

Light and Matter



Assignment (due: M, 9/20):

- 1.) Read Ch. 14
- 2.) Ch. 4 problems 1 - 12; Ch. 5 problems 29 - 38.



Key Concepts:

1. The Experience of Light

2. The Physical Properties of Light

3. Properties of Matter: Atoms and Molecules

4. Learning from Light

5. Doppler Effect

The Everyday Experience of Light

1. Energy and Power

2. Light and Color

3. Light and Matter Interactions



The Everyday Experience of Light

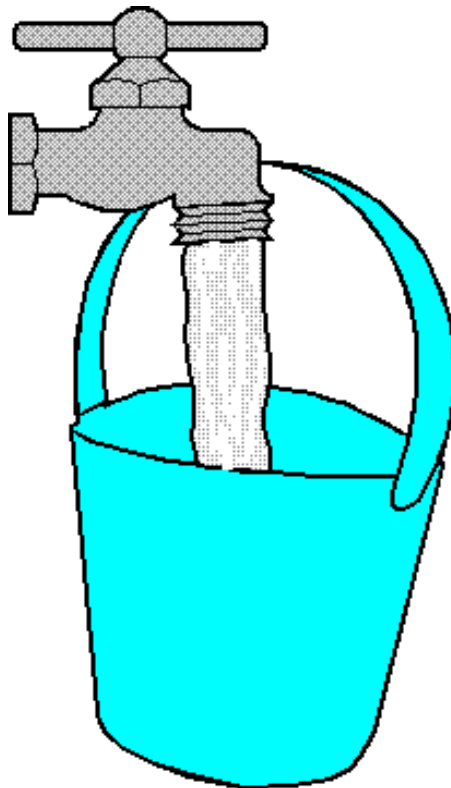
I. Energy and Power

What's the difference?

I. Energy and Power

Power is the *rate* at which *energy* is delivered or received.

e.g., 1 watt = 1 joule/s



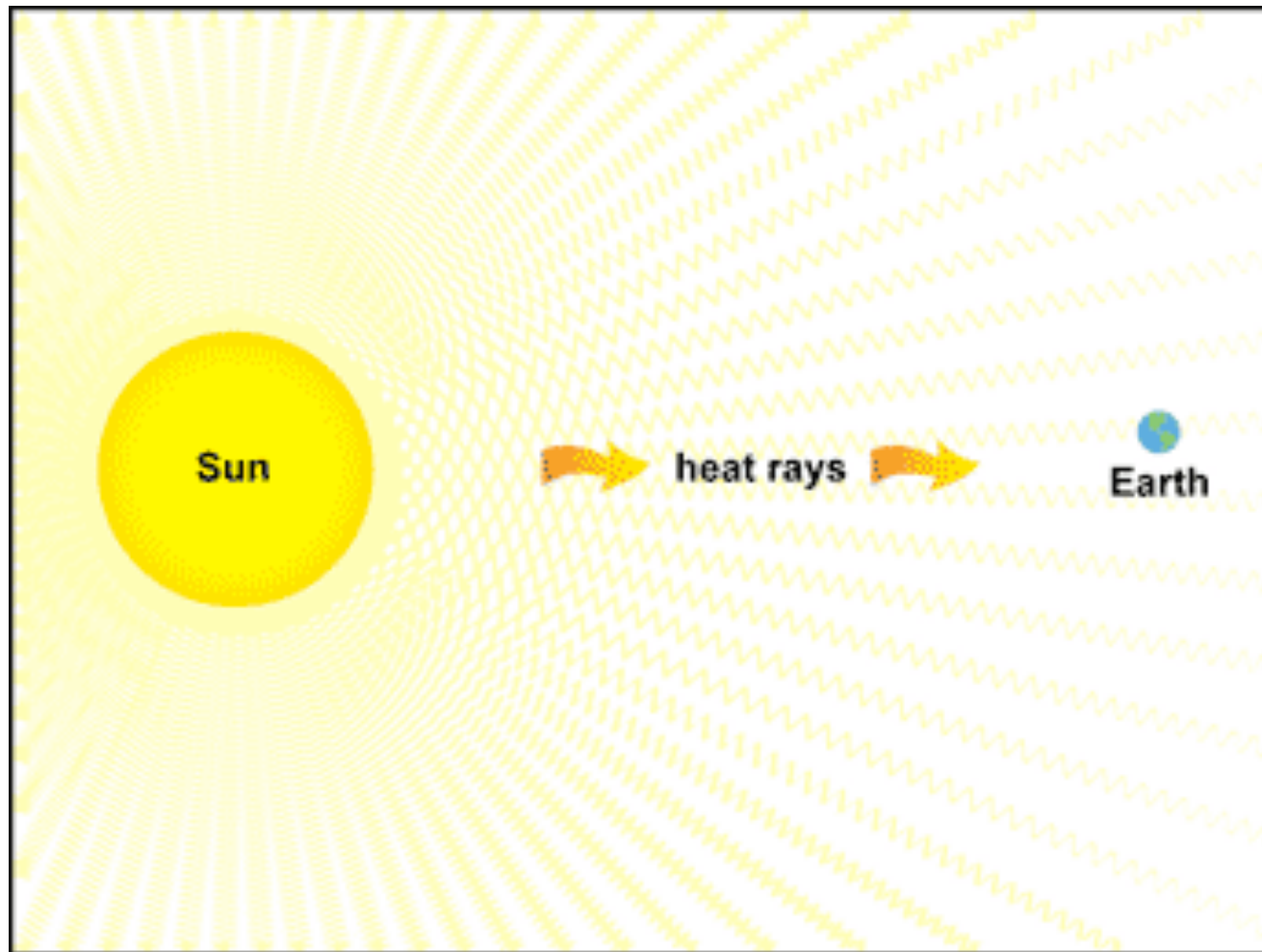
I. Energy and Power

Power is the *rate* at which *energy* is delivered, received, or transmitted.



I. Energy and Power

Light *transmits* energy because each photon has a certain energy associated with it.



I. Energy and Power

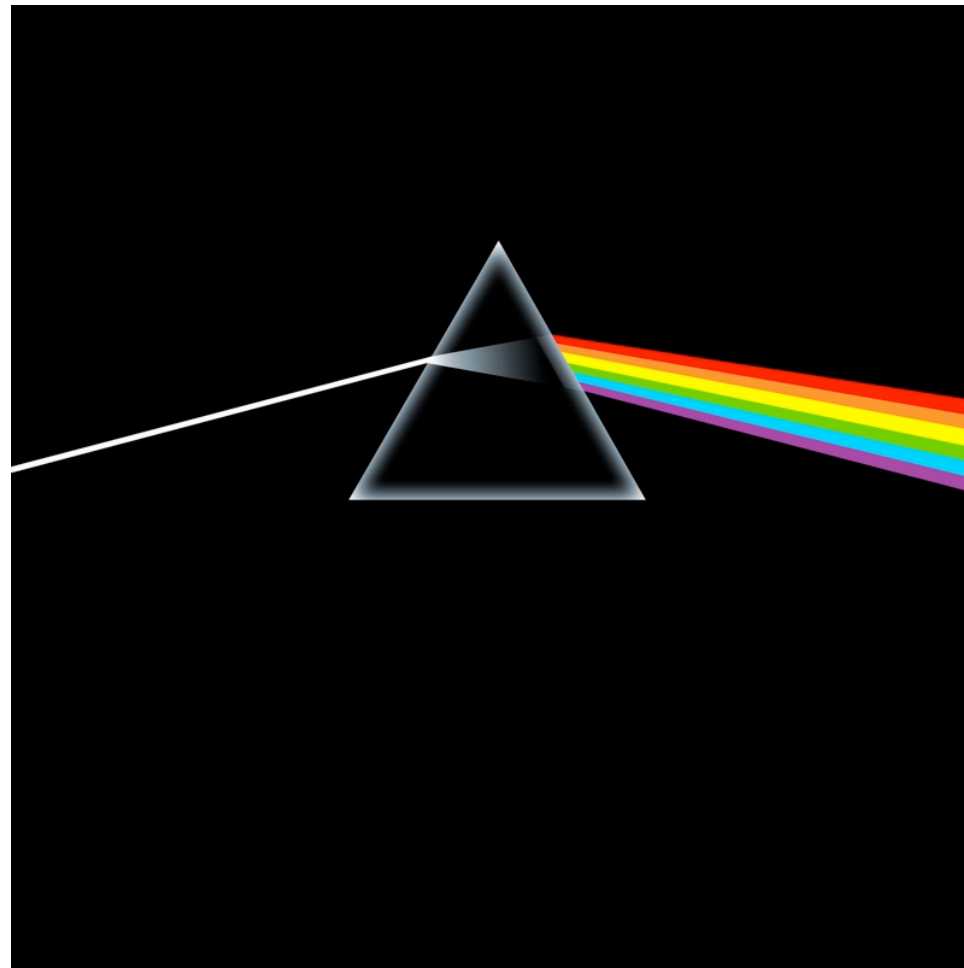
Home energy usage:

1 kw-h (killo-watt hour = 1 kilo-watt * 1 hour)



The Everyday Experience of Light

2. Light and Color



White Light

Spectrum

The Everyday Experience of Light

2. Light and Color



3. Interaction of Light and Matter:

a. Emission

b. Absorption

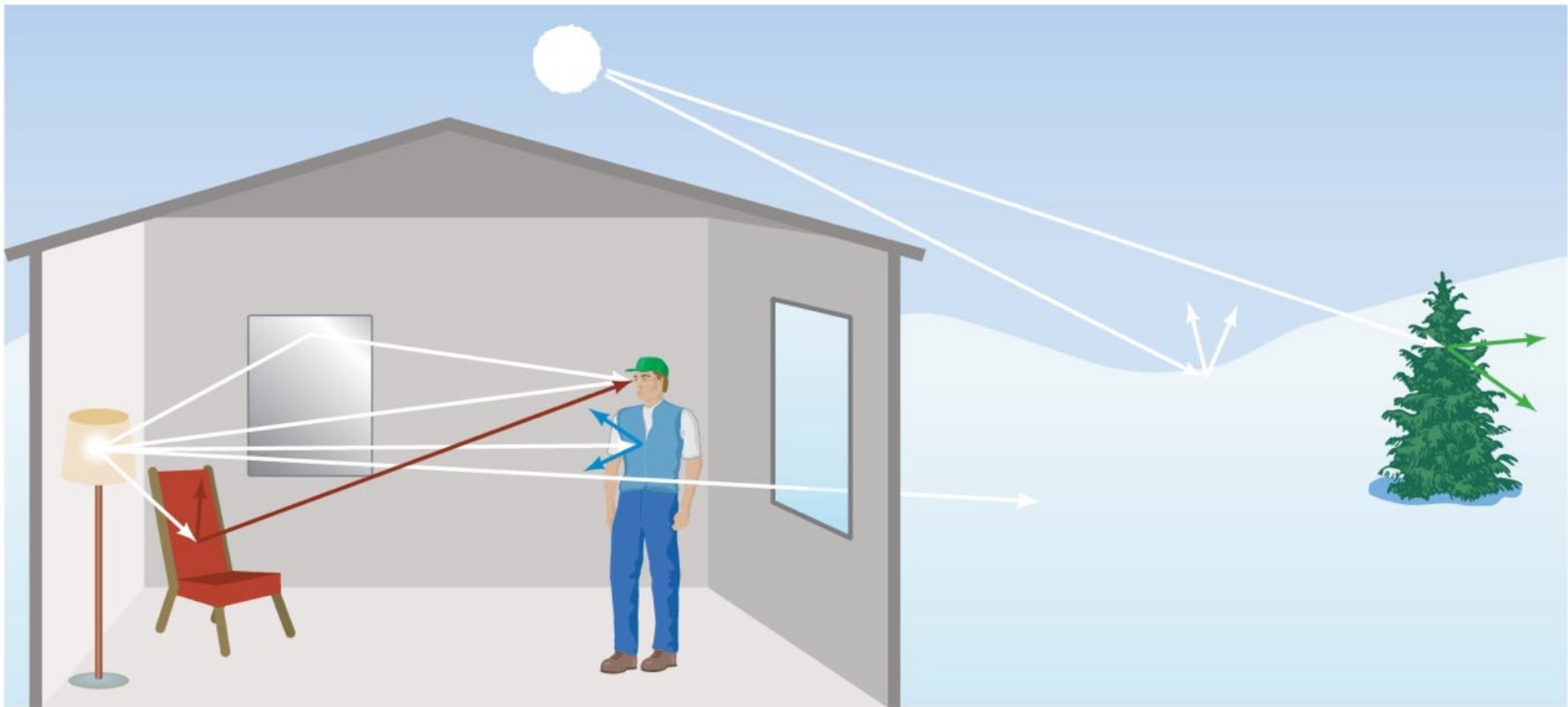
c. Transmission

d. Reflection / Scattering

3. Interaction of Light and Matter

Interaction of Light and Matter:

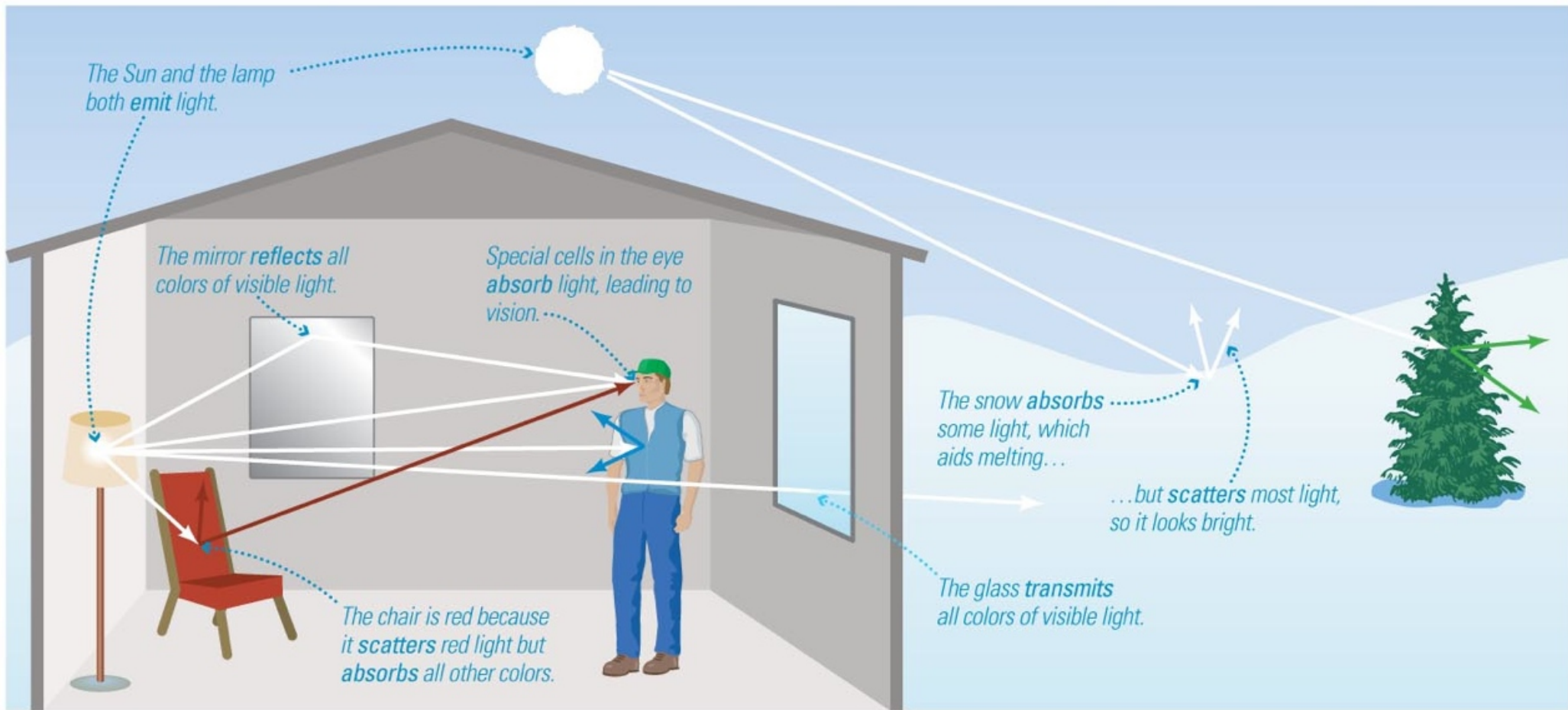
a. Emission, b. Absorption, c. Transmission, d. Reflection / Scattering



3. Interaction of Light and Matter

Interaction of Light and Matter:

a. Emission, b. Absorption, c. Transmission, d. Reflection / Scattering



The Everyday Experience of Light

3. Interaction of Light and Matter



The Everyday Experience of Light

3. Interaction of Light and Matter



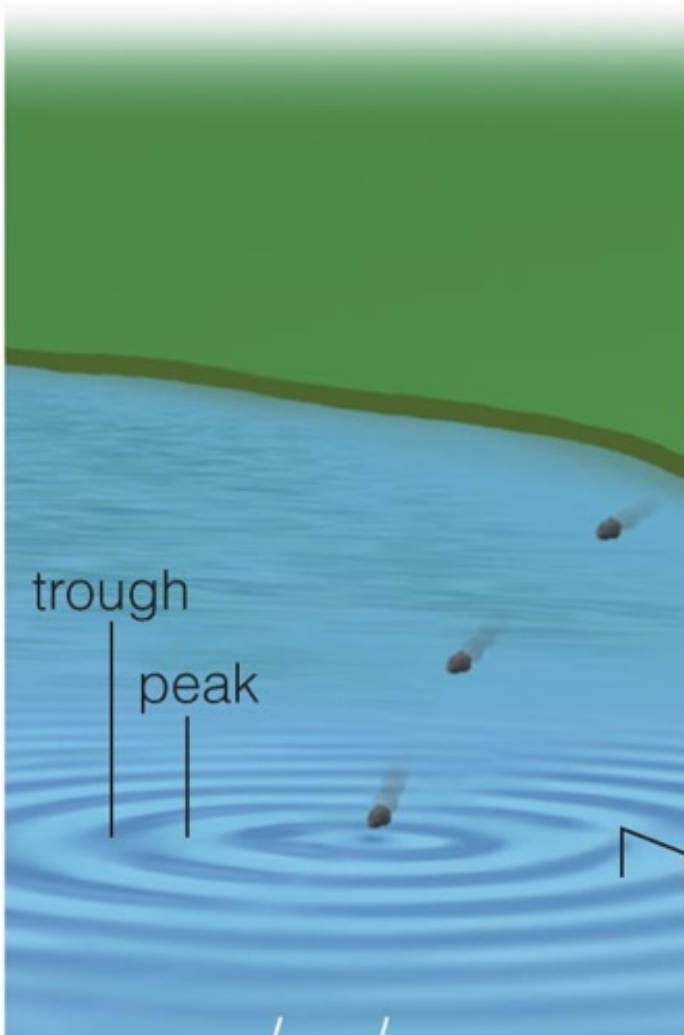
Physical Properties of Light

What is light?

