PH 202

INTRODUCTION

Team:

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Lectures will be a mix of PPT slides with chalk and board combination!

Class Schedule

Subject	Day	Time
PH202	Wednesday	(8:25 –9:20) AM
PH202	Thursday	(12:35 – 1:30) PM
PH202	Friday	(9:25 – 10:20) AM

Credits : 5

Distribution

Lecture : Tutorial : Practical = 3:1:1 credits

Evaluation

- **Mid-Sem I : 20 marks**
- **Mid-Sem II : 20 marks**
- **Internal/Assignments/Quiz :10 marks**
- **Laboratory: 20 marks**
- **Final Examination : 30 marks**

Passing Marks : 35

Evaluation

No one’s perfect. So partial credit will be given.

But do not fight for marks !!

The Importance of attending Class

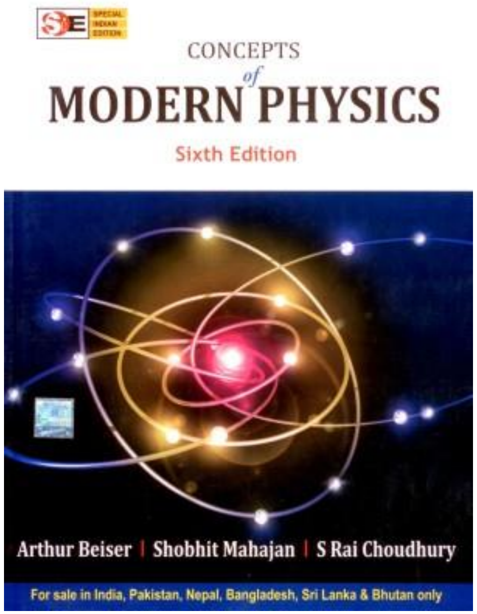
You should attend classes regularly because ppts do not contain everything !!

Last semesters, people who have skipped a lot of classes, received very bad grades. Conversely, people who came to most or all of the classes nearly always received A’s and B+’s.

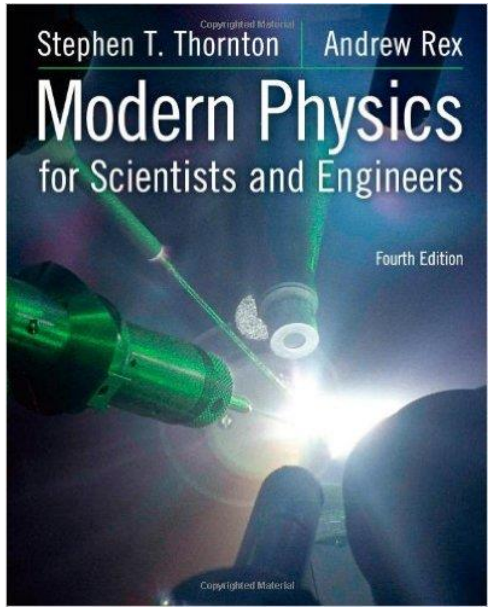
PH202 Syllabus

- Particle Properties of Waves
- Wave Properties of Particles
- Quantum Mechanics
- Solid State Physics
- Optics

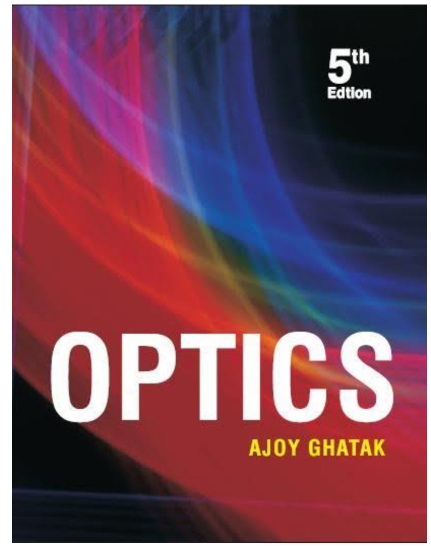
BOOKS



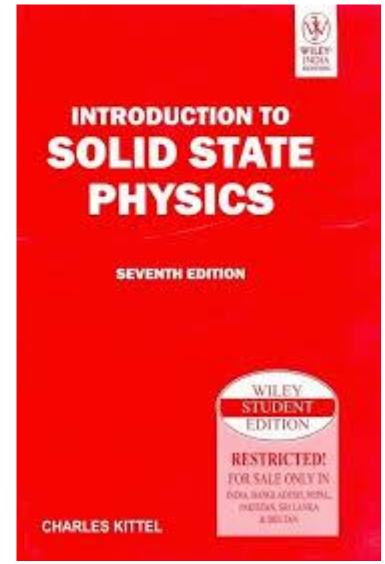
Modern Physics by Arthur C Beiser



Modern Physics for Scientists and Engineers by Thornton & Rex



Quantum Mechanics by Ajay Ghatak



Solid State Physics by Charles Kittel

Bible for Modern Physics

Particle Properties of Waves

- Black body Radiation
- Photo Electric Effect
- X-rays Diffraction
- Compton Effect

Wave Properties of Particles

- De Broglie Waves
- Particle Diffraction
- Particle in a box
- Uncertainty Principle

Quantum Mechanics

- Wave Equation
- Schrodinger Equation: Time dependent form
- Expectation Values, Operators
- Schrodinger’s Equation in steady state form
- Potential Well, Tunnel Effect
- Harmonic Oscillator, Hydrogen Atom

Solid State Physics

- Crystalline and Amorphous Solids
- Ionic and Covalent Crystals
- Vander Walls Bond and Metallic Bond
- Band Theory of Solids
- Semiconductor Devices
- Super Conductivity

Optics

- Fermat’s Principles
- Huygens Principle
- Superposition of waves
- Reflection, refraction, diffraction

Why modern physics

- Essentially Post – 1900 era
- Two major developments: Quantum Mechanics & Theory of Relativity
- Beyond Newtonian and Maxwellian Physics

Electricity & Magnetism

Maxwell Equations
- Gauss' Law
- Faraday's Law
- Ampere's Law
- No magnetic monopoles

Statistical Mechanics
- 3 Laws of Thermodynamics
- Kinetic Theory

Conservation Laws
- Energy
- Linear & Angular Momentum

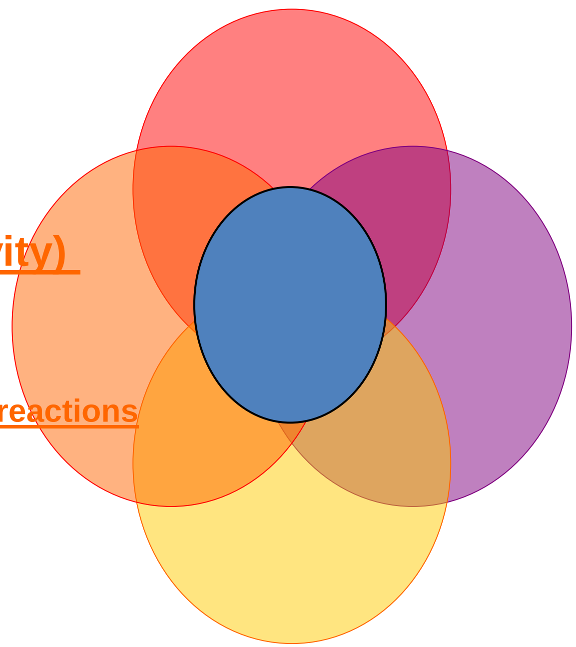
Mechanics (Gravity)

Newton's Laws

1-Law of inertia

2-F=ma

3-Equal and opposite reactions



Development in post-1900, Era of Modern Physics

1. Enhanced increase in understanding of statistical physics based on Bose-Einstein and Fermi-Dirac statistics for integer and half integer spin objects.

