Announcements for Wednesday, 18SEP2024

- Conflicts with Exam 1 on Tuesday, 01OCT2024, 7:45 – 9:05 PM
  - Due by **Friday, 20SEP2024, 11:59 PM (EDT)**
  - See Canvas Announcement from 16SEP2024 for more details
- Week 3 Homework Assignments available on Canvas/eLearning
  - **Readiness Assessment** is **re-opened; Final Deadline of Thursday, 19SEP2024, at 11:59 PM (EDT)**
  - *Metacognition* Digital Badge Assignment due **Friday, 20SEP2024, at 11:59 PM (EDT)**
- Teaching Intern (TI) Problem-Solving Sessions and Office Hours Begin This Week
  - Check "TIs' schedule" page on Canvas for more information
- Any **TECHNICAL ISSUES** associated with eLearning (quizzes, practice assignments, etc.) must be reported to **eLearning Tech Support** **(https://techsupport.elearning.rutgers.edu)**

ANY GENERAL QUESTIONS? Feel free to see me after class!

Try This On Your Own

What is the wavelength of electromagnetic radiation, in micrometers (μm), having a frequency of 105.5 MHz? (remember prefix "Mega" = 10^6)

2.842×10^6 μm

Mathematical description of the photoelectric effect

$$\overbrace{E_{photon}}^{\text{from the incoming photon's point-of-view}} = \overbrace{BE + KE}^{\text{from the ejected electron's point-of-view}}$$

E_{photon}: $h\nu$ or $\dfrac{hc}{\lambda}$

BE: *constant* for a particular metal

KE: e^- velocity increases as E_{photon} increases beyond BE

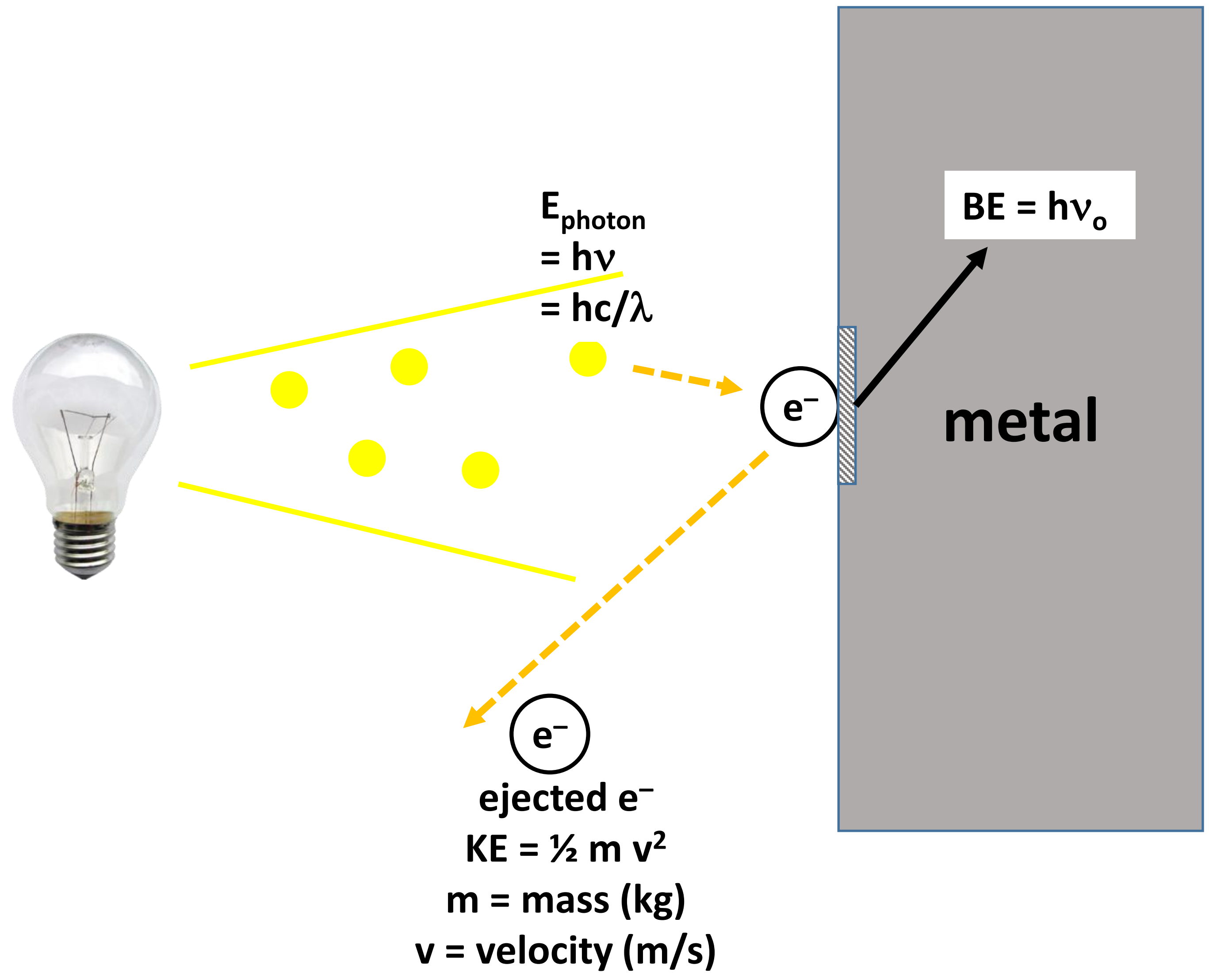
where :

