Physics 2D Lecture Slides
Oct 14

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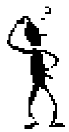
Ch 2 : Quantum Theory Of Light

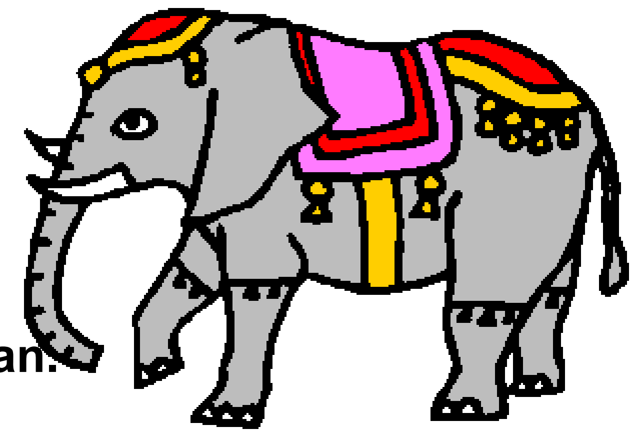
- What is the nature of light ?
  - When it propagates ?
  - When it interacts with Matter?
- What is Nature of Matter ?
  - When it interacts with light ?
  - As it propagates ?

- Revolution in Scientific Thought
  - Like a firestorm of new ideas (every body goes nuts!..not like Evolution)
    - Old concepts violently demolished , new ideas born
      - Interplay of experimental findings & scientific reason
- One such revolution happened at the turn of 20^{th} Century
  - Led to the birth of Quantum Theory & Modern Physics

Blindmen & an Elephant

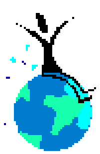

touched the trunk of the elephant, said elephant was like a **branch of a tree**.


touched the tail of the elephant, said elephant was like a **snake.**




touched an ear. He said elephant was a **huge fan.**


felt a leg of the elephant., elephant was like a **pillar**.


touched the side of the elephant, said the elephant was like a **wall**


The Physicist: Gentlemen, all five of you have touched only one part of the Elephant…...elephant **is all of above**

LIKEWISE WITH LIGHT !

Classical Picture of Light : Maxwell's Equations

- Maxwell's Equations:

$$\oint_S \mathbf{E}\cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

$$\oint_S \mathbf{B}\cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E}\cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0 I + \mu_0\epsilon_0 \frac{d\Phi_E}{dt}$$

$$\frac{\partial^2 E}{\partial x^2} = \mu_0\epsilon_0 \frac{\partial^2 E}{\partial t^2}$$

$$\frac{\partial^2 B}{\partial x^2} = \mu_0\epsilon_0 \frac{\partial^2 B}{\partial t^2}$$

