Median and mean grade: ~ 21 = ~ 85

Affiliation
N/A

Question 1: Indicate whether you are from other or in Columbia.

a: Engineering	42%
b: Barnard	22%
c: General Studies	0%
d: Other	36%
e: College	1%
N/A	0%

Question 2: If 'Other,' please specify

No Comments	58%
Comments	42%

Helpfulness
Please rank the following in terms of their assistance to you in preparing for the exam.

Question 1: Class Lectures

a: very useful	16%
b: useful	73%
c: not useful	10%
N/A	1%

Question 2: Homework assignments from the text

a: very useful	59%
b: useful	39%
c: not useful	2%
N/A	0%

Question 3: Recitation section

a: very useful	26%
b: useful	58%
c: not useful	16%
N/A	0%

N/A 0%

Question 4: Multiple choice homework assignments

a: very useful 62%
b: useful 35%
c: not useful 2%
N/A 1%

Question 5: Other (please specify):

No Comments 52%
Comments 48%

Question 6: Comments:

No Comments 38%
Comments 62%

CourseWorks

N/A

Question 1: Courseworks worked well for me to obtain information on the course syllabus and exam materials.

a: strongy agree 59%
b: agree 35%
c: disagree 5%
d: strongy disagree 1%
N/A 0%

Question 2: Comments

No Comments 38%
Comments 62%

Exam

Exam
N/A

Question 1: On the average, how many hours per week have you spent preparing for the course by reading, studying for quizzes or completing homework assignments?

a: Less than 5 h	19%
b: 5-10 h	43%
c: 11-15 h	28%
d: 16-20 h	7%
e: More than 20 h	3%
N/A	1%

Question 2: Please indicate your opinion of the exam.

The exam covered materials that were stressed in the homework.

a: strongly agree	32%
b: agree	59%
c: disagree	7%
d: strongly disagree	1%
N/A	0%

Question 3: The exam covered materials that were stressed in the lectures.

a: strongly agree	24%
b: agree	67%
c: disagree	7%
d: strongly disagree	2%
N/A	1%

Question 4: The exam covered materials that were stressed in the practice multiple choice questions.

a: strongly agree	67%
b: agree	29%
c: disagree	3%
d: strongly disagree	0%
N/A	1%

Question 5: The exam covered materials that were stressed in the recitation sections.

a: strongly agree	21%
b: agree	61%
c: disagree	13%
d: strongly disagree	5%
N/A	0%

Question 6: Based on the information presented concerning the exam, the exam was fair.

a: strongly agree	45%
b: agree	50%
c: disagree	3%
d: strongly disagree	1%
N/A	0%

Study Methods

N/A

Question 1: Indicate whether you studied for this course most often

a: Alone	67%
b: With one other	22%
c: In a small group	11%
N/A	0%

Ratings

N/A

Question 1: Instructor: Organization and Preparation

a: excellent	39%
b: very good	46%
c: satisfactory	13%
d: poor	0%
e: disastrous	1%
N/A	0%

Question 2: Instructor: Approachability

a: excellent	33%
b: very good	45%
c: satisfactory	20%
d: poor	2%
e: disastrous	0%
N/A	1%

Question 3: Course: Amount Learned

a: excellent	28%
b: very good	47%
c: satisfactory	24%
d: poor	1%
e: disastrous	1%
N/A	0%

Question 4: Course: Appropriateness of Workload

a: excellent	27%
b: very good	48%
c: satisfactory	22%
d: poor	2%
e: disastrous	1%
N/A	0%

Question 5: Course: Overall Quality

a: excellent	29%
b: very good	52%
c: satisfactory	17%
d: poor	2%
e: disastrous	0%
N/A	0%

Question 6: Quality of Textbook

a: excellent	21%
b: very good	43%
c: satisfactory	29%
d: poor	5%
e: disastrous	2%
N/A	0%

Question 7: Comments:

No Comments	39%
<u>Comments</u>	61%

Tentative material to be covered for Exam 2 (Wednesday, October 27)

Chapter 16Quantum Mechanics and the Hydrogen Atom

16.1Waves and Light
16.2Paradoxes in Classical Physics
16.3Planck, Einstein, and Bohr
16.4Waves, Particles, and the Schroedinger Equation
16.5The Hydrogen Atom

Chapter 17Many-Electron Atoms and Chemical Bonding

17.1Many-Electron Atoms and the Periodic Table
17.2Experimental Measures of Orbital Energies
17.3Sizes of Atoms and Ions
17.4Properties of the Chemical Bond
17.5Ionic and Covalent Bonds
17.6Oxidation States and Chemical Bonding

Chapter 18Molecular Orbitals, Spectroscopy, and Chemical Bonding

18.1Diatomic Molecules
18.2Polyatomic Molecules
18.3The Conjugation of Bonds and Resonance Structures
18.4The Interaction of Light with Molecules
18.5Atmospheric Chemistry and Air Pollution

Chapter 16Quantum Mechanics and the Hydrogen Atom

16.1Waves and Light

Atomic Spectra I

16.2Paradoxes in Classical Physics

Ultraviolet Catastrophe
Photoelectric effect

16.3Planck, Einstein, and Bohr

Planck's Constant, Quanta and Photons
Bohr Atom
Atomic Spectra II

16.4Waves, Particles, and the Schroedinger Equation

Schroedinger Equation (Wave Equation)

16.5The Hydrogen Atom

Sizes and Shapes of Orbitals
Electron Spin

What is matter?

Lucretius: ca 99-55 BC

All *matter* consists of tiny fundamental building blocks, ***atoms***

All nature consists of twain of things: of *atoms* and of the void in which they're set.

"**DE RERUM NATURA**"
(Everything you wanted to know about the universe but were afraid to ask!)

John Dalton 1766-1844

All matter is composed of small indivisible particles termed *atoms*. Atoms of a given element possess unique characteristics and weight.

"A New System of Chemical Philosophy"

Paradigm: Matter consists of tiny particles called atoms.

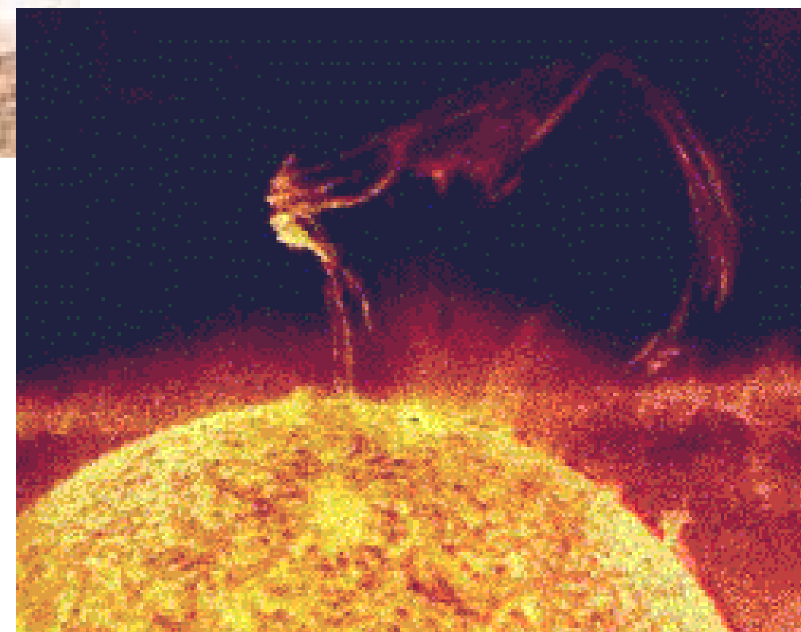
What is light?

God said: Let there be light..

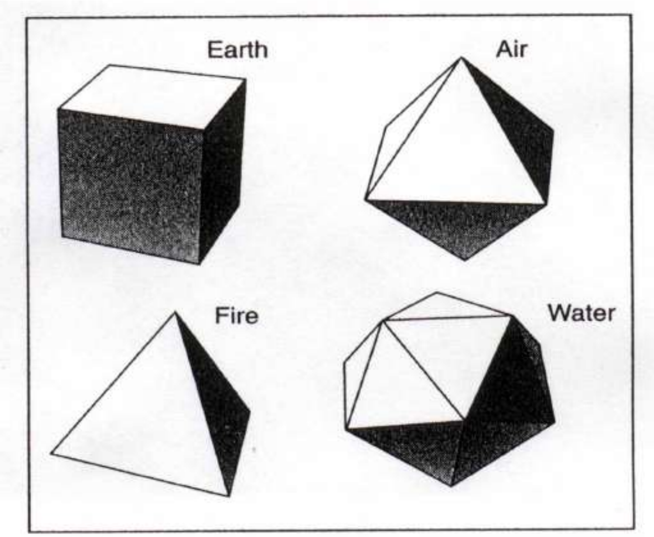
..And there was light (and matter and energy and space).

How does light carry energy get from place to place? Like a particle or like a wave?

And in the beginning…



Emedocles (500 BC) postulated that Aphrodite made the human eye out of the four elements (fire, air, earth and water) and that she lit the fire in the eye which shone out from the eye making sight possible.



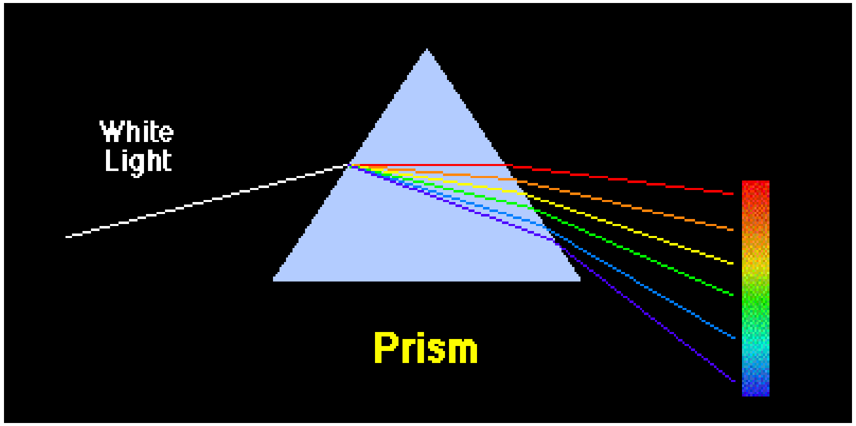
Lucretius (50 BC) postulated that light is composed of minute atoms which, when they are shoved off, lose no time is shooting right across the interspace of air in the direction imparted by the shove.

Paradigm I: Light consists of consists of tiny particles similar to atoms.

Paradigm of 1700s: Light consists of particles (energy is propagated by particles which are highly localized in space)

Issac Newton
1643-1727

Light consists of particles whose motion imparts them with energy. White light can be broken down into components, different colors from violet to red by the action of a prism.



The prism: White light can be decomposed into its"elements", its colors

Paradigm II: *Light consists of particles that carry energy and which can be decomposed into components.*

Paradigm (1800s): Light consists of waves (energy propagated by waves): Energy is spread over space like an oscillating liquid.

