Wave Theory

U Wave theory was the dominant theory for understanding the behavior of light (and other forms of electromagnetic radiation) prior to 1900.

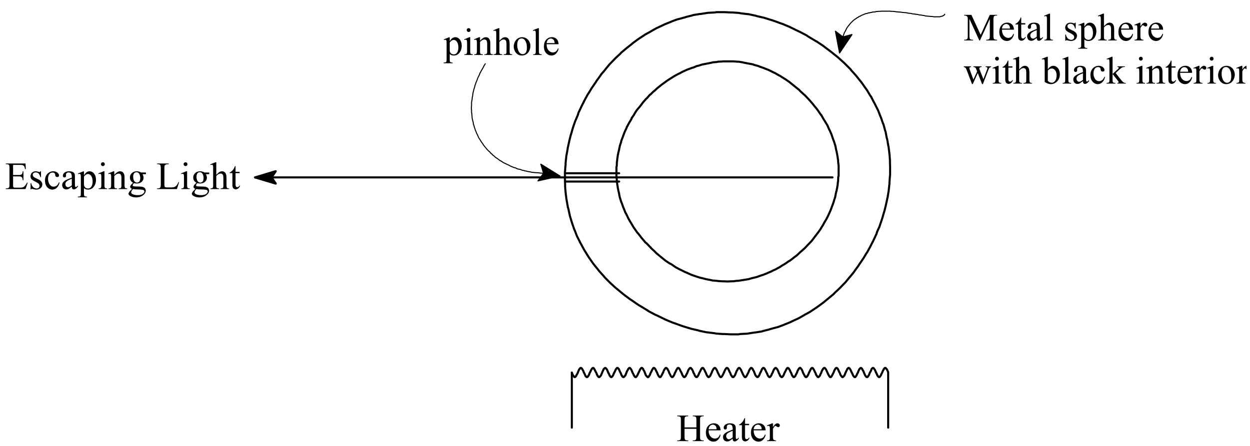
(Wave theory correctly predicted the behavior of light in most optical phenomena.

; Wave theory incorrectly assumed that the energy of electromagnetic radiation was proportional to its intensity:

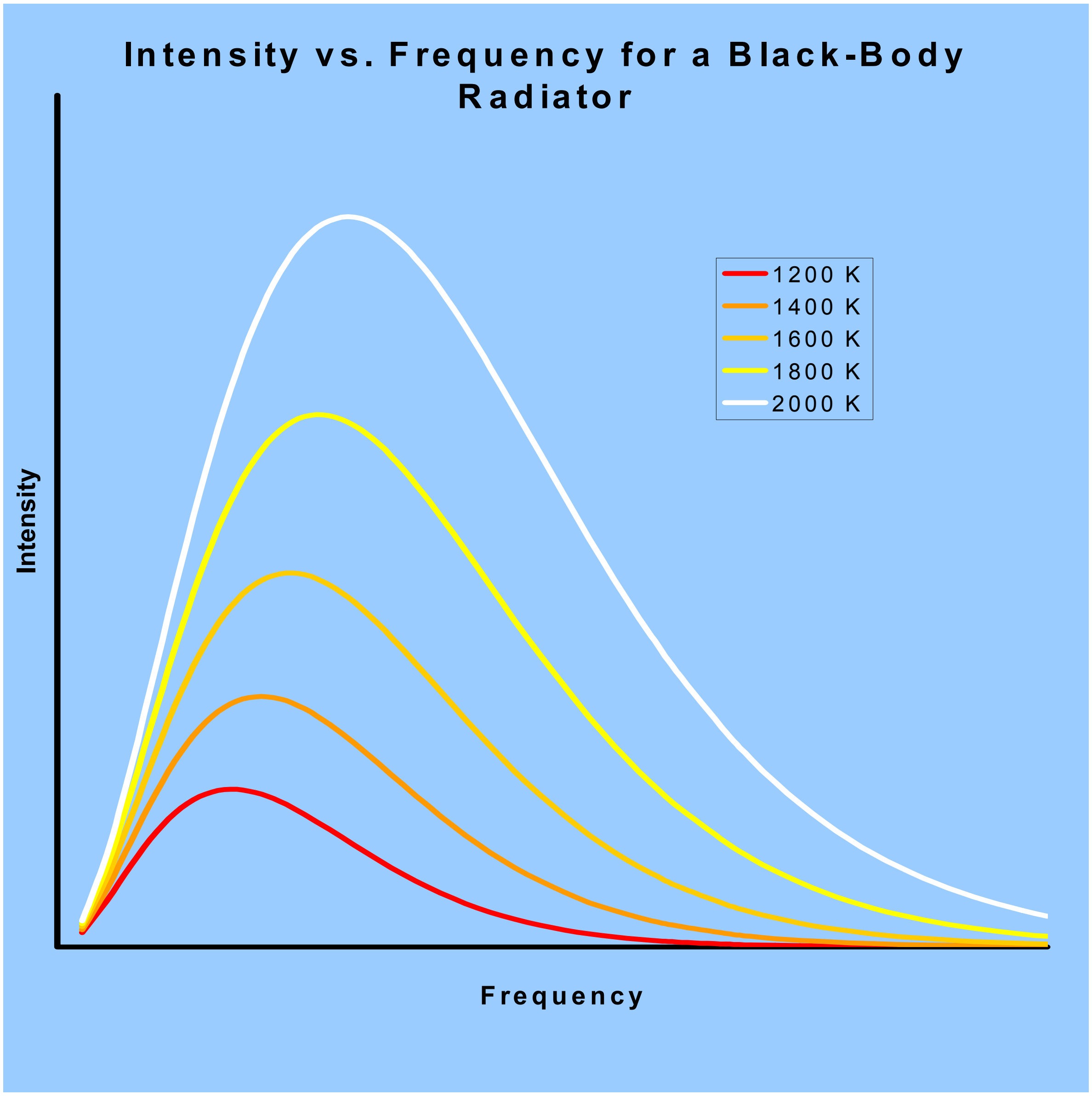
$$E \% I \% A^2$$

; Wave theory incorrectly predicted that the intensity of light emitted by a heated body should increase without limit as the frequency increases ("The Ultraviolet Catastrophe").

The Black-Body Radiator Problem



- In 1900 Max Planck, through his interpretation of the frequency-intensity dependence of the black-body radiator, deduced the fundamental equation $E = h\nu$.


Intensity vs. Frequency for a Black-Body Radiator
Intensity
Frequency
1200 K
1400 K
1600 K
1800 K
2000 K

Assumptions of Planck's Black-Body Radiator Model

1. The body contains "oscillators" with various individual frequencies, ν.

2. Each oscillator has certain energies limited to values given by

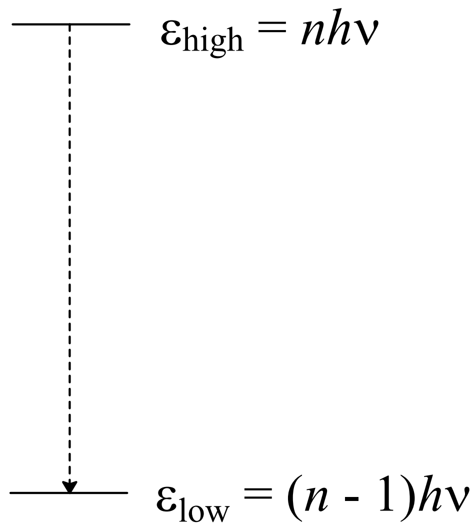
$$g = nh\nu$$

where g = oscillator's energy
h = a constant (Planck's constant)
ν = oscillator's frequency
n = quantum number = 1, 2, 3, ...

