Chapter 5

Electrons in Atoms

Warm - Up

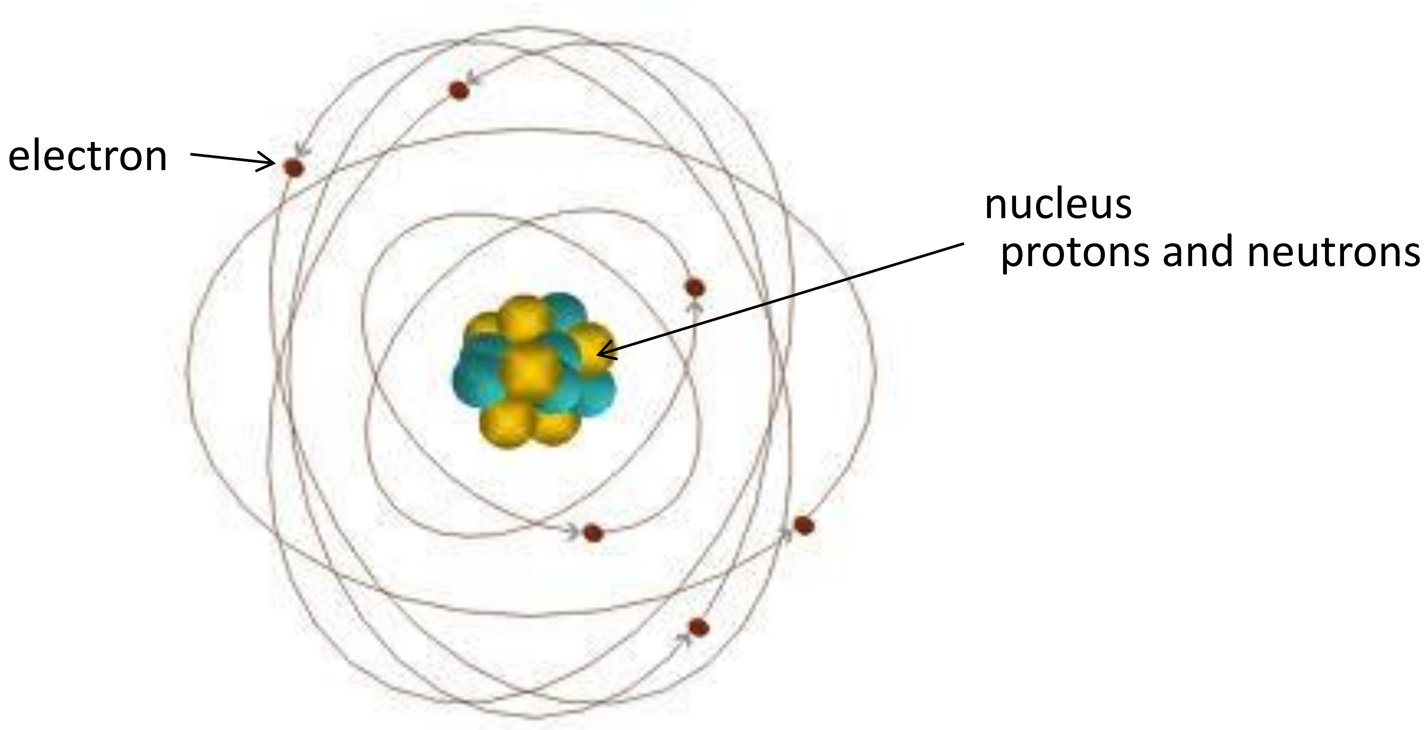
- What kind of light causes you to sunburn?
- Is that the only light that the sun emits?
- What does sunscreen do on a chemical level?

Today’s Agenda

- Question of the day: What is a wave and how does light have wave behavior?

- Compare the wave and particle natures of light.
- Understand and utilize electromagnetic wave relationships.
- Contrast continuous electromagnetic spectra and atomic emission spectra.

Development of Atomic Structure



Certain elements **emit** light when heated. Why?

Li, Na, and K all react violently with water. Why?

Chemical behavior dictated by the **electrons**.

Energy "Waves"

- Electromagnetic radiation –

  A form of energy exhibiting wavelike behavior as it travels through space.

