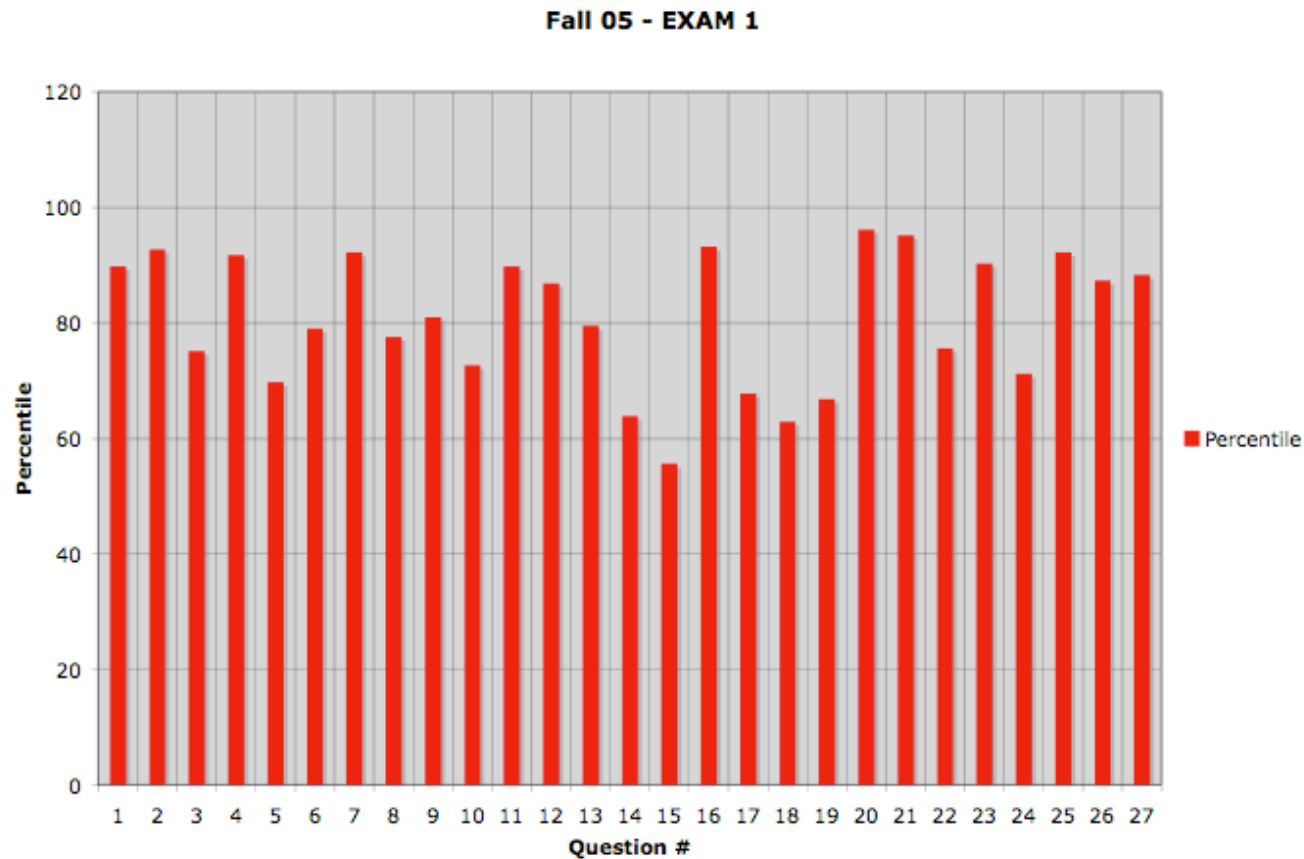


Results of Exam 1 and Survey after Exam 1

Results for Exam 1: Mean grade = 81, Median grade = 85
If you have any questions on the exam, please post them on the discussion board.



Results of online survey (Professor's midterm)

Helpfulness

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

Question 1: **Class Lectures**

a: very useful **27%**

b: useful **63%**

c: not useful **10%**

N/A **0%**

Question 2: **Homework assignments from the text**

a: very useful **60%**

b: useful **37%**

c: not useful **3%**

N/A **0%**

Question 3: **Recitation section**

a: very useful **19%**

b: useful **55%**

c: not useful **26%**

N/A **0%**

Question 4: **Multiple choice homework assignments**

a: very useful **58%**

b: useful **34%**

c: not useful **8%**

N/A **1%**

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 18%
- b: 5-10 h 41%
- c: 11-15 h 30%
- d: 16-20 h 7%
- e: More than 20 h 4%
- N/A 0%

Question 2: Please indicate your opinion of the exam.

The exam covered materials that were stressed in the homework.

- a: strongly agree 40%
- b: agree 56%
- c: disagree 4%
- d: strongly disagree 0%
- N/A 0%

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

- a: strongly agree 29%
- b: agree 59%
- c: disagree 11%
- d: strongly disagree 2%
- N/A 0%

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

- a: strongly agree 79%
- b: agree 19%
- c: disagree 2%
- d: strongly disagree 0%
- N/A 0%

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

- a: strongly agree 15%
- b: agree 60%
- c: disagree 20%
- d: strongly disagree 4%
- N/A 0%

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

- a: strongly agree 59%
- b: agree 38%
- c: disagree 2%
- d: strongly disagree 0%
- N/A 1%

Ratings

Question 1: Instructor: Organization and Preparation

a: excellent	57%
b: very good	35%
c: satisfactory	8%
d: poor	1%
e: disastrous	0%
N/A	0%

Question 2: Instructor: Approachability

a: excellent	51%
b: very good	29%
c: satisfactory	20%
d: poor	1%
e: disastrous	0%
N/A	0%

Question 3: Course: Amount Learned

a: excellent	38%
b: very good	42%
c: satisfactory	19%
d: poor	2%
e: disastrous	0%
N/A	0%

Question 4: Course: Appropriateness of Workload

a: excellent	34%
b: very good	47%
c: satisfactory	20%
d: poor	0%
e: disastrous	0%
N/A	0%

Question 5: Course: Overall Quality

a: excellent	37%
b: very good	48%
c: satisfactory	15%
d: poor	0%
e: disastrous	0%
N/A	0%

Question 6: Quality of Textbook

a: excellent	21%
b: very good	39%
c: satisfactory	29%
d: poor	8%
e: disastrous	3%
N/A	0

***Tentative material to be covered for Exam 2
(Wednesday, November 2, 2005)***

Chapter 16

Quantum Mechanics and the Hydrogen Atom

16.1

Waves and Light

16.2

Paradoxes in Classical Physics

16.3

Planck, Einstein, and Bohr

16.4

Waves, Particles, and the Schroedinger Equation

16.5

The Hydrogen Atom

Chapter 17

Many-Electron Atoms and Chemical Bonding

17.1

Many-Electron Atoms and the Periodic Table

17.2

Experimental Measures of Orbital Energies

17.3

Sizes of Atoms and Ions

17.4

Properties of the Chemical Bond

17.5

Ionic and Covalent Bonds

17.6

Oxidation States and Chemical Bonding

Chapter 18

Molecular Orbitals, Spectroscopy, and Chemical Bonding

18.1

Diatomic Molecules

18.2

Polyatomic Molecules

18.3

The Conjugation of Bonds and Resonance Structures

18.4

The Interaction of Light with Molecules

18.5

Atmospheric Chemistry and Air Pollution

Chapter 16 **Quantum Mechanics and the Hydrogen Atom**

- 16.1** **Waves and Light**
Atomic Spectra I

- 16.2** **Paradoxes in Classical Physics**
Ultraviolet Catastrophe
Photoelectric effect
Death spiral of Rutherford's atom
Line spectra of atoms

- 16.3** **Planck, Einstein, and Bohr**
Planck's Constant, Quanta and Photons
Bohr Atom, Atomic Spectra II

- 16.4** **Waves, Particles, and the Schroedinger Equation**
Schroedinger Equation (Wave Equation)
deBroglie's Proposes the Electron has wave properties

- 16.5** **The Hydrogen Atom**
Quantum numbers: Sizes and Shapes of Orbitals
Electron Spin

C1403_Ch16_Learning Goals

- (1) Be able to describe the wave properties (c , ν , λ) of electromagnetic radiation and how these properties are related to the energy (E) of an electromagnetic wave.
- (2) Be able to describe the essential features of quantum theory such as the quantized nature of energy of light (quanta) and of the quantization of light itself (photons).
- (3) Be able to describe the reason why the ultraviolet catastrophe, the photoelectric effect, the predicted instability of the atom and line atomic spectra required a complete paradigm shift from the classical theory of light.
- (4) Be able to describe how Bohr designed a model of the atom to patch up the Maxwell's classical model of light.
- (5) Be able to explain the origin of atomic line spectra (absorption and emission) in terms of transitions between energy levels and the Bohr model of the atom.

C1403_Ch16_Learning Goals (continued)

- (6) Be able to compute energies corresponding to the transitions between energy levels for the hydrogen atom and one electron atoms.
- (7) Be able to describe why the Bohr model failed and why the Schroedinger model is the current paradigm for electrons.
- (8) Be able to describe the concepts and properties of wavefunctions, orbitals and quantum numbers.
- (7) Be able to describe the uncertainty principle and wave-particle duality to your grandparents.
- (9) Be able to describe the concept of electron spin.

C1403_Ch16_Learning Goals (continued)

- (6) Be able to compute energies corresponding to the transitions between energy levels for the hydrogen atom and one electron atoms.**
- (7) Be able to describe why the Bohr model failed and why the Schroedinger model is the current paradigm.**
- (8) Be able to describe the concepts and properties of wavefunctions, orbitals and quantum numbers.**
- (7) Be able to describe the uncertainty principle and wave-particle duality to your grandparents.**
- (9) Be able to describe the concept of electron spin.**

Einstein's Annus Mirabilis: 1905

Five papers published in 1905 that shook the foundations of science. Three with profound importance to chemistry.

Photoelectric effect: Proof that light could have both wave and particle properties. Invention of the concept of photons.

Brownian Motion: Proof of the existence of molecules. A means of determining Avogadro's number.

Matter-Energy duality: Proposal that energy and mass are interconnected as a function of motion. $E = mc^2$



Light meets matter

A brief history of the role of paradigms in the intellectual and scientific history of views of light and matter.

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.

©1994 Beltmann



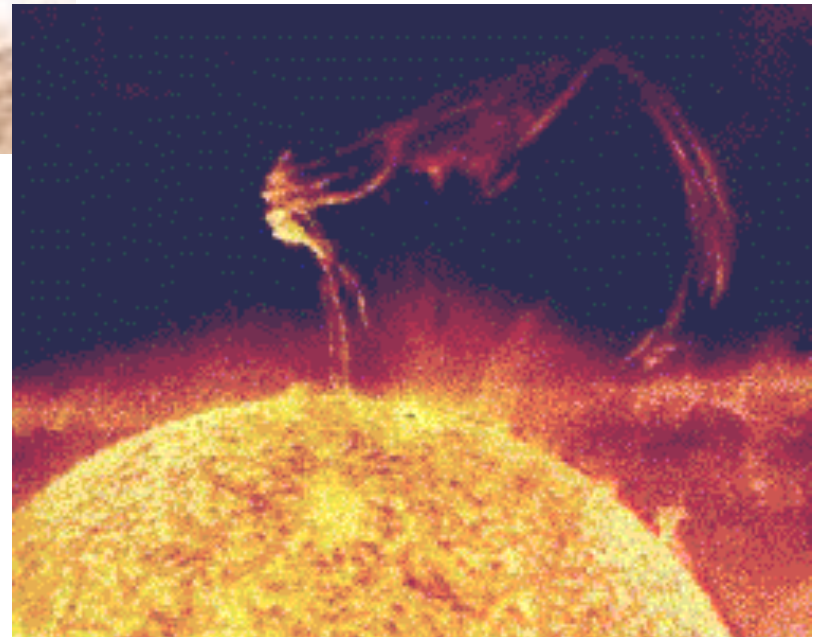
What is light?

God said: Let there be light..

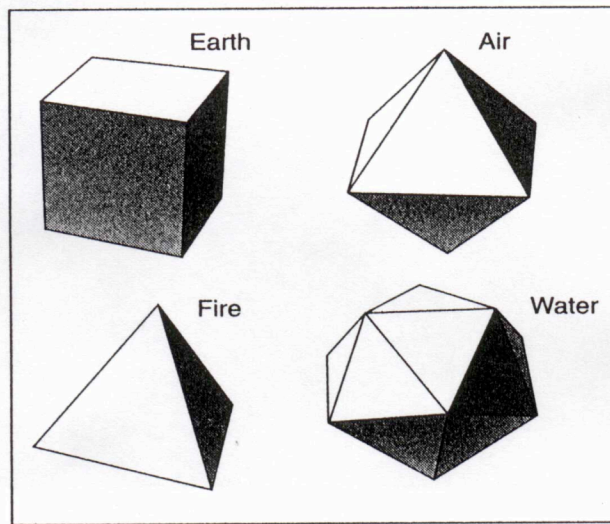
..And there was light (and matter and energy and space).

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 in shooting right across the interspace of air in the direction imparted by the shove.

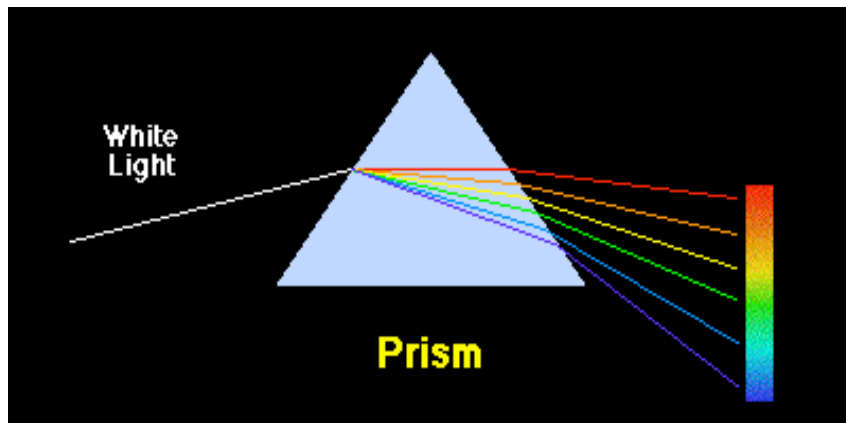
Paradigm I: Light consists of consists of tiny particles similar to atoms.¹⁴

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.*



James Clerk Maxwell
1831-1879

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

Maxwell's theory is called the **classical** theory of light.

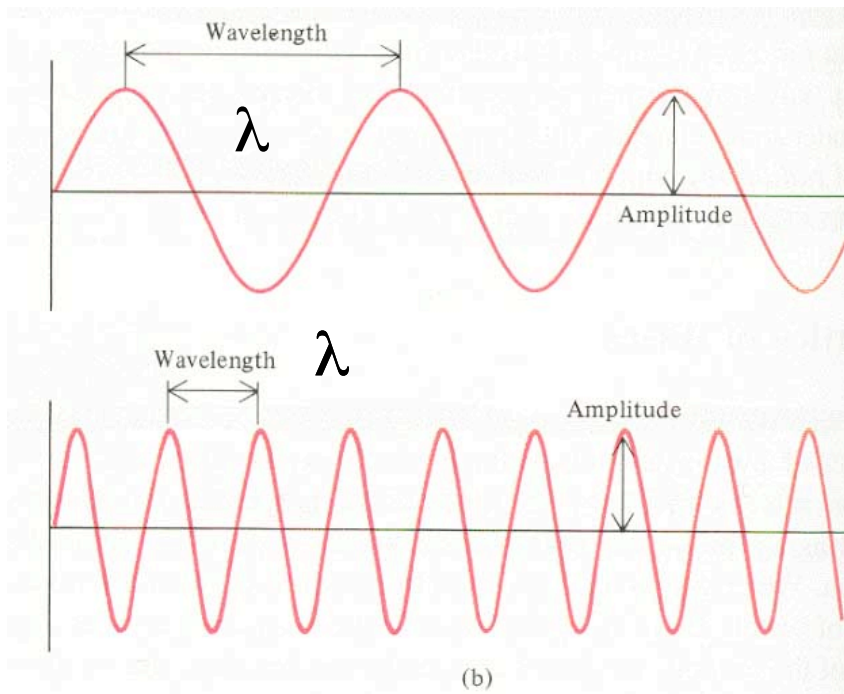
Key equations:

$$c = \lambda \nu \quad \lambda \text{ (Gk lambda), } \nu \text{ (Gk nu)}$$

c = speed of light wave wave propagation

λ = wavelength, ν = frequency

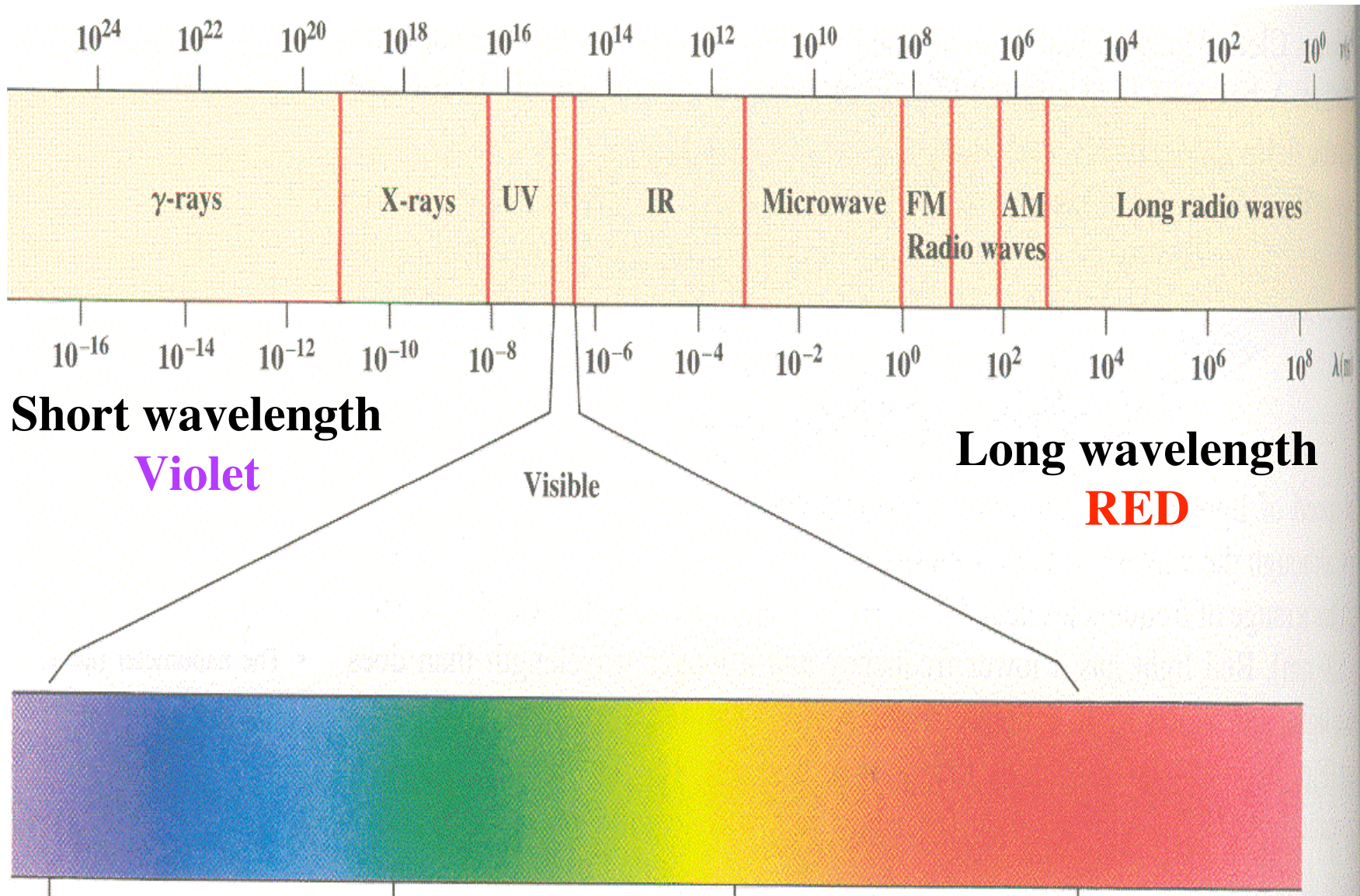
Classical Paradigm: Energy carried by a light wave is proportional to the *Amplitude* of wave. Big wave, small wave.