James Clerk Maxwell
1831-1879

Key equations:

$c = \lambda\nu$ λ (Gk lambda), ν (Gk nu)

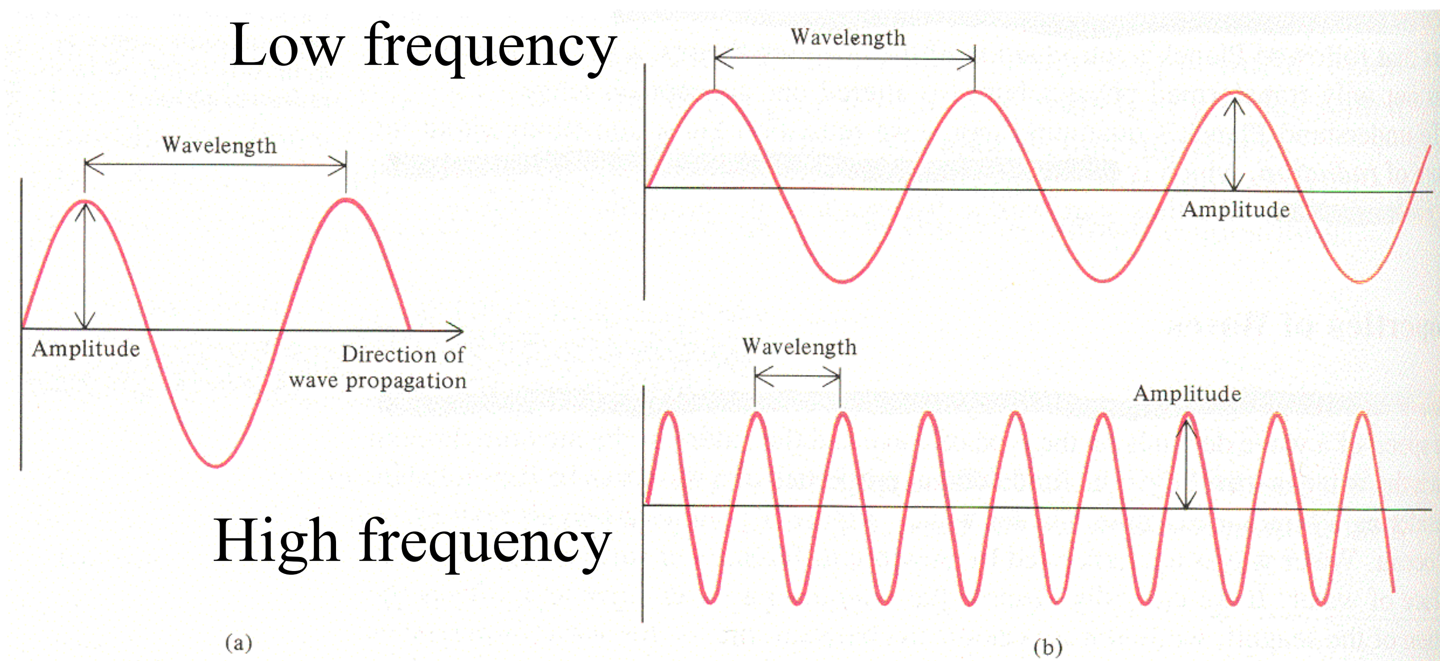
c = speed

λ = wavelength, ν = frequency

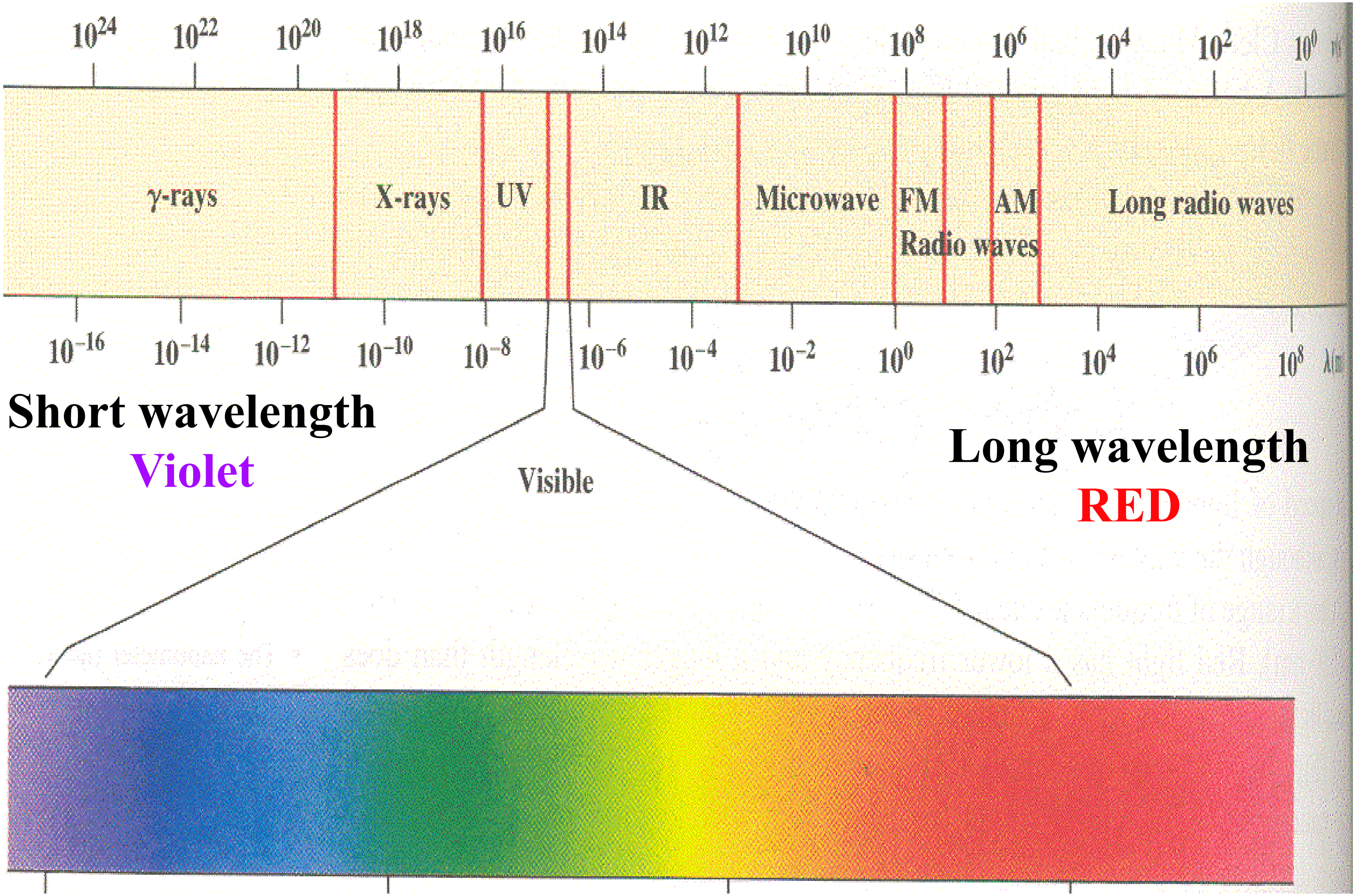
Paradigm III: Light is an electromagnetic wave

λ

Energy proportional to the Amplitude of wave.



The electromagnetic spectrum from g-rays to radio waves



The visible portion of the electromagnetic specrum

Paradox I

The Ultraviolet Catastrophe.

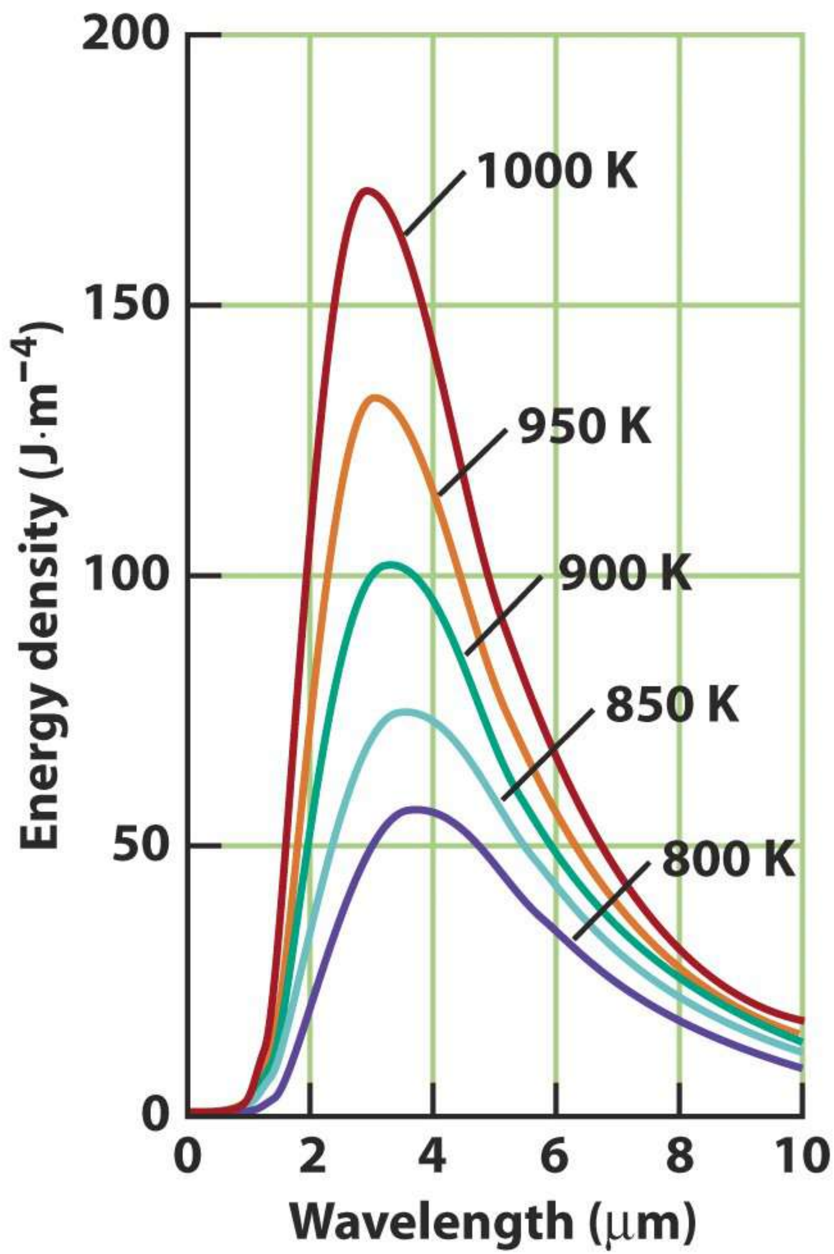
Paradigm III. Cannot explain the wavelenght dependence of the intensity (I) of the light that is emitted from a simple heated object (an idealized "black body" that absorbs all light)!

