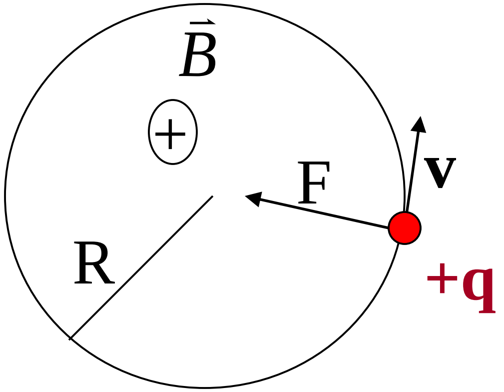
Black body radiation ROY G BIV

$$\lambda_{max} = \frac{[const.]}{T}$$

$$\frac{E_{radiated}}{surf.\ area} = \sigma T^4$$

Thompson electron identification



$$F = \frac{mv^2}{R} = qvB = F_B$$

$$F_E = qE$$

Planck

$$\mathbf{E = hf}$$

Einstein Photo-electric effect- Photons

$$E_f = W + KE$$

Atom structure

…like firing a 16" shell at a piece of tissue paper and seeing it bounce back.

- E Rutherford.

Black Body Radiation

10-1

$$\lambda_{max} = \frac{[const.]}{T} \quad T(^\circ K)$$

1893 Wiens Law

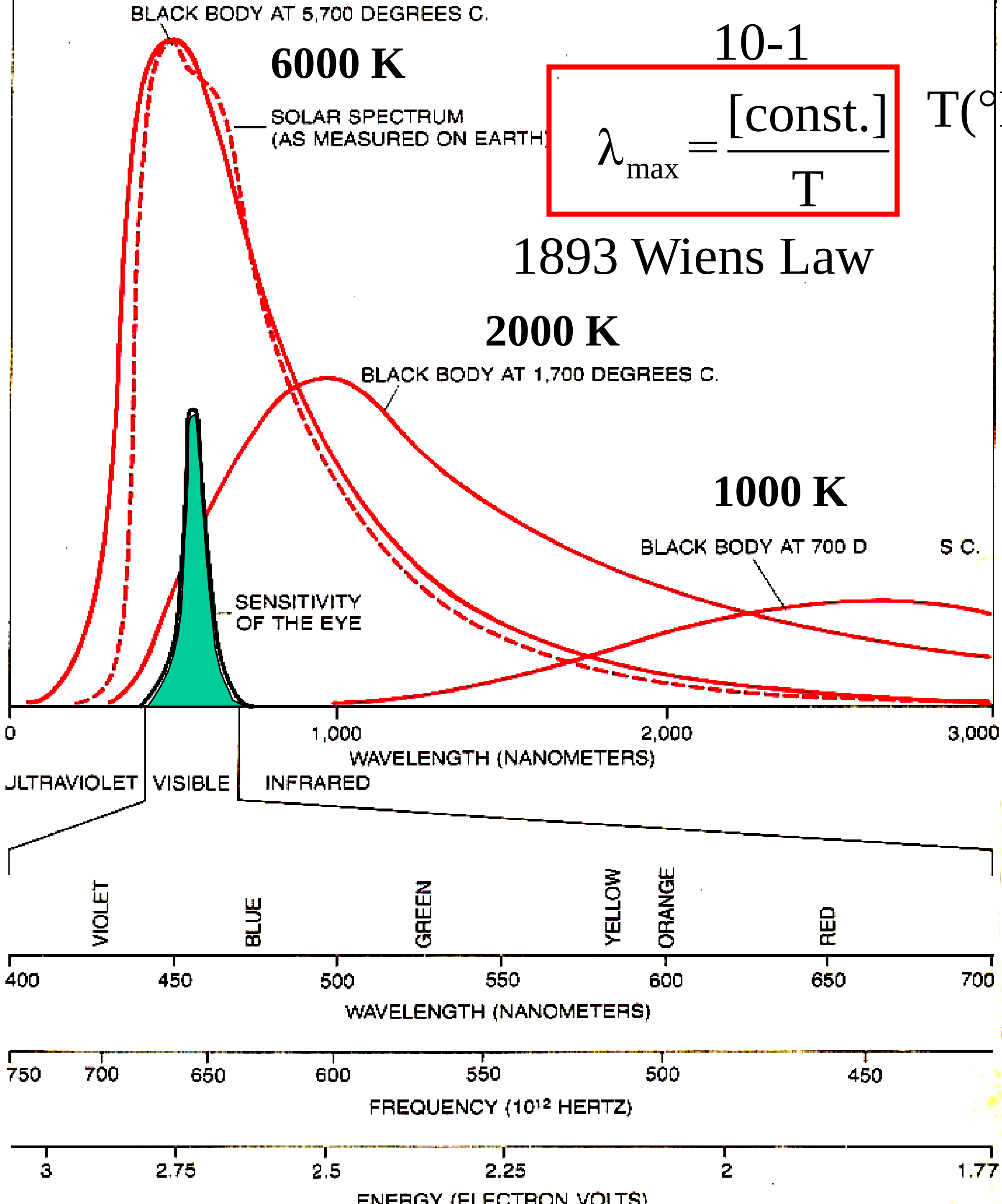
Stefan Boltzman Law

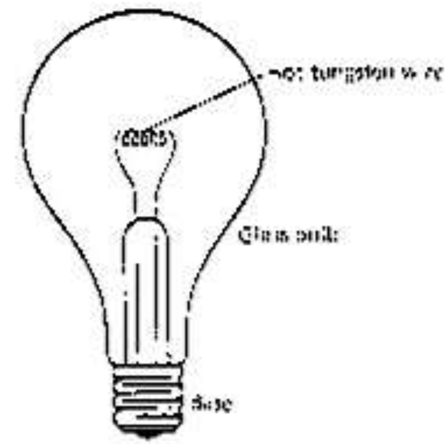
$$\frac{E_{radiated}}{surf.\ area} = \sigma T^4$$

