ECE 162A
Mat 162A

John Bowers
Bowers@ece.ucsb.edu
Engineering Science Building, Room 2221C
Assistant: Christine, Room 2221

ECE 162A

"The Quantum Description of Electronic Materials"

Fall, 2008

Tuesdays and Thursdays

12:00 - 1:50, 1437 Phelps

Professor:		John Bowers
Teaching Assistant:		Sidharth Jain
Discussion period:		Thursdays, 1:00 to 1:50
Office hours:	Bowers:	Mondays, 3:00 to 4:00 pm, By appt.
	Ramu:	Mondays and Wednesdays 4-5 pm

Text: Robert Eisberg and Robert Resnick, “Quantum physics: of atoms, molecules, solids, nuclei, and particles” 2nd edition (January 1985) John Wiley & Sons.

References: A.P. French and Edwin F. Taylor, “An introduction to quantum physics” (Norton, 1978).
P.A. Cox, Introduction to quantum theory and atomic structure, Oxford Science Publications, OUP
Herbert Kroemer, “Quantum mechanics for engineering, materials science and applied physics” (Prentice Hall, 1994).

Rules

- There will be a homework set assigned every Tuesday which will be due at the beginning of class the following Tuesday. You are encouraged to work together on solving the homework problems but the final write up must be your own.

- Homework which is one day late can earn a maximum of 75 % of the total score, two days late 50 %, three days late 0. Homework turned in after the Tuesday class is considered 1 day late. The purpose of this policy is to allow your TA to discuss solutions during the Thursday discussion time. Your lowest score won't count towards your grade, so you can skip one homework completely if you are sick/travelling/busy, etc.

- You'll be allowed to bring in one single-sided page of notes (8.5 x 11) into the mid-term. For the final you can have notes on both sides.

Final: Tuesday, Dec. 9 from 12-3

Midterm: Thursday, Oct. 30 from 12-1:50.

Lectures posted at http://www.ece.ucsb.edu/courses/ECE162/162A_F07Bowers

Grading

• Homework	40%
• Midterm	20%
• Final exam	30%
• Class Participation	10%

ECE 162A Lecture topics and Reading, Fall, 2008

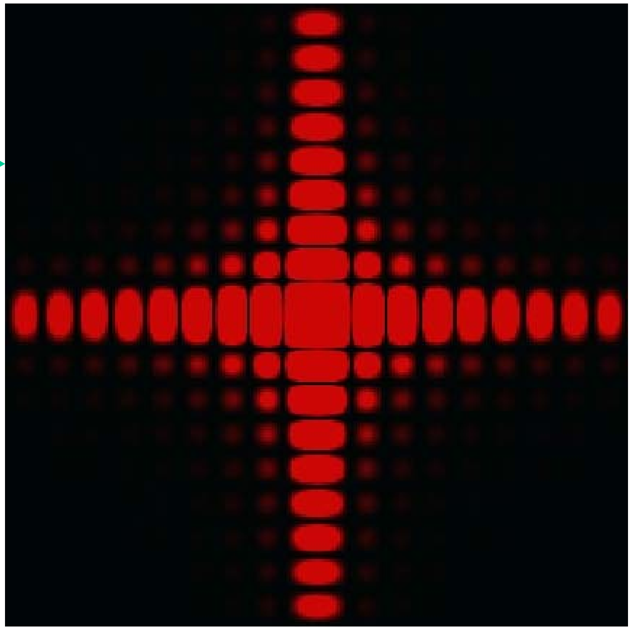
Lecture topics	Reading		
	Eisberg/Resnick	*Kroemer*	*French/Taylor*
Electrons as particles and waves	2,3	1.1-1.2	2
Electron diffraction, wave equations	3	1.3, 2	3
Schrodinger equation, eigenstates	5	1.4-1.6	3
Square well	6, App. H	2.1-2.2	4
Harmonic oscillator	6	2.3	4
Approximation methods	Appendix J		14, 15
Computer calculation, matrix solution	Appendix G	4.5	
Expectation values	5.4	2.4, 7.1	5
Time-dependence of quantum states	-	2.3-2.4, 2.6	8
Wave packets	3	4.1-4.2	8
Uncertainty relations	3	4.3	8
Tunneling and transmission	6	5.1-5.3, 6.4	9
Scattering	6	5.5-5.6	9
Hydrogen atom, atomic structure	7	3.1-3.2	10, 11, 12
Exclusion principle, periodic table		9.1-9.3 -	13
Free electrons in metals	13	-	13
Bonds	13	-	-
Periodic potentials	13	5.4, 14.3	-
Energy bands	13	5.4, 14.3	-

