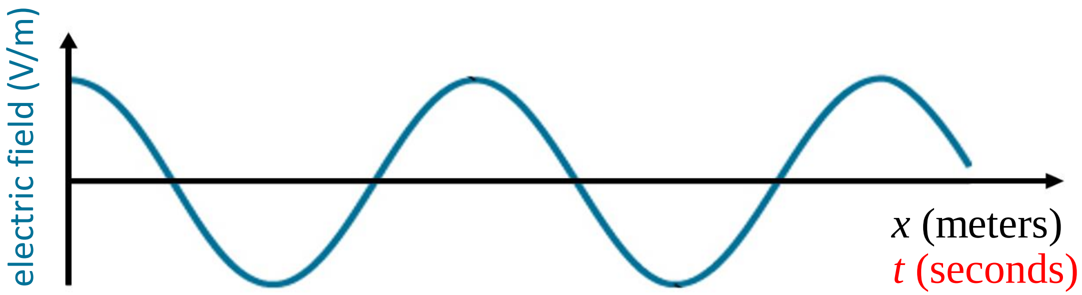
Today's Topics

Wednesday, September 18, 2019 (Week 3, lecture 9) – Chapter 5.

1. Light basics: EM waves & photons
2. Electronic structure of atoms
3. Spectroscopy
4. Doppler effect

EM Wave Basics



propagation

at speed **c**

magnetic field [Tesla]

$$= \frac{\text{electric field}}{c}$$

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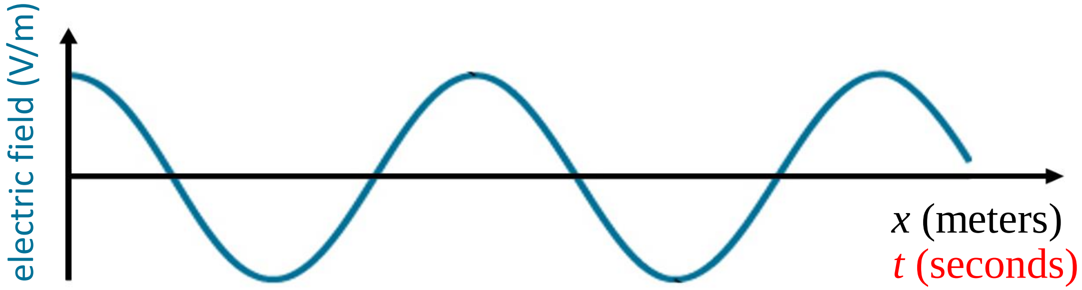

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"brightness" of light (not source)

E = electric field [V/m]

ε_0 = permittivity of vacuum
$= 8.85 \times 10^{-12}$ $C^2/(N{\cdot}m^2)$

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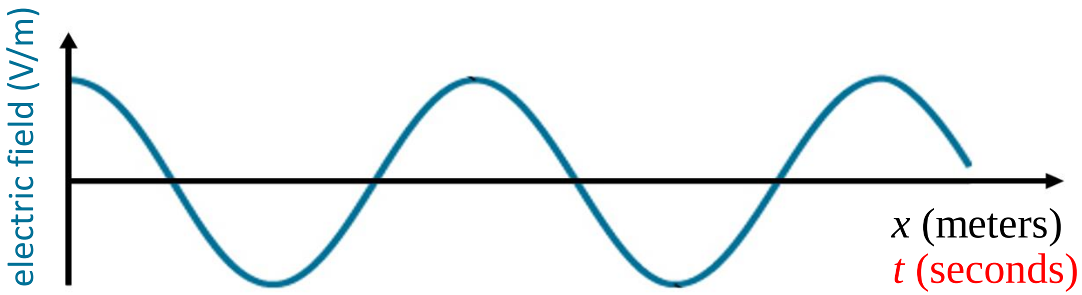

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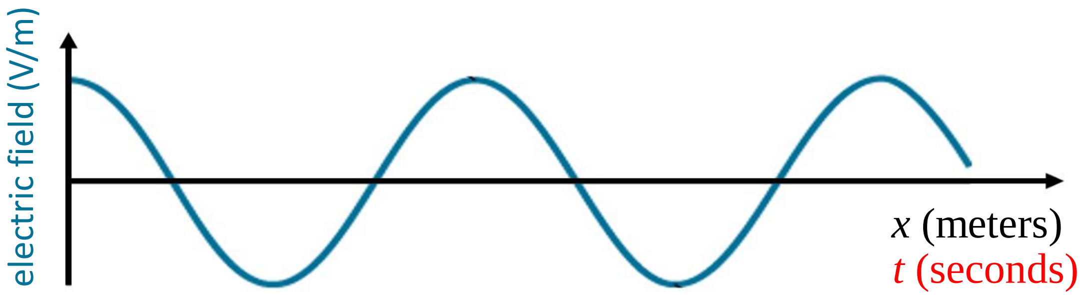

