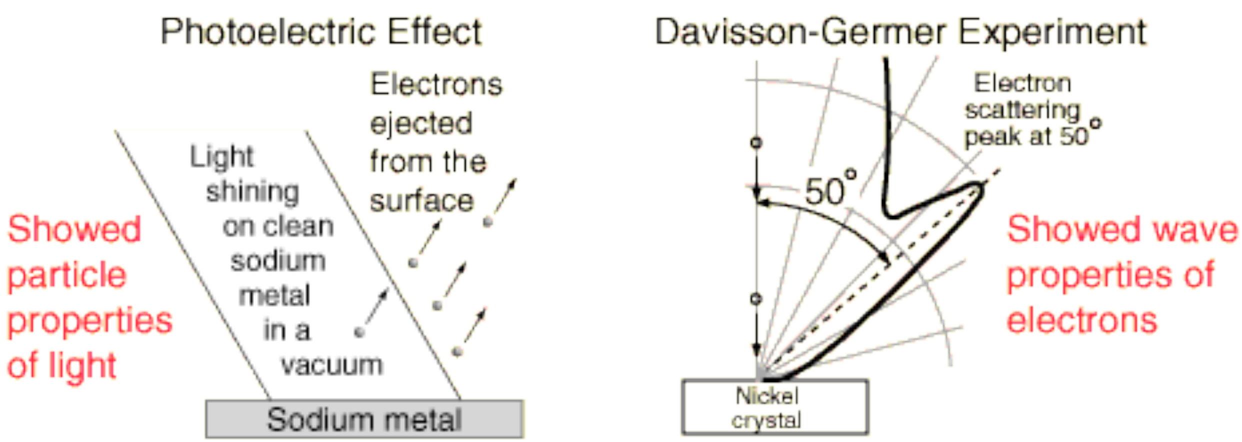
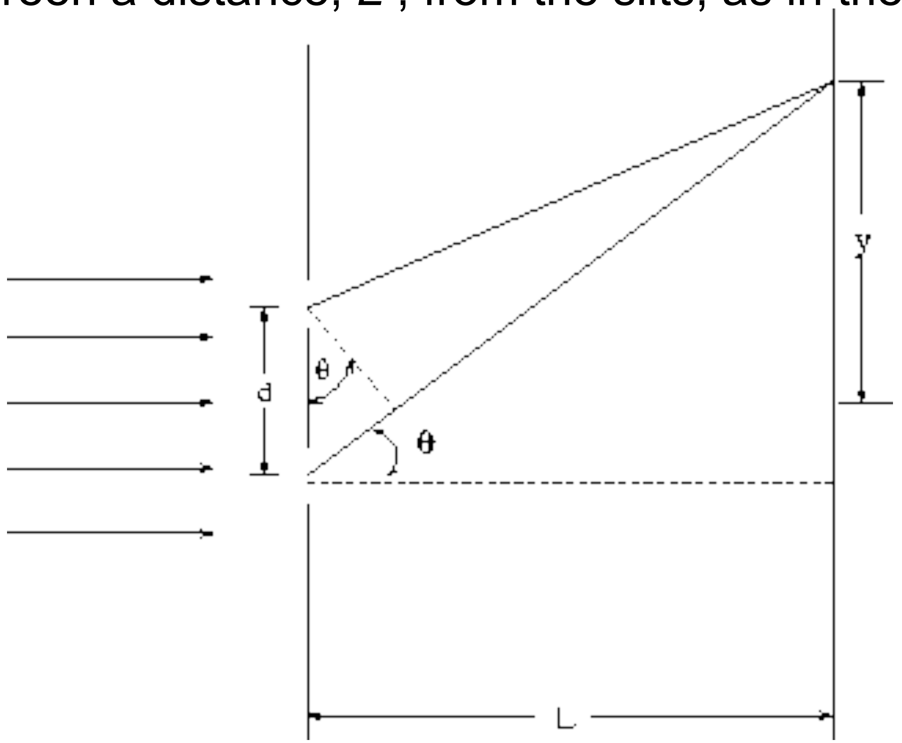
Wave-Particle Duality

Publicized early in the debate about whether light was composed of particles or waves, a wave-particle dual nature soon was found to be characteristic of electrons as well. The evidence for the description of light as waves was well established at the turn of the century when the photoelectric effect introduced firm evidence of a particle nature as well. On the other hand, the particle properties of electrons was well documented when the DeBroglie hypothesis and the subsequent experiments by Davisson and Germer established the wave nature of the electron.