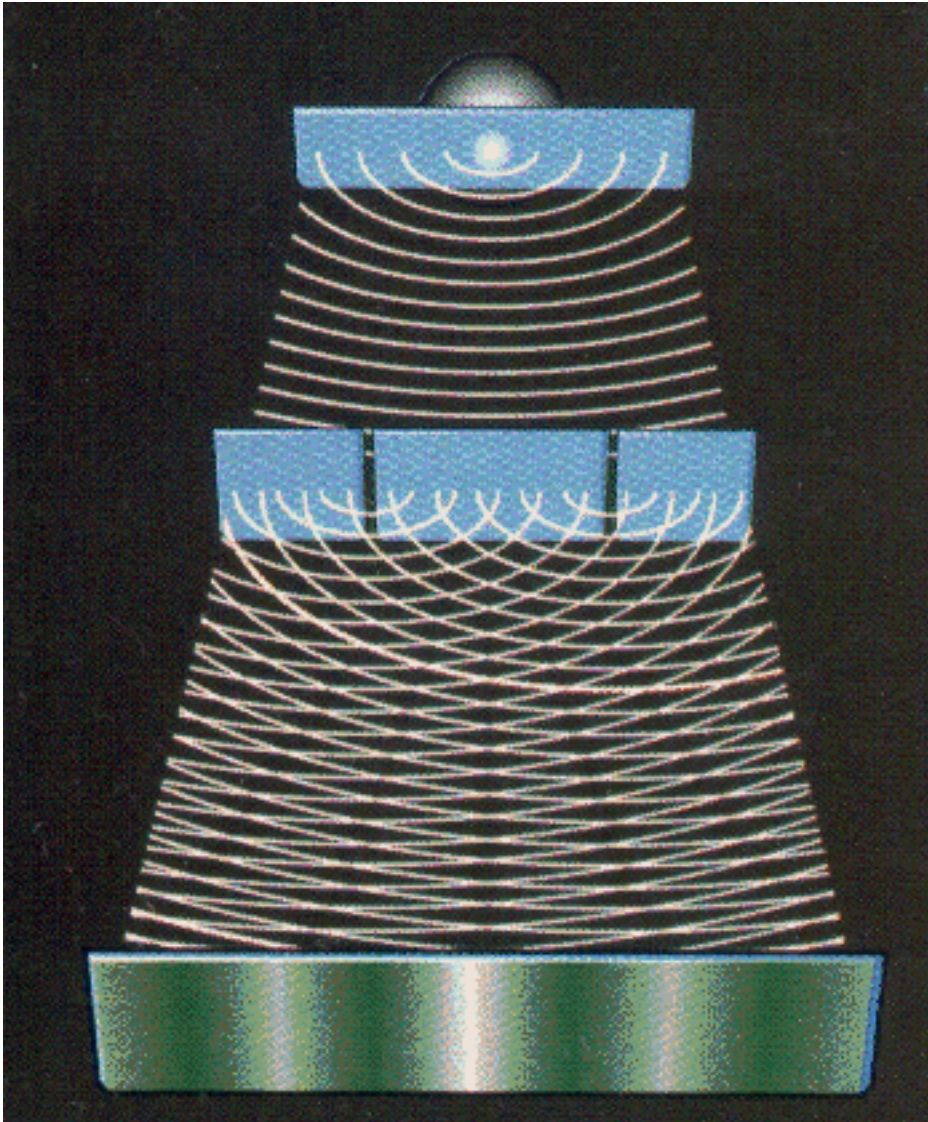
a particle

and

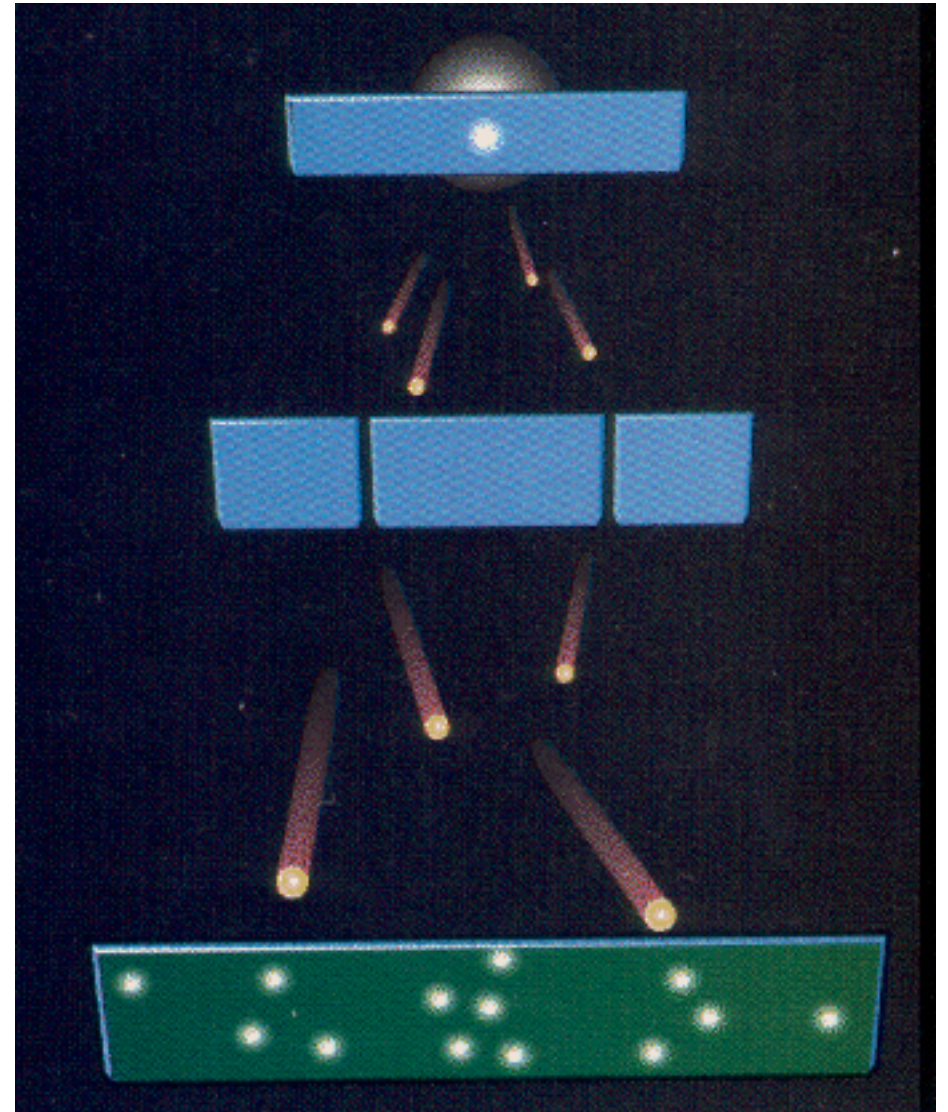
a wave



Physical Properties of Light



Wave



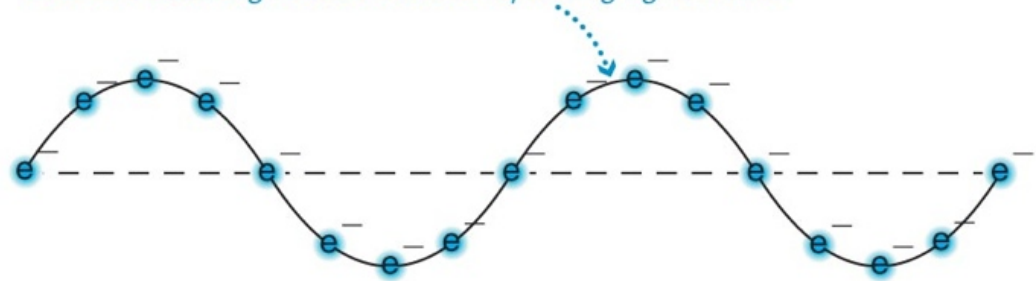
Particle

and

Physical Properties of Light

Electromagnetic Wave

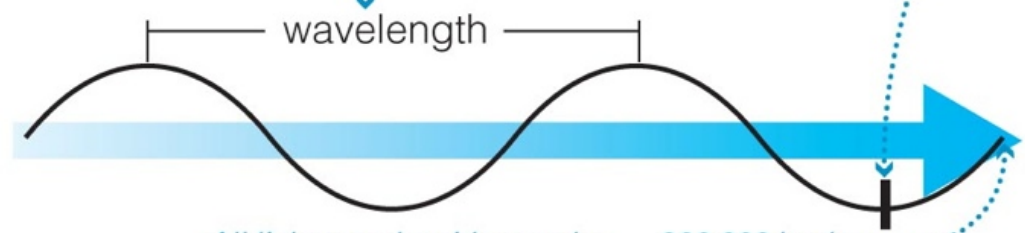
If you could line up electrons, they would bob up and down with the vibrating electric field of a passing light wave.



a Electrons move when light passes by, showing that light carries a vibrating electric field.

Wavelength is the distance between adjacent peaks of the electric (and magnetic) field . . .

. . . while frequency is the number of times each second that the electric (and magnetic) field vibrates up and down (or side to side) at any point.



All light travels with speed $c = 300,000$ km/s.

b The vibrations of the electric field determine the wavelength and frequency of a light wave. Light also has a magnetic field (not shown) that vibrates perpendicular to the direction of the electric field vibrations.

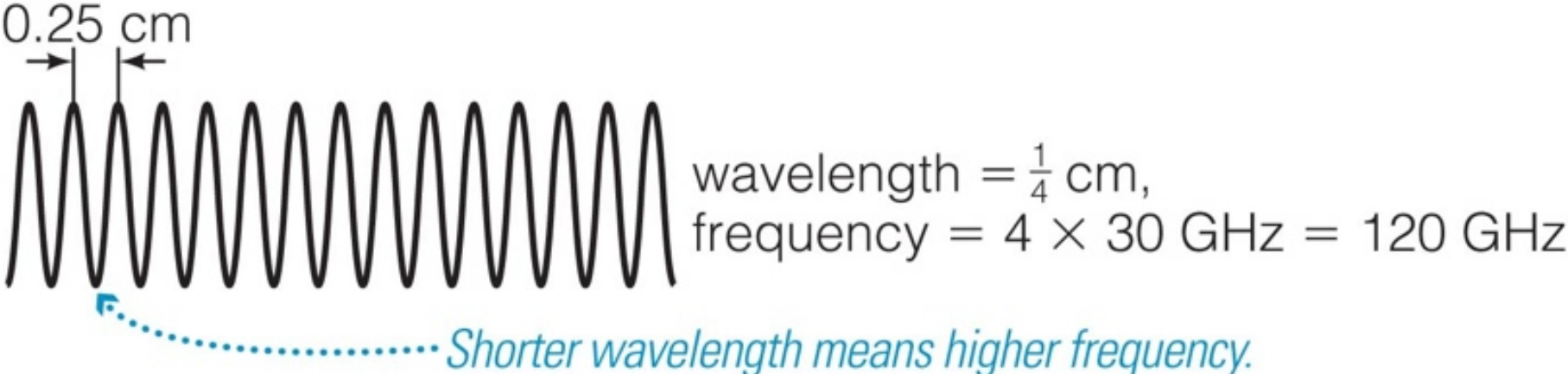
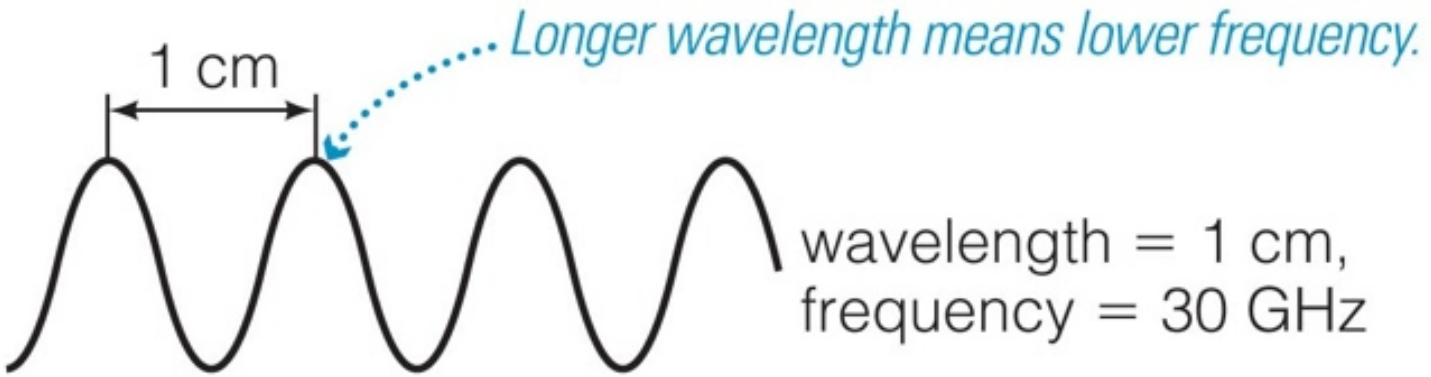
Some properties:

$$\text{wavelength} * \text{frequency} = \text{speed} = c$$

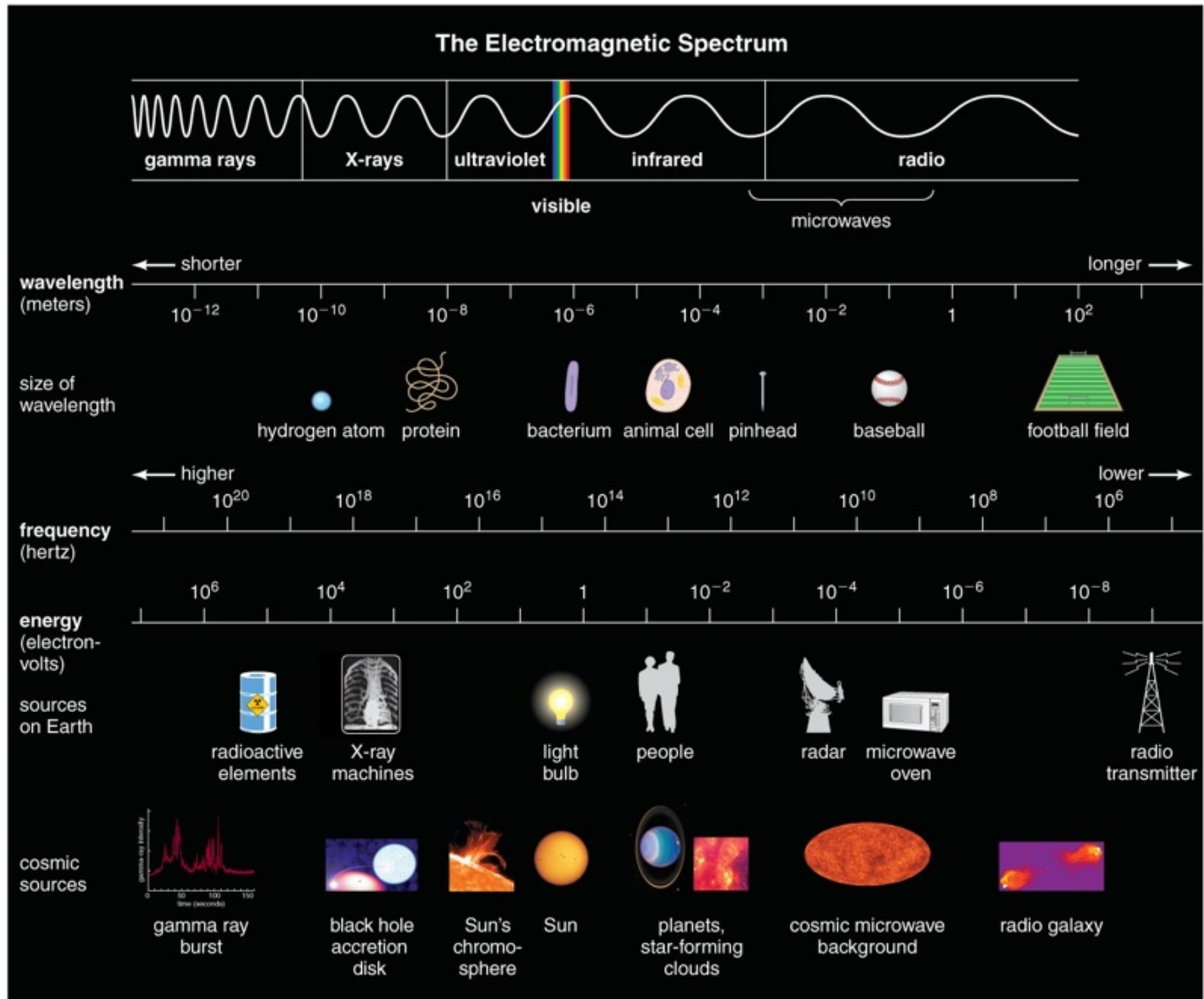
$$\text{energy} = h * \text{frequency}$$