$h = 6.626\times10^{-34}$ J·s

ν = **frequency** of light in Hz

λ = *wavelength* of light in m

$c = 2.998\times10^{8}$ m/s



Conservation of Energy!!

Important Energy Units – the Joule (J) & the electron-volt (eV)

The Joule is derived from the equation of energy

Energy (E) = Force × distance

= mass × acceleration × distance

$$1\ \mathrm{J} = \mathrm{kg} \times \frac{\mathrm{m}}{\mathrm{s}^2} \times \mathrm{m} = \frac{\mathrm{kg} \cdot \mathrm{m}^2}{\mathrm{s}^2}$$

the electron-volt (eV)

1 eV = 1.6022×10^{-19} J

Try This On Your Own

What is the total energy of 2 dozen photons having a wavelength = 523.4 nm?

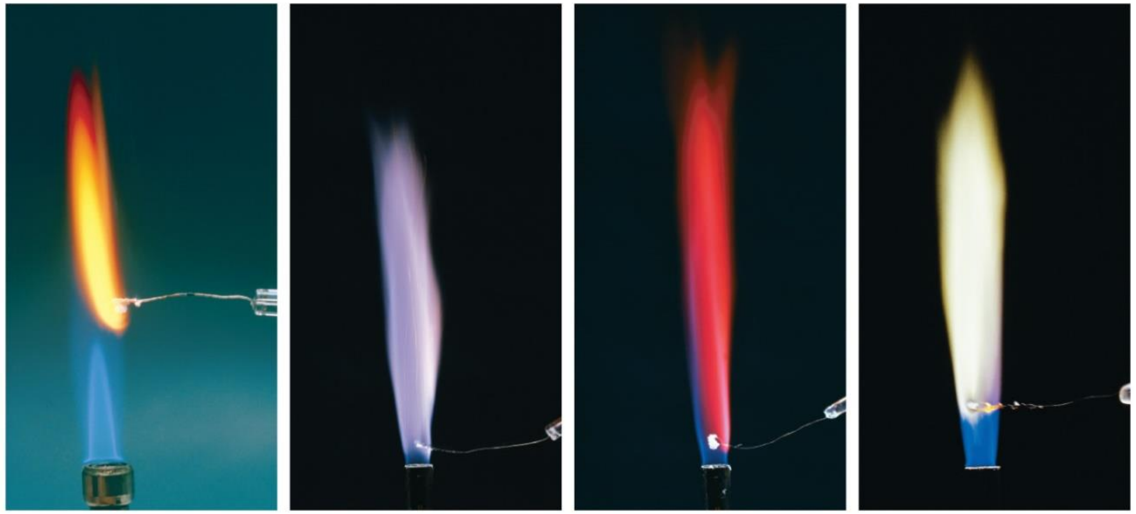
Try These On Your Own

- In 1.0 s, a certain lamp gives out 25 J of energy in the form of yellow light of wavelength 580. nm. How many photons of yellow light does the lamp generate in 1.0 s?
- What is the wavelength (nm) of light that has an energy content of 487 kJ/mol photons?
- The photoelectric effect for mercury is observed when the energy of the photon is not less than 7.25×10^{-19} J.
  - What is the maximum wavelength of light (nm) that causes the photoelectric effect in mercury?
- The threshold energy of lithium metal is 4.65×10^{-19} J. Upon irradiation, an electron is ejected from the surface of lithium with a kinetic energy of 2.00×10^{-19} J. Calculate the energy of light used to irradiate the lithium metal.