2. Increased understanding of molecular structures, bonding and dynamics was rapidly developed.

3. Rapid development in Solid state physics. Much was and still is being learned about how materials form, have quantum mechanically determined energy “bands”, and so forth. Particularly important was the development of a thorough understanding of semiconductors and related devices as well as the discovery and eventual (at least partial) understanding of superconductivity.

Development in post-1900, Era of Modern Physics

4. Lasers are based upon coherent wave phenomena as well as semiconductor physics and have become a part of everyday life.

5. Nuclear physics was developed, eventually leading to the fission and fusion bombs and nuclear energy, an alternate energy source for human being.

6. Areas of cosmology and elementary particle physics in which work is going on understanding the inner structure of matter, e.g. what is inside a proton, what are the actual carriers of forces, what is dark energy, what is dark matter etc.

We will focus on
first 4 points

Developments in pre 1900 era

Newtonian Physics

$$\vec{F} = m\vec{a} = m\frac{d^2\vec{x}}{dt^2} = \frac{d\vec{p}}{dt}$$

$$\vec{p} = m\vec{v}$$

$$\sum \vec{P}_{initial} = \sum \vec{P}_{final} \quad \text{when} \quad \vec{F} = 0$$

Valid for linear as well as angular momentum

Developments in pre 1900 era

$$\sum \mathrm{E}_{\text{initial}} = \sum E_{\text{final}}$$

Conservation of Energy

$$W = \int F \cdot dx = \int mv \cdot dv = C + \frac{1}{2} mv^2$$

Work done

Maxwell’s Theory

$$\oint E \cdot dA = \frac{Q}{\varepsilon}$$ Gauss’s Law of Electricity

$$\oint B \cdot dA = 0$$ Gauss’s Law of magnetism

$$\oint E \cdot dl = -\frac{d\varphi_B}{dt}$$ Faraday’s Law of Induction

$$\oint B \cdot dl = \mu_0 I_{enclosed} + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$ Ampere's Law

Consequence of Maxwell's equations

Electromagnetic waves propagate at the speed of

$$C = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 2 \cdot 997 \times 10^8 \,\mathrm{m}s^{-1}$$

Maxwell deduced in 1865 and Hertz experientially confirmed this in 1887

Classical vs ***Quantum*** world

In everyday life,
quantum effects
can be safely
ignored

At atomic & subatomic scales,
quantum effects
are dominant & must be
considered

This is because
Planck's constant is so small

Laws of nature
developed without
consideration of
quantum effects do not work
for atoms

- World of macro
- Objects are distinguishable

- World of micro or Nano
- Objects are indistinguishable

Need for Quantum Physics

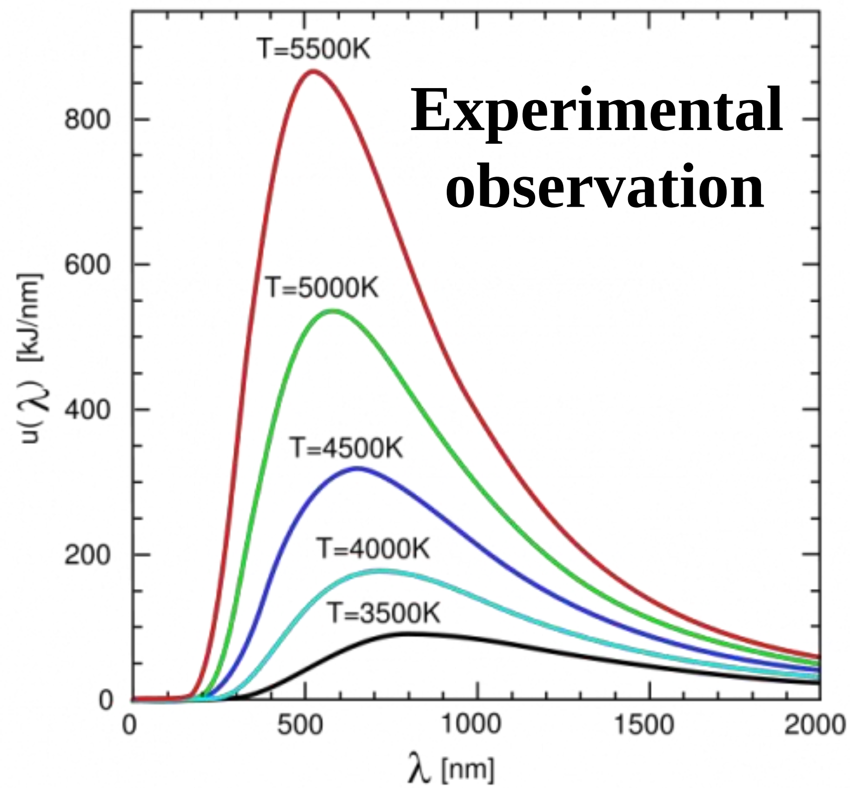
- The laws of classical physics were unsuccessful to explain the phenomena at the atomic scale level.
- Problems included:
  - Blackbody radiation
    - The electromagnetic radiation emitted by a heated object
  - Photoelectric effect
    - Emission of electrons by an illuminated metal

The first explanation using quantum theory was introduced by Max Planck.

Many other physicists were involved in other subsequent developments

- The basic problem was in understanding the observed distribution in the radiation emitted by a black body.

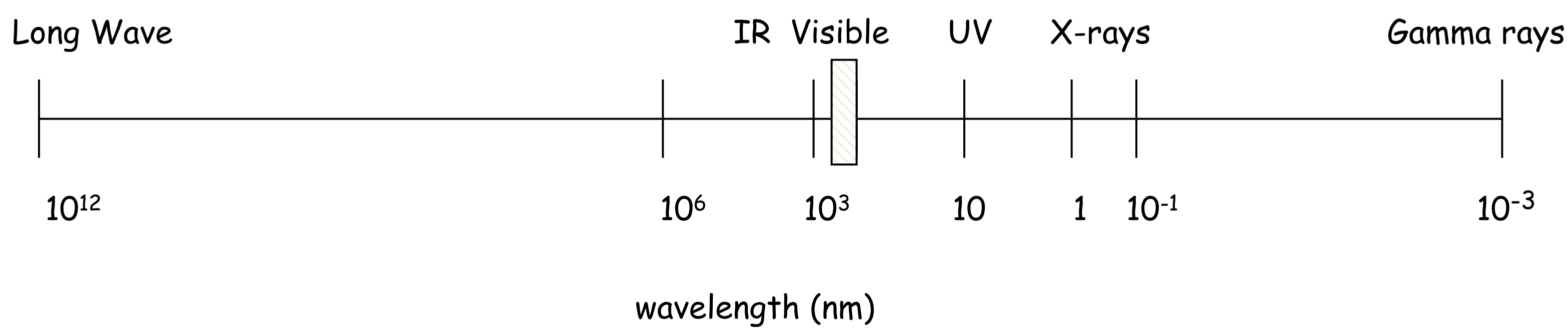
  – Classical physics didn't adequately describe the observed distribution.