Physical Properties of Light

Electromagnetic Wave

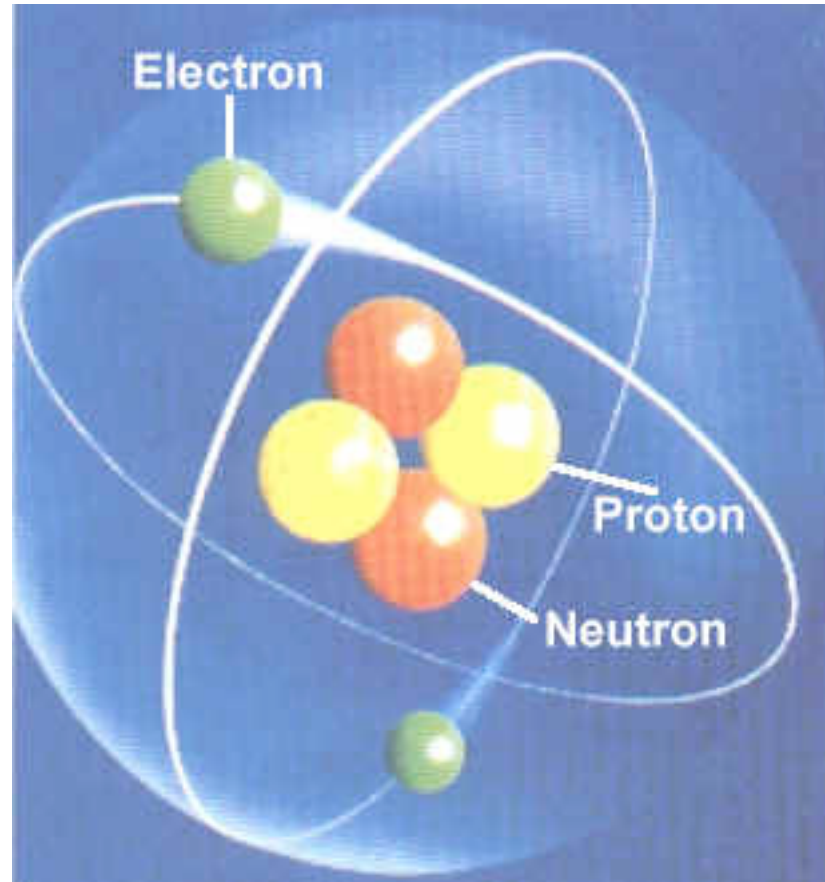


Physical Properties of Light



Properties of Matter

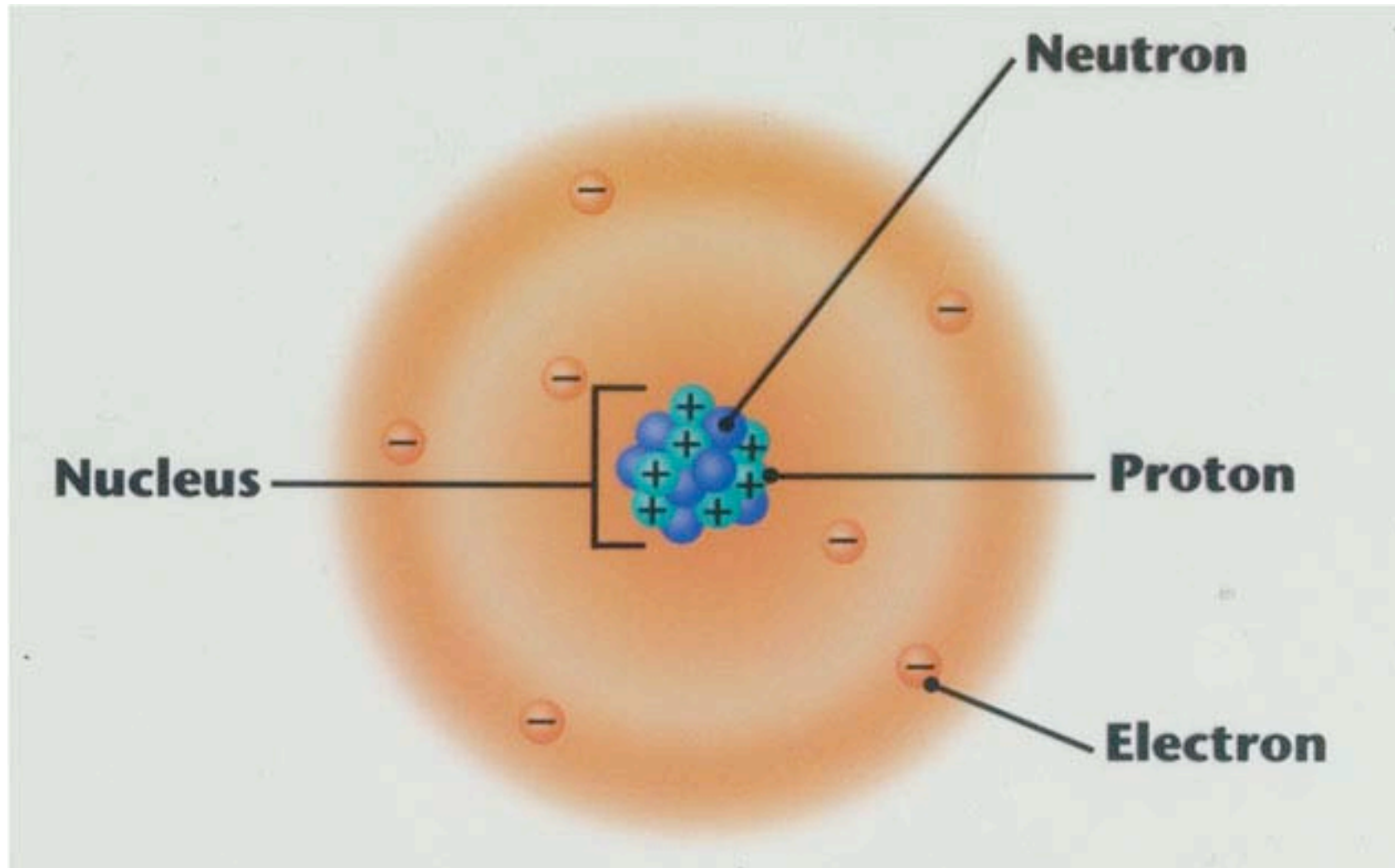
I. The Structure of Matter



old school picture

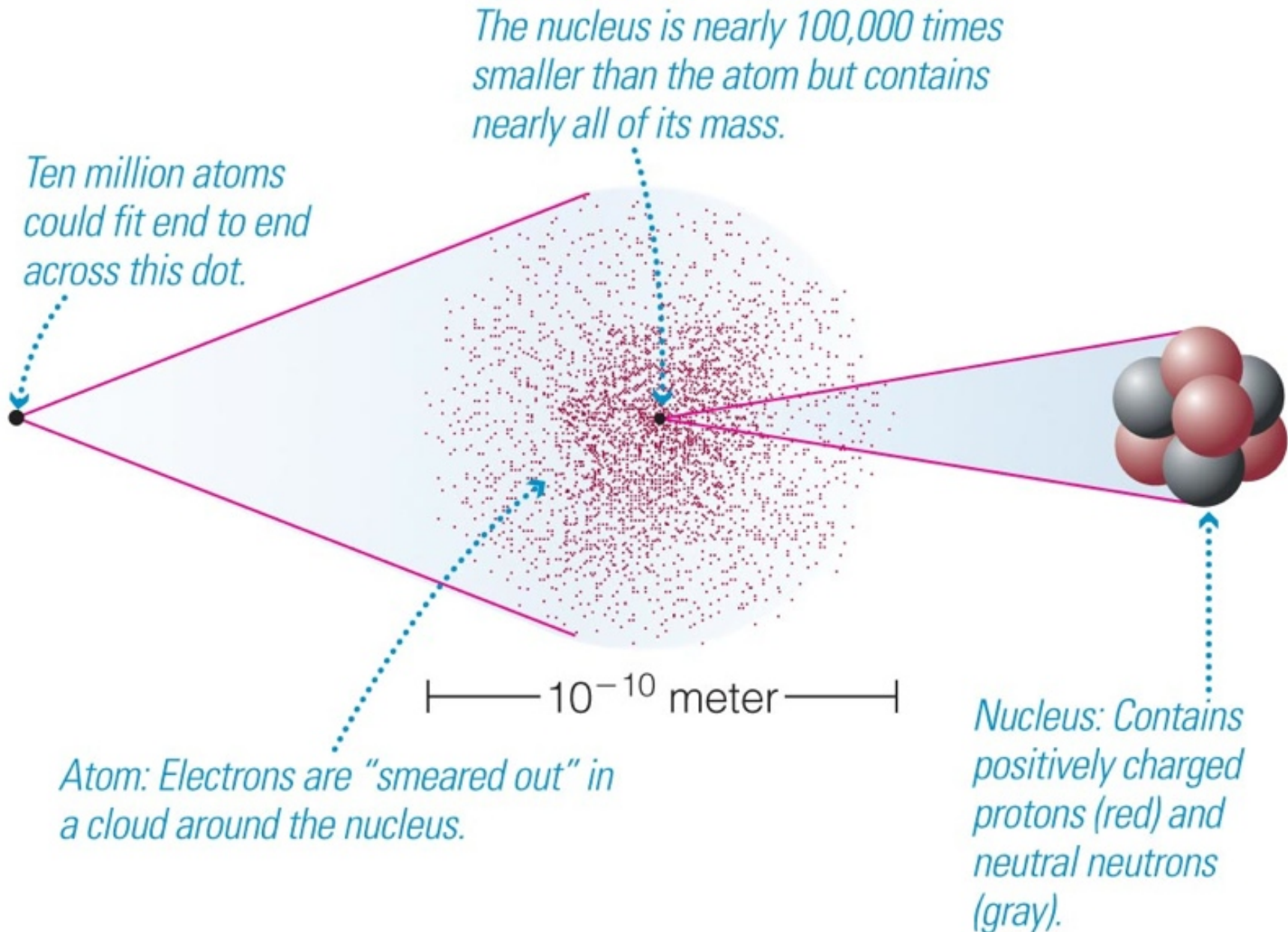
Properties of Matter

I. The Structure of Matter



Properties of Matter

I. The Structure of Matter



Properties of Matter

Vocabulary:

Atom

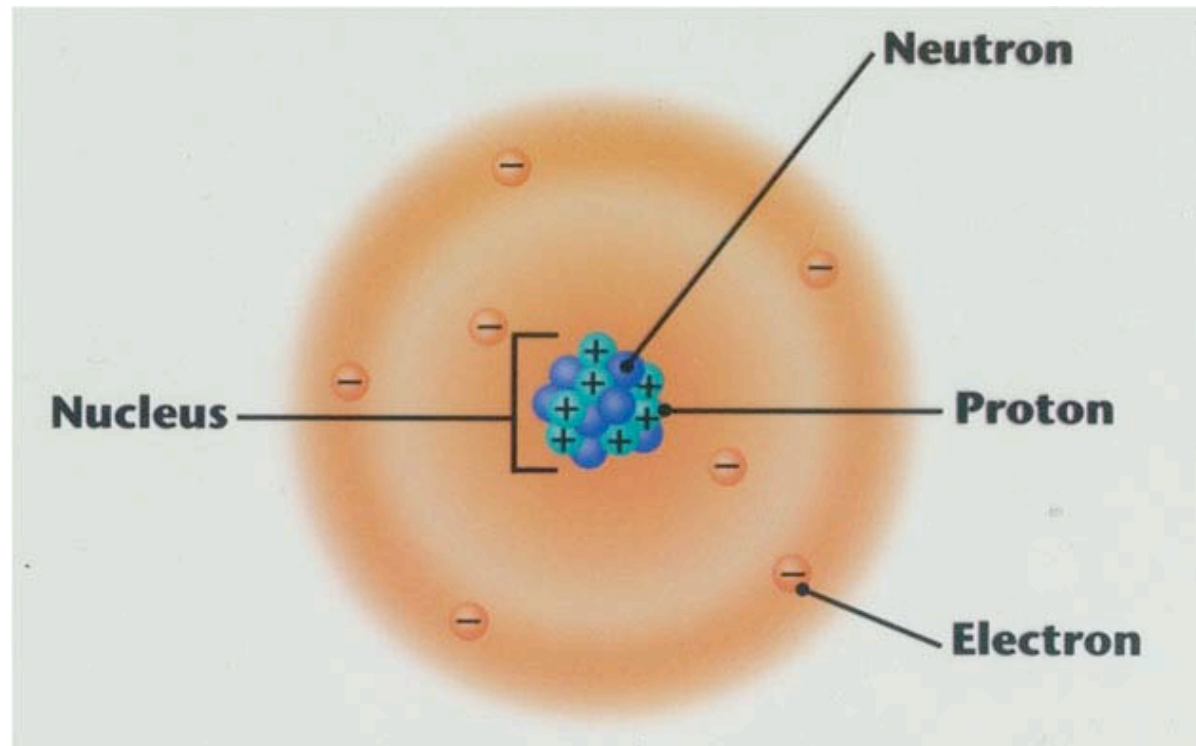
Nucleus

Protons

Neutrons

Electrons

The Atom



Properties of Matter

Vocabulary:

Atomic Number, Z

Atomic Mass, A

Isotope: Same Z , different A

Examples: C^{12} , C^{13}

Periodic Table of the Elements

1	IA	1	H	2	He	0																															
2		3	Li	4	Be	5	B	6	C	7	N	8	O	9	F	10	Ne																				
3		11	Na	12	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																				
4		19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
5		37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
6		55	Cs	56	Ba	57	*La	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn
7		87	Fr	88	Ra	89	+Ac	104	Rf	105	Ha	106	Sg	107	Ns	108	Hs	109	Mt	110	110	111	111	112	112	113	113										

* Lanthanide Series

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

+ Actinide Series

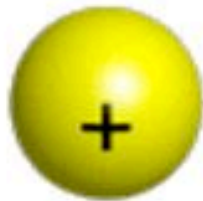
90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Properties of Matter

Isotopes

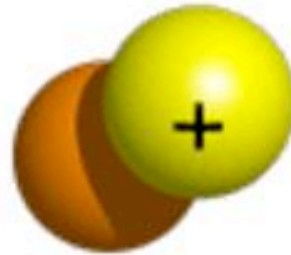
The Nuclei of the Three Isotopes of Hydrogen

Protium



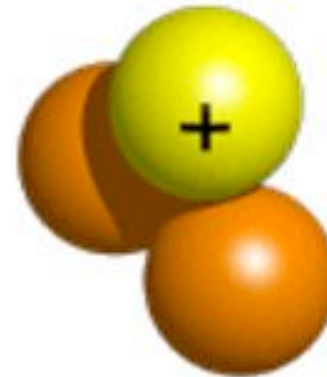
1 proton

Deuterium



1 proton
1 neutron

Tritium



1 proton
2 neutrons

Properties of Matter: Isotopes

Hydrogen
1 proton



${}^1\text{H}$



${}^2\text{H}$



${}^3\text{H}$

Helium
2 protons

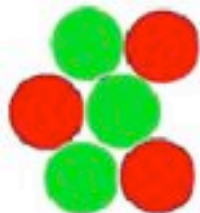


${}^3\text{He}$

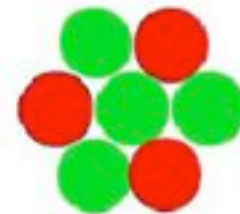


${}^4\text{He}$

Lithium
3 protons



${}^6\text{Li}$



${}^7\text{Li}$

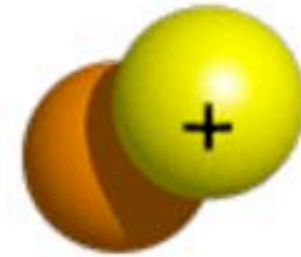
Properties of Matter

Vocabulary:

Isotope

Electrical Charge

Deuterium



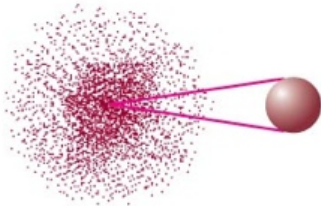
1 proton
1 neutron

Q: Why isn't matter charged, in general?

Properties of Matter

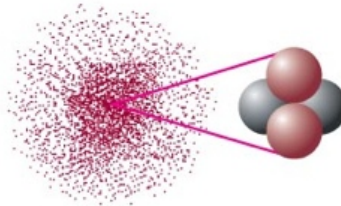
atomic number = number of protons
atomic mass number = number of protons + neutrons
(A neutral atom has the same number of electrons as protons.)

Hydrogen (${}^1\text{H}$)



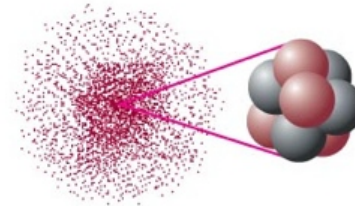
atomic number = 1
atomic mass number = 1
(1 electron)

Helium (${}^4\text{He}$)



atomic number = 2
atomic mass number = 4
(2 electrons)

Carbon (${}^{12}\text{C}$)



atomic number = 6
atomic mass number = 12
(6 electrons)

Different isotopes of a given element contain the same number of protons, but different numbers of neutrons.