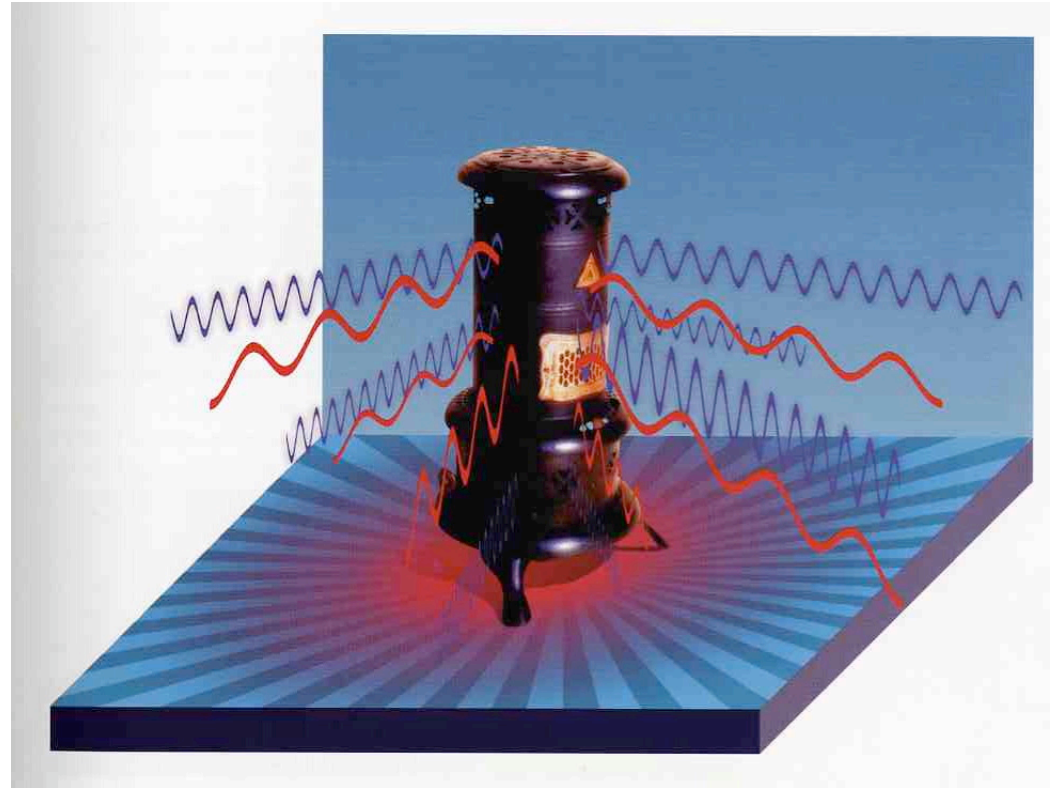
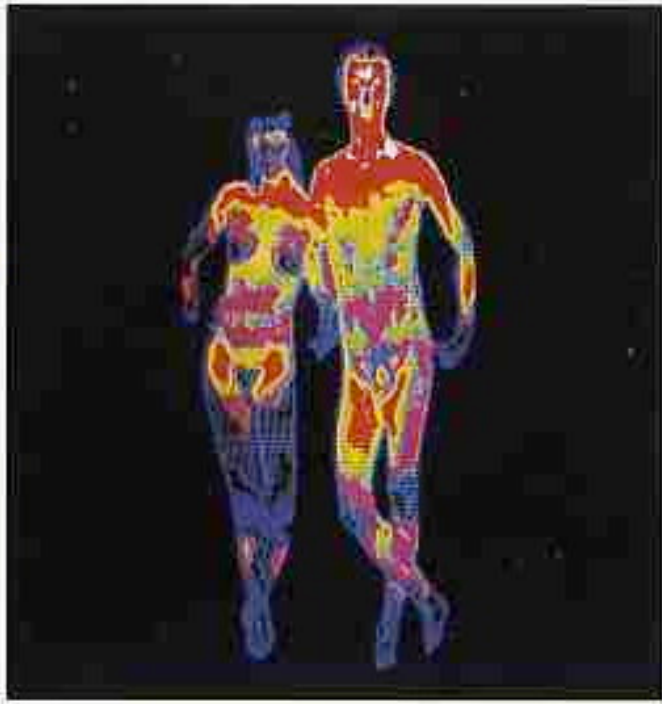
Low Frequency

High Frequency

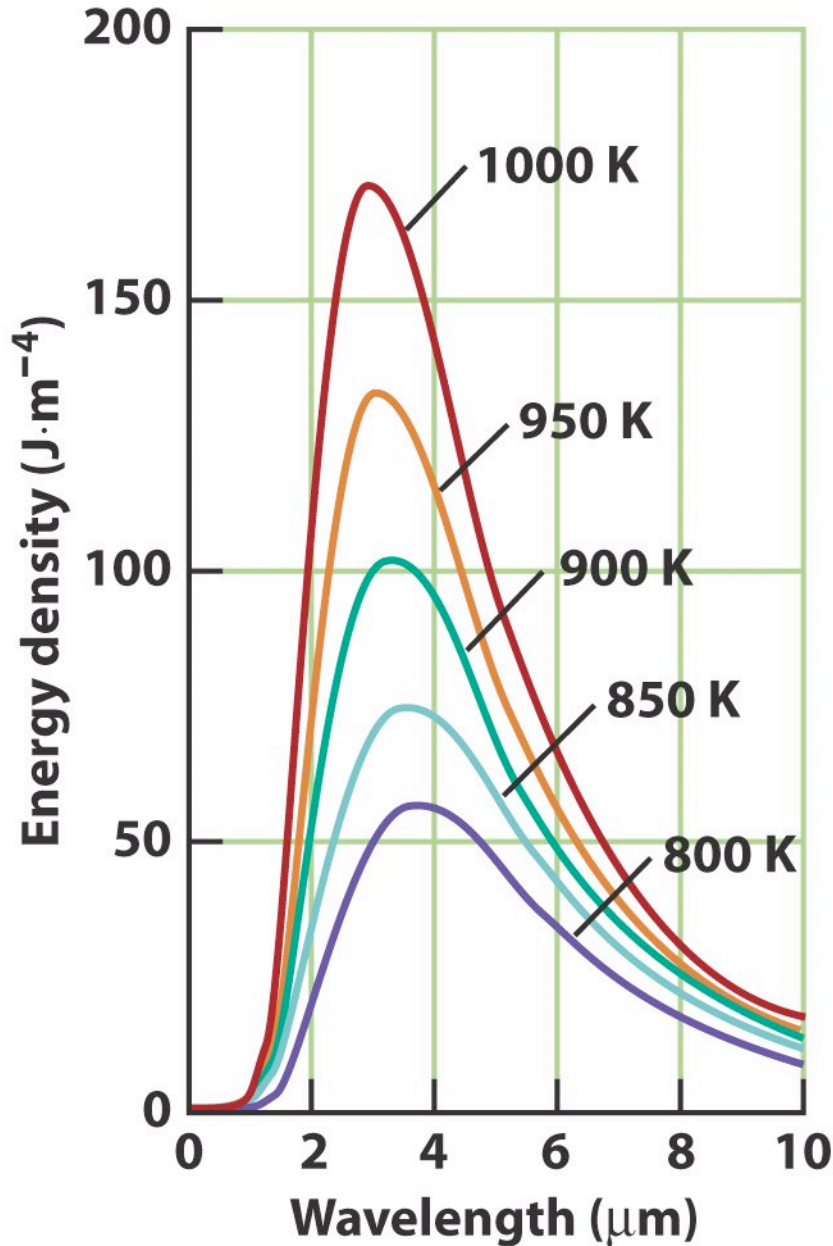
The electromagnetic spectrum from γ -rays to radio waves



The **visible** portion of the electromagnetic spectrum



A couple and a stove emitting electromagnetic radiation of varying wavelengths. All matter is made of electrical charged particles that jiggle and which emit electromagnetic radiation.



An important problem for Paradigm III: Predict the wavelength distribution of light intensity (energy) emitted by a heated metal as a function of temperature: so called "Black body" radiation.

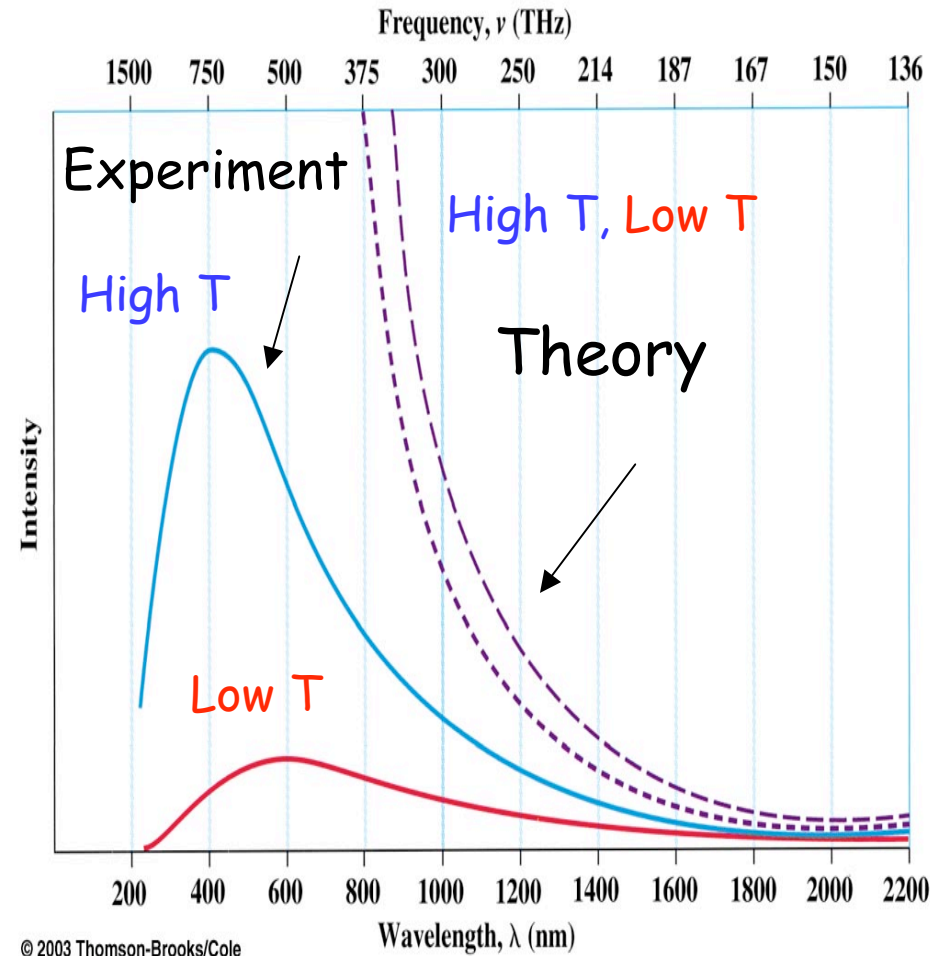
Paradox I The Ultraviolet Catastrophe.

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

I (Intensity) predicted to be proportional to $1/\lambda^4$

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

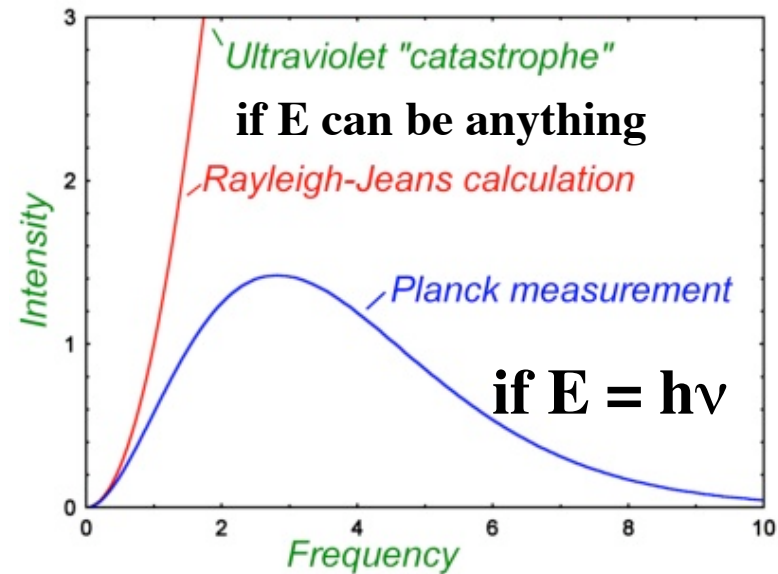
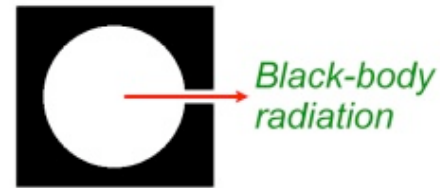
Experiment: Maximum observed!





Max Planck
Nobel Prize 1918
“for his explanation of the
ultraviolet catastrophe”, namely
 $E = h\nu$, the energy of light is
bundled and comes in quanta.

Planck explains the ultraviolet catastrophe by **quantizing** the energy of light. Light can only have energies given by $E = h\nu$. The value of $h = 6.6 \times 10^{-34}$ Js fits experiment!



$$I(\nu) = \frac{2h\nu^3}{c^2} \frac{1}{\exp(h\nu/kT) - 1}$$

Planck was
here at
Columbia
in 1915!

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

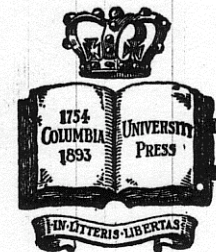
DELIVERED AT COLUMBIA UNIVERSITY
IN 1909

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



NEW YORK
COLUMBIA UNIVERSITY PRESS

1915

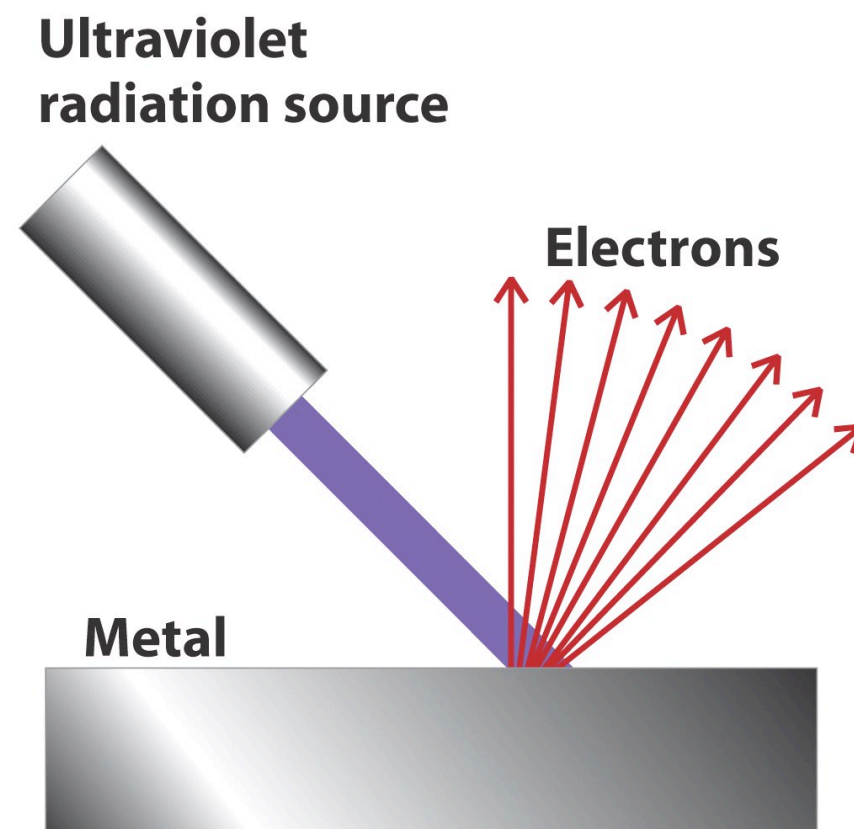
COLUMBIA
UNIVERSITY
LIBRARY

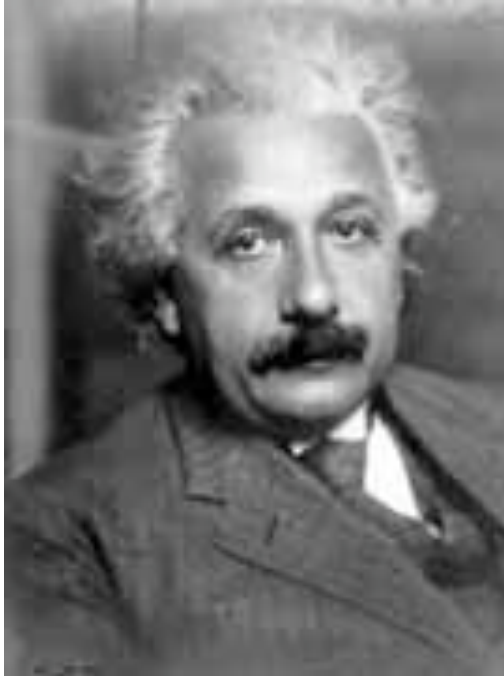
Paradox II: The Photoelectric Effect

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 (I) of the light and **independent of the frequency (ν) of the light.**

