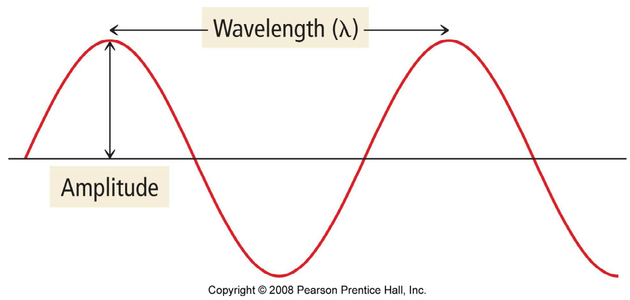
Chapter 7: The Quantum-Mechanical Model of the Atom

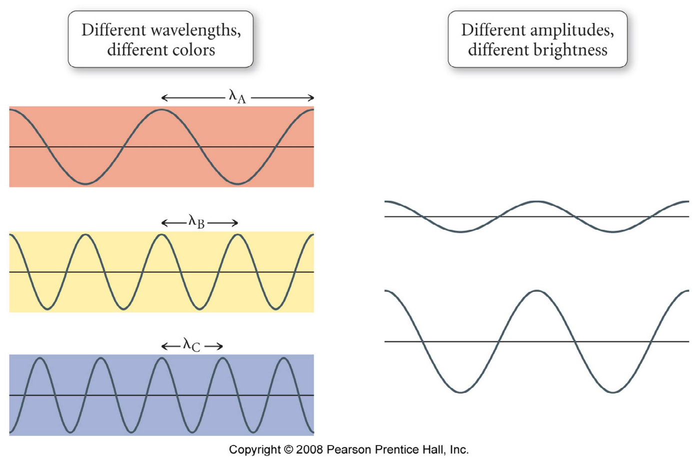
Light = electromagnetic radiation

Wave-particle duality: light has wave-like AND particle-like properties

The wave nature of light



amplitude: dist from origin to peak



wavelength (λ): dist from one peak to next

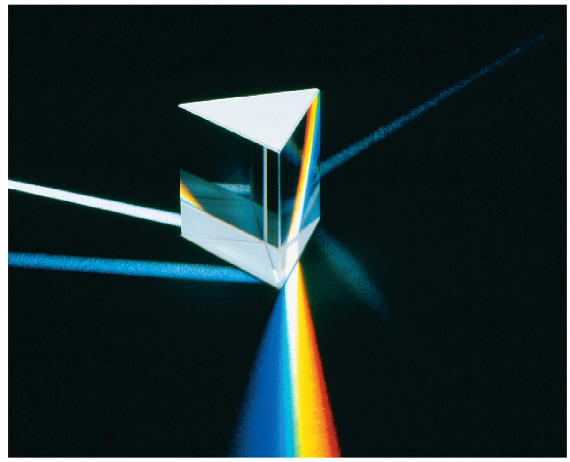
frequency (ν): # of full waves that pass a point per unit of time

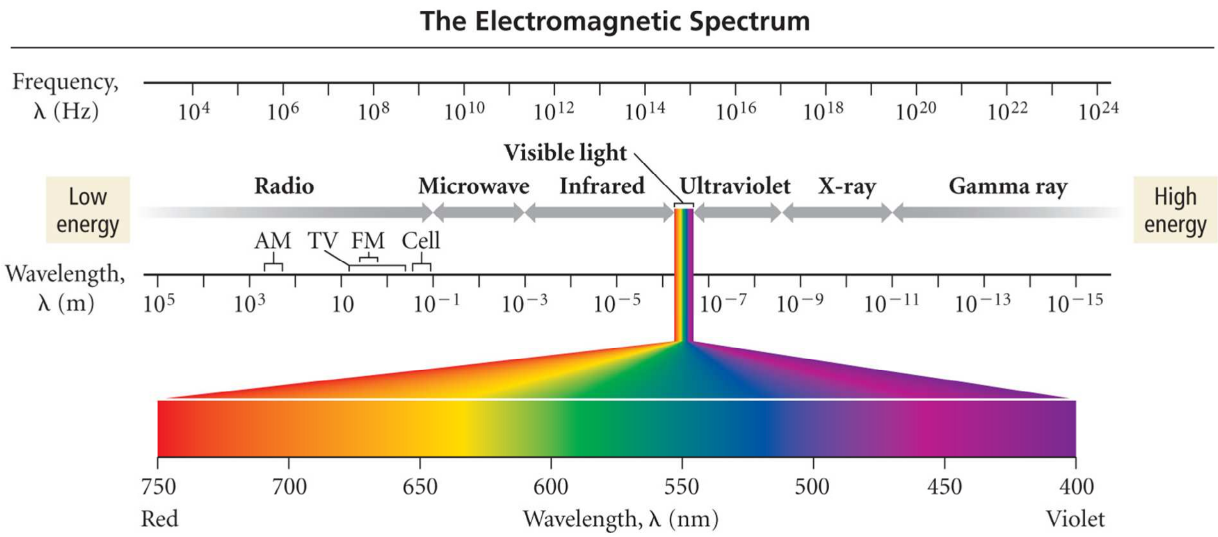
frequency unit: hertz = Hz = s^{-1} (cycles per second)