This is a classic example of interference effects in light waves. Two light rays pass through two slits, separated by a distance *d* and strike a screen a distance, *L* , from the slits, as in the Fig.



If $d << L$ then the difference in path length $r_1 - r_2$ travelled by the two rays is approximately:

$$r_1 - r_2 = d\sin\theta$$

where θ is approximately equal to the angle that the rays make relative to a perpendicular line joining the slits to the screen.

If the rays were in phase when they passed through the slits, then the condition for constructive interference at the screen is:

$$d\sin\theta = m\lambda, \quad m = 0, \pm 1, \pm 2, \ldots$$

whereas the condition for destructive interference at the screen is:

$$d\sin\theta = (m + 1/2)\lambda, \quad m = 0, \pm 1, \pm 2, \ldots$$

The points of constructive interference will appear as bright bands on the screen and the points of destructive interference will appear as dark bands. These dark and bright spots are called *interference fringes*. **Note:**

•In the case that y, the distance from the interference fringe to the point of the screen opposite the center of the slits is much less than L ($y << L$), one can use the approximate formula:

$$\sin\theta \sim y/L$$

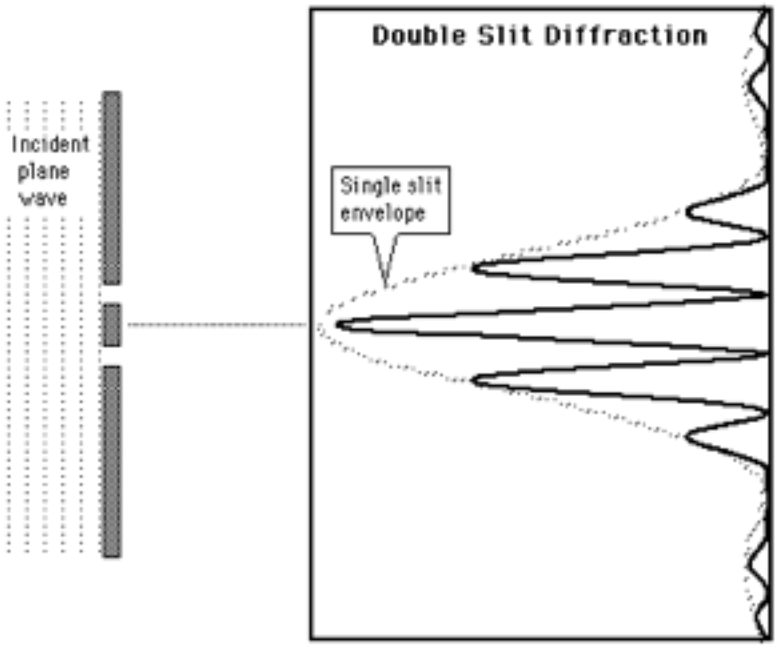
so that the formulas specifying the y - coordinates of the bright and dark spots, respectively are:

$$y = \frac{m\lambda L}{d} \quad \text{for the bright}$$

$$\frac{(m+\frac{1}{2})\lambda L}{d} \quad \text{for the dark}$$

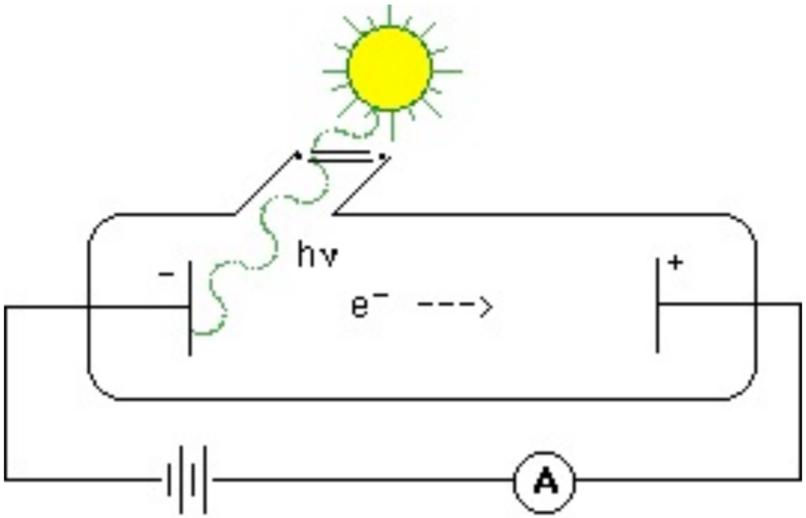
The spacing between the dark spots is

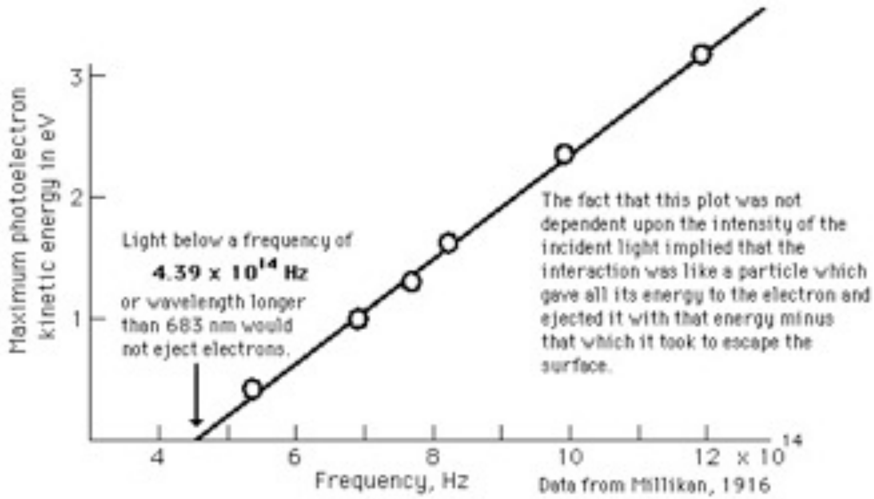
$$\Delta y = \frac{\lambda L}{d}$$

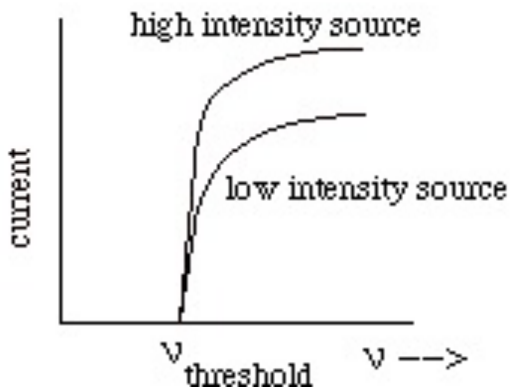


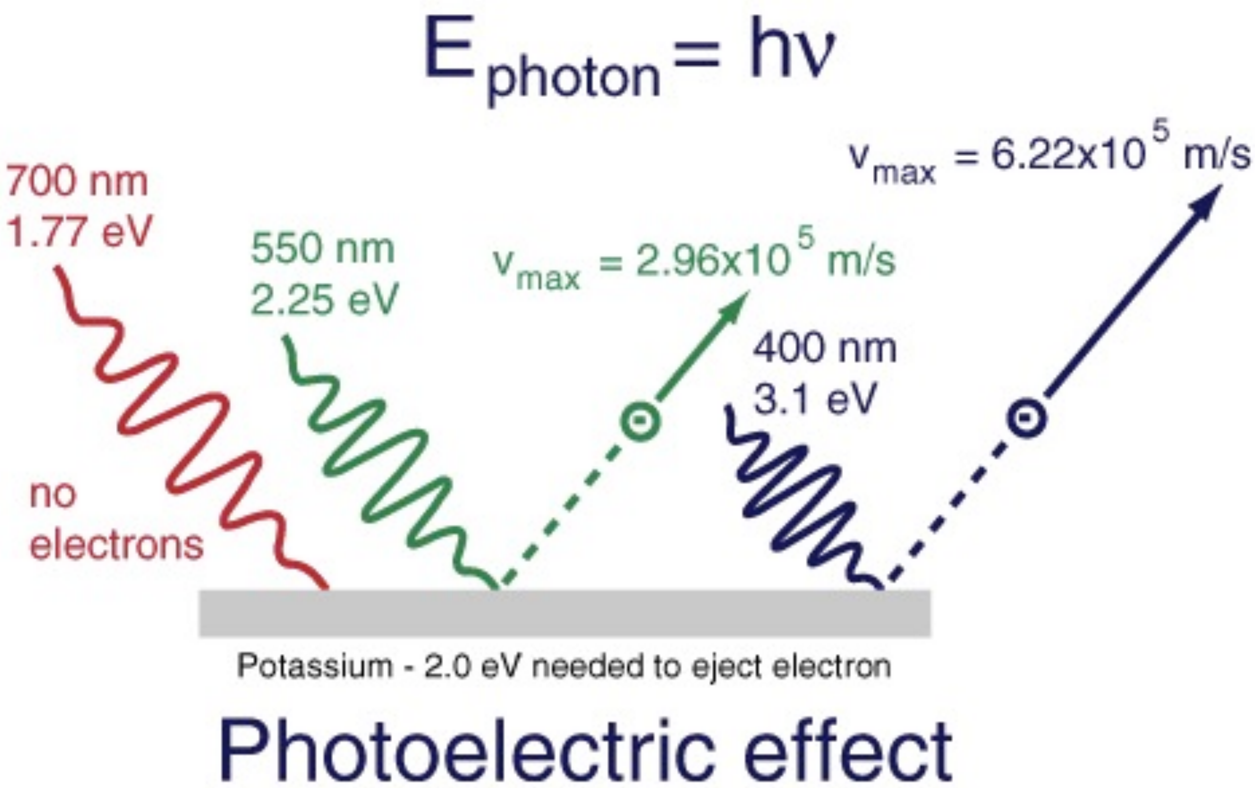
- If $d << L$ then the spacing between the interference can be large even when the wavelength of the light is very small (as in the case of visible light). This give a method for (indirectly) measuring the wavelength of light.