- A **black body** is an ideal system that absorbs all radiation incident on it.
- The electromagnetic radiation emitted by a black body is called **blackbody radiation.**

Blackbody Radiation

- An object at any temperature is known to emit thermal radiation.
  - Radiation characteristics depend on the temperature and surface properties.
  - The radiation consists of a continuous distribution of wavelengths from all portions of the electromagnetic spectrum.



Every object is black body !!

If so why we can’t see the radiations emitted by our body

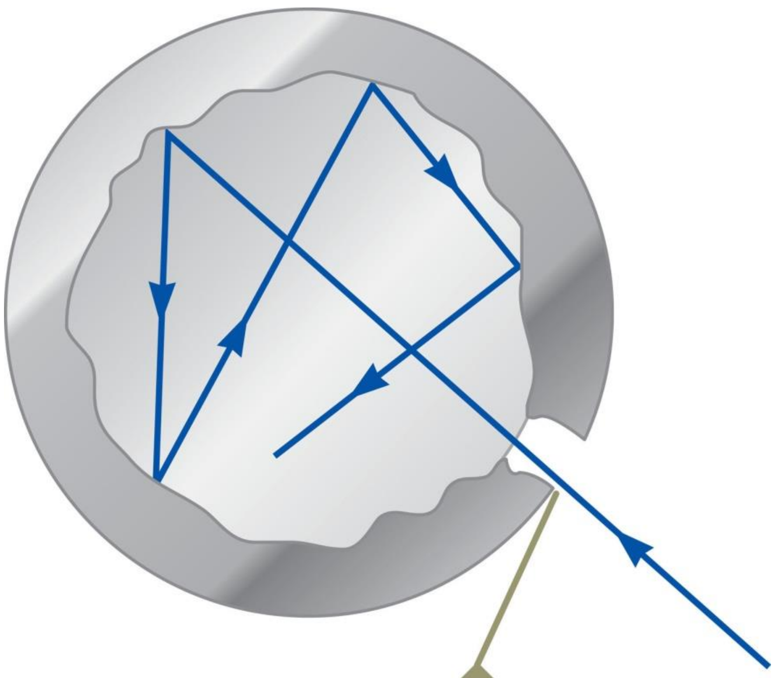
- At room temperature, the wavelengths of the thermal radiation are mainly in the infrared region.
- As the surface temperature increases, the wavelength changes. It will glow red and eventually white.

Quantum nature of radiation

1st evidence from spectrum emitted by a black-body

What is a black-body? Why black ?

An object that absorbs all incident radiation, *i.e.* no reflection



The opening to a cavity inside a hollow object is a good approximation of a black body: the hole acts as a perfect absorber.

<u>A typical example</u>

A small hole cut into a cavity is the most popular and realistic example.

⇒None of the incident radiation escapes

What happens to this radiation?

How the cavity resemblances blackbody

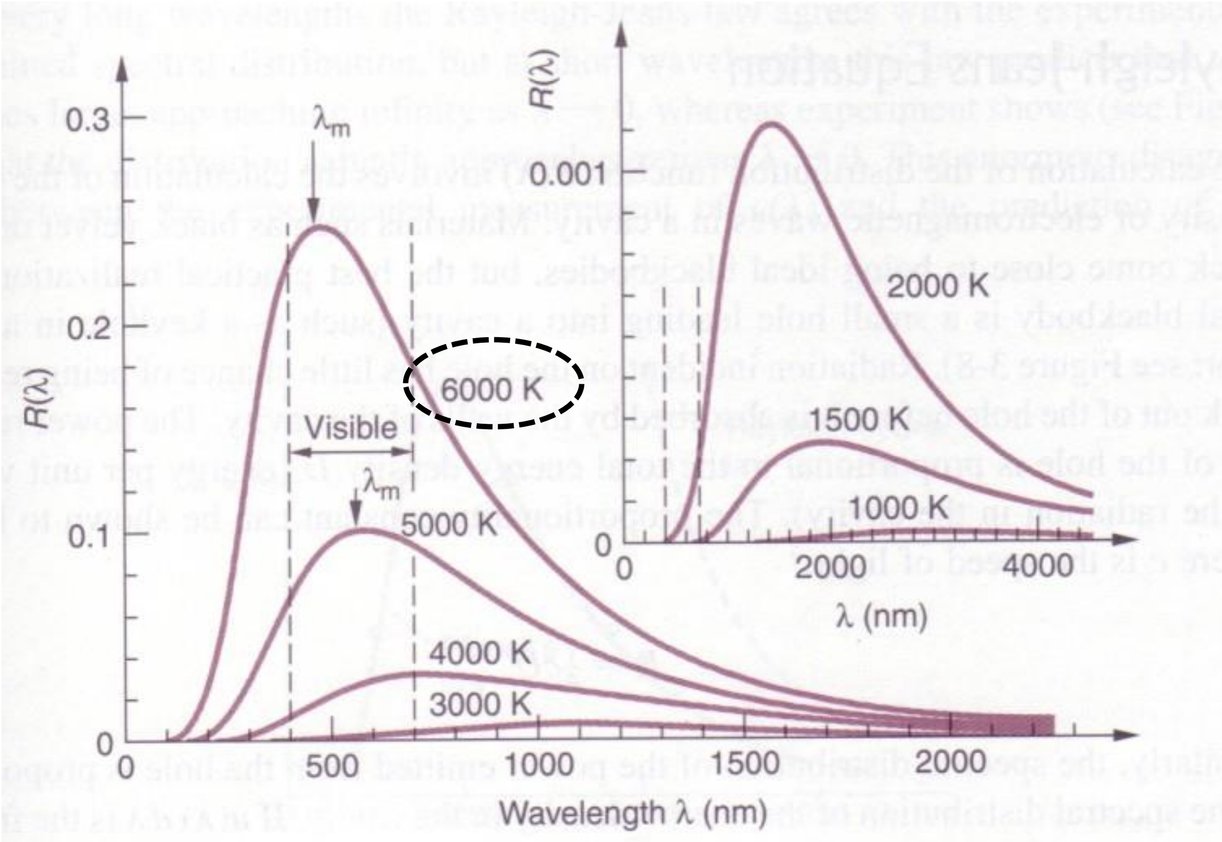
• The radiation is absorbed in the walls of the cavity through multiple reflections
• This causes a heating of the cavity walls
• Atoms in the walls of the cavity will vibrate at frequencies characteristic of the temperature of the walls
• These atoms then re-radiate the energy at this new characteristic frequency