Isotopes of Carbon

carbon-12



${}^{12}\text{C}$
(6 protons
+ 6 neutrons)

carbon-13



${}^{13}\text{C}$
(6 protons
+ 7 neutrons)

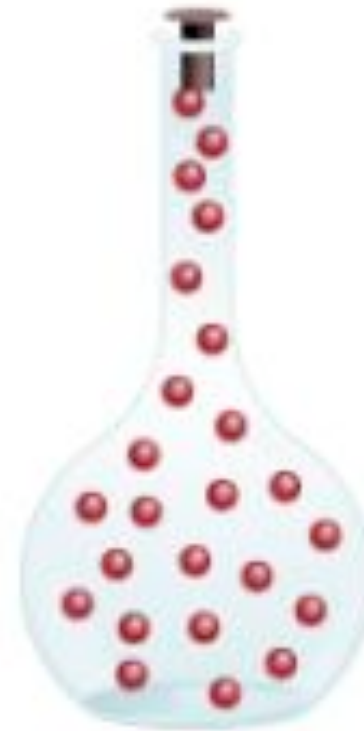
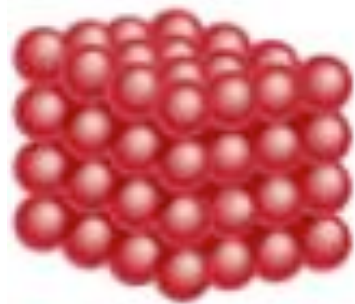
carbon-14



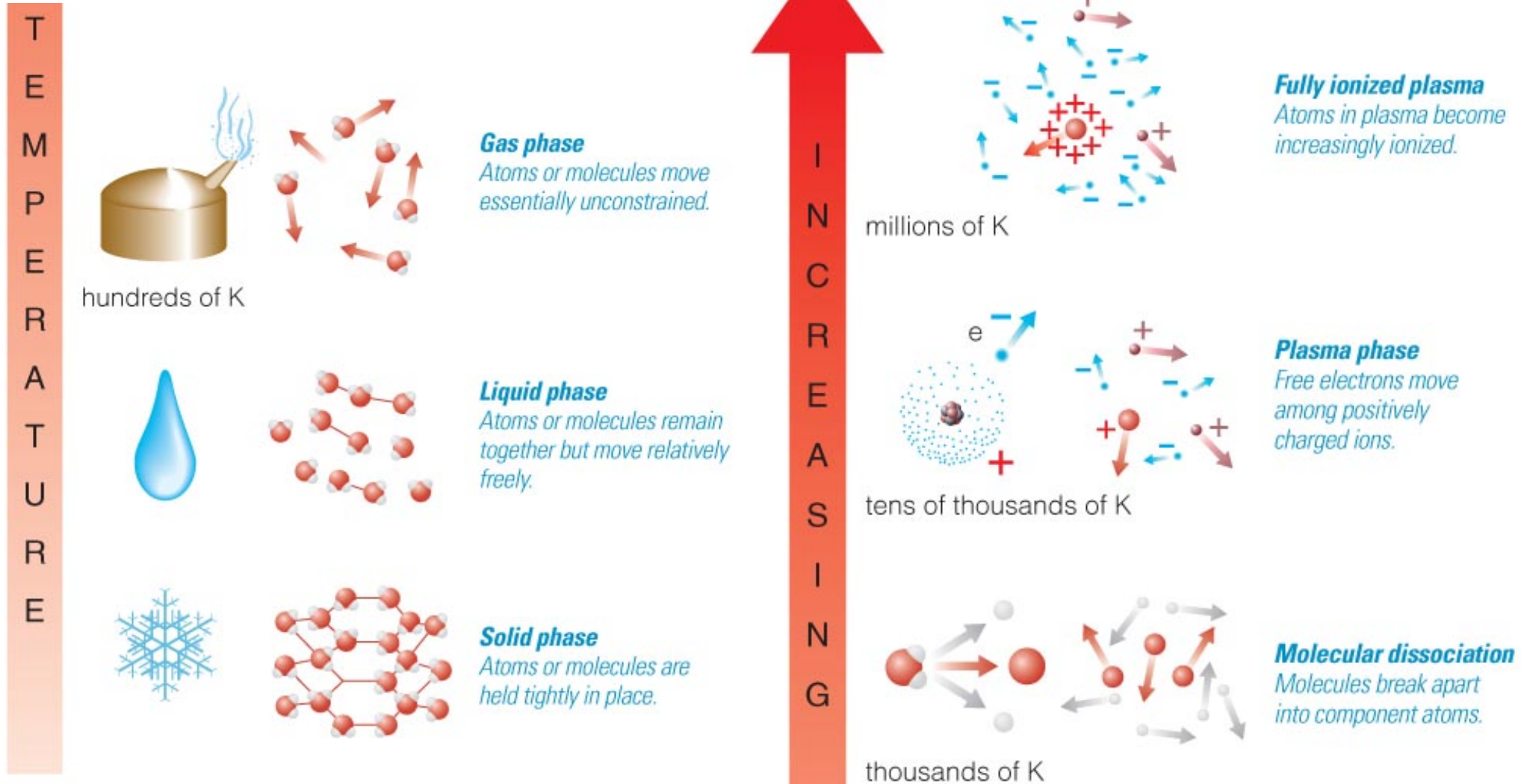
${}^{14}\text{C}$
(6 protons
+ 8 neutrons)

Properties of Matter: **Phases**

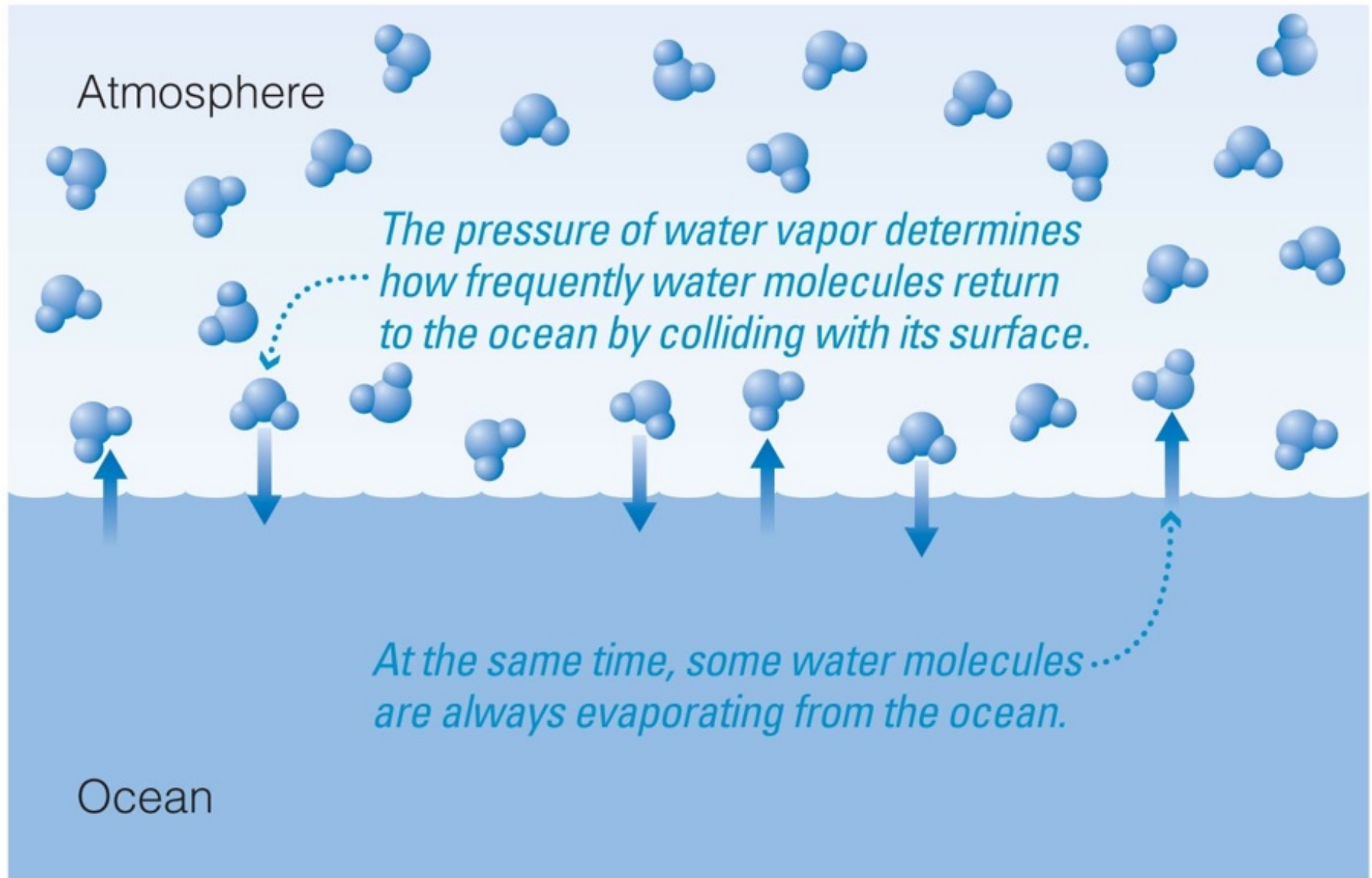
Copyright © The McGraw-Hill Companies, Inc. Permission is required for reproduction or display.



Properties of Matter: Phases

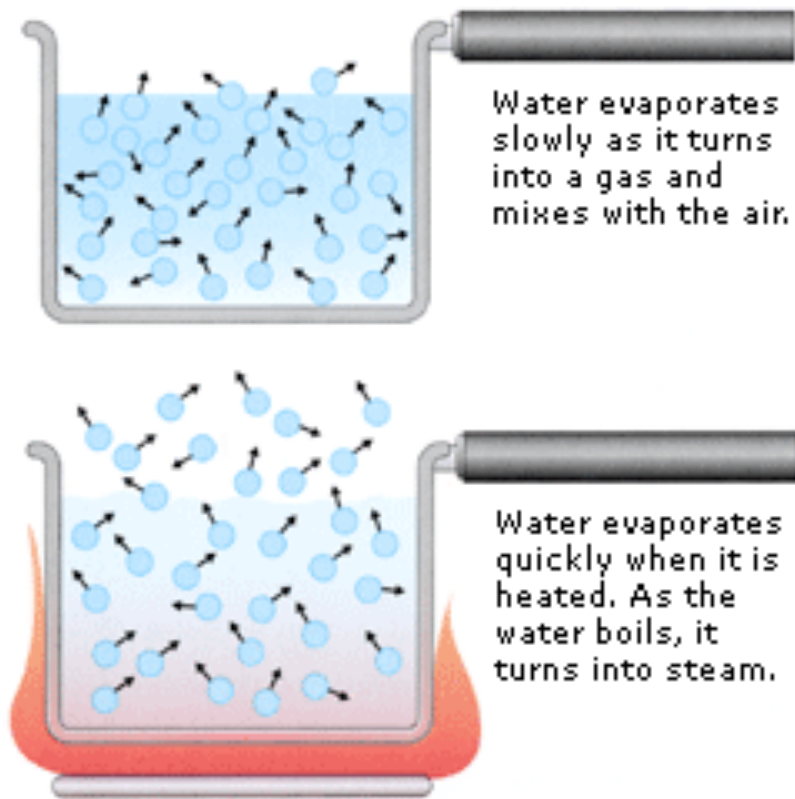


Properties of Matter: **Phases**



Properties of Matter: **Phases**

Evaporation



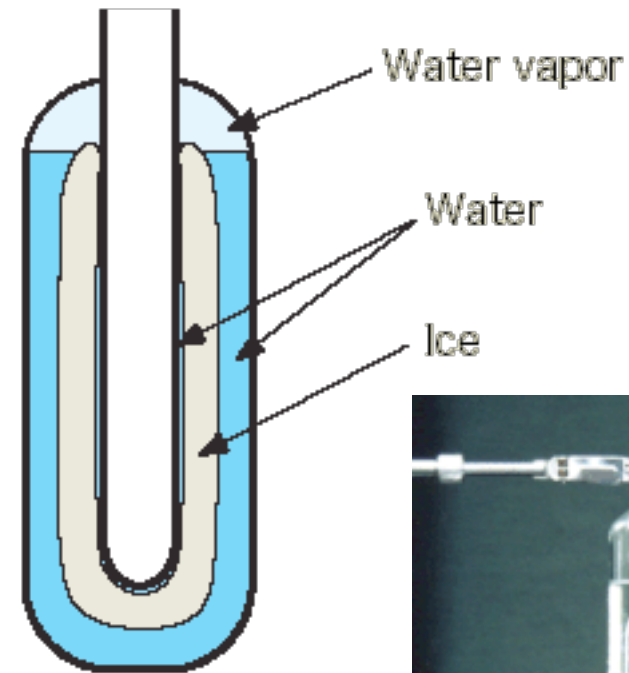
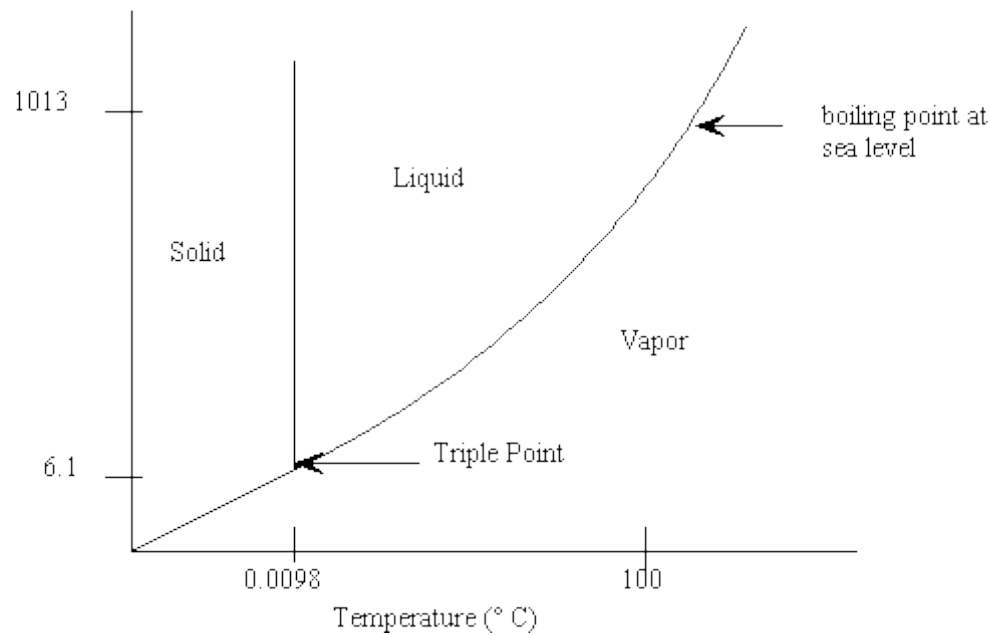
Sublimation



Properties of Matter: **Phases**

Triple Point of Water: Phase Coexistence

Phase Diagram for Water



Phase depends on:
Temperature and Pressure

Properties of Matter: **Phases**

Vocabulary:

Ion

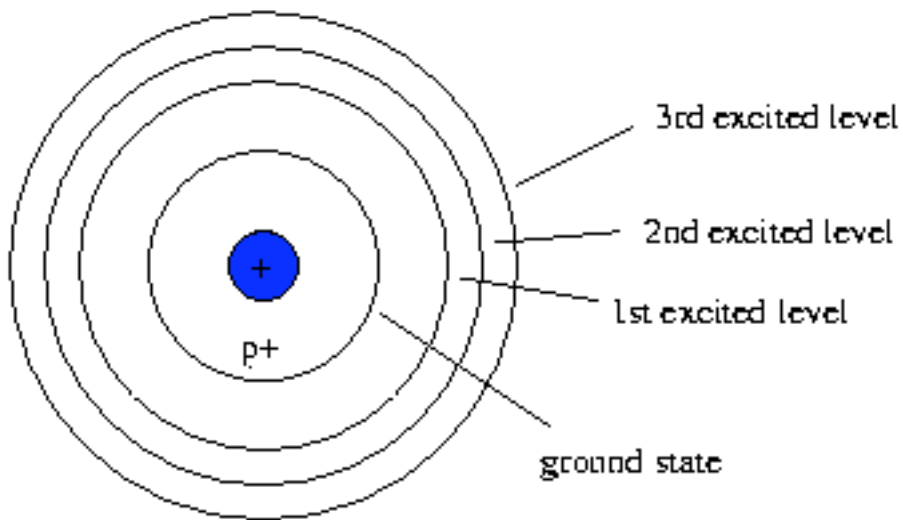
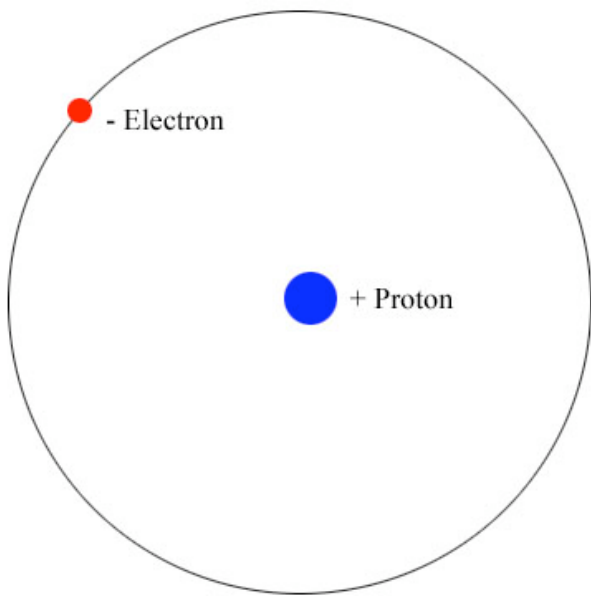
Ionization