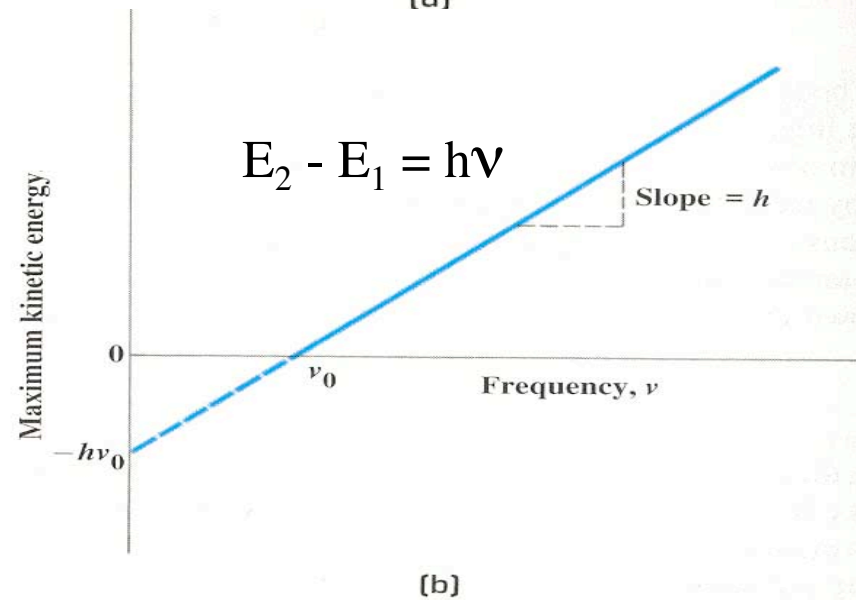
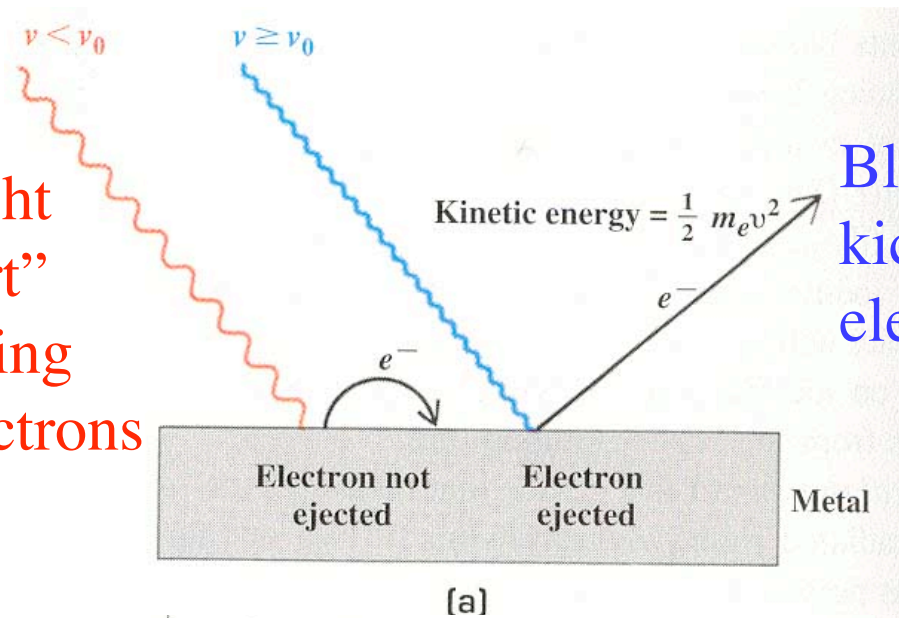
Experiment: the energy of the ejected electrons is independent of the intensity (I) and **depends directly on the frequency (ν) of the light.**





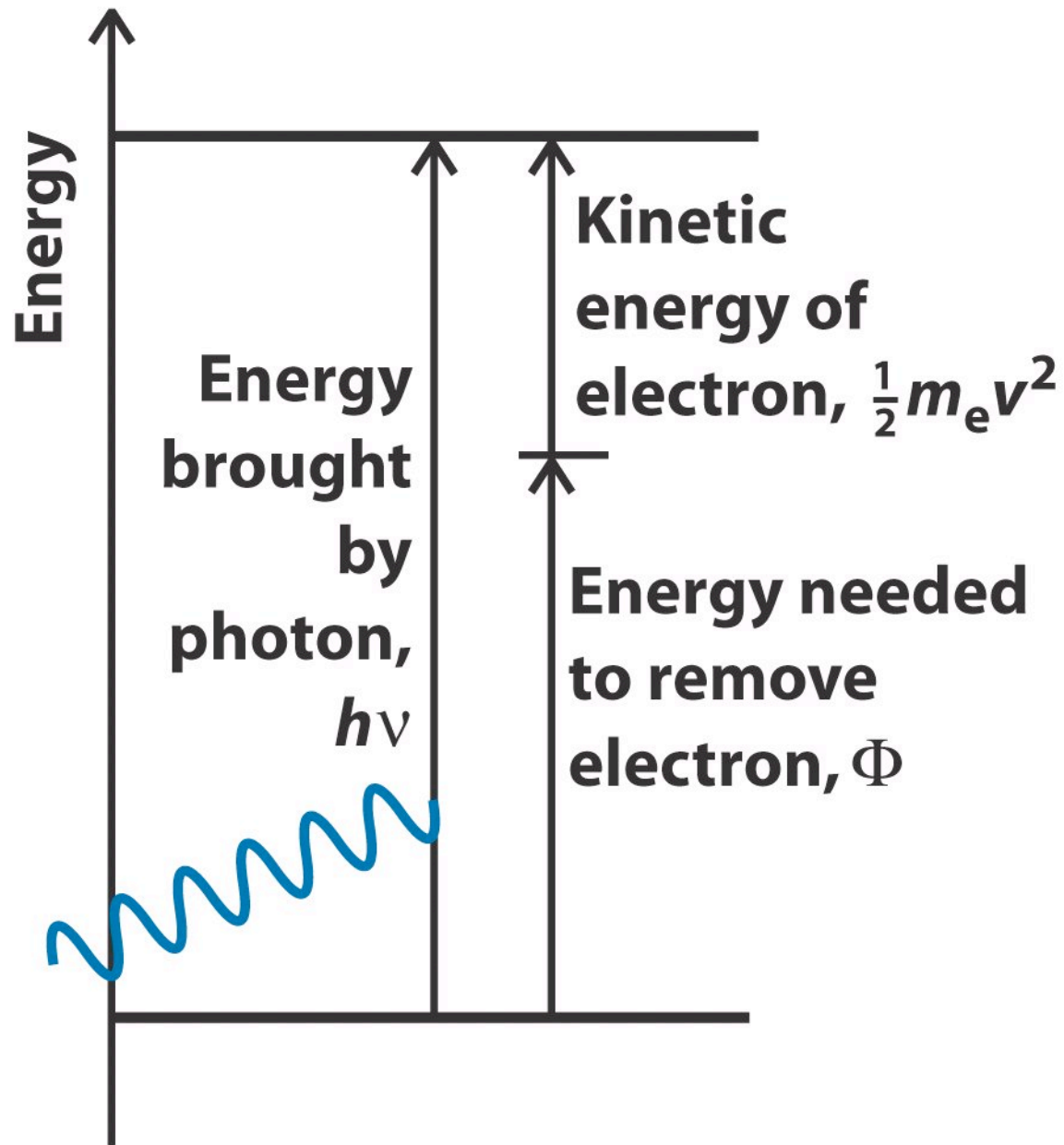
Red light is “inert” to kicking out electrons

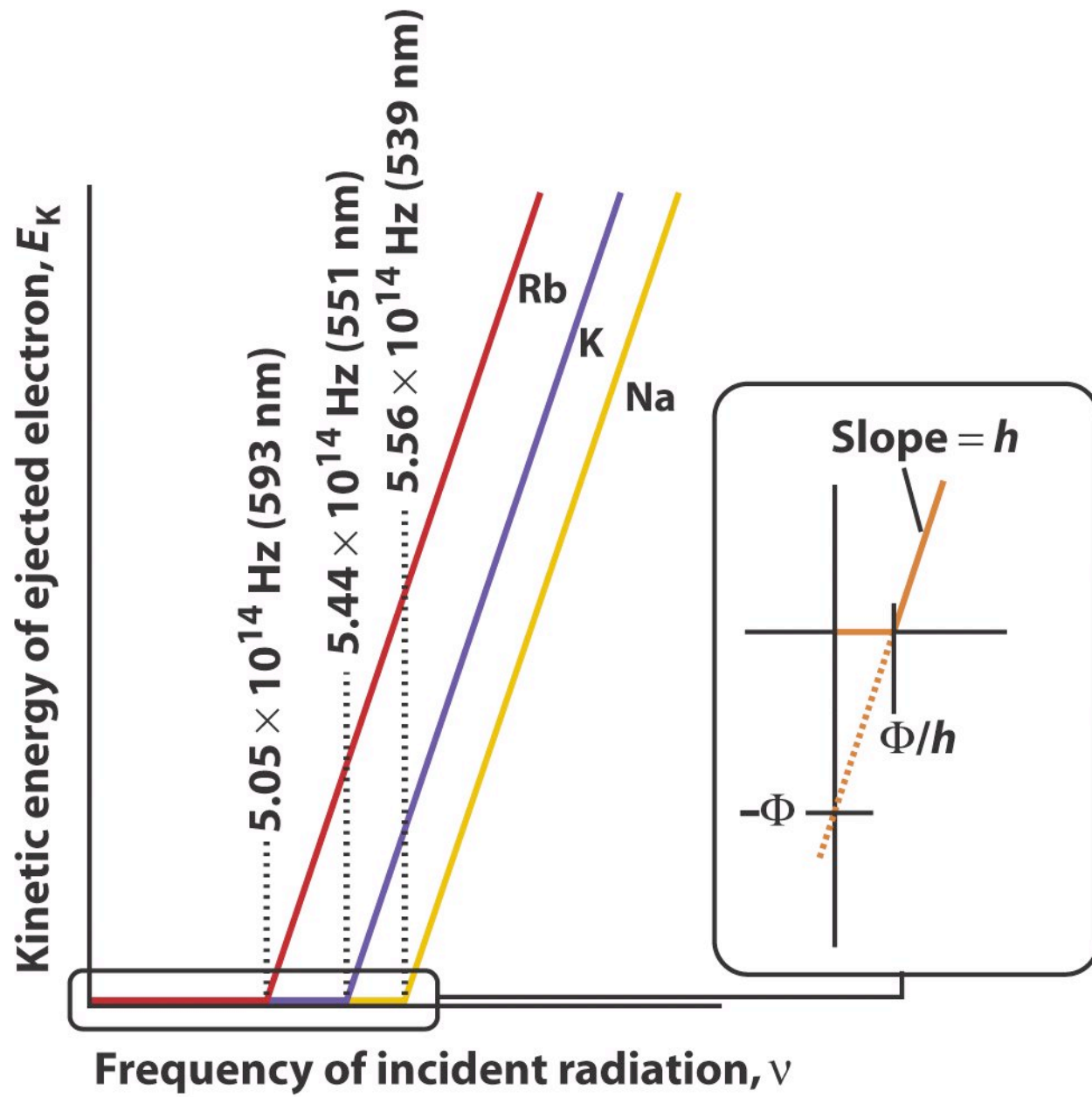
Blue light kicks out electrons!



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

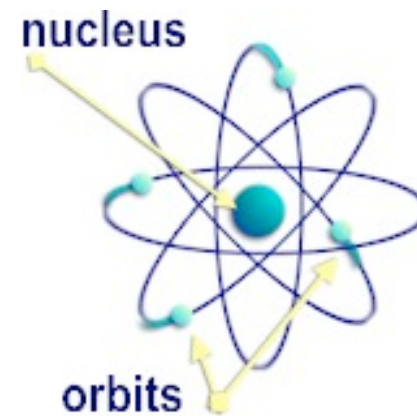
The slope of KE_{Max} vs ν is h !!!! ²⁴



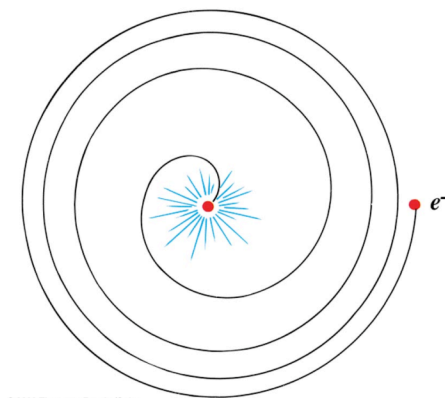


Paradox III: The electrons about a positive nucleus should execute a death spiral and collapse into the nucleus!

According to classical theory, the model for Rutherford's atoms are not stable. The motion of moving electrons should cause them to radiate energy in their orbits and to quickly execute a death spiral and collapse into the nucleus.

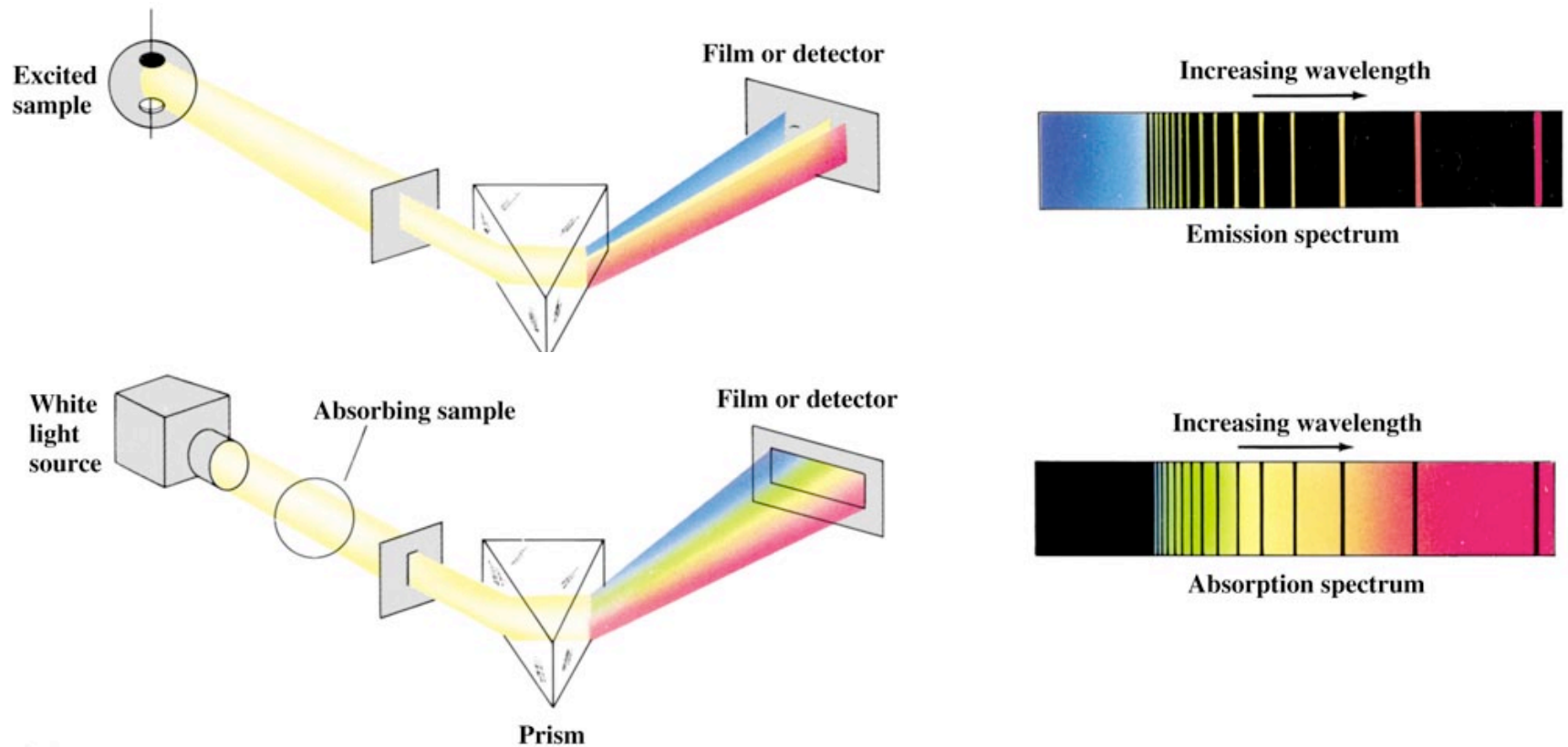


Rutherford's atom



The predicted death spiral
of the electron!

Paradox IV: The absorption and emission spectra of atoms are not continuous. The classical theory predicts that electromagnetic radiation is continuous and cannot explain the "line spectra" of atoms.



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Fig 16-9

Putting It All together: The Bohr Atom

Solving Paradox III: The unstable orbiting electron of Rutherford's atom.

Make the orbiting electron stable by assuming that the electron's orbit and energy is quantized to certain values and for these values the orbiting electron does not radiate. The electron is stable in these orbits. Thus, the orbits and energies of electrons are quantized.

Solving Paradox IV: The line spectra of emitting or absorbing atoms.

Since only certain energies are allowed for orbiting electrons, only jumps between orbits can be observed. These jumps correspond to discrete frequencies (ν) and wavelengths (λ). Thus, line spectra as expected because of the quantized energies of the orbits.