- The above formulas assume that the slit width is very small compared to the wavelength of light, so that the slits behave essentially like point sources of light.

Photoelectric effect









The details of the photoelectric effect were in direct contradiction to the expectations of very well developed classical physics.

The explanation marked one of the major steps toward quantum theory.

The remarkable aspects of the photoelectric effect when it was first observed were:

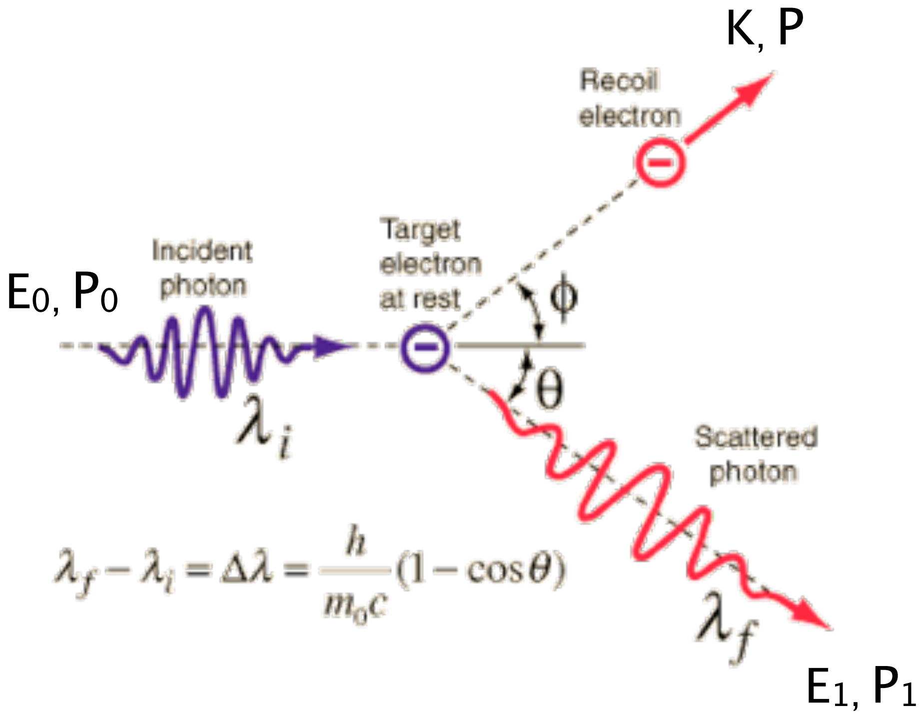
1. The electrons were emitted immediately - no time lag!