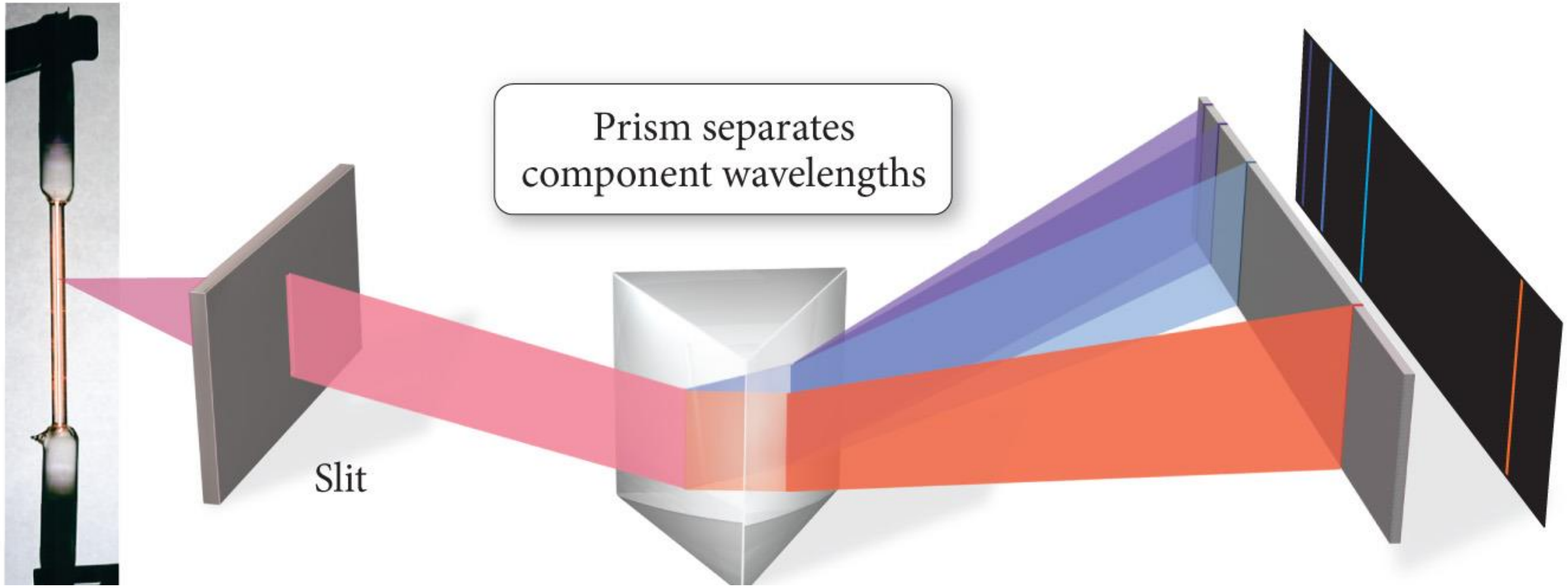
What Atoms Do When They Get Excited?

- When atom or molecules absorb energy (heat, light, electricity), the energy is usually re-emitted as light
  - example: heating a metal until it glows, neon signs, fireworks, etc.

- This is another phenomena that can be explained by the particle nature of light



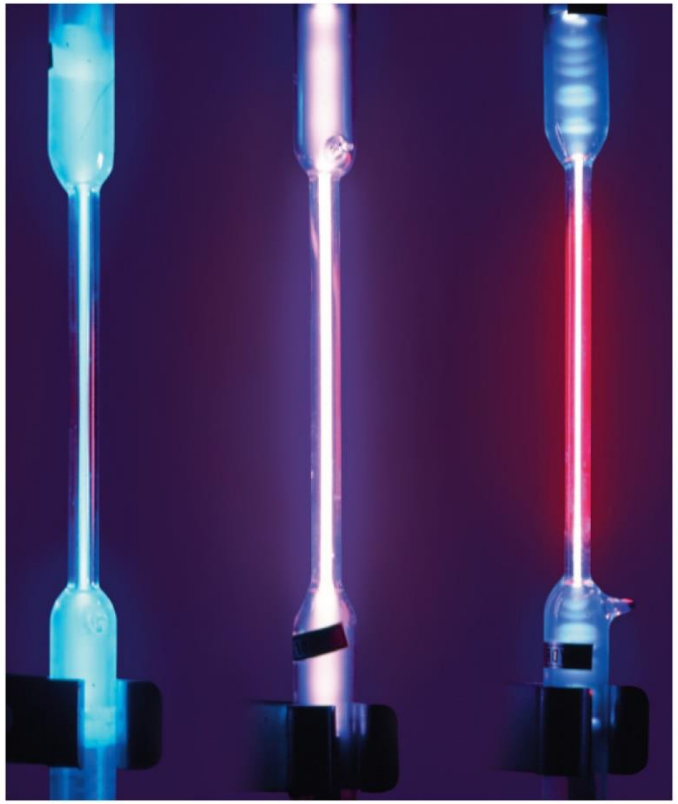
What is an emission spectra?