EM wave absorbed ⟹ Energizes the molecules

Radiation of energy

A sequential process

Black-body spectrum

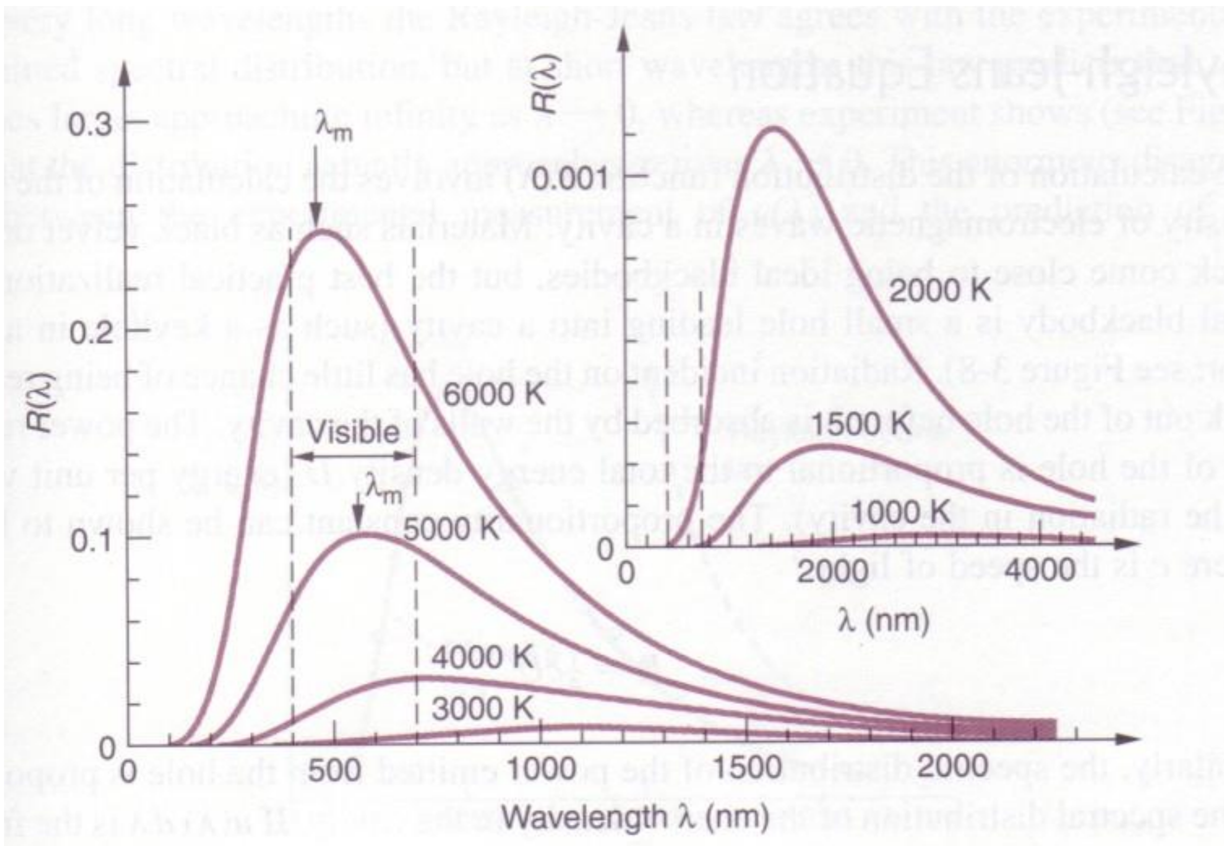


- ➢ λ_m is temperature dependent
- ➢ λ_m is peak wavelength

• Black-bodies do not “REFLECT" but re-radiate, the emission characterizes the black-body only

• The emission from a black-body depends on its temperature

Black-body spectrum



Objects around (at 300 K) radiate in the infrared
Objects at (600 – 700) K start to glow

At high T, objects may become white hot **Why**

How can you determine the surface Temperature of STARS, SUPERNOVA etc **hint: Blackbody radiation**

Rayleigh-Jeans equation (Classical Physics)

Consider the cavity as it emits blackbody radiation

Spectral energy distribution $u(\lambda)d\lambda$ is the energy per unit volume in the cavity within the wavelength range λ to $\lambda + d\lambda$.

$u(\lambda)d\lambda$ = (Number of modes in cavity in range $d\lambda$) × (average energy of modes)

n(λ) is calculated from statistical physics.

Number of modes in cavity in range $d\lambda$, $n(\lambda)d\lambda = 8\pi\lambda^{-4}\,d\lambda$
From kinetic theory, average energy per mode is k_BT

Therefore spectral energy density is

$$\Rightarrow \quad u(\lambda) = k_BTn(\lambda) = 8\pi k_BT\lambda^{-4}$$

The ultraviolet catastrophe

- Serious flaws in the reasoning by Rayleigh and Jeans
- The result does not agree with experiment
- Even worse, it predicts an infinite energy density as $\lambda \rightarrow 0$!

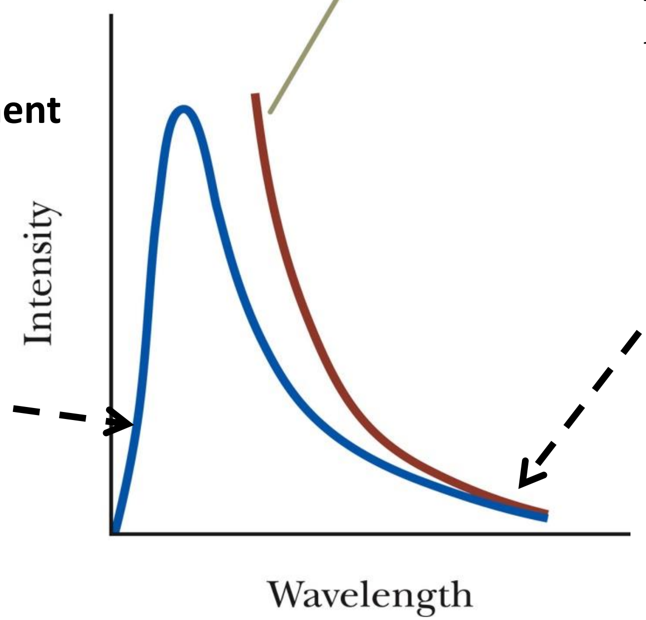
(This was termed the ultraviolet catastrophe at the time by Paul Ehrenfest)

The classical theory (red-brown curve) shows intensity growing without bound for short wavelengths, unlike the experimental data (blue curve).

Agreement between theory and experiment is only to be found at very long wavelengths.

UC characteristics

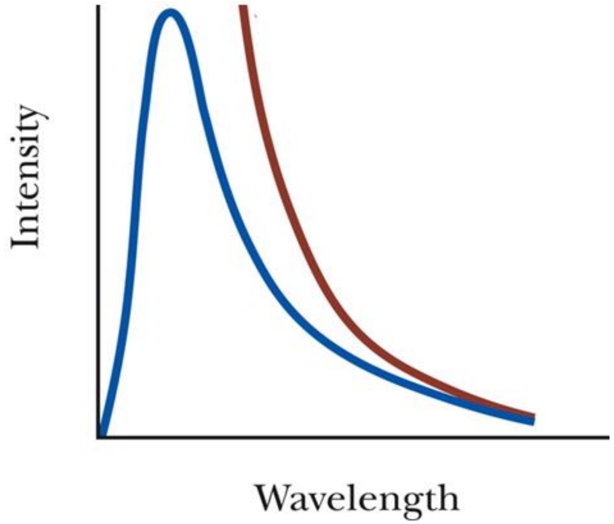
- **At short wavelengths, a major disagreement between the Rayleigh-Jeans law and experiment.**
- **It predicts infinite energy as the wavelength approaches zero.**



The ultraviolet catastrophe

$$n(\lambda)d\lambda = \frac{8\pi}{\lambda^4}d\lambda$$

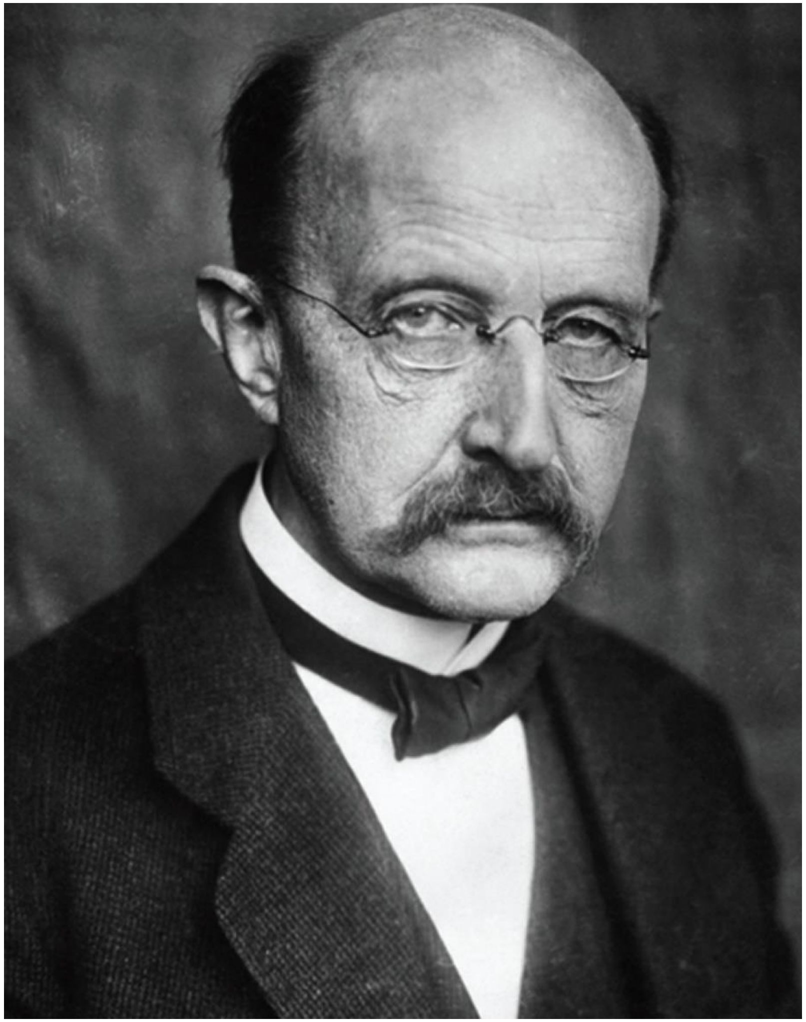
Result is ultra violate catastrophe
Energy going unbounded



- The problem is that statistics predict an infinite number of modes as $\lambda \rightarrow 0$
- Classical kinetic theory ascribes an energy k_BT to all these modes!

How Planck solved this problem

- 1858 – 1947
- German physicist
- Introduced the concept of “quantum of action”
- In 1918 he was awarded the Nobel Prize for the discovery of the quantized nature of energy.

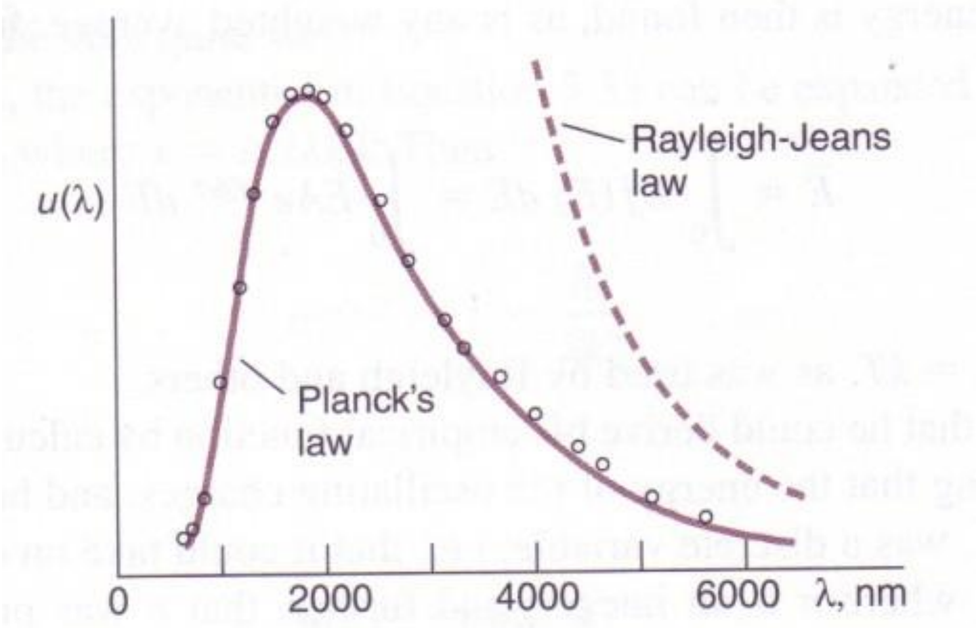


Max Planck

Planck's Theory of Blackbody Radiation

- In 1900 Planck developed the theory of blackbody radiation leading to the intensity of the radiation.

- This equation is in complete agreement with experimental observations.
- Planck made two assumptions for his theory.