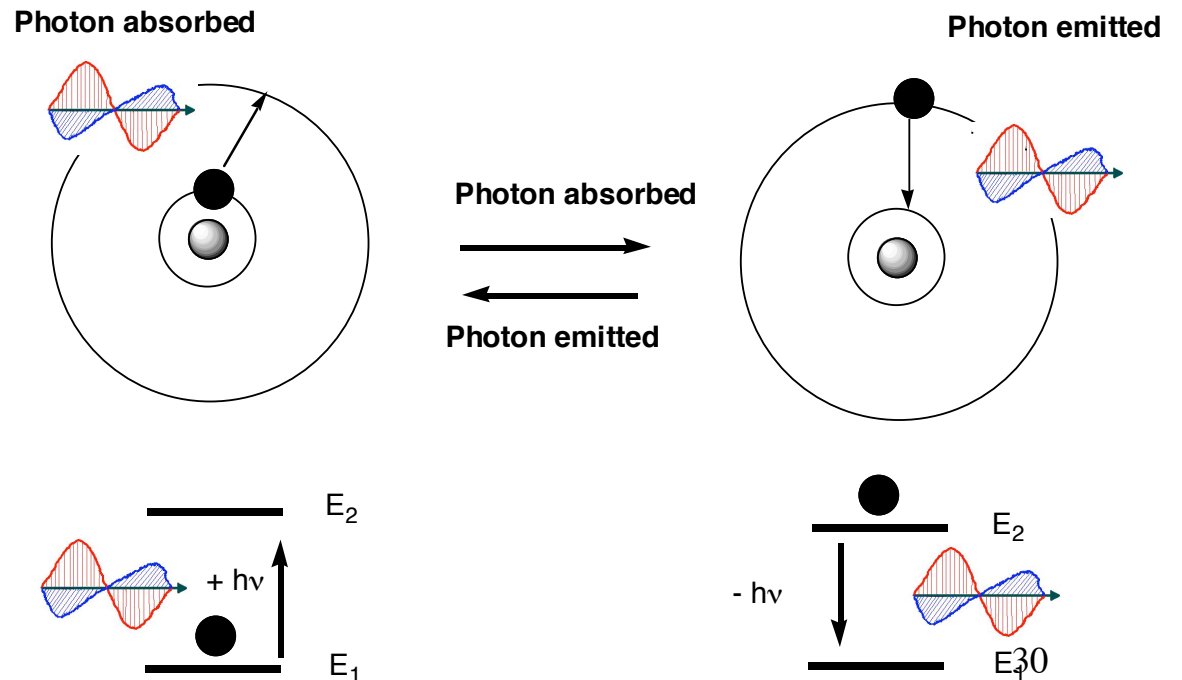
Light is **emitted** when an electron jumps from a higher orbit to a lower orbit and **absorbed** when it jumps from a lower to higher orbit.

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

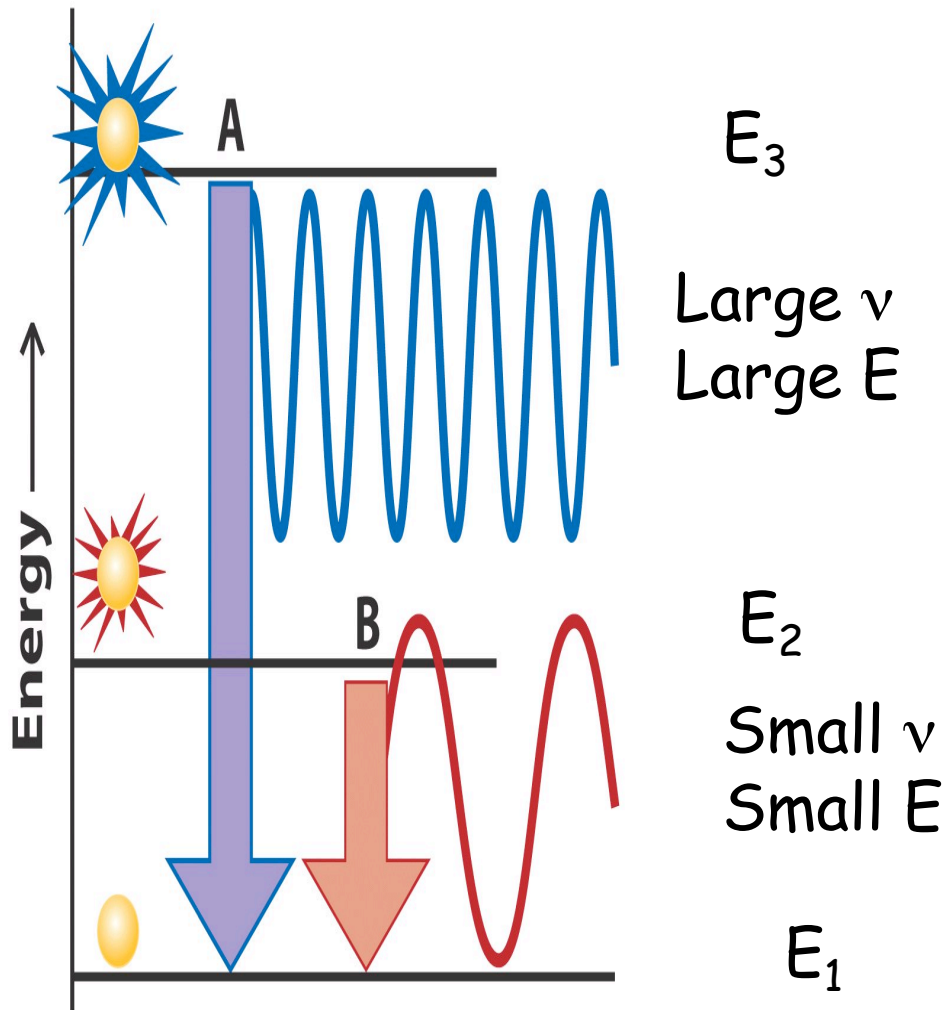
$$E(\text{photon}) = E_2 - E_1 \text{ (Energy difference)} = h\nu$$

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

The basis of all photochemistry and spectroscopy!



Frequency, not amplitude
determines energy absorbed or
emitted.



Einstein: $E = h\nu$

Bohr: $E_n - E_1 = h\nu$

$$E_3 - E_1 = h\nu_{31}$$

$$E_2 - E_1 = h\nu_{21}$$

$$E_3 - E_1 > E_2 - E_1$$

$$h\nu_{31} > h\nu_{21}$$

Bohr resonance
condition:
 $E_n - E_1 = h\nu$

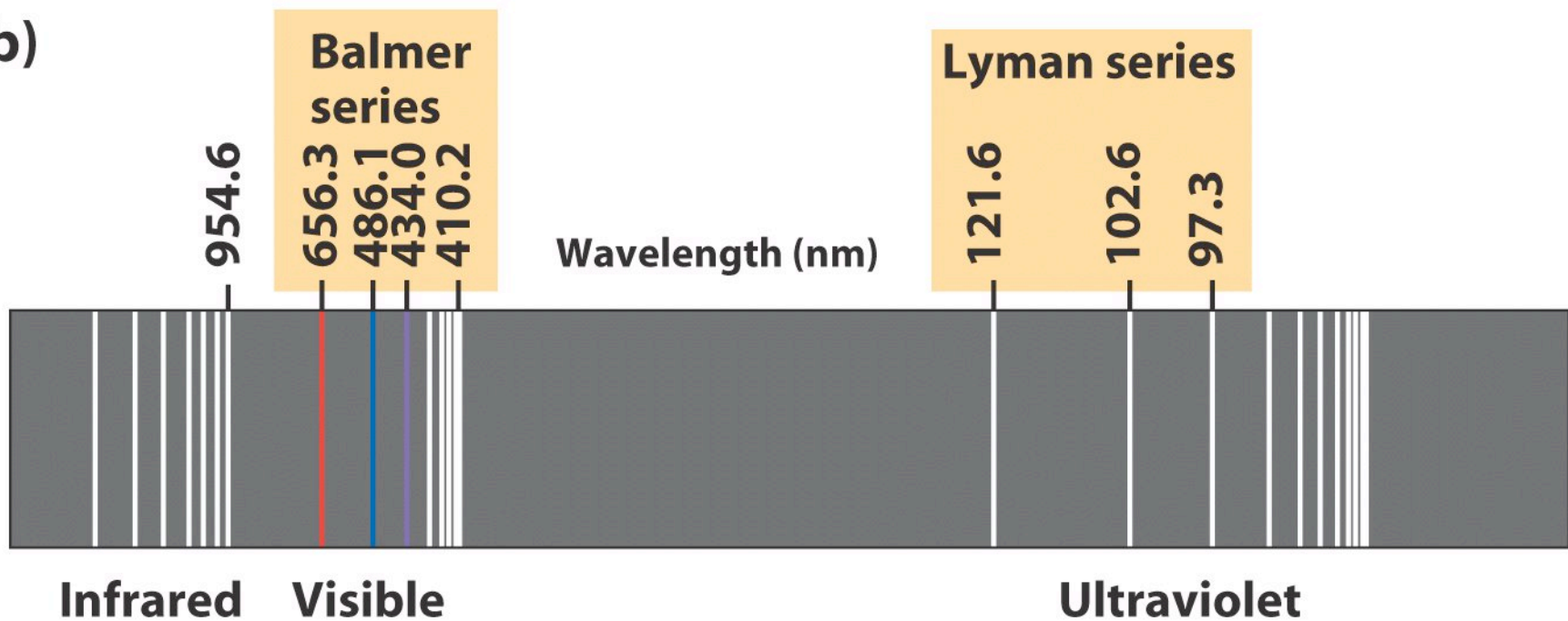
The Bohr Atom and the Absorption and Emission of Light

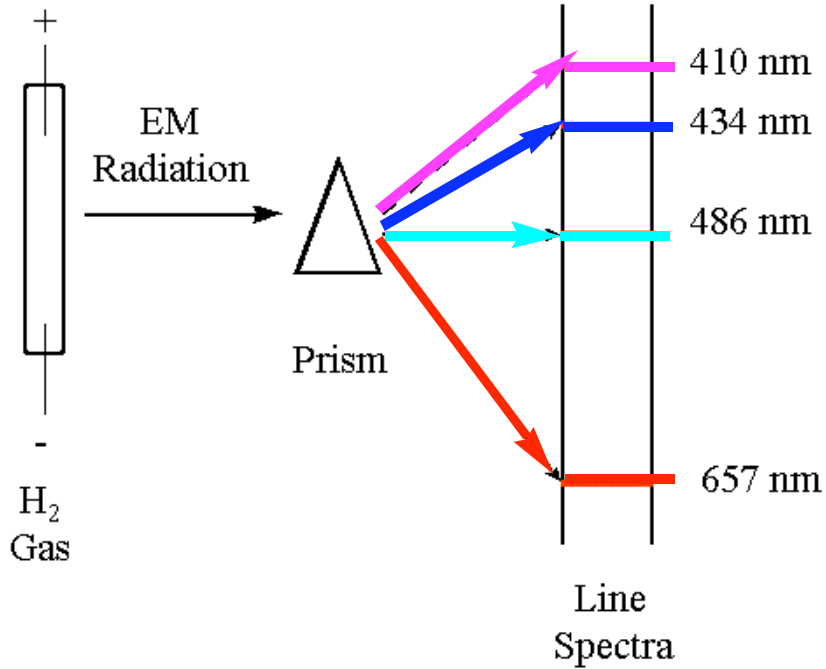
The emission from discharge lamps

(a)

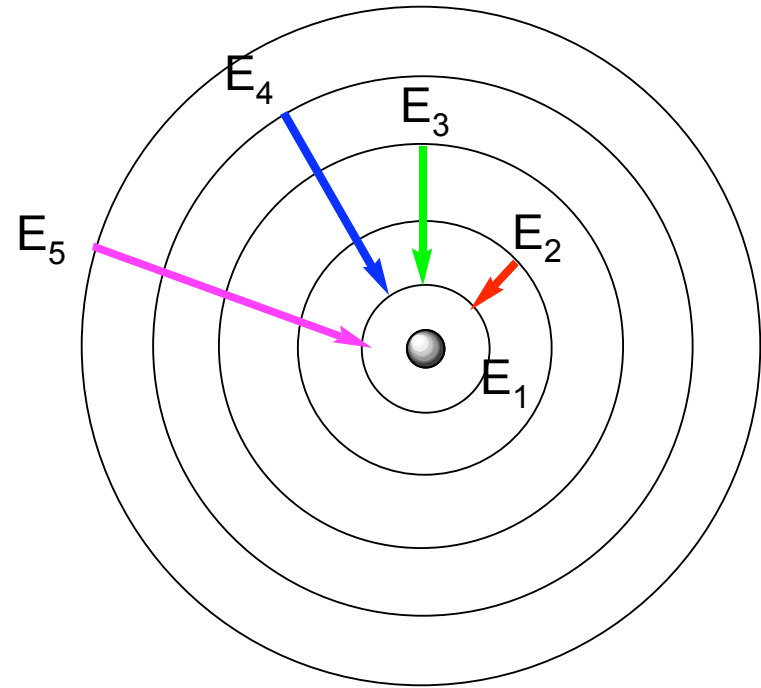


(b)

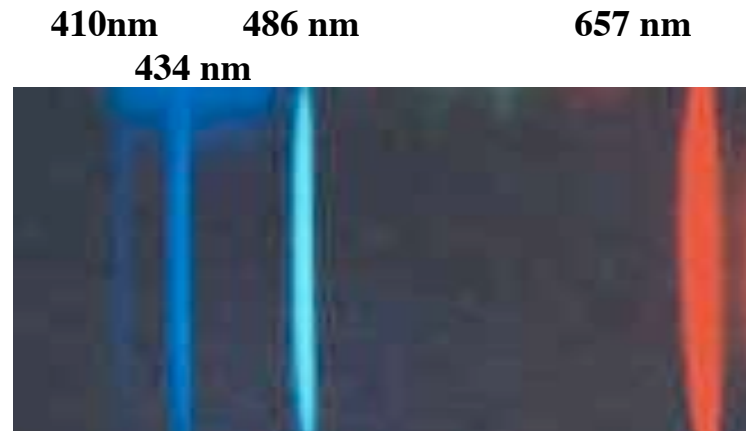




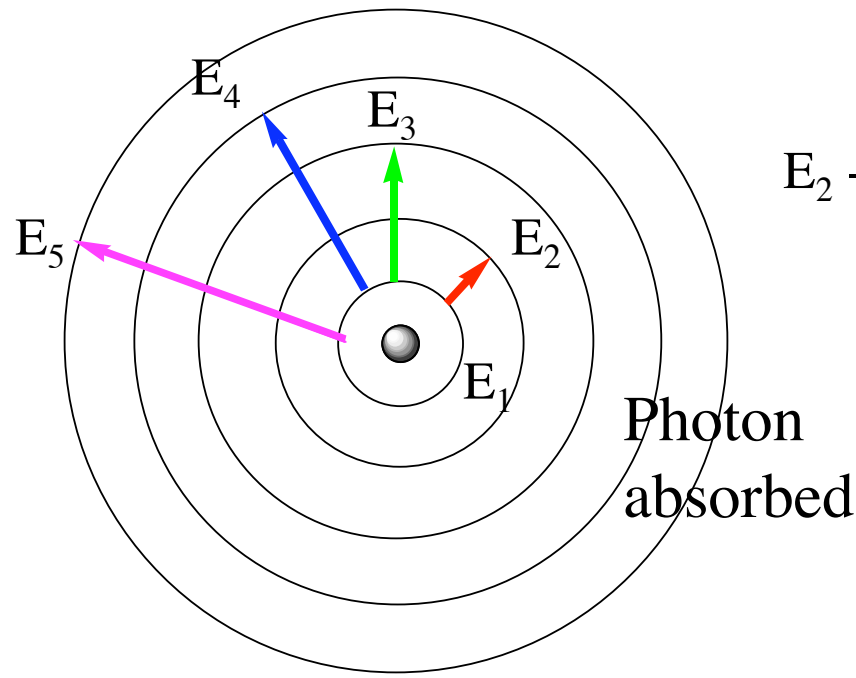
Schematic of the Experiment



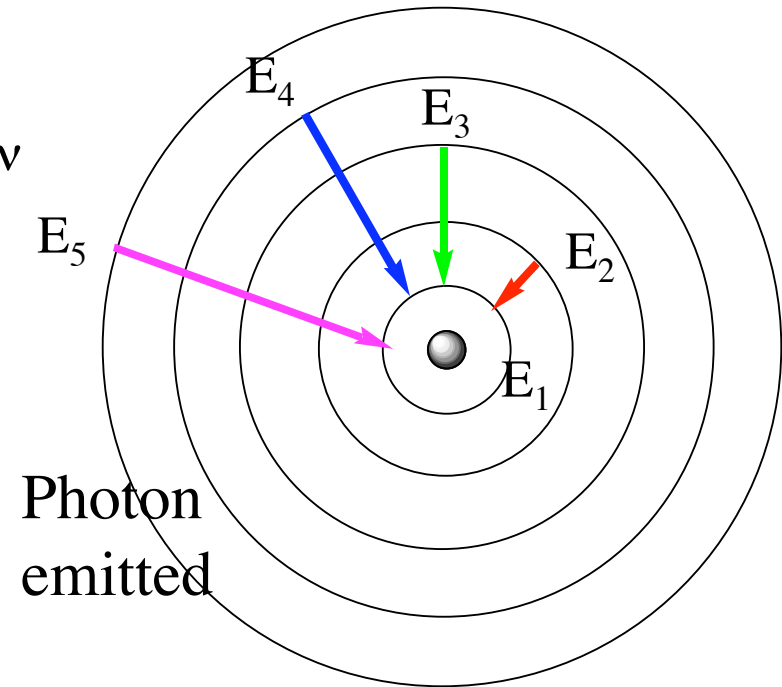
If all this is true then you should be able to “see” the spectrum of the electrons jumping from E₅, E₄, E₃, E₂, to E₁ and here is what we should see.