- examples: microwaves, X rays

and radio waves

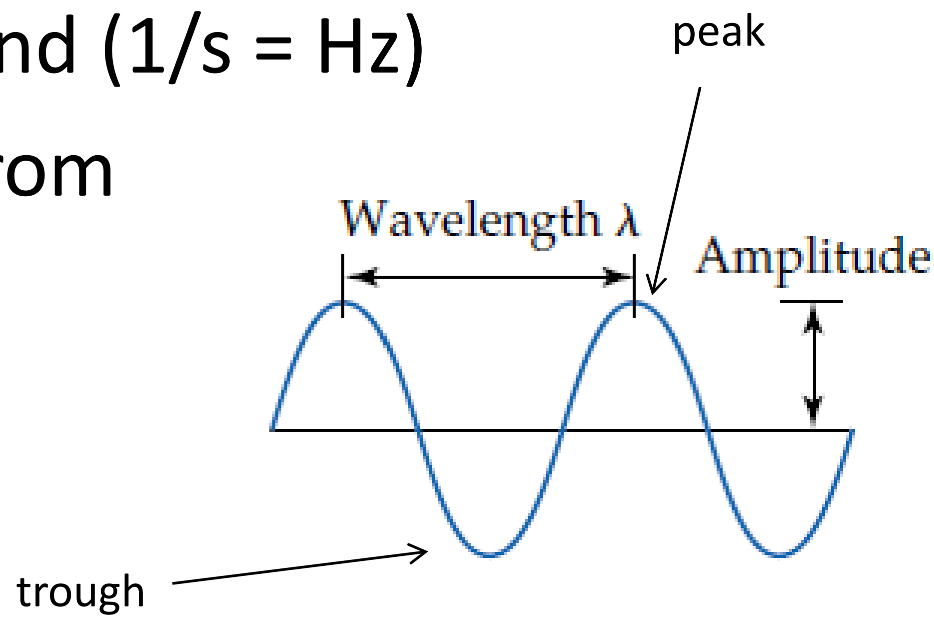
Parts of a Wave

- **Wavelength** (λ) shortest distance between to peaks (or troughs) on a wave.
  – Expressed in nm (1×10^9 nm = 1 m)
- **Frequency** (ν) number of waves that

pass a given point/second (1/s = Hz)

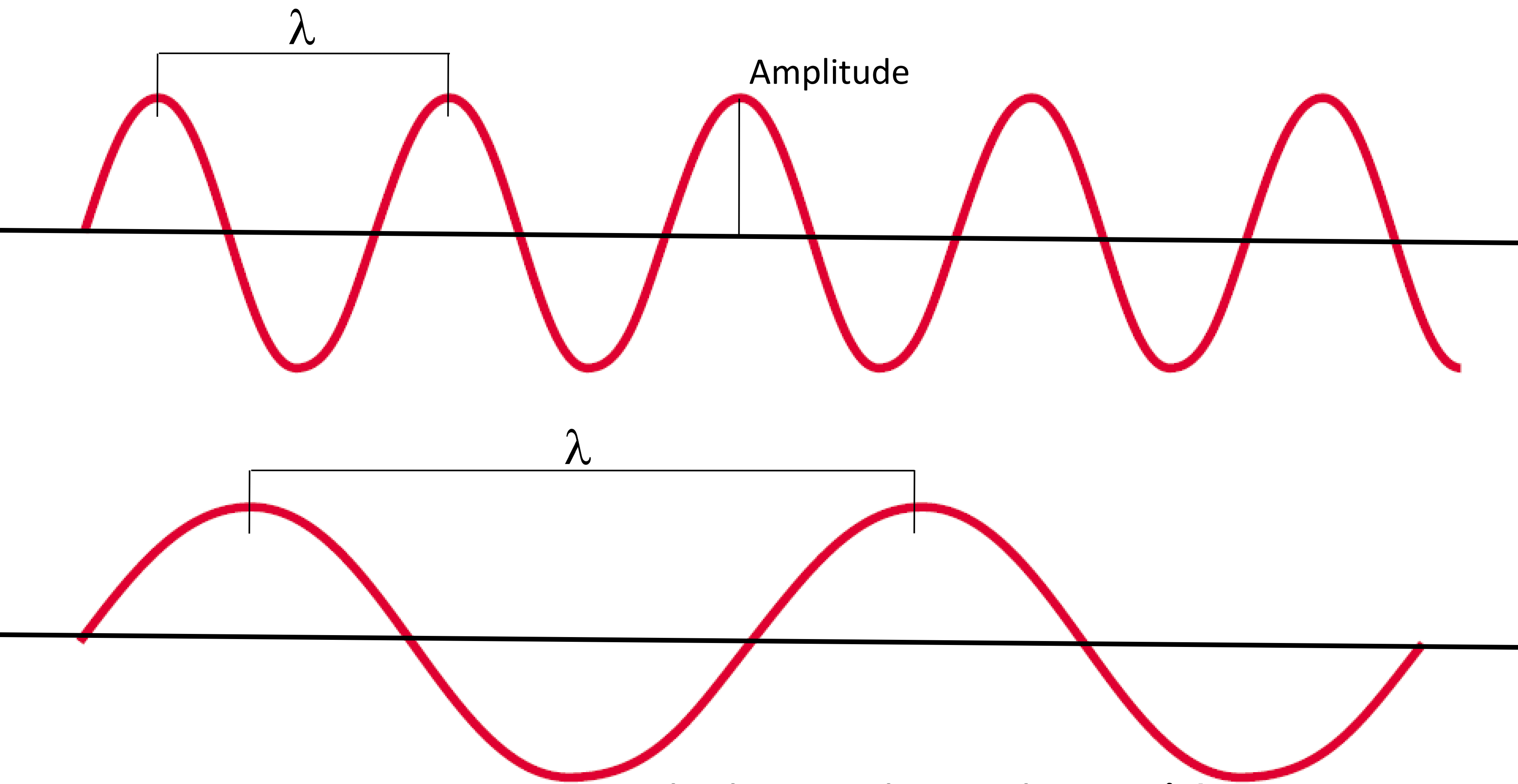
- **Amplitude** – height from

origin.