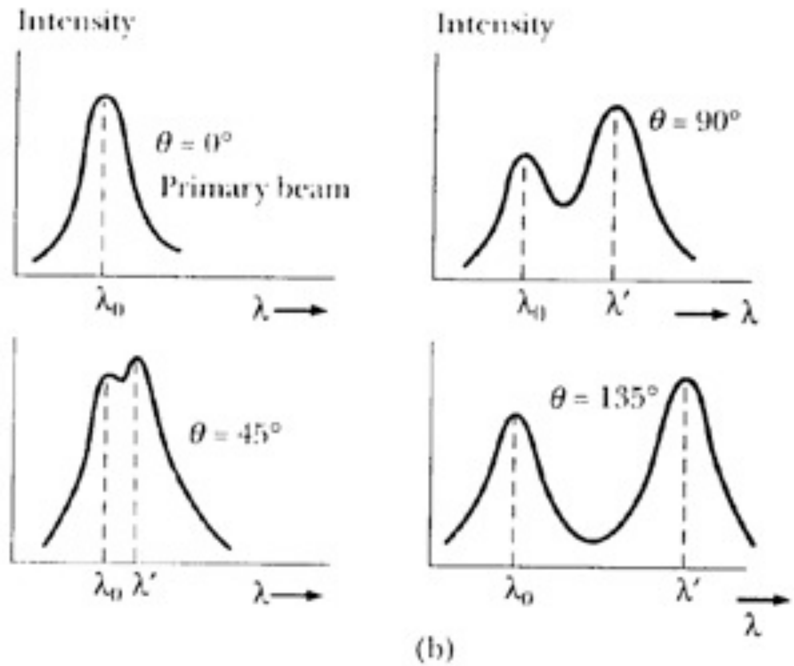
2. Increasing the intensity of the light increased the number of photoelectrons, but not their maximum kinetic energy!

3. Red light will not cause the ejection of electrons, no matter what the intensity!

4. A weak violet light will eject only a few electrons, but their maximum kinetic energies are greater than those for intense light of longer wavelengths!

