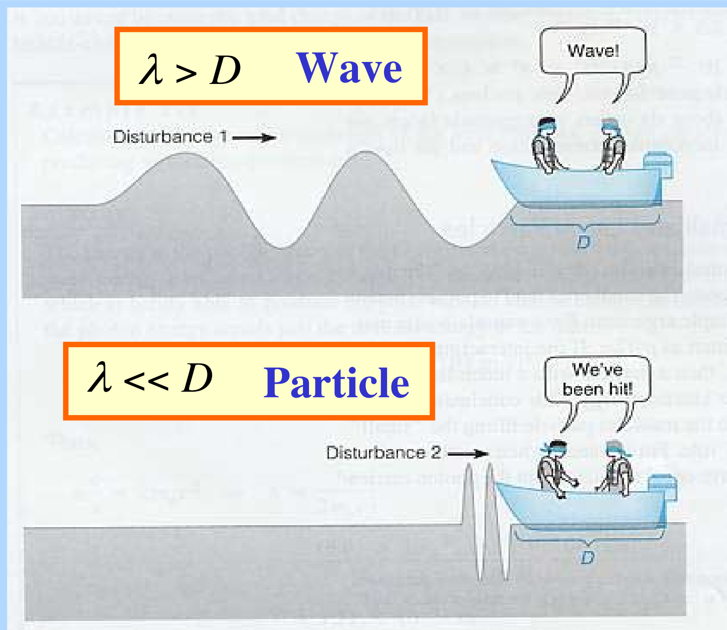
| | | | |
|---|---|---|---|
| **Photon properties:** | | | |
| $E = hf$ | (2-1) | $p = \frac{h}{\lambda}$ | |
| **Photoelectric effect:** | | **Compton effect:** | |
| $KE_{max} = hf - \phi$ | (2-2) | $\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$ | |

# Is It a Wave or a Particles? Duality

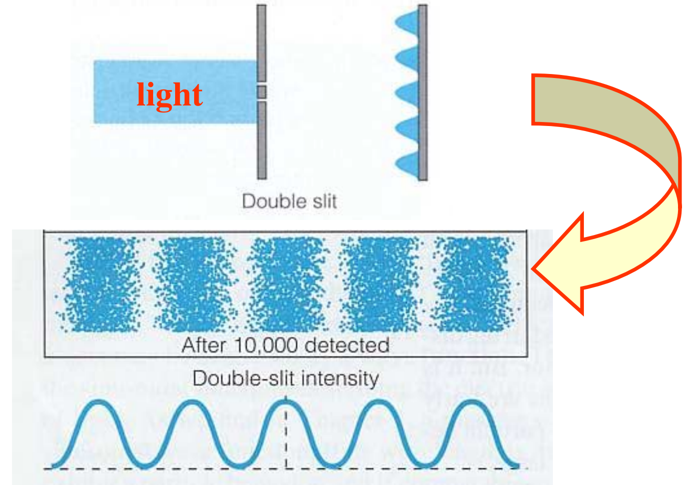
**Ch.2:: EM-Waves behaving like Particles**
**Ch.3:: Particles behaving like Waves**

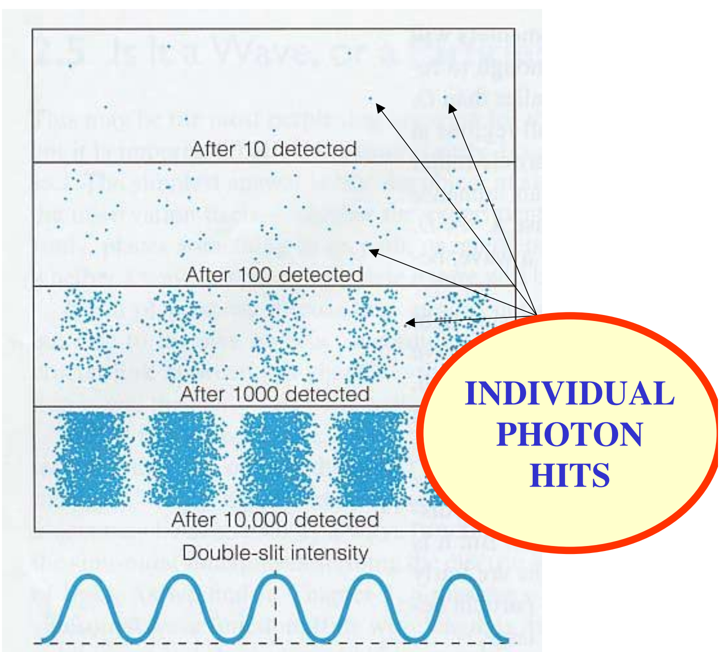
***Outline:***

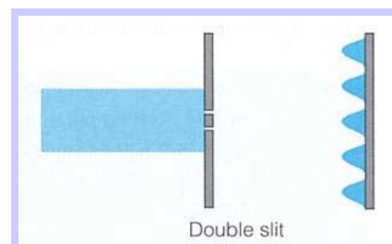
- Particles or Waves
- A Double-Slit Experiment – Light Interference
- A Double-Slit Experiment – Matter Wave Interference
- Properties of Matter Waves
- **Uncertainty Princeiple**



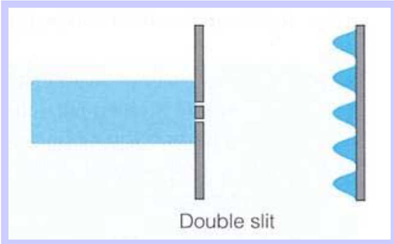

## Double-slit Diffraction Experiment




**Although diffraction of light is a *wave phenomenon*, there is no smooth distribution of light in the diffraction pattern, but the pattern is rather formed of many *individual hits of particles – the photons***




A ***single photon***
**DOES NOT**
**get "disintegrated" in the Diffraction process to make a smooth diffraction pattern**

When a phenomenon is detected as *particles*, it cannot be predicted with certainty where a given particle will be found. The most that can be determined is a probability of finding it in a given region, and this "probability density" is proportional to the square of the amplitude of the associated *wave* in that region.

$$\text{probability density of finding } particle \propto (\text{amplitude of } wave)^2$$

**Coming back to that soon…**

**Electromagnetic waves (light)** → **Particles (photons)**

**?**

**Waves** ← **Massive Particles**