(a) Two complete cycles of wavelength λ

Parts of a Wave



Which wave has a shorter λ?
Which wave has a higher frequency?

What's nu (ν)?

- If wavelength is short, is frequency high or low?
- λ and ν INVERSELY PROPORTIONAL - as λ decreases, ν increases
- Both related to the speed of light $c = 3x10^8$m/s

$$c = \lambda\nu$$

Pretend, $c = 10$, $\lambda = 5$, whats ν?
Now if $c = 10$, $\lambda = 2$, whats ν?

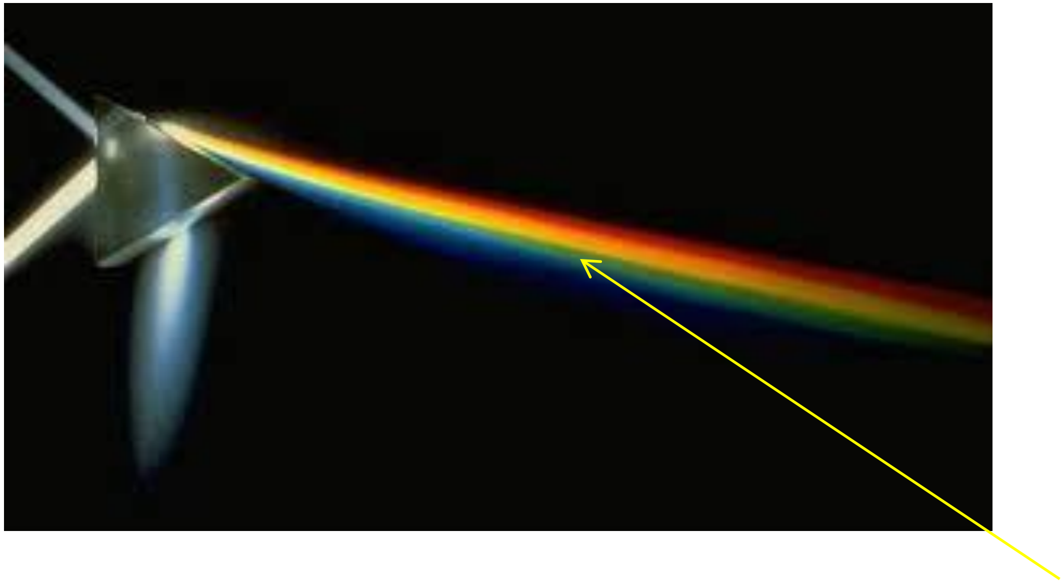
$$\frac{c}{\lambda} = \nu \qquad \frac{c}{\nu} = \lambda$$

Practice!

- What is the wavelength of a microwave that has a frequency of 1.56×10^9 Hz?
- The red-colored light in a fireworks display might be produced when Strontium salts are heated. What is the frequency of such red light with a wavelength of 650 nm?
- After careful analysis, an electromagnetic wave is found to have a frequency of 7.8×10^6 Hz. What is the speed of the wave?