Molecular Dissociation

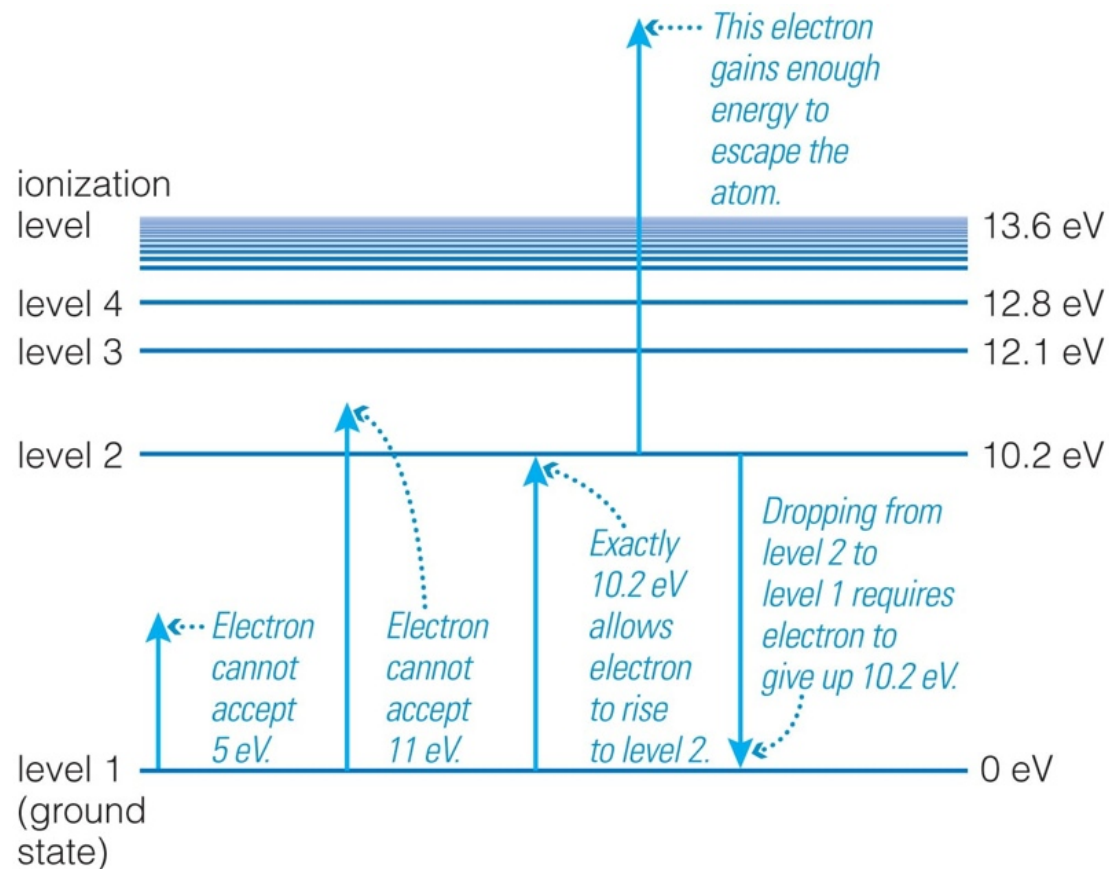
Plasma

Pressure

Properties of Matter: **Energy** *and* **Energy Levels**

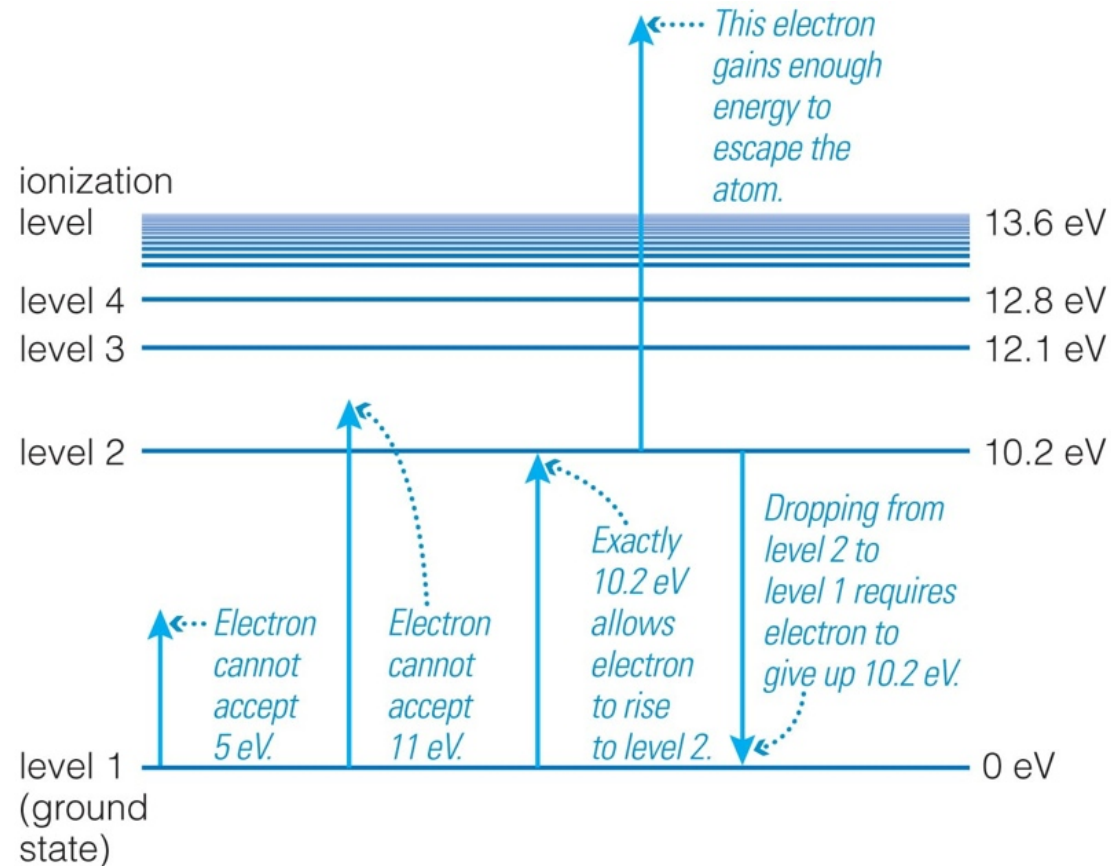


Hydrogen Atom -- lowest four "allowed" energy levels



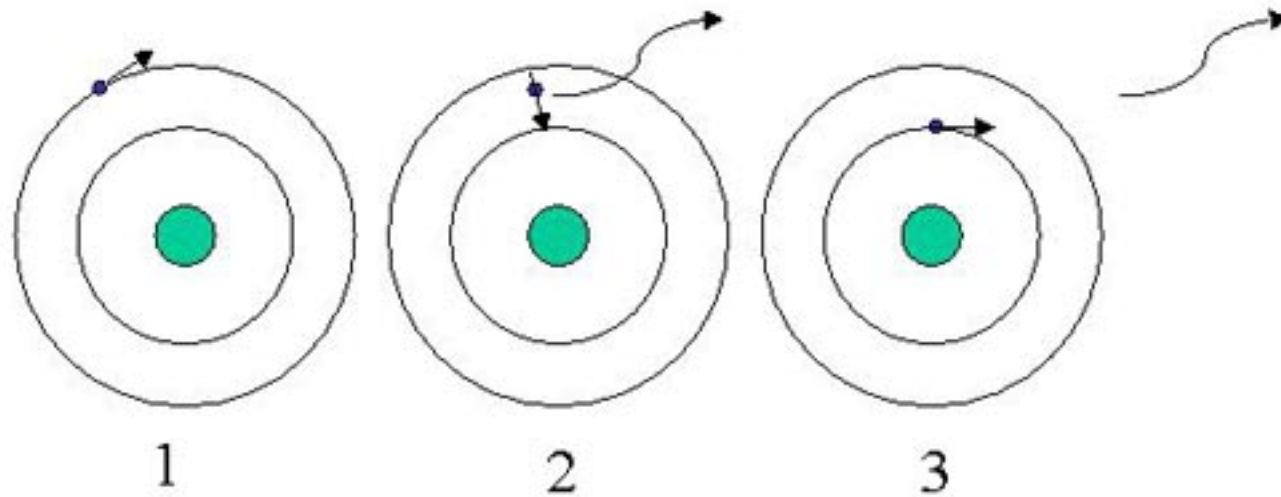
© 2010 Pearson Education, Inc.

Properties of Matter: **Energy** *and* **Energy Levels**



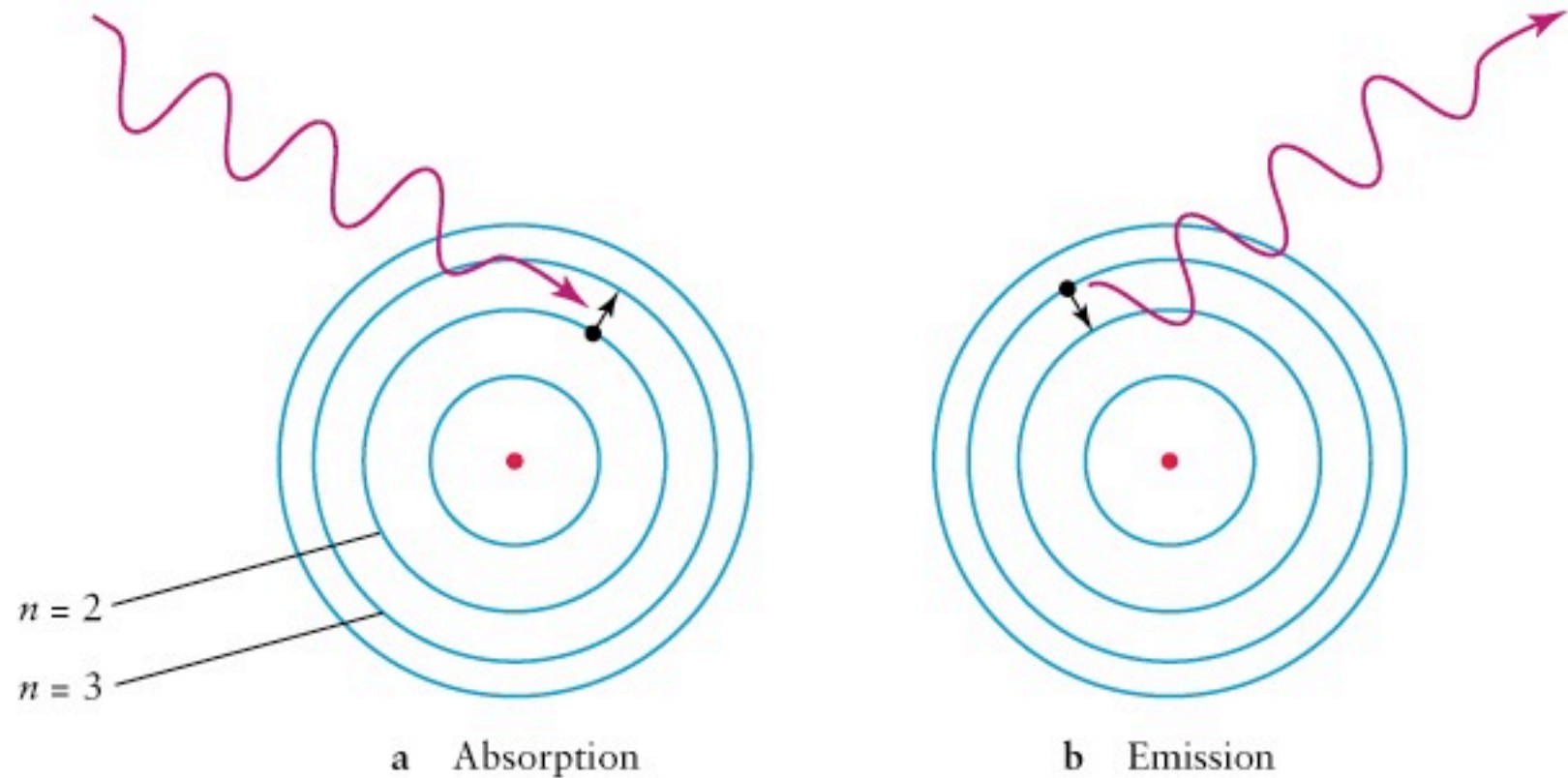
Energy Level Transitions

Properties of Matter: **Energy** *and* **Energy Levels**



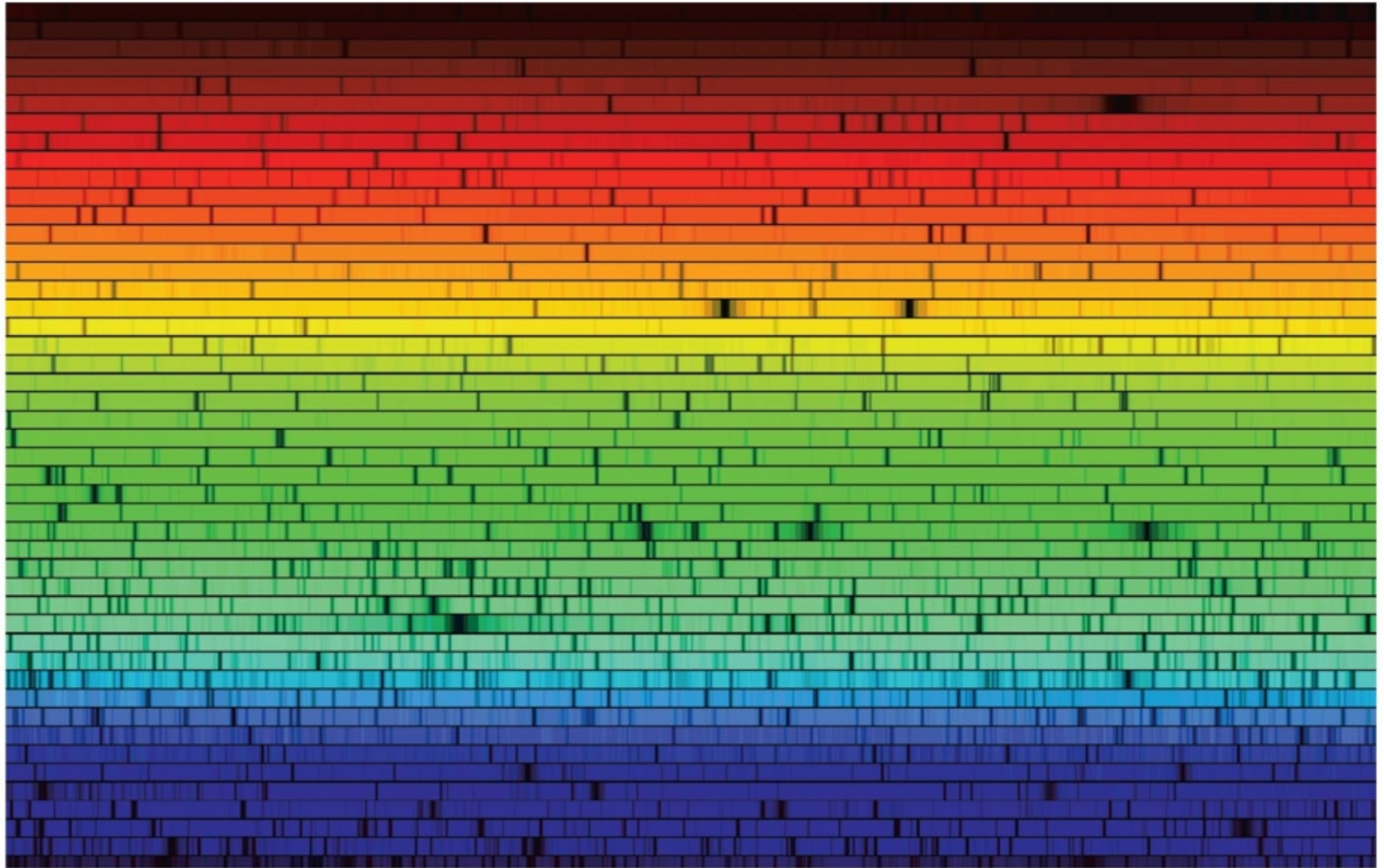
Photon/light emission

Properties of Matter: **Energy** *and* **Energy Levels**

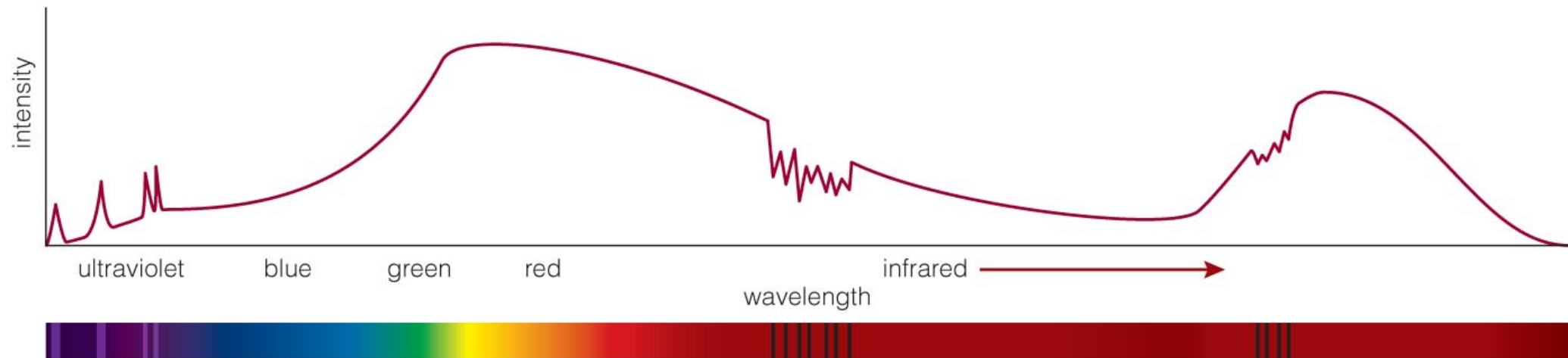


Photon/light absorption and emission

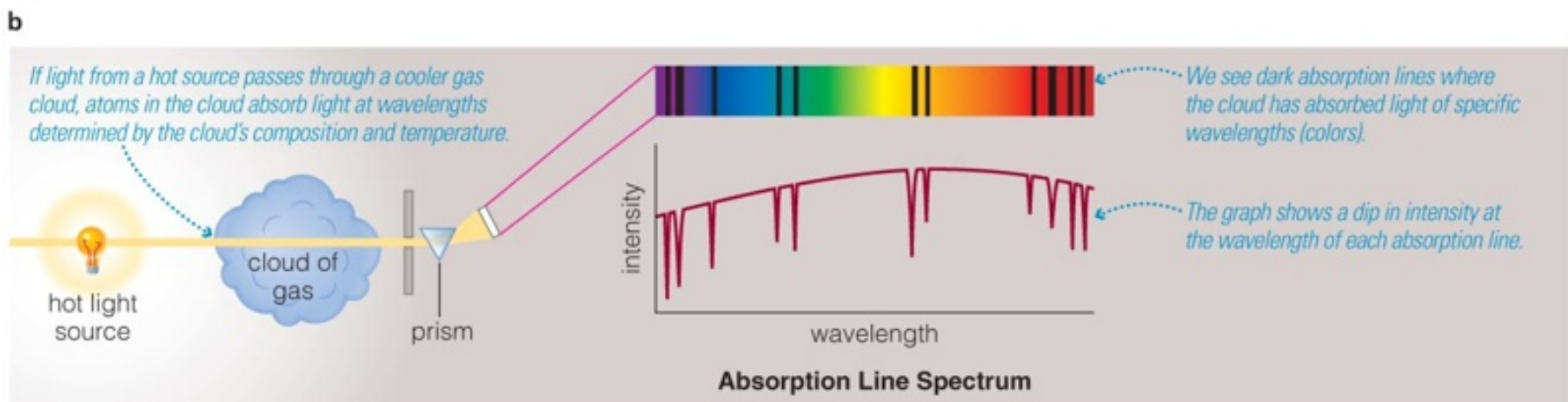
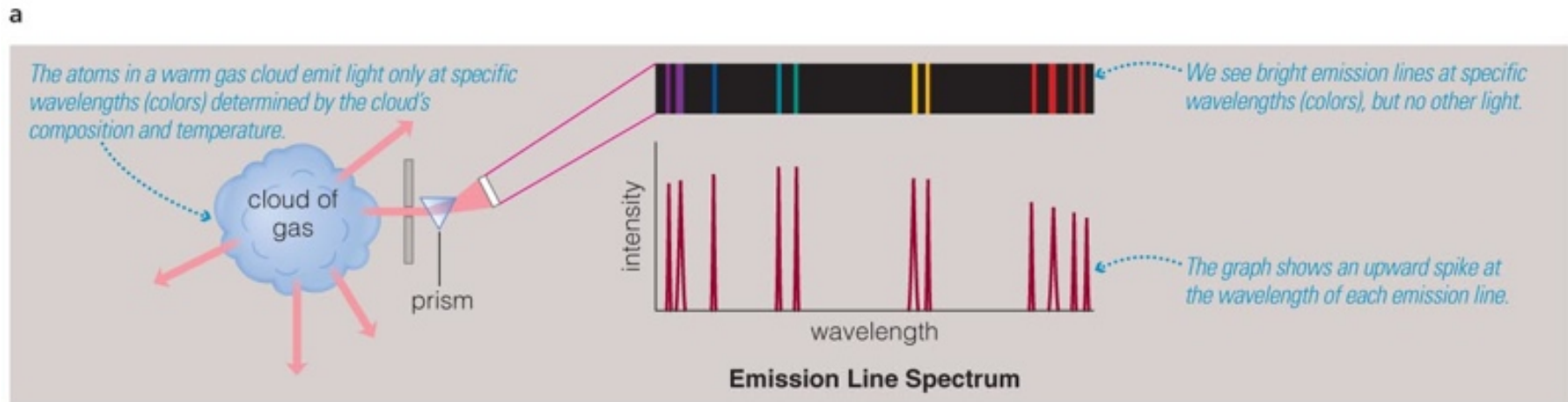
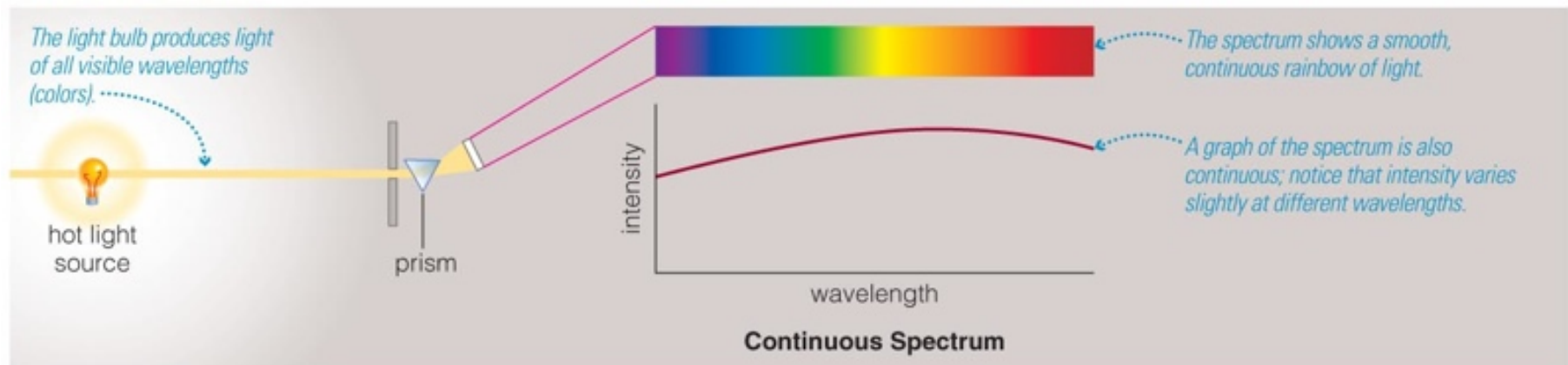
Light as an Investigative Tool