I (Intensity) proportional to ν

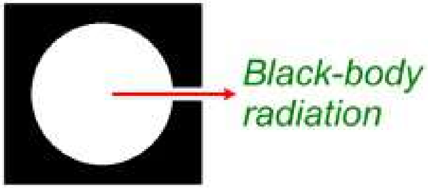
I (Intensity) proportional to λ

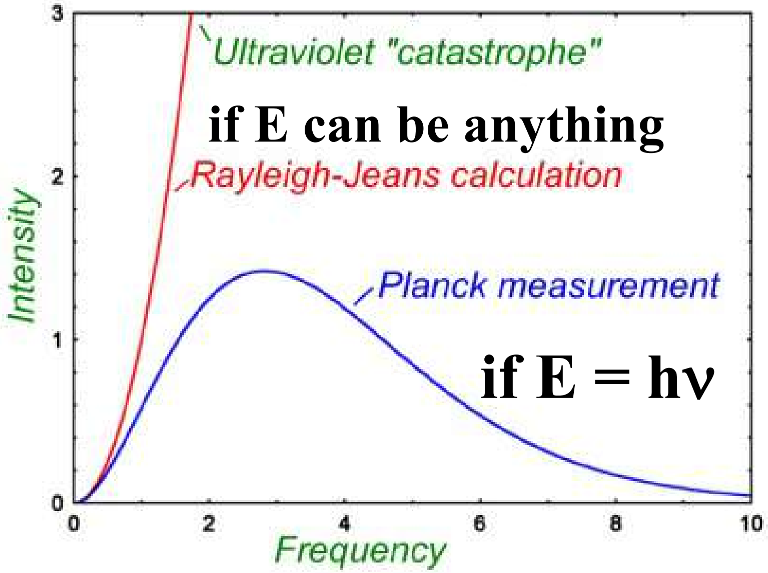
I (Intensity)goes to infinity as λ goes to zero!

Experiment: Maximum observed!



Planck explains the ultraviolet catastrophe by quantizing the energy of light. Light can only have energies given by hν





Max Planck
Nobel Prize 1918
"for his explanation of the ultraviolet catastrophe", namely **E = hν**, the energy of light is bundled and comes in quanta.

Planck was here at Columbia!

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK
PUBLICATION NUMBER THREE
OF THE ERNEST KEMPTON ADAMS FUND FOR PHYSICAL RESEARCH
ESTABLISHED DECEMBER 17TH, 1904

EIGHT LECTURES
ON THEORETICAL PHYSICS

DELIVERED AT COLUMBIA UNIVERSITY
IN 1909

BY

MAX PLANCK

PROFESSOR OF THEORETICAL PHYSICS IN THE UNIVERSITY OF BERLIN
LECTURER IN MATHEMATICAL PHYSICS IN COLUMBIA UNIVERSITY FOR 1909

TRANSLATED BY

A. P. WILLS

PROFESSOR OF MATHEMATICAL PHYSICS IN COLUMBIA UNIVERSITY

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IN LITTERIS LIBERTAS

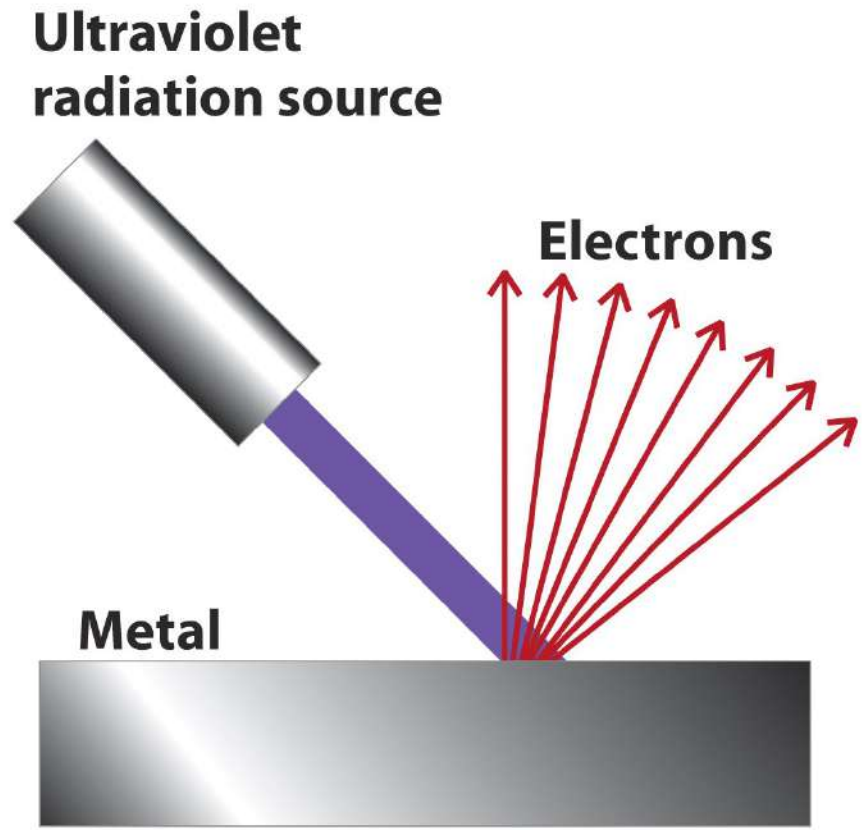
NEW YORK
COLUMBIA UNIVERSITY PRESS
1915

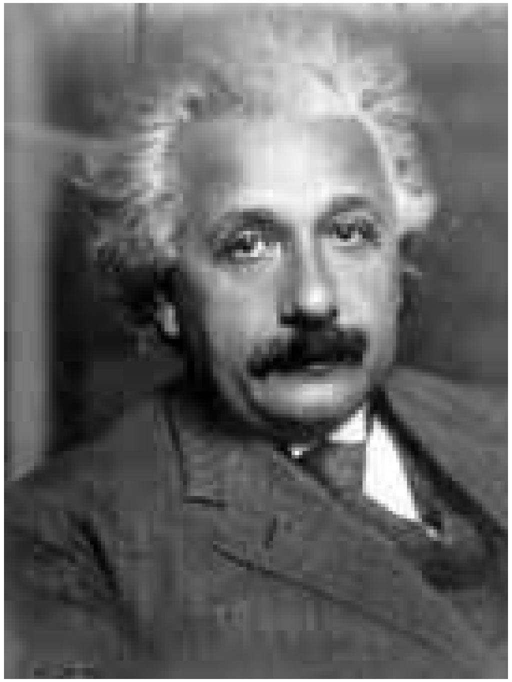
Paradox II: The Photoelectric Effect

A beam of light hitting a metal surface can cause electrons to be ejected from the surface.

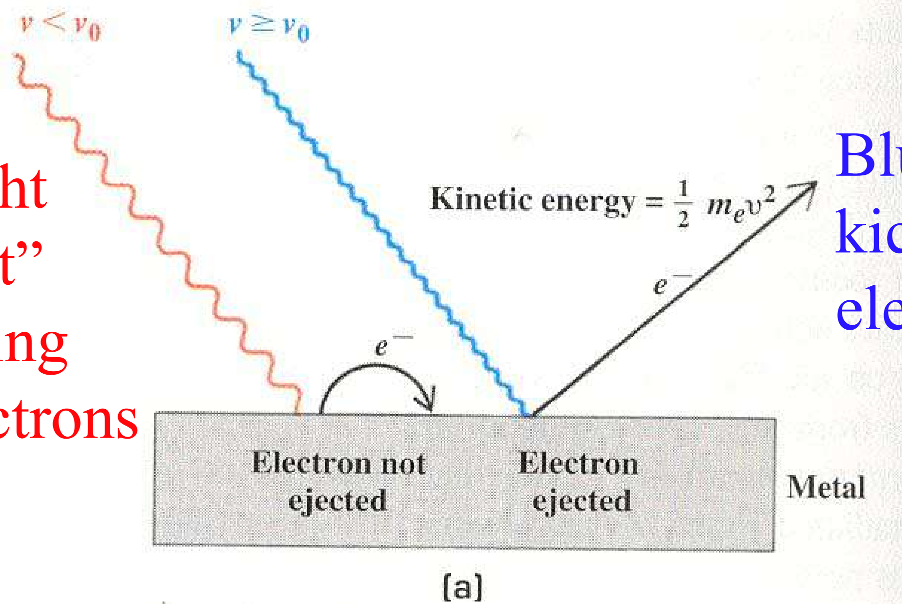
Classical Paradigm: the energy of the ejected electrons should be proportional to the intensity of the light and independent of the frequency of the light.

Experiment: the energy of the ejected electrons is independent of the intensity and depends directly on the frequency.