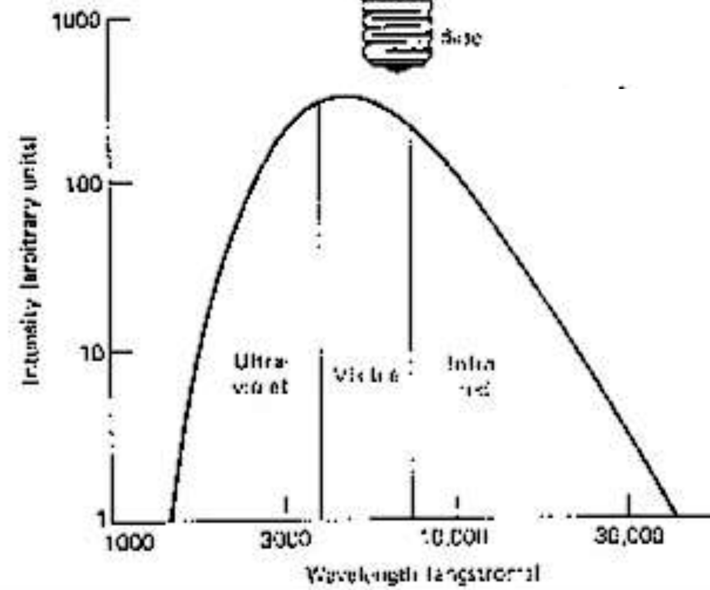
6000 K

2000 K

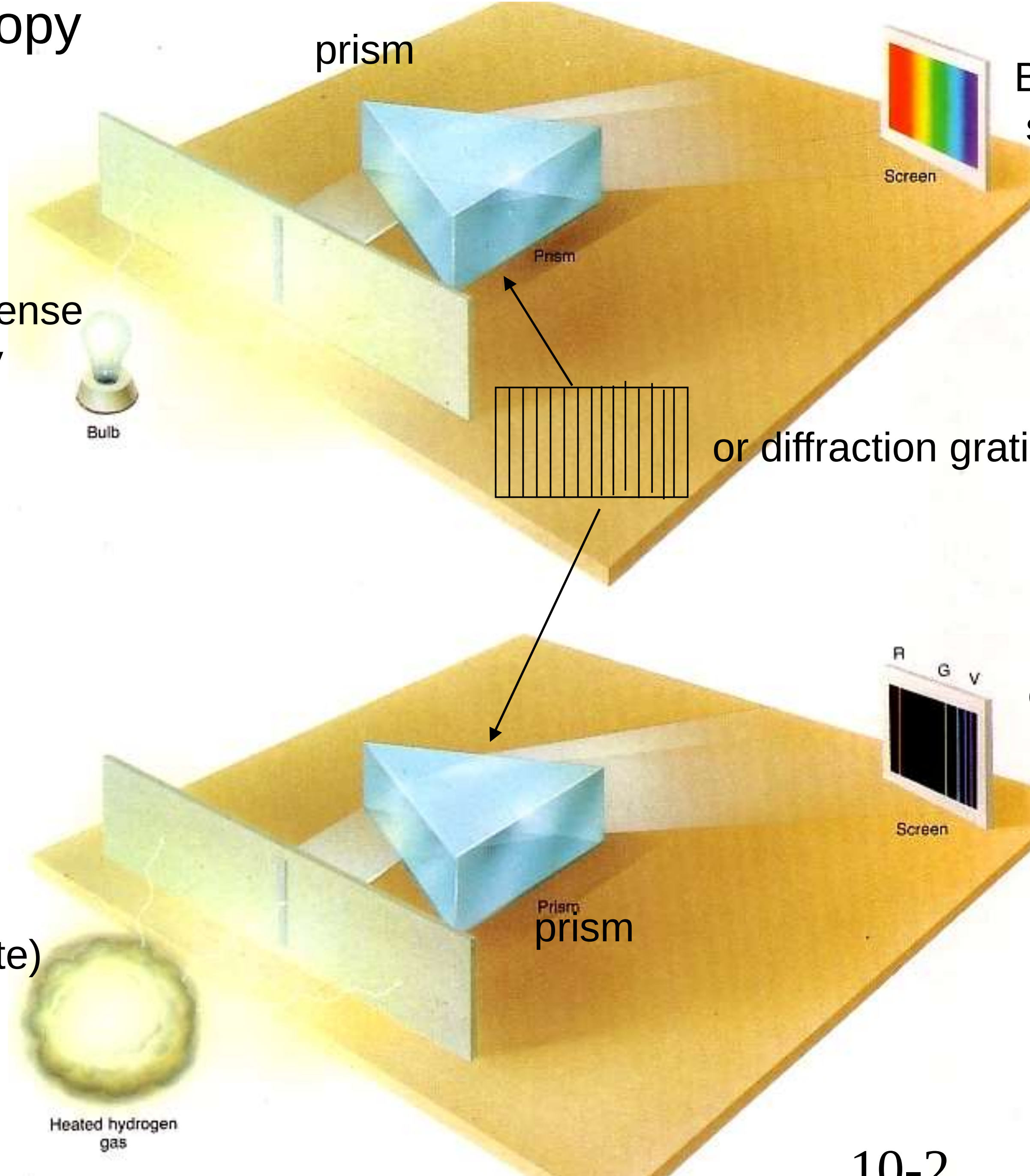
1000 K







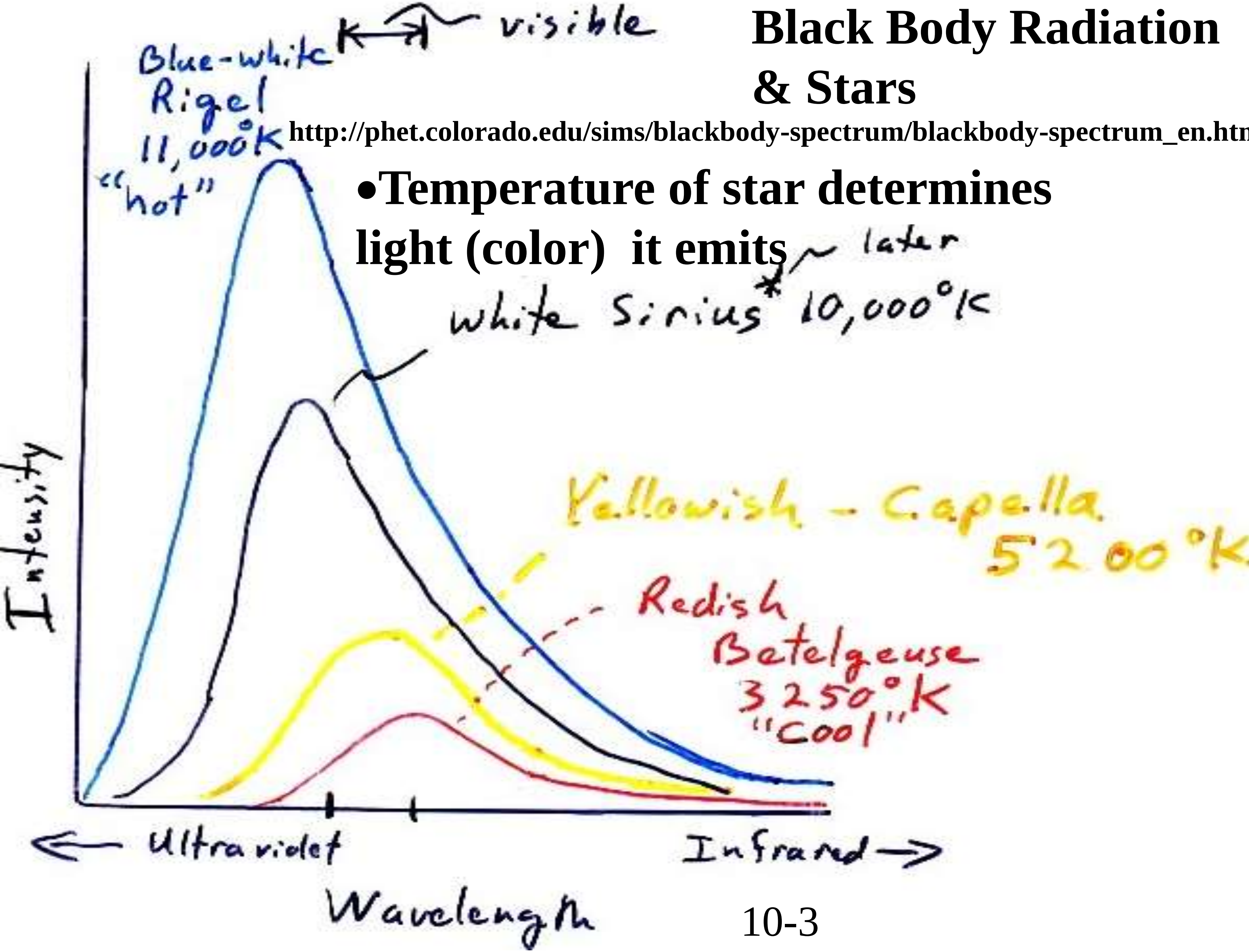
Spectroscopy (emission)

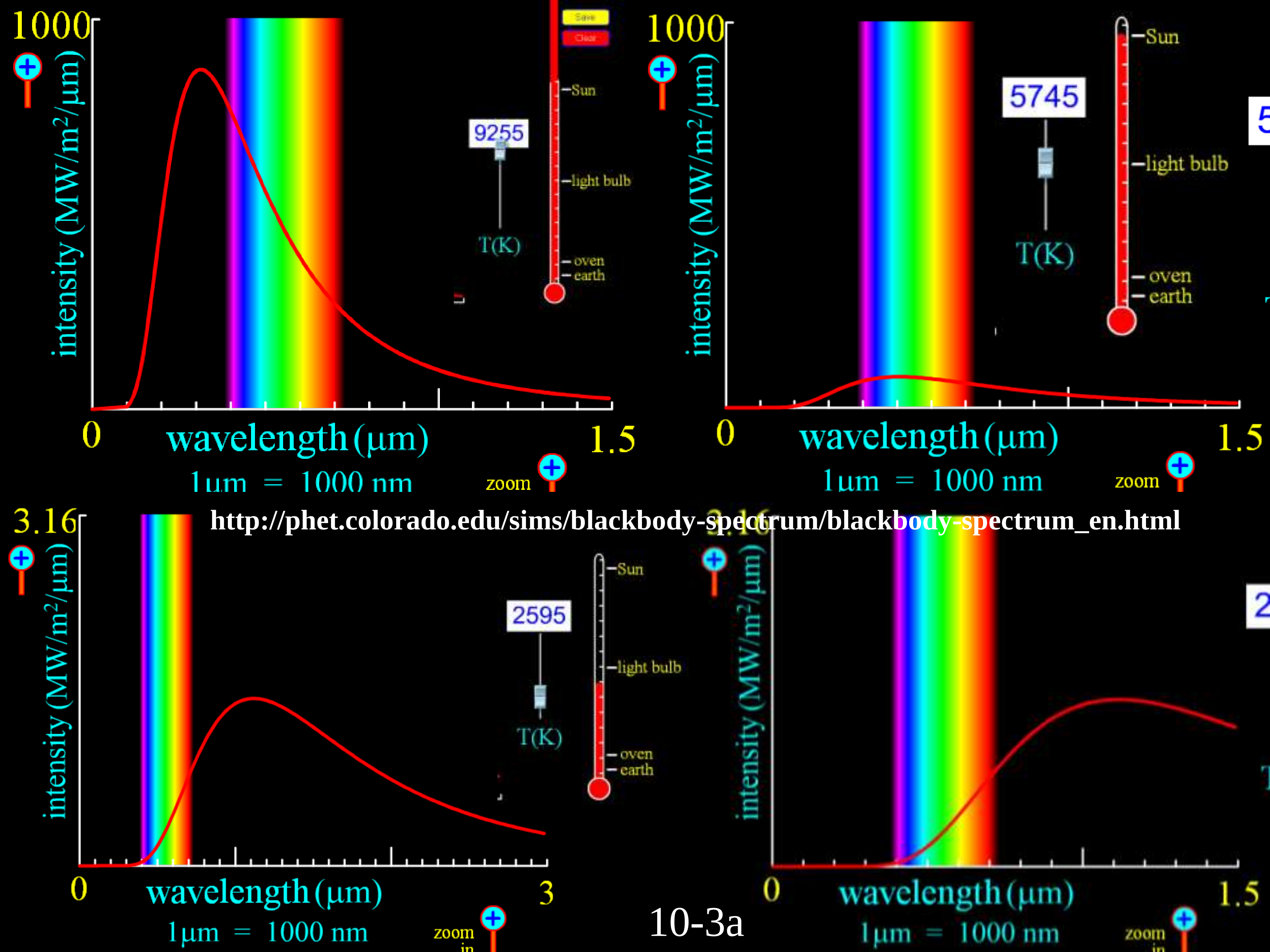


Black Body Radiation & Stars

http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html

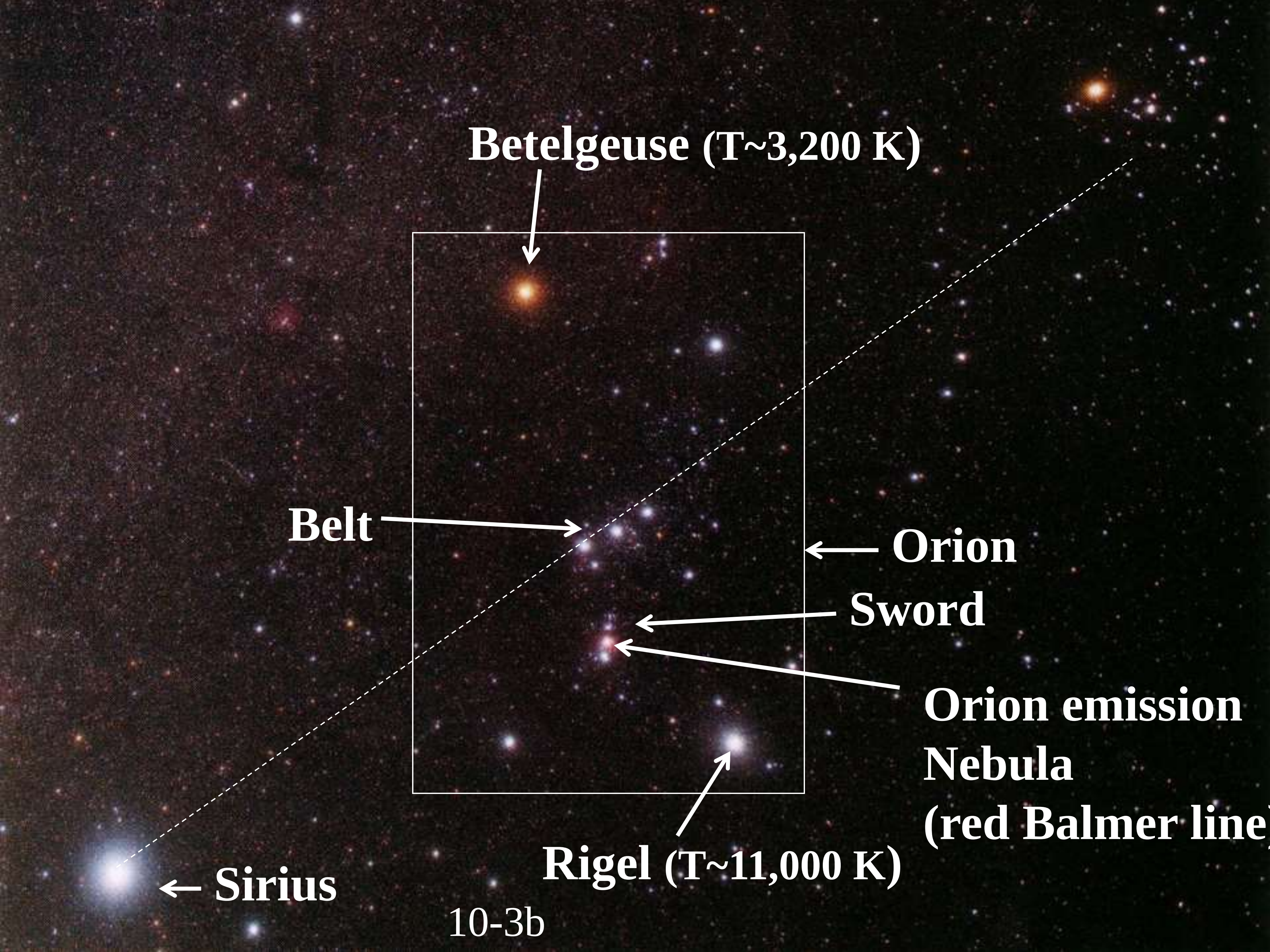
- **Temperature of star determines light (color) it emits**