- light emitted by excited atoms can be separated by a prism into the different wavelengths present
  - the pattern of emitted wavelengths is unique and can be used to identify the atom/molecule
  - the pattern is called an ***emission spectrum***
- Different sources of light emit different types of spectra

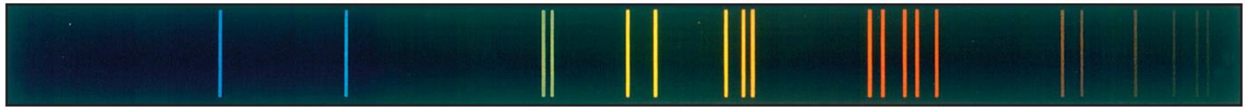
Line vs. Continuous Spectra

gas-discharge tubes



vs.

the sun



a line spectrum (non-continuous)

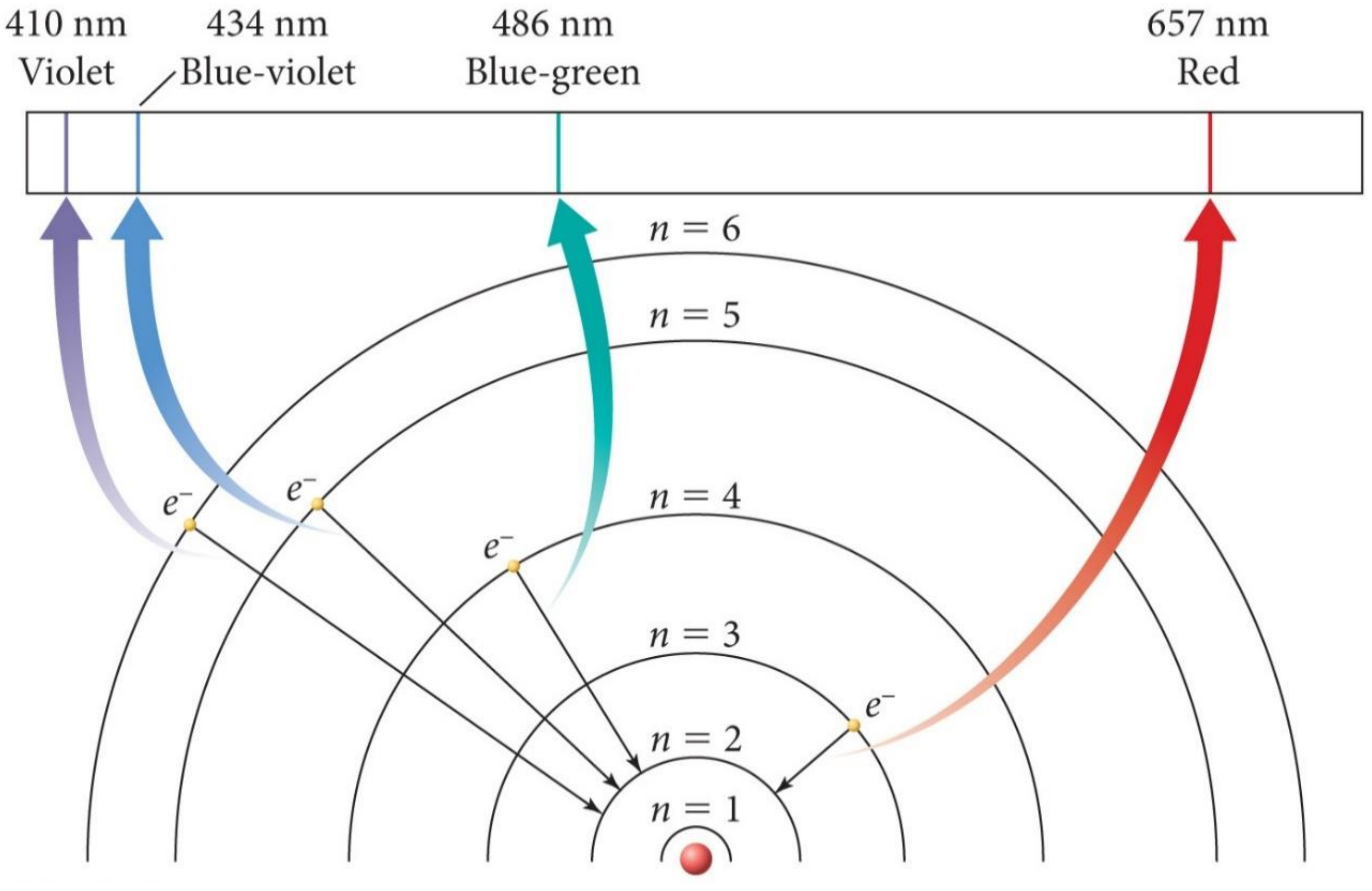
a white light spectrum (continuous)