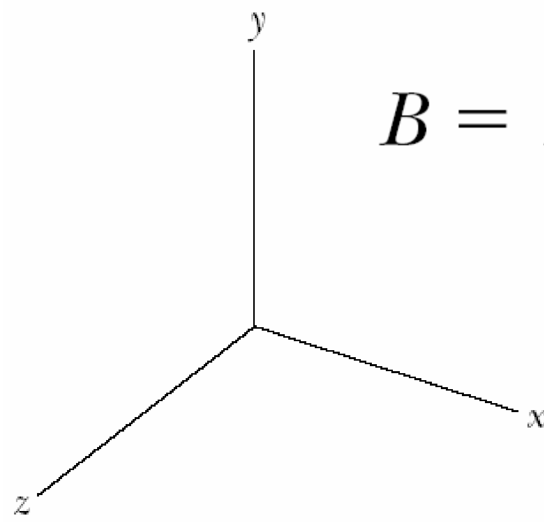
$$E = E_{\max}\cos(kx - \omega t)$$

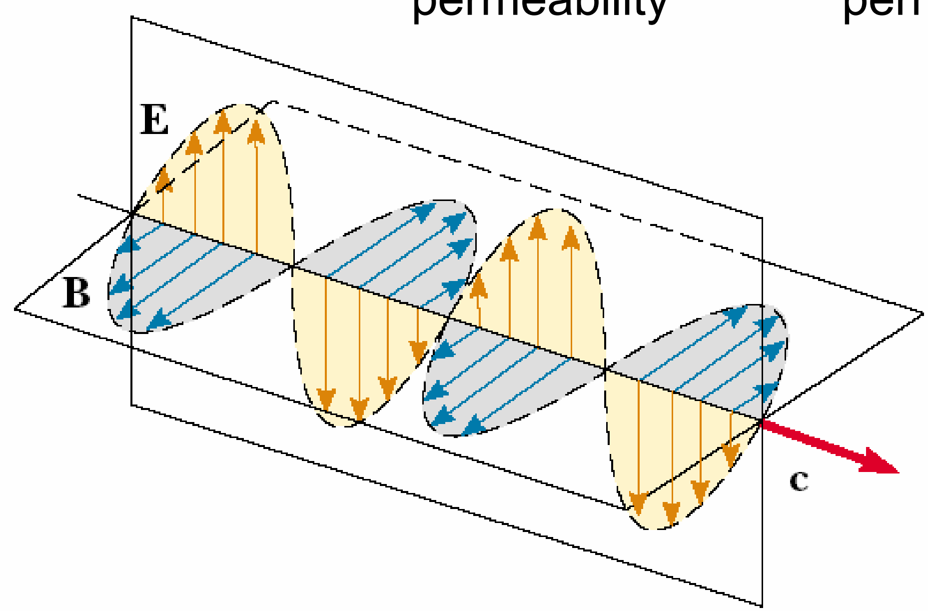
$$B = B_{\max}\cos(kx - \omega t)$$

$$c = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

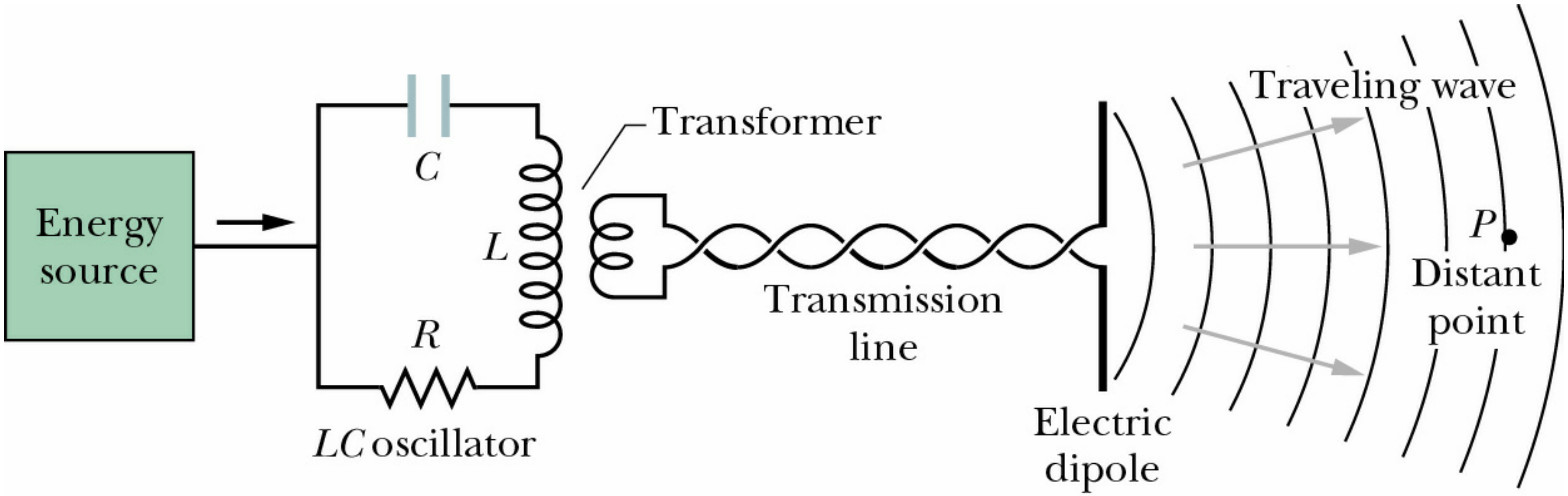
permeability

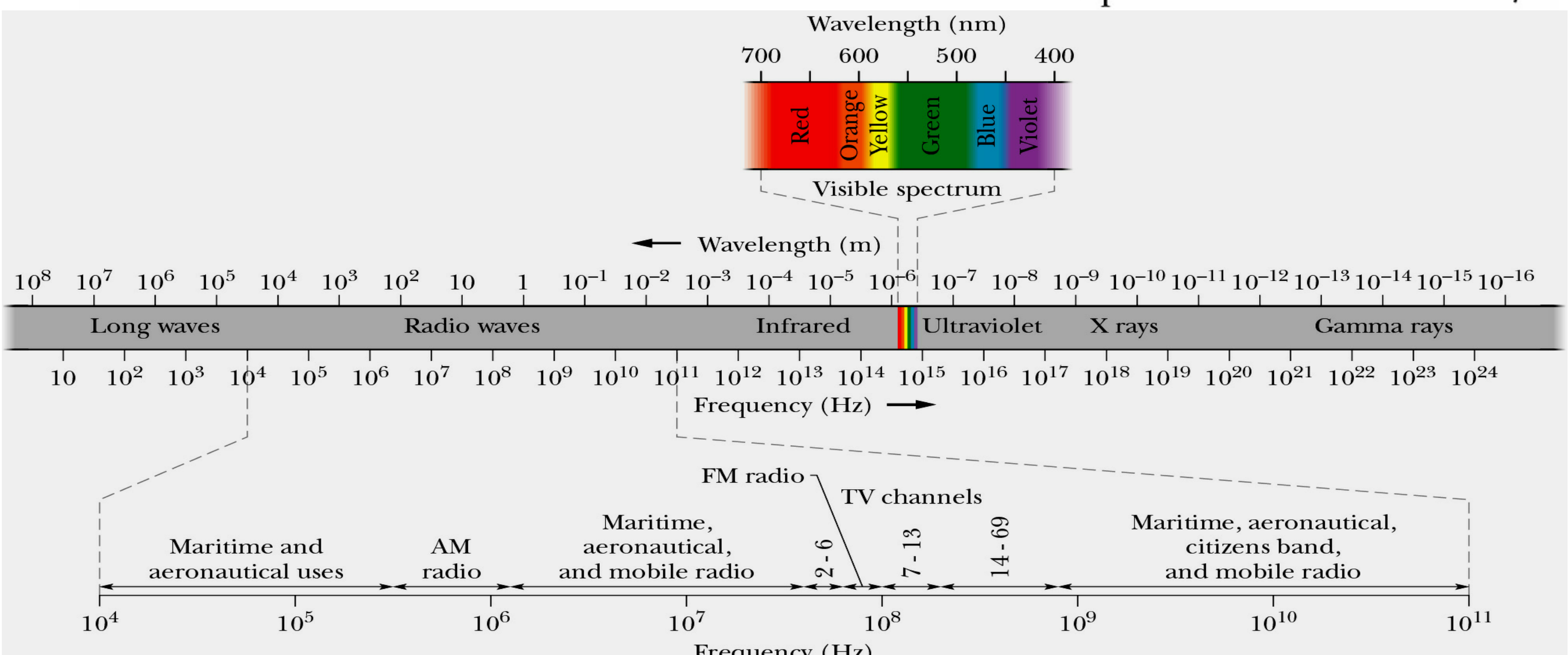
permittivity



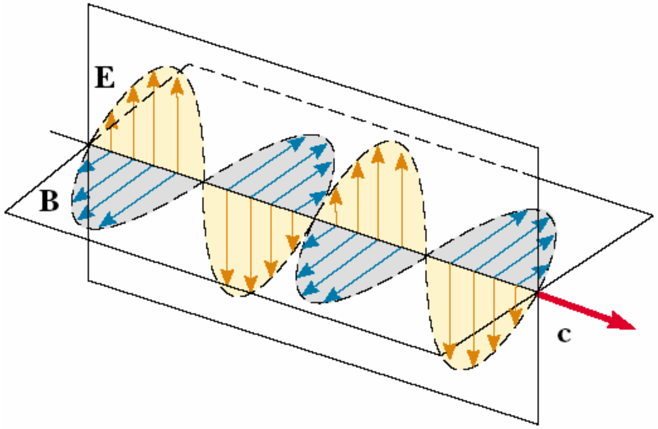


Hertz & Experimental Demo of Light as EM Wave





Properties of EM Waves: Maxwell's Equations



Energy Flow in EM Waves :

Poynting Vector $\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B})$

Power incident on an area A $= \vec{S}.\vec{A} = \frac{1}{\mu_0}\left(A E_0 B_0 Sin^2(kx - \omega t) \right)$

Intensity of Radiation $I = \frac{1}{2\mu_0 c} E_0^2$

Larger the amplitude of Oscillation
More intense is the radiation

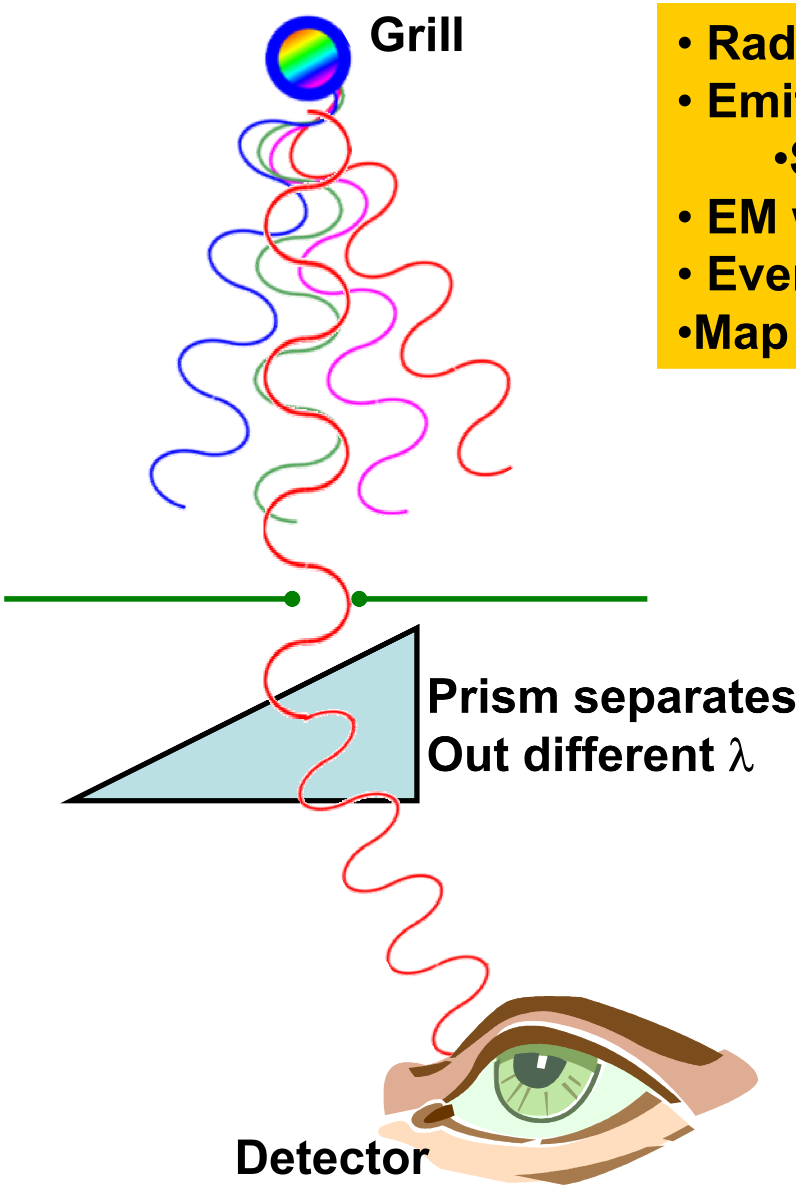
Disasters in Classical Physics (1899-1922)

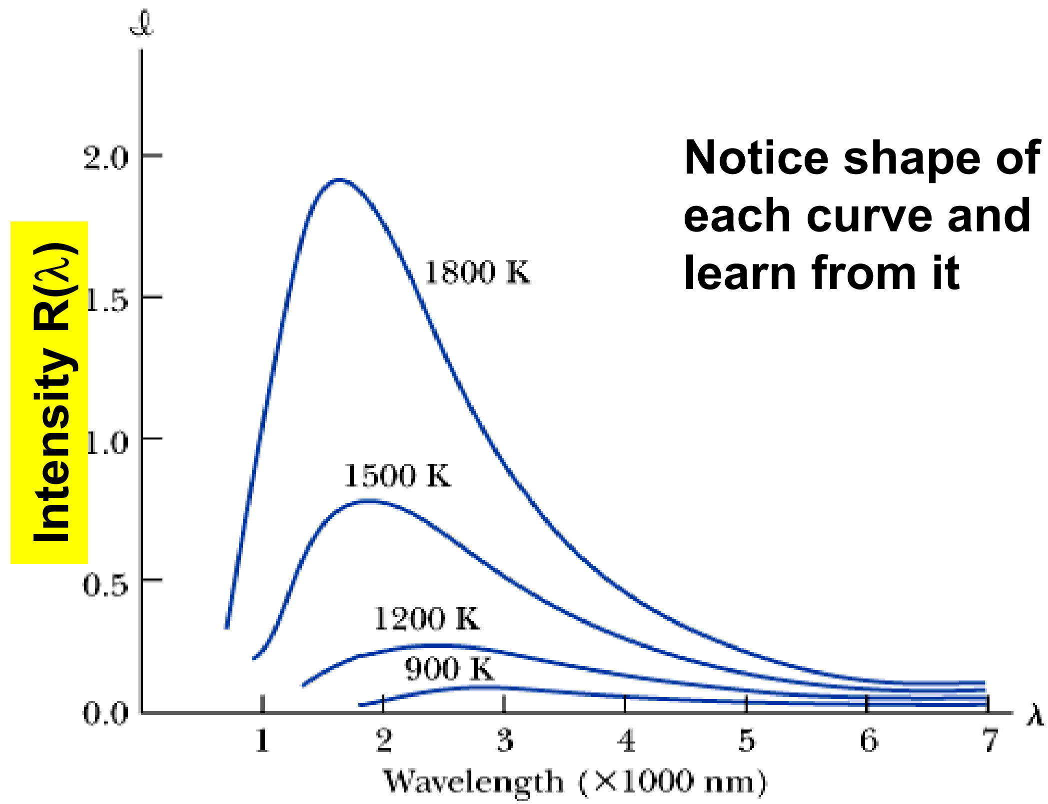
- Disaster → Experimental observation that could not be explained by Classical theory (Phys 2A, 2B, 2C)
  - Disaster # 1 : Nature of Blackbody Radiation from your BBQ grill
  - Disaster # 2: Photo Electric Effect
  - Disaster # 3: Scattering light off electrons (Compton Effect)
- Resolution of Experimental Observation will require radical changes in how we think about nature
  - → QUANTUM MECHANICS
    - The Art of Conversation with Subatomic Particles

Nature of Radiation: An Expt with BBQ Grill

Question : Distribution of Intensity of EM radiation Vs T & λ

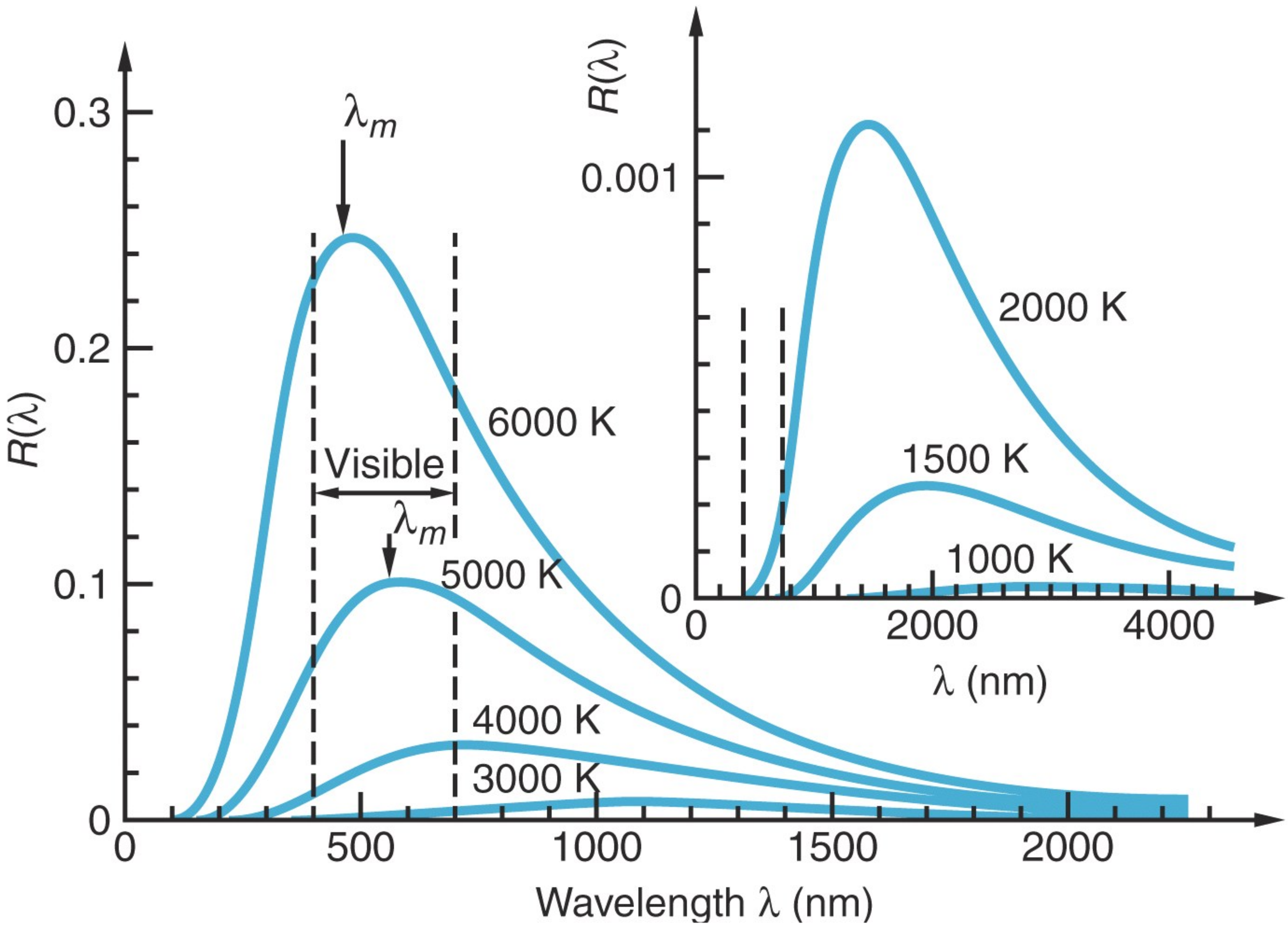
- Radiator (grill) at some temp T
- Emits variety of wavelengths
  - Some with more intensity than others
- EM waves of diff. λ bend differently within prism
- Eventually recorded by a detector (eye)
- Map out emitted Power / area Vs λ