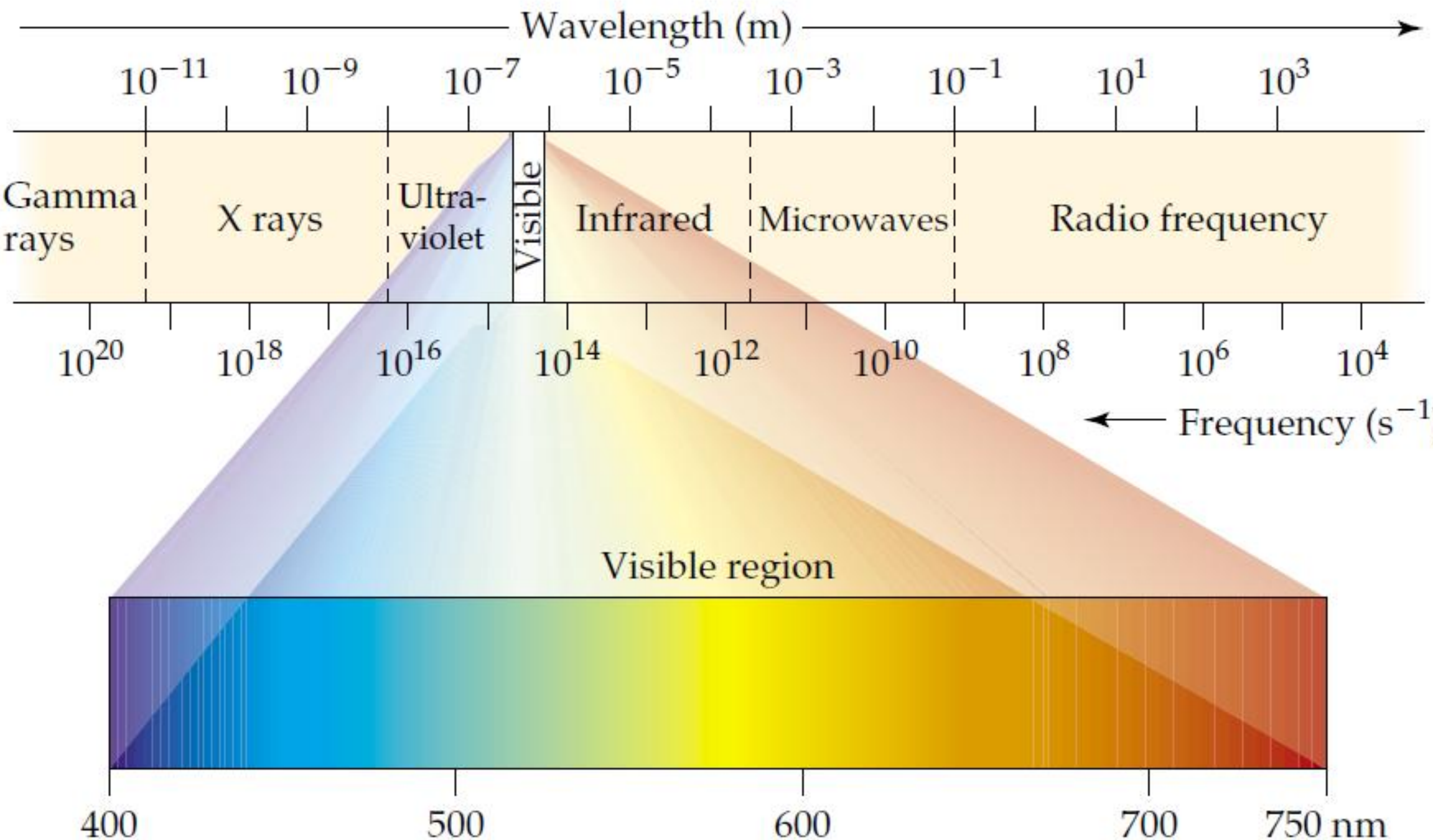
Continuous Spectrum

White light is separated into ALL of its visible components.



Continuous because each color corresponds to a unique wavelength and frequency.

Electromagnetic Spectrum



ROY G BIV

Energy of Waves

- We want to be able to understand the energy given off by these waves…
- Are they harmful to us? (too much energy)
- Can we use them for medicinal imaging?
- Technology?
- Transmission of information?

What is the relationship between λ, ν and Energy?!

Energy and Frequency

- Energy, $E = h\nu$
- h = Plank's constant = 6.626×10^{-34} Js

Named for Max Plank – German physicist.

- Whats J? Joule = $(kg \times m^2)/s^2$ unit of energy

How much energy is possessed by a single photon of UV-A electromagnetic radiation with a frequency 9.231×10^{14} Hz?

Calculations

- We know $c = \lambda\nu$ and $E = h\nu$
- Rearrange both equations to solve for ν

$$\nu = c/\lambda \qquad\qquad \nu = E/h$$

$$c/\lambda = E/h$$

$$E = hc/\lambda$$

- We can relate wavelength, energy, and frequency with those relationships!

Practice Problems

- A Zn salt emits orange light at a wavelength of 450 nm. What is the energy of this light?

- The energy of a wave is 1.24×10^{-18} J. What is the wavelength and frequency?

- The frequency of a radiowave is 300 kHz what is the energy and wavelength of this wave?

Warm Up!

- ν is the symbol for ________________
- λ is the symbol for ________________
- The value of c is always _________
- The value of h is always _________
- The unit for wavelength is ______
- The unit for frequency is _______ or ________
- $c = \lambda\nu$ describes light as a _________
- E = h___/____ and E = h______

What is the energy for a wave with a frequency of 3.24×10^{14} 1/s ?

Today's agenda

- Question of the day: What is the theory behind all those EM calculations?

- Quanta
- Photoelectric Effect and calcs

- Homework set Ch 5 due date TBD
- Complete Graphical Clock and Marble lab for Monday

Now to the theory…

- There is theoretical reasoning behind the math!

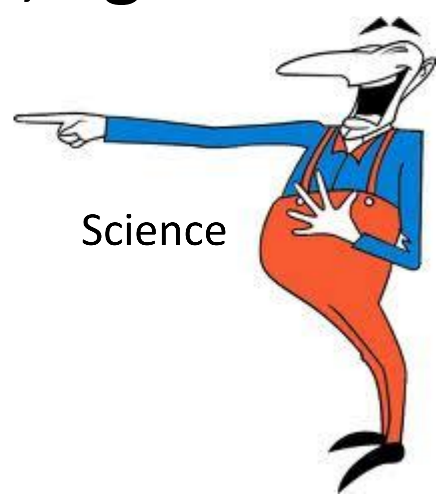
- Light energy can be separated out into a continuous spectrum. In the classical world the wave-like behavior makes sense!