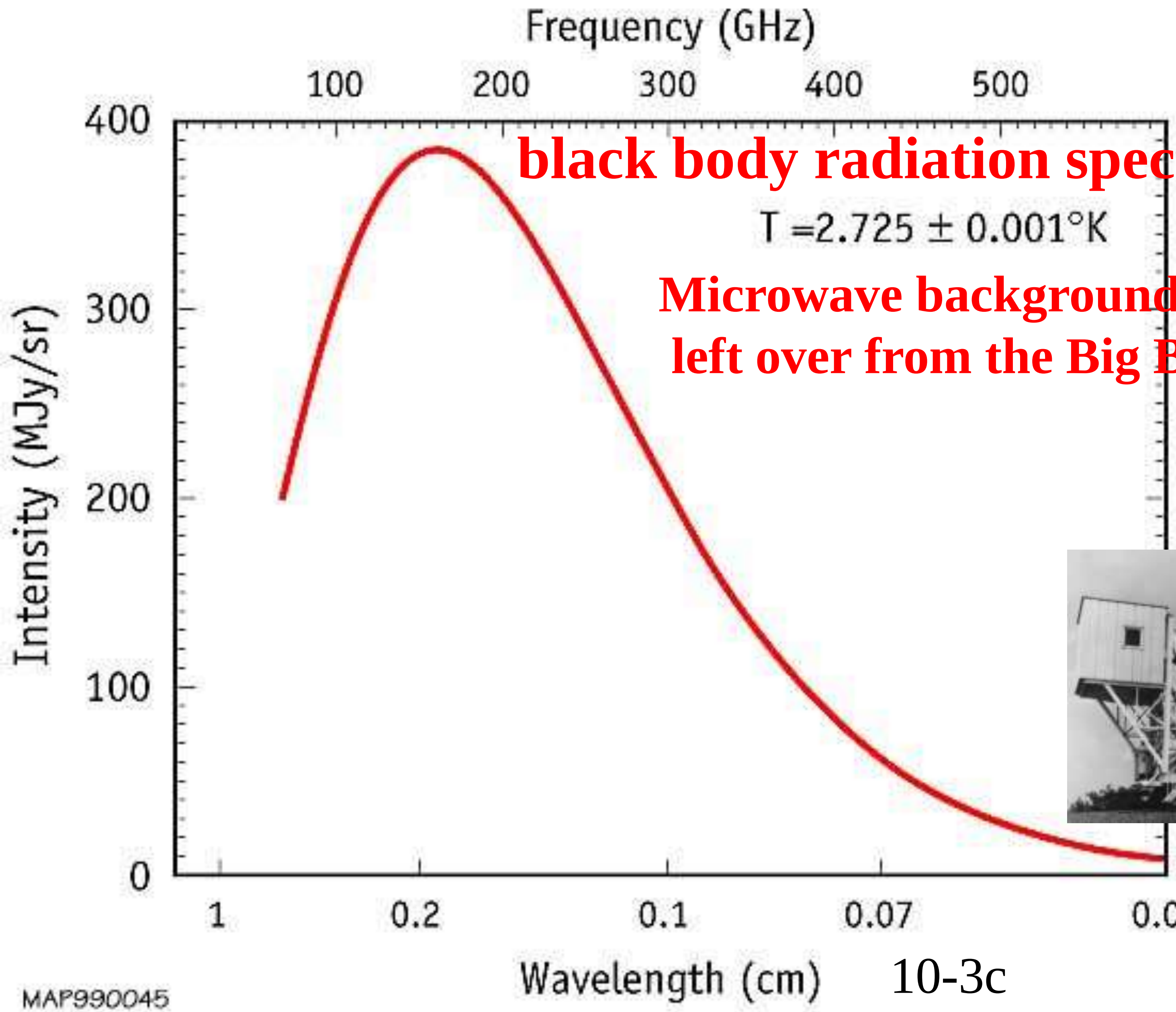
http://phet.colorado.edu/sims/blackbody-spectrum/blackbody-spectrum_en.html

10-3a

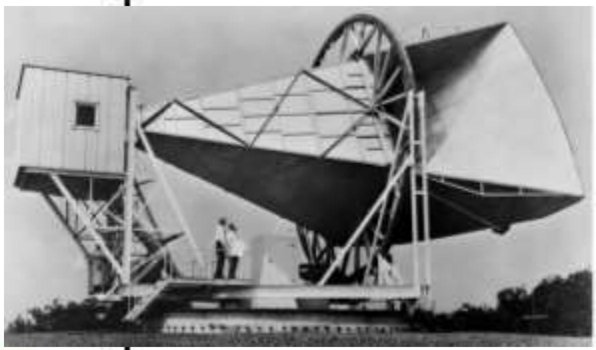

Betelgeuse (T~3,200 K)
Belt
Orion
Sword
Orion emission
Nebula
(red Balmer line)
Rigel (T~11,000 K)
Sirius

10-3b

Spectrum of the Cosmic Microwave Background



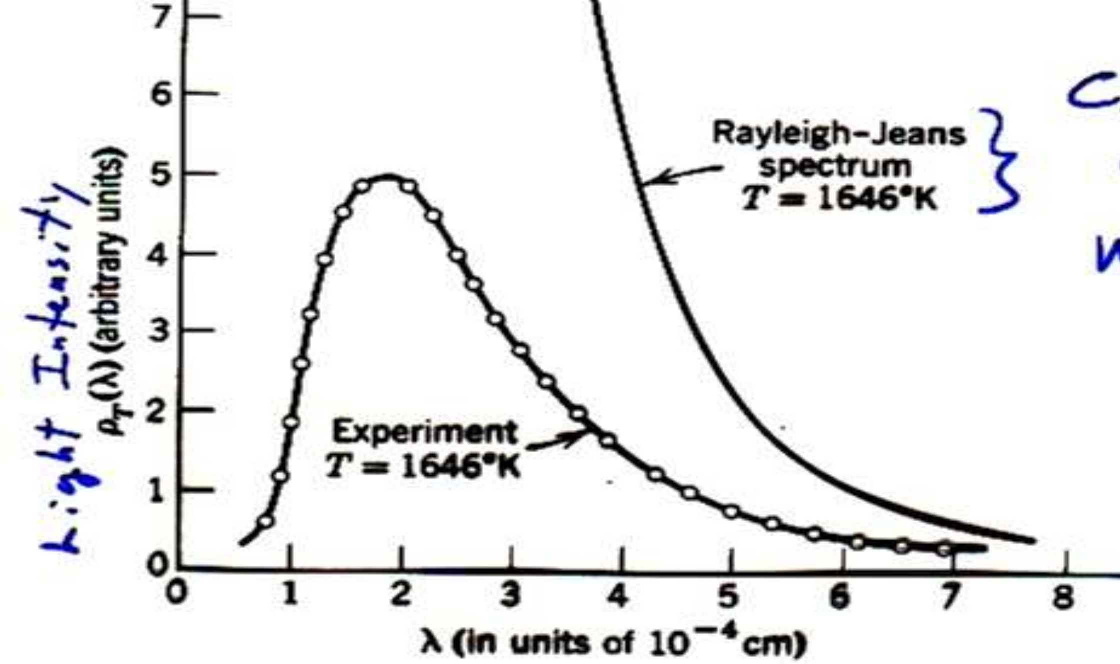
Bell labs



Holmdel NJ, ~1965

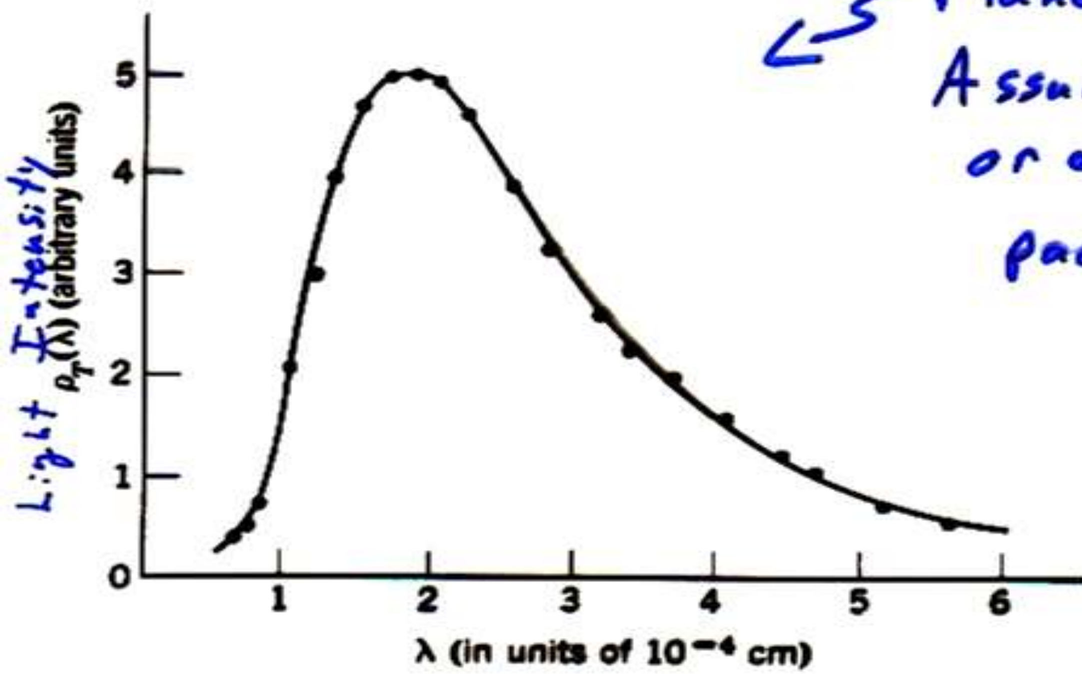
Horn Antenna

Penzias & Wilson



Classical Theory of E&M Radiation

Wave Theory for E&M radiation



Planck's Theory 1900

Assumed light absorbed or emitted only in small packages or quanta.

(photons) → Eins

$E = hf$

$f\lambda = c$

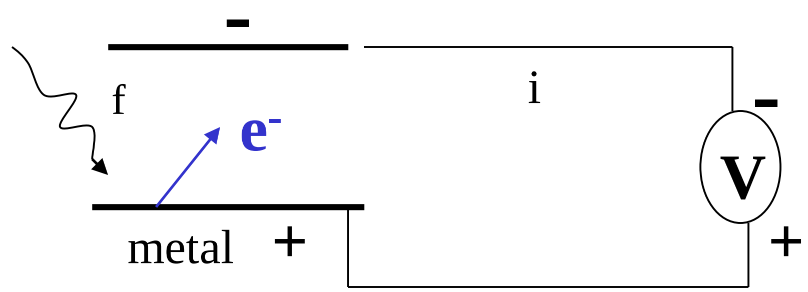
Einstein 1905

Photoelectric Effect

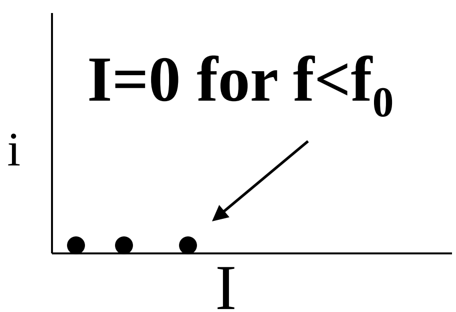
http://phet.colorado.edu/en/simulation/photoelectric

Einstein (1905) explained/ predicted with photons = light particles (bundles).