The “line” spectrum of hydrogen



$$E_2 - E_1 = h\nu$$



$$E_2 - E_1 \quad E_2 - E_1 \quad E_2 - E_1$$

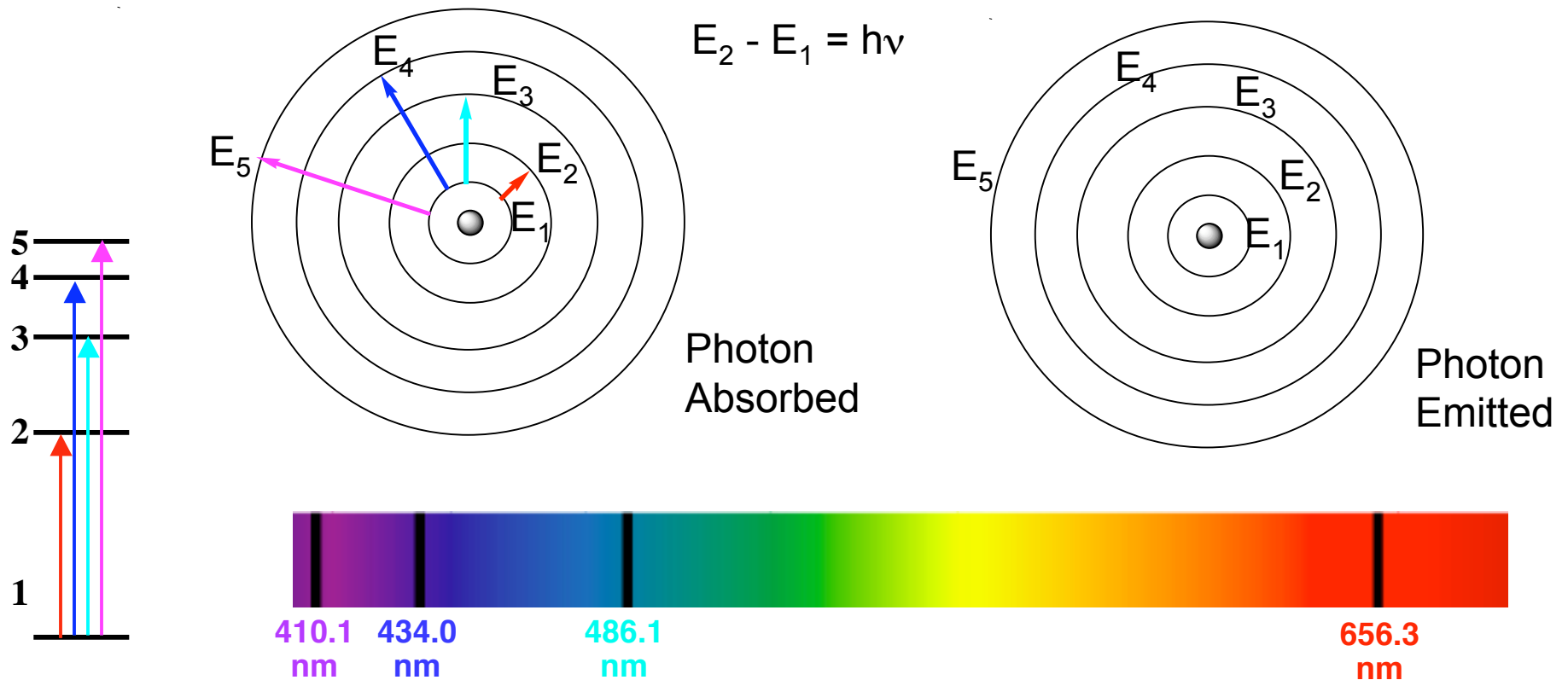
$$E_2 - E_1$$



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.

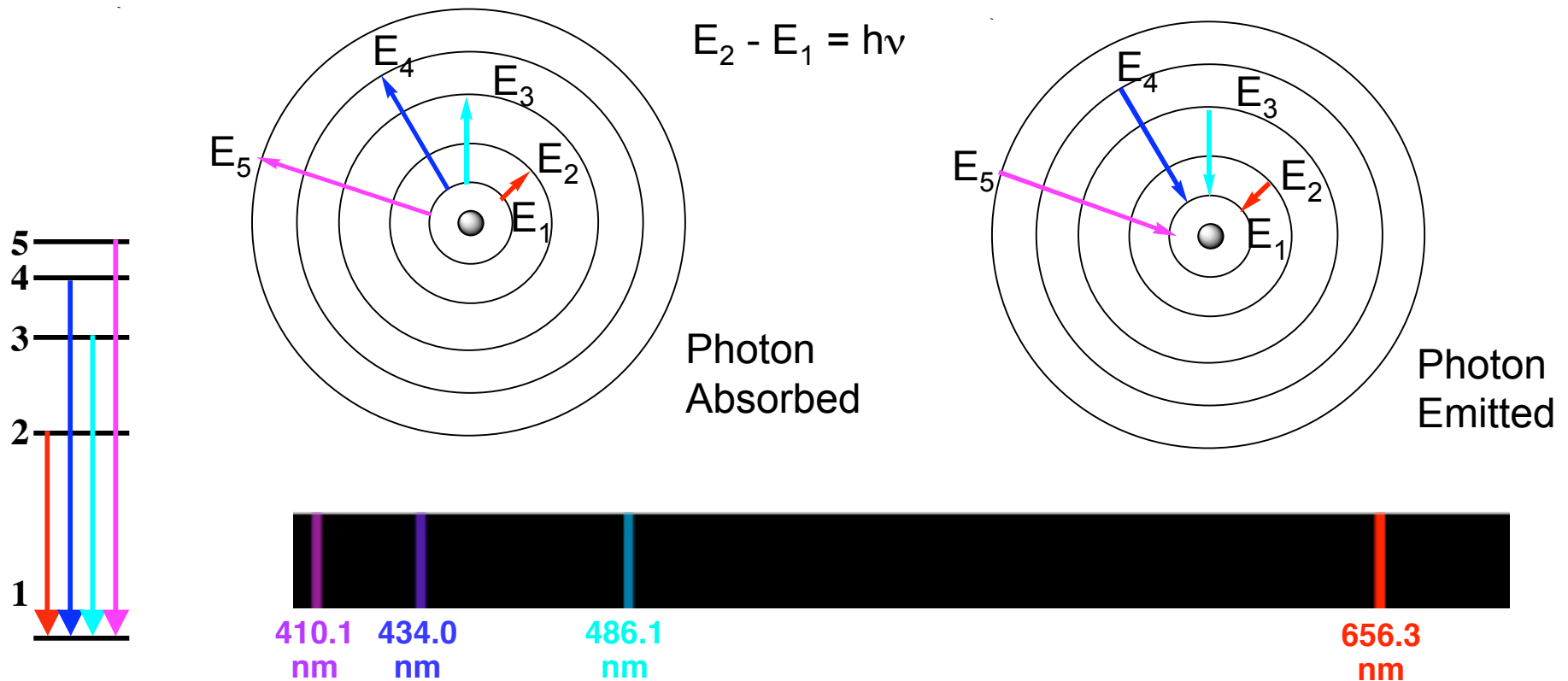
Energy & Resonance: The Bohr Atom



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.**

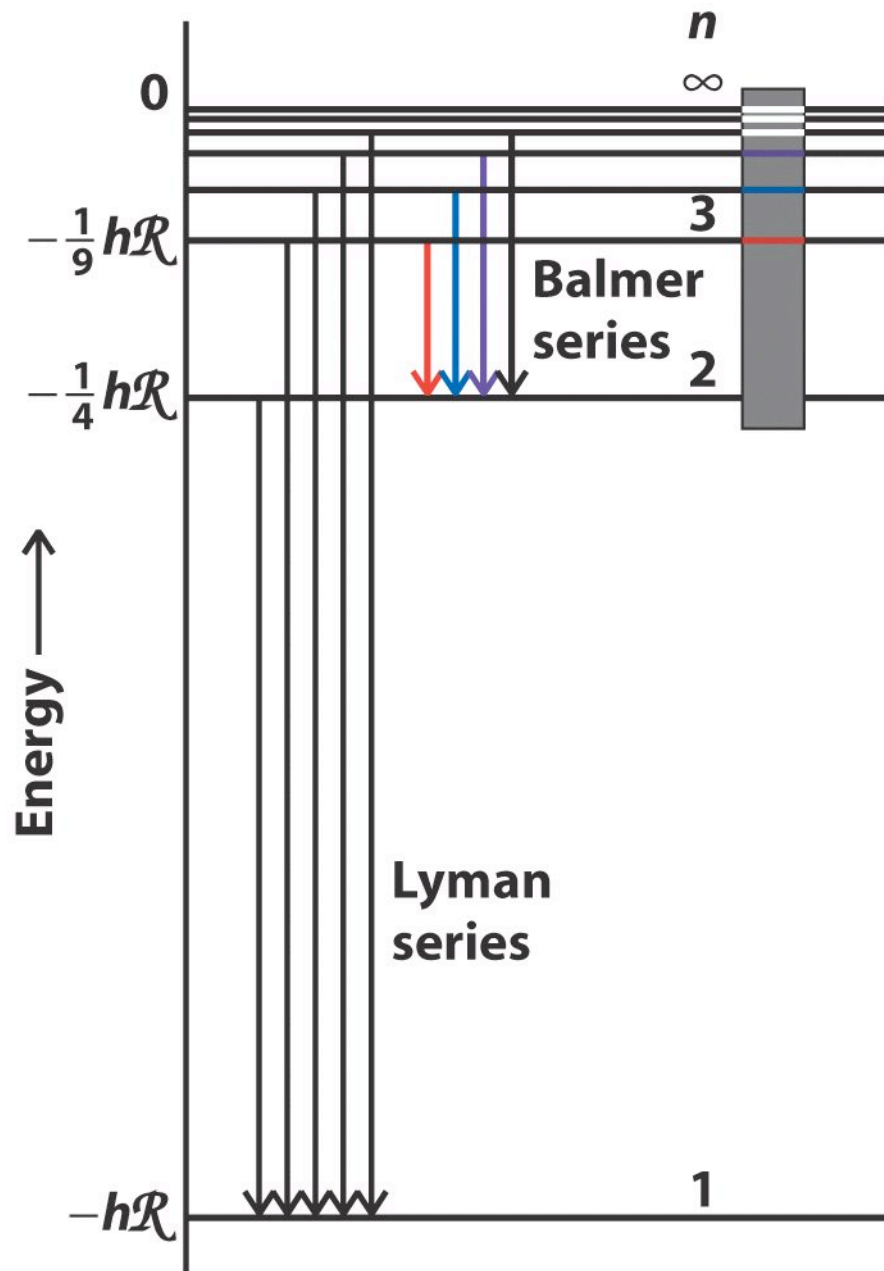
Bohr atom: Light emission occurs when an electron makes a transition from a higher energy orbital to a lower energy orbital and a **photon is emitted**. **Emission spectra appear as sharp lines.**

Energy & Resonance: The Bohr Atom



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.**



An energy level diagram describing the allowed emissive transitions of a Bohr atom.

The series are connected by the final value of n .

Lyman: $n = 1$
 Balmer: $n = 2$

What next? If **waves** can mimic **particles**, then perhaps **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)

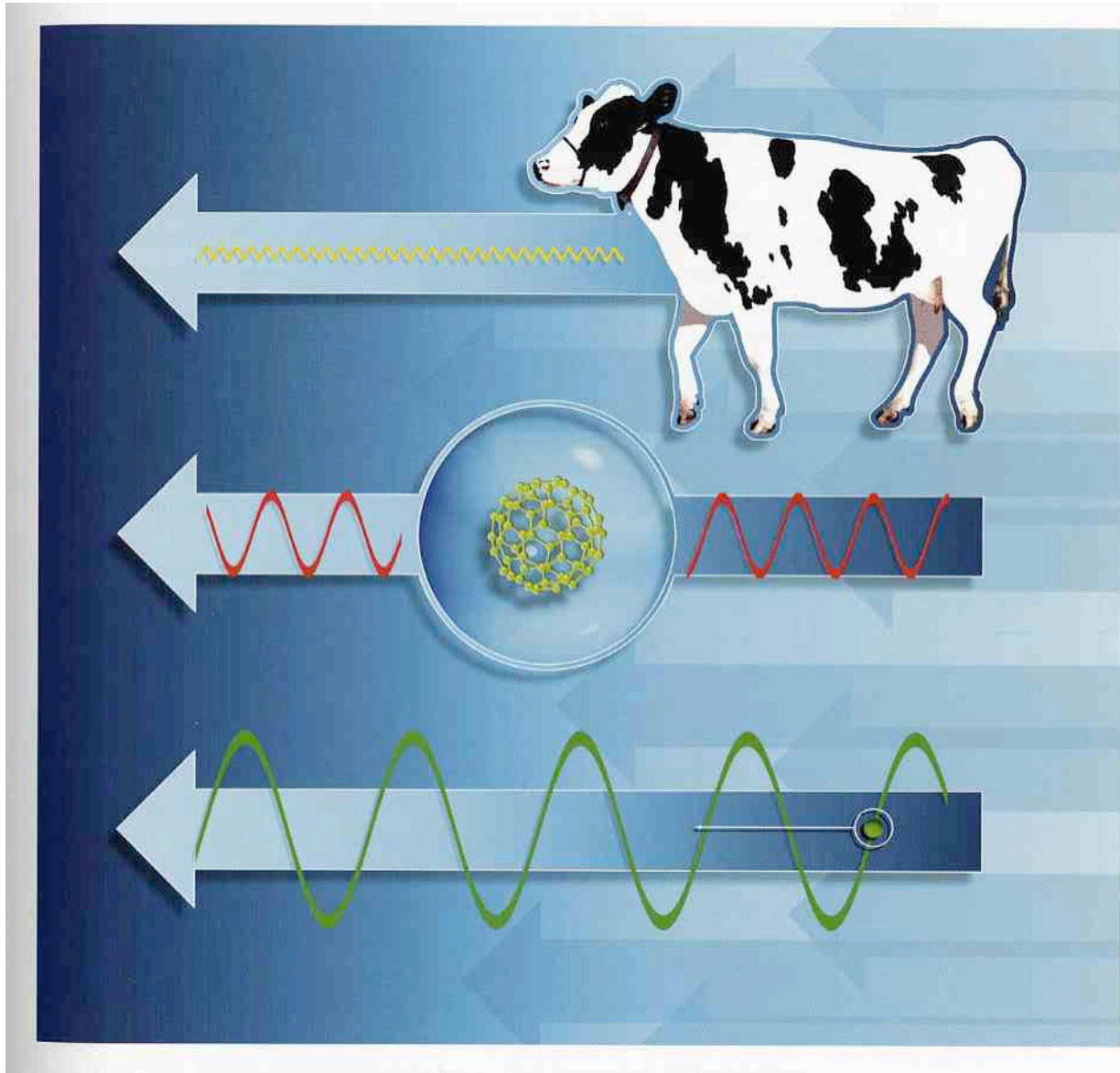
then

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

Light = Matter

$\lambda = h/mv$

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*₃₈



Wavy cows?

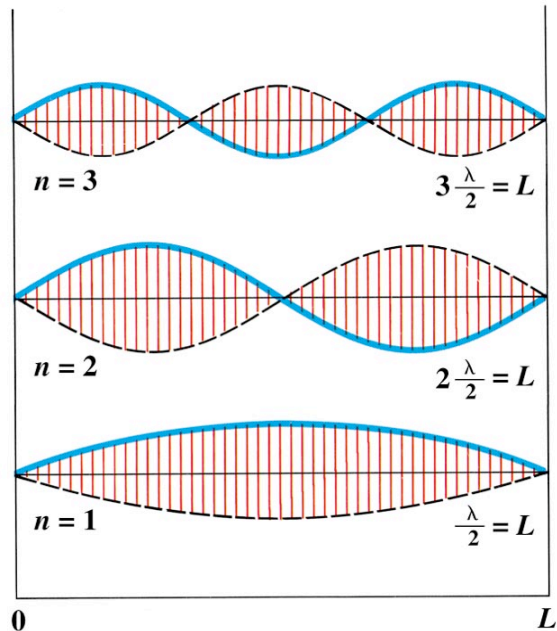
$$\lambda = h/mv$$

The value of
 $h = 6.6 \times 10^{-34} \text{ Js}$

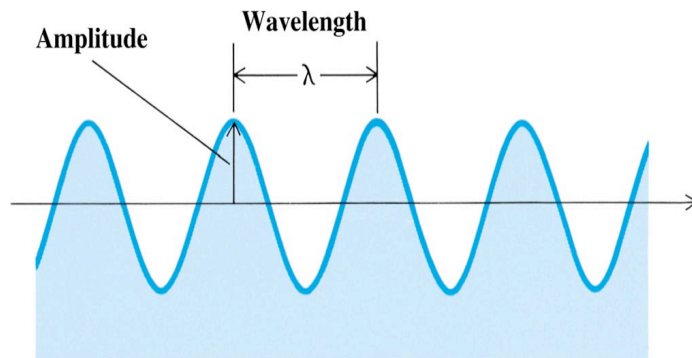
Electrons show
wave properties,
cows do not.

The wave properties of matter are only apparent
for very small masses of matter.

Two familiar macroscopic waves: a vibrating guitar string and a traveling water wave.



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$$\text{Speed} = c = \frac{\text{distance}}{\text{time}}$$

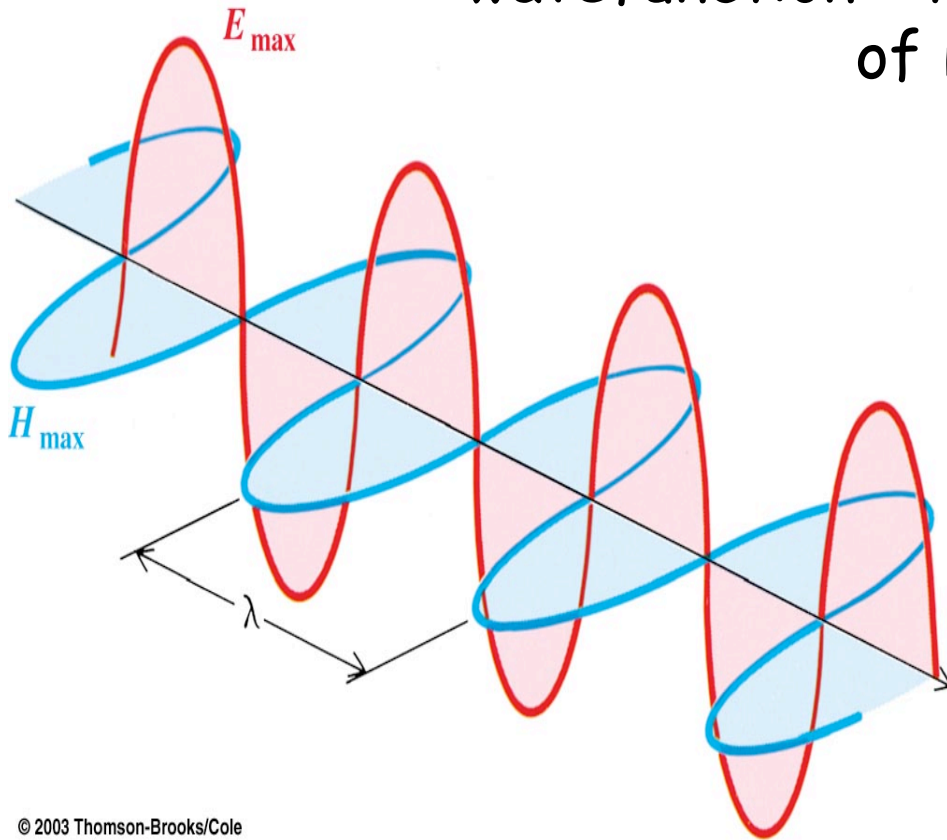
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Harmonics (stable standing waves) of a linear string fixed at both ends is characterized by its speed, its wavelength (frequency) and its amplitude

A traveling water wave is characterized by its speed, its wavelength (frequency) and its amplitude.

