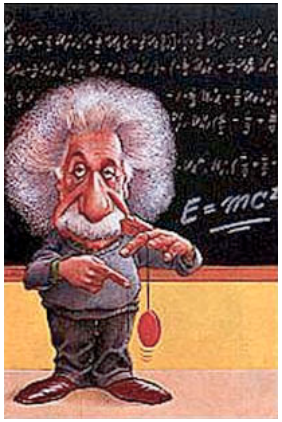

PH0008

Quantum Mechanics and Special Relativity

Lecture 02 (Quantum Mechanics)

020402v1

Photoelectric Effect & Blackbody Radiation

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Brown University

Main source at Brown Course Publisher

background material may also be available at http://gaitskell.brown.edu

Section: Quantum Mechanics Week 1

START OF WEEK

- Homework (due for M 4/1)
  - [SpecRel] Done
- I will return Exam I on Friday

THIS WEEK

- Reading (Prepare for 4/1)
  - SpecRel for Exam
    - Revise Ch2-6 (look at Ch 1 also)
  - QuantMech
    - Ch1,2 & 3
- Lecture 01 (M 4/1)
  - Quantum Mechanics
    - Introduction
    - Photoelectric Effect Demo
- Lecture 02 (W 4/3)
  - Quantum Mechanics
    - Photoelectric Effect
    - Blackbody Radiation
- Lecture 03 (F 4/5)
  - Quantum Mechanics
    - Atomic Line Spectra
    - Bohr Atom

NEXT WEEKEND

- Reading (Prepare for 4/8 after recess)
  - SpecRel
    - Revise
  - QuantMech
    - Ch1,2 & 3
- No Homework (M 4/8)
  - Revision for Exam (M4/8)
- Homework #9 (M 4/15)
  - (see web "Assignments")

Question Section

Question Quant Mech L02-Q1

- What is Planck's constant … a constant of direct proportionality between which two properties of a particle…?
  - (1) Energy and Wavelength
  - (2) Momentum and Wavelength
  - (3) Energy and Frequency
  - (4) Momentum and Frequency

Classical Physics in Crisis

The Birth of Modern Physics

- Experiments that were at odds with Classical Model of Physics (around 1900)
  - Problems for both Newtonian physics, and purely wave theory of light
- Those we will consider
  - Photoelectric Effect
  - Blackbody Radiation
  - Atomic Line Spectra

- Further experiments that study QM effects
  - Davisson-Germer (1925)
    - Electron (30-600 eV) scattering from surface of single crystal metal
  - GP Thomson (1927)
    - Electron (10-40 keV) transmission through micro-crystalline foils
  - Double Slits - Single Photons (1909…)

The Great Grand-daddy of The Crises

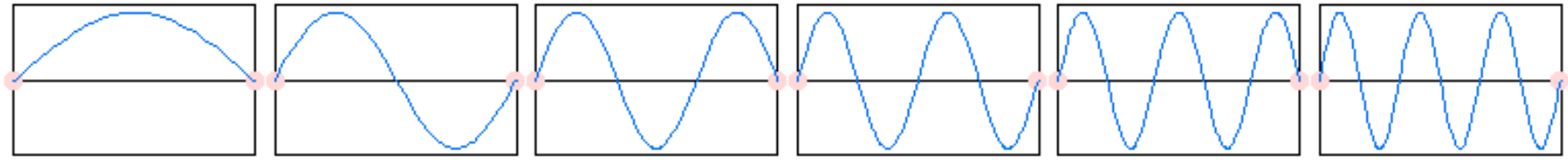
Blackbody (thermal) Radiation

Definition of Blackbody Radiation

- Consider a box with all walls at a given temperature
- Outside:
  - The spectrum of electromagnetic radiation given off by the outside is dependent on the material that the box is made of…
- Inside:
  - It is a result of thermodynamics (empirically tested) that the spectrum of radiation inside the box is independent of the material of the walls
    - This spectrum is know as blackbody spectrum.
    - It would be characteristic of an object which was a perfect absorber, and so a perfect emitter as well…
      - A good example is a hole in a box!