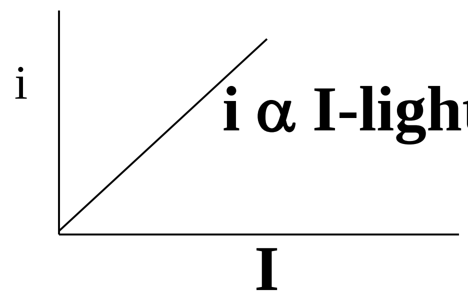
$$\frac{1}{2}mv^2 = K$$



Voltage source V



1.



i α I-light intensity (for f>f$_0$)

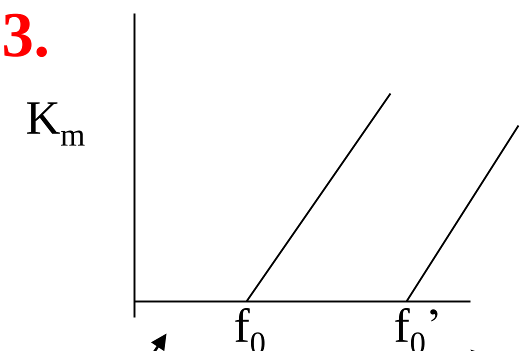
Low I

i: high I

2. $K_{max} = \frac{1}{2}mv^2_{max}$

K_{max} depends on f (not I) ie measure retarding V needed to stop i K_{max}= eV$_0$

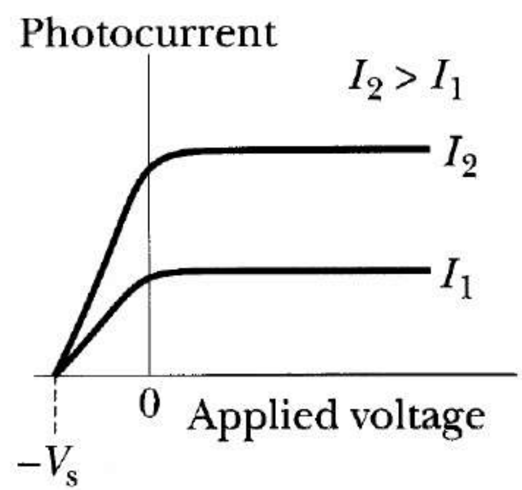
3.



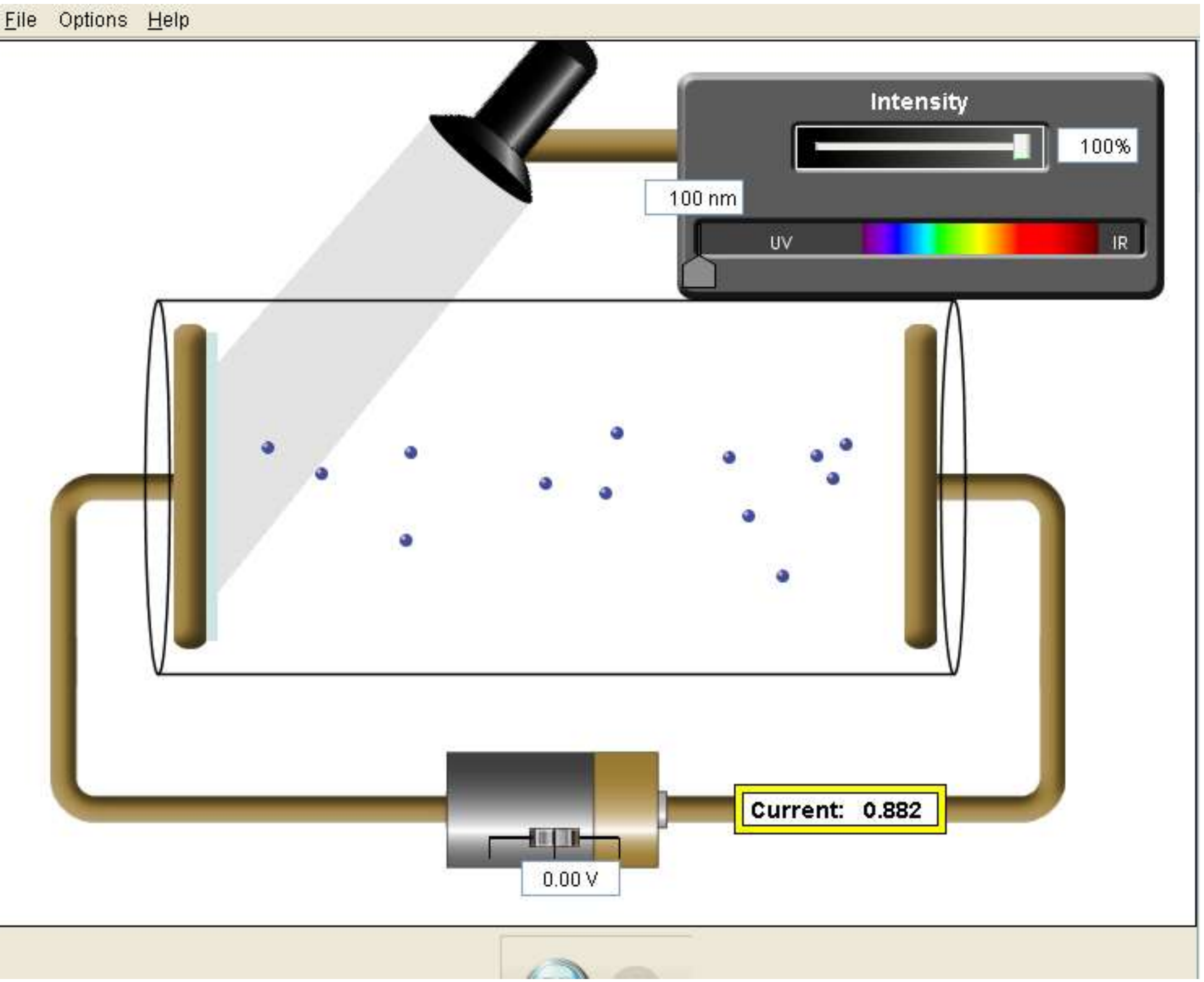
No I below f$_0$

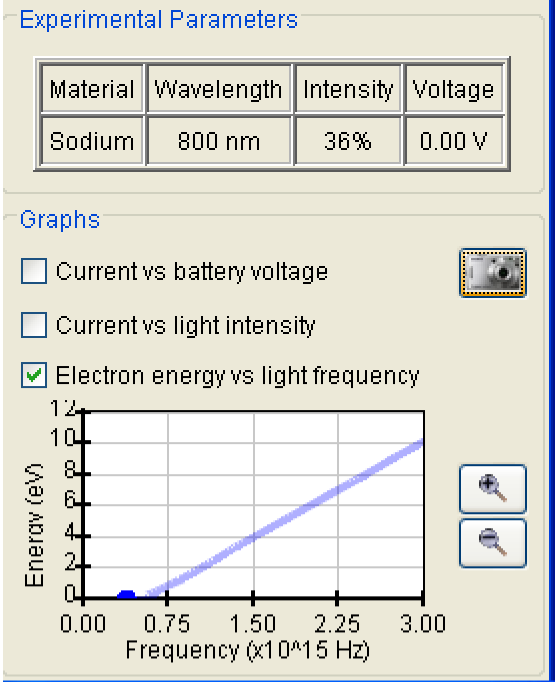
Another material

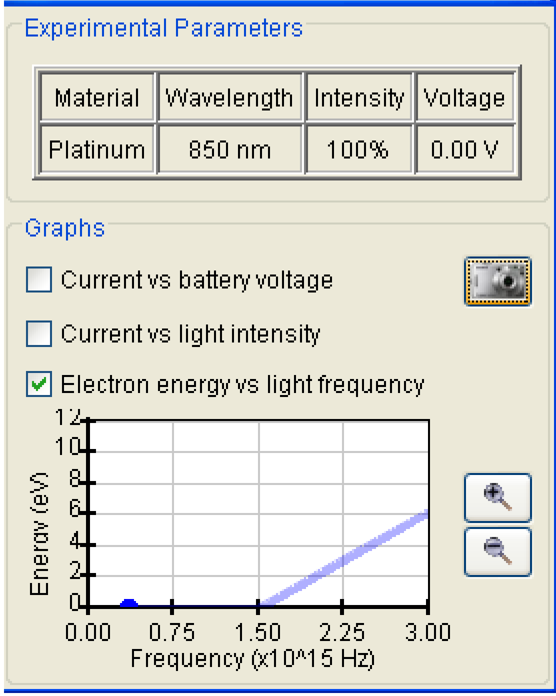
4.



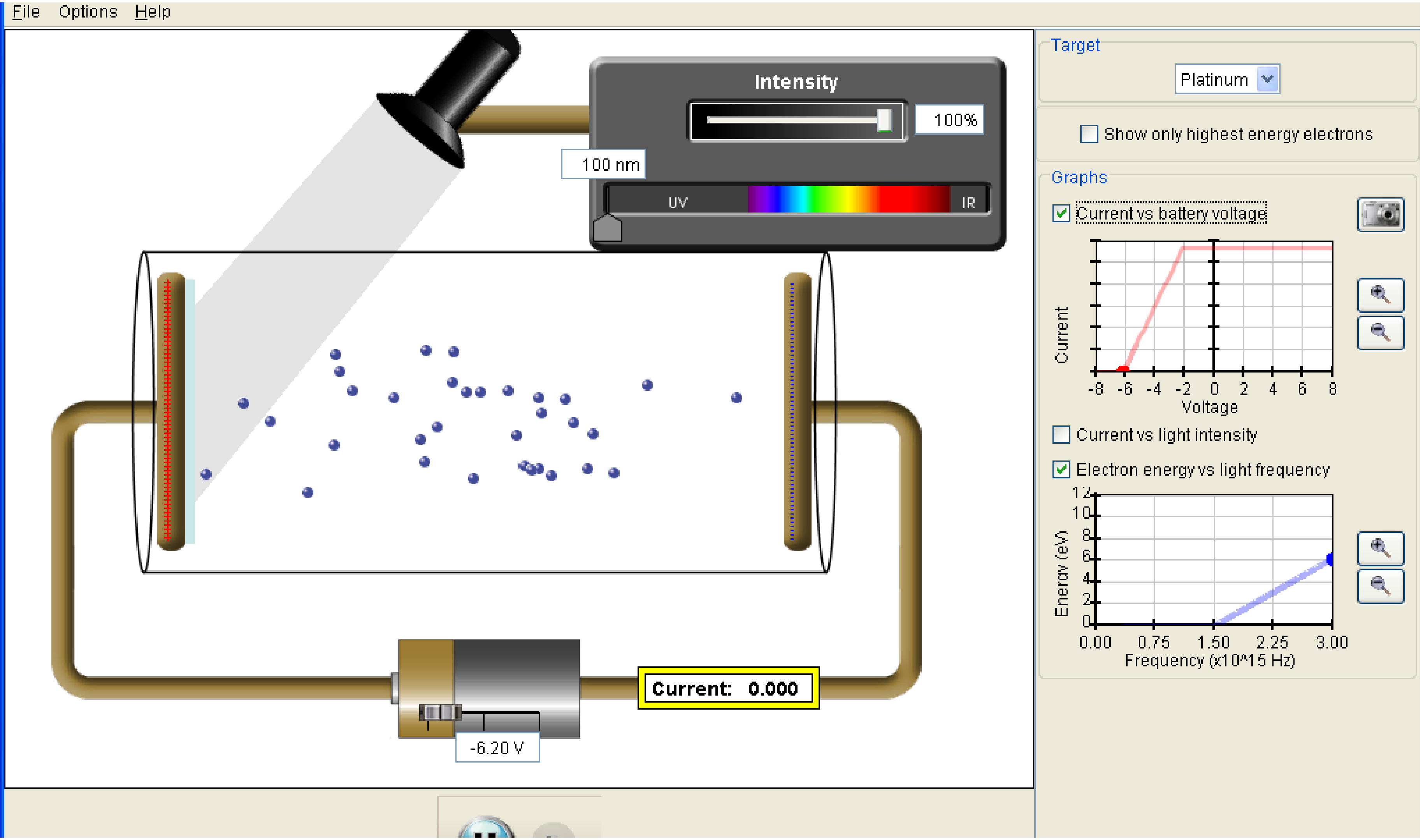
http://phet.colorado.edu/en/simulation/photoelectric