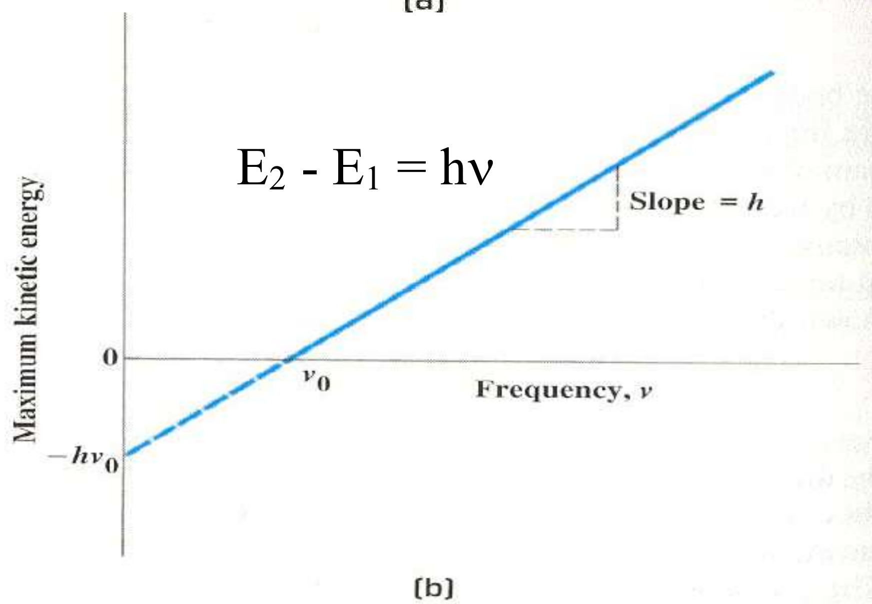




Red light is "inert" to kicking out electrons



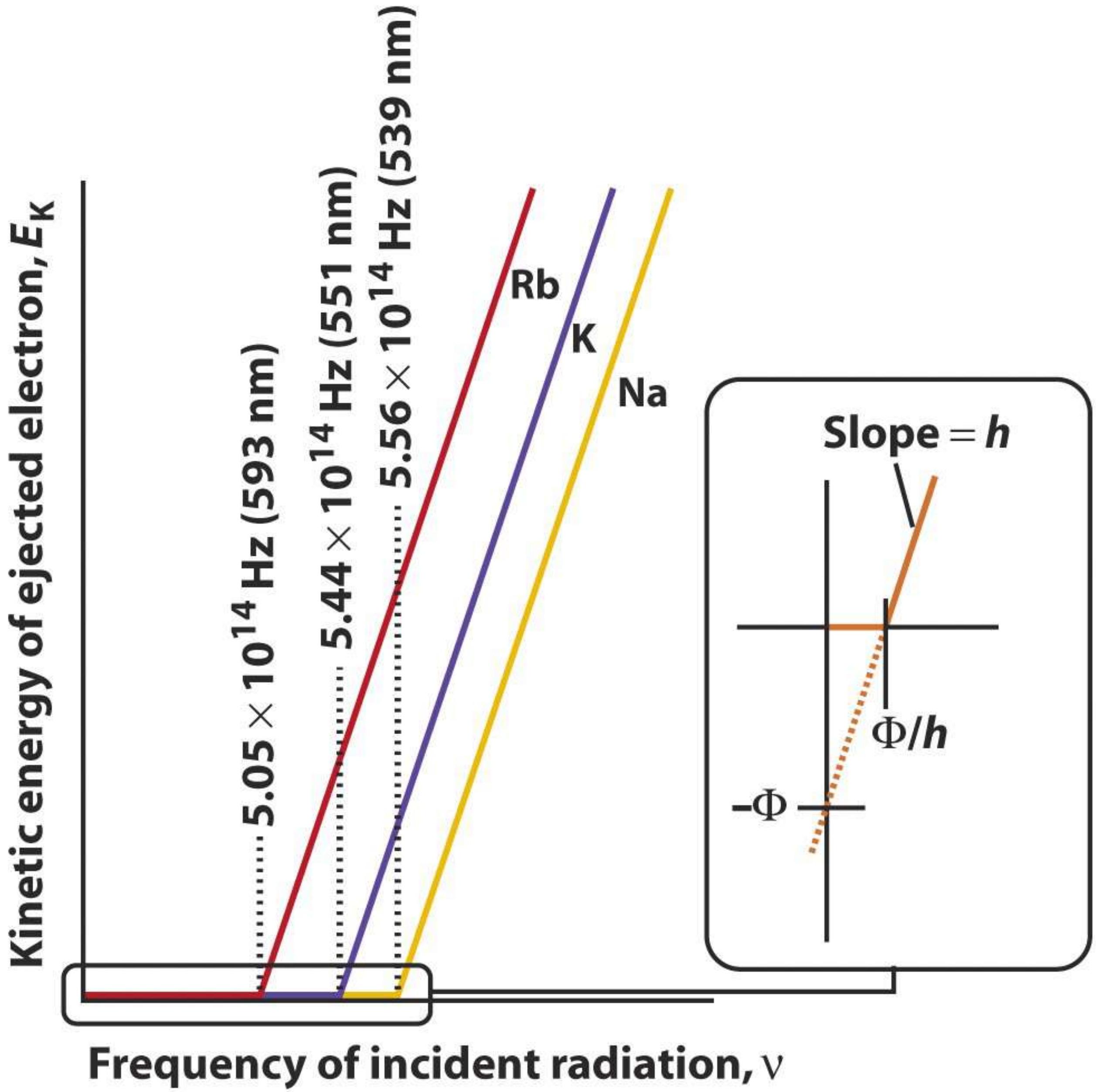
Blue light kicks out electrons!



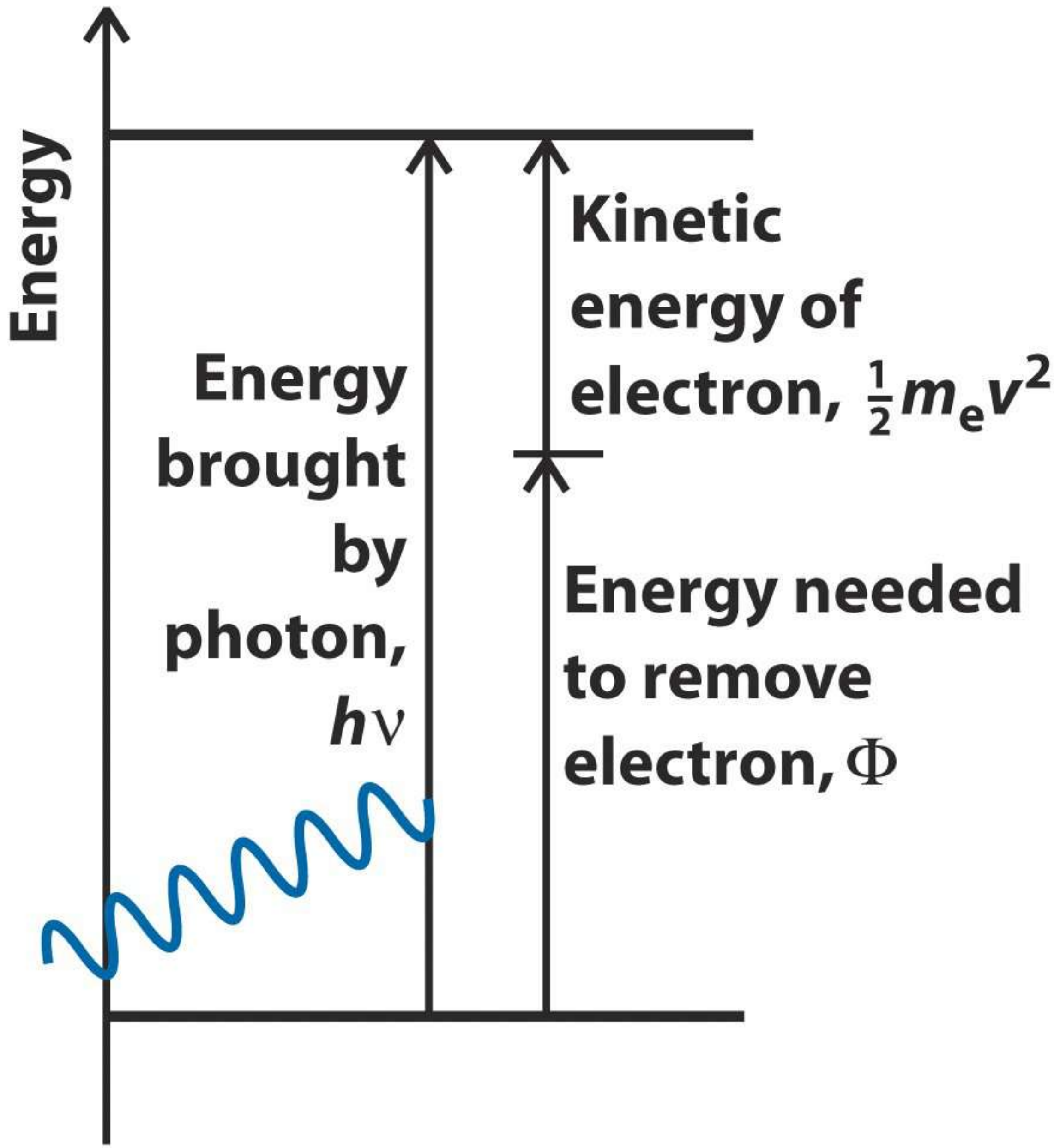
$E_2 - E_1 = h\nu$

Albert Einstein
Nobel Prize 1921
"For his explanation of the photoelectric effect", namely, $E_2 - E_1 = h\nu$, light is quantized as photons.

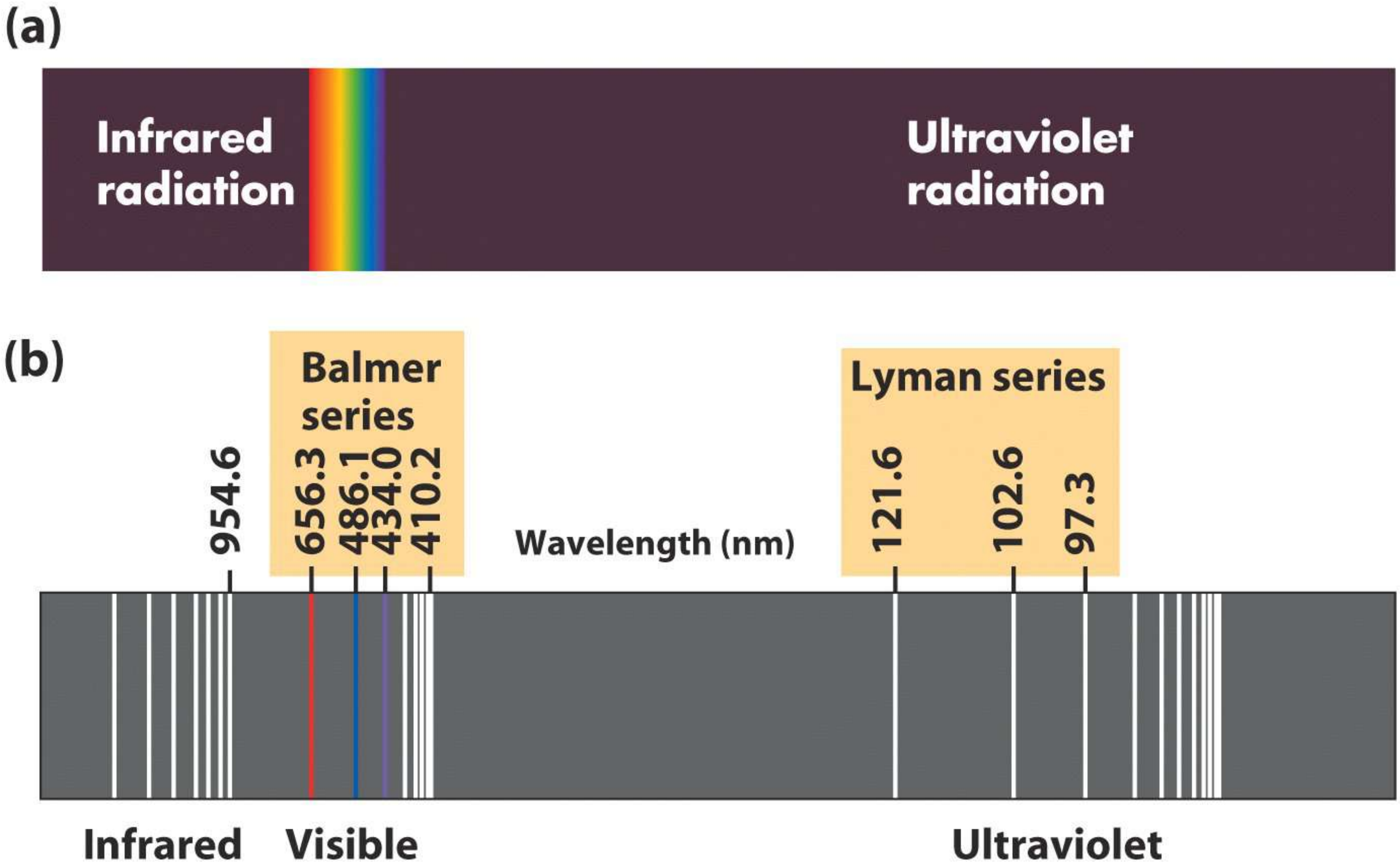
The slope of KE_{Max} vs ν is h!!!!!



Kinetic energy of ejected electron, E_K
5.05 × 10^14 Hz (593 nm)
5.44 × 10^14 Hz (551 nm)
5.56 × 10^14 Hz (539 nm)
Rb
K
Na
Slope = h
Φ/h
–Φ
Frequency of incident radiation, ν


Energy
Kinetic energy of electron, $\frac{1}{2}m_e v^2$
Energy brought by photon, $h\nu$
Energy needed to remove electron, Φ

The Bohr Atom and the Absorption and Emission of Light
The emission from discharge lamps



Putting It All together: The Bohr Atom

Niels Bohr
Nobel Prize 1922
"the structure of atoms and the radiation emanating from them"

Light is emitted when an electron jumps from a higher orbit to a lower orbit and absorbed when it jumps from a lower to higher orbit.

The energy and frequency of light emitted or absorbed is given by the difference between the two orbit energies, e.g.,

E(photon) = E_2 - E_1 (Energy difference)

The basis of all photochemistry and spectroscopy!