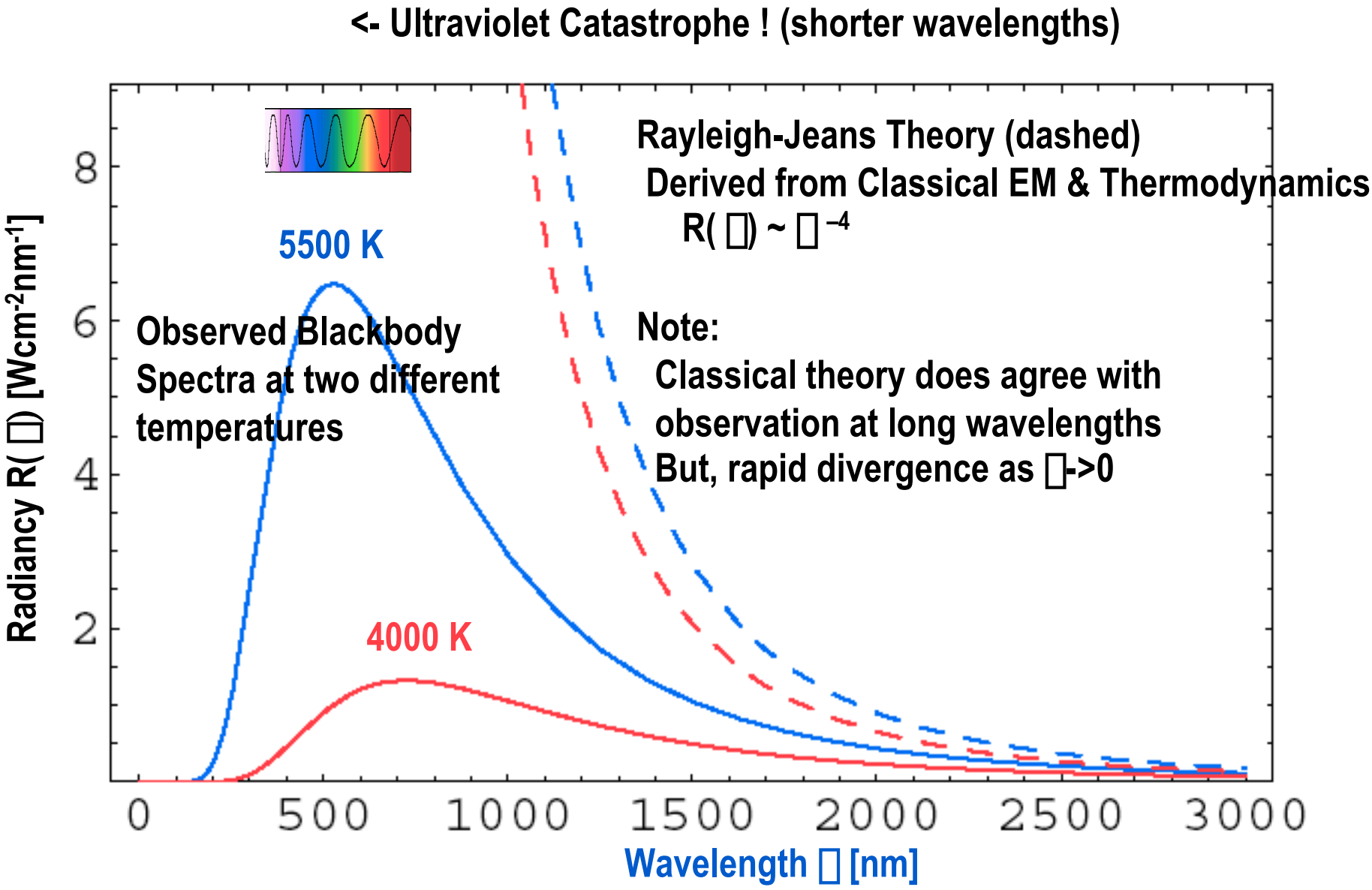
Normal Models in Cavity (Box)

- Consider Electromagnetic Waves in Cavity (box)
  - The standing waves have zero amplitude at walls - this looks like are previous normal mode analysis…