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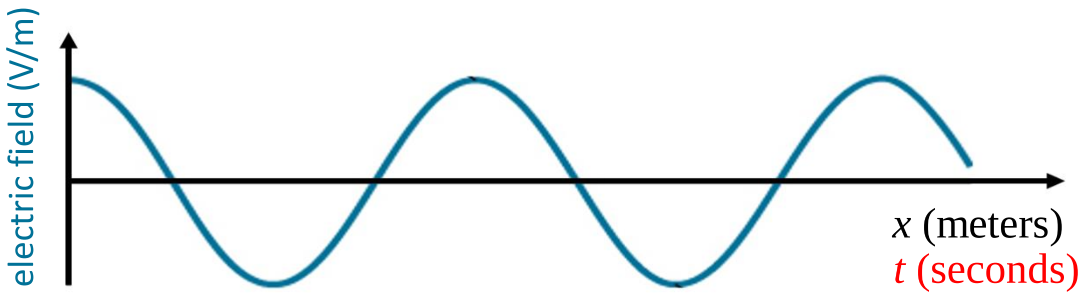

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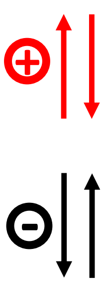
Answer: *oscillate charge (or accelerate it).*

→ generates "dipole radiation."



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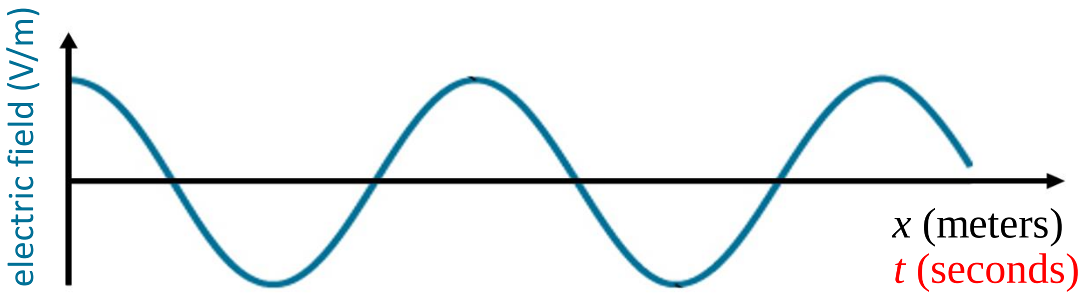

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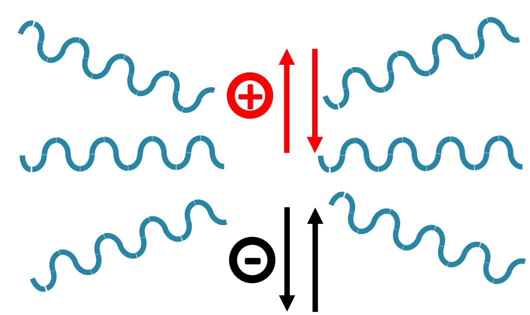
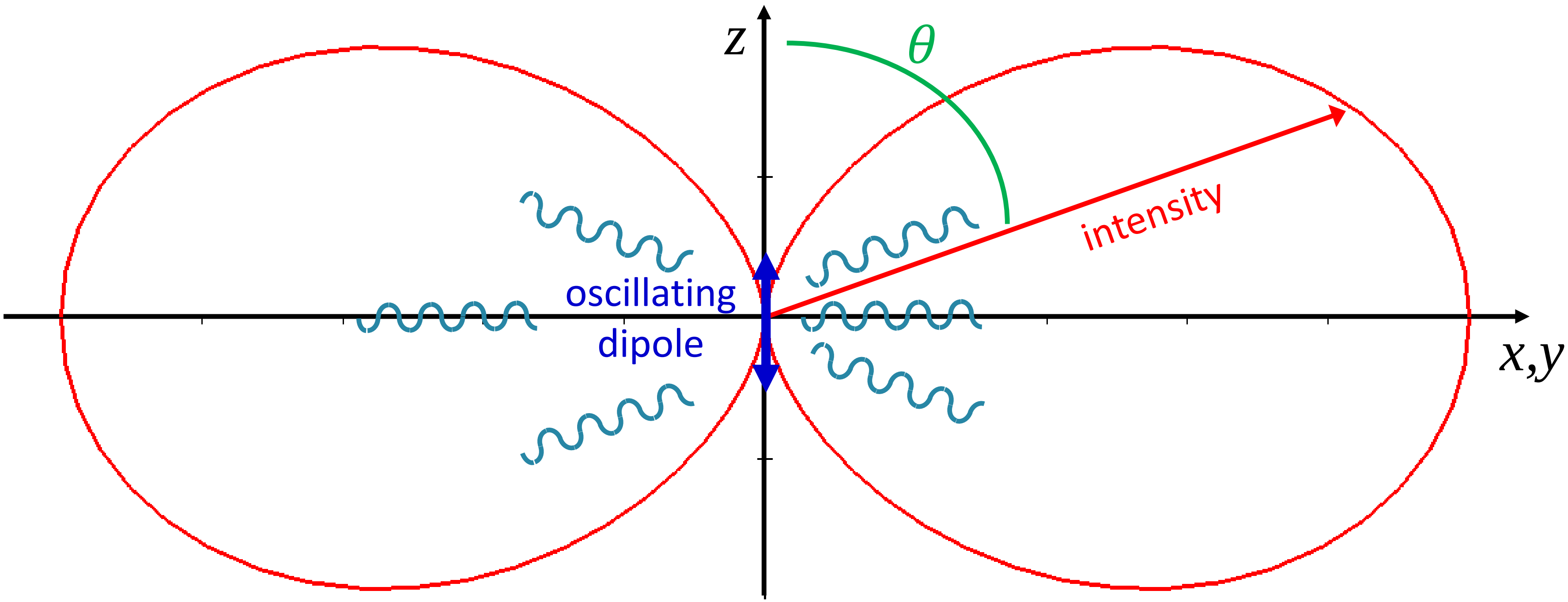