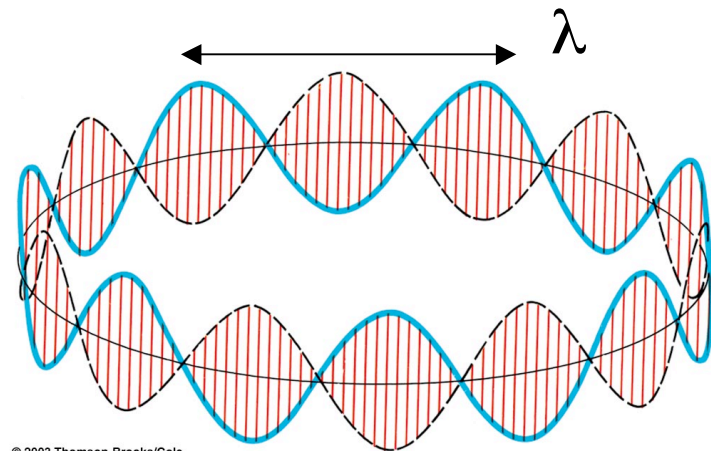
Traveling waves and standing waves

Every wave has a corresponding "wavefunction" that completely describes all of its properties.



© 2003 Thomson-Brooks/Cole

Light as a traveling wave



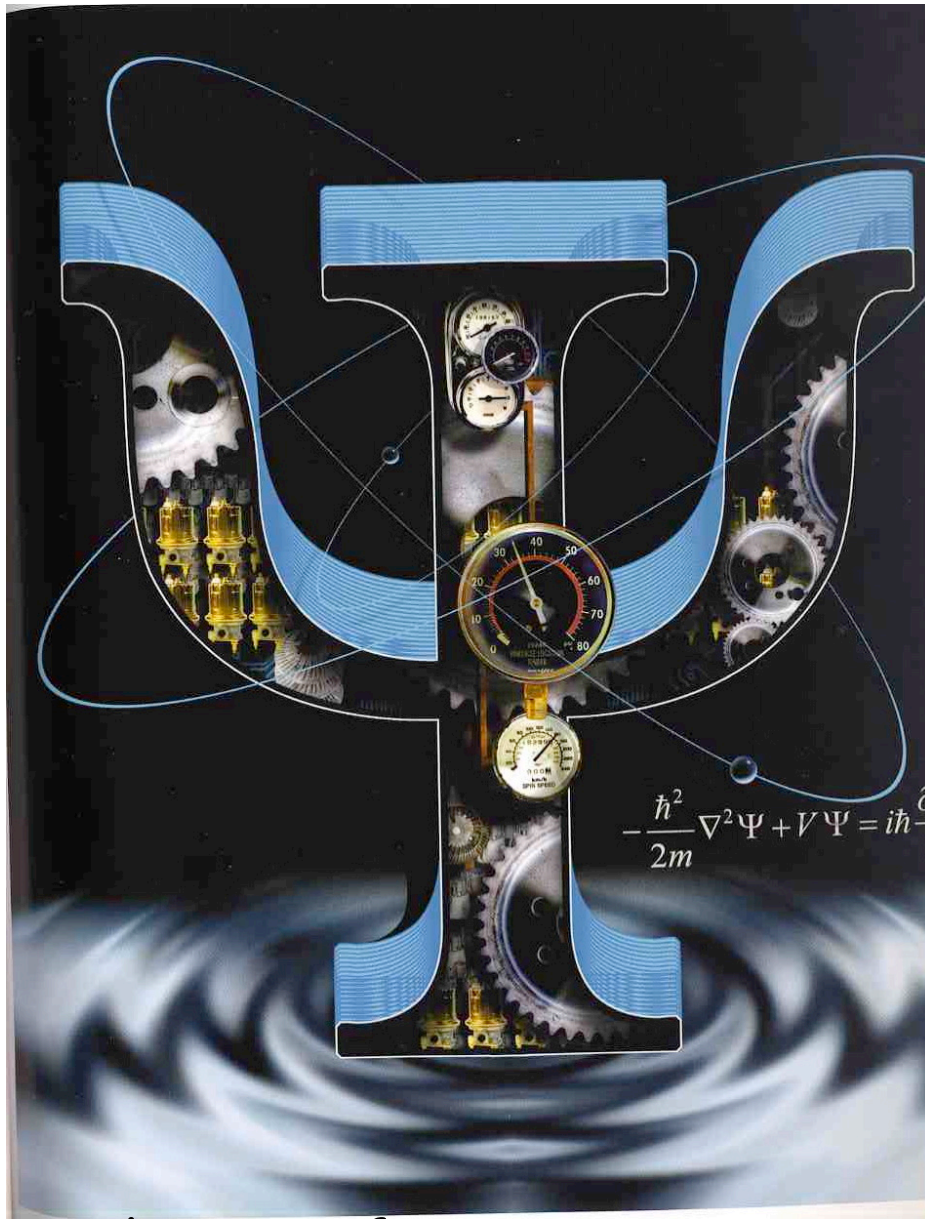
© 2003 Thomson-Brooks/Cole

A circular standing wave
With 7 wavelengths around
the circle



Schroedinger: If electrons are waves, their position 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.



The wavefunction, Ψ

Planck's constant

Called the 'del-squared operator', this quantity describes how the wavefunction, Ψ , changes from one place to another

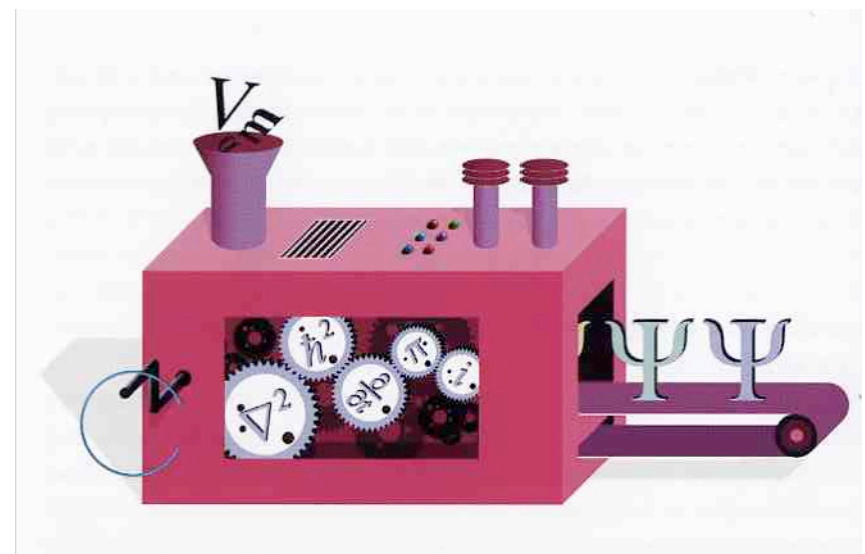
A mathematical quantity called an 'imaginary number'. It is equal to the square root of minus one

$$-\frac{\hbar^2}{2m} \nabla^2 \Psi + V\Psi = i\hbar \frac{\partial \Psi}{\partial t}$$

The mass of the particle being described

Describes the forces acting on the particle

Describes how Ψ changes its shape with time



The mathematics of wavefunctions

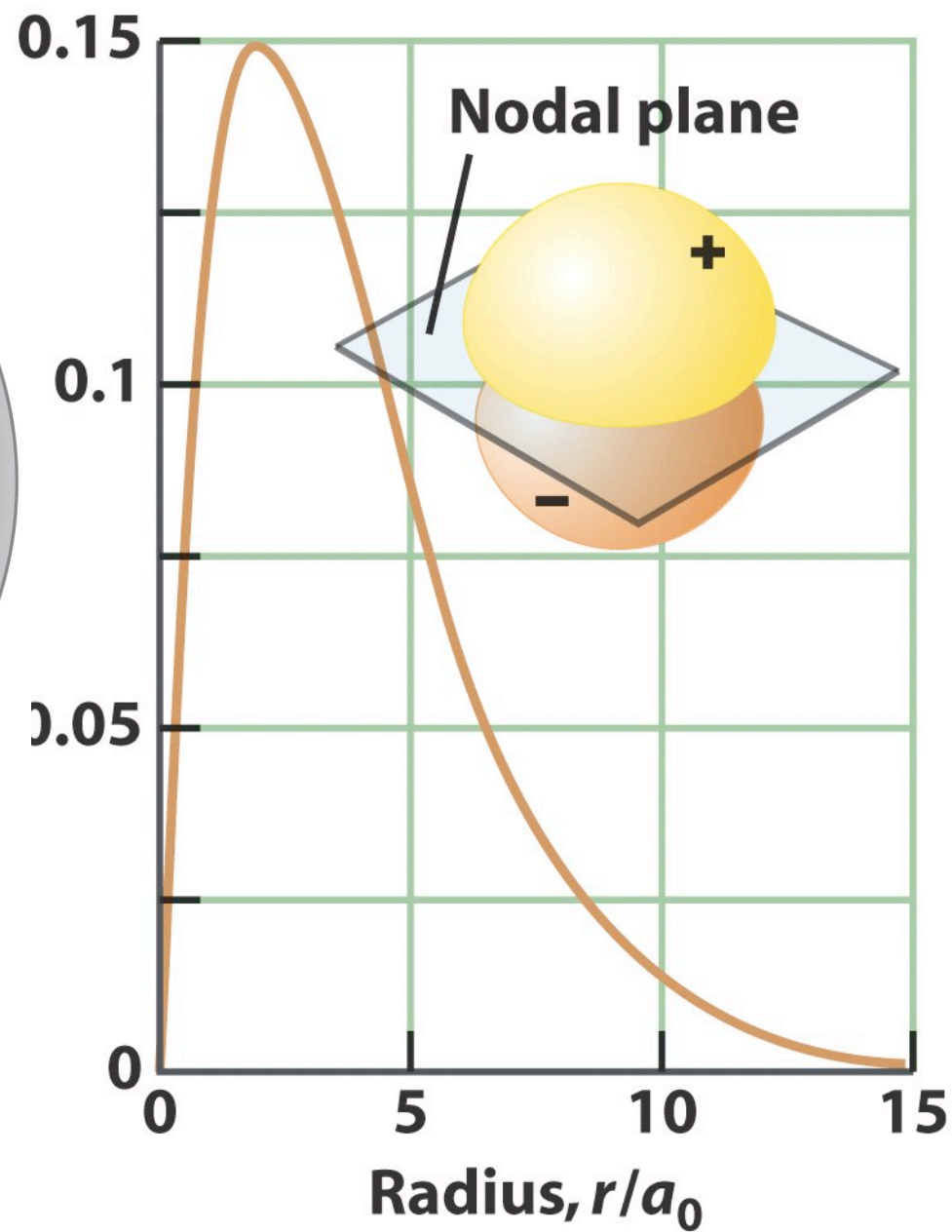
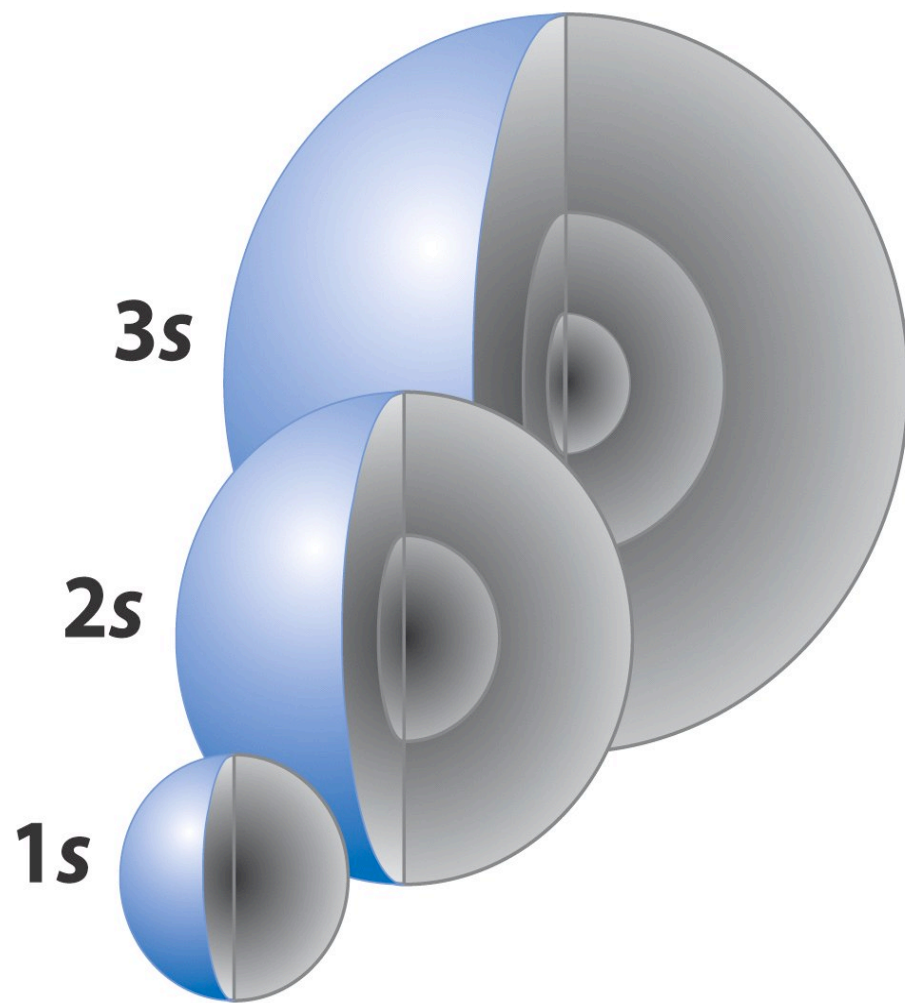
TABLE 1.2 Hydrogen Wavefunctions (Atomic Orbitals), $\psi = RY$

(a) Radial wavefunctions, $R_{nl}(r)$			(b) Angular wavefunctions, $Y_{lm_l}(\theta, \phi)$		
n	l	$R_{nl}(r)$	l	“ m_l ”*	$Y_{lm_l}(\theta, \phi)$
1	0	$2\left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0}$	0	0	$\left(\frac{1}{4\pi}\right)^{1/2}$
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	x	$\left(\frac{3}{4\pi}\right)^{1/2} \sin \theta \cos \phi$
	1	$\frac{1}{2\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2}\left(\frac{Zr}{a_0}\right)e^{-Zr/2a_0}$		y	$\left(\frac{3}{4\pi}\right)^{1/2} \sin \theta \sin \phi$
3	0	$\frac{1}{9\sqrt{3}}\left(\frac{Z}{a_0}\right)^{3/2}\left(3 - \frac{2Zr}{a_0} + \frac{2Z^2r^2}{9a_0^2}\right)e^{-Zr/3a_0}$	2	z	$\left(\frac{3}{4\pi}\right)^{1/2} \cos \theta$
	1	$\frac{2}{27\sqrt{6}}\left(\frac{Z}{a_0}\right)^{3/2}\left(2 - \frac{Zr}{3a_0}\right)e^{-Zr/3a_0}$		xy	$\left(\frac{15}{16\pi}\right)^{1/2} \sin^2 \theta \cos 2\phi$
	2	$\frac{4}{81\sqrt{30}}\left(\frac{Z}{a_0}\right)^{3/2}\left(\frac{Zr}{a_0}\right)^2 e^{-Zr/3a_0}$		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, $a_0 = 4\pi\epsilon_0^2/m_e e^2$, 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

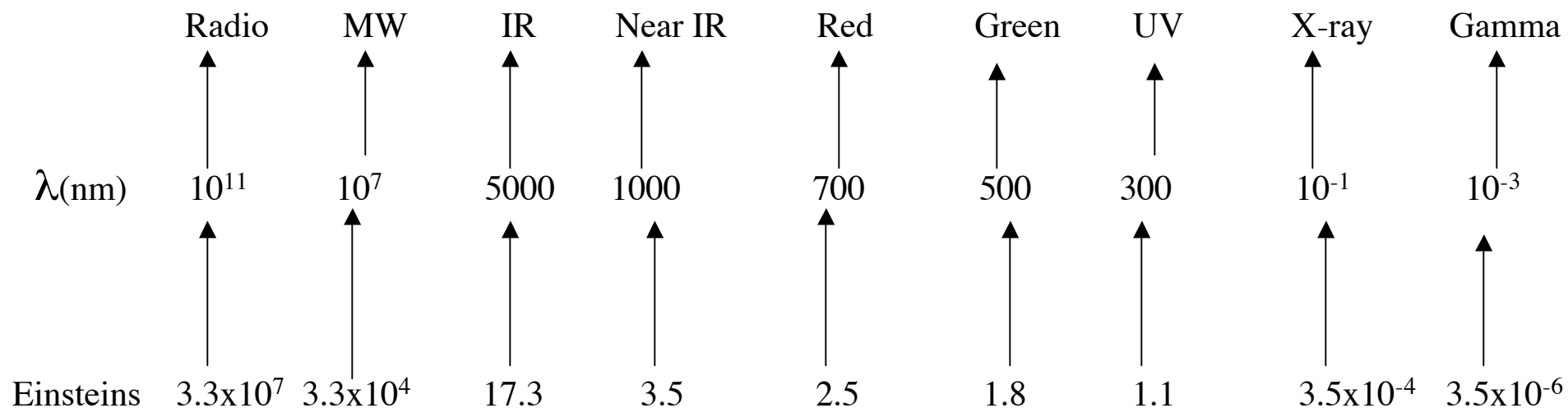


Photochemistry: The chemical interaction of light and matter

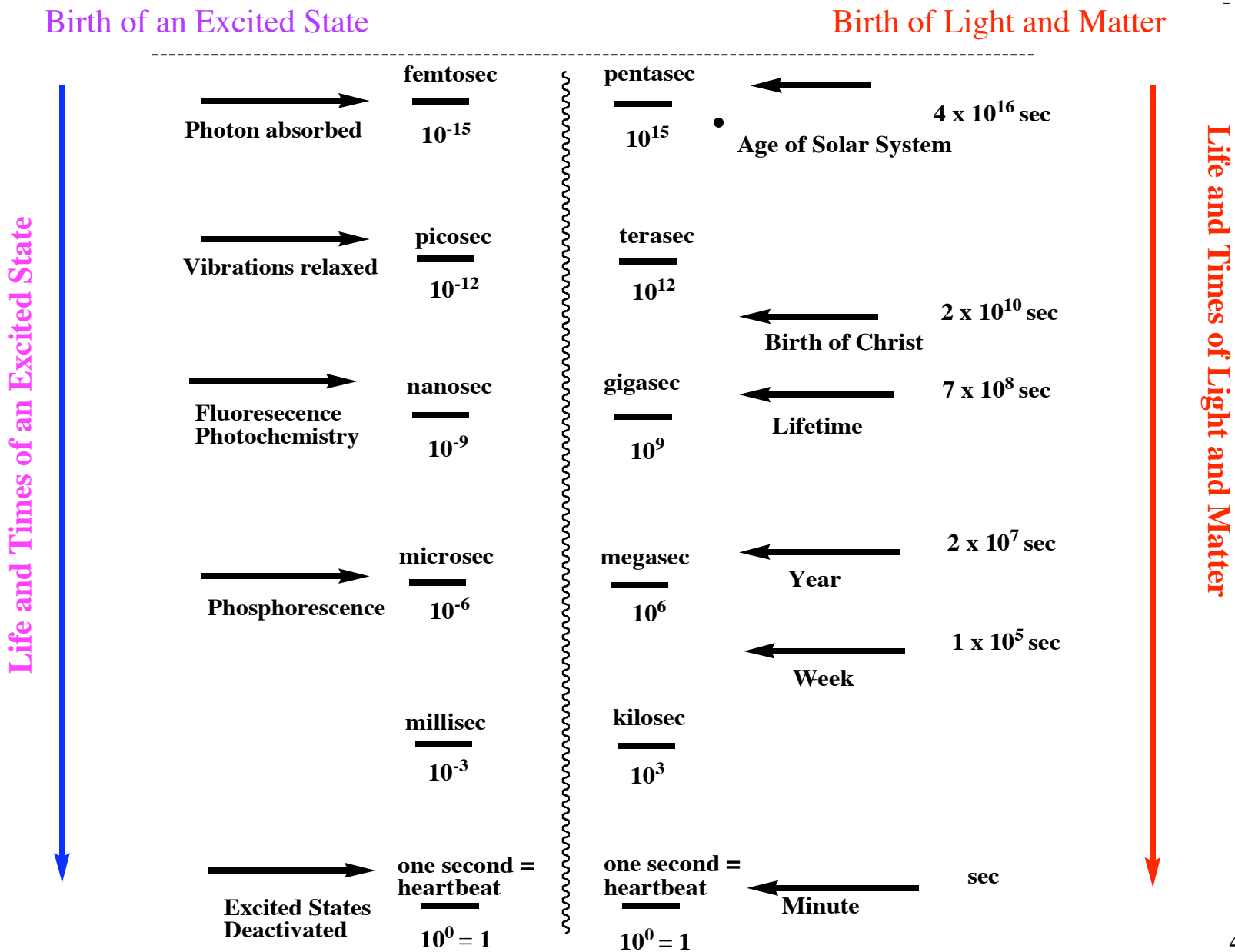
Photosynthesis: The source of most of our energy on earth.