Light as a Wave

- Light transfers energy through a wave with a specific frequency and wavelength.

$c = \nu\lambda$, $E = h\nu$, $E=hc/\lambda$

- HOWEVER, because science laughs at us for trying to figure out the universe, light doesn’t **ALWAYS** act like a wave…



Light as a PARTICLE

- Scientists noticed that some of the time, light acts more like a particle than a wave, and classical descriptions no longer work!

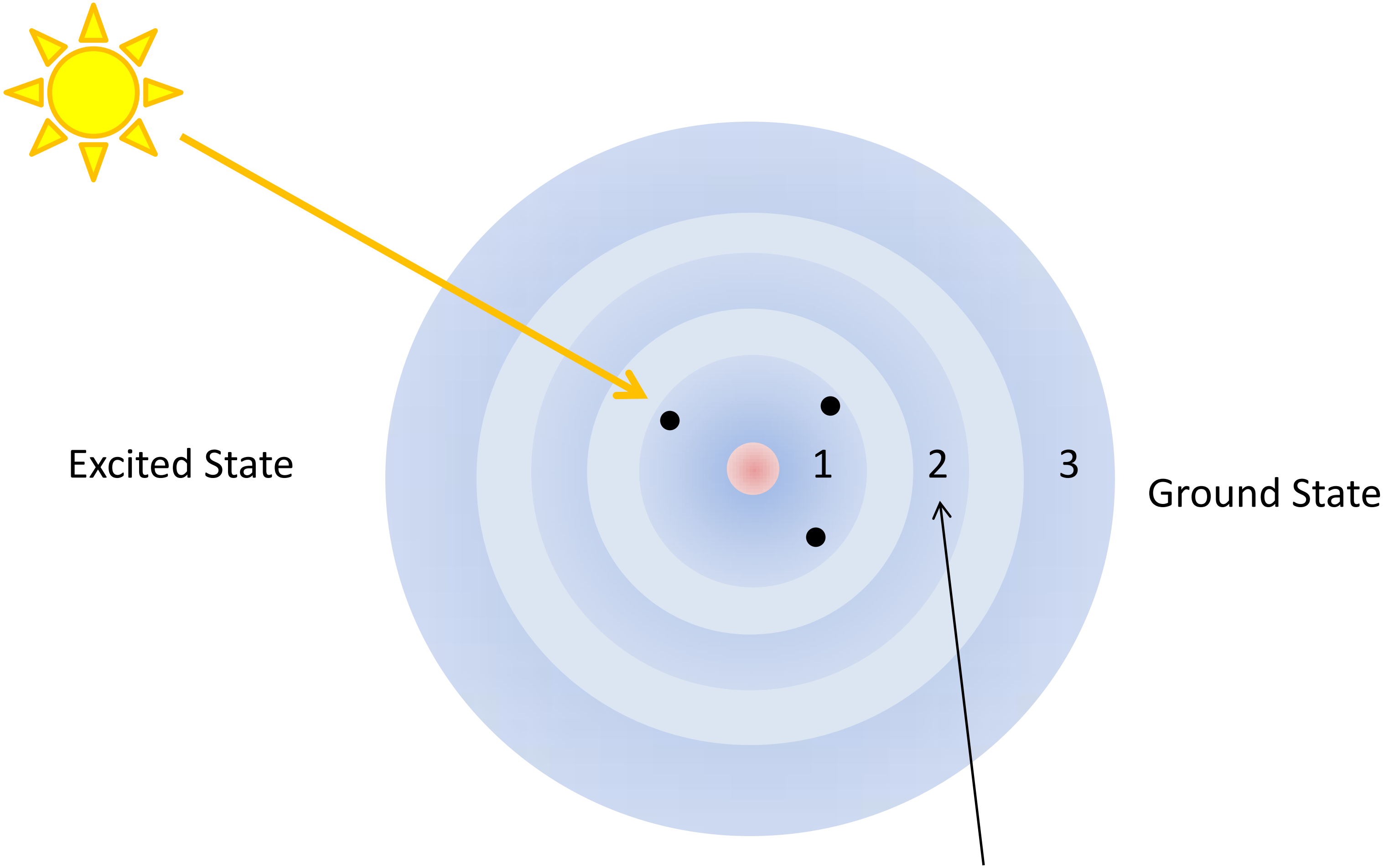
- Okay fine, but why doesn't an electron spiral into the nucleus??

- Max Plank - emitted energy cannot be any value it feels like, only discreet packages of energy (related to h).