$c = \lambda\nu$ where $c = 3.00 \times 10^8$ m/s (speed of light in vacuum)

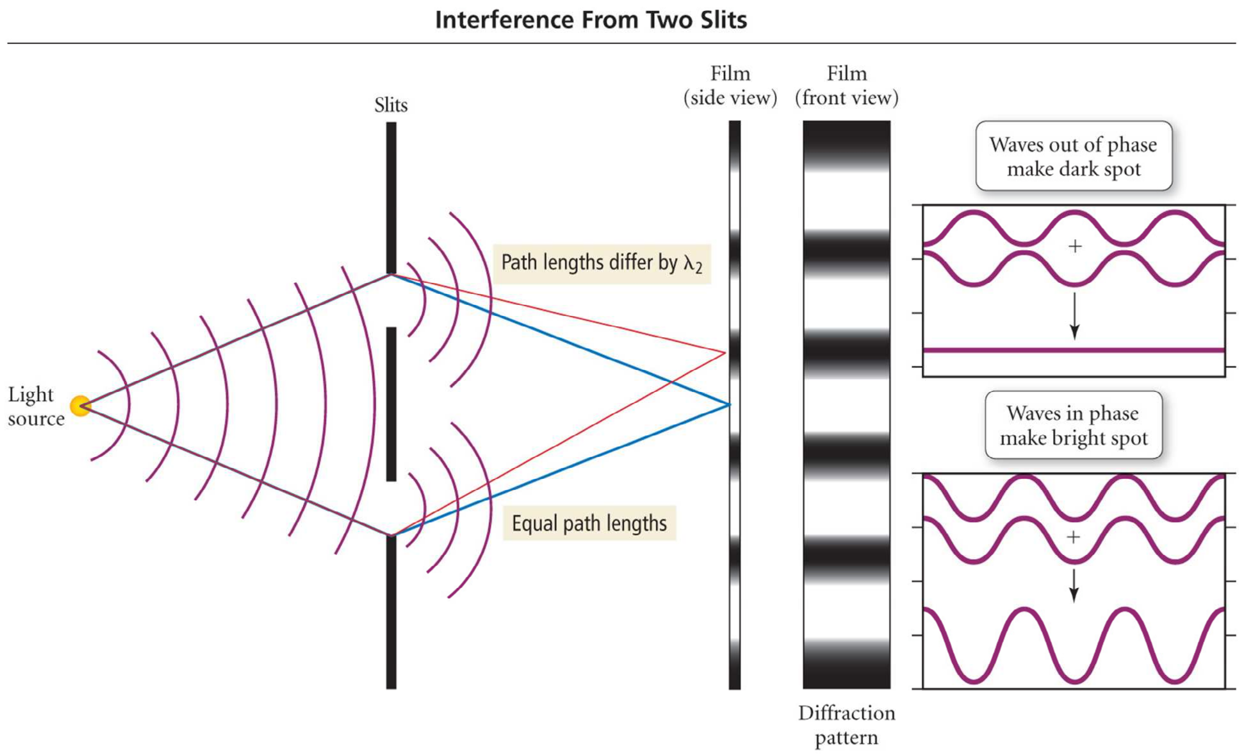
The electromagnetic spectrum

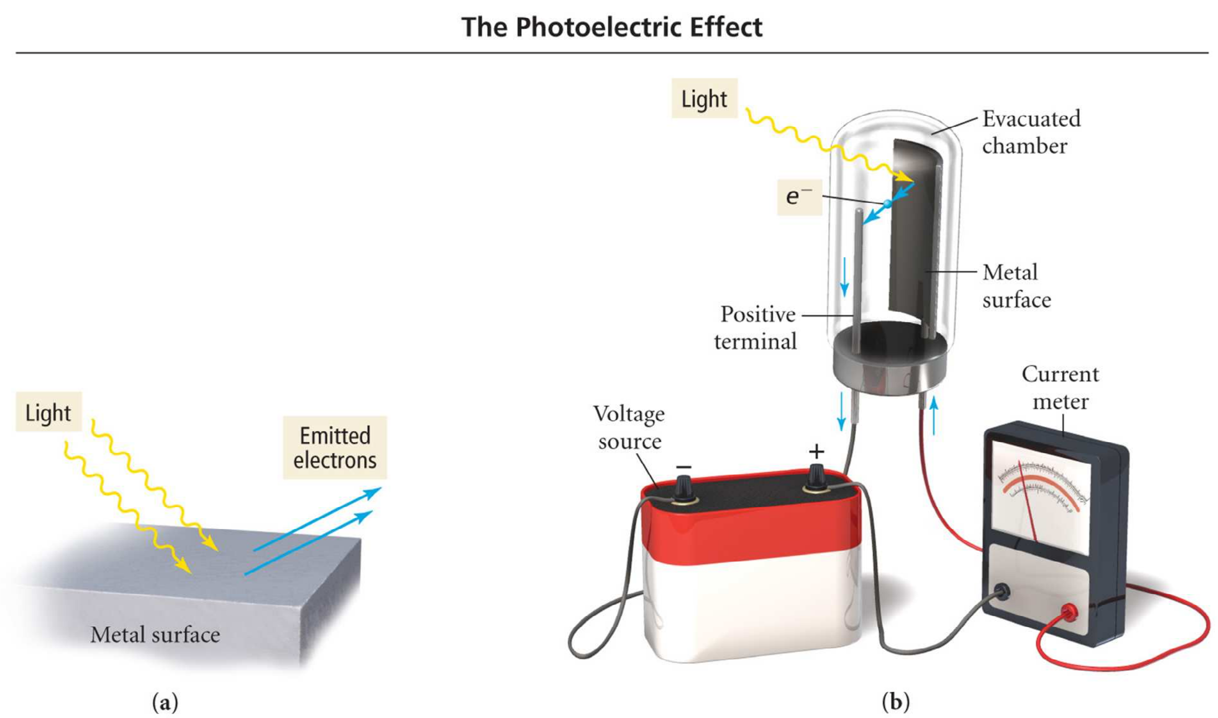
White visible light can be separated into its component colors through a prism





Evidence for the wave and particle natures of light





The particle nature of light

1905: Albert Einstein: **photoelectric effect**