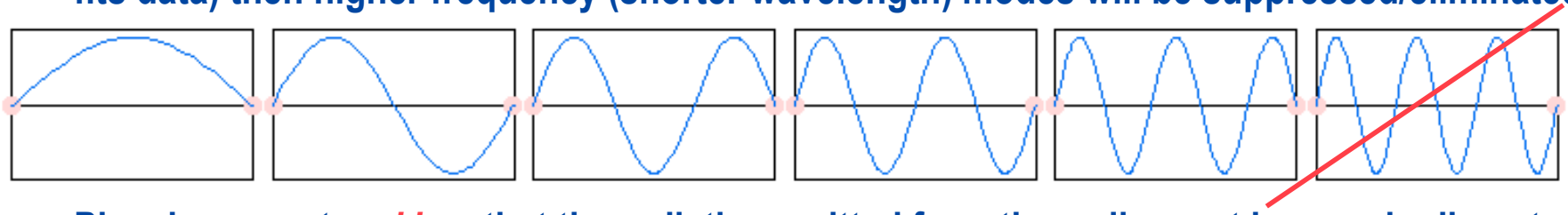
- 1-D Standing waves can be established with $n\lambda / 2 = L$
  - Classically there is NO limit to how short the wavelength can become
    - There is no limitation due to "medium" (no aether); EM-Maxwell doesn't have a length scale
  - Each Normal mode is a "degree of freedom"
    - A result of classical physics is that at equilibrium each degree of freedom will contain the same amount of energy (thermodynamics tells us $E_{per\ dof} \sim k_B T$, where k_B is known as the Boltzmann constant)…
    - …this creates a problem because there are an infinite number of normal modes… most of them with very small wavelengths…(we get more normal modes per $d\lambda$ interval)
    - … the Radiancy $R(\lambda)$ is the power in spectrum per unit area per unit wavelength bin $d\lambda$
  - Extrapolate this to all 3 dimensions…

Blackbody Spectrum Observed vs Rayleigh-Jeans



Resolving Crisis: The beginning…

- **Planck 1900**
  - Suggest that "if" it is assumed that energy of normal mode is quantised such that $E=h\nu$ (h is an arbitrary constant, Planck's arbitrary constant, experimentaly determined so that theory fits data) then higher frequency (shorter wavelength) modes will be suppressed/eliminated.