E_4 E_3

E_5 E_2

E_1

Photon absorbed

$E_2 - E_1 = h\nu$

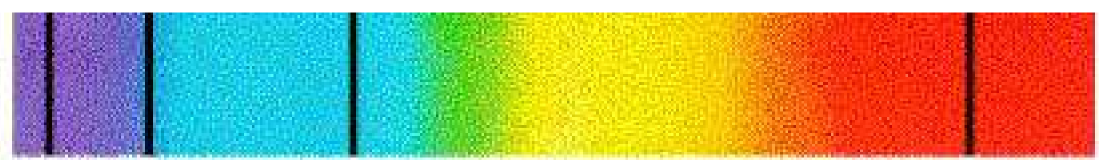
E_4 E_3

E_5 E_2

E_1

Photon emitted

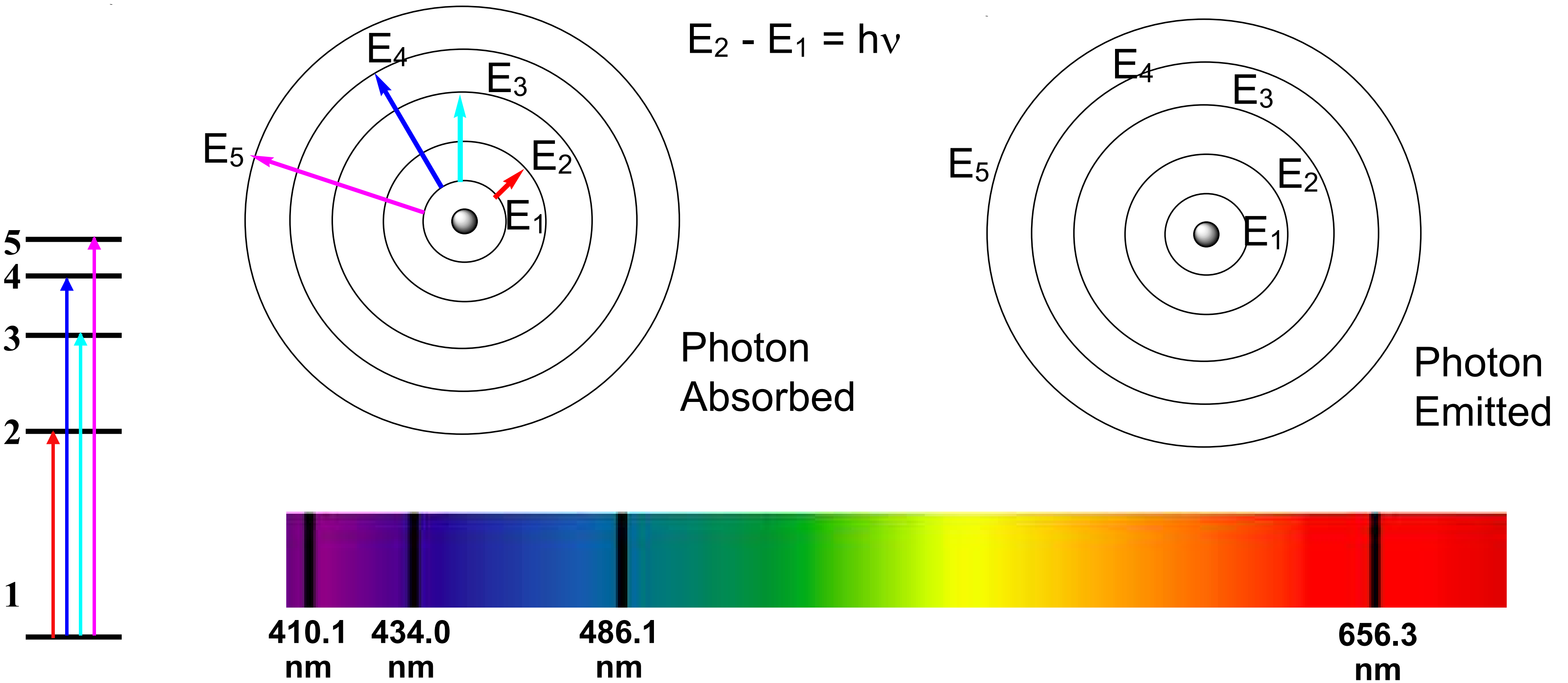
$E_2 - E_1$ $E_2 - E_1$ $E_2 - E_1$ $E_2 - E_1$



Bohr atom: Light absorption occurs when an electron absorbs a photon and makes a transition for a lower energy orbital to a higher energy orbital. Absorption spectra appear as sharp lines.

Bohr atom: Light emission occurs when an electron makes a transition from a higher energy orbital to a lower energy orbital and a **photon is emitted. Emission spectra appear as sharp lines.**

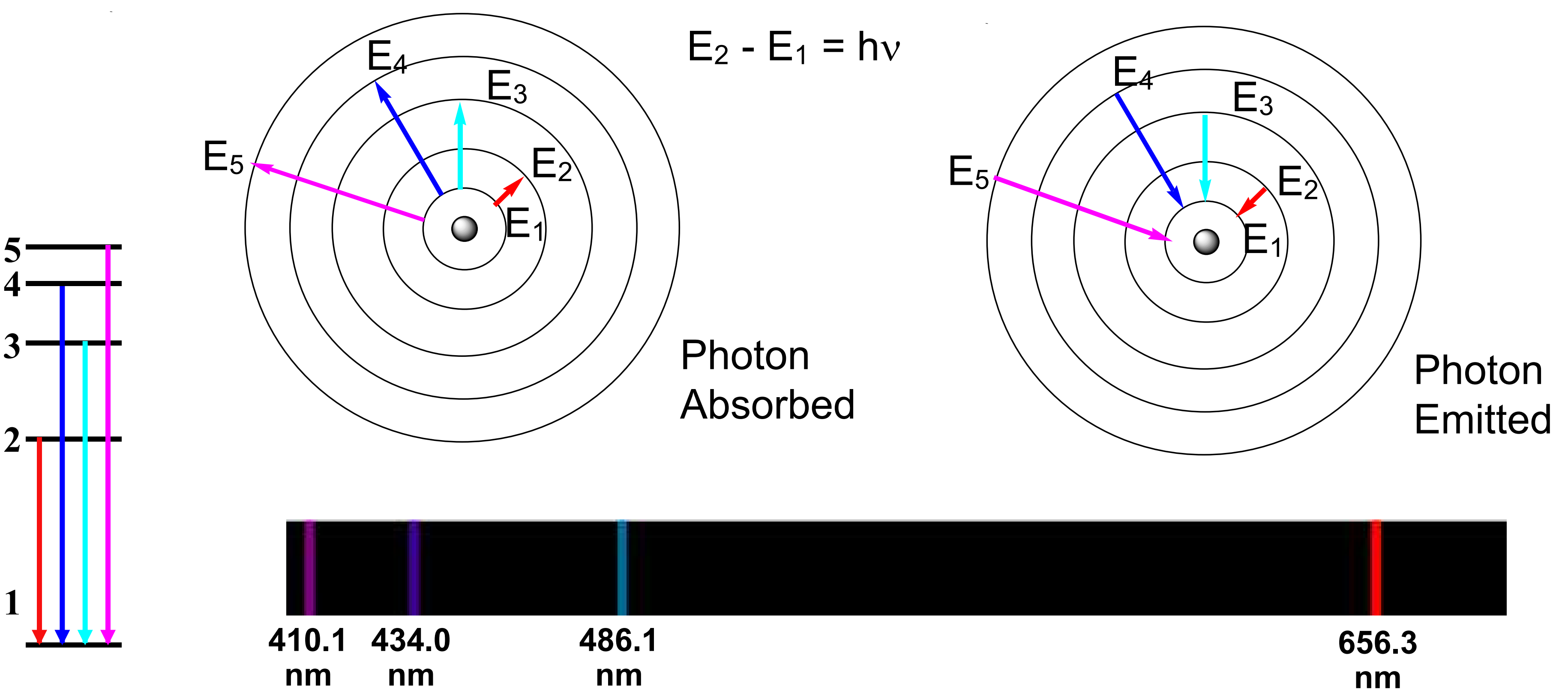
Energy & Resonance: The Bohr Atom



<u>Bohr atom:</u> Light absorption occurs when an electron absorbs a photon and makes a transition for a lower energy orbital to a higher energy orbital. <u>***Absorption spectra appear as sharp lines.***</u>

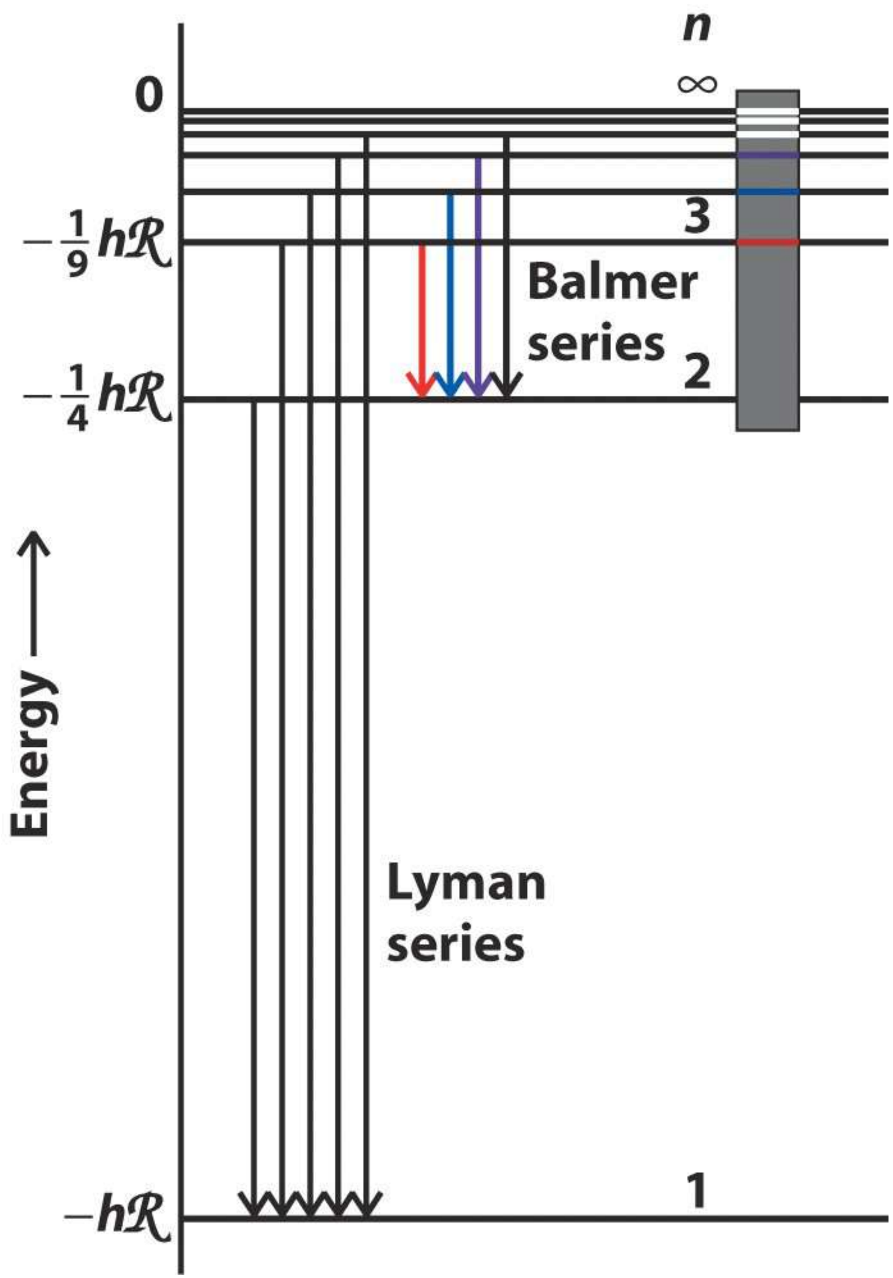
<u>Bohr atom:</u> Light emission occurs when an electron makes a transition from a higher energy orbital to a lower energy orbital and a **photon is emitted.** <u>***Emission spectra appear as sharp lines.***</u>