- electrons are ejected from metal only after a certain frequency (ν) of light hits it
- 1 photon of light can eject 1 electron - IF that photon has enough energy

photon: a individual packet or "particle" of light

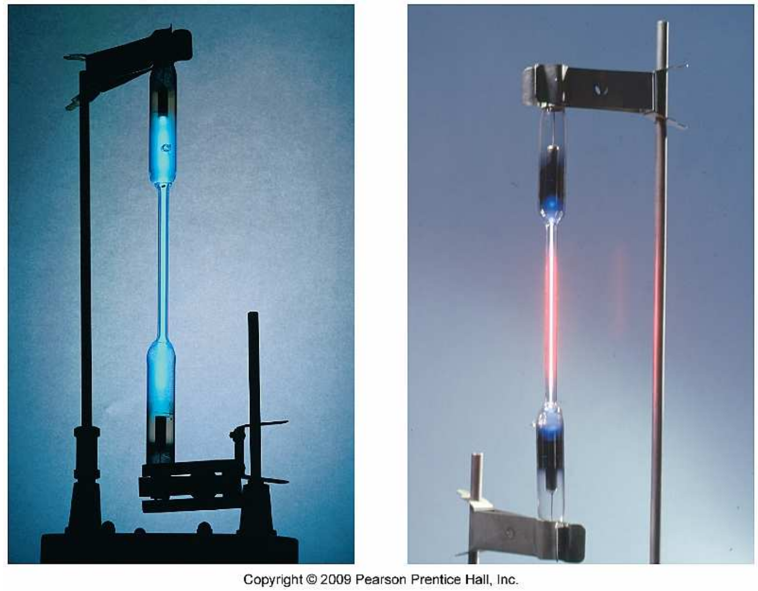
$E = h\nu$ where:

- E = energy of one photon
- h = Planck's constant = 6.63×10^{-34} J·s

since $c = \lambda\nu$, $\nu =$ and $E =$

How much energy is in one photon of blue light with a wavelength of 473 nm?