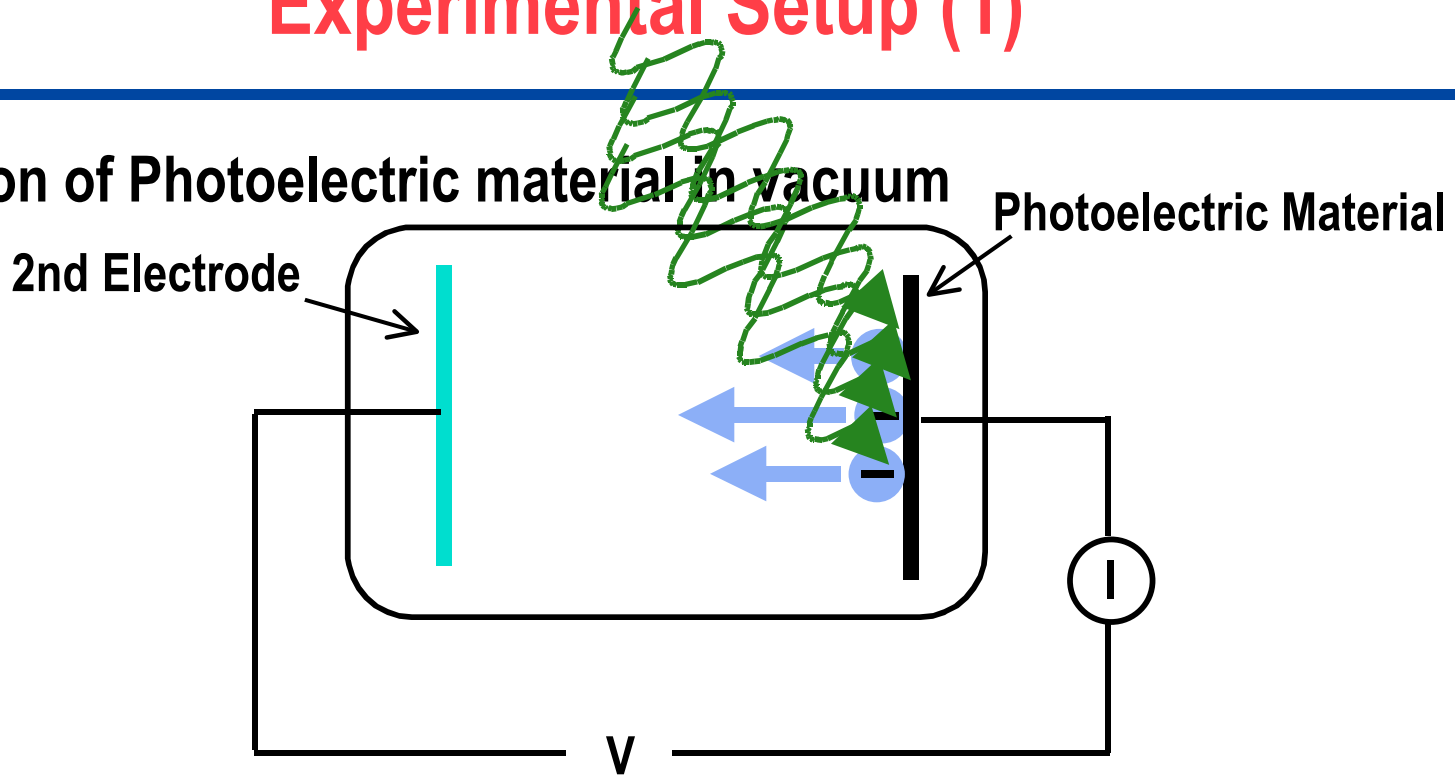


  - Planck suggests *ad hoc* that the radiation emitted from the walls must happen in discrete bundles (called *quanta*) such that $E=h\nu$. Mathematically this additional effect generates an expression for spectrum that fits data well.
    - The Planck constant is determined empirically from then existing data
    - The short wavelength modes are eliminated
  - In a classical theory, the wave amplitude is related to the energy, but there is no necessary link between the frequency and energy
    - Classically one can have low freq. waves of high energy and *vise versa* without constraint
    - Planck is unable to explain how such an effect could come about in classical physics
- **Einstein 1905**
  - Based on Photoelectric effect, Einstein proposed quantisation of light (photons)
    - Photons are both emitted and absorbed in quanta

Photoelectric Effect

Experimental Setup (1)

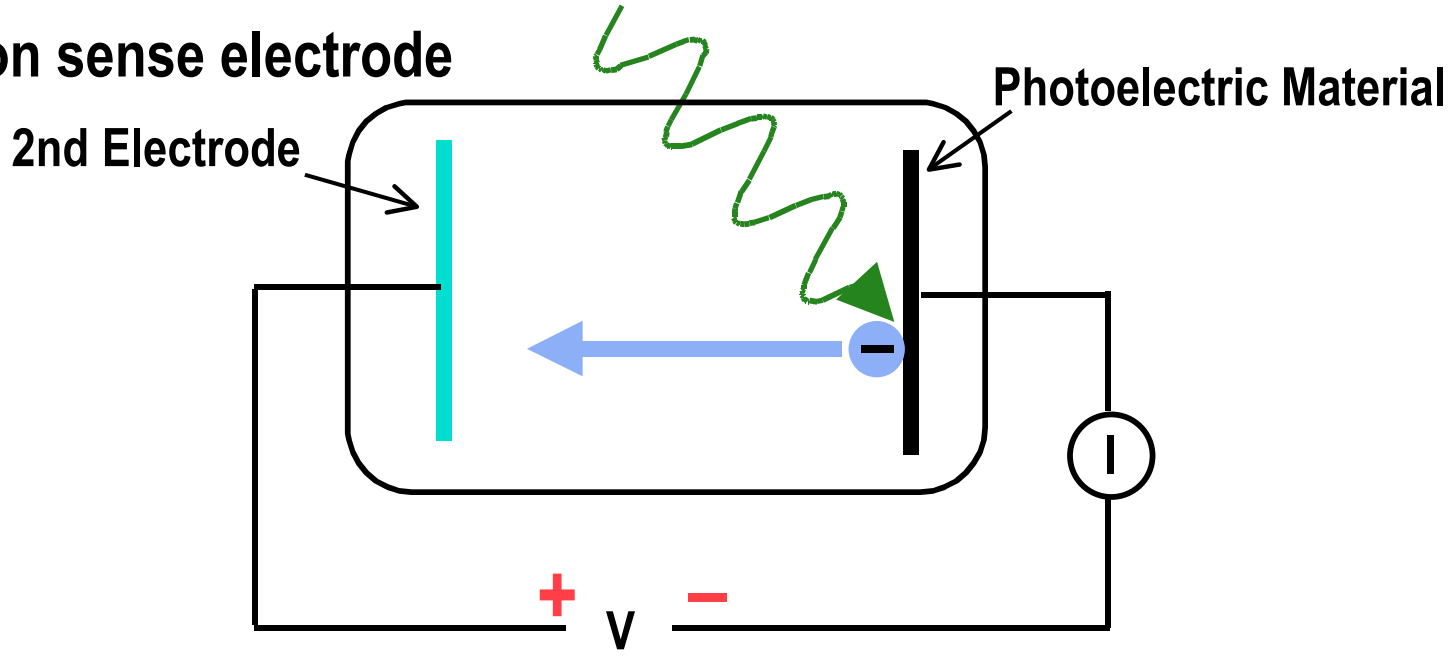
- Illumination of Photoelectric material in vacuum



- Electromagnetic waves couple to electrons
  - Ejecting some of them from material if they are given sufficient energy to overcome binding into material (known as “work function”)
  - Ejected electrons have a range of Kinetic Energies

Experimental Setup (2)

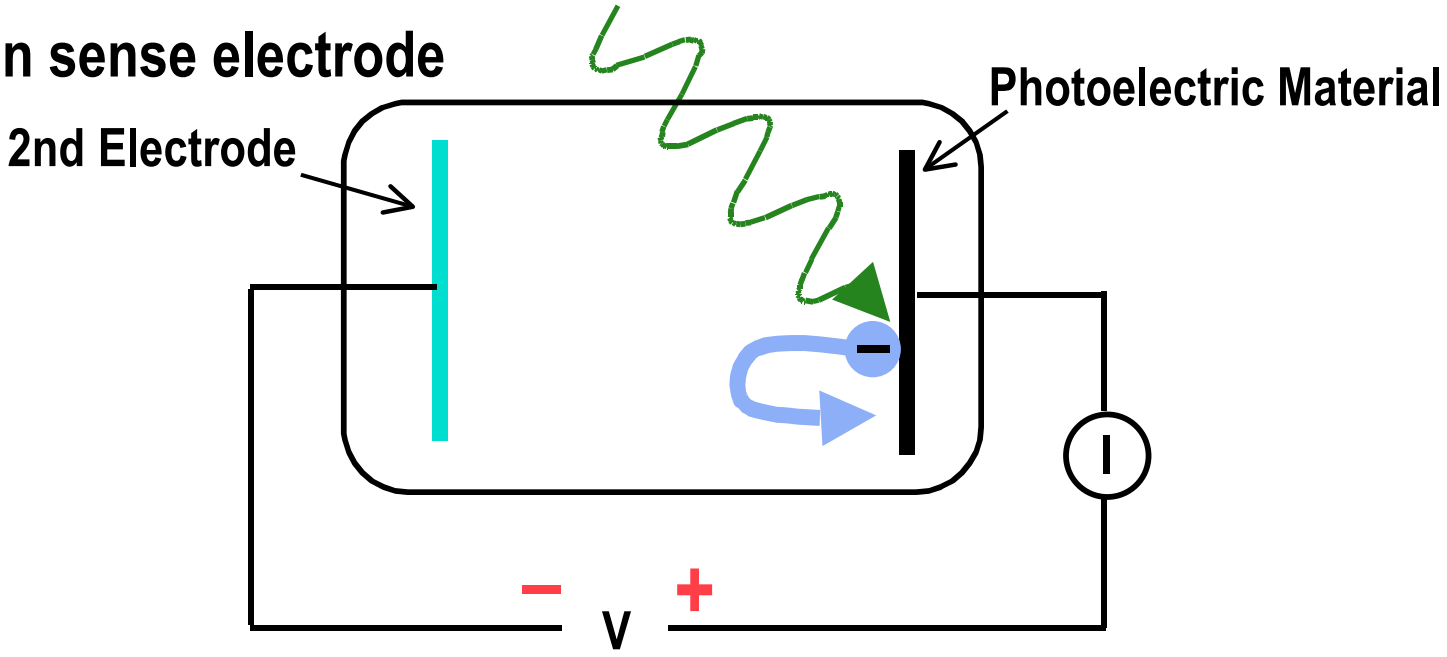
- +ve bias on sense electrode



  - Bias accelerates electron toward sense plate

Experimental Setup (3)