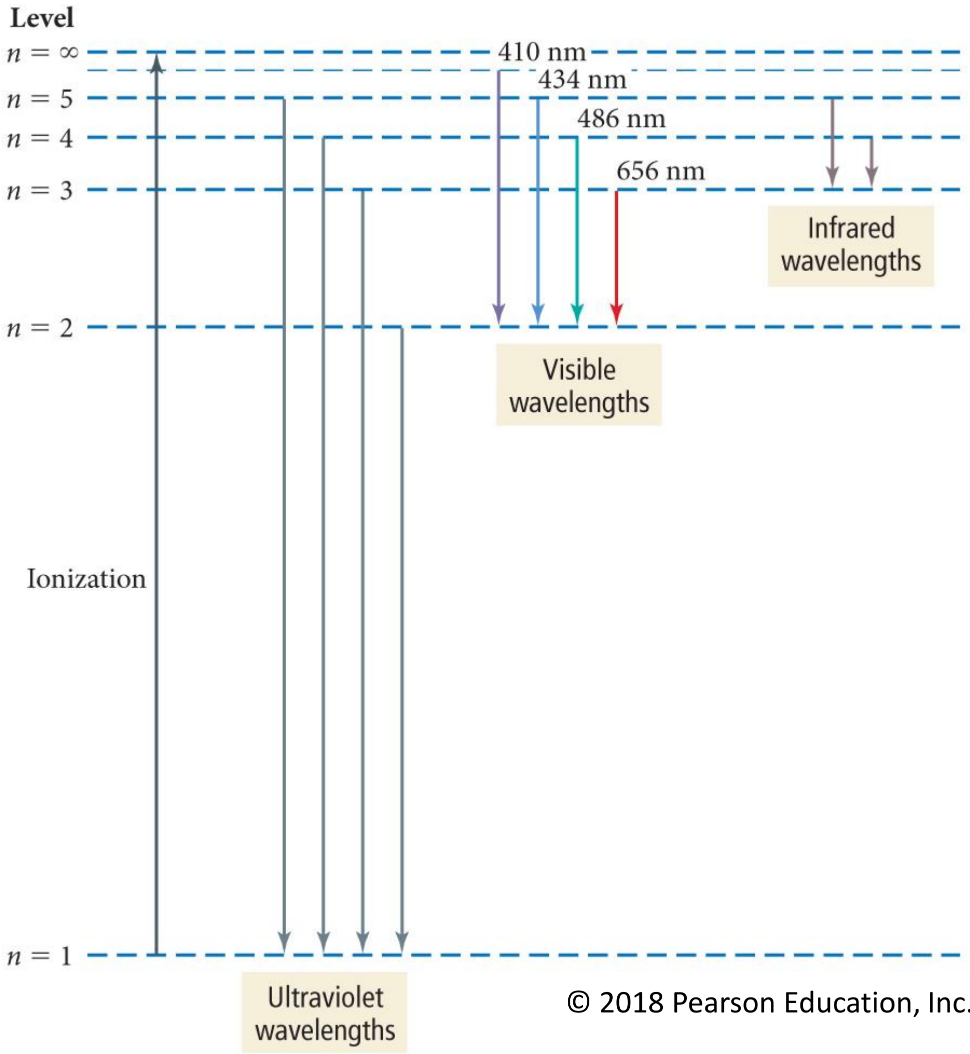
Line Spectrum of Hydrogen