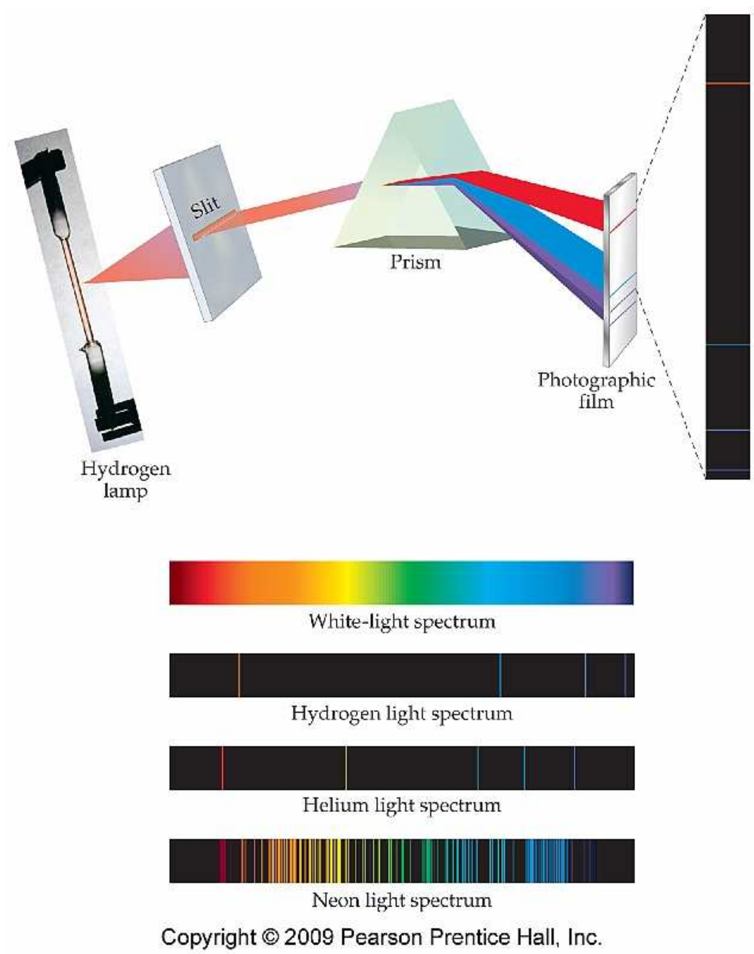
A **gas lamp** is a sealed glass tube that contains a gas sample, and **glows** when a high voltage is applied to it.