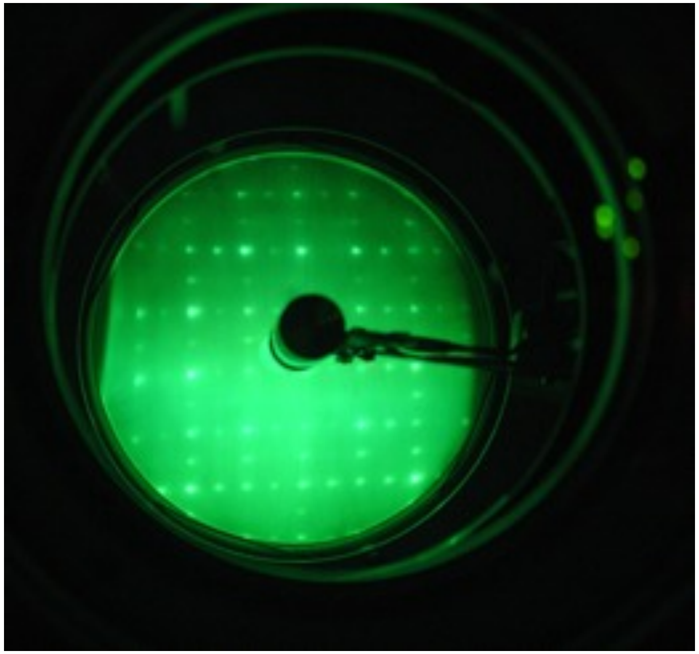
Compton Scattering



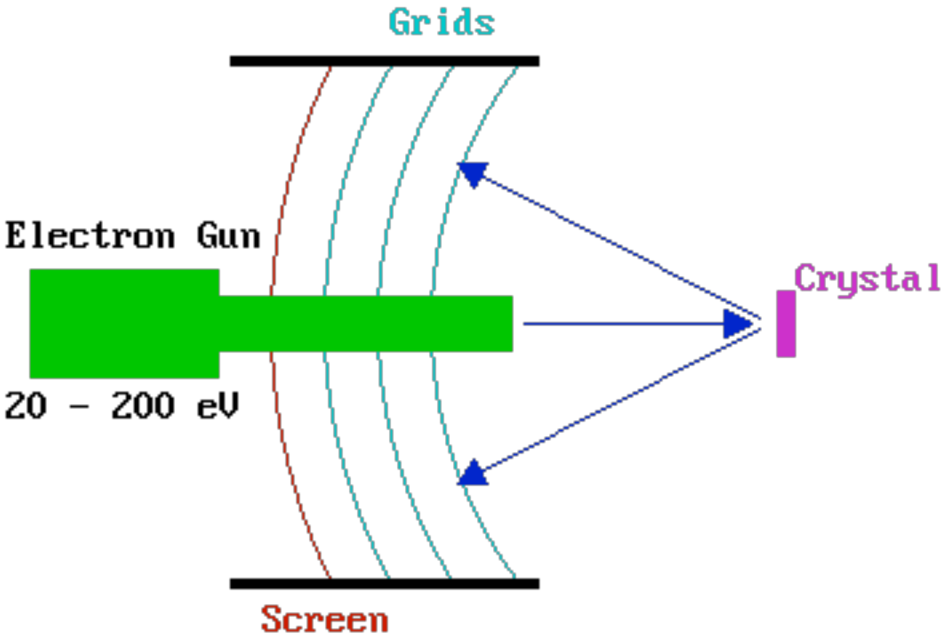


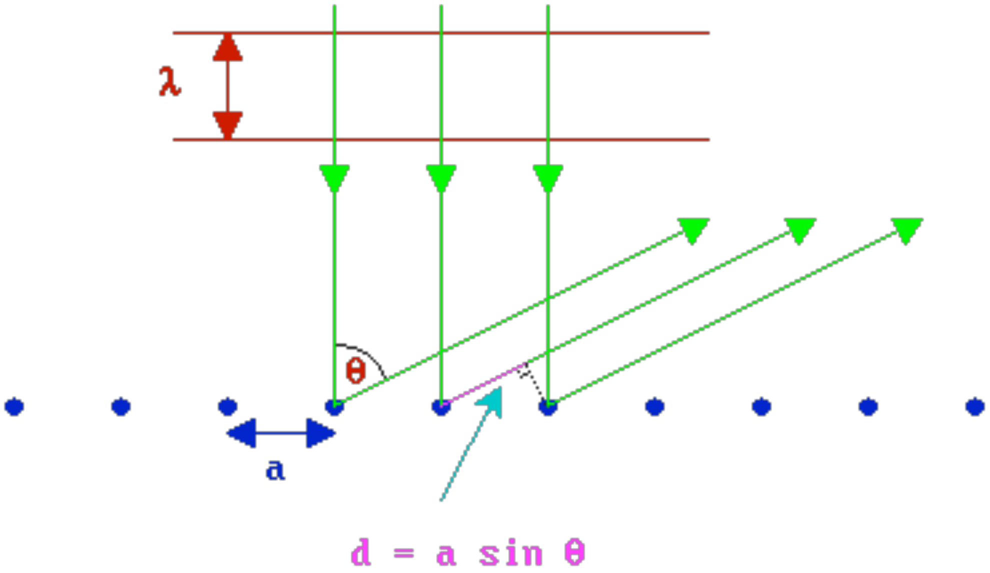
Compton wavelength $\lambda_C = h/m_0c = 0.0243\text{Å}$

Low energy electron diffraction



LEED pattern acquired on Si(100) surface





De Broglie wavelength: $\lambda = h/(mv)$

For electrons: $\lambda = (150/E_0)^{1/2}$ E_0 in eV, λ in Å

For 100 eV-electrons: λ = 1.22 Å

From $E = h\nu$

de Broglie wavelength:

$\lambda = h/p$

Uncertainty Principle

The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa.
--Heisenberg, uncertainty paper, 1927

$$\Delta X \Delta P \geq \frac{\hbar}{2}.$$

Homework #2

In a photoelectric experiment in which monochromatic light and a sodium photocathode are used, we find a stopping potential of 1.85 eV for λ = 3000 A and of 0.82 eV for λ = 4000 A. From these data determine (a) a value for Planck's constant, (b) the work function of sodium in eV, and (c) the threshold wavelength for sodium.