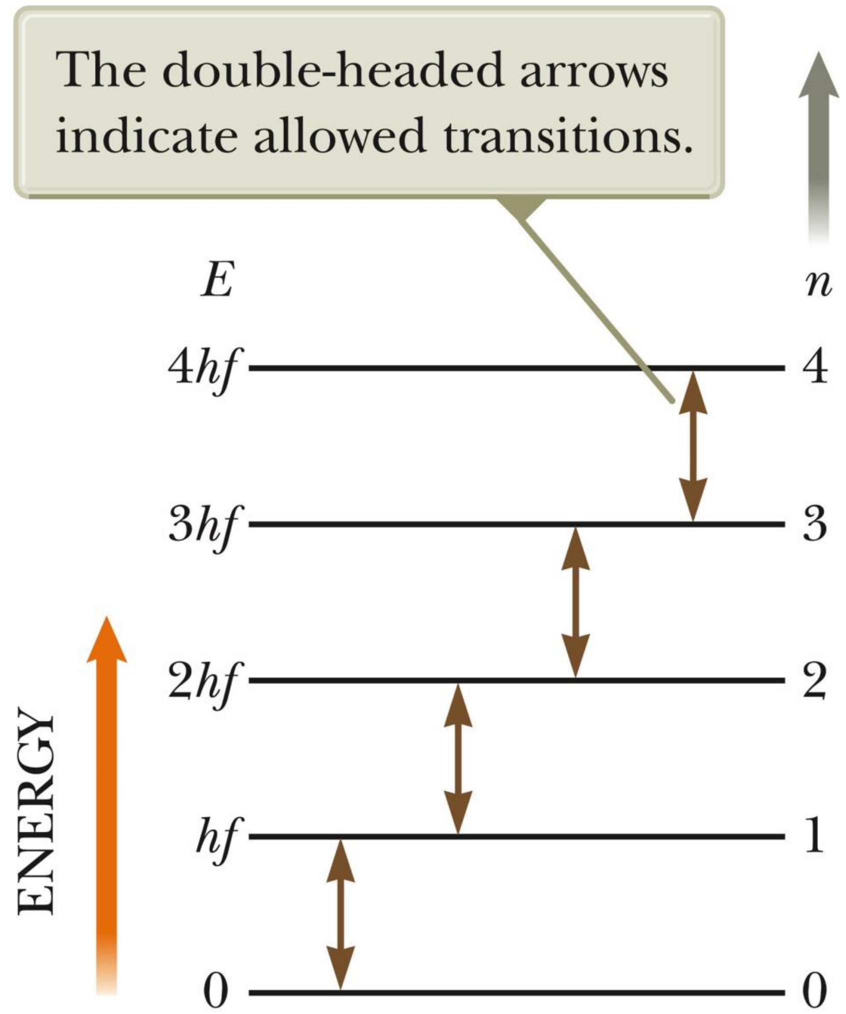


Planck's Assumption, 1

- The energy of an oscillator can have only certain discrete values $E_{n.}$
  - $E_n = n\,h\,f$
    - n is a positive integer called the quantum number
    - f is the frequency of oscillation
    - h is Planck's constant
  - This says the energy is <u>quantized</u>.
  - Each discrete energy value corresponds to a different quantum state.
    - Each quantum state is represented by the quantum number, *n.*

Planck's Assumption, 2

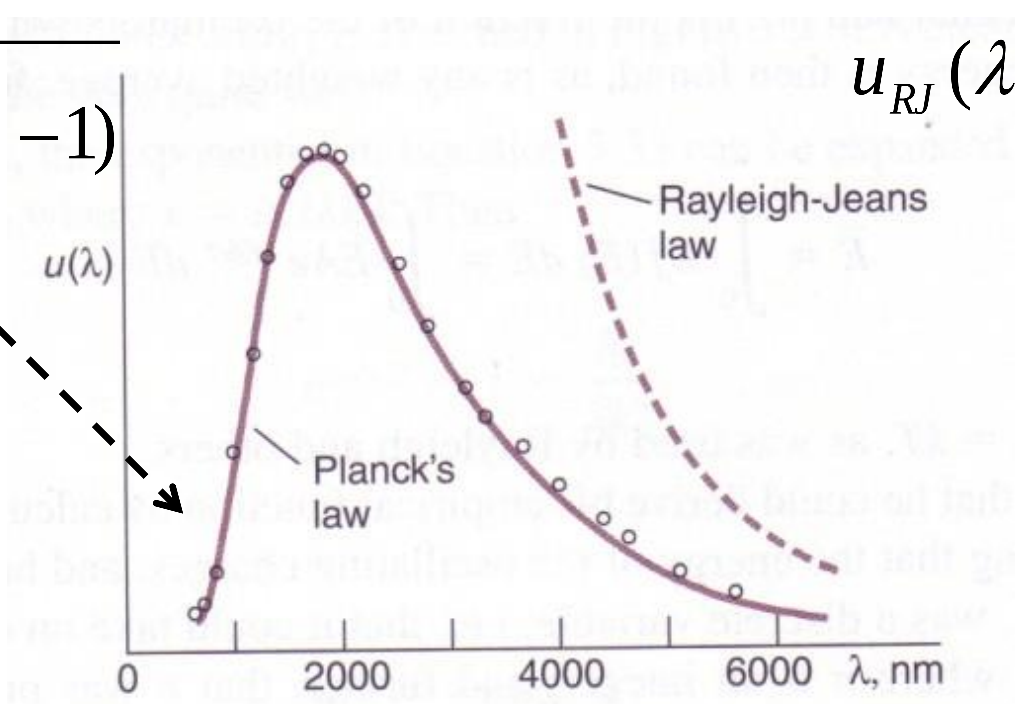
- The oscillators emit or absorb energy when making a transition from one quantum state to another.
  - An oscillator emits or absorbs energy only when it changes quantum states.
  - The energy carried by the quantum of radiation is $E = h f$.



Planck's Wavelength Distribution Function

$$u_P(\lambda) = \frac{8\pi hc}{\lambda^5 \left(e^{hc/\lambda k_B T} - 1\right)}$$

$$u_{RJ}(\lambda) = \frac{8\pi kT}{\lambda^4}$$



- h = 6.626 x 10^{-34} J·s
- h is a fundamental constant of nature.

Average energy per mode

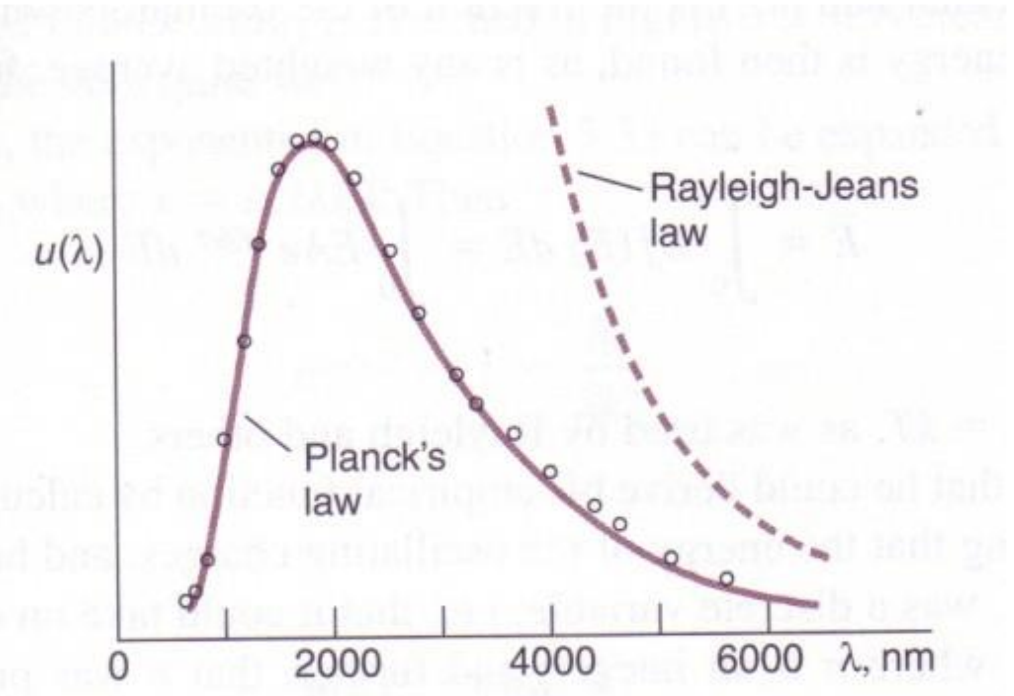
$$u_P(\lambda) = \frac{8\pi \overbrace{hc/\lambda}}{\lambda^4 \left(e^{hc/\lambda k_B T} - 1\right)}$$

