Day 4

## Outline for Day 4

Office hours: 2 - 5

In which we learn that EM radiation really must be quantized in packets of E = hf based on two experiments

- Blackbody Radiation
  - What is it?
  - Ultraviolet catastrophe requires E = hf
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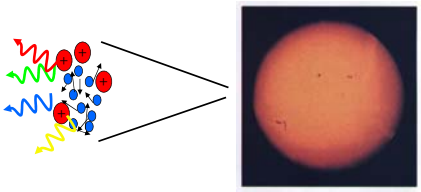
## Why the Sun Shines



Surface of sun = very hot →
Lots of free electrons whizzing around crazily (i.e. accelerating)
→ EM radiation.

(Equal number of protons, but heavier so moving slower, so less EM waves generated from those.)

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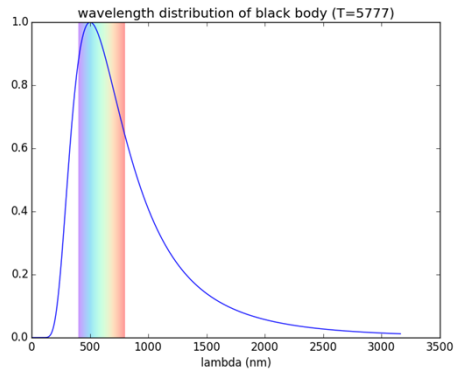
## Charged Particles Flying Around Yields Blackbody Radiation

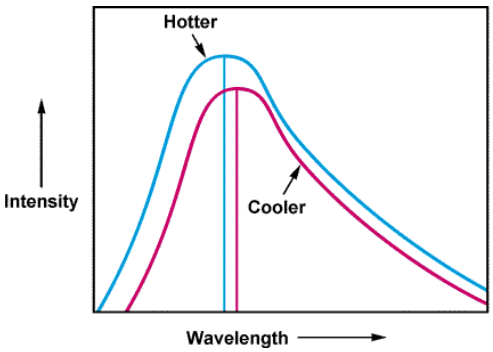
Phet ideal gas simulation

## Blackbody Radiation Distribution for the Sun

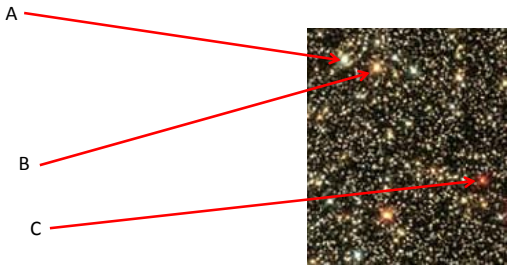



Phet blackbody simulation

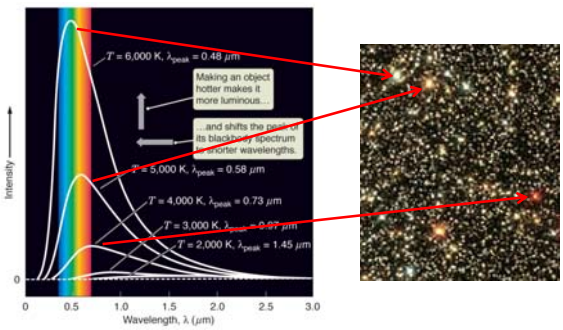
## Blackbody Radiation Distribution Changes with Temperature




## Which is the hottest star?



## Stars at Different Temperatures have Shifted Blackbody Radiation Distributions

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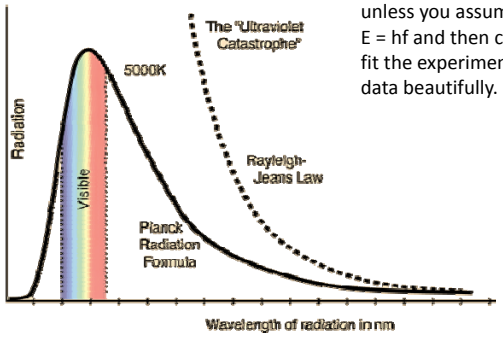
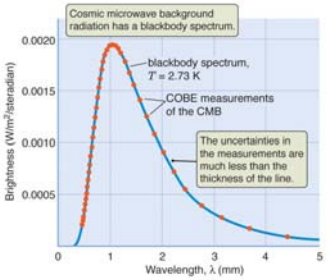
## The Problem: Classical Physics Can't Predict the Observed Distribution



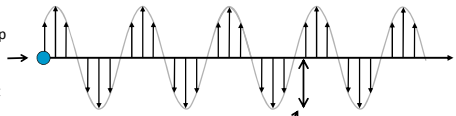

unless you assume E = hf and then can fit the experimental data beautifully.