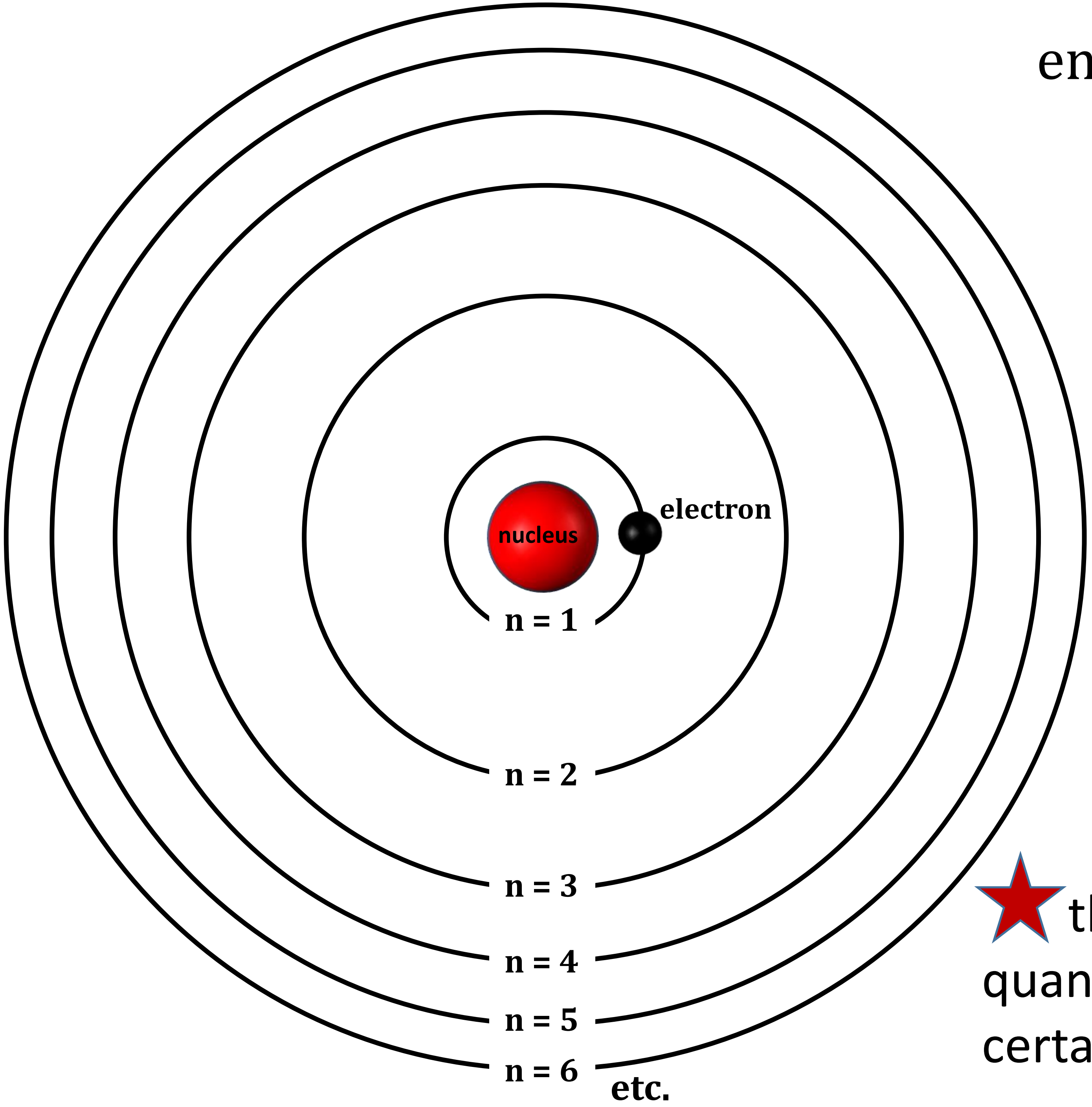
Why are only certain discrete wavelengths emitted?