Number of modes

Planck's Wavelength Distribution Function

$$u_P(\lambda) = \frac{8\pi hc}{\lambda^5 \left(e^{hc/\lambda k_B T} - 1\right)}$$

A lucky guess



- At long wavelengths, Planck's equation reduces to the Rayleigh-Jeans expression.

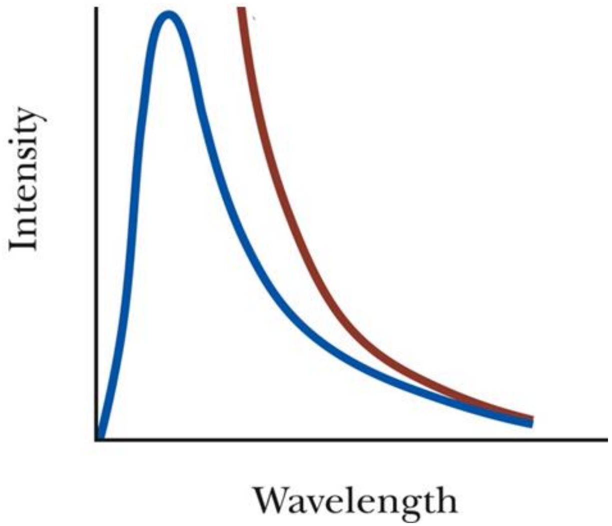
$$\lambda^5 (e^{hc/\lambda k_B T} - 1)$$

$$\Big\Downarrow \quad \lambda \text{ large}$$

$$\lambda^5 \left(1 + \frac{hc}{\lambda k_B T} - 1\right)$$

$$\Big\Downarrow$$

$$\lambda^4 \frac{hc}{k_B T}$$



$$u_P(\lambda) = \frac{8\pi hc}{\lambda^5 (e^{hc/\lambda k_B T} - 1)} \quad \Longrightarrow \quad u(\lambda) = \frac{8\pi k_B T}{\lambda^4}$$

Rayleigh-Jeans Law

- At short wavelengths, it predicts an exponential decrease in intensity ($u(\lambda)$) with decreasing wavelength.