## Blackbody Radiation Distribution for Cosmic Microwave Background



## What does E = hf mean?

Electron moving up and down at a certain frequency makes light at that frequency



How much you wiggle electron gives intensity (energy delivered) of light

How **fast** the electron is wiggled determines a minimum of how **much** the electron is wiggled

or in fancier words

**The frequency of light determines a packet of minimum energy delivered.**

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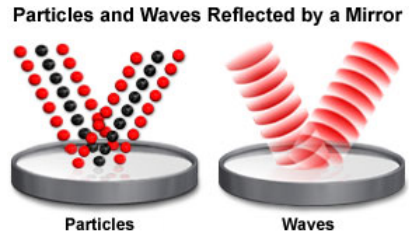
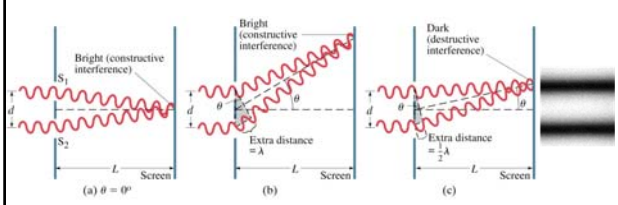
## What does E = hf mean?

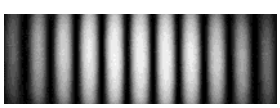
A given frequency of light comes in a "packet" of a minimum amount of energy.

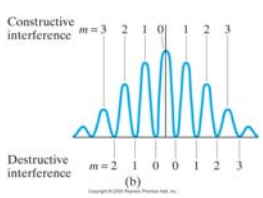
"Packet" is called a photon.




## 2 slit experiment with light waves



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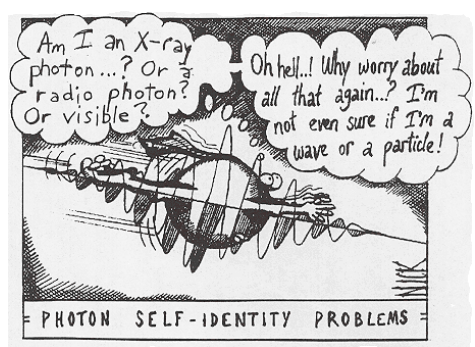

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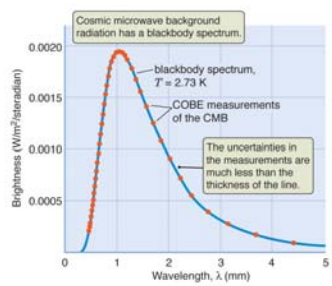
## Planck Intensity Distribution Function

$$I(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

Equ. 4.28

Assumes E = hf




Area under this curve gives total power radiation by object I(T)= $\sigma T^4$ (HW 4.4)

Peak wavelength gives temperature of body (Wien's law)

$$\lambda_{max} \propto \frac{1}{T}$$

(Computer problem 4.33)

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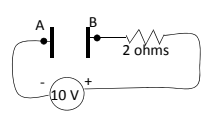
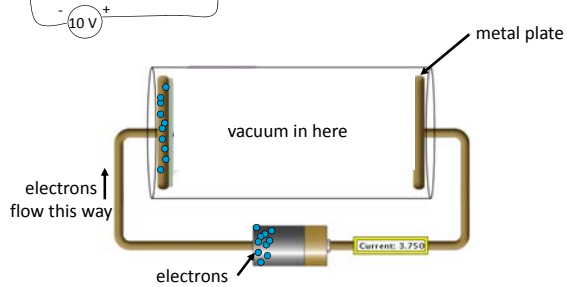



What is the current from A to B?