the Bohr Model of the (Hydrogen) Atom

Niels Bohr expanded upon Rutherford's model of the atom to explain why hydrogen emits the specific line spectra that it does







energy of electron in energy level, n

$$E_n = -\frac{B}{n^2}$$

$B = 2.179 \times 10^{-18}$ J

n = 1, 2, 3, 4…

$\mathbf{E_1} = -\,2.179 \times 10^{-18}$ J **ground state**

$\mathbf{E_2} = -\,5.447 \times 10^{-19}$ J

$\mathbf{E_3} = -\,2.421 \times 10^{-19}$ J

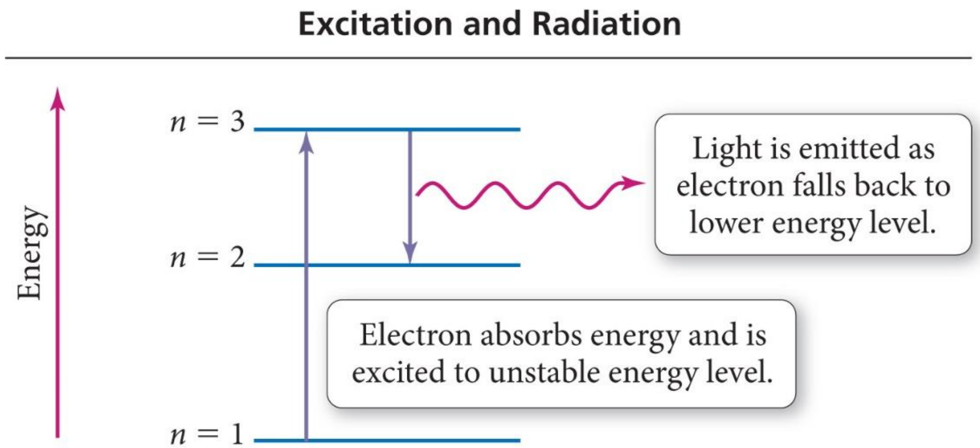
$\mathbf{E_4} = -\,1.362 \times 10^{-19}$ J

etc.

excited states

★ the energy of the electron is quantized and can only occur in certain ***discrete*** amounts

Electron Transitions in the Hydrogen Atom



- recall that energy levels designated by values of n
  - n = 1, 2, 3…
- the energy of an electron in an energy level is given by
  - $E_n = -2.179\text{x}10^{-18}\text{J}\left(\frac{1}{n^2}\right)\ (n = 1, 2, 3 \ldots)$
- the energy difference between two energy levels (ΔE)
  - $\Delta E = E_{final} - E_{initial}$
  - $\Delta E = -2.179\text{x}10^{-18}\text{J}\left(\frac{1}{n_f^{\,2}} - \frac{1}{n_i^{\,2}}\right)$
  - ΔE also equals the energy of the photon associated with the electron transition
  - $\Delta E = E_{photon} = h\nu = hc/\lambda$

- When **ΔE (+), photon/energy ABSORBED** by the atom and electron goes from a low energy level to a higher energy level

- When **ΔE (−), photon/energy RELEASED** by the atom and electron goes from a high energy level to a lower energy level
  - Not only visible light is emitted; so is UV and infrared

Try This On Your Own

The electron in the hydrogen atom undergoes a transition from n = 4 to n = 2. Determine the wavelength of the photon (nm) associated with this transition and determine if the photon is absorbed or released.

The Wave Nature of Matter

- We see that light, which usually acts as a wave, can behave as a particle under certain circumstances (i.e., wave-particle duality)
- What about the opposite? Can particles behave as waves?!?
- Louis de Broglie investigated this question in 1924 and came up with a mathematical relationship for the wave nature of particles