3. An oscillator emits energy in the form of light in a transition from a higher energy state to a lower energy state:

$$E_{light} = *g_{low} - g_{high}*$$

Energy Transition of an Oscillator

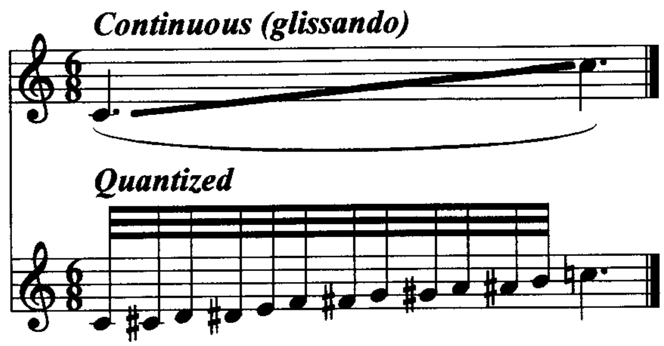
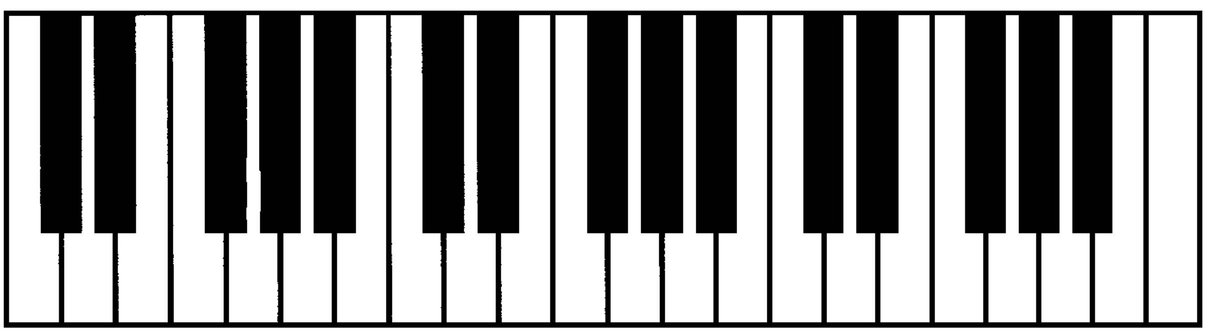


$$E_{light} = *g_{low} - g_{high}* = *(n - 1)h\nu - nh\nu* = h\nu$$

Consequences of Plank's Quantum Theory

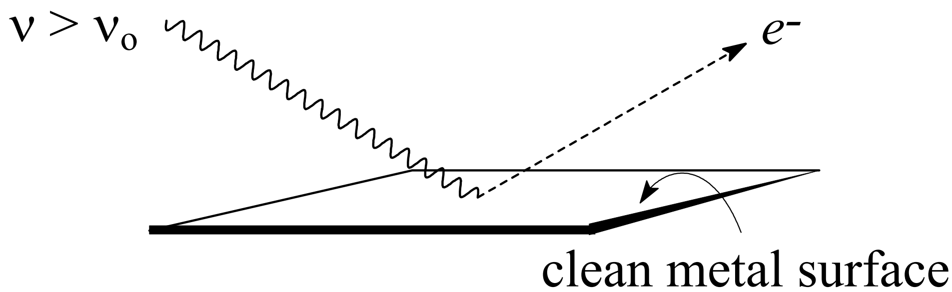
1. Light energy is proportional to frequency, *not* intensity.

2. Energies of individual particles of matter (e.g., atoms, molecules) are not continuous, but rather are *quantized* into certain allowed values.