Prequantum Theory READ Chapter 1: Thermal Radiation, Plank's Constant

- Light is a wave. Maxwell's equations give rise to a wave equation that explain light propagation quite well. (Undergrad education…)
- Classical:
  - Wavelength may be quantized (satisfying boundary conditions)
  - Wave can have any energy (continuous)
- Classical theory predicts **diffraction, refraction, propagation** very well.
- Electromagnetic radiation spreads through space like water waves spread across water.

Diffraction

- Diffraction from a square.
- Well understood from wave theory.
- Diffraction from a three dimensional periodic structure such as atoms in a crystal is called Bragg diffraction. It is similar to what occurs when waves are scattered from a diffraction grating. Bragg diffraction is a consequence of interference between waves reflecting from different crystal planes. The condition of constructive interference is given by Bragg's law:
- $m\lambda = 2d\sin\theta$
- where
- λ is the wavelength,
- d is the distance between crystal planes,
- θ is the angle of the diffracted wave.
- and m is an integer known as the order of the diffracted beam.



Blackbody Radiation

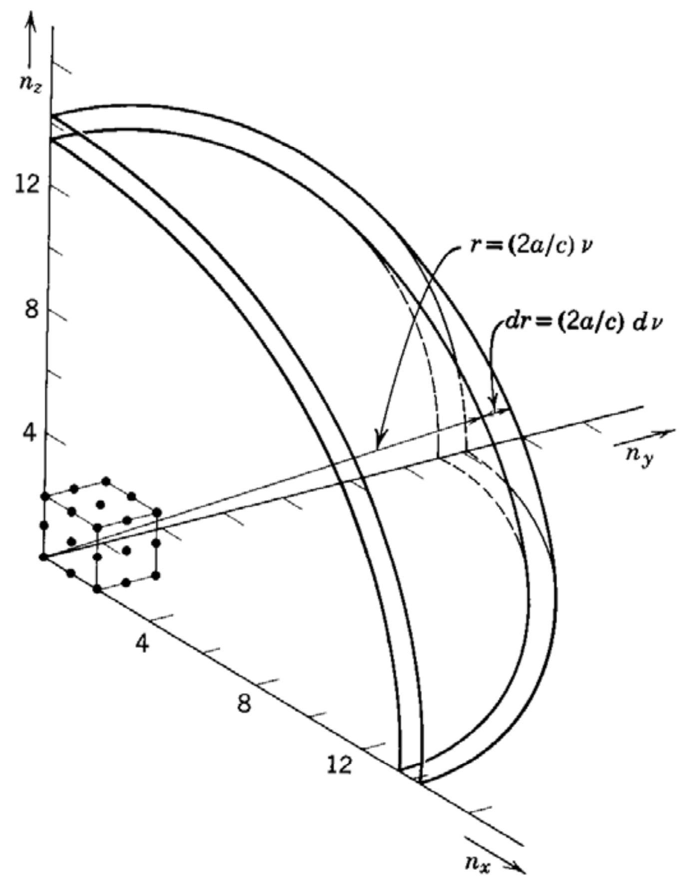
- Matter emits a spectrum of radiation.
  - Examples: A hot piece of metal appears red.
  - A filament (light bulb) appears white
- Blackbody: A material that absorbs all the thermal radiation incident on it. All blackbodies at the same temperature emit thermal radiation with the same spectrum.
- Spectral radiancy: $R_T(\nu)$ spectral distribution of blackbody radiation.
- Radiancy: integral over all energy
- Radiancy proportional to T^4 (Stafan Boltzman constant)

Prequantum Theory (cont.)