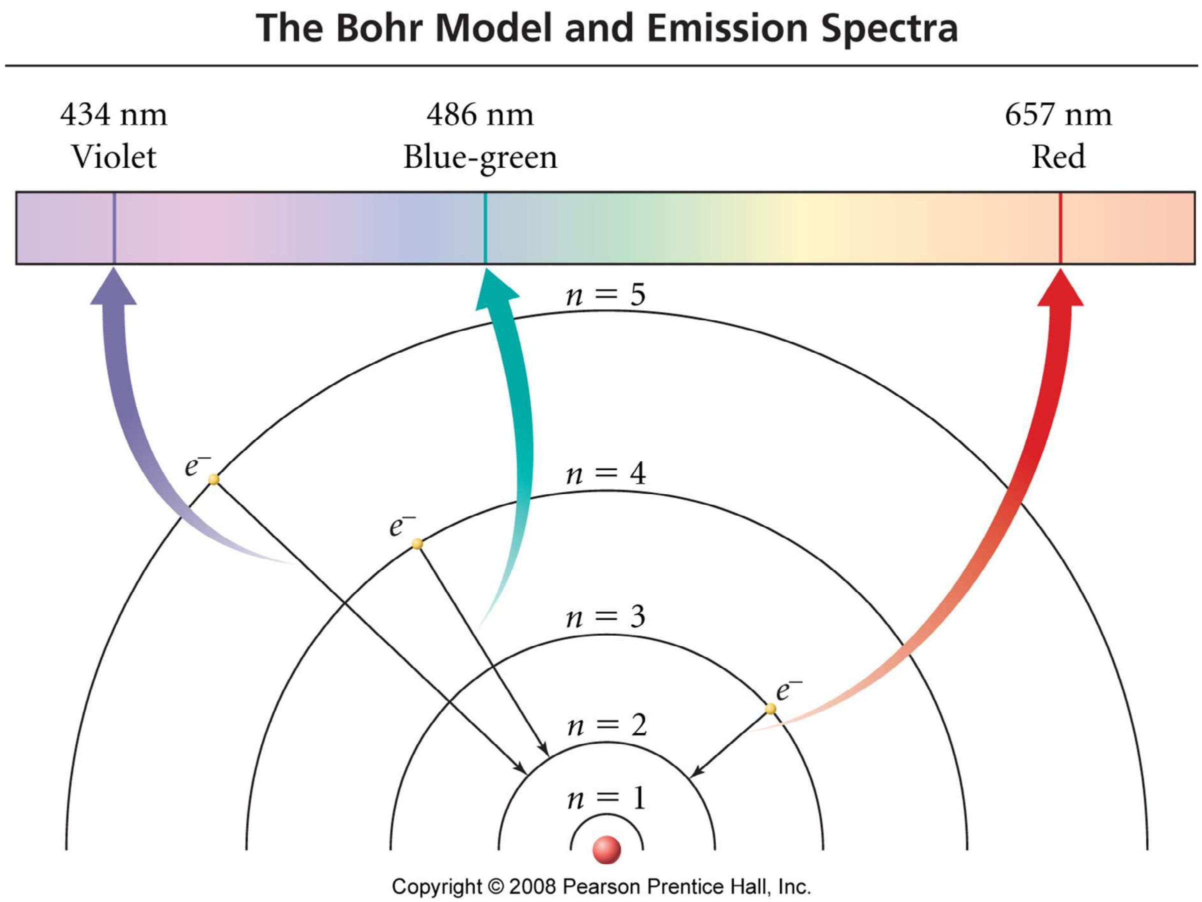
Hg(*g*) H_2(*g*)

But **only certain wavelengths** of light are given off by a gas lamp.

Compare with the continuous spectrum given off by a white light source like a light bulb.