Vision: A simple photochemical reaction that allows us to observe the world around us.

Comparing Wavelength to Number of Einsteins in 100 kcal/mol



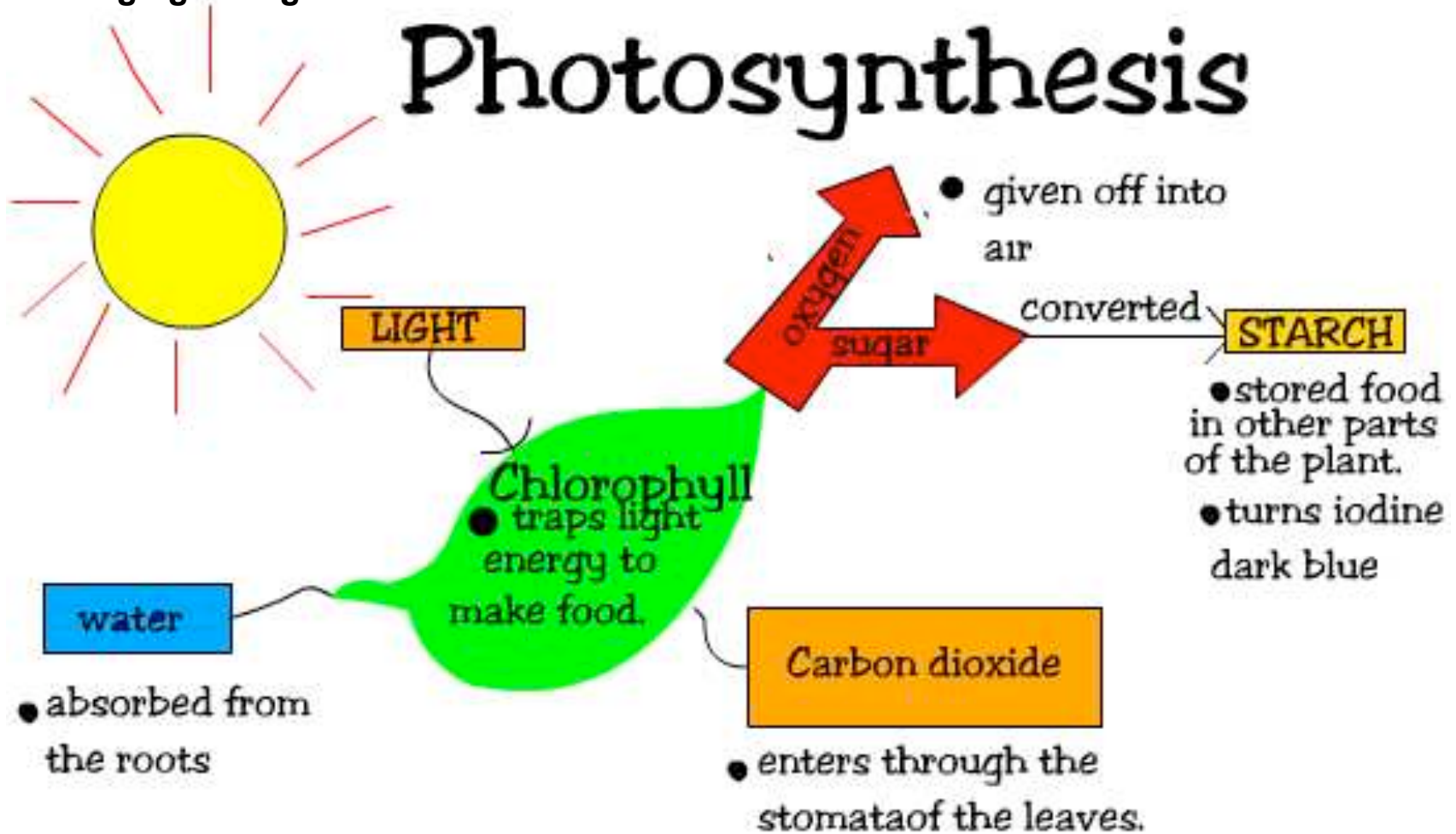
Time Scales of Photochemistry



Water + Carbon dioxide = Food (carbohydrates) + Oxygen

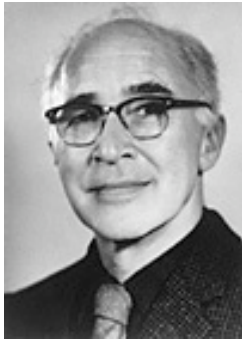
Sun: like a bell ringing out light

Photosynthesis



Vision: Early theories of light were theories of vision.

Photosynthesis: Life requires the capture, storage and release of the sun's energy.



Wald

Nobel in Medicine
Mechanism of Vision

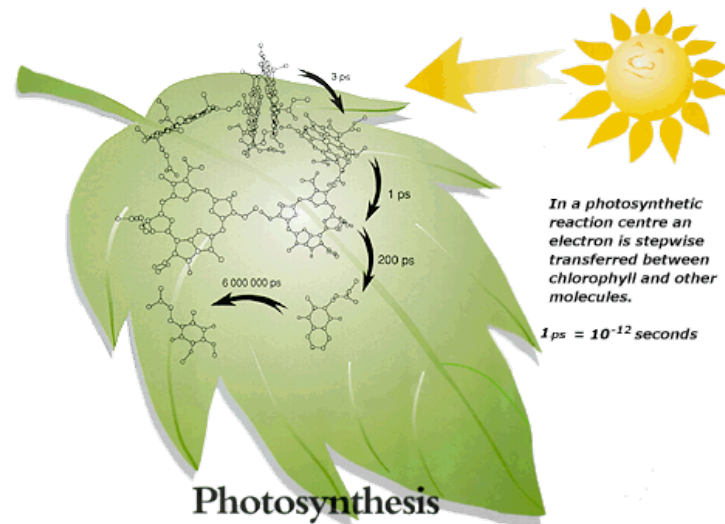
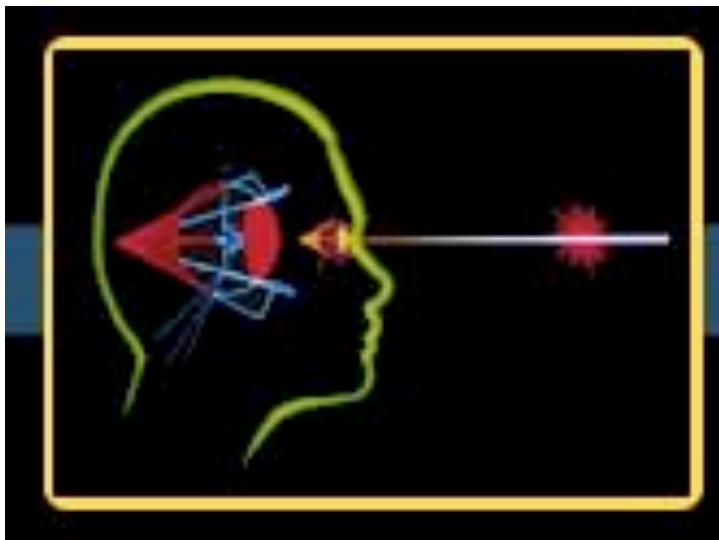


Calvin



Marcus

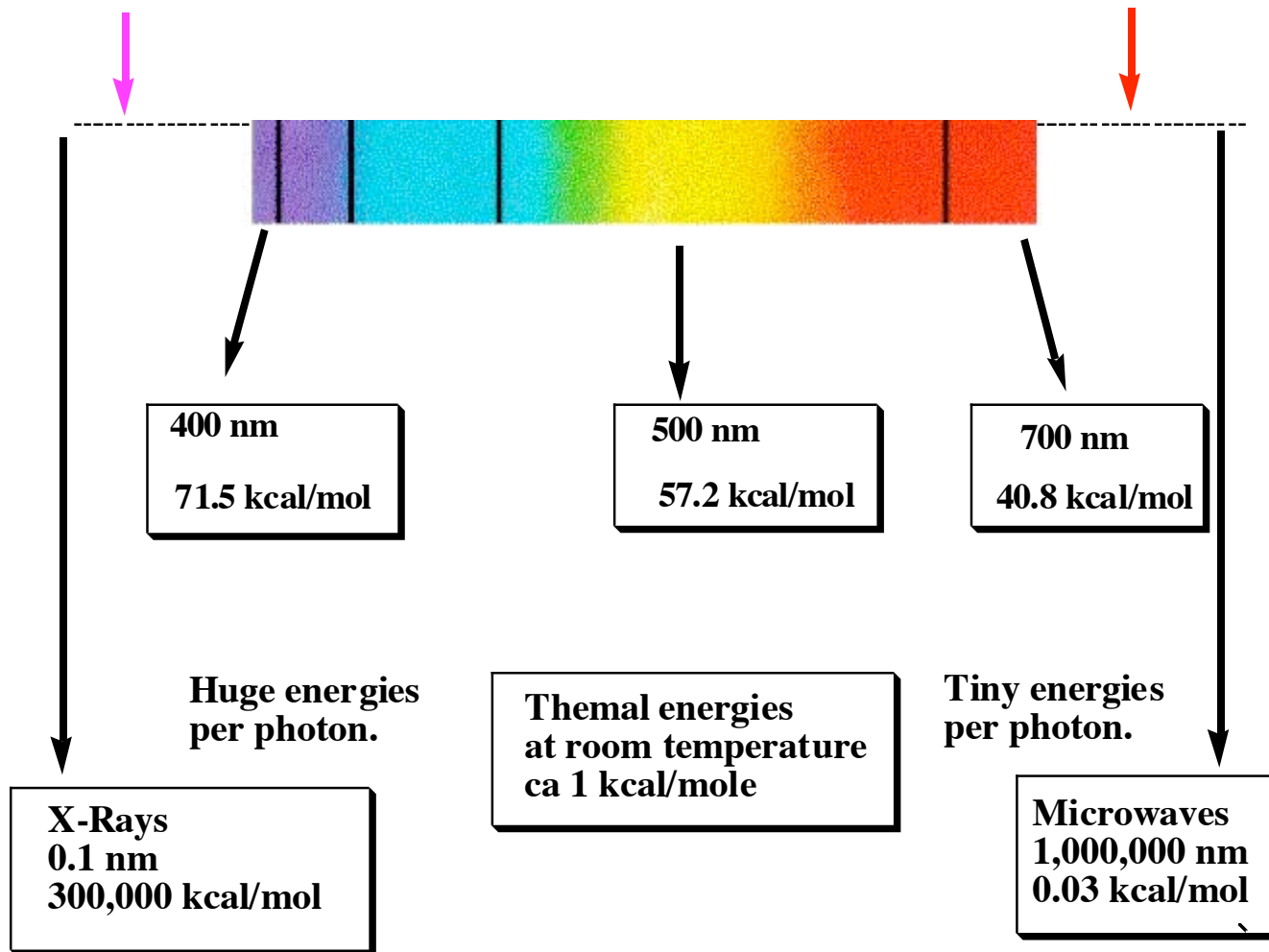
Nobels in Chemistry
Mechanism of Photosynthesis

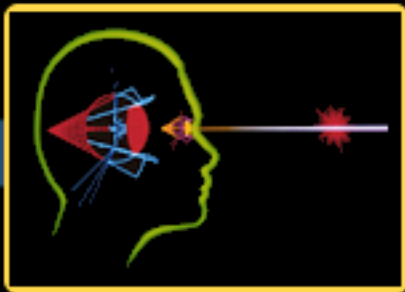
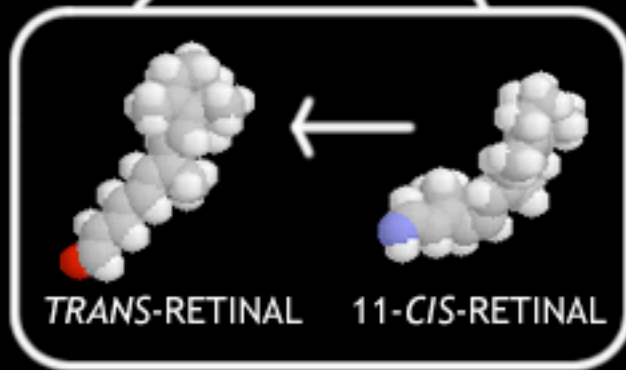
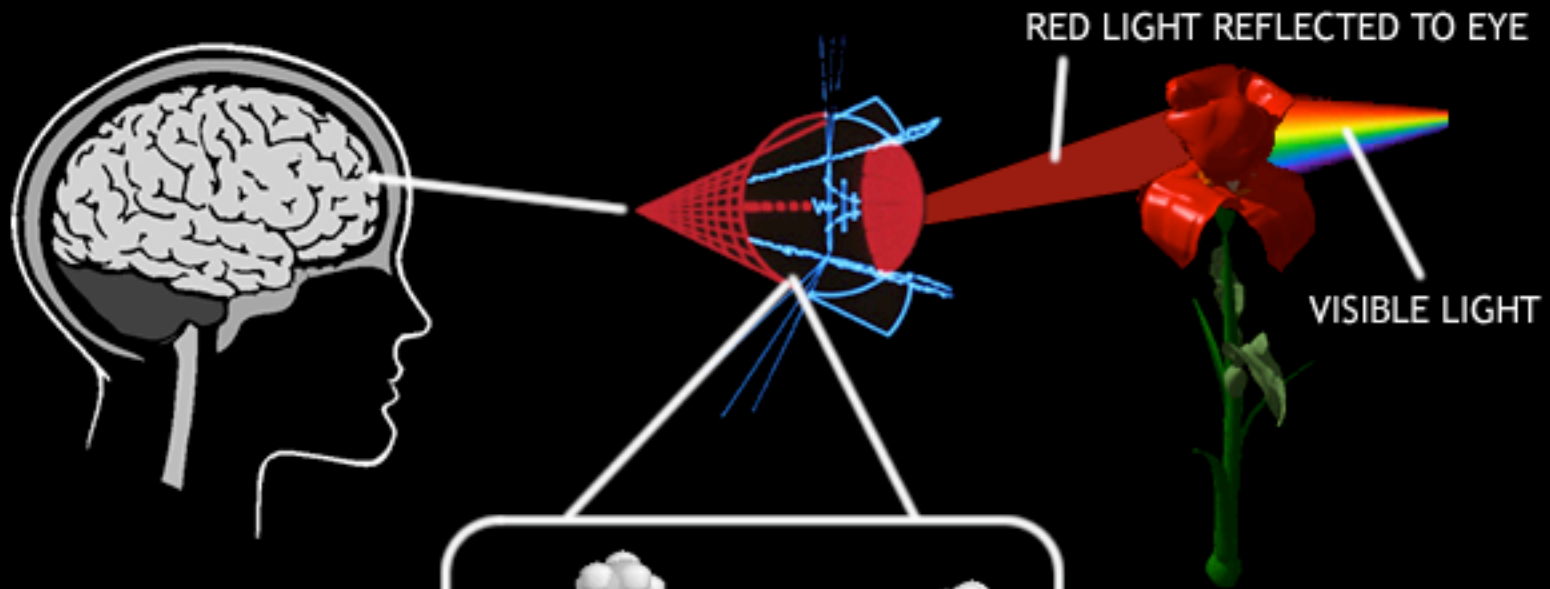


Energy Scales: Why the visible region works for vision

Ultraviolet Region
Chemical Bonds of
DNA and Proteins
Damaged

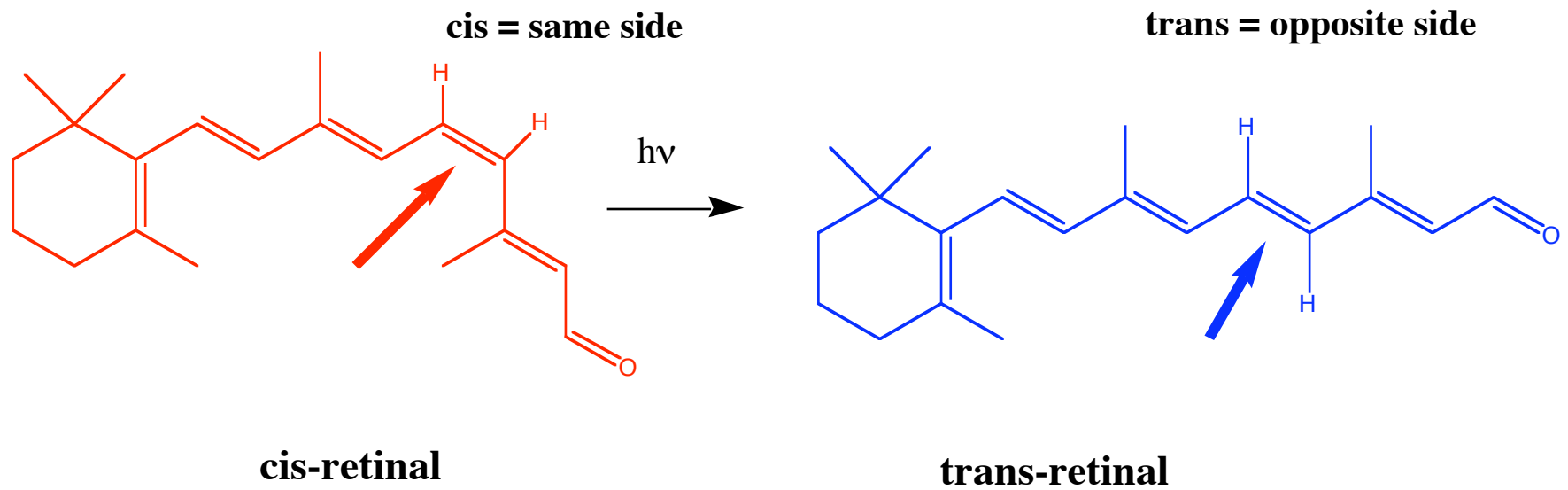
Infrared Region
Chemical Bonds Energy
too low to make or break
chemical bonds.