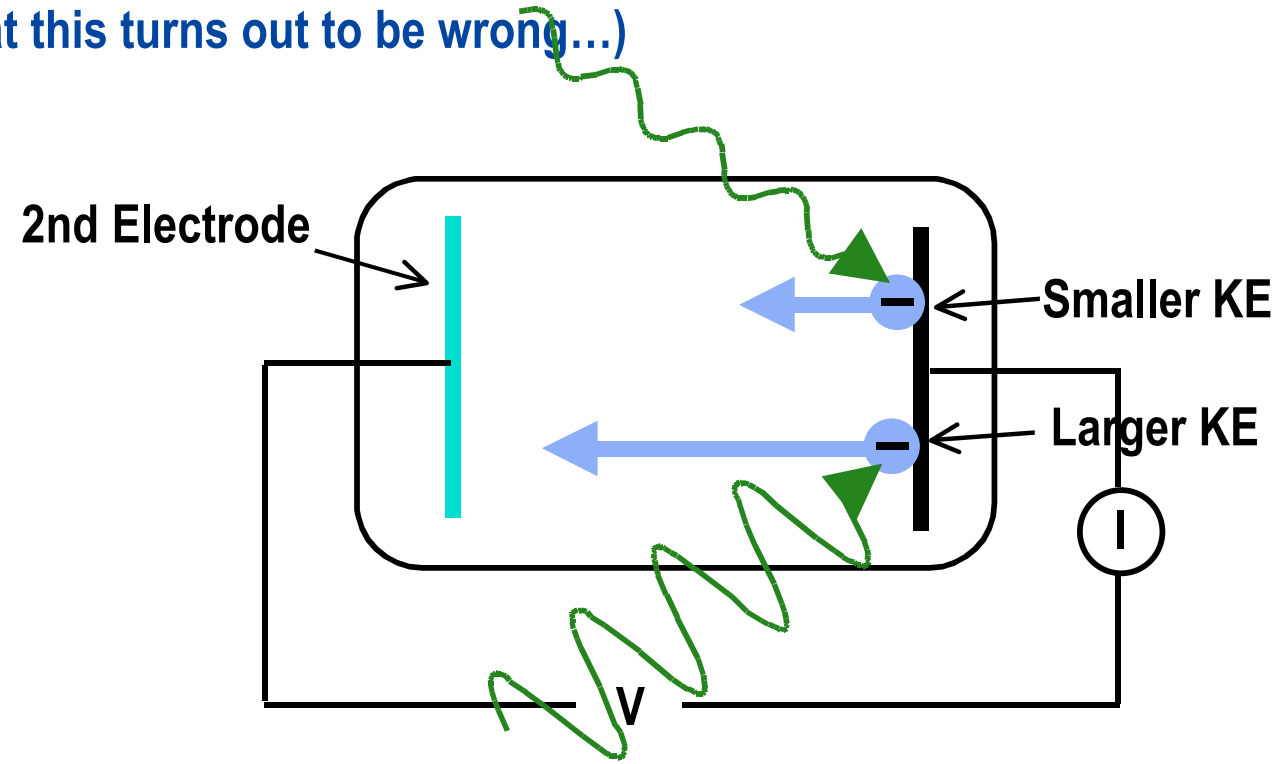
- –ve bias on sense electrode



  - Voltage raised to the a level where Potential overcomes Kinetic Energy of ejected electron
    - Current measured falls to zero