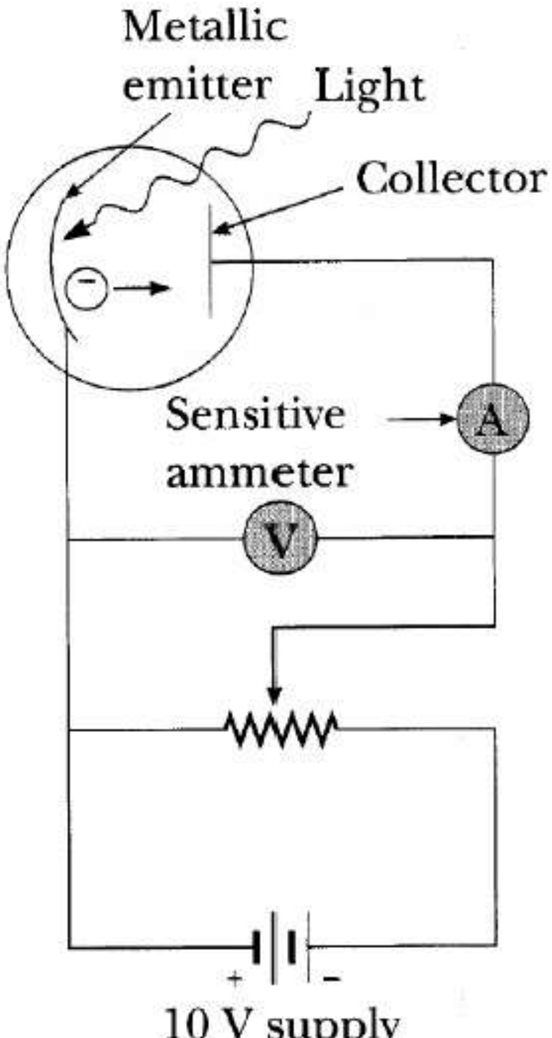


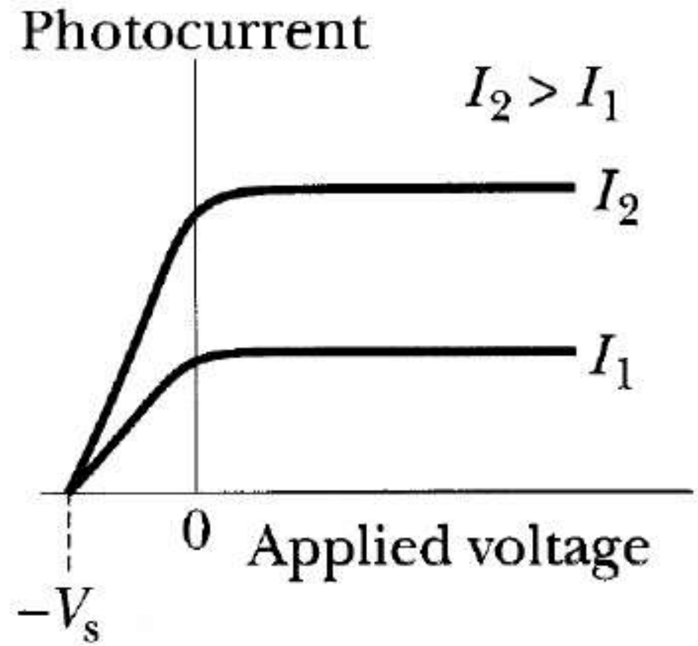


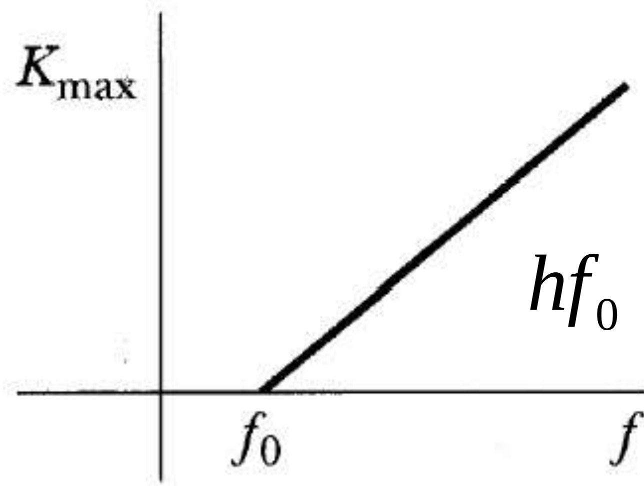
http://phet.colorado.edu/en/simulation/photoelectric



The Photoelectric Effect

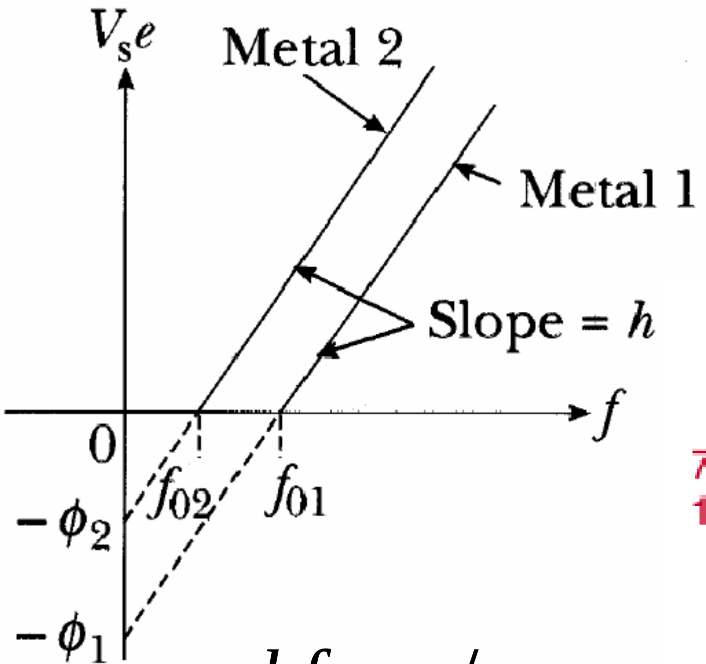






$$hf_0 = \phi_0$$

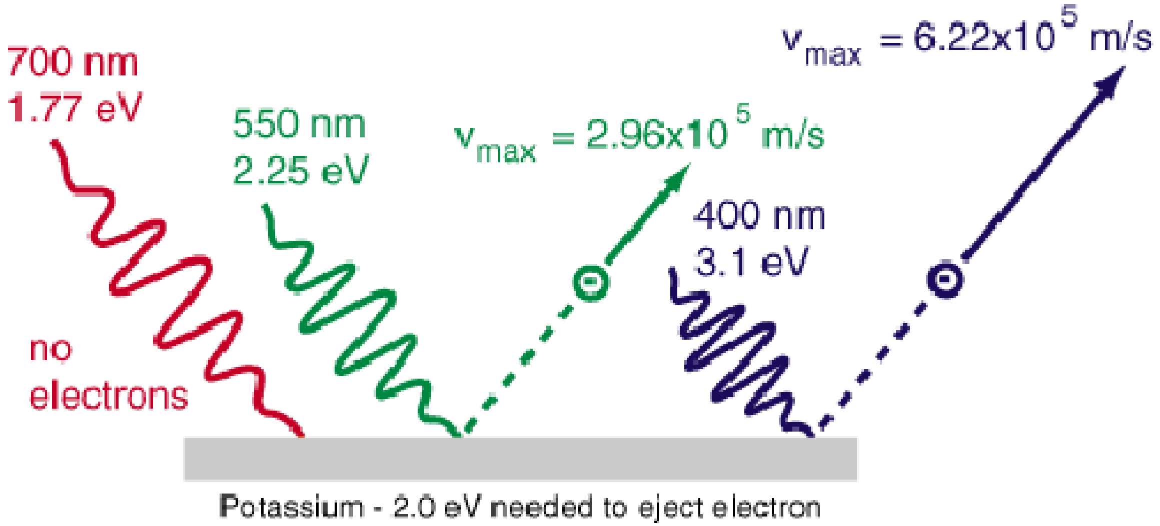
$$V_s e = hf - \phi$$



$$hf_0 = \phi_0$$

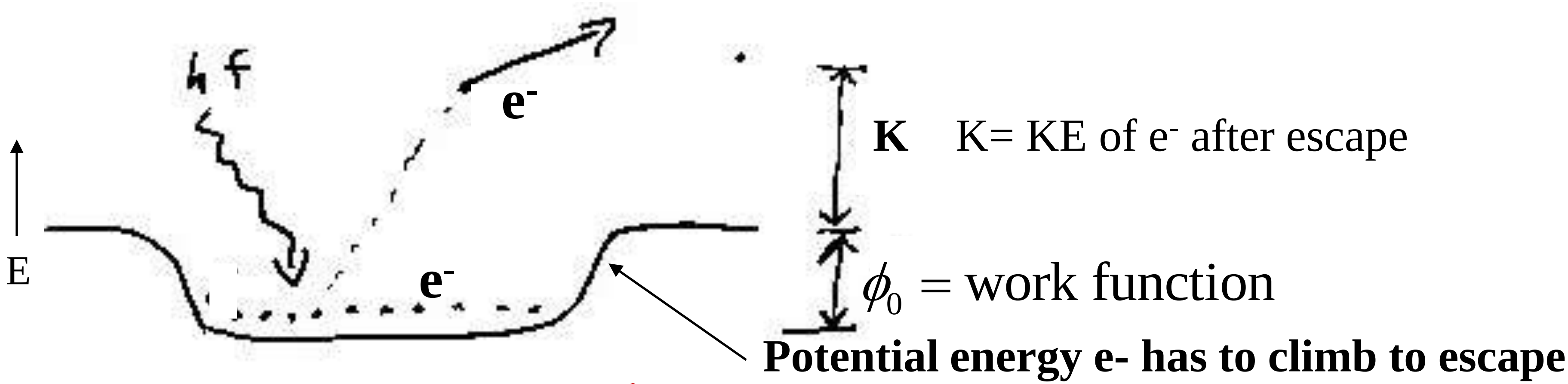
Metal	• •[eV]
Na	2.28
Al	4.08
Cu	4.70
Zn	4.31
Ag	4.73

$$E_{photon} = h\nu$$



Photoelectric effect

Quantum theory of photoelectric effect : Einstein 1905 (his Nobel Prize)



Energy Conservation

$$hf = K + \phi_0$$

Photon energy in → hf

KE of e- after escape → K

Work function → ϕ_0

Q: What is velocity of e- **(for Na next page)**

$$\frac{1}{2} m\mathrm{v}^2 = \mathrm{K}$$

$$\mathrm{v} = \sqrt{\frac{2(\mathrm{K})}{m}} = \sqrt{\frac{2(1.19)(10)^{-19}}{9.1(10)^{-31}}}$$

$$\mathrm{v} = 0.511(10)^6 \frac{m}{s}$$

v <<c OK!