Energy & Resonance: The Bohr Atom

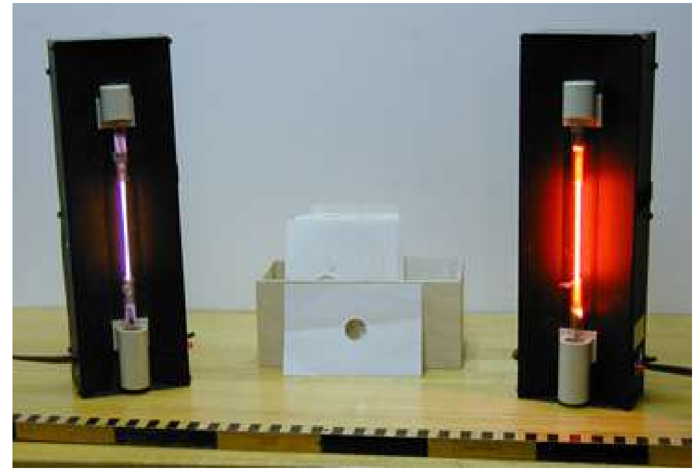


Bohr atom: Light absorption occurs when an electron absorbs a photon and makes a transition for a lower energy orbital to a higher energy orbital. ***Absorption spectra appear as sharp lines.***

Bohr atom: Light emission occurs when an electron makes a transition from a higher energy orbital to a lower energy orbital and a **photon is emitted.** ***Emission spectra appear as sharp lines.***



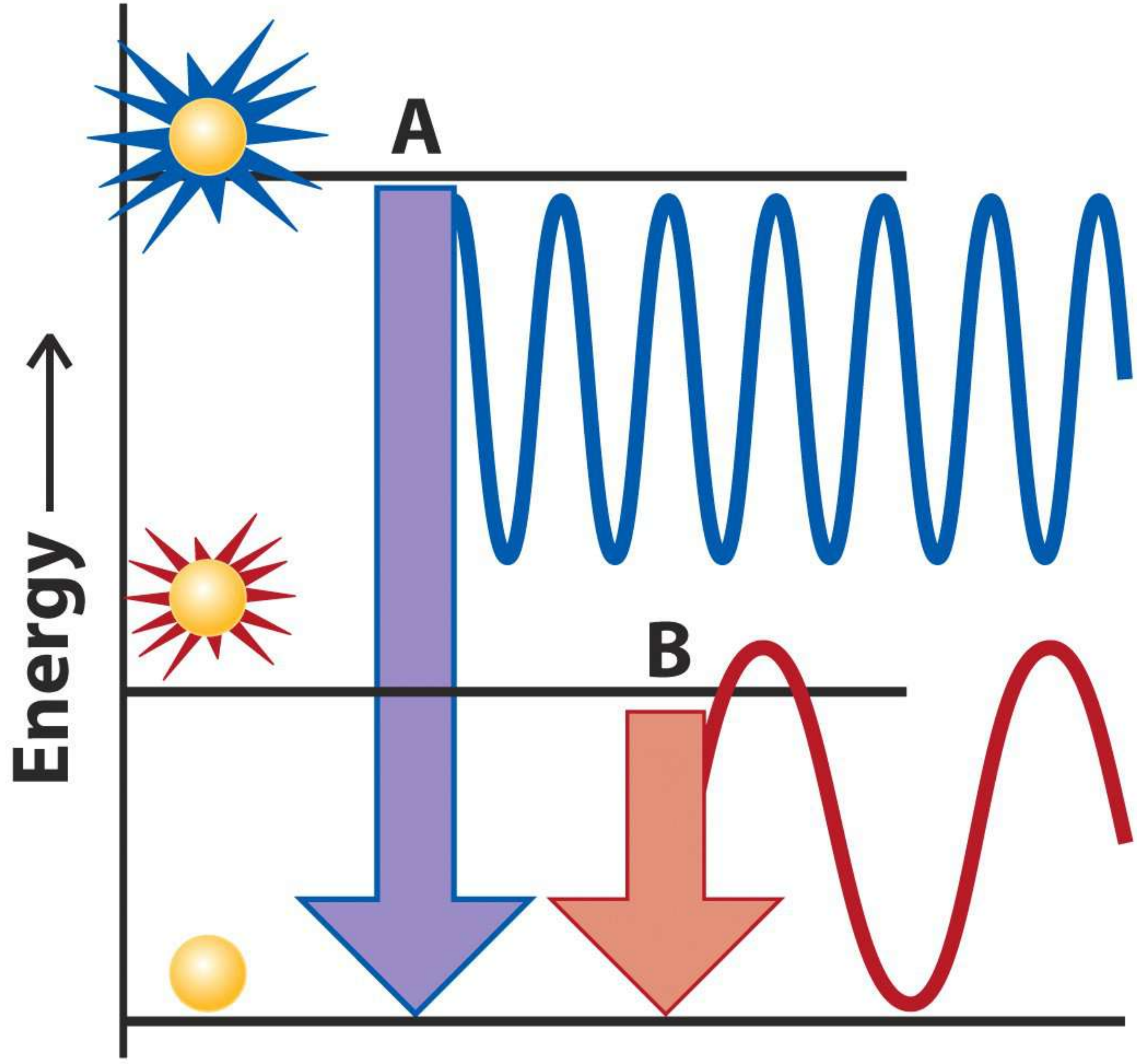
n
∞
0
3
$-\frac{1}{9}h\mathcal{R}$
Balmer
series
2
$-\frac{1}{4}h\mathcal{R}$
Energy
Lyman
series
1
$-h\mathcal{R}$

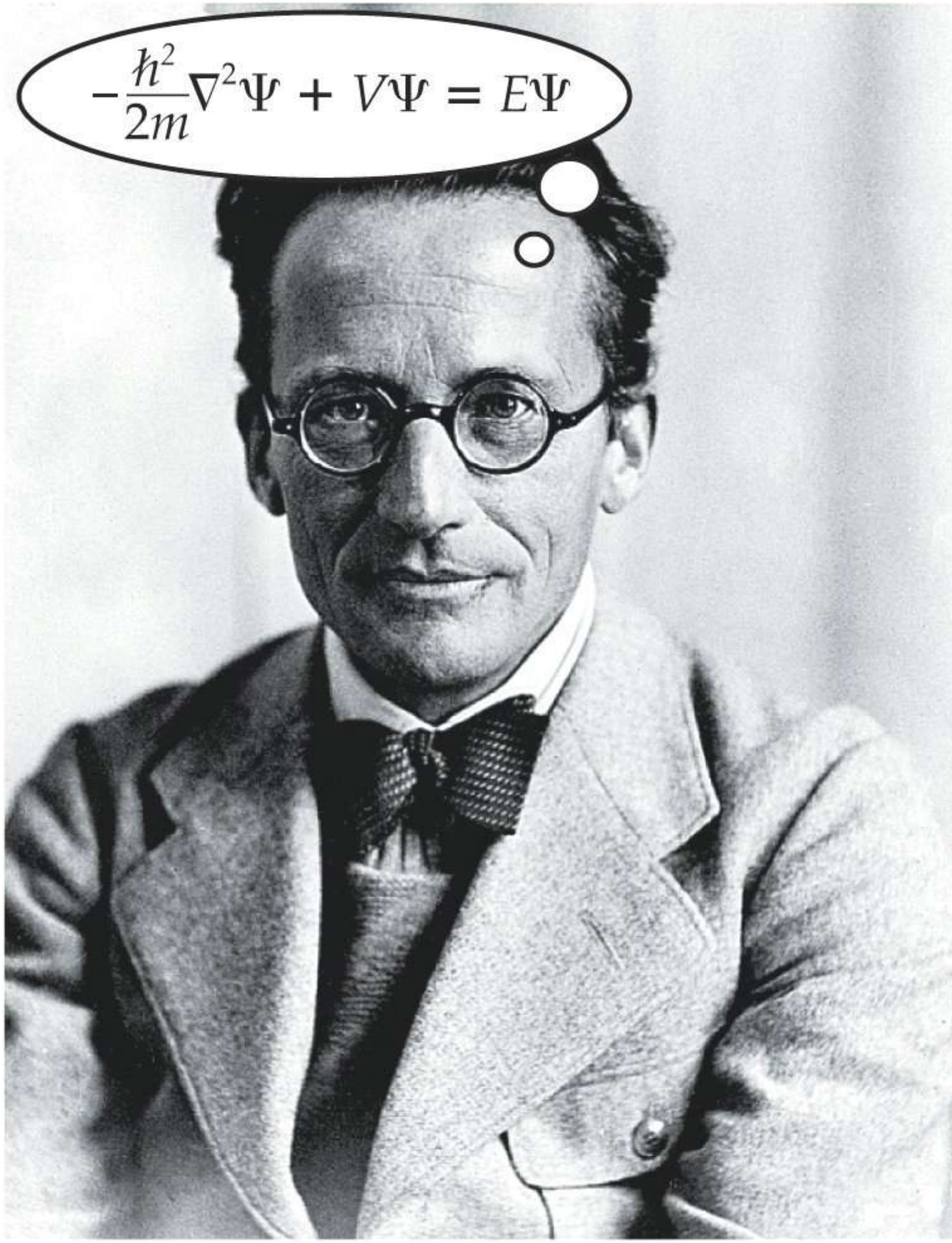


You’ll see something like this somewhere in the auditorium.

Schematic of the Experiment

Let’s do an experiment: Look at the discharge lamps through the diffraction glasses. They work just like a prism and break up light into its components. Notice the dark spots between the “lines” of the different colors. The number and positions of the lines are the unique signature of the elements. A lab experiment. Note the number and color of the lines. See if you can identify the element.


A
B
Energy



Schroedinger: If electrons are waves, their postion and motion in space must obey a wave equation.

Solutions of wave equations yield wavefunctions, Ψ, which contain the information required to describe ALL of the properties of the wave.