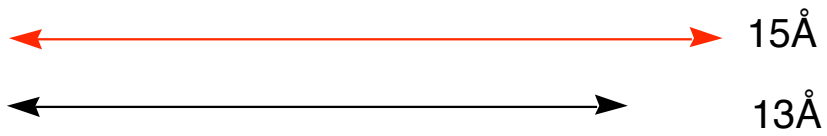
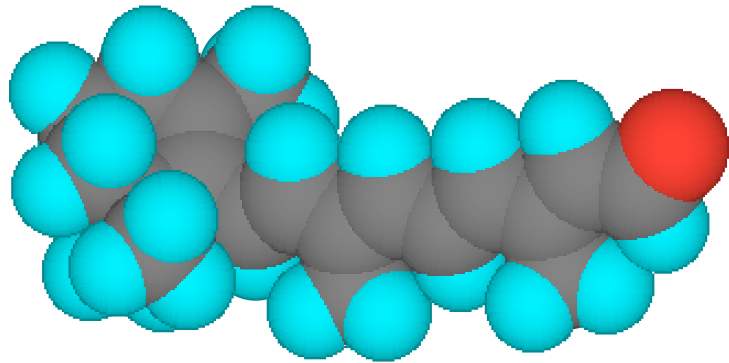


HOW THE EYE PERCEIVES LIGHT

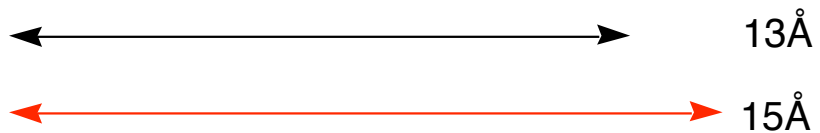
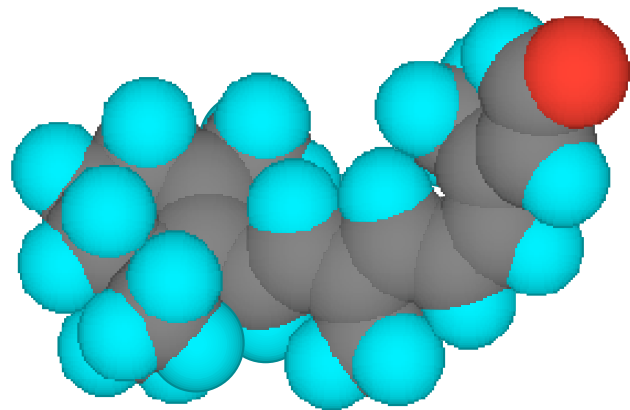
**The photochemical change which triggers vision.
A simple cis-trans isomerization: rotation about a double bond.**



Vision results from the change of a shape of ca
.2 nm = 0.2×10^{-9} m



trans-retinal

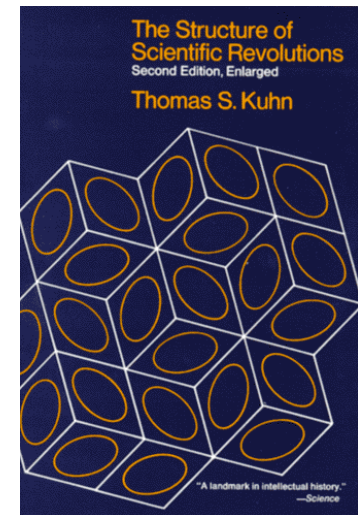


cis-retinal



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.





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).



H. Kolbe



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.”

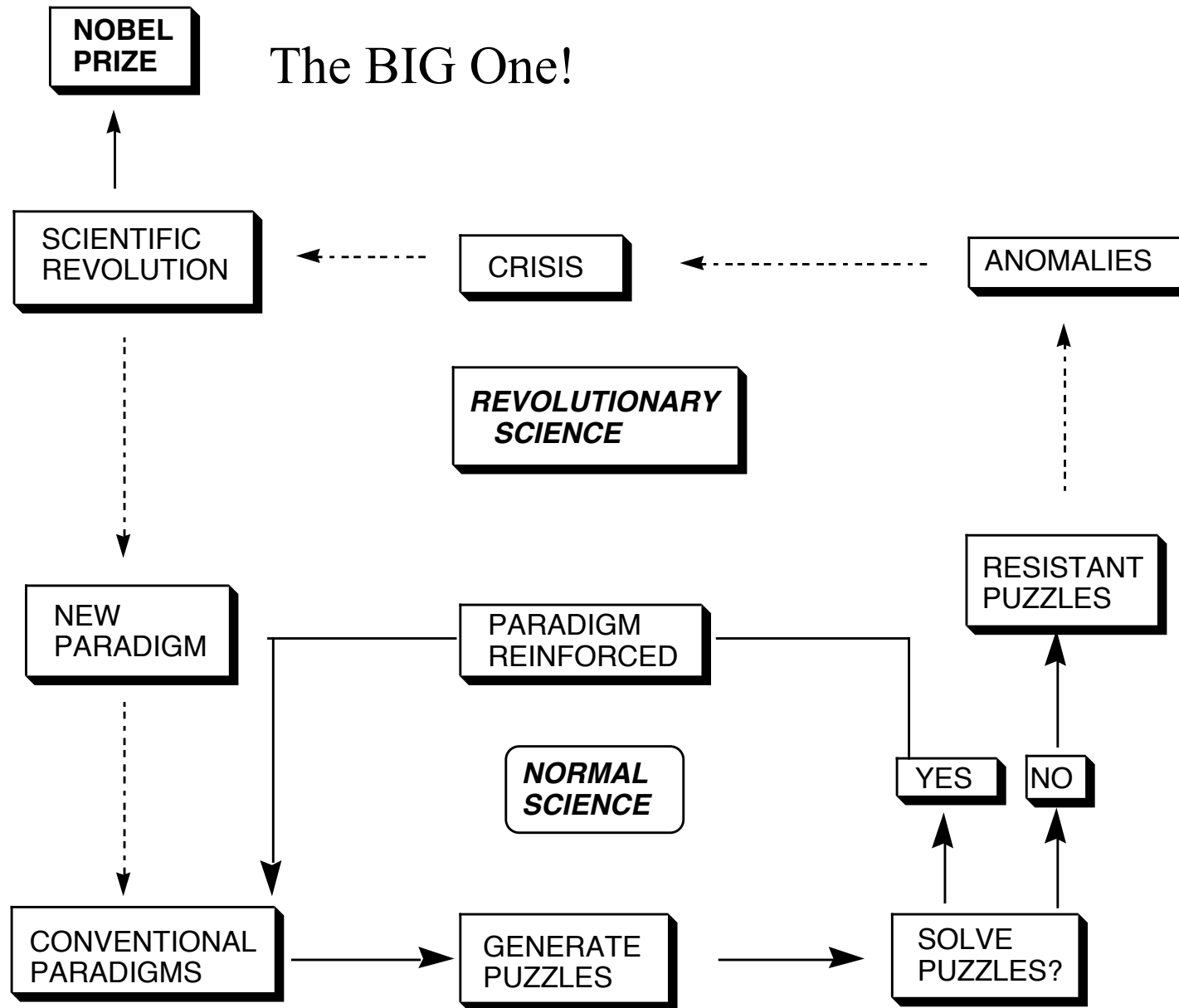
H. Kolbe, “A Sign of the Times
J. Prakt. Chem., 15, 474 (1877).



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

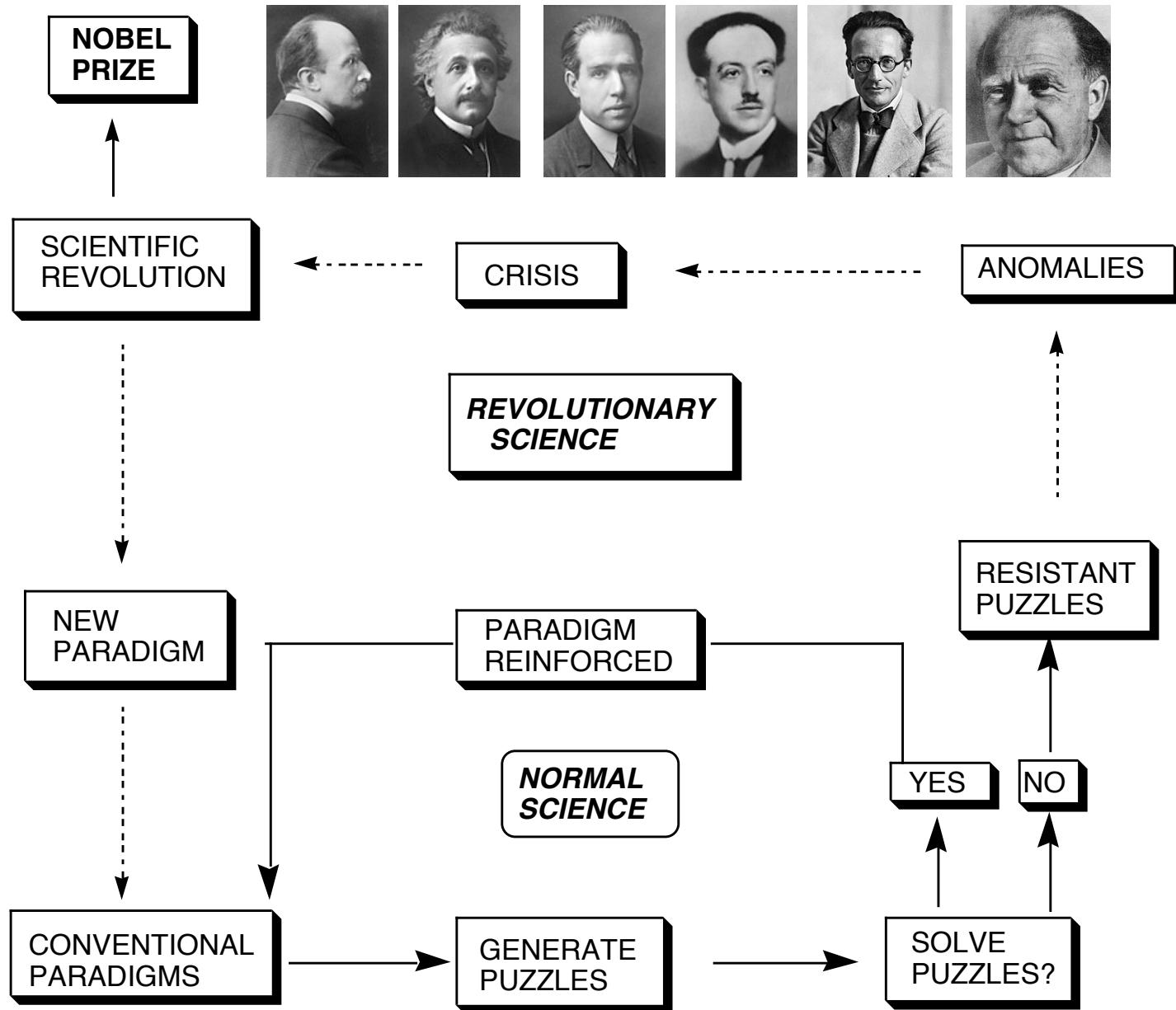
"New scientific truth usually becomes accepted, not because its opponents become convinced, but *because opponents gradually die* and because the rising generations are familiar with the new truth at the outset."

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

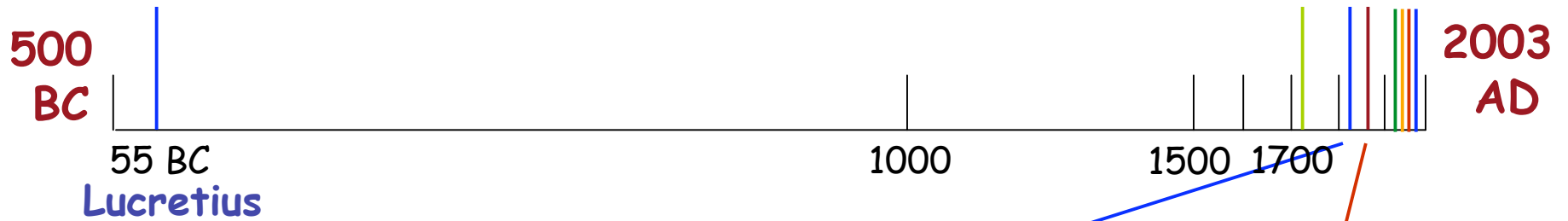


Flow diagram for revolutionary science: Extraordinary claims that become accepted and are integrated into “normal science.”

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



The Light Paradigm (500 BC-1850 AD)



**Newton
(1643-1727)**



Particles!

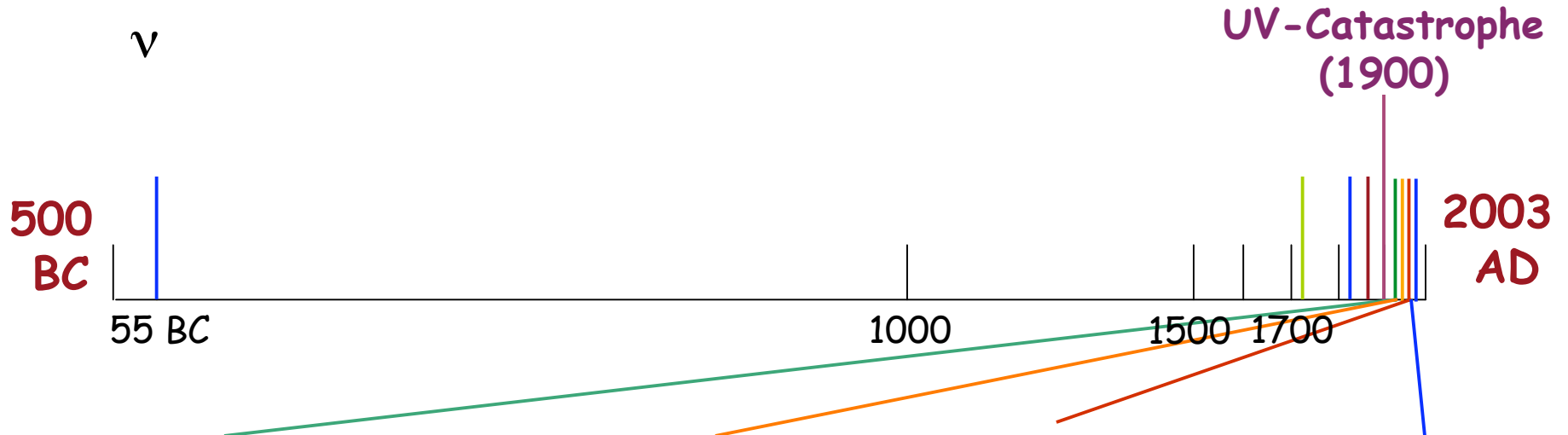
**Maxwell
(1831-1879)**



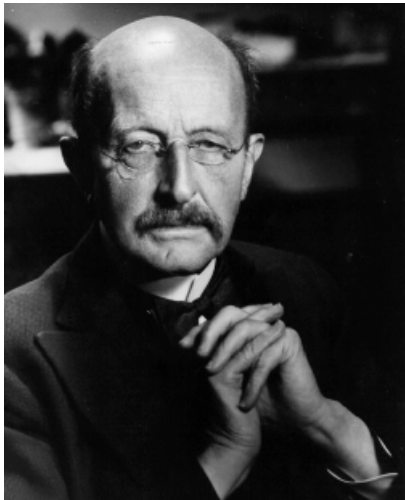
Waves!

...but then came the 1900's - new people, tools, and paradigms!

The Light Paradigm (1850 AD-1900 AD)

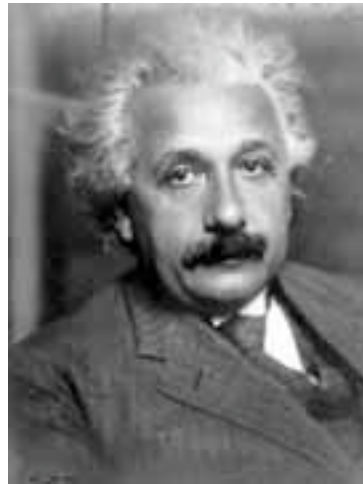


**Max Planck
(1918)**



$E = h\nu$, quanta

**Albert Einstein
(1921)**



$E = h\nu$, photons

**Niels Bohr
(1922)**



$E_2 - E_1 = h\nu$,
transitions

**De Broglie
(1929)**



$E = h\nu = mc^2$
62

"If, in some cataclysm, all scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, **what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis: that all things are made of atoms, little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.** In that one sentence you will see there's an enormous amount of information about the world, if just a little imagination and thinking are applied." Richard Feynman

Let's add. The universe is also made of photons, **tiny packets of energy that fill and carry energy around the universe, that travel at incredible speeds, and that behave as particles or waves depending on the manner in which they interact with matter.**