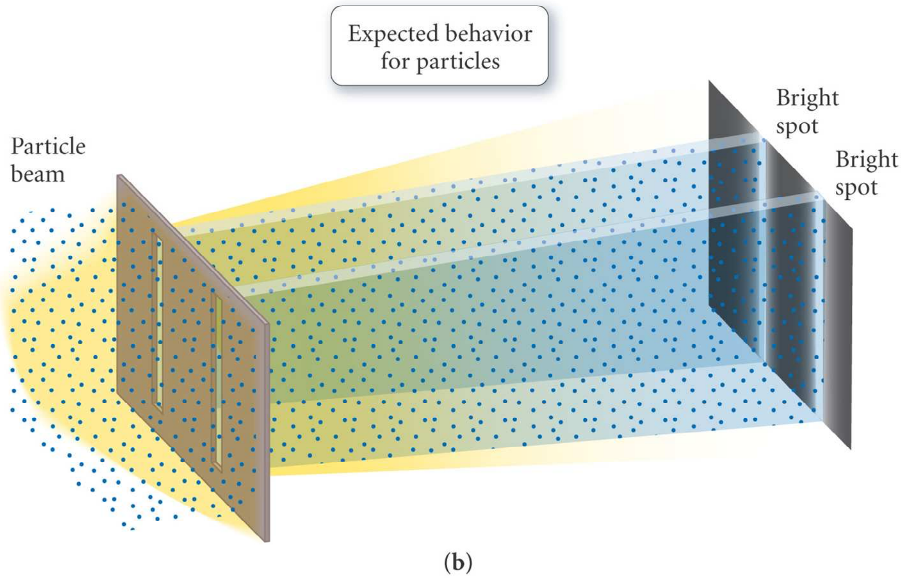
Bohr model and emission spectra

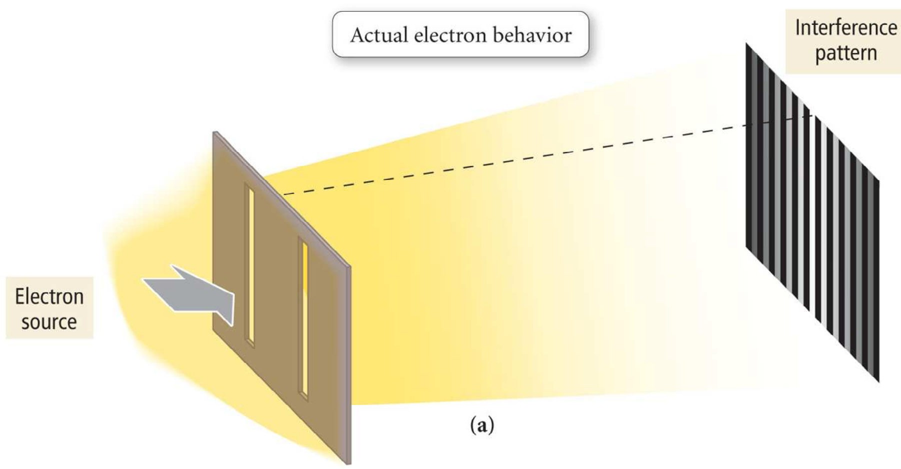


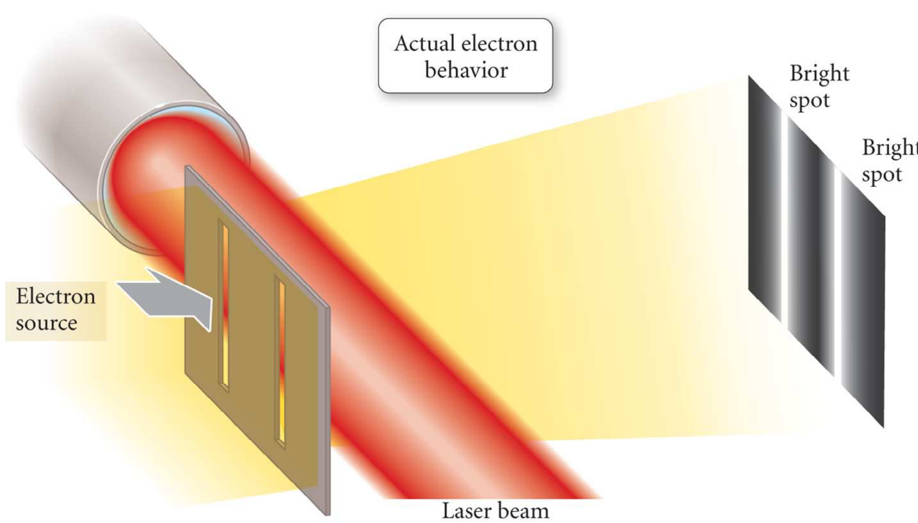
Bohr's hydrogen atom model: (Niels Bohr, ~ 1910)

- Electrons in the H atom can occupy only certain energy levels, and the energy of the electron determines which energy level it occupies.
- If an electron is promoted to a higher energy level, it must absorb energy
- If an electron drops to a lower energy level, it gives off energy
- The amount of energy transferred = the energy difference between the levels

The wave-particle duality for electrons







The wave and particle natures of the electron are **complimentary** properties - the more you know about one, the less you know about the other

Heisenberg uncertainty principle:

- Position of an electron: particle nature
- Momentum of an electron: wave nature
- It's impossible to know both precisely at any one time

$$(\Delta x) \cdot (m\Delta v) \geq \frac{h}{4\pi}$$

But, quantum mechanics allows us to calculate the **probability** of an electron behaving a certain way:

Wavefunction (ψ): mathematical equation that describes the wavelike properties of an electron

Quantum numbers: 4 variables in the wavefunction that, combined, describe a single electron

Orbital: a solution to a wavefunction with a certain combination of quantum numbers -
a 3-dimensional volume inside of which an electron is likely to be found