Notice shape of each curve and learn from it

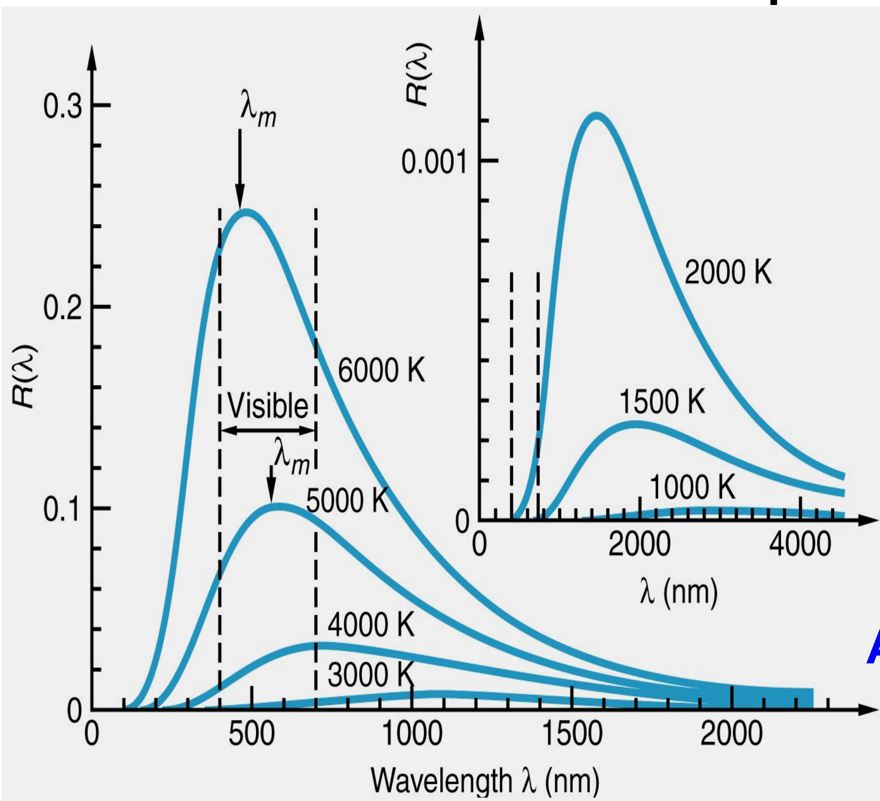
Radiation from A Blackbody



(a) Intensity of Radiation $\mathbf{I} = \int R(\lambda)d\lambda \propto T^4$

$$I = \sigma T^4 \text{(Area under curve)}$$

Stephan-Boltzmann Constant $\sigma = 5.67 \; 10^{-8}$ **W / m^2 K^4**



(b) Higher the temperature of BBQ Lower is the λ of PEAK intensity

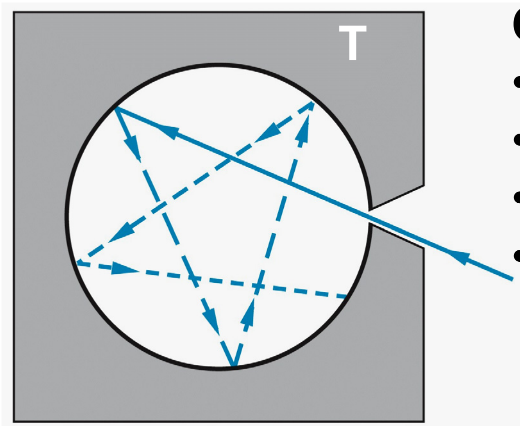
$$\lambda_{MAX} \propto 1 / T$$

Wein's Law λ_{MAX} **T = const = 2.898** 10^{-3} **mK**

As a body gets hotter it gets more RED then White

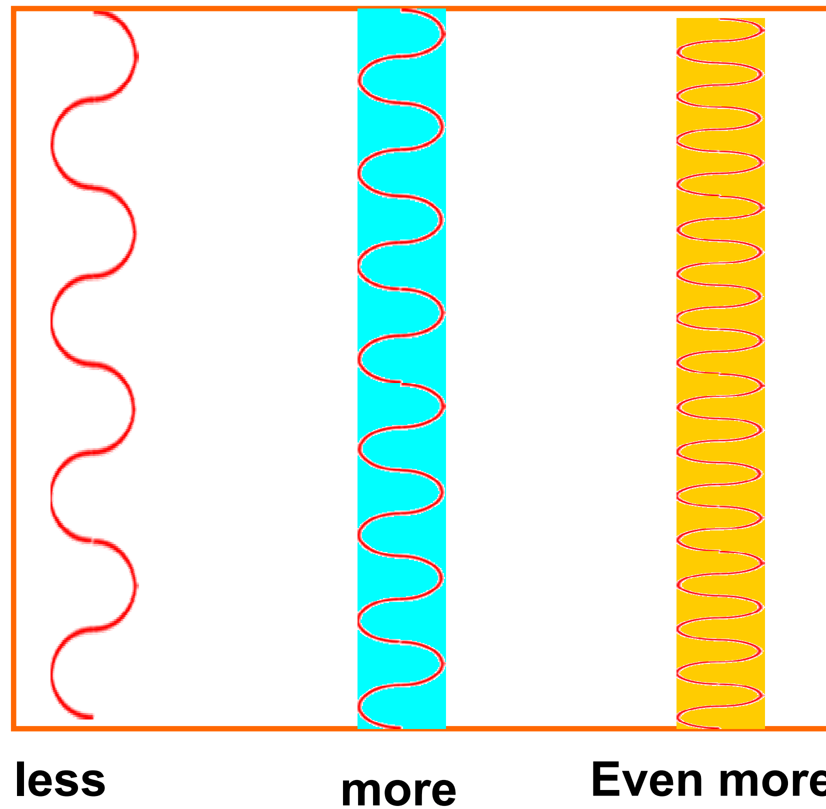
Reason for different shape of R(λ) Vs λ for different temperature?
Can one explain in on basis of Classical Physics (2A,2B,2C) ??