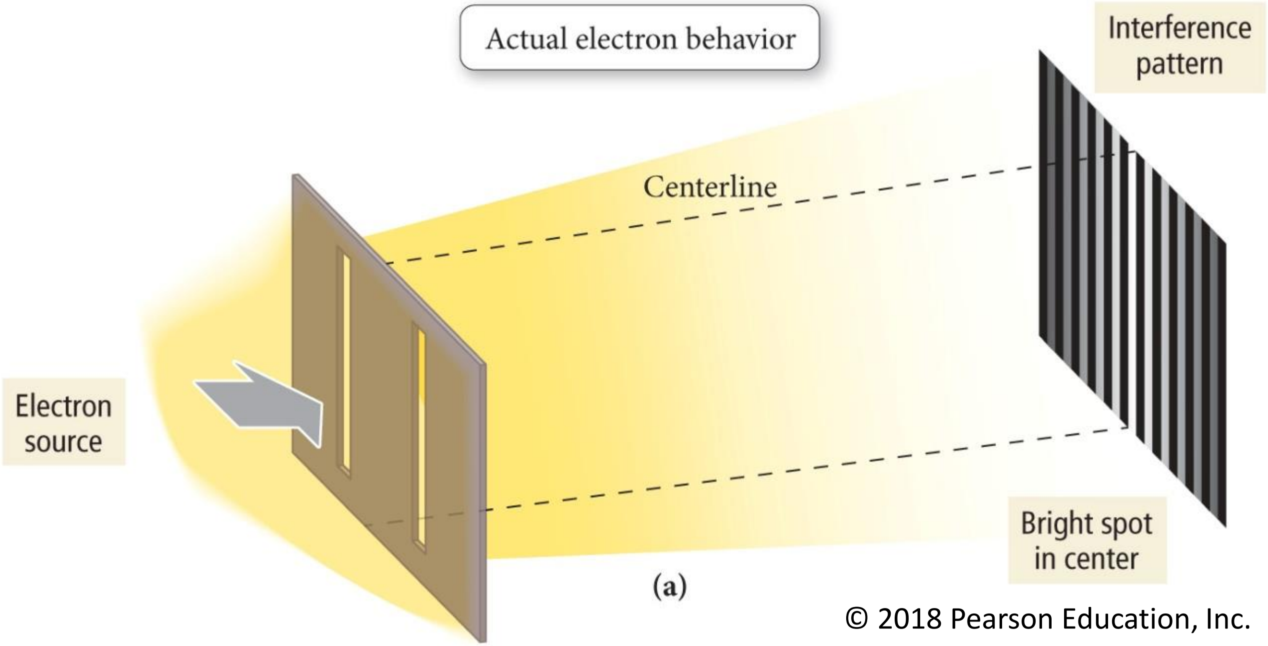
$$\lambda = \frac{h}{m\mathrm{v}}$$

$$\begin{gathered} \textit{where } \lambda = \textit{de Broglie wavelength} \\ m = \textit{mass of particle} \left(\boldsymbol{in\ kg}!\ \ \textit{Why kg}?\right) \\ \mathrm{v} = \textit{speed of the particle } (\textit{in } m/s) \\ h = 6.626x10^{-34} J \cdot s \end{gathered}$$

- It took until 1927 for the wave nature of particles to be experimentally observed.

(1927) Experimental Proof of the Wave Nature of Electrons

- The double-slit experiment was performed using a beam of electrons



- an INTERFERENCE PATTERN WAS FORMED!!
  - an interference pattern with the double-slit experiment can only be explained if the electrons were acting as waves NOT PARTICLES
- Conclusion: particles have wave properties and have a wave-particle duality just like light!

So, why don't we experience the wave nature of particles in the macroscopic world?

- For example, a baseball thrown at 95 miles/hr
  - look at the mathematical relationship $\lambda = \dfrac{h}{mv}$

Compare the wavelength of an **electron** moving at 10.0% the speed of light (3.00×10^{7} m/s) with a **baseball** moving at 95 mi/h (42 m/s)

- mass of one electron = 9.109×10^{-31} kg, mass of one baseball = 0.145 kg

$$\lambda_{\text{electron}} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{(9.109\times10^{-31}\ \text{kg})(3.00\times10^{7}\ \text{m/s})}$$

$$\boldsymbol{\lambda_{\text{electron}} = 2.42\times10^{-11}\ \text{m}\ (0.0242\ \text{nm})}$$

$$\lambda_{\text{baseball}} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{(0.145\ \text{kg})(42\ \text{m/s})}$$

$$\boldsymbol{\lambda_{\text{baseball}} = 1.1\times10^{-34}\ \text{m}}$$

- because an electron is so small, the size of its wavelength is comparatively large and relatively significant
- the baseball's wavelength is much too small to be detectable

Heisenberg's Uncertainty Principle

- Another example of the weird world of quantum mechanics
- An electron exhibits both particle and wave properties
- But both properties CANNOT be observed at one time
  - one property can only be observed at the expense of the other
- the same goes for an electron's position and velocity
  - unlike our everyday experiences, you cannot know both the position and velocity of a particle at the quantum level
  - if you know the position of a particle with high certainty, you know almost nothing about its velocity and vice versa
- **you cannot predict the future locations of particles with certainty**
  - **the best you can do is give the probability of future events**

$$\boldsymbol{\Delta x \times m\Delta \mathrm{v} \geq \frac{h}{4\pi}} \ \ where$$

$$\Delta x = uncertainty\ in\ position\ and\ \Delta \mathrm{v} = uncertainty\ in\ velocity$$