Threshold frequency

$$K \rightarrow 0 \quad \mathrm{i} \rightarrow 0$$

$$hf_0 = \phi_0$$

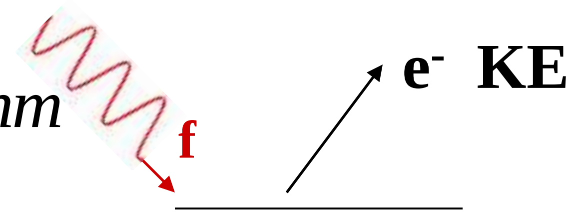
I very low

even 1 photon or will give i !!

Photoelectric Effect

Example: Na: metal Work function=2.28eV

$$\lambda = 410nm$$



see next page

$$f = 7.31(10)^{14}\frac{1}{s}$$

KE electron =?

$$E_f = hf = [6.63(10)^{-34}]7.31(10)^{14}\ [Js]/s$$

$$E_f = 4.84(10)^{-19}J = \frac{4.84(10)^{-19}J}{1.6(10)^{-19}\frac{J}{ev}} = 3.02eV$$

$$E_f = W + KE$$

$$3.02eV = 2.28eV + KE$$

$$KE = .74eV = .74eV1.6(10)^{-19}\frac{J}{eV}$$

$$KE = 1.19(10)^{-19}J$$

$$c = \lambda f$$

$$f = \frac{c}{\lambda} = \frac{3(10)^8 \frac{m}{s}}{410(10)^{-9} m}$$

$$= 7.31(10)^{-3} 10^8 \ 10^9$$

$$f = 7.31(10)^{14} \frac{1}{s}$$

17 Circular motion of a charge in a uniform magnetic field

Recall

electron

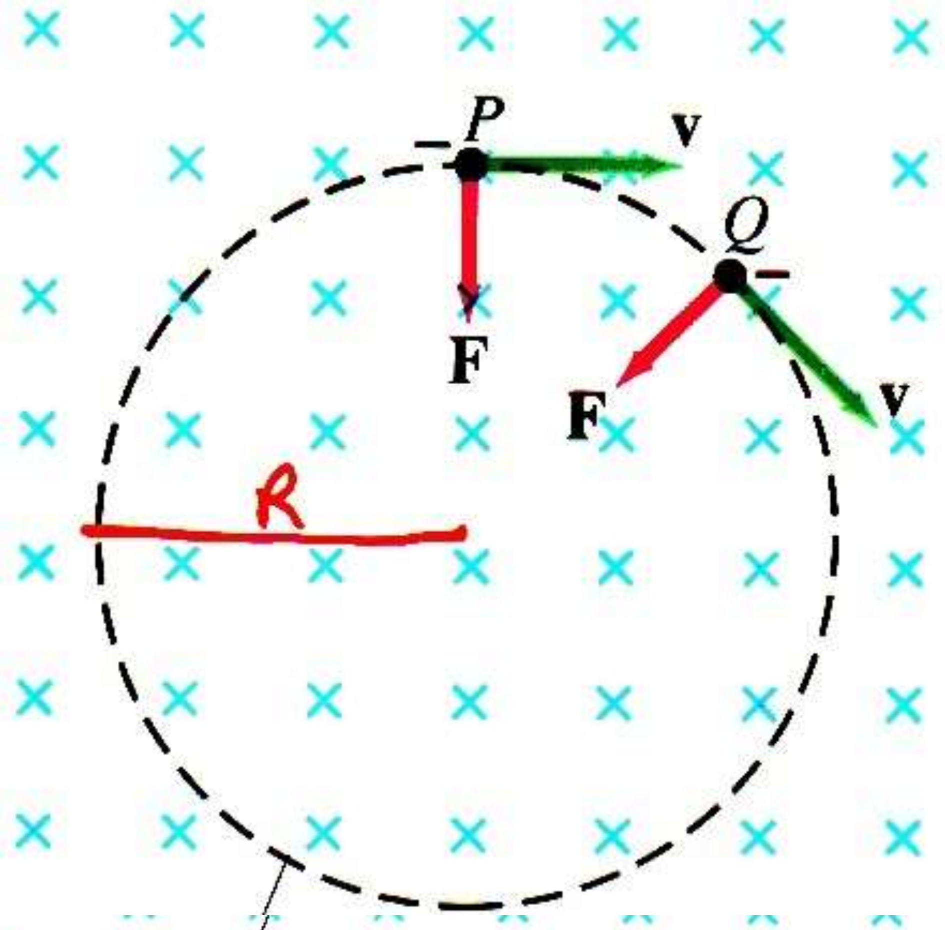
$$F = ma = \frac{mv^2}{R} = evB$$

$$\frac{e}{m} = \frac{v}{RB}$$

or

$$v = \left(\frac{e}{m}\right)RB$$

save for later



Path of electron B is into the page

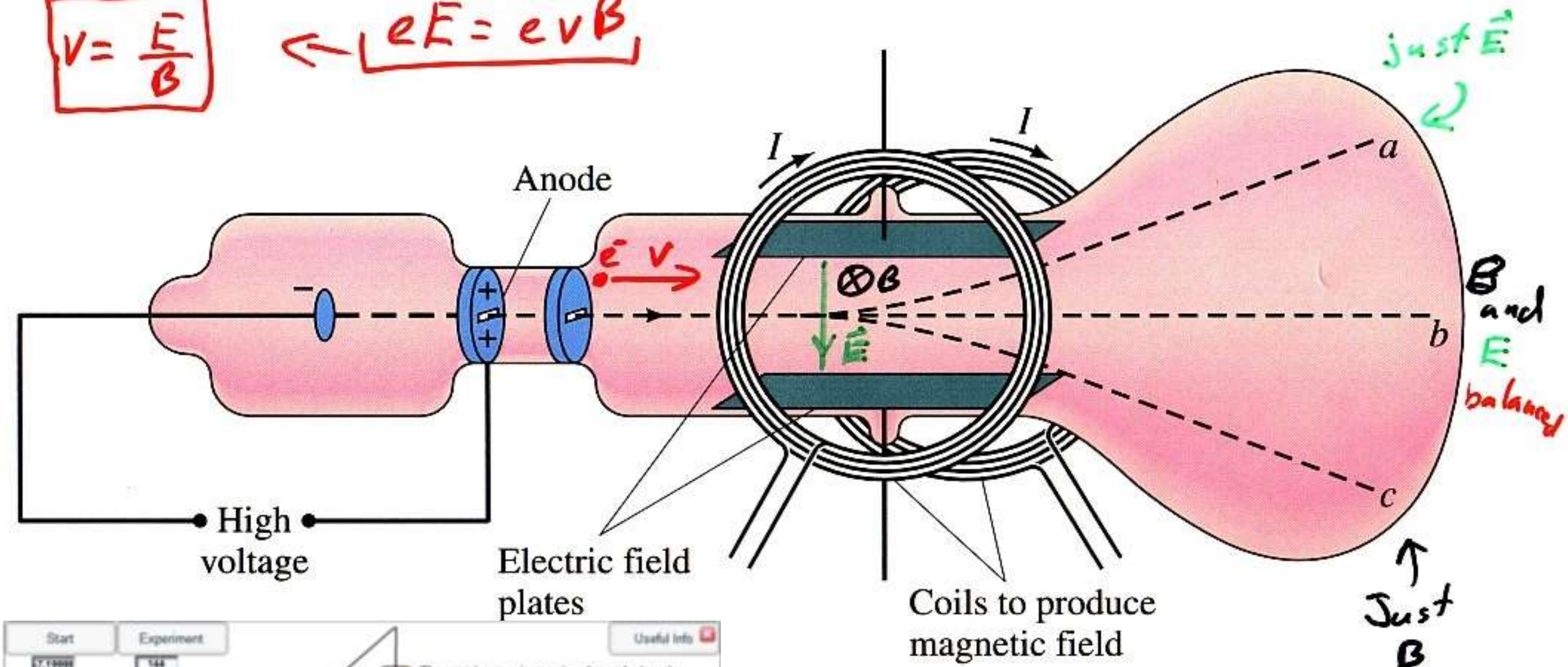
Thompson electron identification

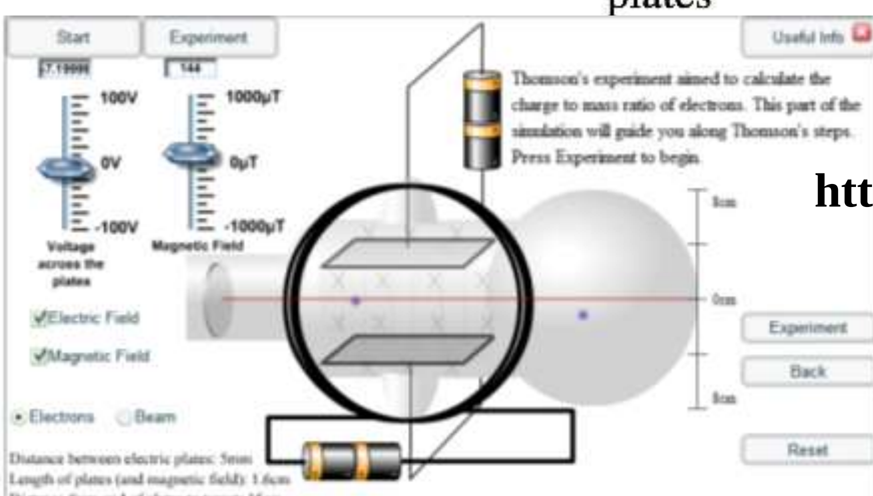
Elect. Force = eE

Magnetic Force = evB

when balanced

$eE = evB$ ← $v = \frac{E}{B}$

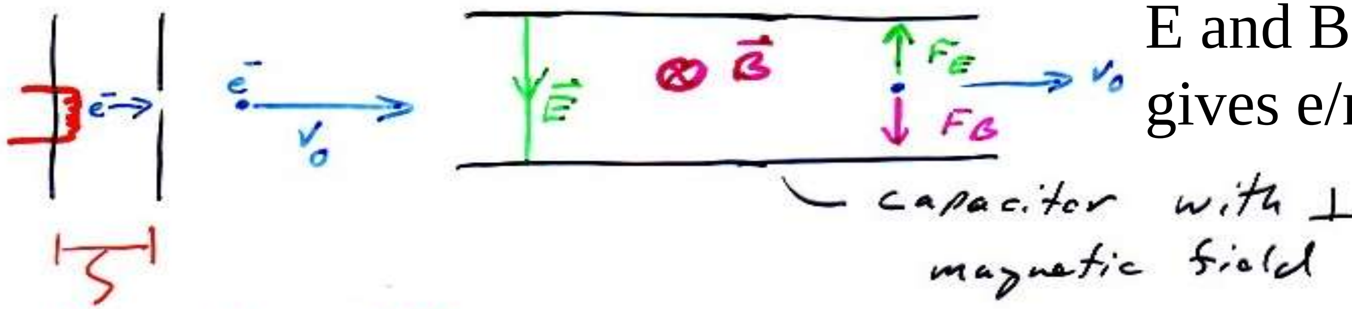




http://www.hscphysics.edu.au/resource/template.swf

Thompson – e/m determination

Thompson crossed E and B experiment gives e/m



V = voltage difference

Energy Conserv.