Quantum Theory

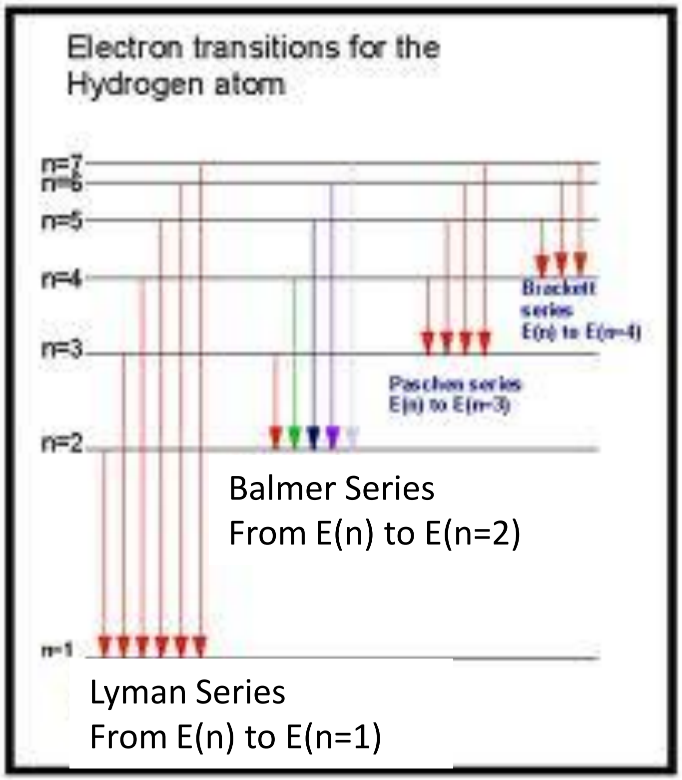
- **Quantum concept:** Matter can gain or lose energy in small specific amounts called **quanta.**
- **Quanta**: minimum amount of energy that can be gained or lost by an atom

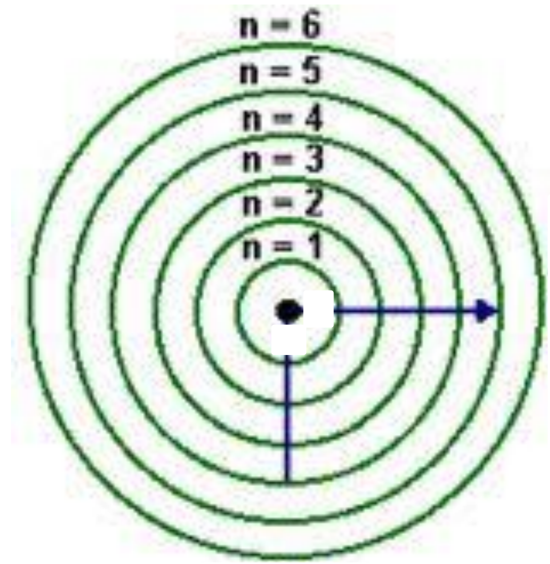
Bohr Model of the Atom



Principle Quantum Number :
How far is the e^- away from the nucleus?

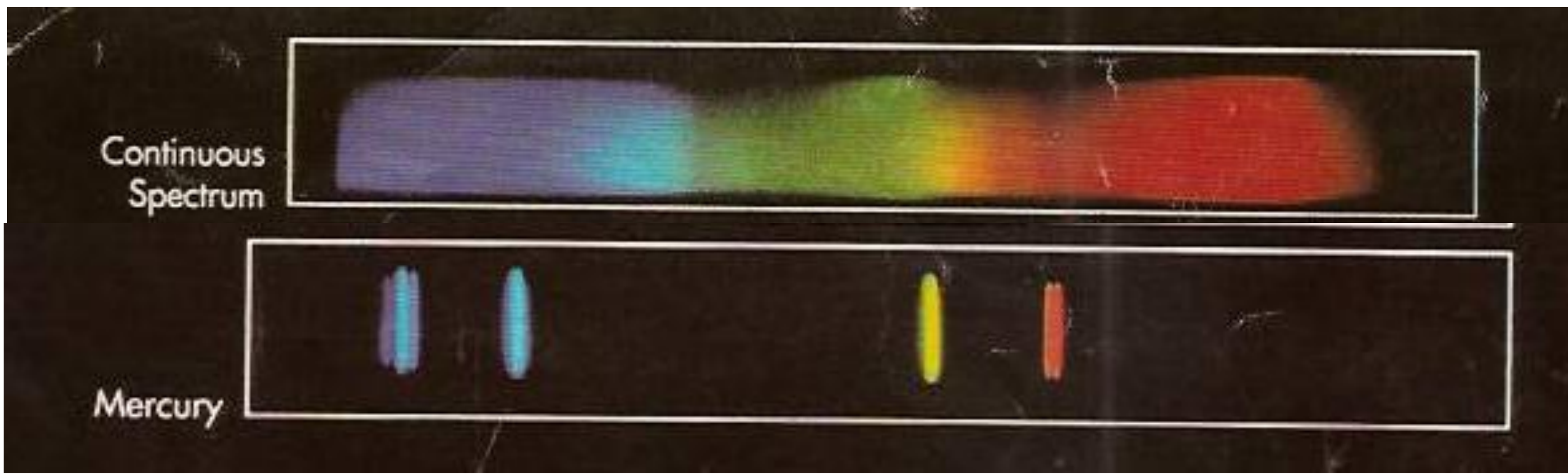
Different Colors from Different Transitions





Atomic Emission Spectra

- Each element's atomic emission spectrum is unique, and can be used to identify that element.