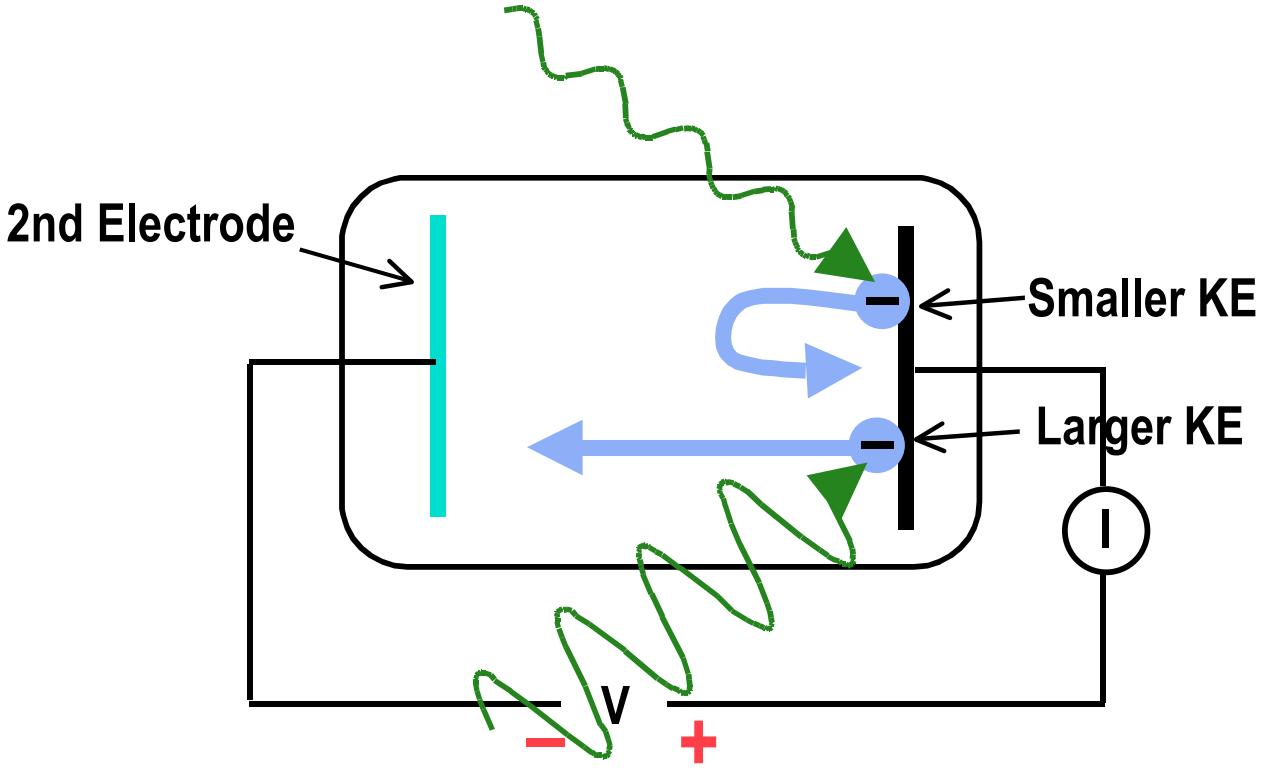
Experimental Setup (4) - Classical Interpretation

- Response to different incoming wave intensities
  - (Note that this turns out to be wrong…)



Experimental Setup (5) - Classical Interpretation

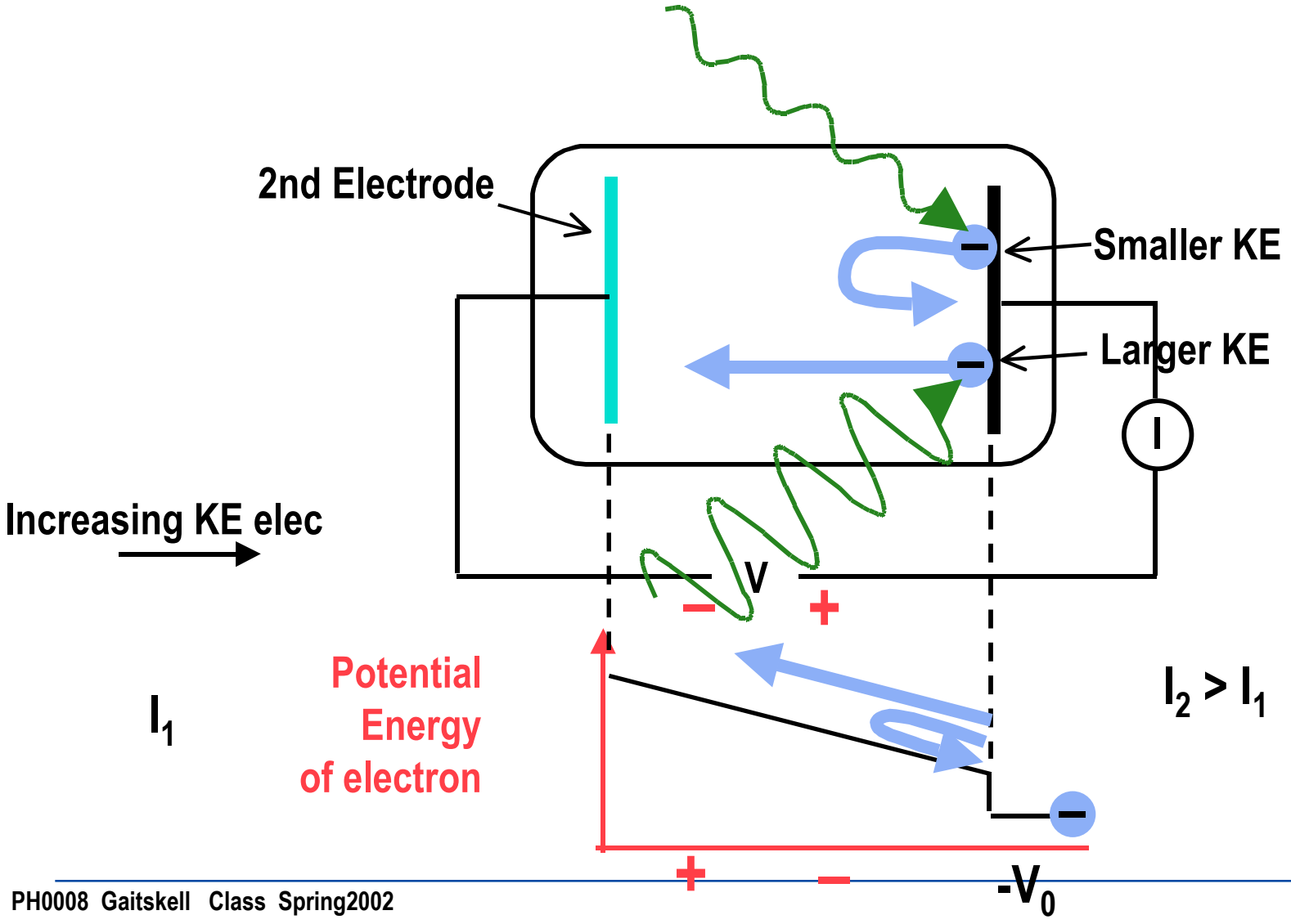
- Response to different incoming wave intensities - apply –ve bias