Dipole Radiation Pattern

dipole moment = p_0 = charge × separation



$$Intensity = \frac{\pi^2 p_0^2}{2\epsilon_0 c^3} \cdot f^4 \cdot \frac{\sin^2\theta}{r^2} \propto f^4 \frac{1}{r^2}$$

r = distance from dipole

f = frequency

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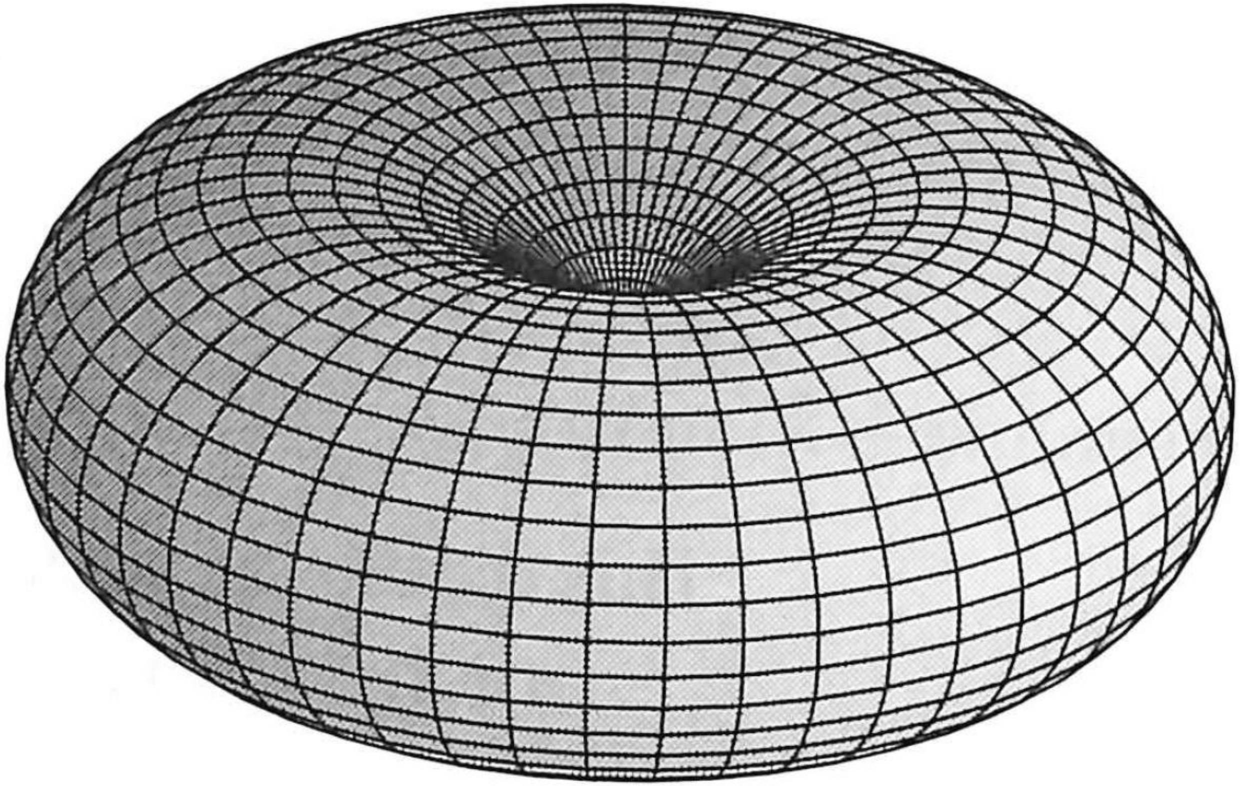

[Figure 11.4, *Introduction to Electrodynamics*, by D. Griffiths, 4th Ed.]