Rayleigh: Calculated the energy density of a cavity. (Metal walls at temp T, standing waves,…

- Ultraviolet catastrophe:
  - Theory: energy density of a blackbody rises as frequency squared. (density of states proportional to frequency squared, equal partition of energy (kT/2 energy per degree of freedom)

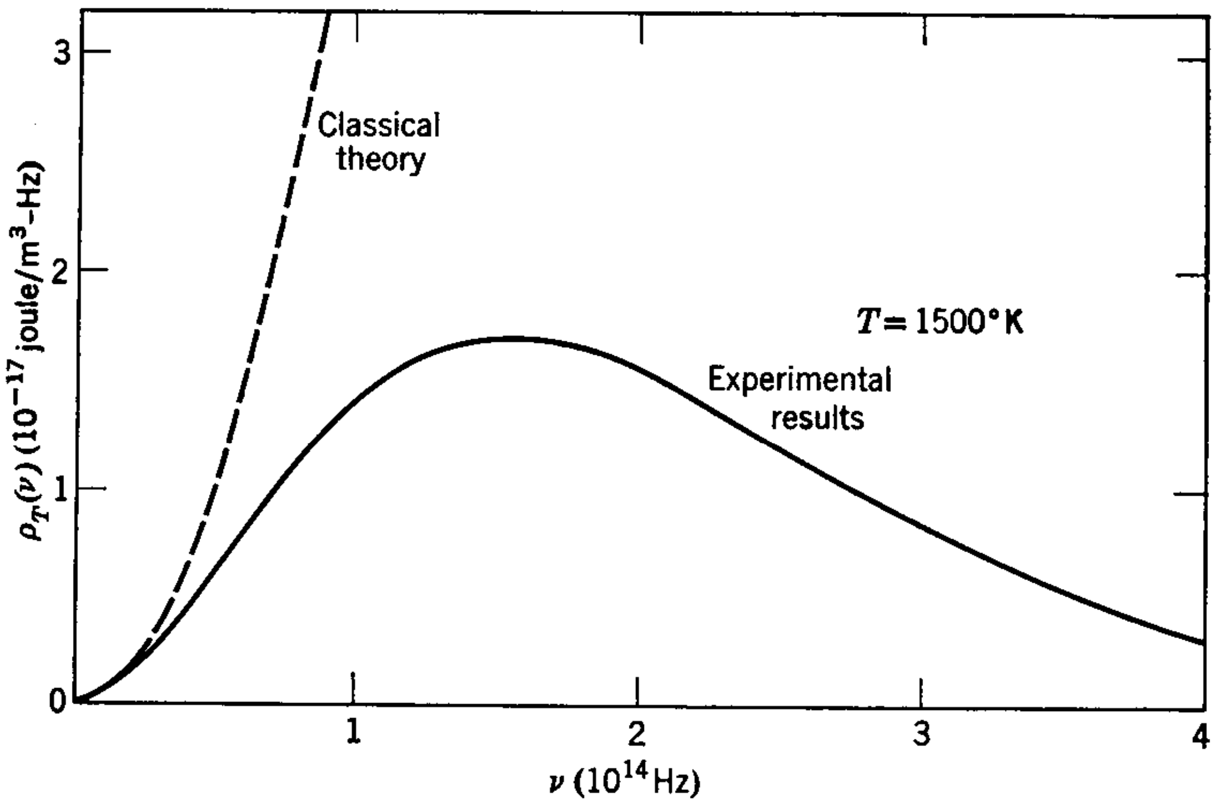
- Planck addressed the Ultraviolet catastrophe in 1900.



Energy density

Prequantum Theory (cont.)

- Problem addressed by Planck: Ultraviolet catastrophe:
  - Theory: energy density of a blackbody rises as frequency squared.
  - Experiment: energy density rises, and falls off.



Energy density

Solution to Ultraviolet Catastrophe

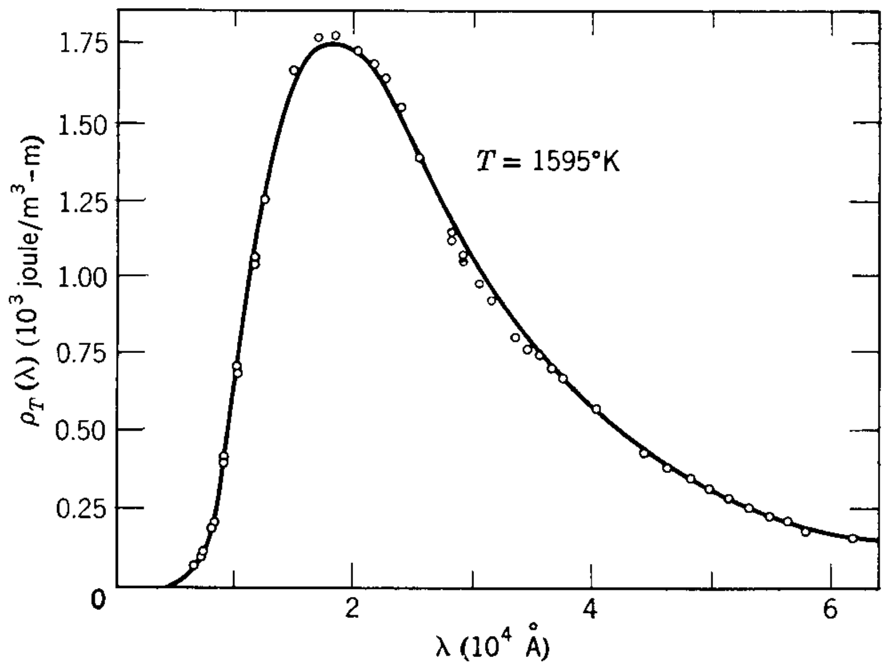
- Planck solution: Modify calculation by treating energy as a discrete variable
  - $E = 0, h\nu, 2h\nu, 3h\nu, \ldots$
- Planck able to calculate $h = 6.6 \times 10^{-34}$ j sec