$$eV = \frac{1}{2} m v_0^2$$

$$\Downarrow$$

$$v_0 = \sqrt{\frac{2eV}{m}}$$

$$F_E = eE \qquad F_B = eBv_0$$

Choose $F_E = F_B$ (no deflection)

$$eE = eBv_0$$

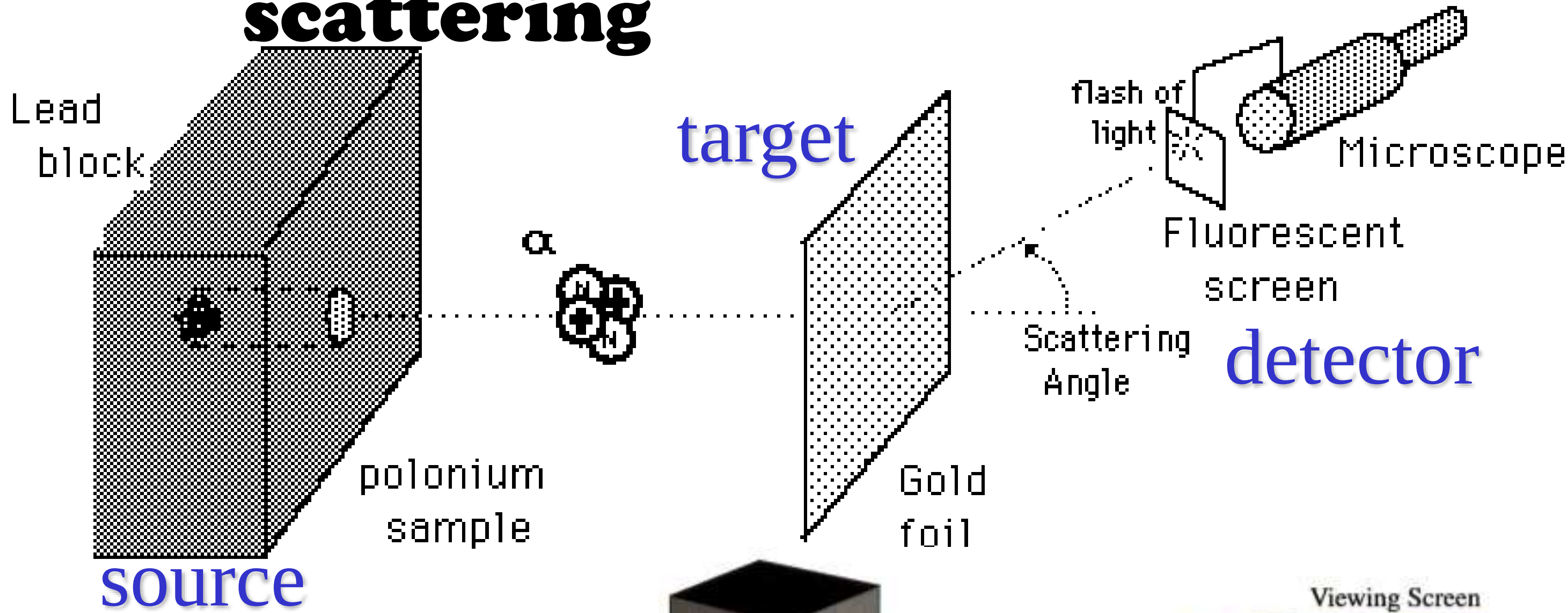
$$\frac{E}{B} = \sqrt{\frac{2eV}{m}}$$

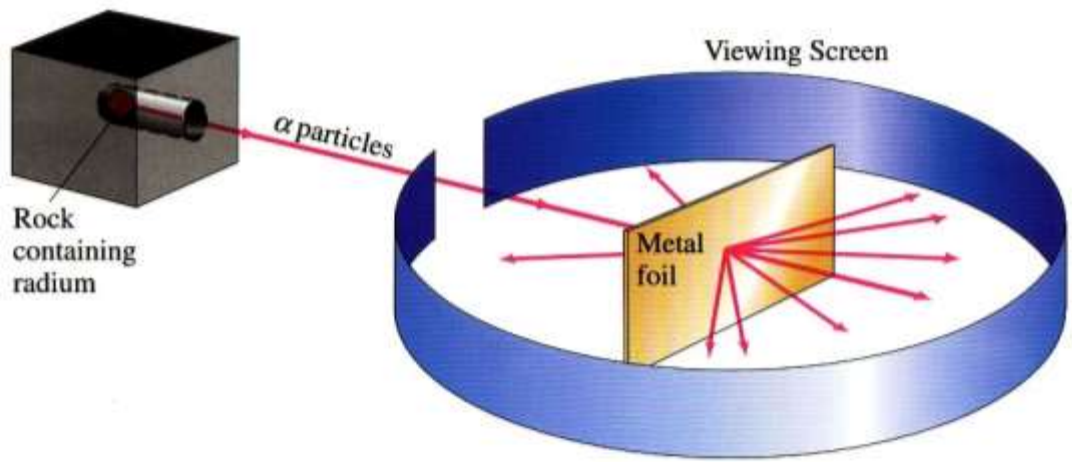
$$\boxed{\frac{E^2}{2B^2V} = \frac{e}{m}}$$

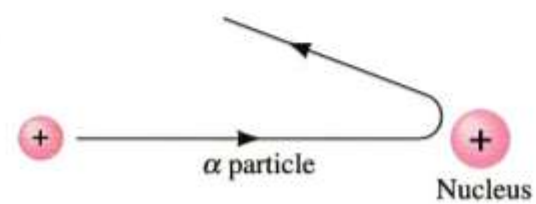
Milliken Oil Drop experiment gives e charge

$$\frac{e}{m} = 1.7588(10)^{11} \frac{C}{kg}$$

Rutherford back scattering







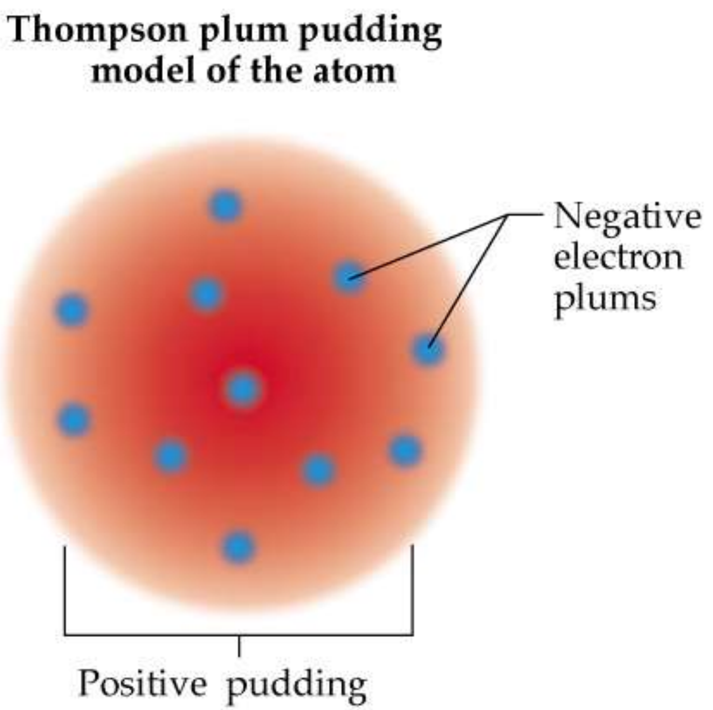
Thomson Model: Plum Pudding

-J.J. Thomson-cathode rays- particles (e^-)much smaller than the atom

-the plum-pudding model of an atom

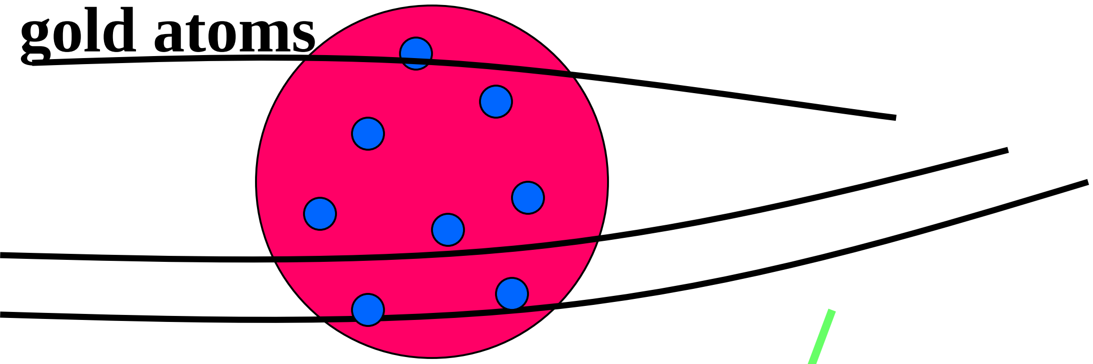
- e^- are embedded in the atom like raisins in the pudding
- positive charge is equally and uniformly distributed inside the atom

Picture of the Atom ~1900

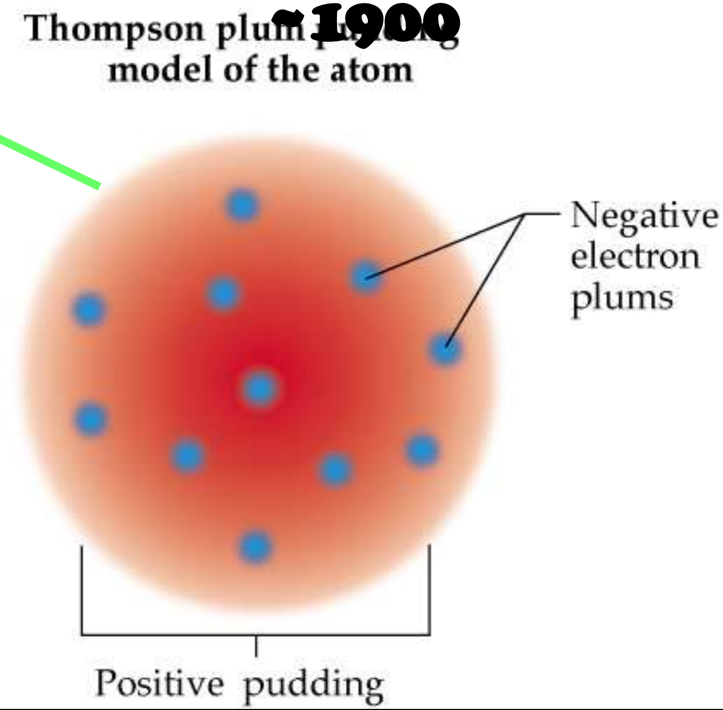


What Rutherford Expected

Projectiles (very fast He nuclei called *alpha particles*) will be slightly deflected by gold atoms