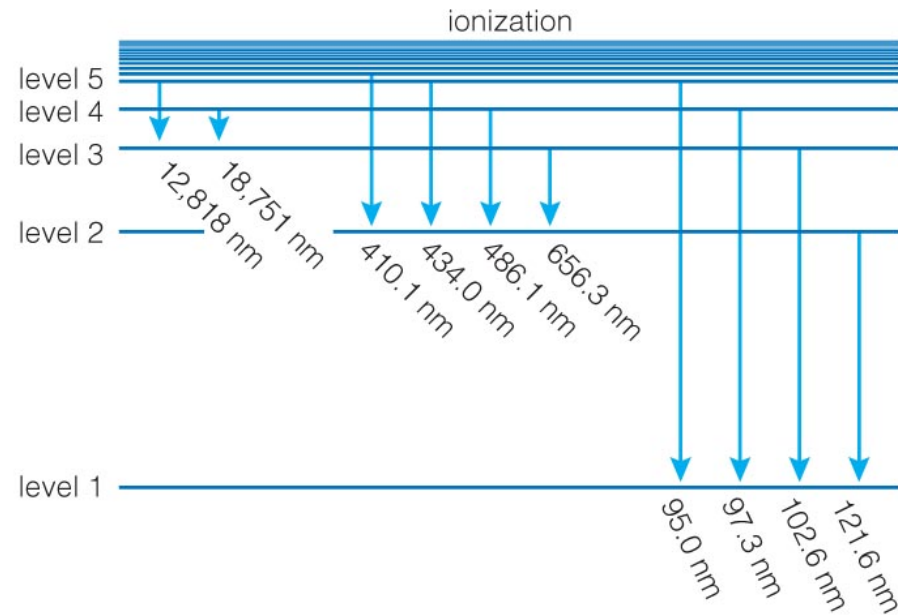
Light as an Investigative Tool



Light as an Investigative Tool



Light as an Investigative Tool



a Energy level transitions in hydrogen correspond to photons with specific wavelengths. Only a few of the many possible transitions are labeled.



b This spectrum shows emission lines produced by downward transitions between higher levels and level 2 in hydrogen.



c This spectrum shows absorption lines produced by upward transitions between level 2 and higher levels in hydrogen.

Light as an Investigative Tool

helium



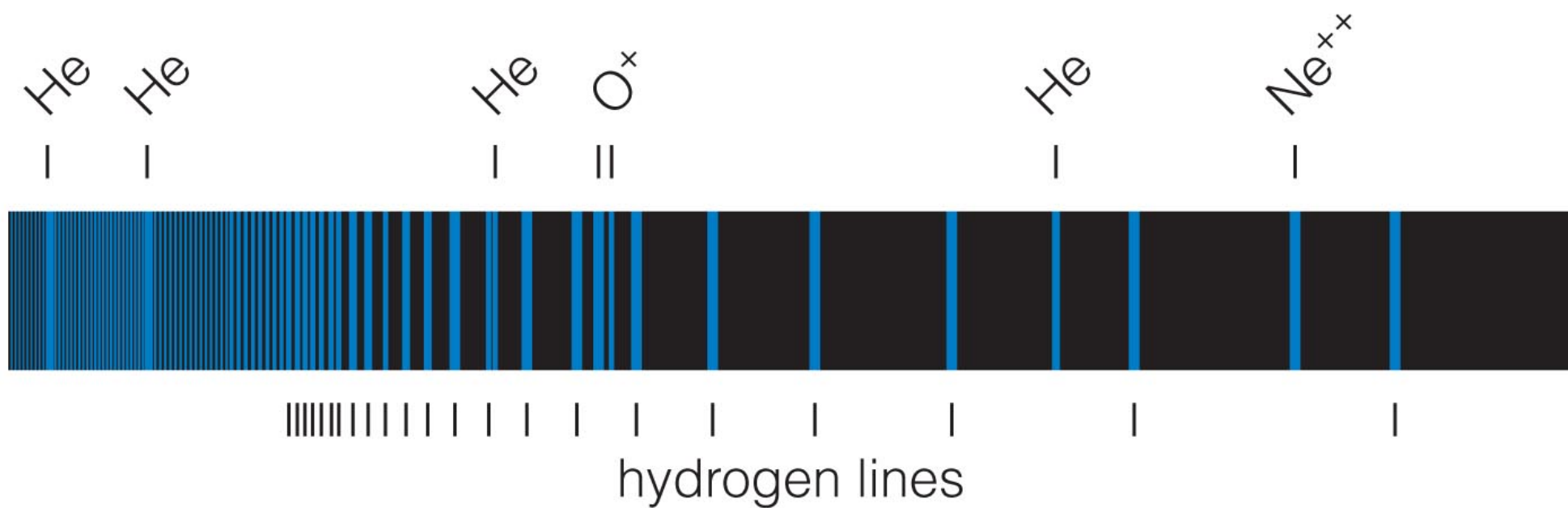
sodium



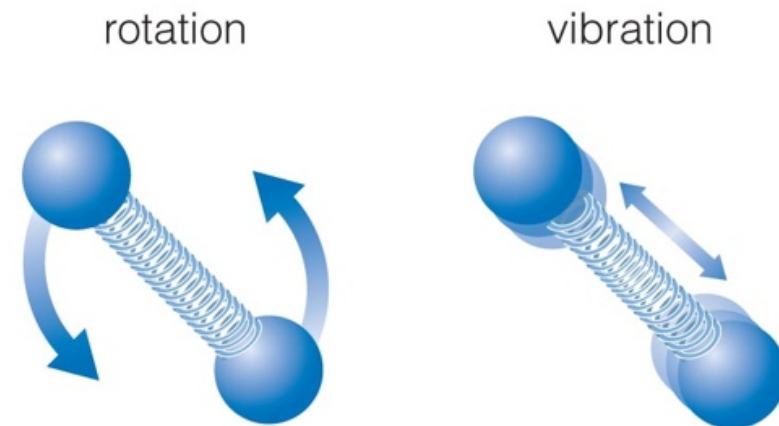
neon



Light as an Investigative Tool



Light as an Investigative Tool



a We can think of a two-atom molecule as two balls connected by a spring. Although this model is simplistic, it illustrates how molecules can rotate and vibrate. The rotations and vibrations can have only particular amounts of energy and therefore produce unique spectral fingerprints.

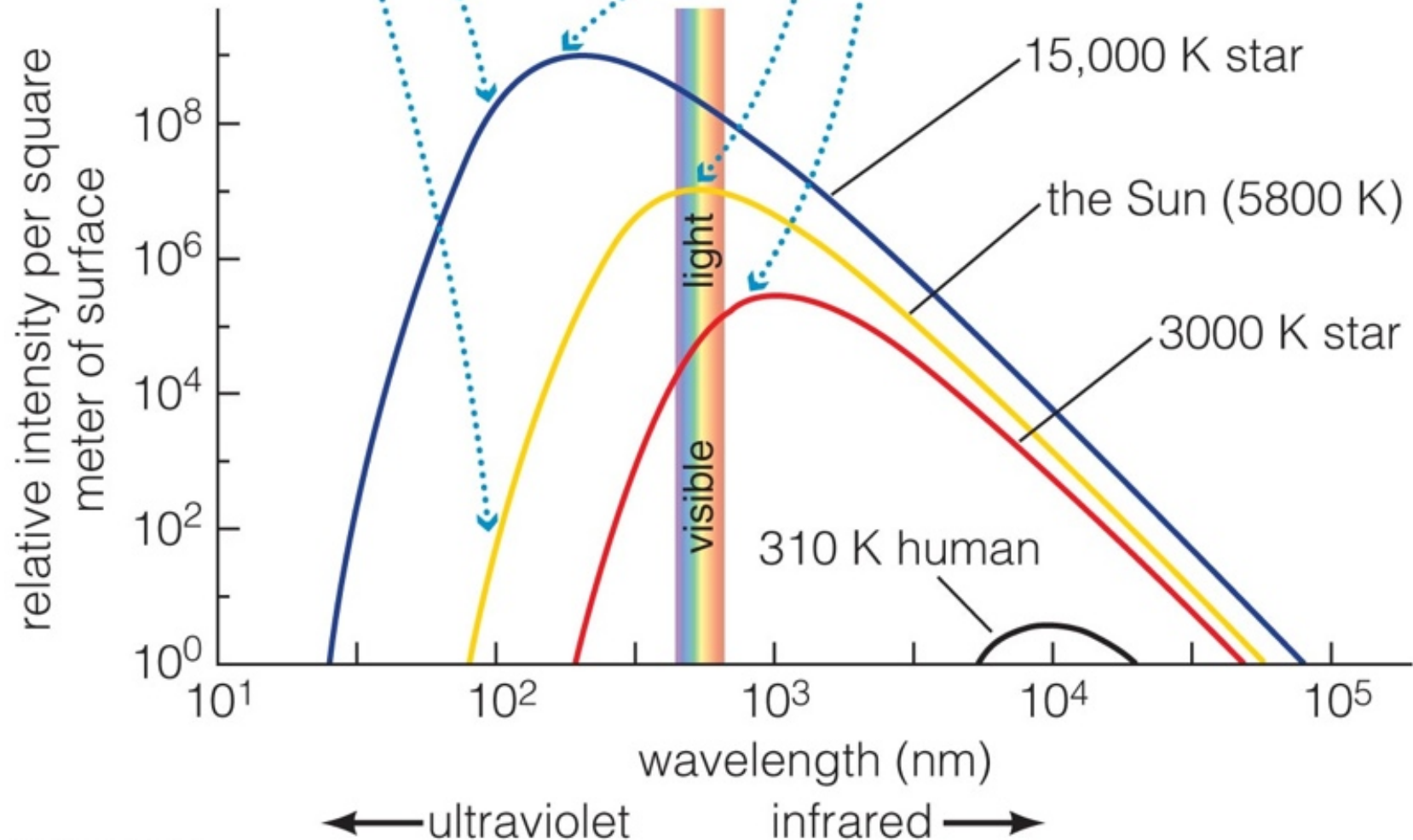


b This spectrum of molecular hydrogen (H_2) consists of lines bunched into broad molecular bands.

Light as an Investigative Tool

The curve for a hotter object is everywhere above the curve for a cooler object, showing that hotter objects emit more radiation per unit surface area at every wavelength.

The peak wavelength is further to the left for hotter objects, showing that hotter objects emit more of their light at shorter wavelength (high energy).



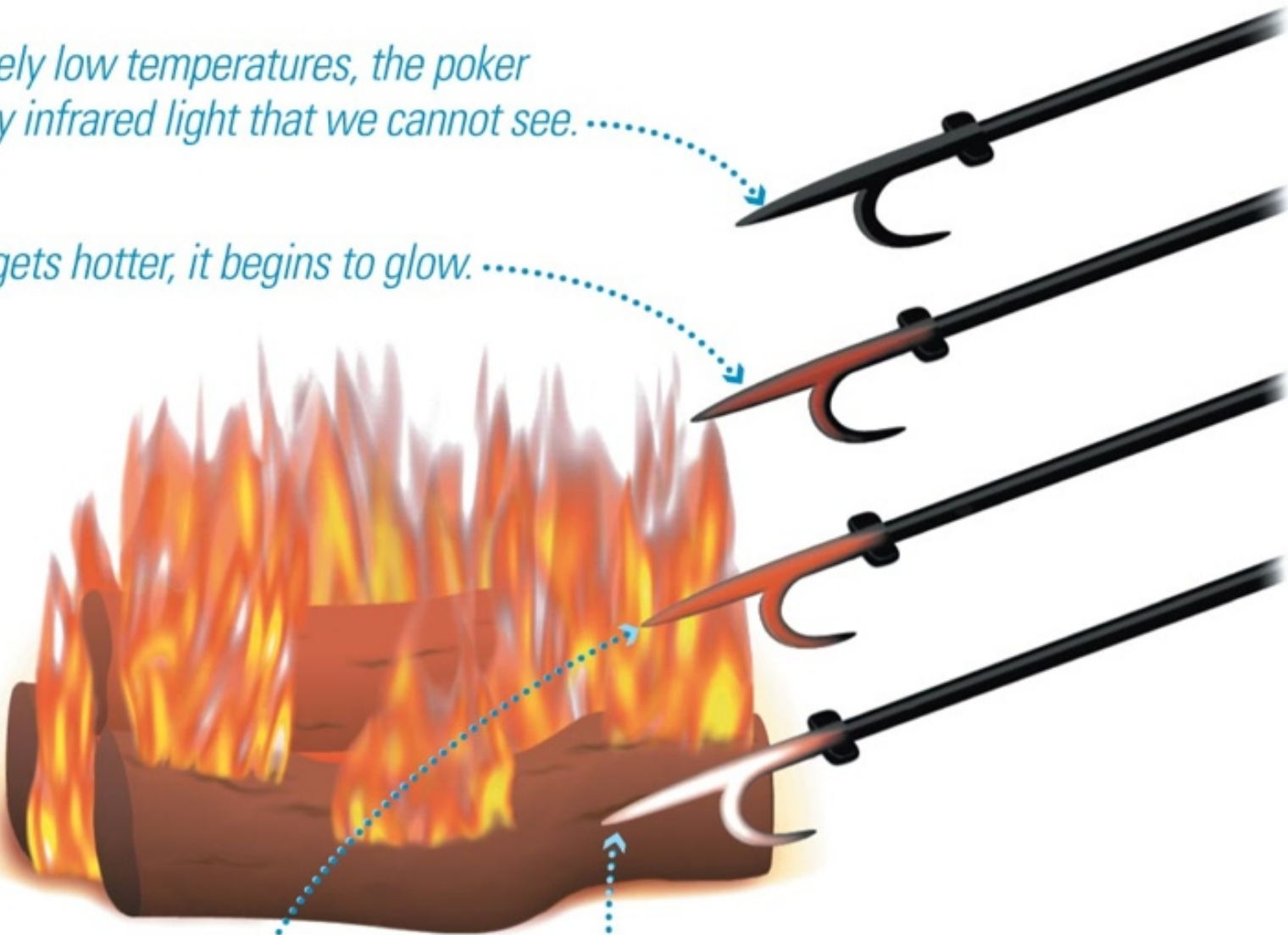
Light as an Investigative Tool

At relatively low temperatures, the poker emits only infrared light that we cannot see.

As it gets hotter, it begins to glow.

*It gets brighter as it heats up
(demonstrating Law 1) . . .*

*. . . and changes from red to white
in color (demonstrating Law 2).*



Light as an Investigative Tool

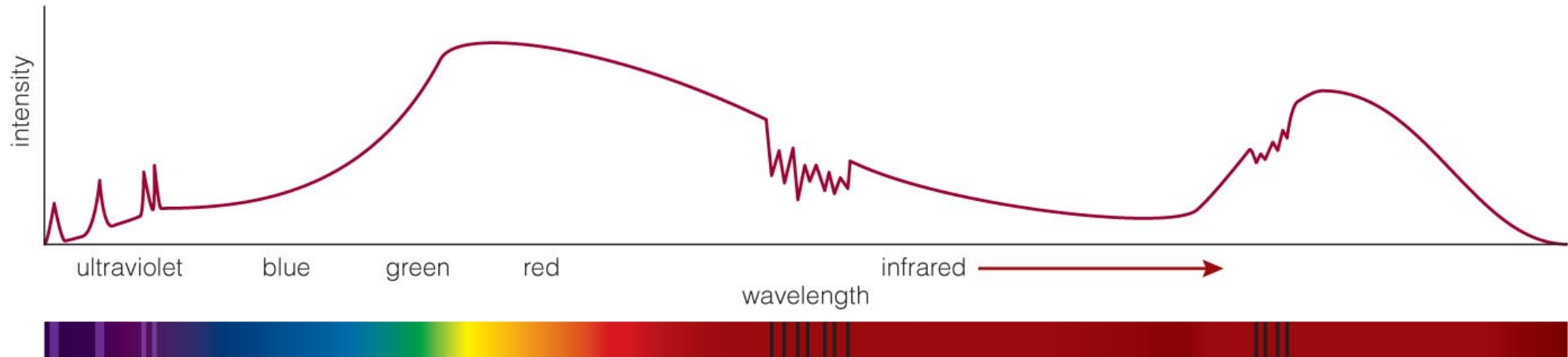
Light as an Investigative Tool

- 1 **Continuous Spectrum:** The visible light we see from Mars is actually reflected sunlight. The Sun produces a nearly continuous spectrum of light, which includes the full rainbow of color.