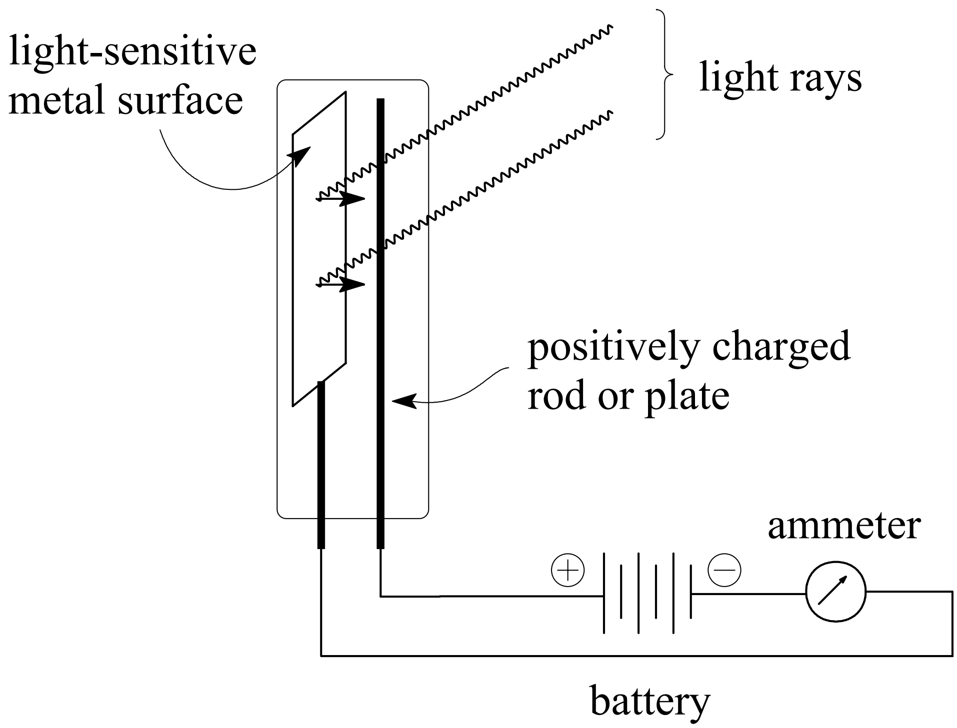
Continuous vs. Quantized Energy
Musical Analogy



Photoelectric Effect

Phillip Eduard Anton Lenard - 1900.



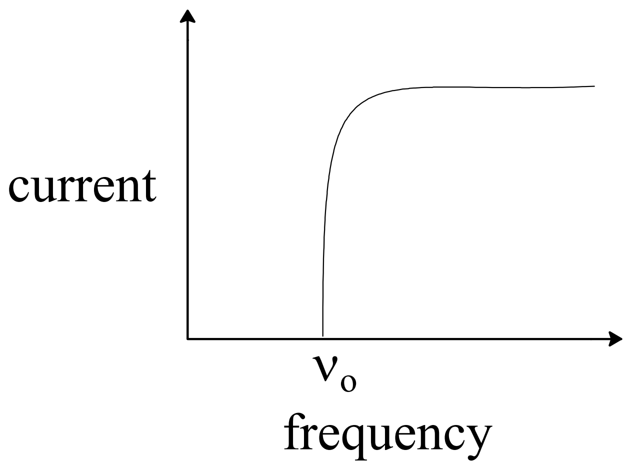
Photoelectric Cell



Photoelectrons create the electrical current in the circuit, which is read on the ammeter.

Photoelectric Effect

1. The light must have a frequency greater than a certain minimum value, ν_o, characteristic of the metal.



2. Energy of emitted electrons *does not* depend on light intensity.

3. Number of emitted electrons (photoelectric current) increases with light intensity.

4. Electron energy is proportional to light frequency, if $\nu > \nu_o$.

Einstein's Interpretation of the Photoelectric Effect

1905

$$E_{\text{light}} = h\nu = g_o + K$$

g_o = energy of attraction between electron and metal that must be overcome to eject photoelectrons

K = kinetic energy of ejected electrons

From Plank

$$g_o = h\nu_o$$

so $$E_{\text{light}} = h\nu = h\nu_o + K$$

But $$K = \tfrac{1}{2}mv^2$$

so $$E_{\text{light}} = h\nu = h\nu_o + \tfrac{1}{2}mv^2$$