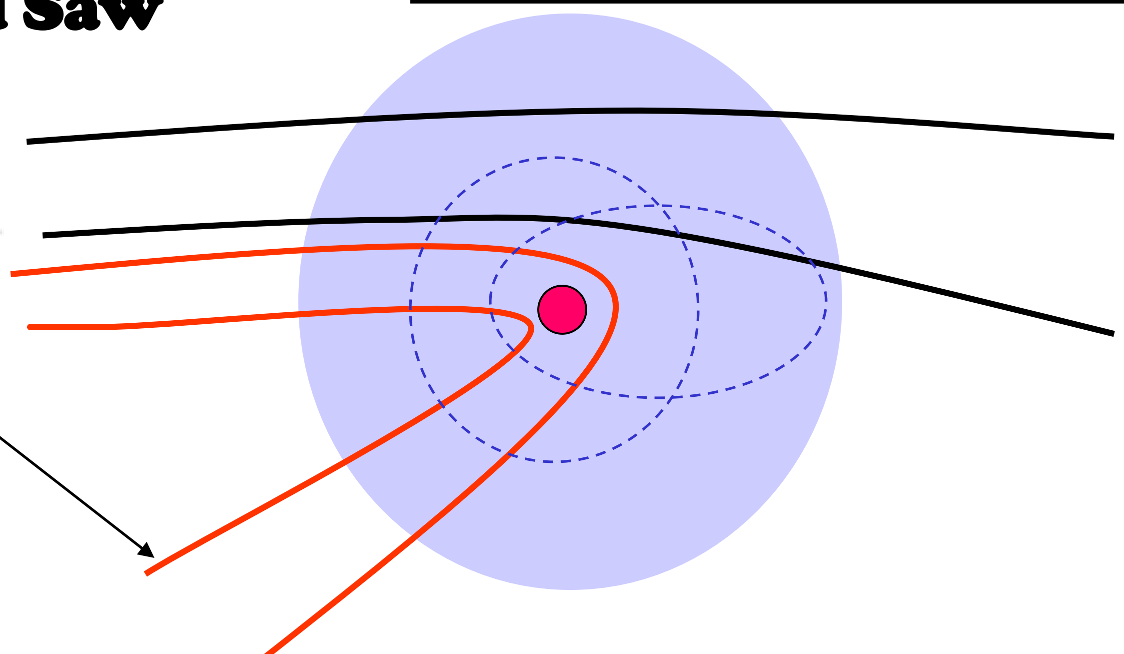


Picture of the Atom ~1900

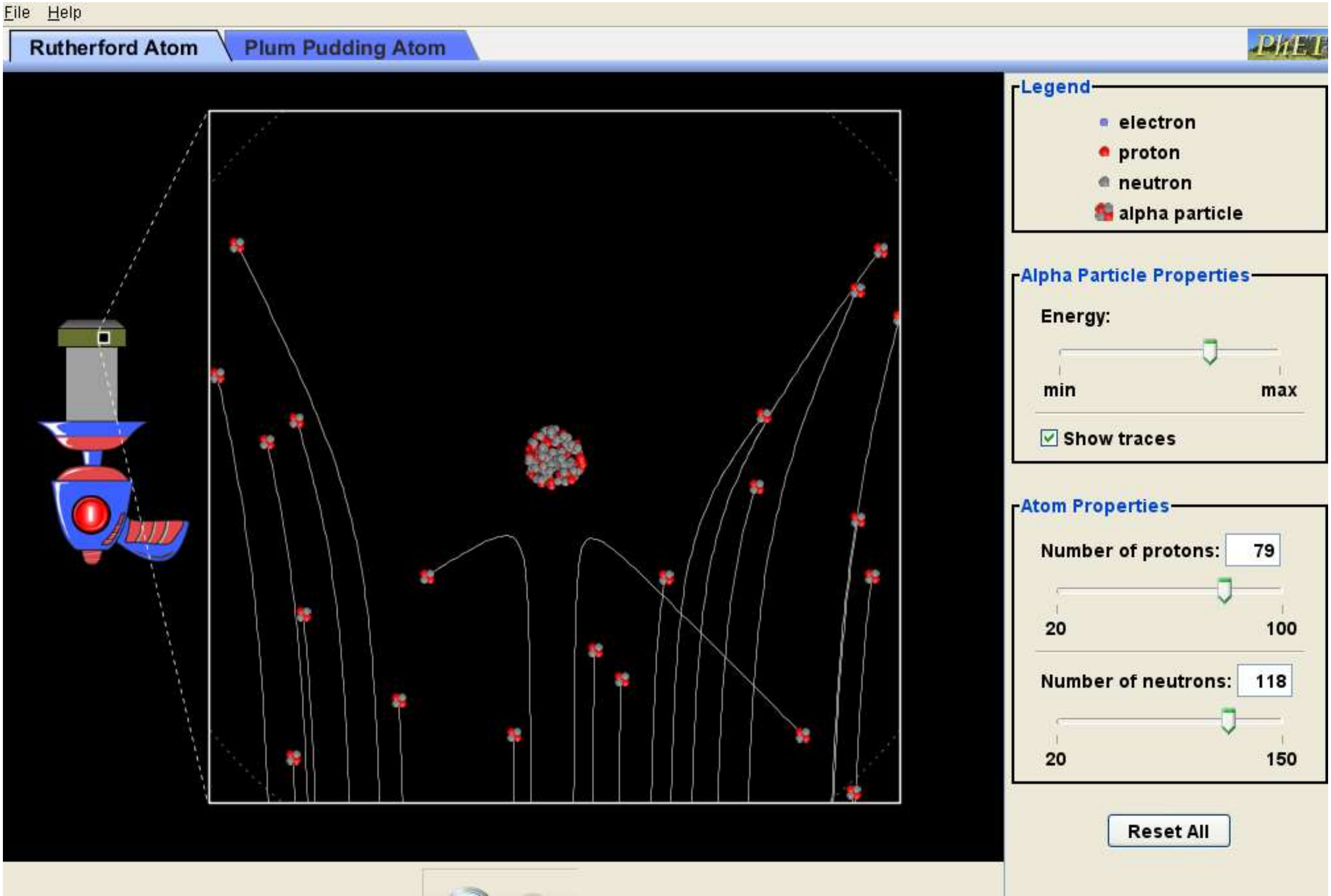


What Rutherford Saw

Occasionally (rarely) the projectile scattered at huge angles !



http://phet.colorado.edu/en/simulation/rutherford-scattering



…like firing a 16" shell at a piece of tissue paper and seeing it bounce back.
- E Rutherford.

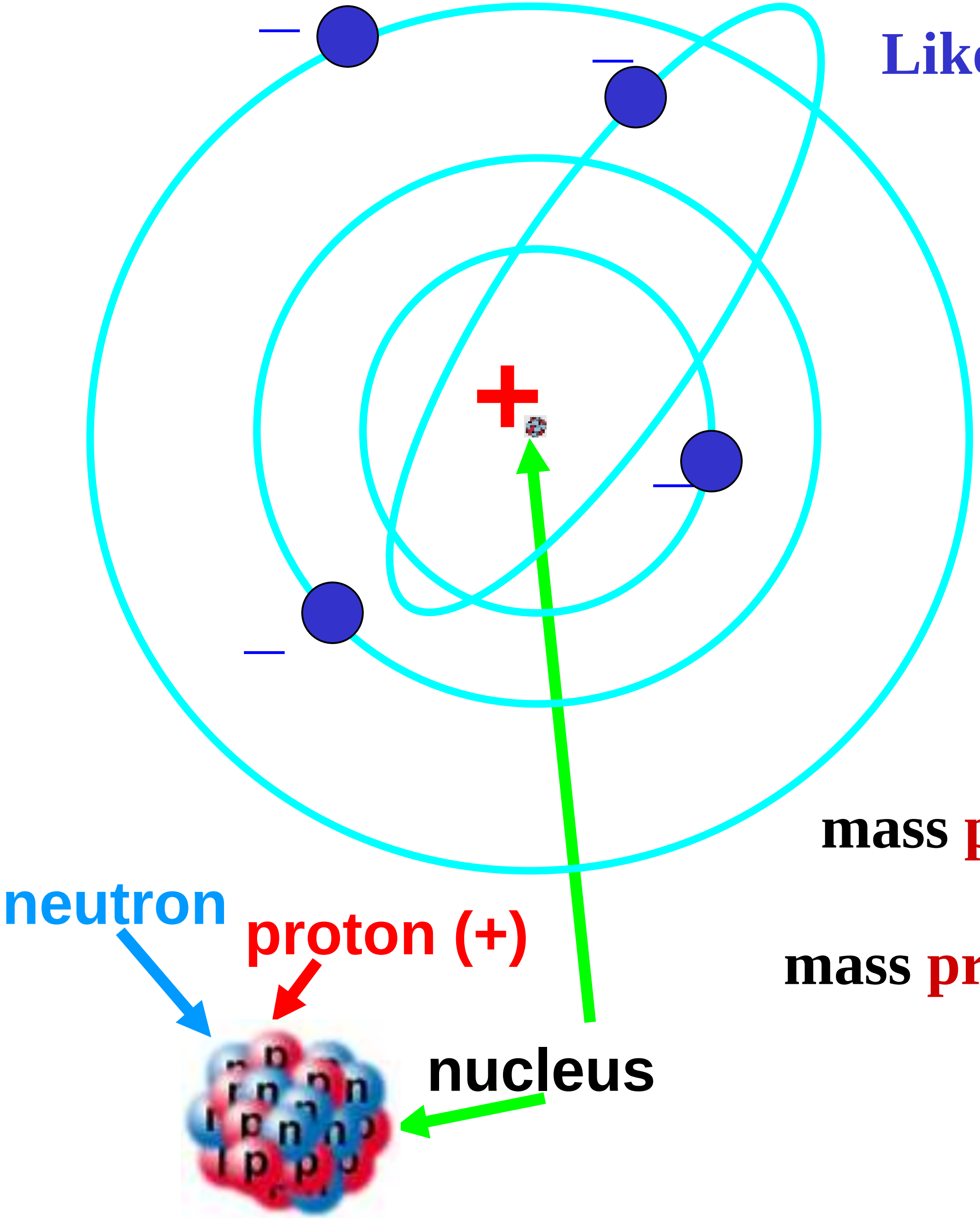
Rutherford Atom

- An atom's mass must be concentrated in a **small positively charged nucleus** as only a very small number of alpha particles either deflected or rebounded off the foil.
  - Atom:Yankee Stadium :: Nucleus:grain of sand.
- Most of the atom must be **empty space**. This space must contain the electrons.
  - The electrons orbit the nucleus like planets around the sun.

The Atom

electrons (-) orbit around massive nucleus

Like solar system on 1A scale.



Force that binds atom together

Electric Force

$1/r^2$ like gravity

but 10^{39} times stronger

mass proton p^+ = mass n

mass proton p^+ ~ 2000 mass electron

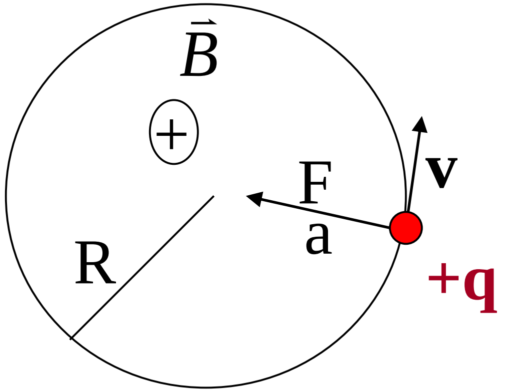
Gigantic problem

e^- in circular orbit $\Rightarrow$ e^- accelerating

$\Rightarrow$ should emit EM radiation !!!!

$\Rightarrow$ e^- should lose kinetic energy !!!!

$\Rightarrow$ e^- should spiral into the nucleus !!!!



Atoms should <u>not exist</u> except briefly

There must exist some new physical "stationary state" for e^- in its orbit.

New physics needed.

The Atom