TABLE 1.2 Hydrogen Wavefunctions (Atomic Orbitals), $\psi = RY$

(a) Radial wavefunctions, $R_{nl}(r)$

n	l	$R_{nl}(r)$
1	0	$2\left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0}$
2	0	$\frac{1}{2\sqrt{2}}\left(\frac{Z}{a_0}\right)^{3/2}\left(2-\frac{Zr}{a_0}\right)e^{-Zr/2a_0}$
	1	$\frac{1}{2\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2}\left(\frac{Zr}{a_0}\right)e^{-Zr/2a_0}$
3	0	$\frac{1}{9\sqrt{3}}\left(\frac{Z}{a_0}\right)^{3/2}\left(3-\frac{2Zr}{a_0}+\frac{2Z^2r^2}{9a_0^2}\right)e^{-Zr/3a_0}$
	1	$\frac{2}{27\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2}\left(2-\frac{Zr}{3a_0}\right)e^{-Zr/3a_0}$
	2	$\frac{4}{81\sqrt{30}}\left(\frac{Z}{a_0}\right)^{3/2}\left(\frac{Zr}{a_0}\right)^2 e^{-Zr/3a_0}$

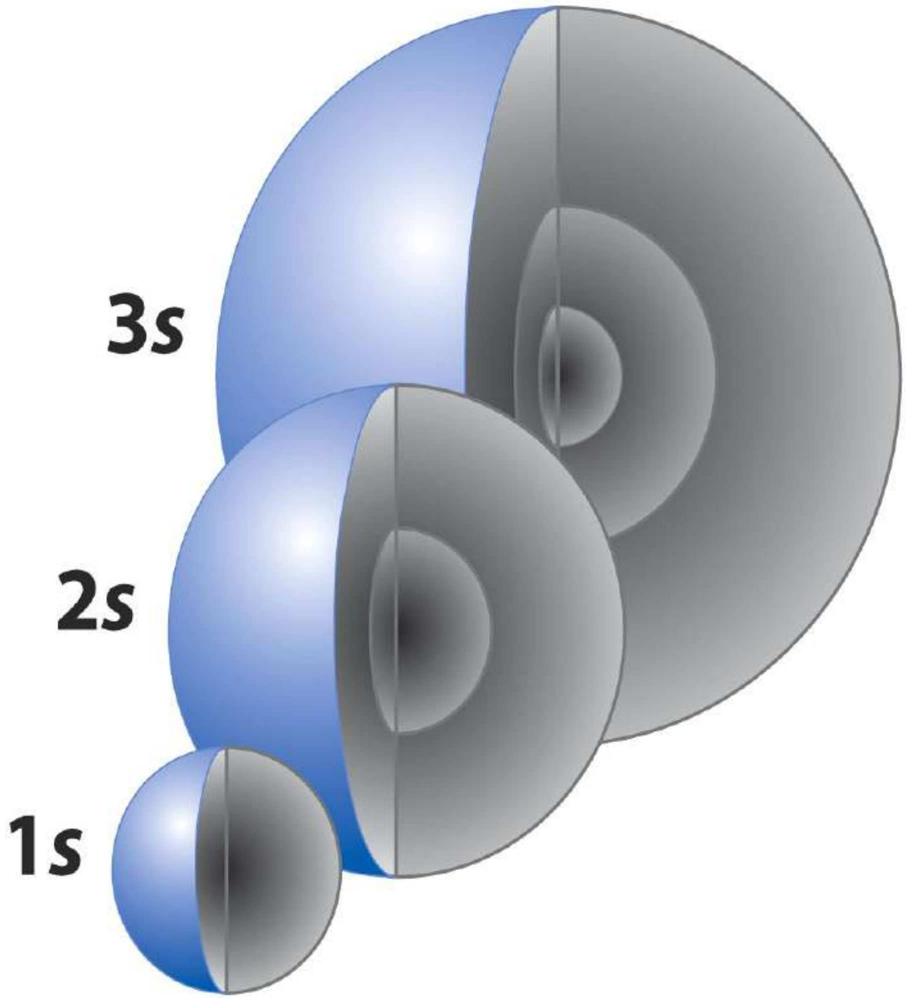
(b) Angular wavefunctions, $Y_{lm_l}(\theta,\phi)$

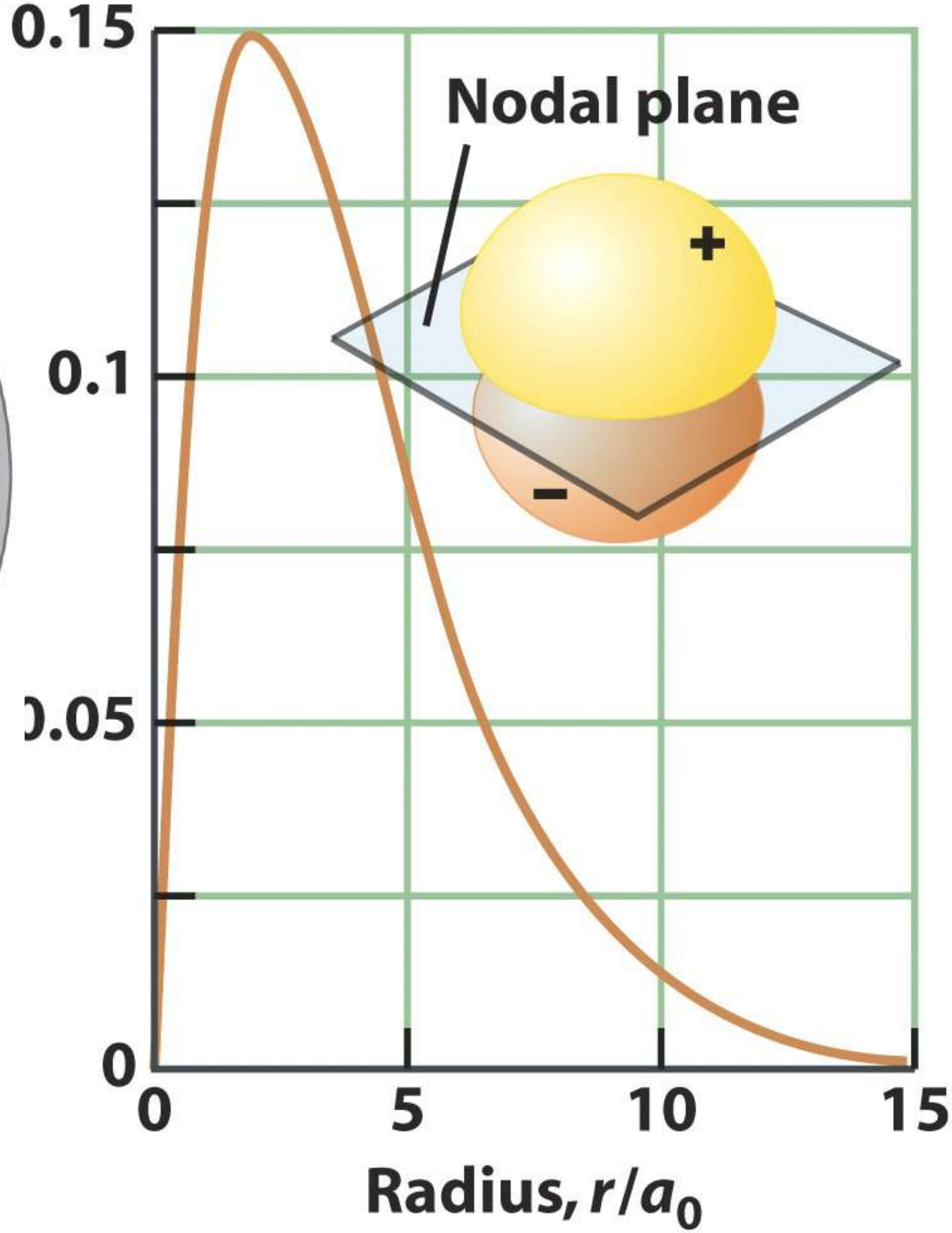
l	"m_l"*	$Y_{lm_l}(\theta,\phi)$
0	0	$\left(\frac{1}{4\pi}\right)^{1/2}$
1	x	$\left(\frac{3}{4\pi}\right)^{1/2}\sin\theta\cos\phi$
	y	$\left(\frac{3}{4\pi}\right)^{1/2}\sin\theta\sin\phi$
	z	$\left(\frac{3}{4\pi}\right)^{1/2}\cos\theta$
2	xy	$\left(\frac{15}{16\pi}\right)^{1/2}\sin^2\theta\cos 2\phi$
	yz	$\left(\frac{15}{4\pi}\right)^{1/2}\cos\theta\sin\theta\sin\phi$
	zx	$\left(\frac{15}{4\pi}\right)^{1/2}\cos\theta\sin\theta\cos\phi$
	x^2-y^2	$\left(\frac{15}{16\pi}\right)^{1/2}\sin^2\theta\sin 2\phi$
	z^2	$\left(\frac{5}{16\pi}\right)^{1/2}(3\cos^2\theta-1)$

Note: In each case, $a_0 = 4\pi\varepsilon_0{}^2/m_e e^2$, or close to 52.9 pm; for hydrogen itself, $Z = 1$.

*In all cases except $m_l = 0$, the orbitals are sums and differences of orbitals with specific values of m_l.

Pictures of Wavefunctions: Orbitals





What next? If waves can mimic particles, then particles can mimic waves

Louis de Broglie 1892-1987
Nobel Prize 1929
"for his discovery of the wave nature of electrons"

Light: $E = h\nu$ (Planck)

Mass: $E = mc^2$ (Einstein)

then

$h\nu = h(c/\lambda) = mc^2$ (de Broglie)

Light=Matter

Two seemingly incompatible conceptions can each represent an aspect of the truth ... They may serve in turn to represent the facts without ever entering into direct conflict. ***de Broglie, Dialectica***

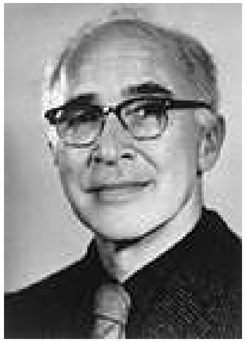
Time Scales of Photochemistry

Birth of an Excited State

Birth of Light and Matter

•

Vision: Early theories of light were theories of vision.
Photosynthesis: Life requires the capture, storage and release of the sun's energy.