Atomic Emission Spectra

Atomic Emission Spectra – set of frequencies of waves given off by atoms of a specific element. Not continuous! Each element has it's own emission spectrum (because of energy steps).

- Neon signs!

Neon gas **absorbs** energy and

becomes **excited**. Electrons return to their stable state by **emitting** that energy as light!

Question:

- What is the difference between a continuous spectrum and an atomic emission spectrum?

A) Atomic emission gives off light, continuous does not.

B) Continuous spectra contain all λ's light and atomic emission have selected λ's of light.

C) A continuous spectrum requires a prism, atomic emission spectrum does not.

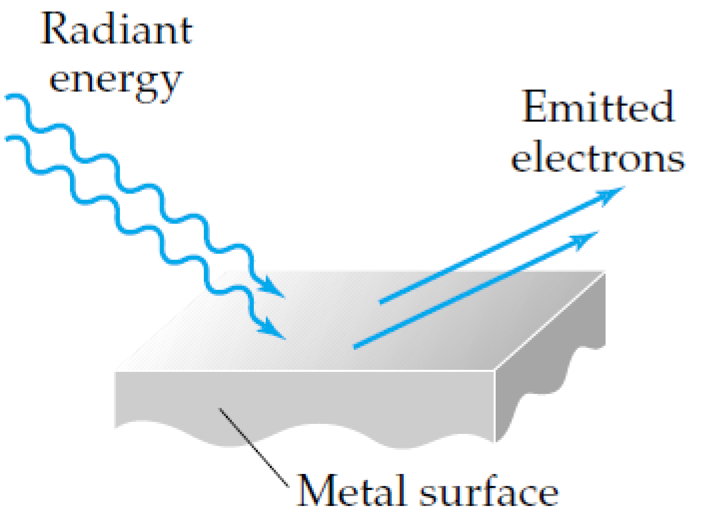
Bohr Model : FAIL

- Bohr model did not describe _more___ __complex____ atoms.
- Scientific data supports that electrons do not travel in _circular___ _orbits______.

- Quantum model : electron cloud where electrons can appear in different energy levels without travelling there. (it's like they apparate…)

Photoelectric Effect & Einstein

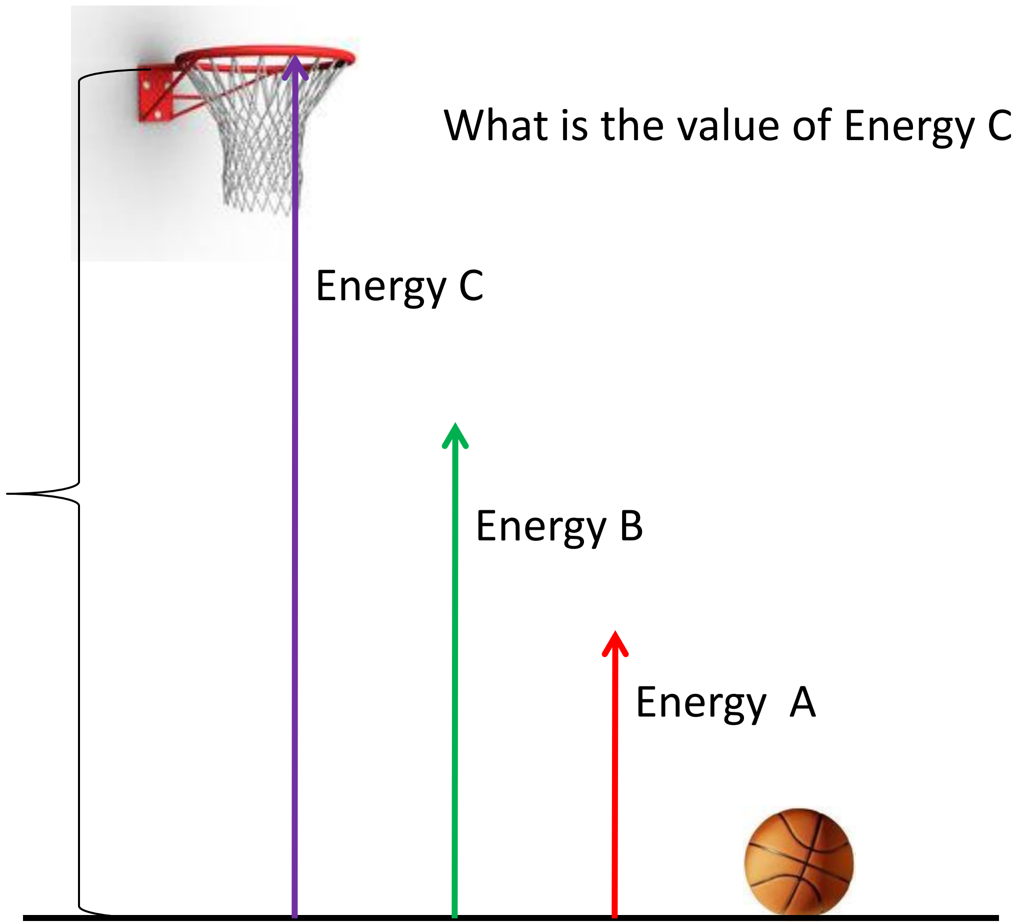
- Electrons (photoelectrons) are emitted from a metal's surface when a certain energy light shines on the surface.
- **Photon** is a massless particle that carries a quantum of energy.
- If light was a wave, energy and intensity of light would matter, but only E matters!