Blackbody Radiator: An Idealization



Classical Analysis:

- Box is filled with EM standing waves
- Radiation reflected back-and-forth between walls
- Radiation in thermal equilibrium with walls of Box
- How may waves of wavelength λ can fit inside the box ?



Blackbody Absorbs everything
Reflects nothing
All light entering opening gets absorbed (ultimately) by the cavity wall

Cavity in equilibrium T w.r.t. surrounding. So it radiates everything It absorbs

Emerging radiation is a sample of radiation inside box at temp T

Predict nature of radiation inside Box ?

The Beginning of The End ! How BBQ Broke Physics

Classical Calculation

of standing waves between Wavelengths λ and λ+dλ are

$$N(\lambda)d\lambda = \frac{8\pi V}{\lambda^4} \bullet d\lambda \; ; \; V = \text{Volume of box} = L^3$$

Each standing wave contributes energy E= kT to radiation in Box

Energy density $u(\lambda)$= [# of standing waves/volume]× Energy/Standing Wave

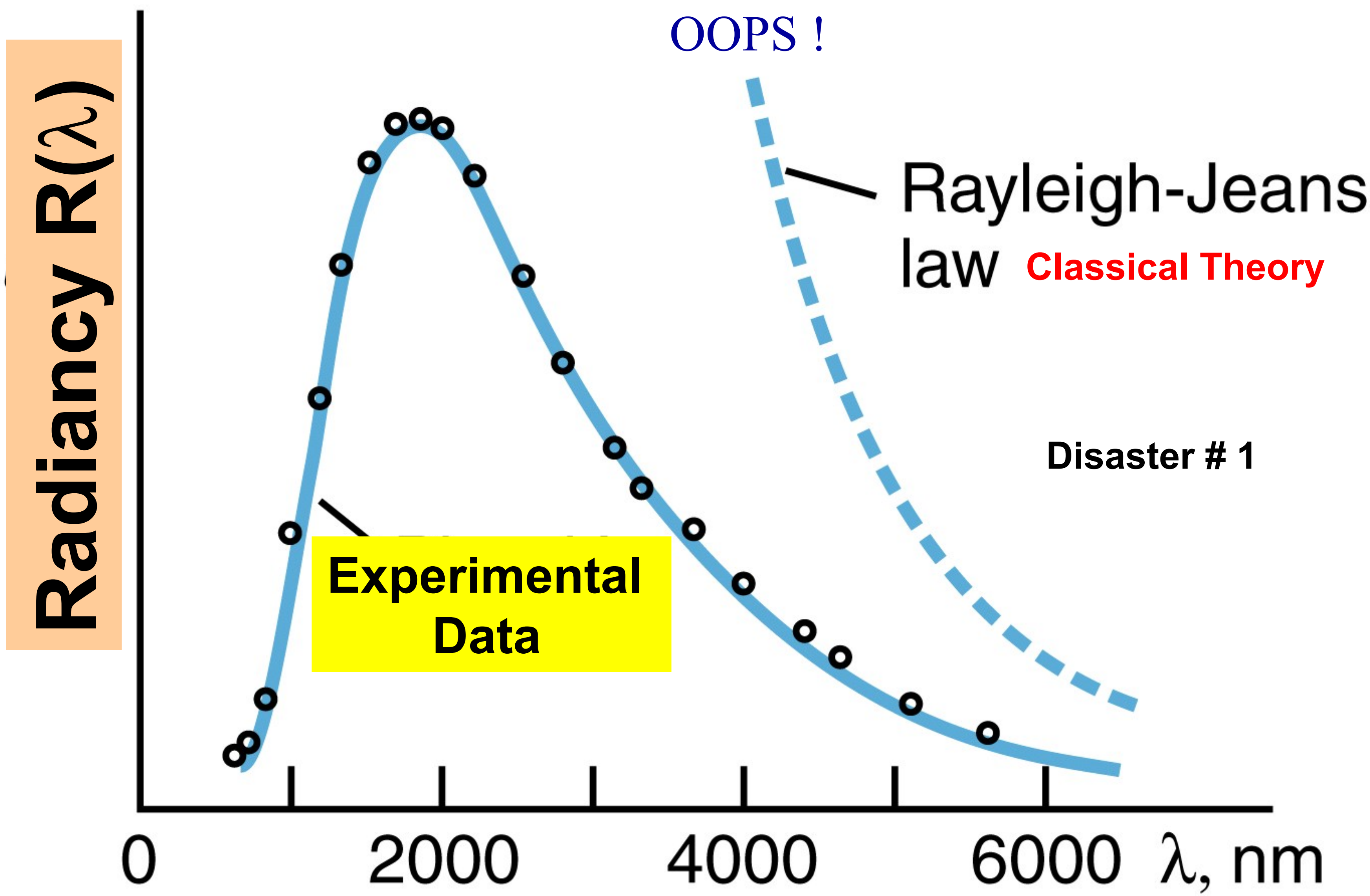
$$= \frac{8\pi V}{\lambda^4} \times \frac{1}{V} \times kT = \frac{8\pi}{\lambda^4} kT$$

$$\boxed{\text{Radiancy } R(\lambda) = \frac{c}{4} u(\lambda) = \frac{c}{4}\frac{8\pi}{\lambda^4} kT = \frac{2\pi c}{\lambda^4} kT}$$