Principal quantum number, *n*

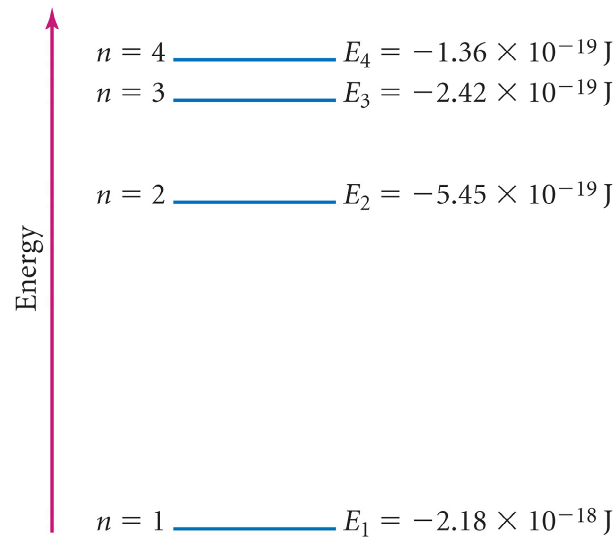
Principal quantum number, *n*: determines overall size and energy of an orbital.

$n = 1, 2, 3, \ldots$

Energy of an electron **in a hydrogen atom** depends only on *n*:

$$E = -2.18 \times 10^{-18}\ \text{J} \cdot \frac{1}{n^2}$$

$$\Delta E = E_{final} - E_{initial}$$



$$E_{photon} = -\Delta E_{electron}$$

Calculate the energy and wavelength (in nm) of a photon emitted when an electron in a hydrogen atom makes a transition from an orbital in $n = 3$ *to* $n = 2$.

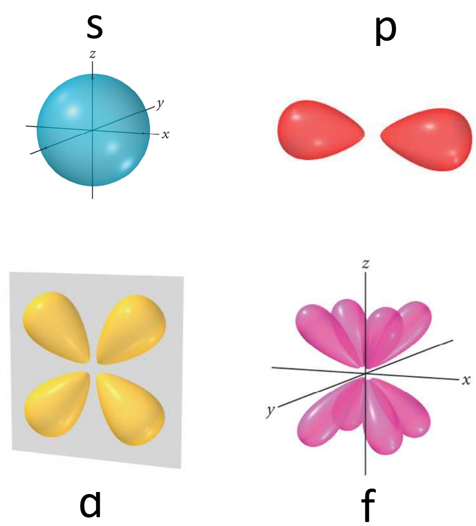
$h = 6.626 \times 10^{24}$ J·s, $c = 3.00 \times 10^{8}$ m/s

Angular momentum quantum number, ℓ

<u>Angular momentum quantum number</u>, ℓ, determines the shape of the orbital.

Possible values of **ℓ =** 0, 1, 2, … (n - 1)

ℓ	letter	shape
0	s	spherical
1	p	2 lobes
2	d	clover
3	f	complex



n and ℓ define **<u>subshells</u>**:

n	ℓ	subshell
1	0	1s
2	0	2s
2	1	2p

Magnetic quantum number, m_ℓ, defines the orientation of individual orbitals within a subshell

Possible values for m_ℓ: integers $-\ell$ to $+\ell$

n	ℓ	subshell	m_ℓ	number of orbitals
1	0	1s	0	1
2	0	2s	0	1
2	1	2p	-1, 0, 1	3
3				

subshell	# or orbitals
s	
p	
d	
f	

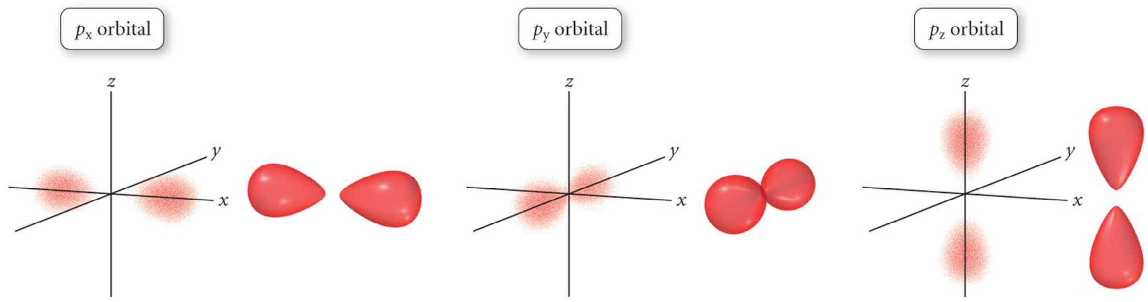
n, ℓ, and m_ℓ define an orbital

n:
ℓ:
m_ℓ:

Orbitals

Every s subshell has a single spherical orbital

Every p subshell has 3 dual-lobed orbitals:



Every d subshell has 5 orbitals: