

4E : The Quantum Universe



Lecture 1

Vivek Sharma

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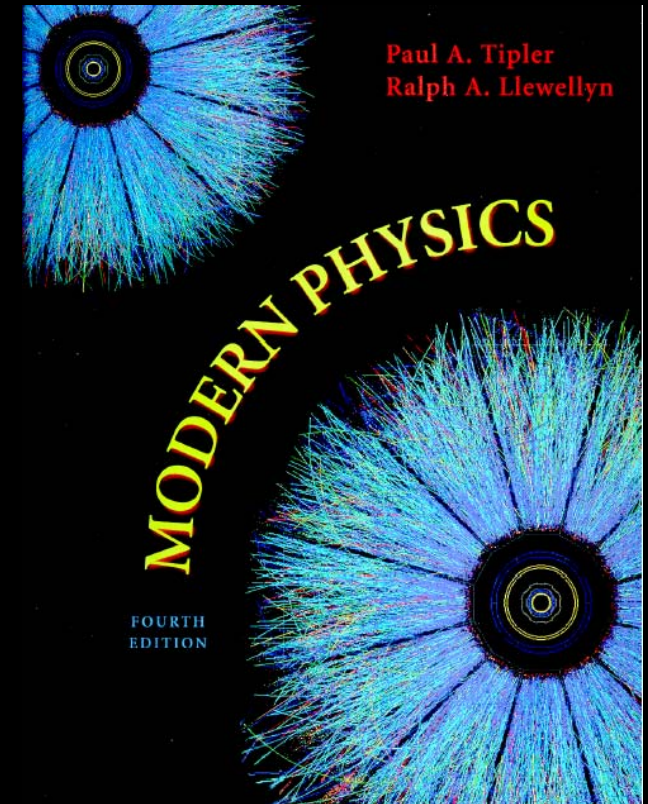
4E : A Course on the Quantum Universe



- Quantum physics is the most exciting advance in the history of science. Its firestorm like birth and development makes it an excellent example of the symbiosis between theory and experimentation
- It is the fountainhead of Modern Chemistry, Biology and many fields of Engineering
- What to expect in this course:
 - You will see Quantum mechanics a few times as UCSD UG
 - For Example, 130 A,B,C series will be a formal and mathematical account of the methods of quantum Mechanics
 - This course will be a more conceptual and “intuitive” introduction to quantum physics
 - The last part of this course will be a survey of some interesting examples of the Quantum Universe:
 - Particle Physics
 - Astrophysics and Cosmology

Some Bookkeeping Issues Related to This Course

- Course text: Modern Physics by Tipler, Llewellyn
 - 4th edition, Published by WH Freeman
- Instructor :
 - Vivek Sharma: modphys@ucsd.edu
 - 3314 Mayer Hall, Ph: 534 1943
 - Office Hours:
 - Mon: 2:00-3:00pm, Tue:2:30-3:30pm
 - Weekends by appointment
- Teaching Assistant:
 - Brian Wecht: bwecht@physics.ucsd.edu
 - 4234 Mayer Hall, Ph: 534 5910
 - Office Hour: Thu: 1:00-2:00pm (Negotiable)
- Class Web Site: <http://modphys.ucsd.edu/4es04>
 - Web page is important tool for this class, make sure you can access it



UCSD Physics Department

Welcome to the Spring '04 Modern Physics (PHYS 4E) Web Site

<u>Announcements</u>	<u>Course Handouts</u>
<u>Office Hours</u>	<u>Weekly Schedule</u>
<u>Homework Solutions</u>	<u>Lecture Slides</u>
<u>Quiz & Finals Solutions</u>	<u>[Absolute] Grading Scale</u>
<u>Quiz & Final Grades</u>	<u>Scientific American</u>
<u>Material on E-Reserve</u>	<u>The Edge of Physics</u> (Free From UCSD location or Proxy)

E-Mail: [Prof. Sharma](#) [Brian Wecht](#)

Free Stuff You Need: [Acrobat Reader](#)

Weekly Schedule

You must be able to attend discussion session on Wednesday and Problem session on Thursday

Lecture	Monday	11:00-11:50 am	WLH 2113	Prof. Sharma
Prof. Office Hour	Monday	2:00 - 3:00 pm	Mayer 3314	Prof. Sharma
Lecture	Tuesday	5:00-5:50 pm	WLH 2207	Prof. Sharma
Prof. Office Hour	Tuesday	2:30-3:30 pm	Mayer 3314	Prof. Sharma
Lecture	Wednesday	11:00-11:50 am	WLH 2113	Prof. Sharma
Discussion	Wednesday	4:00-4:50 pm	WLH2205	B.Wecht/ V.Sharma
TA Office Hour	Thursday	1:00-2:00pm	Mayer 4234	Brian Wecht
Problem Solving	Thursday	5:00-5:50 pm	SEQUO 148	Brian Wecht
Lecture or Quiz (biweekly)	Friday	11:00-11:50 am	WLH 2113	Quiz on April 9, 23. May 7, 21, June 4th
Prof. Office Hour	<u>Weekend</u>	<u>By Appointment</u>	Mayer 3314	Prof. Sharma

Quizzes, Final and Grades



- Course score = 60% Quiz + 40% Final Exam
 - 5 quizzes (every other Friday), best 4 scores used
 - Two problems in each quiz, 45 minutes to do it
 - One problem HW like, other more interesting
 - Closed book exam, but you can bring one page “CHEAT SHEET”
 - Blue Book required, Code numbers will be given at the 1st quiz. Bring calculator, check battery !
 - No makeup quizzes
 - See handout for Quiz regrade protocol
- Final Exam : TBA, but in Week of June 7-12.
 - Inform me of possible conflict within 2 weeks of course
 - Don't plan travel/vacation before finals schedule is confirmed !
 - No makeup finals for any reason

Course Grade



- Our wish is that every body gets an A ! ...So no curve
- Grading is on an absolute scale. Roughly it looks like this :

Total Score	Grade
> 85	A+
> 75	A
> 60	B
> 45	C
< 30	F

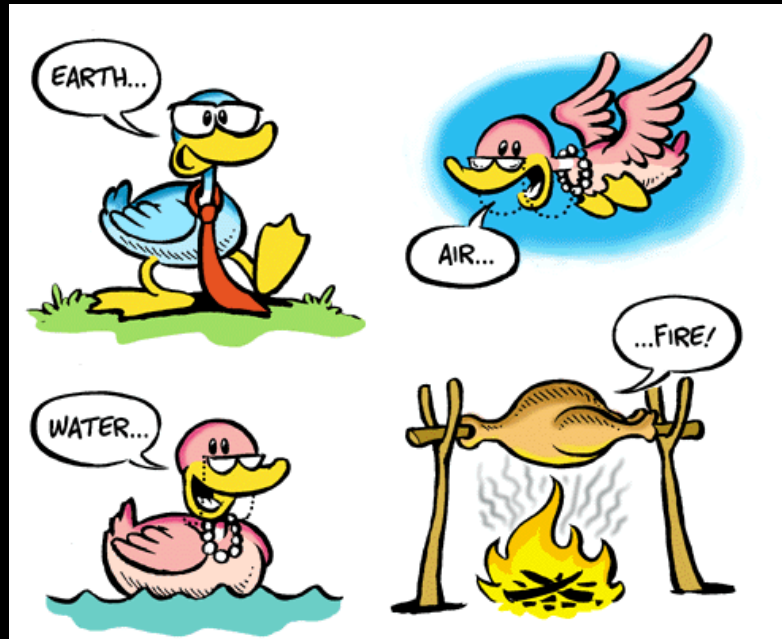
How To Do Well In This Course



- Read the assigned text **BEFORE** lecture to get a feel of the topic
- Don't rely on your intuition ! The concepts are quite abstract.
- Attend lecture (ask questions during/before/after lecture) and discussion.
- **Do not just accept a concept without understanding the logic**
- Attempt all homework problems yourself
 - Before looking at the problem solutions (available on web by Tuesday afternoon) & before attending Problem Solving session
- The textbook, the lectures and the discussions are all integral to this course. Just following lectures is not sufficient (I won't cover every thing)
- Quarter goes fast, don't leave every thing for the week before exam !!
- Don't hesitate to show up at Prof. or TA office hour (they don't bite !)

Constituents of Nature: The Ancient View

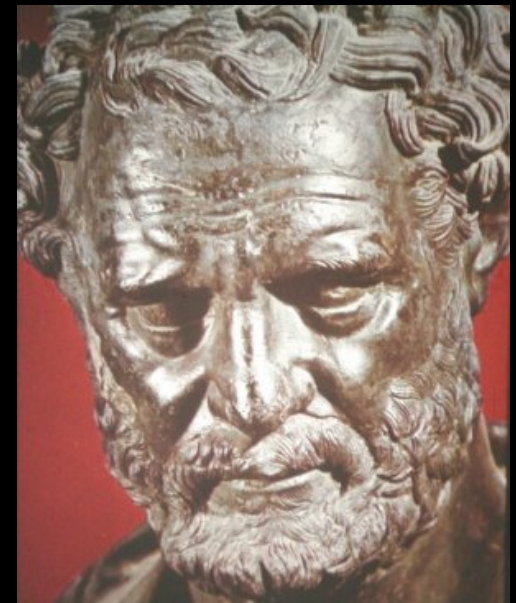
Every civilization has speculated about the constitution of the Universe. The Greek philosophers thought that the universe was made up of just four elements: Earth, air, Fire and Water



This was a great “scientific” theory because it was simple but it had one drawback: **It was wrong!** There was no experimental proof for it.

Concept of An Atom

- Around 6th-5th century BC, Indians and more famously the Greeks speculated on “indivisible” constituents of matter
- In 5th BC, Leucippus and his follower Democritus set the scene for modern physics by asking “what would happen if you chopped up matter into ever smaller pieces. There would be a limit beyond which you could chop no more!”
- They called this indivisible piece an *Atom* (or *Anu* in Sanskrit)



Some Highlights in Understanding Matter



- Lavoisier's measurement of conservation of matter in chemical reactions
- Faraday's Electrolysis experiment (1833) : Same amount of charge F is required to decompose 1 gram-ionic weight of monovalent ions
 - 1 F passed thru NaCl leads to 23gm of Na at cathode and 35.5gm Cl at anode but it takes 2F to disassociate CuSO_4
 - → Mass of element liberated at an electrode is directly proportional to charge transferred and inversely prop. to the valence of the freed element
- Avagadro postulated that pure gases at same temperature and pressure have same number of molecules per unit volume.
 - → $N_A = 6.023 \times 10^{23}$
- Dalton & Mendeleev's theory that all elementary atoms differing in mass and chemical properties
- Discovery of cathode rays and measurement of their properties11

Quantum Nature of Matter



- Fundamental Characteristics of different forms of matter

- Mass

- Charge

- Experimentally measurable

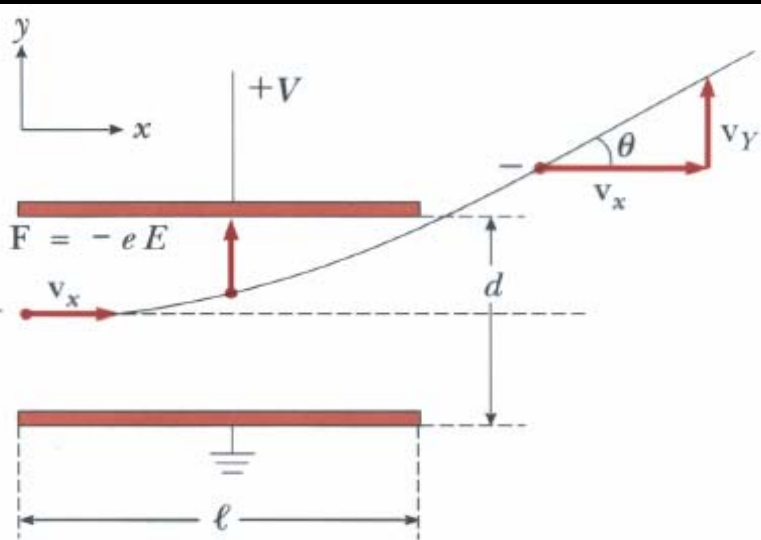
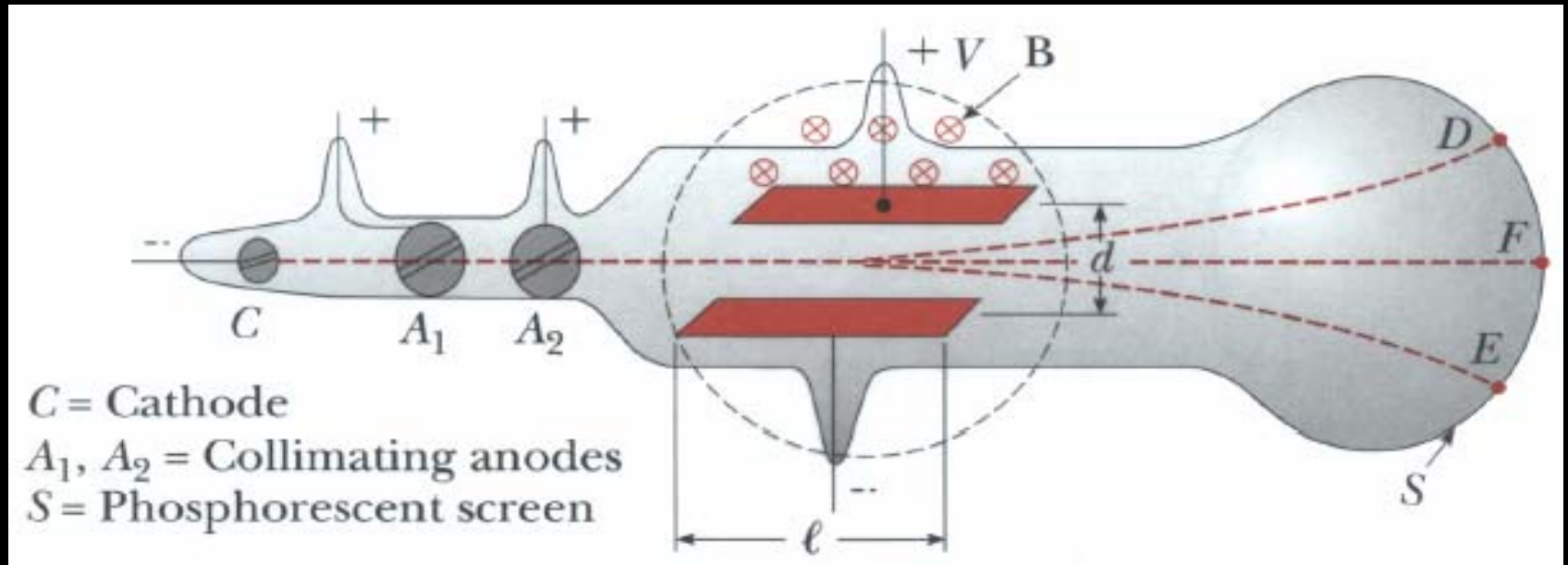
- using some combination of **E** & **B**

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

- **Or E/B and some other macroscopic force**

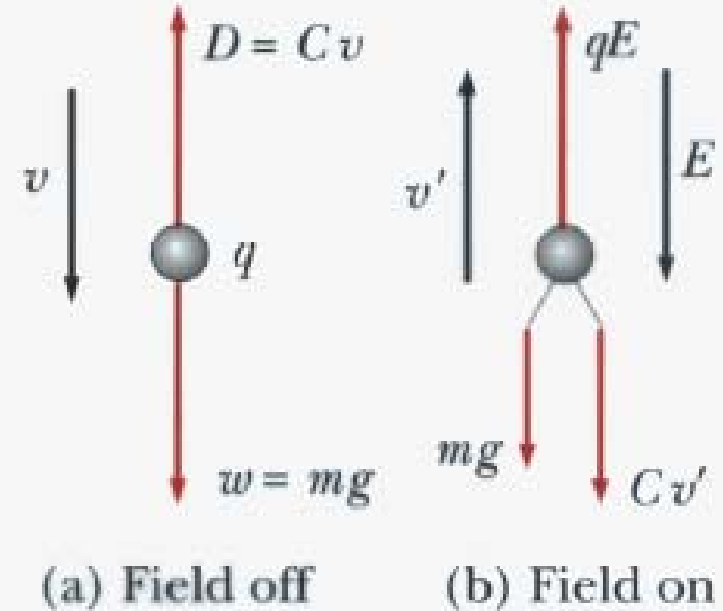
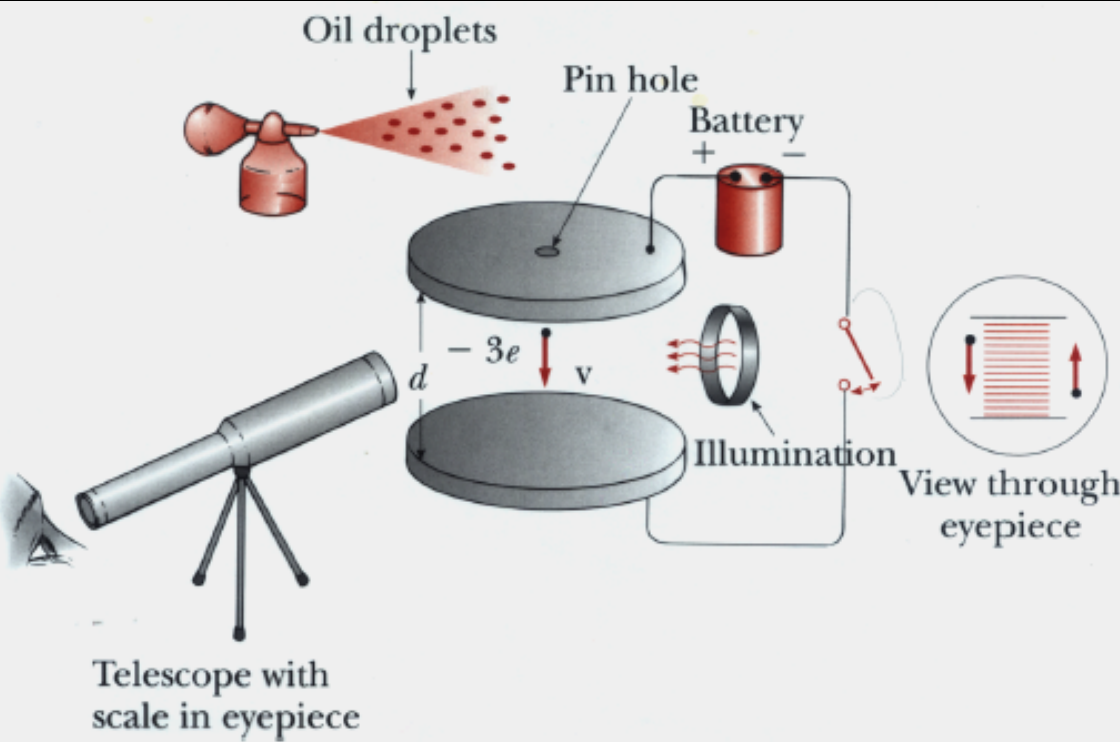
e.g. Drag Force

Thomson's Determination of e/m of Electron



- In E Field alone, electron lands at D
- In B field alone, electron lands at E
- When E and B field adjusted to cancel each other's force \rightarrow electron lands at F
 $\rightarrow e/m = 1.7588 \times 10^{11} \text{ C/Kg}$

Millikan's Measurement of Electron Charge



Find charge on oil drop is always in integral multiple of some Q

$$Q_e = 1.688 \times 10^{-19} \text{ Coulombs}$$

$$\rightarrow M_e = 9.1093 \times 10^{-31} \text{ Kg}$$

\rightarrow Fundamental properties (finger print) of electron
(similarly can measure proton properties etc)

Necessary Homework Reading



- Pl. read Section 3.1, including the discussion detailing the Millikan's oil drop experiment (download from www.freeman.com/modphys4e)
- This is straightforward reading. HW problems are assigned on this and the material may show up in the quiz

Ch 3 : 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
 - A firestorm of new ideas (NOT steady dragged out progress)
 - Old concepts violently demolished , new ideas born
 - Rich interplay of experimental findings & scientific reason
- One such revolution happened at the turn of 20th Century
 - Led to the birth of Quantum Theory & Modern Physics

Classical Picture of Light : Maxwell's Equations

Maxwell's Equations:

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

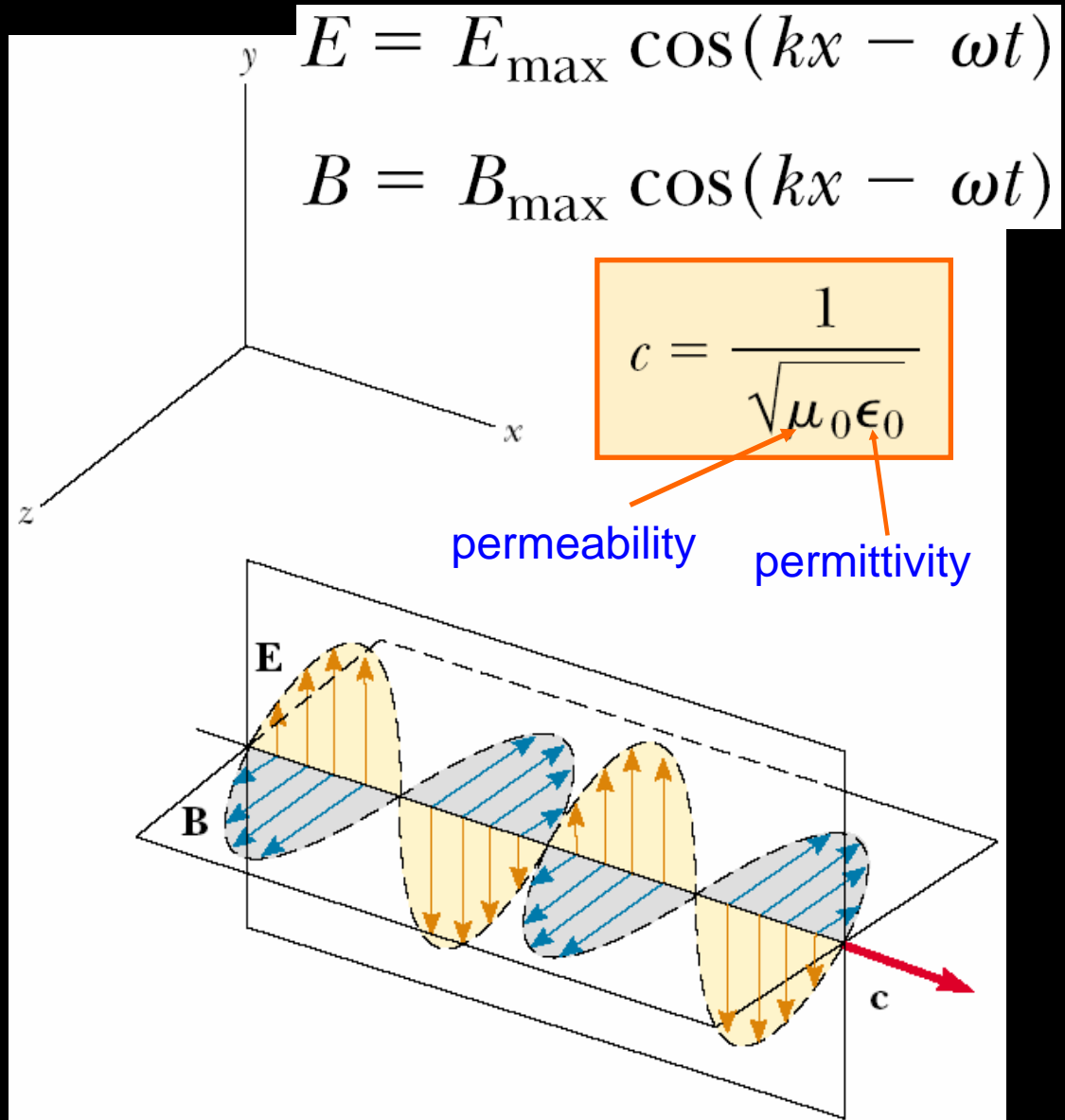
$$\oint_S \mathbf{B} \cdot d\mathbf{A} = 0$$

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

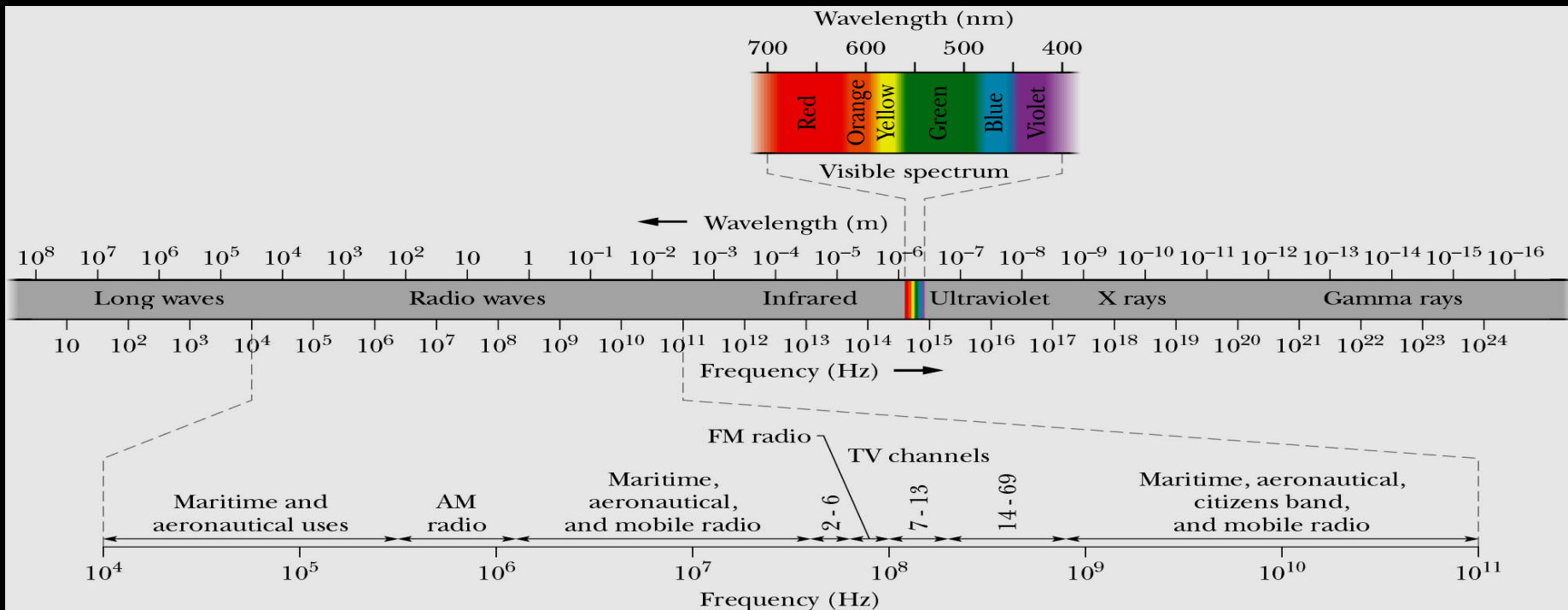
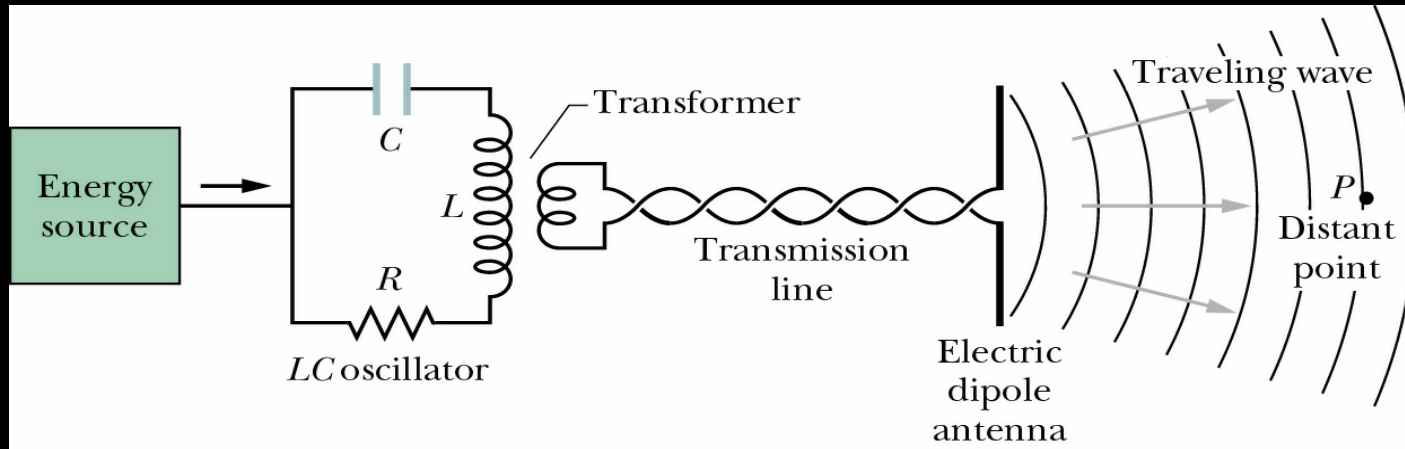
$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

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

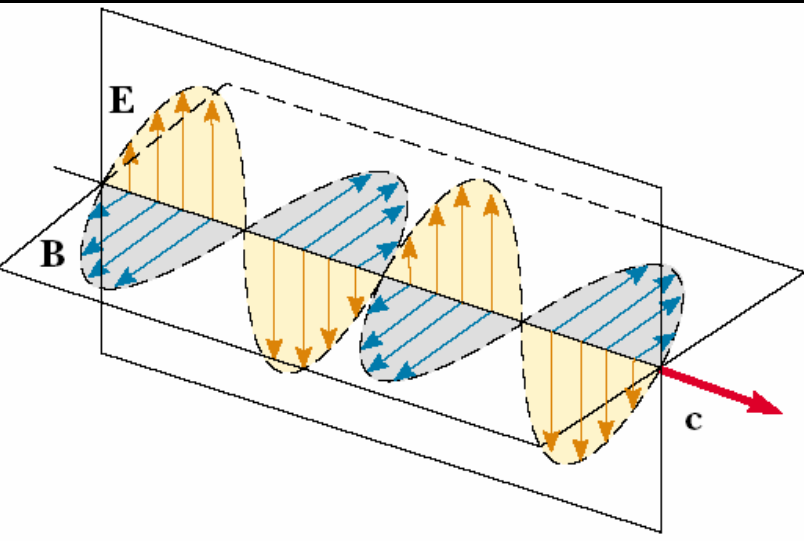
$$\frac{\partial^2 B}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2}$$



Hertz & Experimental Demonstration of Light as EM Wave



Properties of EM Waves: Maxwell's Equations



Energy Flow in EM Waves

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

Power incident on
an area A

$$= \vec{S} \cdot \vec{A} = \frac{1}{\mu_0} (AE_0B_0 \sin^2(kx - \omega t))$$

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

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

- 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

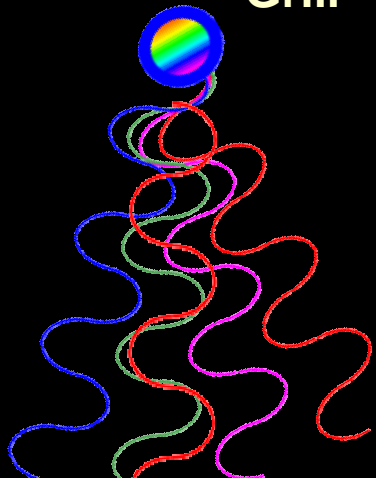
- → **QUANTUM PHYSICS: The Art of Conversation with Subatomic Particles**

Nature of Radiation: An Expt with BBQ Grill

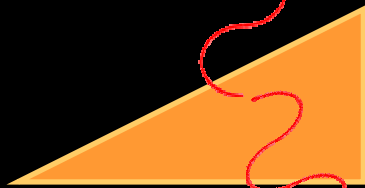
Question : Distribution of Intensity of EM radiation Vs T & λ

- Radiator (BBQ 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

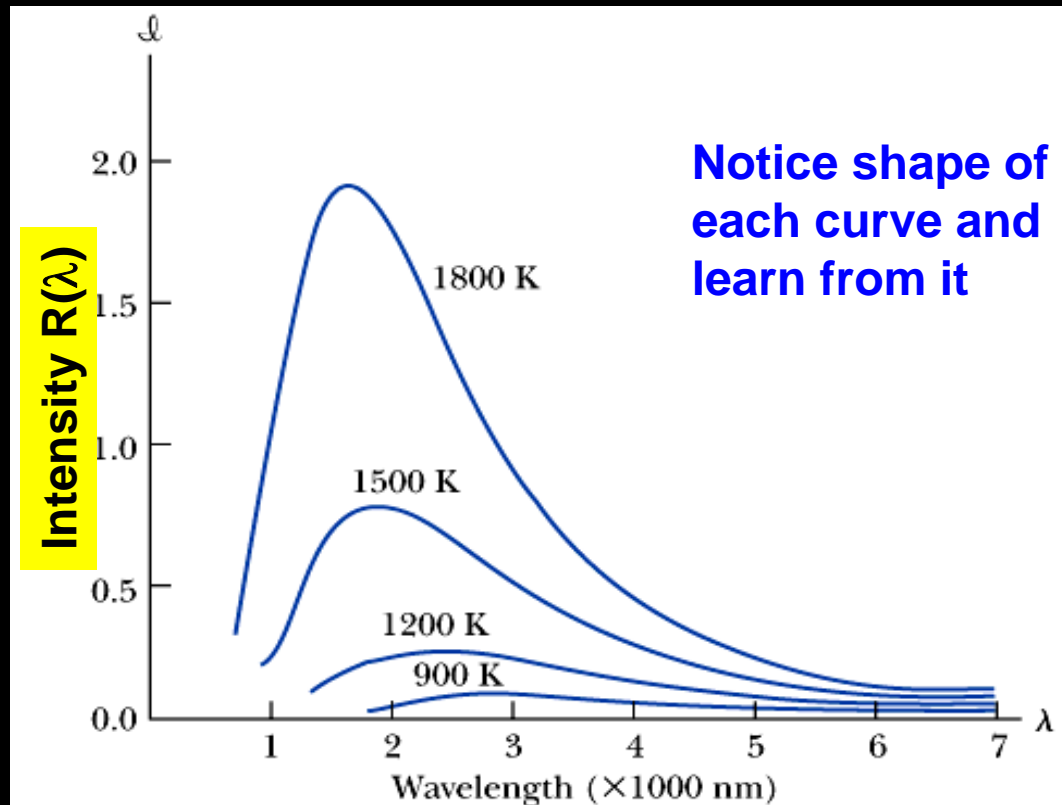
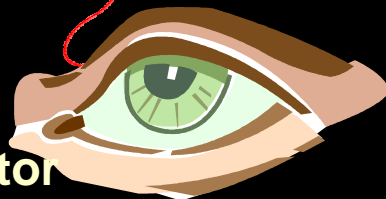
Grill



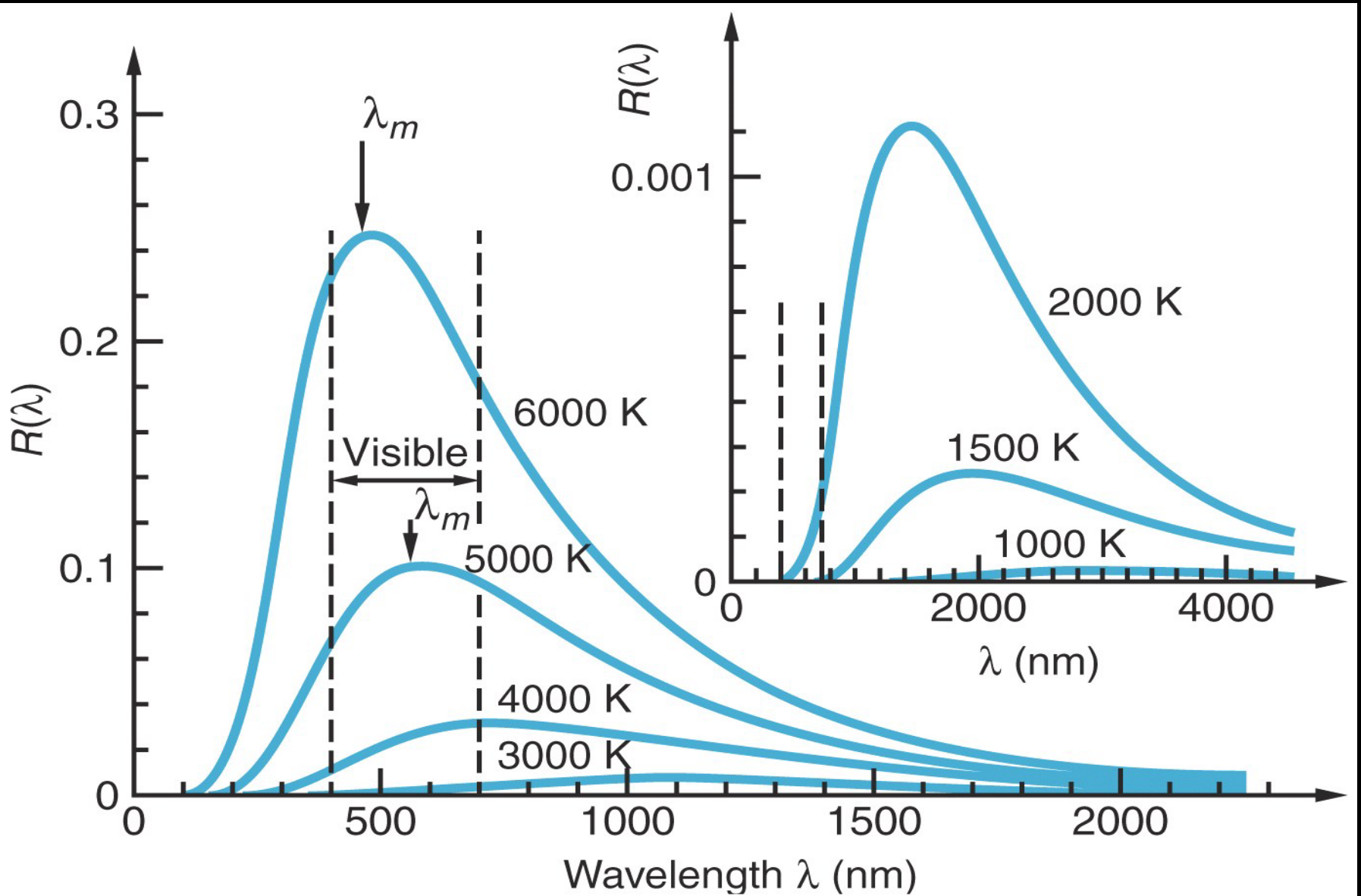
Prism separates
Out different λ



Detector



Radiation From a Blackbody at Different Temperatures

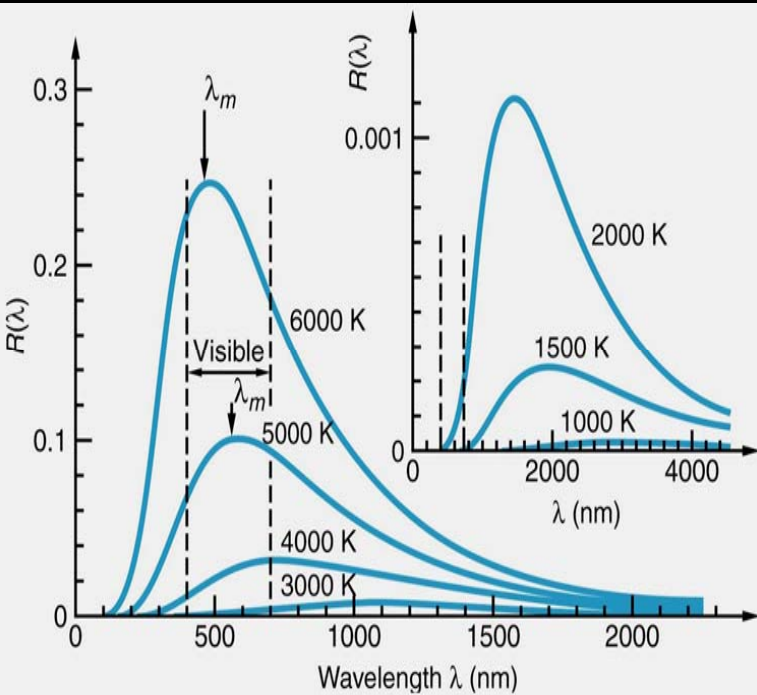


(a) Intensity of Radiation $I = \int R(\lambda) d\lambda \propto T^4$

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

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

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



$$I_{\text{MAX}} \propto 1 / T$$

$$\lambda_{\text{MAX}} T = \text{const} \\ = 2.898 \cdot 10^{-3} \text{ mK}$$

As a body gets hotter it gets more RED
then White : Wein's Law

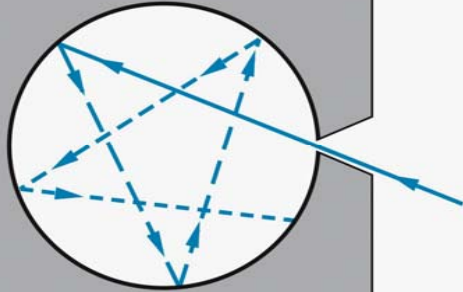
Reason for different shape of $R(\lambda)$ Vs λ for different temperature?
Can one explain in on basis of Classical Physics ??

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 many waves of wavelength λ can fit inside the box ?**

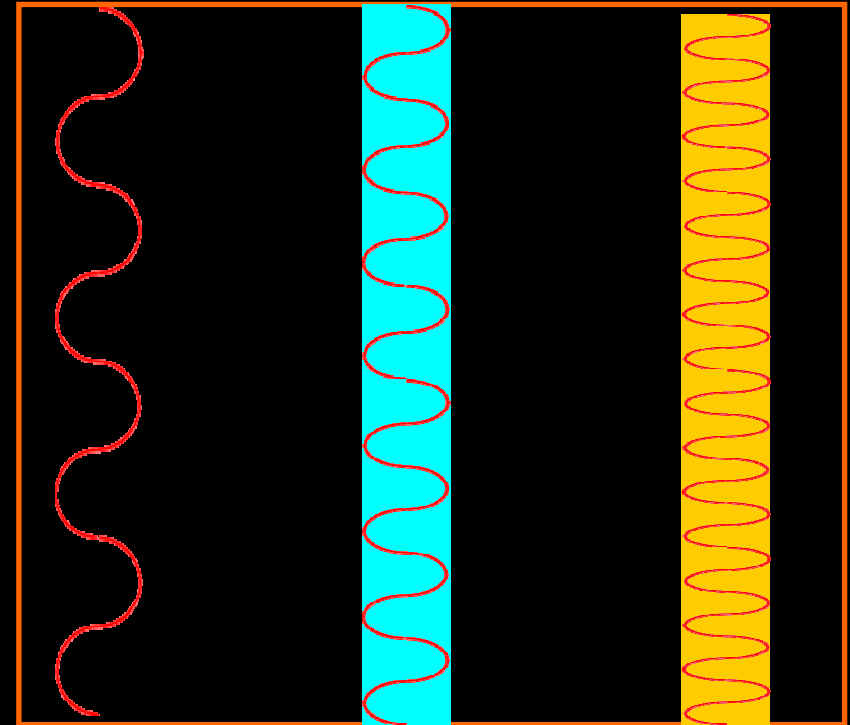


Blackbody Absorbs everything
Reflects nothing
All light entering opening gets absorbed
(ultimately) by the cavity wall

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 ?