- Planck's Postulate:

  Any physical entity with one degree of freedom whose coordinate is a sinusoidal function of time can possess only total energies E which satisfy the relation

$$E = nh\nu$$

Comparison of Exp. & Theory



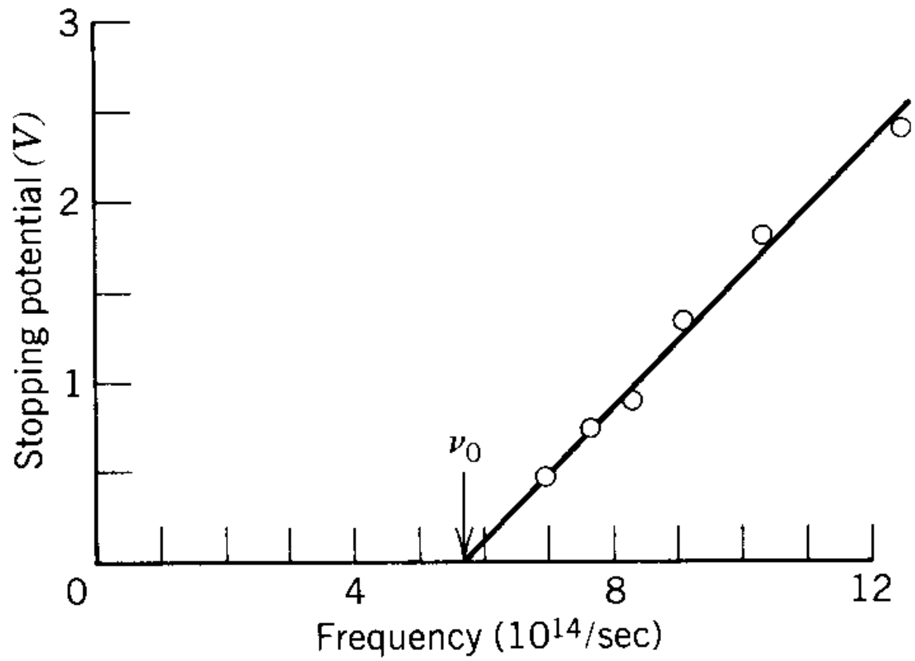
So, Light is an electromagnetic wave! The energy seems to be quantized.

READ Chapter 2: Light: particle and wave characteristics

- Photons: Particle like properties of radiation
- Interaction of light with matter:
  - Photoelectric effect
  - Compton effect
  - Pair production
  - Bremstralung
  - Pair annihilation
- All show experimental evidence of particle nature of light when interacting with matter.

Photoelectric Effect

- Ejection of electrons from a material enhanced by the application of light of high enough frequency
- The light frequency is critical, not the intensity of light.
- Classical theory: If the intensity is high enough, then the electrons will be excited enough to be ejected.

