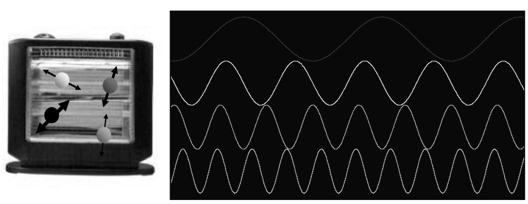
Atomic Physics and Lasers

- The idea of a photon
  - Black body radiation
  - Photoelectric Effect
- The structure of the atom
- How does a Laser work? Interaction of lasers with matter
  - Laser safety
- Applications
  - Spectroscopy, detection of art forgery, flow cytometry, eye surgery.

The idea of a photon

- What is light?
- A wave?
- Well yes, but….
- **The wave picture failed to explain physical phenomena including :**
  - the spectrum of a blackbody
  - the photoelectric effect
  - line spectra emitted by atoms

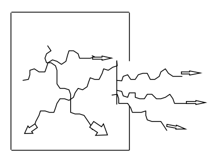
Light from a hot object...



Vibrational motion of particles produces light
(we call the light “Thermal Radiation”)

The first clue that something was very, very wrong…Blackbody radiation

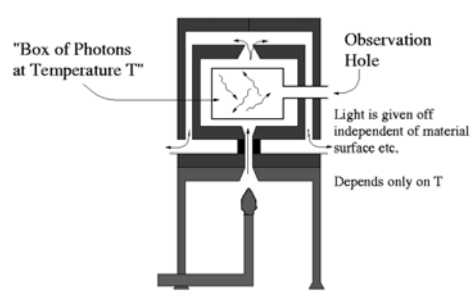
- What is a blackbody?



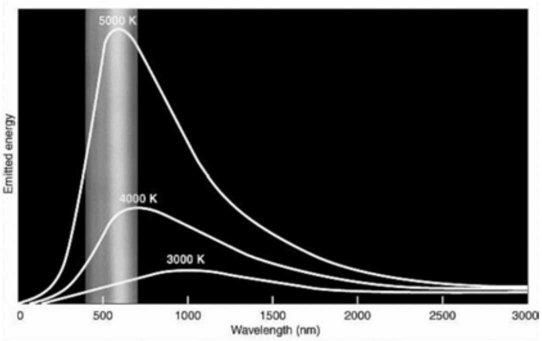
- An object which emits or absorbs all the radiation incident on it.
- Typical black bodies
  - A light globe
  - A box with a small hole in it.

Example of a Blackbody

Example of a Blackbody



We measure radiation as a function of frequency (wavelength)



Thermal Radiation

[redacted]

T = Temp. in Kelvin

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Wavelength where flux is a maximum

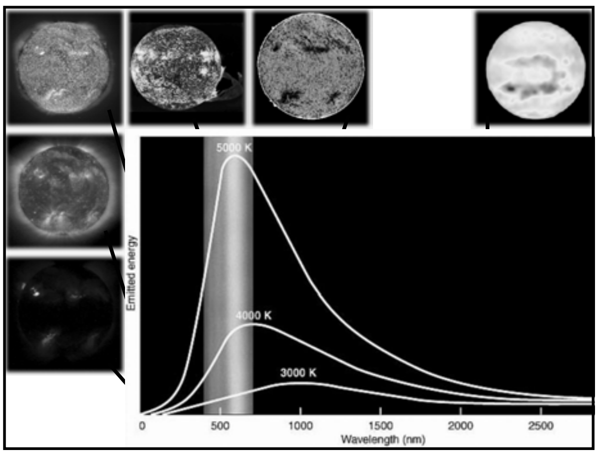
Total energy emitted by an object (or Luminosity W/m^2)

k = 2.898 x 10^{-3} m.K

σ = 5.7 x 10^{-8} W/(m^2.K^4)

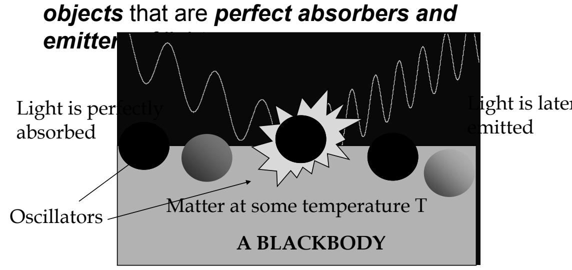
Wien's Law

Stefan's Law



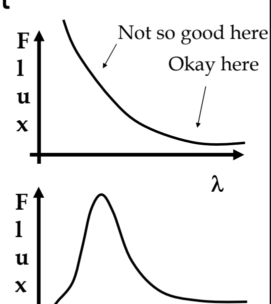
Light and matter interact

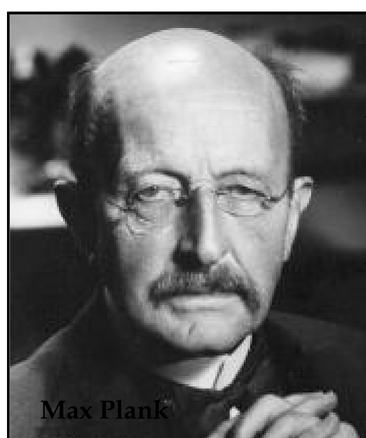
- The spectra we have looked at are for ***ideal objects*** that are ***perfect absorbers and emitter***



Problems with wave theory of light

- Take a Blackbody with a temperature, *T*
- Calculate how the spectrum would look ***if light behaved like a wave*** (Lord Rayleigh)
- Compare with what is actually observed



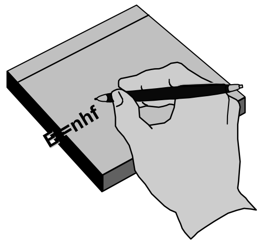


Max Plank Solved the problem in 1900

- Oscillators cannot have any energy! They can be in states with fixed amounts of energy.
- The oscillators change state by emitting/absorbing packets with a fixed amounts of energy

Atomic Physics/Blackbody

- Max Planck (1858-1947) was impressed by the fact spectrum of a black body was a universal property.
- To get agreement between the experiment and the theory, Planck proposed a radical idea: Light comes in packets of energy called photons, and the energy is given by **E= nhf**



The birth of the quantum theory = Planck's hypothesis

The birth of the Photon

- In 1906, Einstein proved that Planck's radiation law could be derived only if the energy of each oscillator is quantized.

  $E_n = nhf$; $n = 0, 1, 2, 3, 4,...$

  h=Planck's constant= 6.626×10^{-34} J.s

  f=frequency in Hz; E=energy in Joules (J).
- Einstein introduced the idea that radiation equals a collection of discrete energy quanta.
- G.N. Lewis in 1926 named quanta **"Photons"**.

Atomic Physics/Photon

- The energy of each photon:

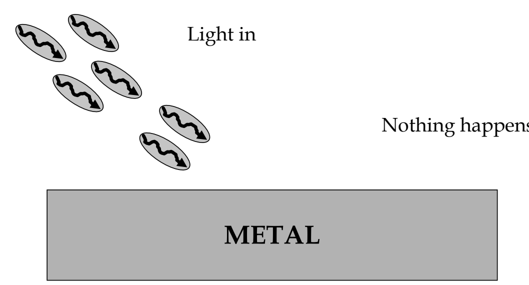
  E = hf h=Planck's constant

  f=frequency

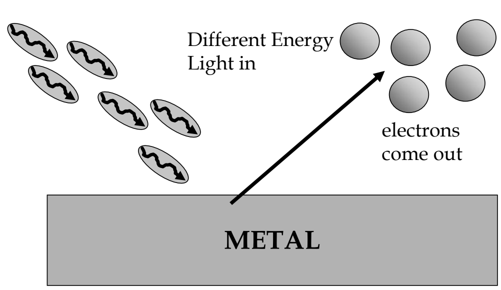
Ex. 1. Yellow light has a frequency of 6.0×10^{14} Hz. Determine the energy carried by a quantum of this light. If the energy flux of sunlight reaching the earth's surface is 1000 Watts per square meter, find the number of photons in sunlight that reach the earth's surface per square meter per second.

Ans. 2.5 eV and 2.5×10^{21} photons / m^2 /s

Shining light onto metals



Shining light onto metals



The Photoelectric Effect

- When light is incident on certain metallic surfaces, electrons are emitted = the *Photoelectric Effect* (Serway and Jewett 28.2)
- Einstein: A single photon gives up all its energy to a single electron

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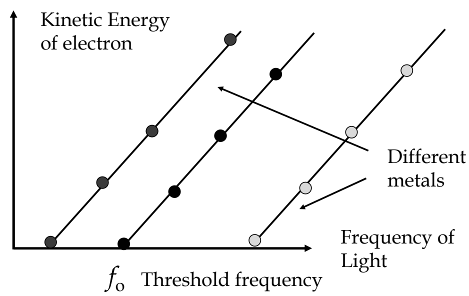
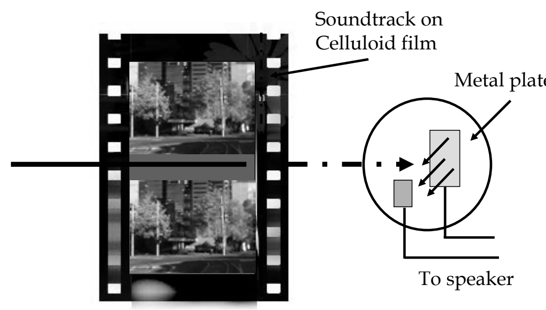
Need ***at least*** this much energy to free the electron

Whatever is left makes it move

The Photoelectric Effect



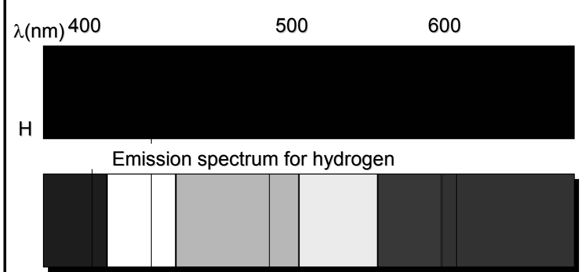
Application of Photoelectric Effect



Another Blow for classical physics: Line Spectra

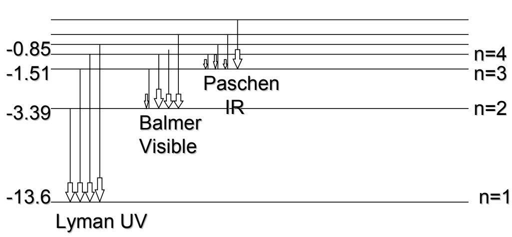
- The emission spectrum from a rarefied gas through which an electrical discharge passes consists of sharp spectral lines.
- Each atom has its own characteristic spectrum.
- Hydrogen has four spectral lines in the visible region and many UV and IR lines not visible to the human eye.
- The wave picture failed to explain these lines.

Atomic Physics/Line spectra



The absorption spectrum for hydrogen; dark absorption lines occur at the same wavelengths as emission lines.

Atomic Physics/Line Spectra



$$\frac{1}{\lambda} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

R =Rydberg Constant = $1.09737 \times 10^{7}\,m^{-1}$

So what is light?

- Both a wave and a particle. It can be both, but in any experiment only its wave or its particle nature is manifested. (Go figure!)

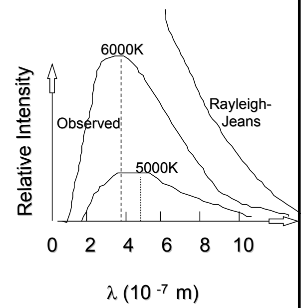
Two revolutions: The Nature of light and the nature of matter

- Light has both a particle and wave nature:
- Wave nature:
  - Diffraction, interference
- Particle nature
  - Black body radiation, photoelectric effect, line spectra
- Need to revise the nature of matter (it turns out that matter also has both a particle and wave nature

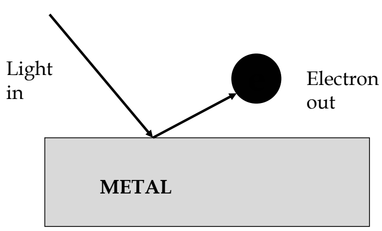
The spectrum from a blackbody

•Empirically:
λ(max)T = constant,
Hotter = whiter

●The wave picture (Rayleigh-Jeans) failed to explain the distribution of the energy versus wavelength. UV Catastrophe!!!!



Photoelectric Effect



The Photoelectric Effect

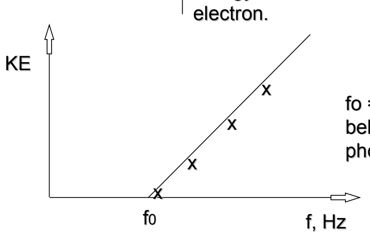
- **Photoelectric effect**=When light is incident on certain metallic surfaces, photoelectrons are emitted.
- **Einstein applied the idea of light quanta**:

In a photoemission process, a single photon gives up all its energy to a single electron.

Energy of photon = Energy to free electron + KE of emitted electron

Atomic Physics/Photoelectric Effect

hf = KE + ϕ | ϕ=work function; minimum energy needed to extract an electron.



fo = threshold freq below which no photoemission occurs

Atomic Physics/The Photoelectric Effect-Application

The sound on a movie film