Wald

Calvin

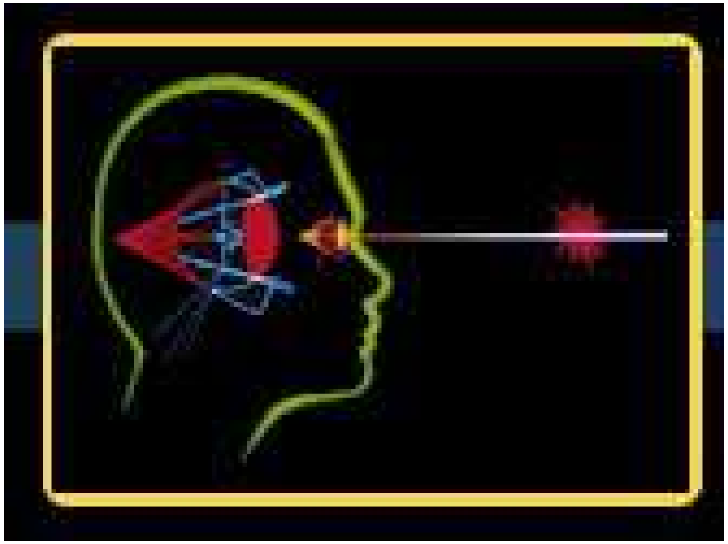
Marcus

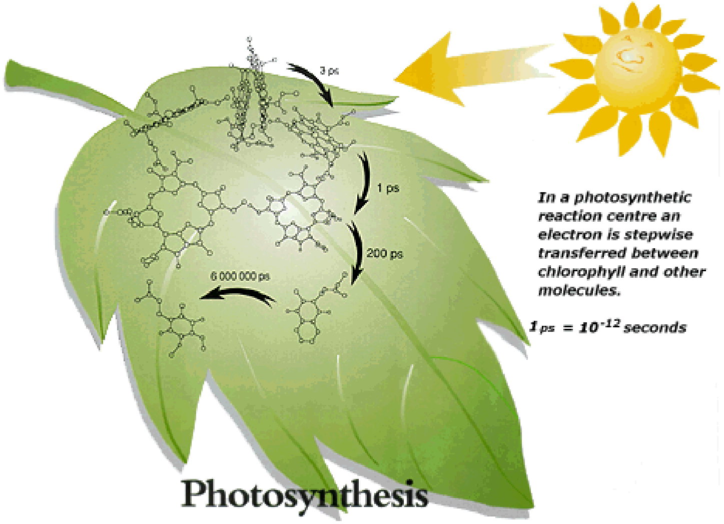
Nobel in Medicine

Mechanism of Vision

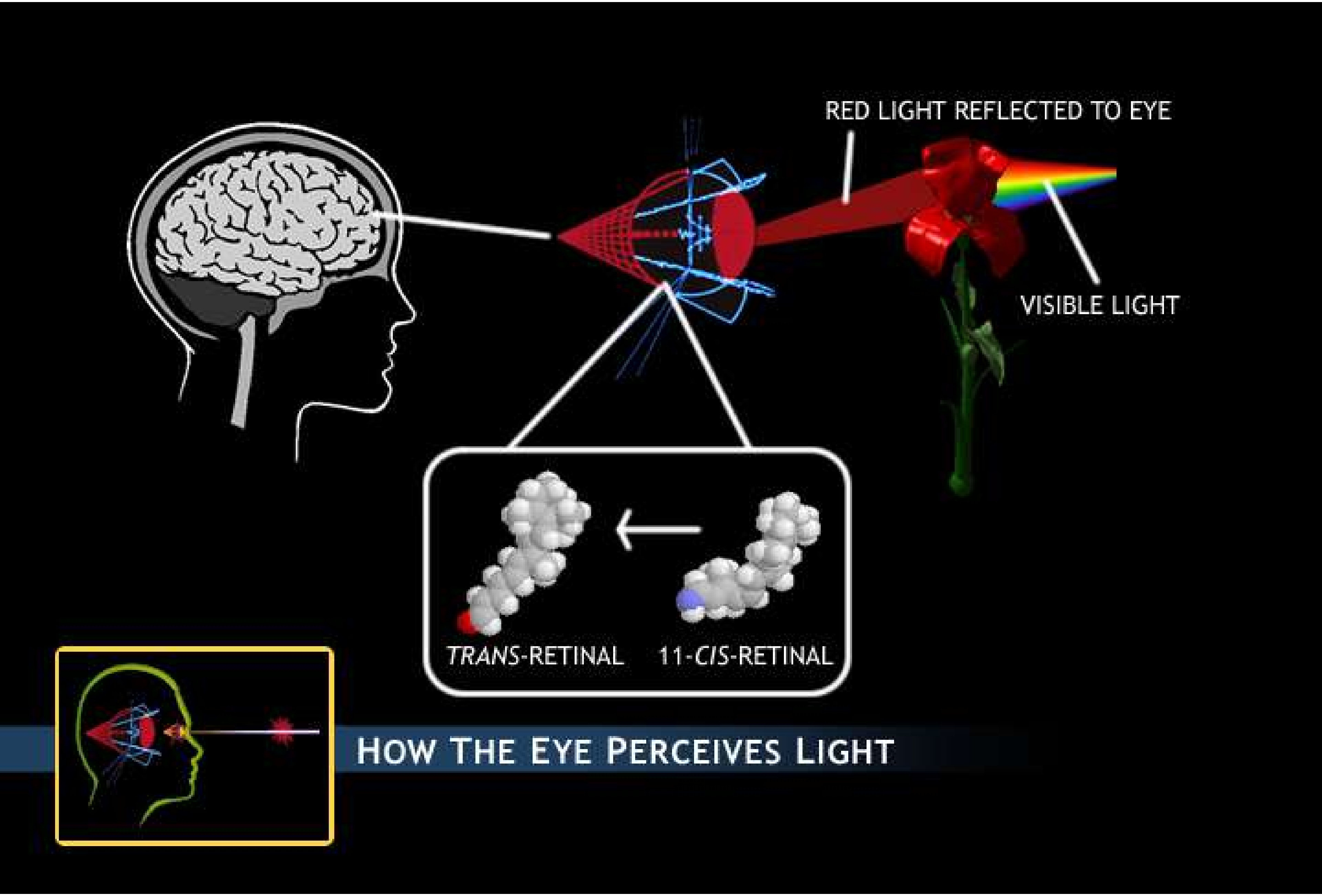
Nobels in Chemistry

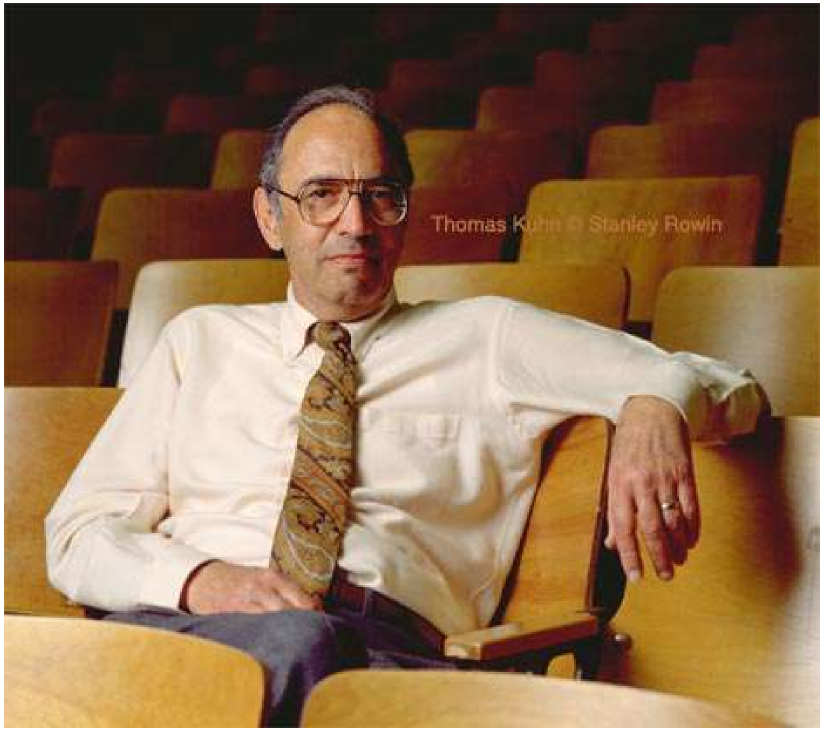
Mechanism of Photosynthesis





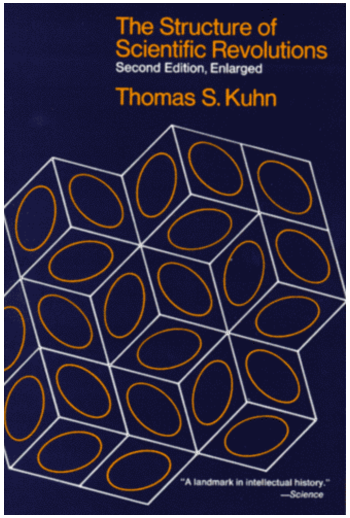
Energy Scales: Why the visible region works for vision

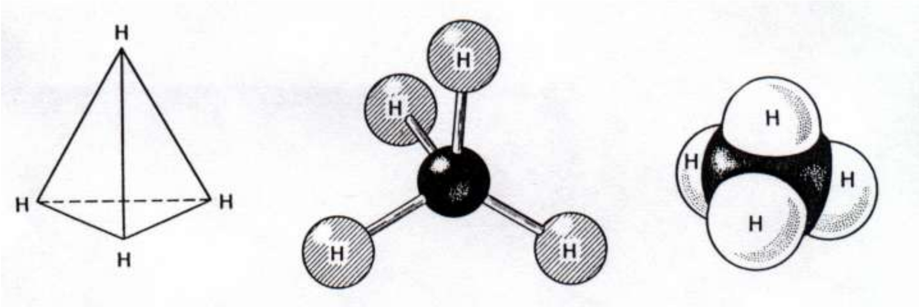

RED LIGHT REFLECTED TO EYE
VISIBLE LIGHT
TRANS-RETINAL
11-CIS-RETINAL
HOW THE EYE PERCEIVES LIGHT



Mr. Paradigm:
Thomas Kuhn. 1923-1996.

Paradigm: **A characteristic set of beliefs and/or preconceptions (theoretical, instrumental, procedural and metaphysical) that is shared by a community of practitioners. In a global sense the paradigm embraces all of the shared commitments of a scientific group.**
An accepted paradigm is what defines a scientific community or discipline.





A chemist's view of the gaseous fuel, methane.
He/she thinks of a molecule of methane as a 3 dimensional geometric object consisting of a carbon atom connected to 4 hydrogens atoms that are directed toward the verticies of a tetrahedron.
The tiniest amount of methane contains zillions of these guys.

H. Kolbe

1818-1884

**"In a recently published paper,
I pointed out that one
of the causes of the present regression
of chemical research in Germany is the
lack of general, and at the same time
thorough chemical knowledge; no
small number of our professors of
chemistry, with great harm to our
science, are laboring under this lack.
A consequence of this is the spread of
the weed of the apparently scholarly
and clever, but actually trivial and stupid,
natural philosophy, which was displaced
fifty years ago by exact science, but which
is now brought forth again, out of the store
room harboring the errors of the
human mind; by pseudoscientists who try
to smuggle it, like a fashionably dressed and
freshly rouged prostitute, into good society,
where it does not belong."**

H. Kolbe, “A Sign of the Times”
J. Prakt. Chem., **15**, 474 (1877).

J. H. van't Hoff
(1852-1911)
First Nobel Prize,
Chemistry, 1901

"A Dr. J. H. van't Hoff, of the Veterinary School at Utrecht, has no liking, apparently, for exact chemical investigation. He has considered it more comfortable to mount Pegasus (apparently borrowed from the Veterinary School) and to proclaim in his book how the atoms appear to him to be arranged in space, when he is on the chemical Mt. Parnassus which he has reached by bold flight."

H. Kolbe, "A Sign of the Times
J. Prakt. Chem., 15, 474 (1877).

"New scientific truth usually becomes accepted, not because its opponents become convinced, but *because opponents gradually die* and because the rising generations are familiar with the new truth at the outset."

M. Planck, Naturwissenschaften, *33*, 230 (1946).

Max Planck
Nobel Prize, Physics, 1918,
"for the discovery of energy quanta".

Flow Diagram for Normal Science

The BIG One!

Flow diagram for revolutionary science:Extraordinary claims that become accepted and are integrated into "normal science."

Flow diagram for revolutionary science:
Extraordinary claims that become accepted and are integrated into “normal science.”