# 7.1 Quantum Physics. Particle Nature of Light

Blackbody Radiation

Photoelectric Effect

## Photons

When light exchanges energy with matter it behaves as a particle - called the photon

The energy of a photon is proportional to the frequency of light

$$E_{photon} = hf$$

Where h is a universal constant called Planck's Constant

$$h=6.626\times10^{-34}\ J\cdot s$$

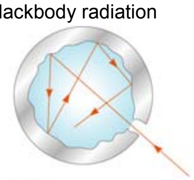
The first evidence for the particle nature of light comes from

Planck's Theory of Black body radiation

Einstein's Theory of the Photoelectric effect.

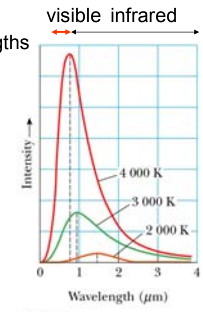
## Thermal Radiation

Blackbody radiation



A container at temperature T in equilibrium with electromagnetic radiation.
Light is absorbed and emitted by the walls.
At equilibrium the spectrum of the light only depends on the temperature.

## Spectrum of Blackbody radiation




A wide spectrum of wavelengths is produced.

The total intensity increases with temperature

The peak wavelength decreases with temperature
Wien's displacement law

$\lambda_{max}T=0.2898\times10^{-2}mK$

The intensity goes down at low wavelengths (I->0, as $\lambda$-> 0)

## Demonstration of blackbody radiation

A tungsten filament light bulb is approximately a black body radiator.

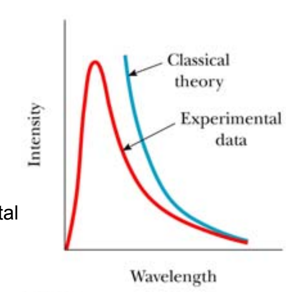
http://www.physics.ucla.edu/demoweb/demomanual/astronomy/quantum_mechanics/blackbody_radiation.html

## Disagreement with classical theory of light

The classical theory predicts that intensity continues to increase with decreasing wavelength.

"Ultraviolet Catastrophe"

To explain the experimental data Planck proposed the quantum hypothesis.



## Planck's constant

Max Planck

Planck proposed that light could only have certain energies

$E=hf$

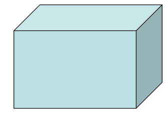
Then the energy of oscillators in the black body could only have certain fixed quantities

$E=nhf$

n is an integer. i.e. Energy is Quantized.

## A simple picture

Suppose we have a box that contains light waves with different wavelengths. The energy is contained in "resonators", particles with different energies



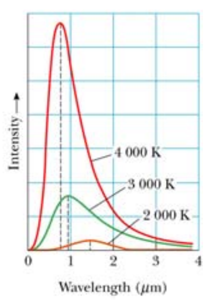
Classical theory predicts that the number of resonators increased with decreasing wavelength. "smaller particles are more numerous"

Planck proposed that in addition the short wavelength particles are more "energetically expensive"

So at short wavelength, they would be hard to produce. This explains the peak in the black body spectrum

## Quantum explanation for the Wein Effect.

- The blackbody spectrum reflects the distribution of photon energies.
- The peak wavelength reflects the average energy.
- The average photon energy increases linearly with temperature

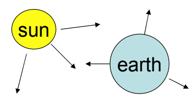



from $\lambda_{max} T = \text{constant}$

since $\lambda = \frac{c}{f}$

then $T \propto \frac{1}{\lambda_{max}} \propto \frac{hf_{max}}{c} \propto$ Average photon energy

## Question




The sun has a surface temperature of 5,800 K. The solar radiation has a peak wavelength of 500 nm. The earth has temperature of about 300 K. What is the maximum wavelength of the blackbody spectrum of the earth?

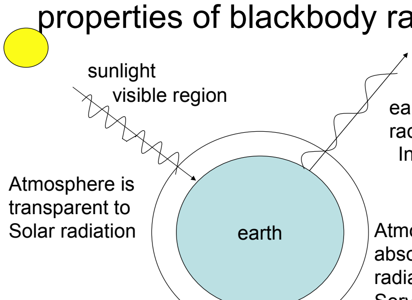
Wein Law $\lambda_{max} T = \text{constant}$

$$\lambda_{max}^{earth} T^{earth} = \lambda_{max}^{sun} T^{sun}$$

$$\lambda_{max}^{earth} = \frac{\lambda_{max}^{sun} T^{sun}}{T^{earth}} = \frac{500\text{x}10^{-9}\text{m}(5800\text{K})}{300\text{K}} = 9.7\text{x}10^{-6}\text{m}$$

10micrometers
infrared region

## Greenhouse effect is based on properties of blackbody radiation

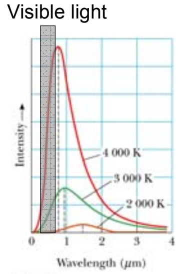



Atmosphere absorbs infrared radiation from Earth. Serves as a "blanket".

## Tungsten Lamp light source

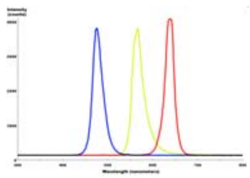
blackbody spectrum

Visible light



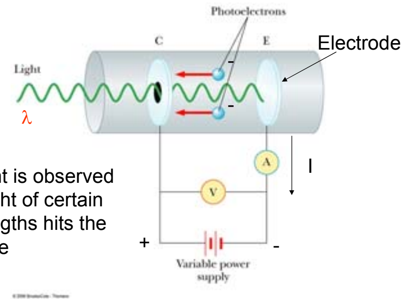

A tungsten lamp is inefficient as a light source because the spectrum at temperatures lower than the melting point includes a large amount of useless infrared radiation.

## Light emitting diode LED



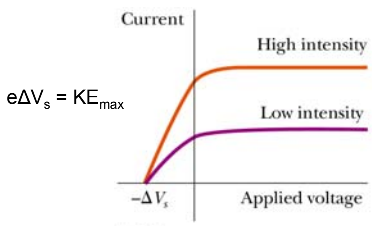

Light emitting diodes are more efficient as an illumination source because the spectrum is not based on blackbody radiation.
The light can be produced at specific wavelengths in the visible region

## Photoelectric effect.



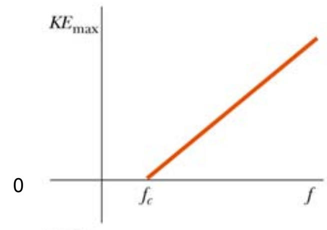

A current is observed when light of certain wavelengths hits the electrode

## Photoelectric effect



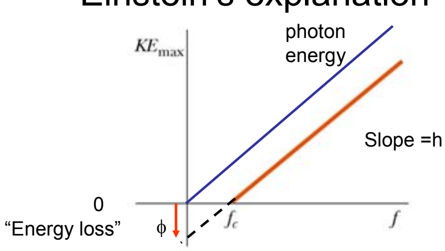

The stopping voltage $\Delta V_s$ is a measure of the kinetic energy of the photo electrons.
When the $\Delta V_s$ is high enough electrons don't reach the electrode C.

## Photoelectric Effect




Kinetic energy rises linearly with the frequency of light.

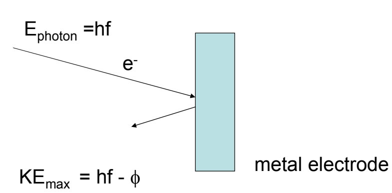
## Einstein's explanation




$$KE_{max} = E_{photon} - \phi = hf - \phi$$

$\phi$ is the work function, the potential energy needed to remove the electron from the electrode.

## Photon concept




A photon interacts with the electron
The light energy can have only specific values.
Light energy is quantized