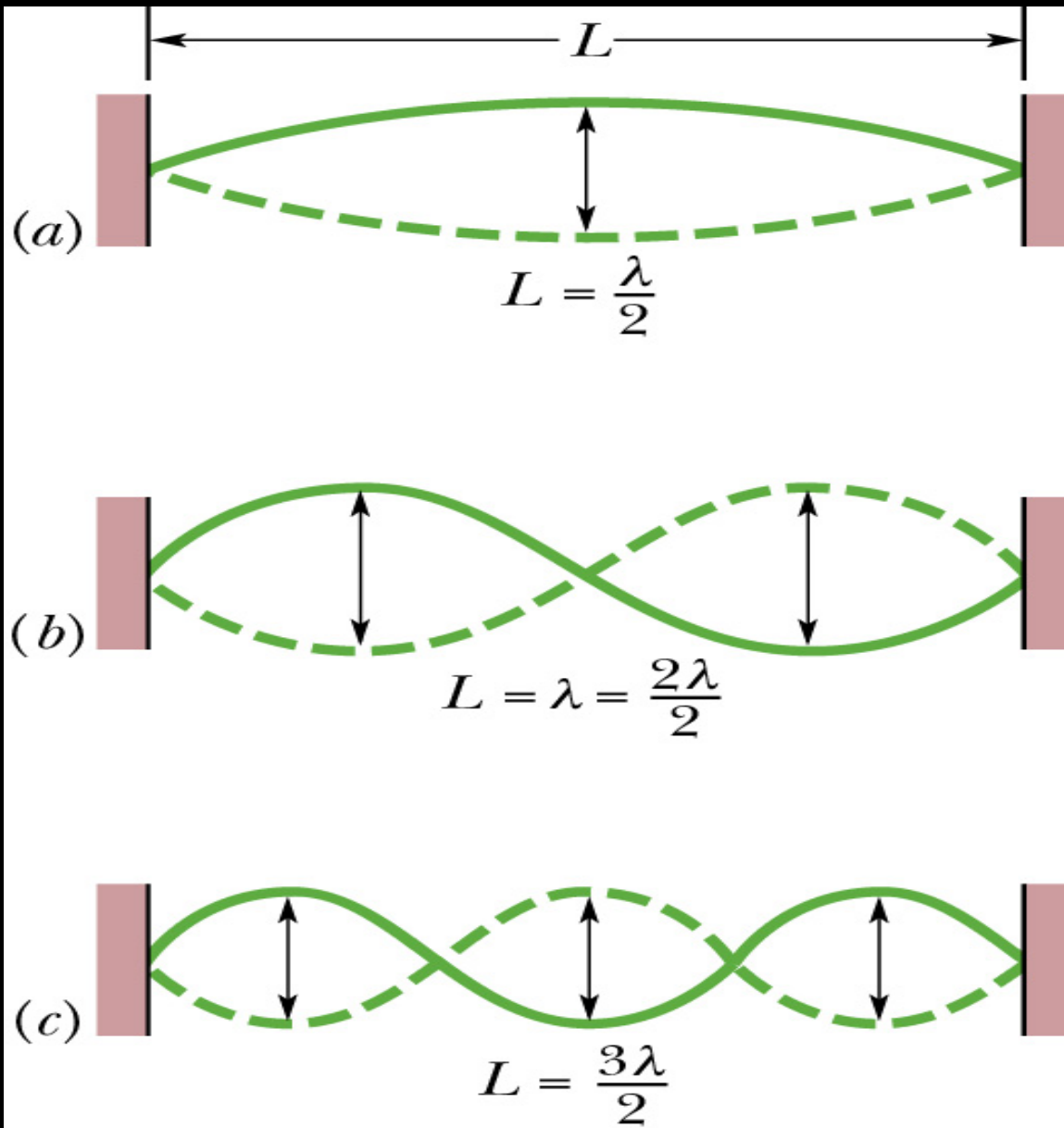


less

more

Even more

Standing Waves



The Beginning of The End ! How BBQ Broke Physics

Classical Calculation

of standing waves between Wavelengths λ and $\lambda+d\lambda$ 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 $u(\lambda) = [\text{\# of standing waves/volume}] \times \text{Energy/Standing Wave}$

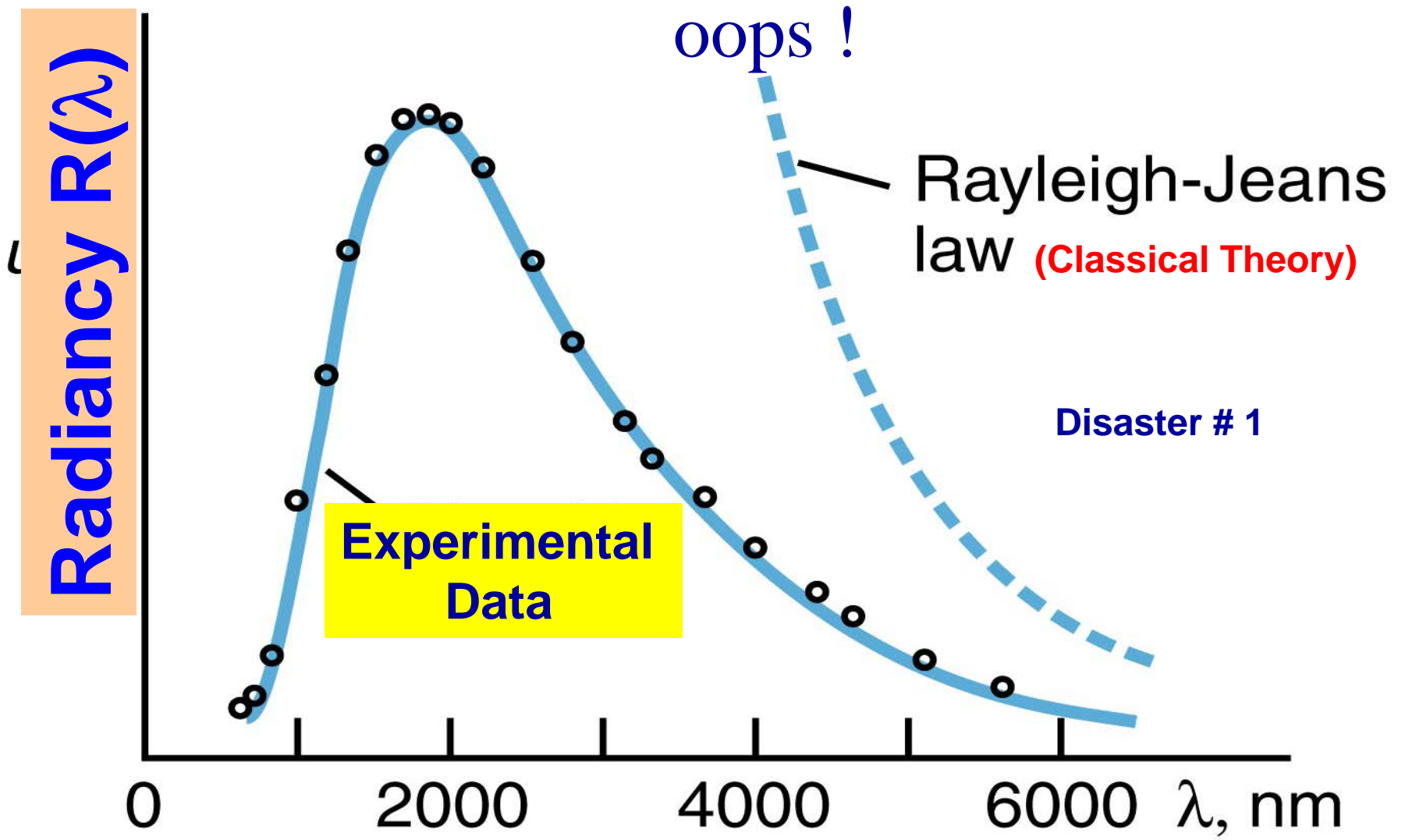
$$= \frac{8\pi V}{\lambda^4} \times \frac{1}{V} \times kT = \frac{8\pi}{\lambda^4} kT$$

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

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

**Prediction : as $\lambda \rightarrow 0$ (high frequency) $\Rightarrow R(\lambda) \rightarrow \text{Infinity} !$
Oops !**

Ultra Violet (Frequency) Catastrophe



That was a Disaster !

(#1)