Photoelectric Effect in Practice

What is the value of Energy C?

Energy = 2.4×10^{-19} J



Building on PE Effect…

New Vocabulary and Notation:

Incident Beam – radiation that is used to eject an electron from a surface. (E_i, λ_i, ν_i)

Threshold energy, frequency, wavelength – the required radiation to eject an electron dictated by a surface. (E_t, λ_t, ν_t)

Kinetic energy (KE) – energy something possesses due to its motion ($\frac{1}{2} mv^2$).

Photoelectric Effect Problems

- Find the **energies** associated with each λ or ν. Use $c=\lambda\nu$ $E=h\nu$ or $E = hc/\lambda$
- Is the **incident energy** more than the **threshold energy**? If so, electron is ejected!
- If the electron is ejected, find it's kinetic energy! Use $E_{KE} = E_i - E_t$

Using the Photoelectric Effect

- A photon in the IR region of the electromagnetic spectrum has a wavelength of 7.23×10^{-9} m.

Will it have enough energy to eject a photon from a sodium surface which has a threshold frequency of sodium is 5.51×10^{14} Hz?

If so, what is the KE?

Solution (a table may help!)

- $E = hc/\lambda \rightarrow$

$$E_i = \frac{(6.626\text{x}10^{-34}\text{Js x } 3\text{x}10^{8}\text{m/s})}{7.23\text{x}10^{-9}\text{ m}} = 2.74 \text{ x } 10^{-17}\text{ J}$$

- $E = h\nu \rightarrow$

$E_t = 6.626\text{x}10^{-34}\text{Js x } 5.51\text{x } 10^{14} 1/\text{s} = 3.65 \text{ x } 10^{-19}\text{ J}$

- $KE = E_i - E_t$

$KE = 2.74 \text{ x } 10^{-17}\text{ J} - 3.65 \text{ x } 10^{-19}\text{ J} = 2.7 \text{ x } 10^{-17}\text{ J}$

Practice Problems

- You have an incident beam of light with a wavelength of 424 nm. This light is shone on a metal surface with a threshold frequency of 4.84×10^{12} Hz. Can we eject electrons? If so, what is their KE? YES! KE = 4.65×10^{-19} J

- An electron is ejected with 5.35×10^{-19} J of KE. If E_t of the surface is 9.24×10^{-20} J. What is the incident beams energy and wavelength?

$E_i = 6.27 \times 10^{-19}$ J $\lambda_i = 317$ nm

More PE Effect

- An incident beam of 702 nm is shone upon a metal surface with a threshold frequency of 1.23 x 1016 Hz. What is the KE of the ejected electron?
- The threshold frequency of a surface is 7.11 x 10^{14} Hz. Light of wavelength 287 nm is shone on the surface and an electron is ejected. If the mass of an electron is 9.11 x 10^{-31} kg, what is the velocity of the ejected electron?

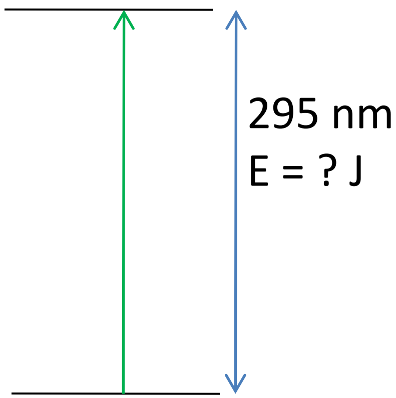
(Hint: Solve for KE first)

PE Effect Summary

- If you have trouble book keeping – make a table! Keep subscripts straight (E_i vs ν_t).
- You will have to convert from λ to ν to E. Know how to do this!
- Solving for KE is just a subtraction problem.
- Once you know KE you can find the velocity using the mass of an electron.

Remember that $E = h\nu$ & $E = hc/\lambda$

- Aluminum has a threshold wavelength of 295 nm. If a sample of aluminum foil is exposed to four types of radiation, which radiation source would eject a photon?
- Microwave? $\nu = 3.82 \times 10^{11}$ 1/s
- Optical wave? $\nu = 5.18 \times 10^{14}$ 1/s
- UV wave? $\nu = 1.02 \times 10^{15}$ 1/s
- X ray wave? $\nu = 4.31 \times 10^{16}$ 1/s



Solar Cells : PE Effect at work!

- The solar cell works in three steps:
- The photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
- Electrons are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.