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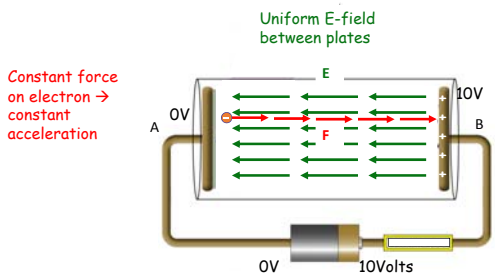
No electrons can get out of plate.
But if stuck one in space at plate A, would move to B and pick up energy equivalent to 10 V.

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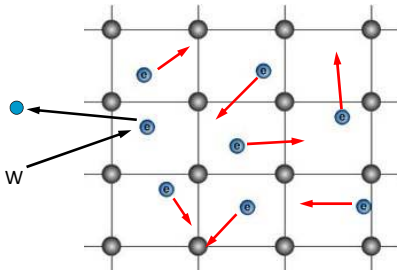
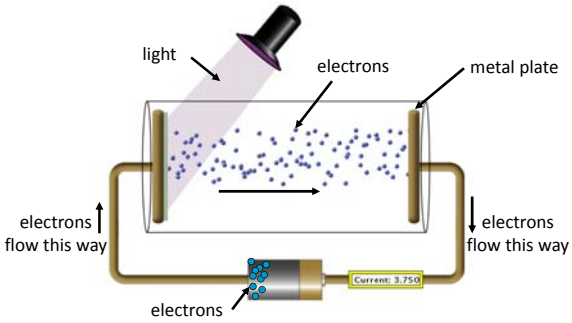
## Work Function




Get electrons for current by popping them out of metal plates.
Takes a certain amount of energy to break electron free from metal = work function = W

## Photoelectric effect experiment apparatus.




- Two metal plates in vacuum
- Adjustable **voltage** between them
- Shine light of variable **brightness** and **frequency** on one plate.
- Measure current between plates.

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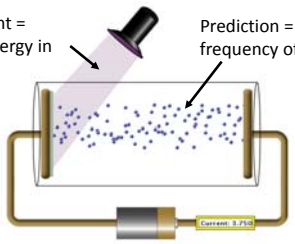
## Photoelectric effect with wave view of light.

Bright light = lots of energy in

Prediction = get current for any frequency of light



Prediction if light is viewed as a wave:

As long as we send in enough energy to overcome work function, electrons should come out of plate thus creating a current so….

Shine really bright (high energy) light in (at any frequency) and ought to get some electrons popping off the plate and hence some current.

Do experiment: http://phet.colorado.edu/en/simulation/photoelectric

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## Photoelectric effect with wave view of light

Prediction if light is viewed as a wave:

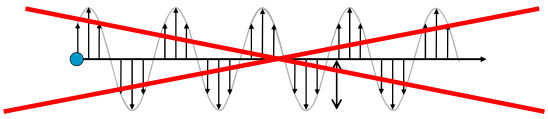
Shine really bright (high energy) light in (at any frequency) and ought to get some electrons popping off the plate and hence some current.

Do experiment: http://phet.colorado.edu/en/simulation/photoelectric

Results

Below certain frequency get no current.
Above certain frequency get more and more current as frequency increases.

**Results do not match prediction from model, so need to revise model**.



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## New Model of Light = Photons

New Model

Light comes in chunks (called photons).
Each photon carries a certain amount of energy that depends on its frequency.

E = h f

Predictions if light is viewed as a photon:

1. If hf < W, there will be no current.
2. Whenever a photon comes in such that hf > W, then an electron will pop out and there will be current.
3. If hf > W, then extra energy brought by photon will result in ejected electron having more kinetic energy, i.e. moving faster after ejection.

Do experiment: http://phet.colorado.edu/en/simulation/photoelectric

Results

1. Below certain frequency get no current.
2. Above certain frequency always get current.
3. As frequency increases get faster and faster moving electrons.

Results match prediction from model so model is valid.

## Photoelectric effect equation

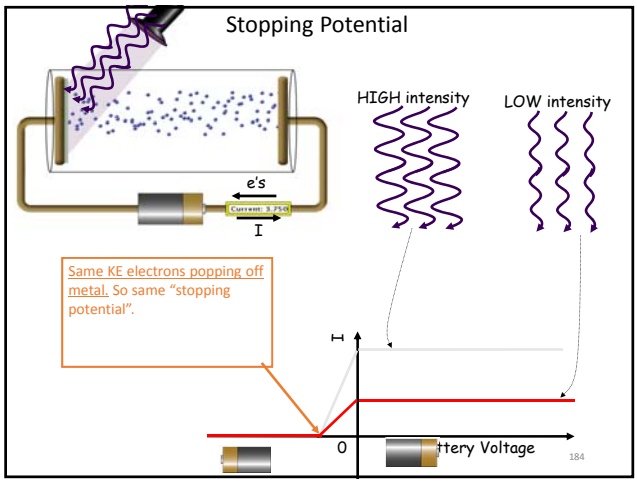
$$hf = W + KE$$

photon energy in — becomes — energy used to pop electron out of metal — kinetic energy of popped out electron

Results

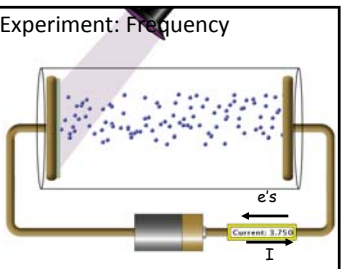
1. Below certain frequency get no current.
2. Above certain frequency always get current.
3. As frequency increases get faster and faster moving electrons.

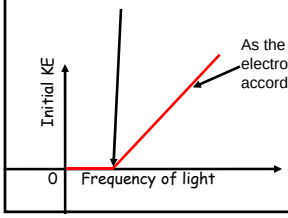
## Stopping Potential




## Photoelectric Effect Experiment: Frequency

There is a minimum frequency below which the light cannot kick out electrons…
even if wait a long time




As the *frequency* of light increases the KE of electrons being popped off increases linearly according to E = hf.

Follow up question:
What happens if change metal?

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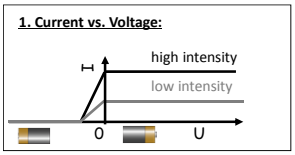
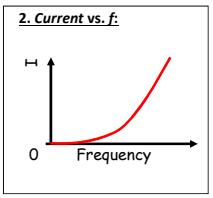
## Summary of photoelectric effect:

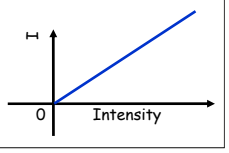
**1. Current vs. Voltage:**



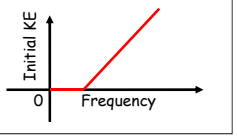

**2. *Current* vs. *f*:**




**3. *Current* vs. intensity:**




or: **Initial KE vs. *f*:**

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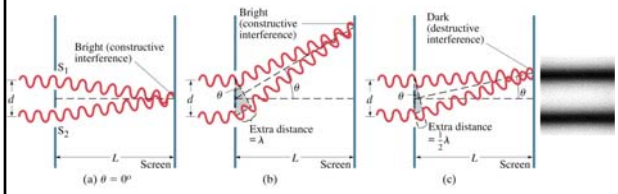

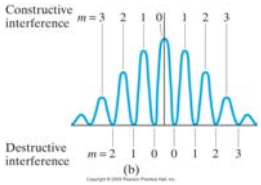

## When is it important to think about particle aspect of light?

**Only if your "detection system" is good enough to see individual photons!**

Examples where important to think about particle behavior:
Photoelectric effect: Individual electrons popping out of metal
Lasers: Electrons in atoms transitioning between energy levels
Molecular bonds: Chemical bonds breaking

Examples where don't need to think about particle behavior (detection system isn't good enough and wave behavior is easier):
Heating: Energy absorbed in microwave or by black asphalt.
Optics: Light bending through lenses or passing through slits
Laser beam: Treat it just like a beam of light… (Understanding the working principle of a laser requires photon picture.)