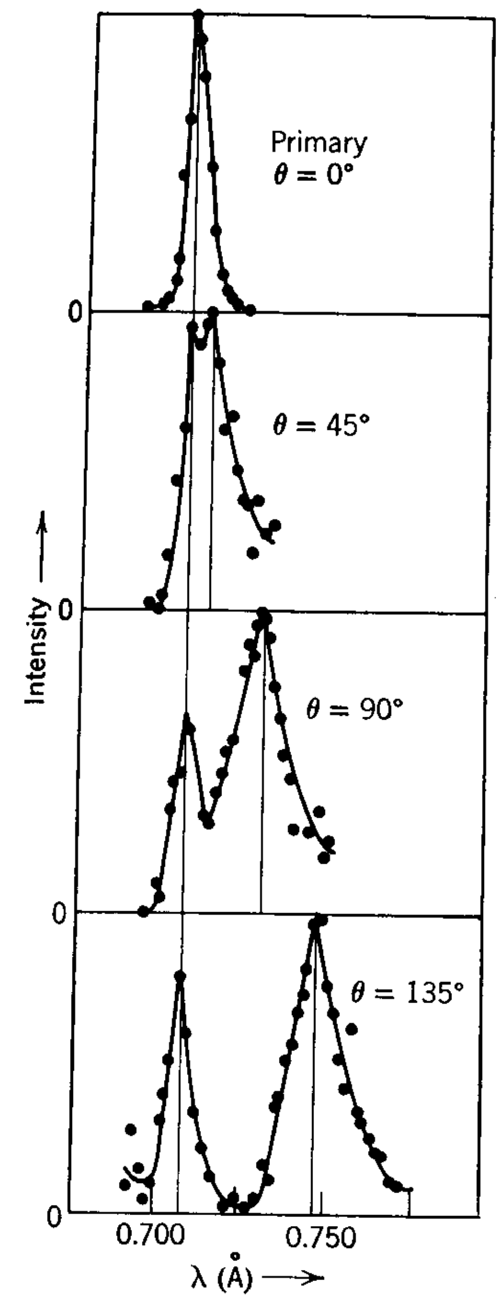


Photoelectric Effect

- 1905 Einstein Theory of Photoelectric Effect
- Light is particle-like in emission and absorption.
- Each bundle of electromagnetic energy (photon) has energy $E=h\nu$ and moves at a velocity c.
- Electron emission energy:
  - $W=h\nu-w$ (w is the work function of the material).
- "That he (Einstein) may have sometimes missed the target in his speculations, as, for example, in his hypothesis of light quanta (photons), cannot really be held too much against him, for it is not possible to introduce fundamentally new ideas, even in the most exact sciences, without occasionally taking a risk."
- 1914: Millikan's experiment: Measure emission current from illuminated surface as a function of potential.
- 1921: Nobel prize

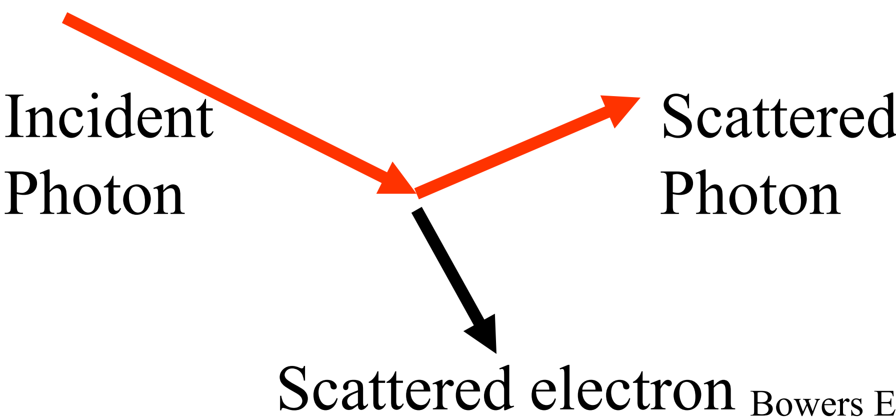
Compton Effect

- Impinge X Rays on a material.
- Measure the spectrum of the scattered beam
- Initial peak and a lower energy peak. ("Compton shift")
- Secondary peak shift depends on angle but not material composition.
- What is going on?



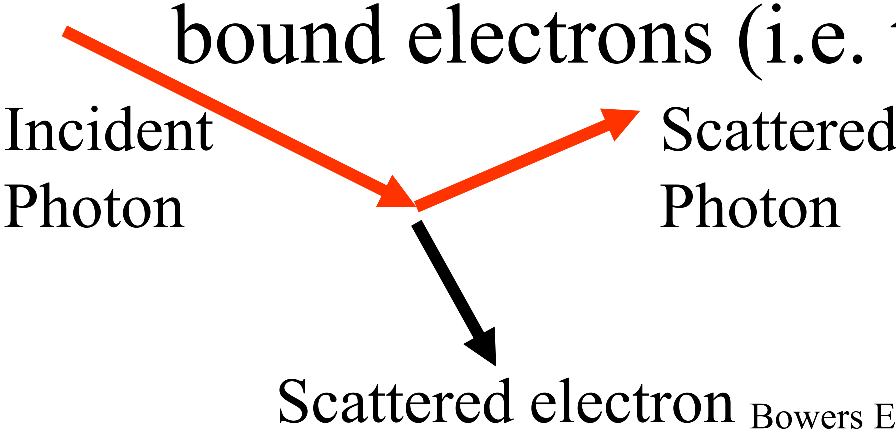
Compton Effect

- A photon scatters off an electron, conserving energy and momentum.
- See page 36-37 for derivation.
- The scattered electron was detected and its angle corresponded to expected scattering.
- What is the nonshifted peak?



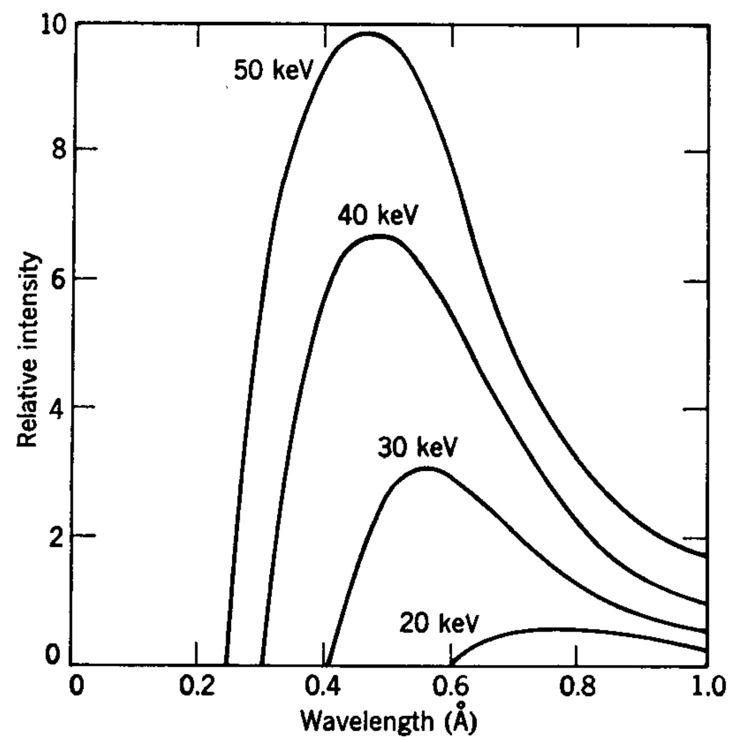
Compton Effect

- A photon scatters off an electron, conserving energy and momentum.
- See page 36-37 for derivation.
- The scattered electron was detected and its angle corresponded to expected scattering.
- What is the nonshifted peak? (Scattering off bound electrons (i.e. the mass of the atom).



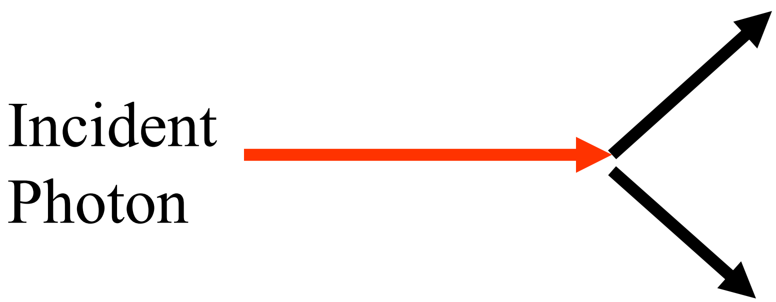
Bremsstrahlung

- When a fast electron impinges on matter, a stream of photons is emitted as the electron slows down.
- There is a maximum frequency of light emitted corresponding to
  - $E=h\nu$
- (This is the inverse of the photoelectric effect).



Pair Production

- A high energy photon can produce an electron and positron pair. Energy and momentum are conserved.



Dual Nature of Radiation

- **Radiation is neither purely a wave phenomenon nor purely a particle phenomenon.**
- A crystal spectrometer used to measure X ray wavelength is using the wave nature.
- A Compton scattering experiment is characterizing the particle nature.

- Read Chapters 1 and 2 of Eisberg and Resnick