Like the Sun, a light bulb produces light of all visible wavelengths (colors).

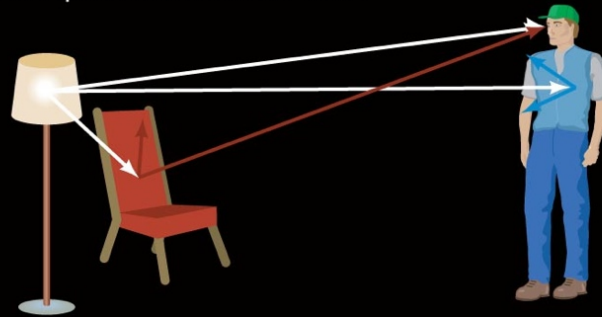
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

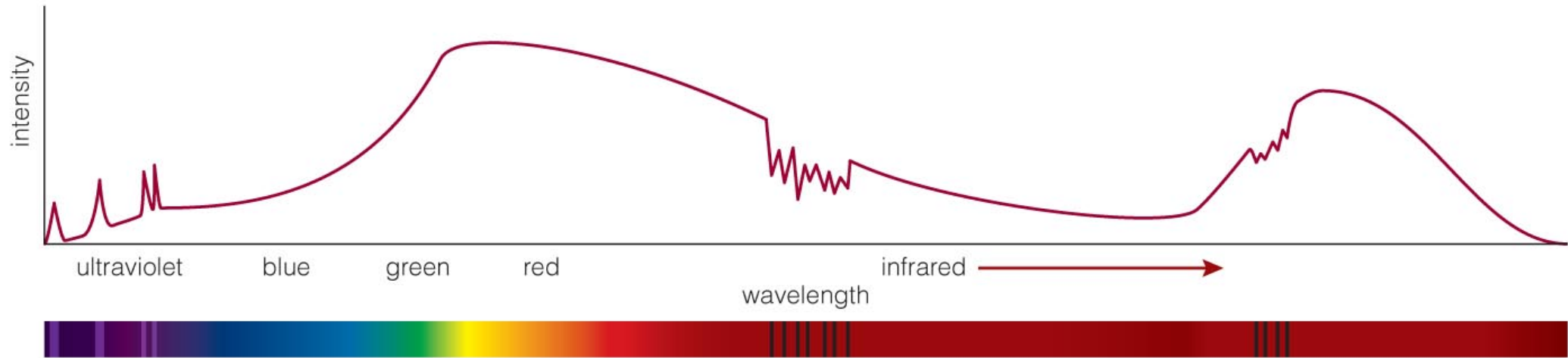
Light as an Investigative Tool

2 **Scattered/Reflected Light:** Mars is red because it absorbs most of the blue light from the Sun but reflects (scatters) most of the red light. This pattern of absorption and reflection helps us learn the chemical composition of the surface.



Like Mars, a red chair looks red because it absorbs blue light and scatters red light.

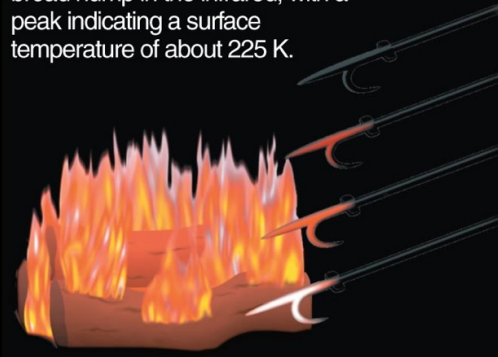
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

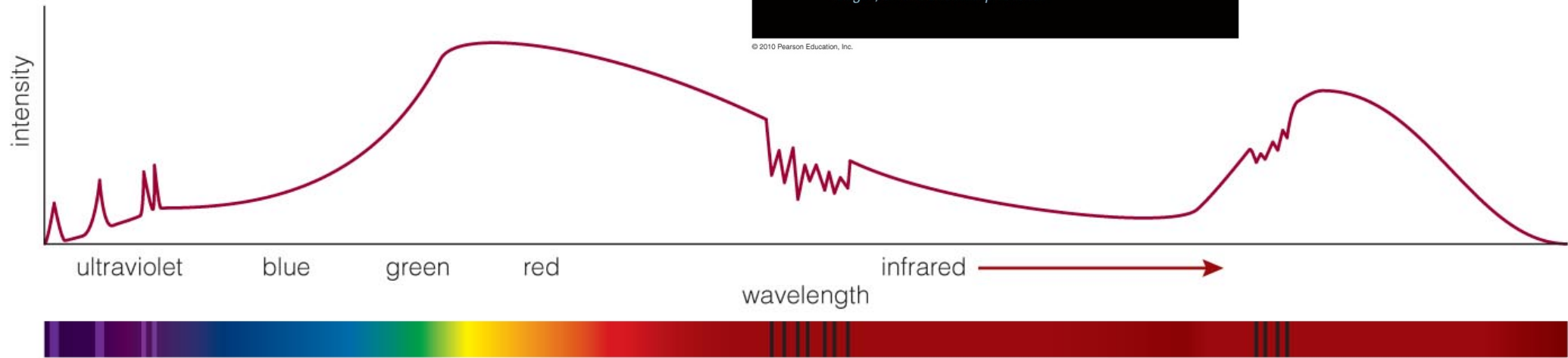
Light as an Investigative Tool

3 **Thermal Radiation:** Objects emit a continuous spectrum of thermal radiation that peaks at a wavelength determined by temperature. Thermal radiation from Mars produces a broad hump in the infrared, with a peak indicating a surface temperature of about 225 K.



All objects—whether a fireplace poker, planet, or star—emit thermal radiation. The hotter the object, (1) the more total light (per unit area); and (2) the higher the average energy (shorter average wavelength) of the emitted photons.

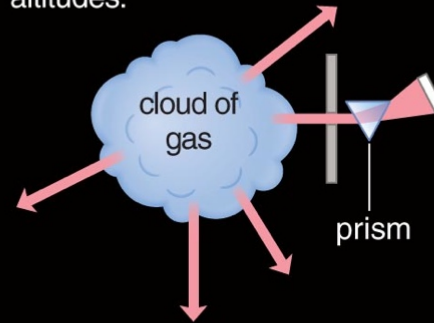
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

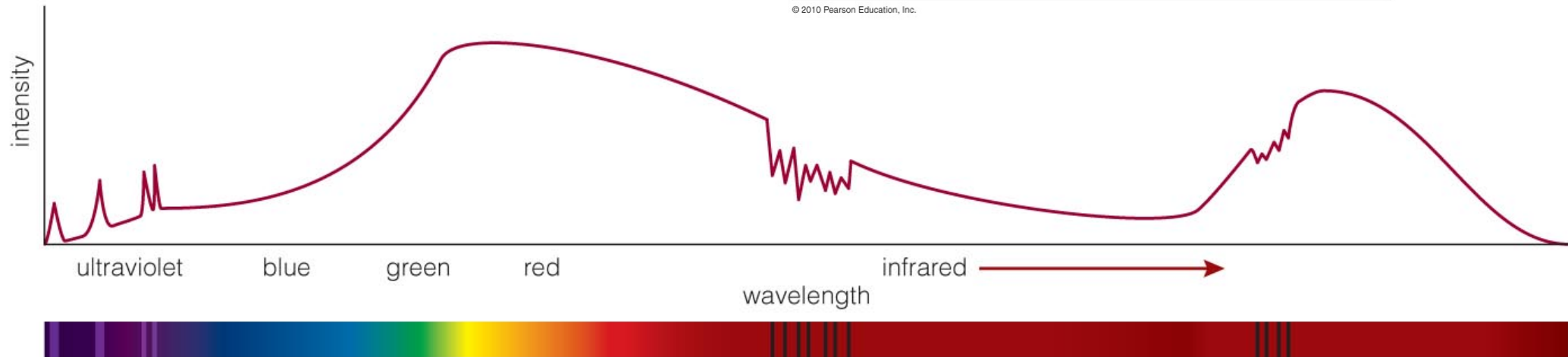
Light as an Investigative Tool

- ④ **Emission Lines:** Ultraviolet emission lines in the spectrum of Mars tell us that the atmosphere of Mars contains hot gas at high altitudes.



We see bright emission lines from gases in which collisions raise electrons in atoms to higher energy levels. The atoms emit photons at specific wavelengths as the electrons drop to lower energy levels.

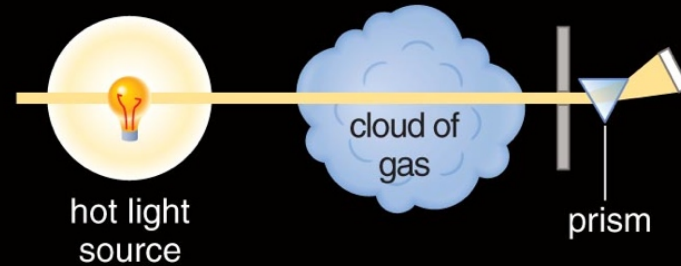
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

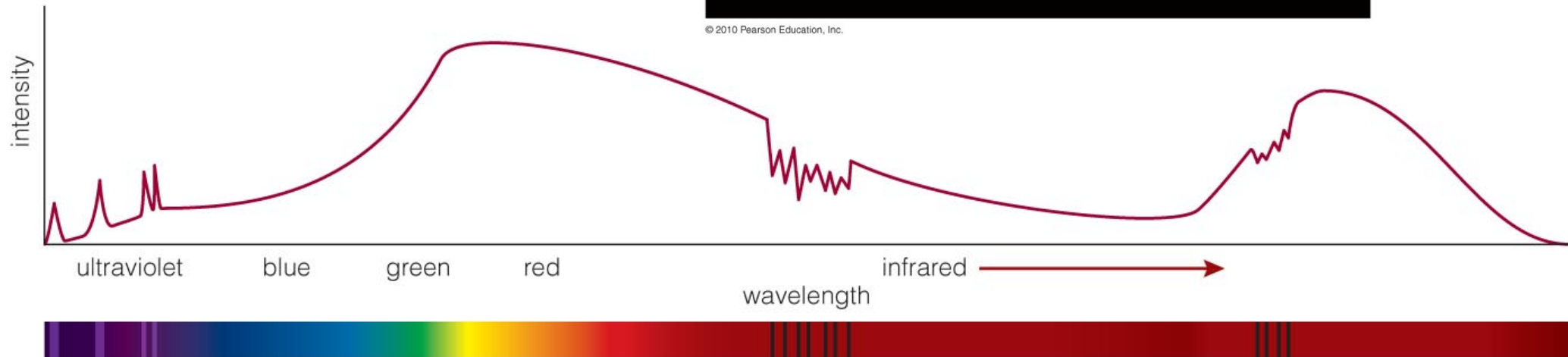
Light as an Investigative Tool

- 5 **Absorption Lines:** These absorption lines reveal the presence of carbon dioxide in Mars's atmosphere.



When light from a hot source passes through a cooler gas, the gas absorbs light at specific wavelengths that raise electrons to higher energy levels. Every different element, ion, and molecule has unique energy levels and hence its own spectral "fingerprint."

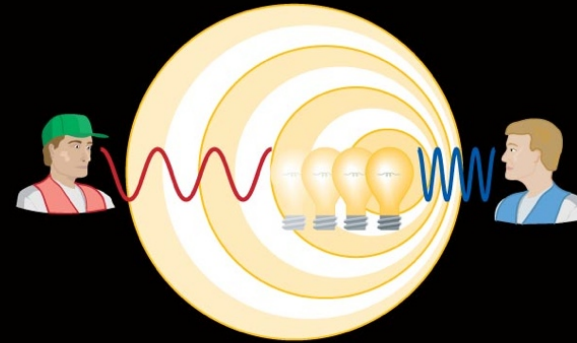
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

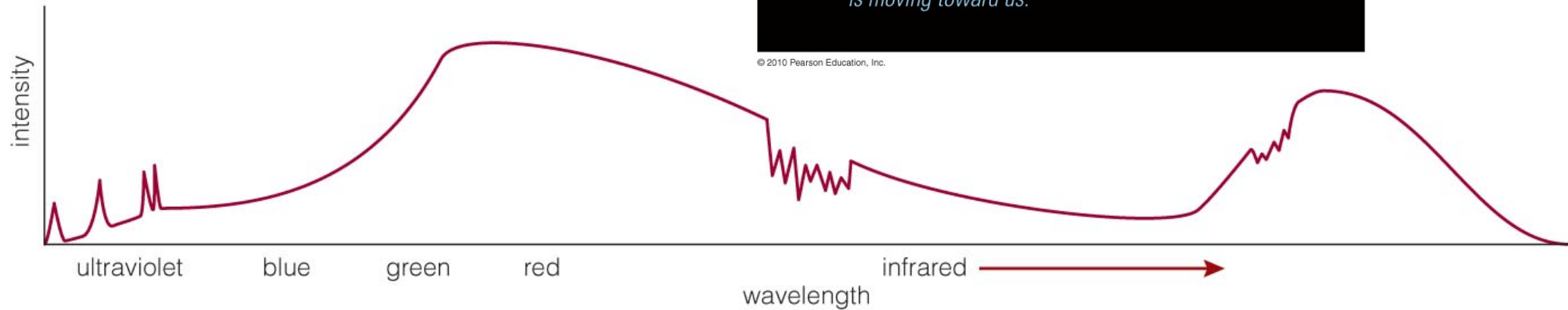
Light as an Investigative Tool

- 6 **Doppler Effect:** The wavelengths of the spectral lines from Mars are slightly shifted by an amount that depends on the velocity of Mars toward or away from us as it moves in its orbit around the Sun.



A Doppler shift toward the red side of the spectrum tells us the object is moving away from us. A shift toward the blue side of the spectrum tells us the object is moving toward us.

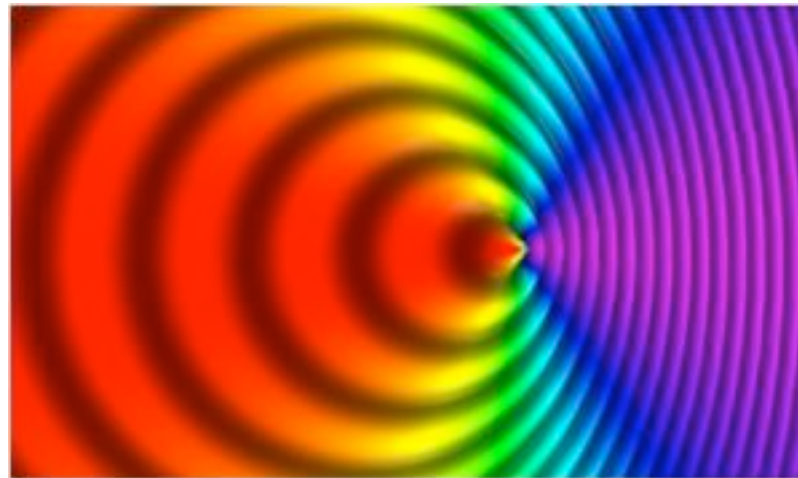
© 2010 Pearson Education, Inc.



© 2010 Pearson Education, Inc.

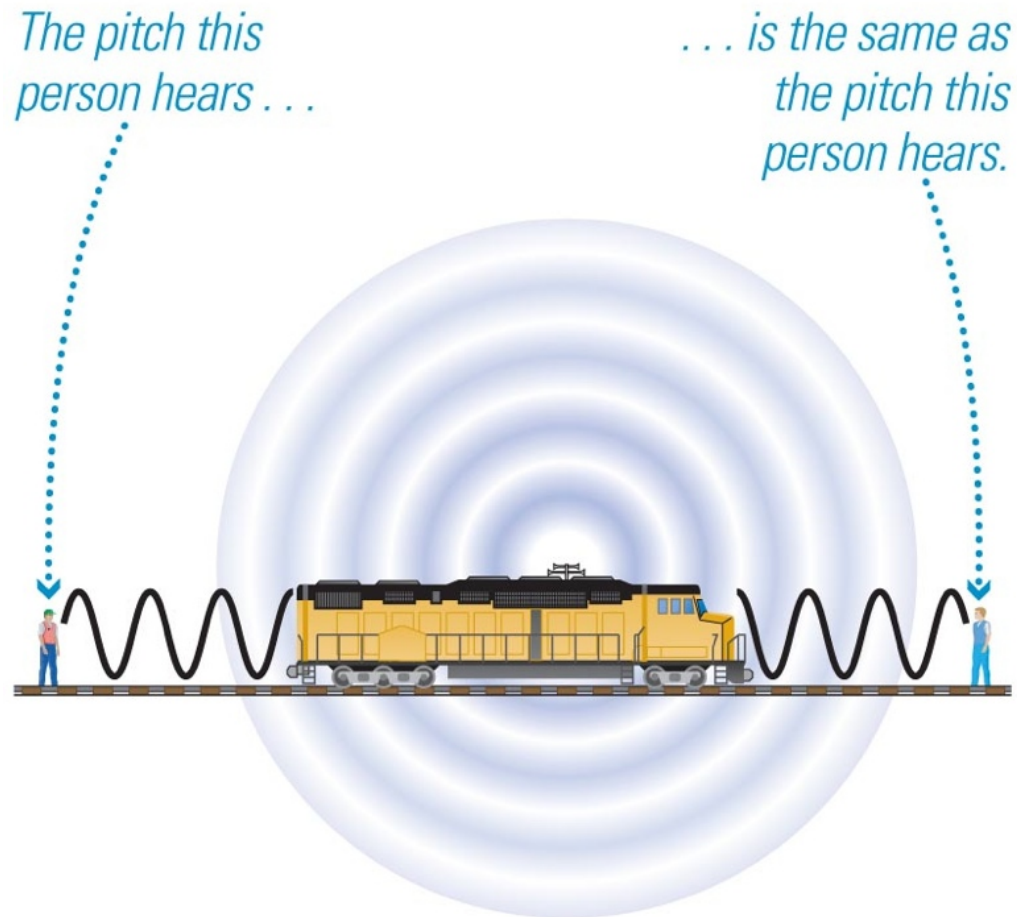
The Doppler Effect

A change in wavelength due to relative motion.
Applies to sound and light.