- Voltage raised to the a level where Potential overcomes Kinetic Energy of ejected electron
  - Current measured falls to zero, we can use the Voltage as an Energy Spectrometer

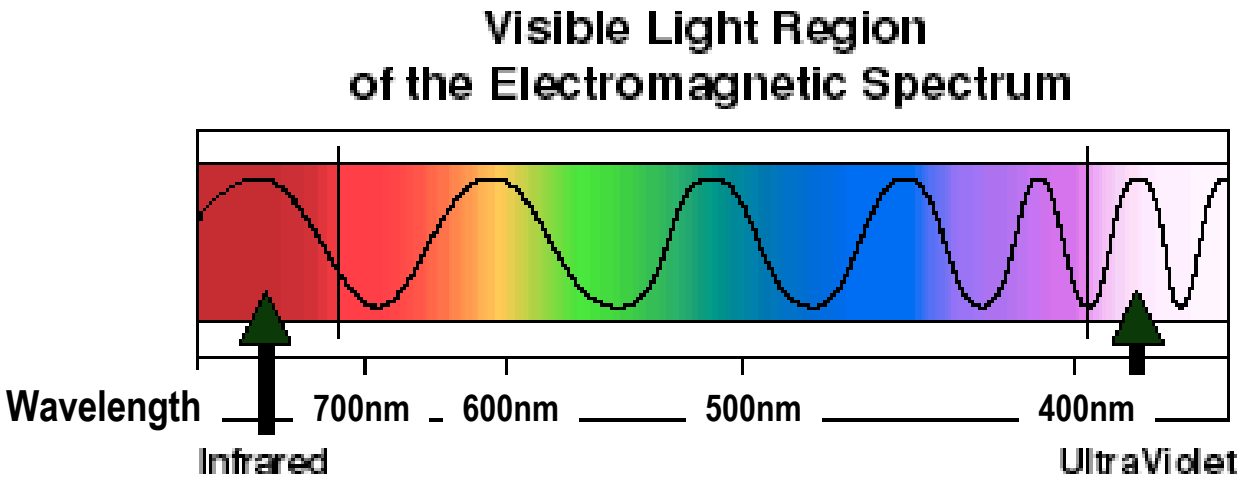
Experimental Setup (6) - Electron Potential Diagram

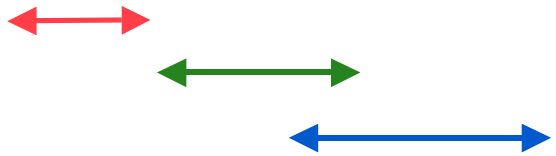
- **Voltage as an Energy Spectrometer - apply –ve bias**



Light Sources

- **Filters - approximate band-pass**
  - Red 600-700 nm
  - Green 520-600 nm
  - Blue 450-550 nm





Visible Wavelength Spectrum from http://imagers.gsfc.nasa.gov/ems/visible.html