Radiancy is Radiation intensity per unit λ interval: Lets plot it

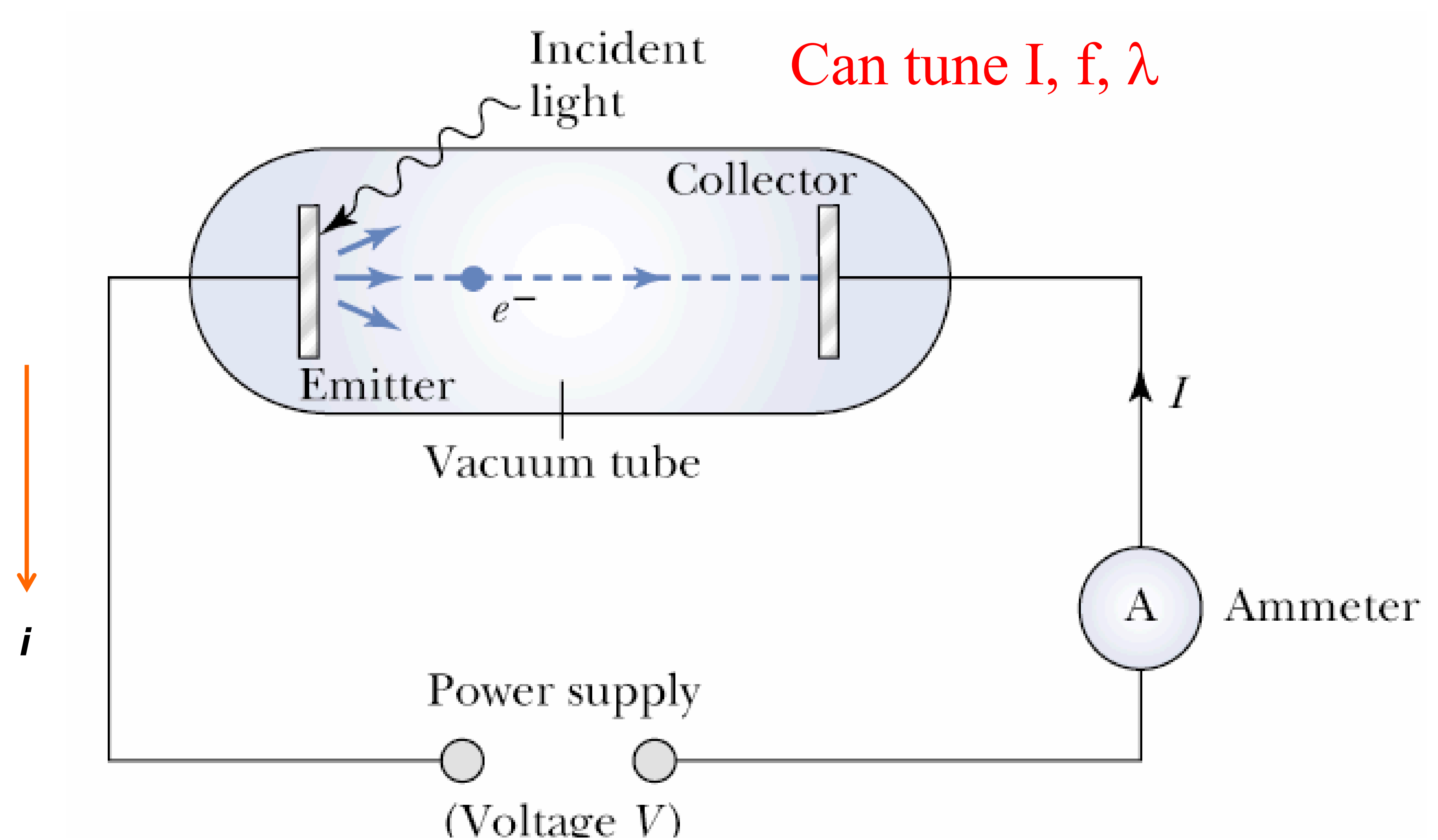
Prediction : as $\lambda \to 0$ (high frequency) $\Rightarrow$ $R(\lambda) \to$ Infinity !
Oops !

Ultra Violet (Frequency) Catastrophe



Disaster # 2 : Photo-Electric Effect

Light of intensity I, wavelength λ and frequency ν incident on a photo-cathode



Measure characteristics of current in the circuit as a fn of I, f, λ