The Doppler Effect

train stationary



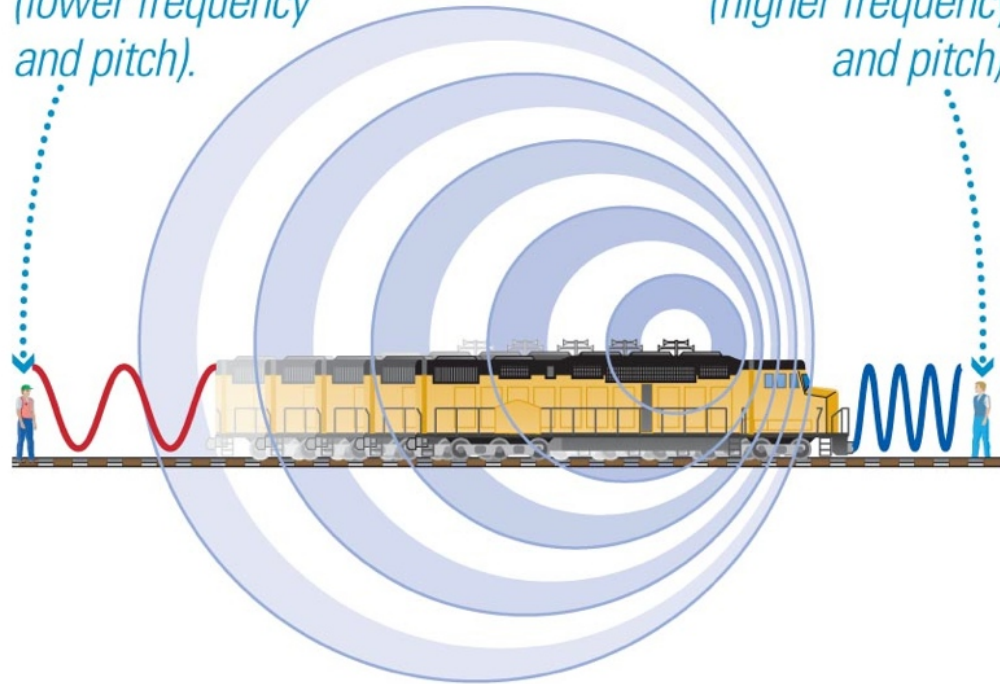
a The whistle sounds the same no matter where you stand near a stationary train.

The Doppler Effect

train moving to right

*Behind the train,
sound waves stretch
to longer wavelength
(lower frequency
and pitch).*

*In front of the train,
sound waves bunch up
to shorter wavelength
(higher frequency
and pitch).*



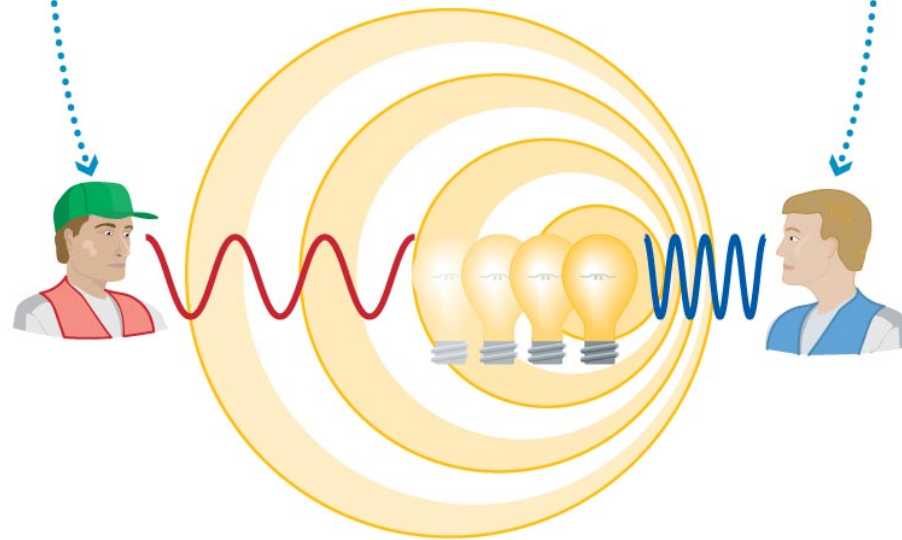
b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

The Doppler Effect

light source moving to right

The light source is moving away from this person so the light appears redder (longer wavelength).

The light source is moving toward this person so the light appears bluer (shorter wavelength).



c We get the same basic effect from a moving light source (although the shifts are usually too small to notice with our eyes).

The Doppler Effect

Laboratory spectrum

Lines at rest wavelengths.



Object 1 *Lines redshifted:*

Object moving away from us.



Object 2 *Greater redshift:*

Object moving away faster than Object 1.



Object 3 *Lines blueshifted:*

Object moving toward us.

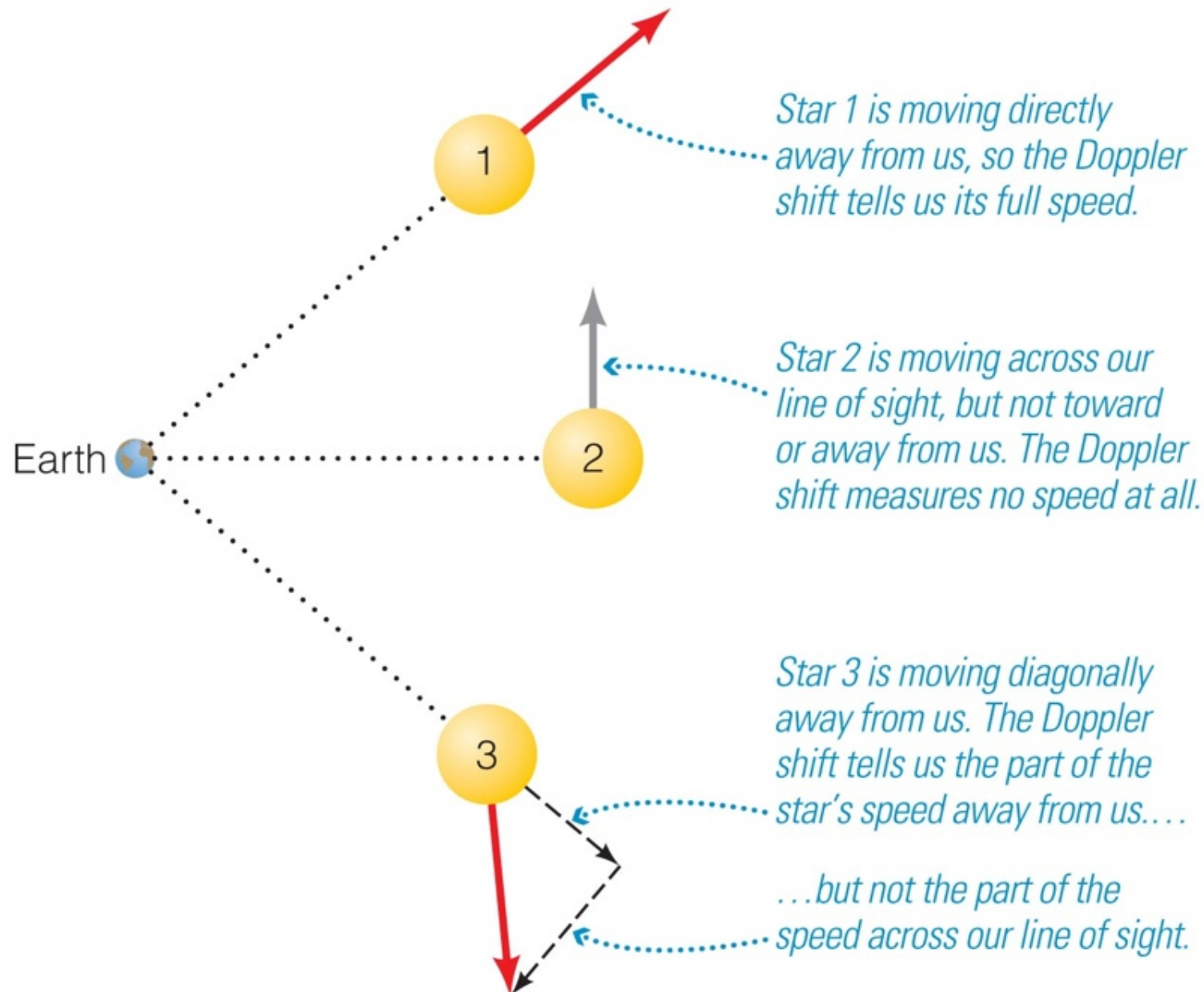


Object 4 *Greater blueshift:*

Object moving toward us faster than Object 3.

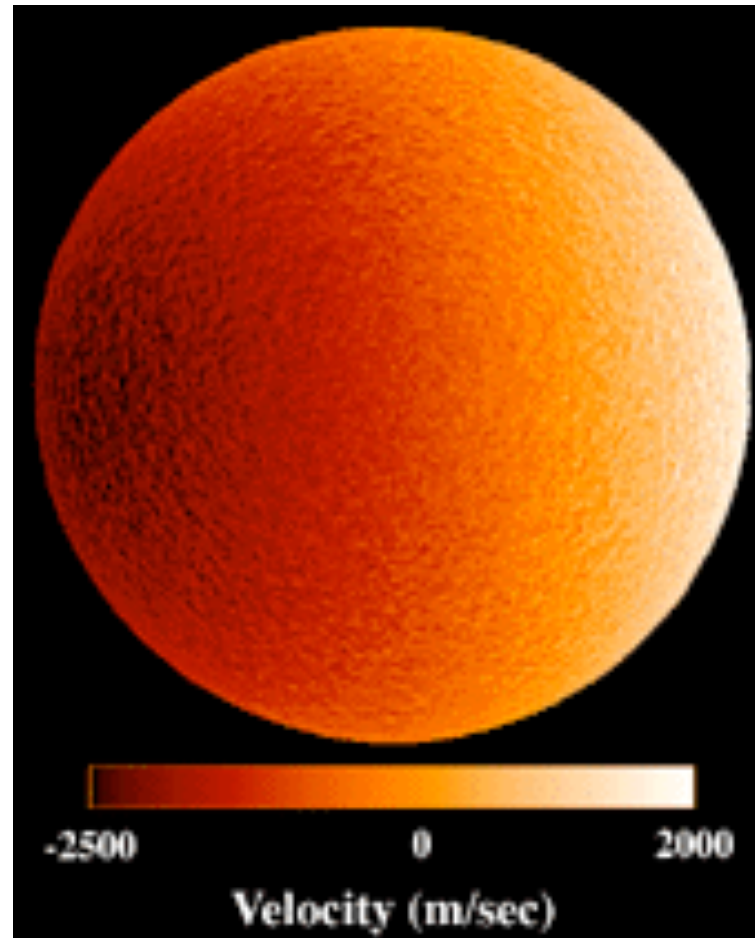


The Doppler Effect: Example



The Doppler Effect: Example

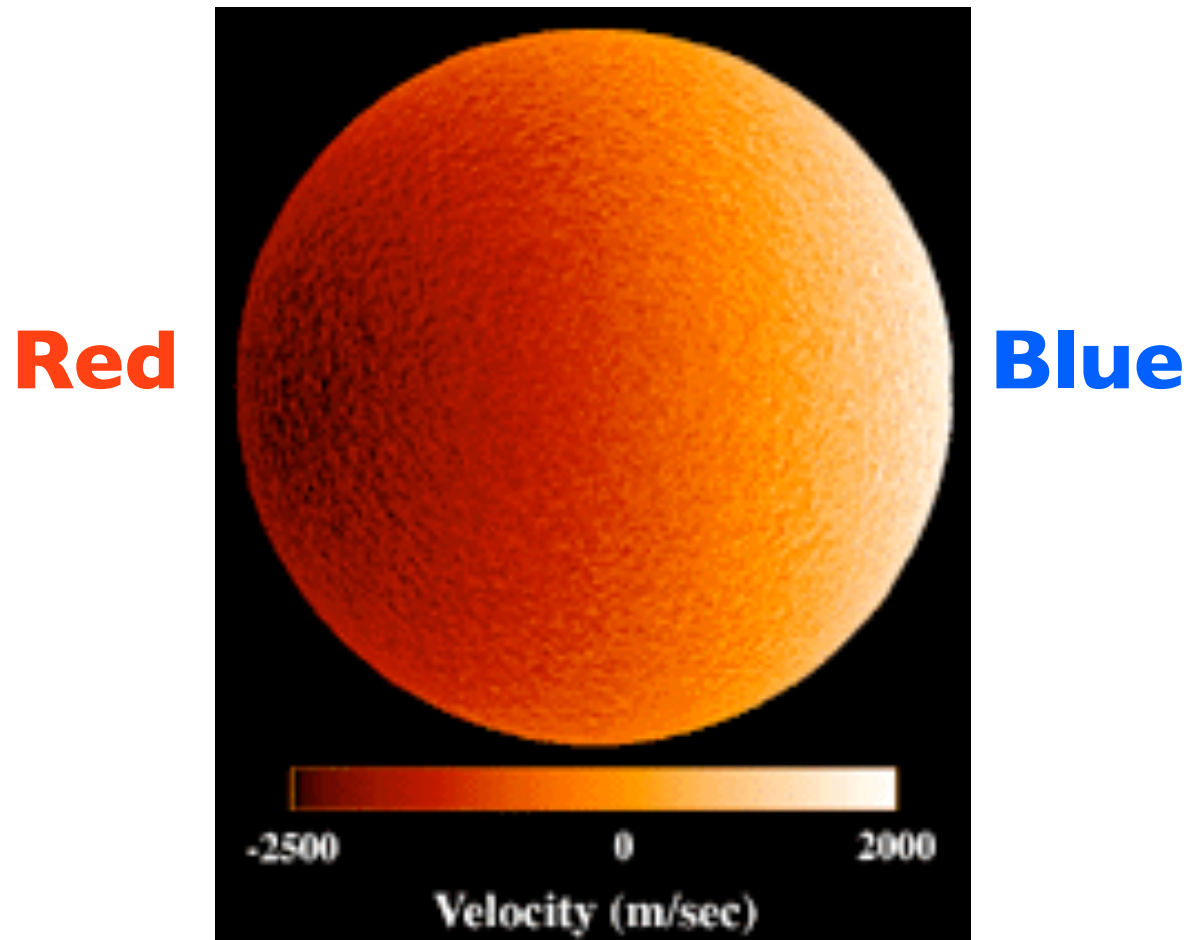
Star Rotation



The Disk of the Sun

The Doppler Effect: Example

Star Rotation



The Disk of the Sun

The Doppler Effect: Example

Star Rotation

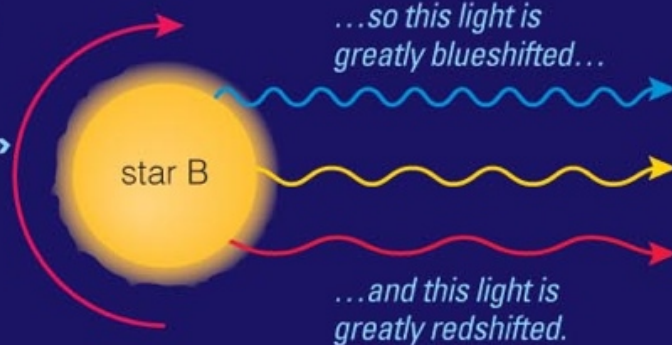
Star A is rotating slowly...



...so this light is slightly blueshifted...

...and this light is slightly redshifted.

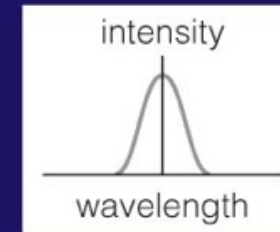
Star B is rotating faster...



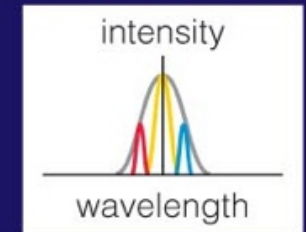
...so this light is greatly blueshifted...

...and this light is greatly redshifted.

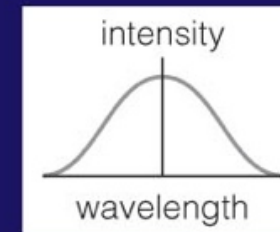
A spectral line from Star A is narrow...



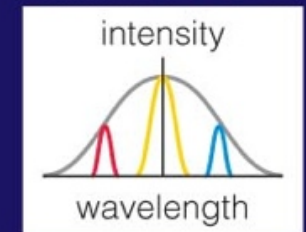
...because light from different parts is shifted only slightly from center.



A spectral line from Star B is broad...



...because light from different parts is shifted farther from center.



HW and Extra Credit Opportunities

1. Mirror Lab Tours: Tu, Fr, 1pm or 3pm, ~60 - 90 minutes
Call Cathi Duncan, 520-626-8792 for reservation

2. Flandrau: *Observatory*:
16 inch Reflector:
W, Th, Fr, Sa: 7pm - 10pm

3. Flandrau: *Planetarium Show* -
Every day. More details online:

<http://www.flandrau.org/programs/planetarium-shows/>

Here are the planetarium show times:

Monday-Thursday

2:30 p.m.: Tucson Sky Tonight or Legends of the Night Sky

Thursdays (Family Night)

7 p.m.: Legends of the Night Sky

Fridays

2:30 p.m.: Tucson Sky Tonight

4:30 p.m.: Legends of the Night Sky

7 p.m.: Legends of the Night Sky

Saturdays

11 a.m.: Legends of the Night Sky

1 p.m.: Touring the Planets

3 p.m.: Tucson Sky Tonight

4:30 p.m.: Legends of the Night Sky

7 p.m.: Legends of the Night Sky

Sundays

1 p.m.: Touring the Planets

3 p.m.: Tucson Sky Tonight

Assignment (**due: M, 9/20**):

1.) Read Ch. 14

2.) Ch. 4 problems 1 - 12; Ch. 5 problems 29 - 38.