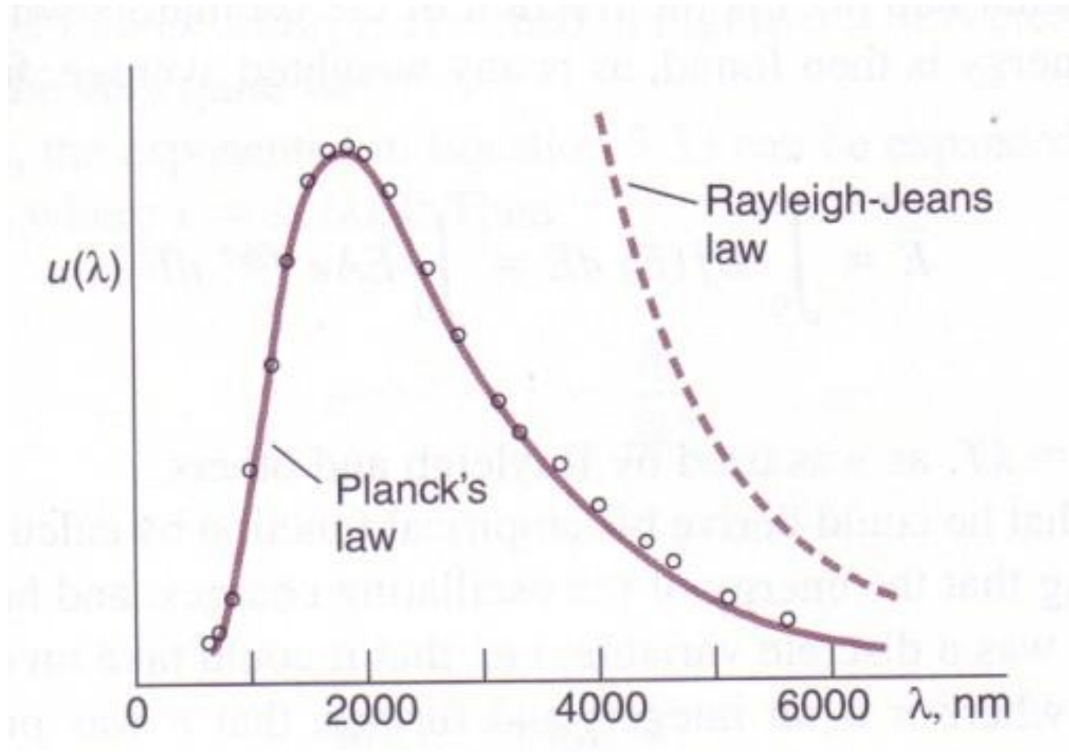
In the denominator,

$$(e^{hc/\lambda k_B T} - 1)$$

λ small
Therefore, $e^{hc/\lambda k_B T}$ **goes up**

$$\infty$$

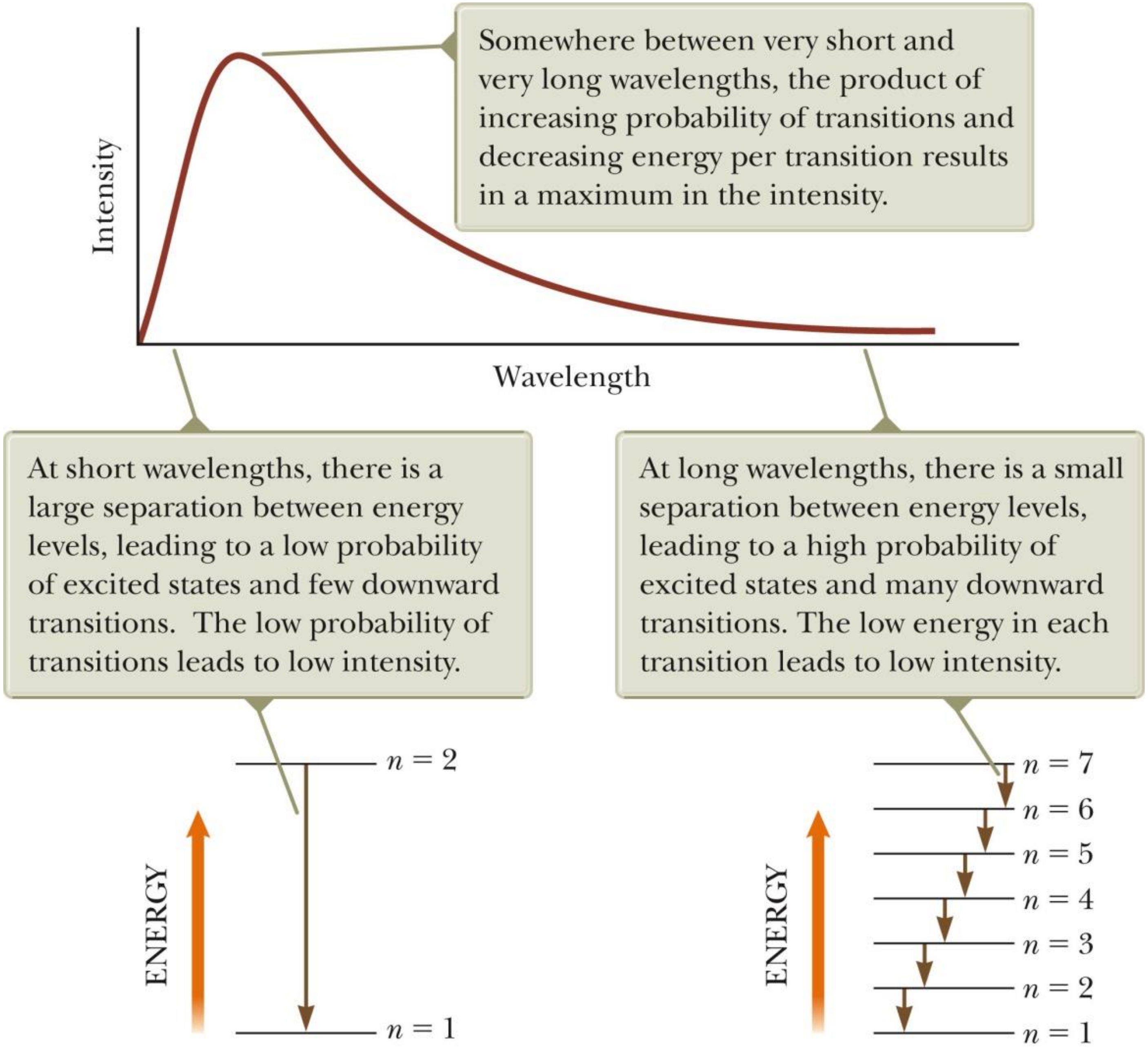
$$u(\lambda) \to 0$$



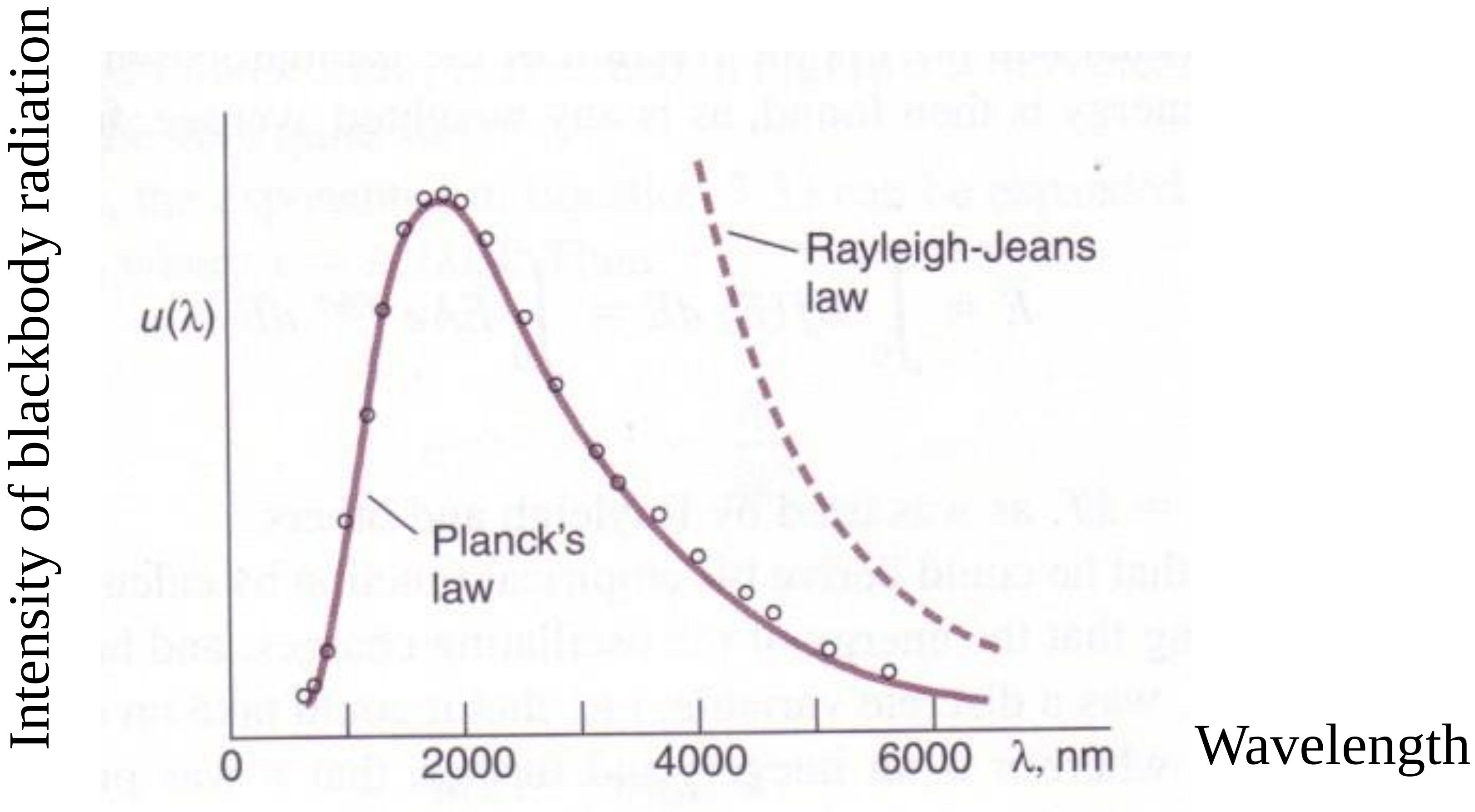
Note: the denominator [$\exp(hc/\lambda k_B T)$] tends to infinity faster than the numerator (λ^{-5}), thus resolving the ultraviolet catastrophe, *i.e.* $u(\lambda) \to 0$ as $\lambda \to 0$.

- Now everything is in agreement with the experimental results.

Planck’s Model, Graph



The Planck Distribution



Planck credited with the birth of quantum mechanics (1900)
- developed the modern theory of black-body radiation