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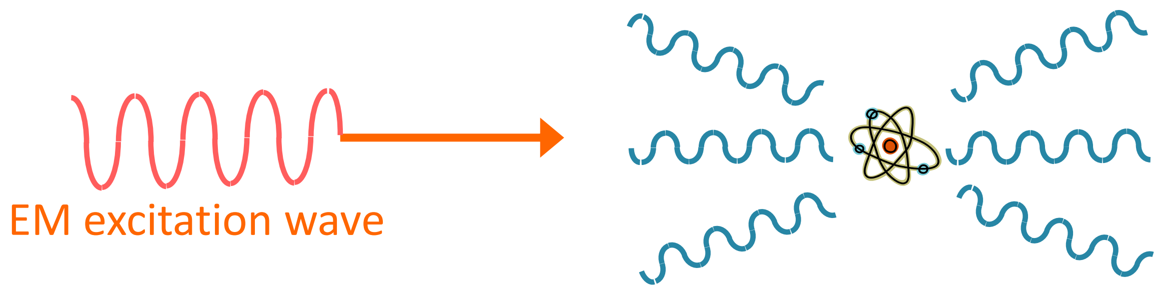
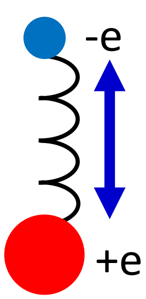
Dipole Radiation Example #1

Atomic fluorescence & photon scattering

Rayleigh scattering: an atom behaves like a perfect electric dipole when excited by an EM wave.





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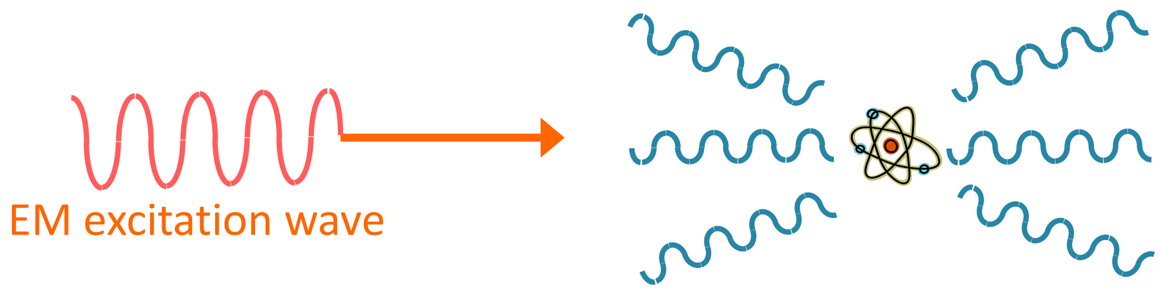
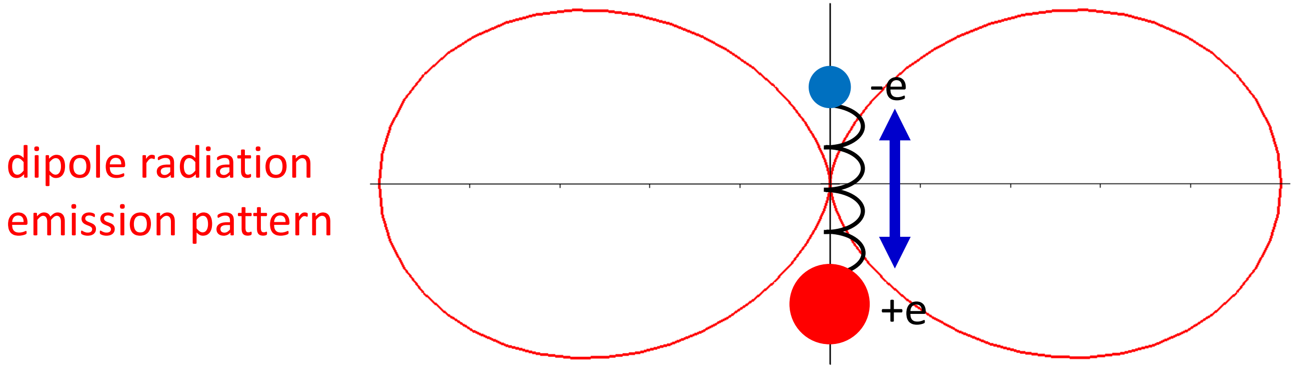
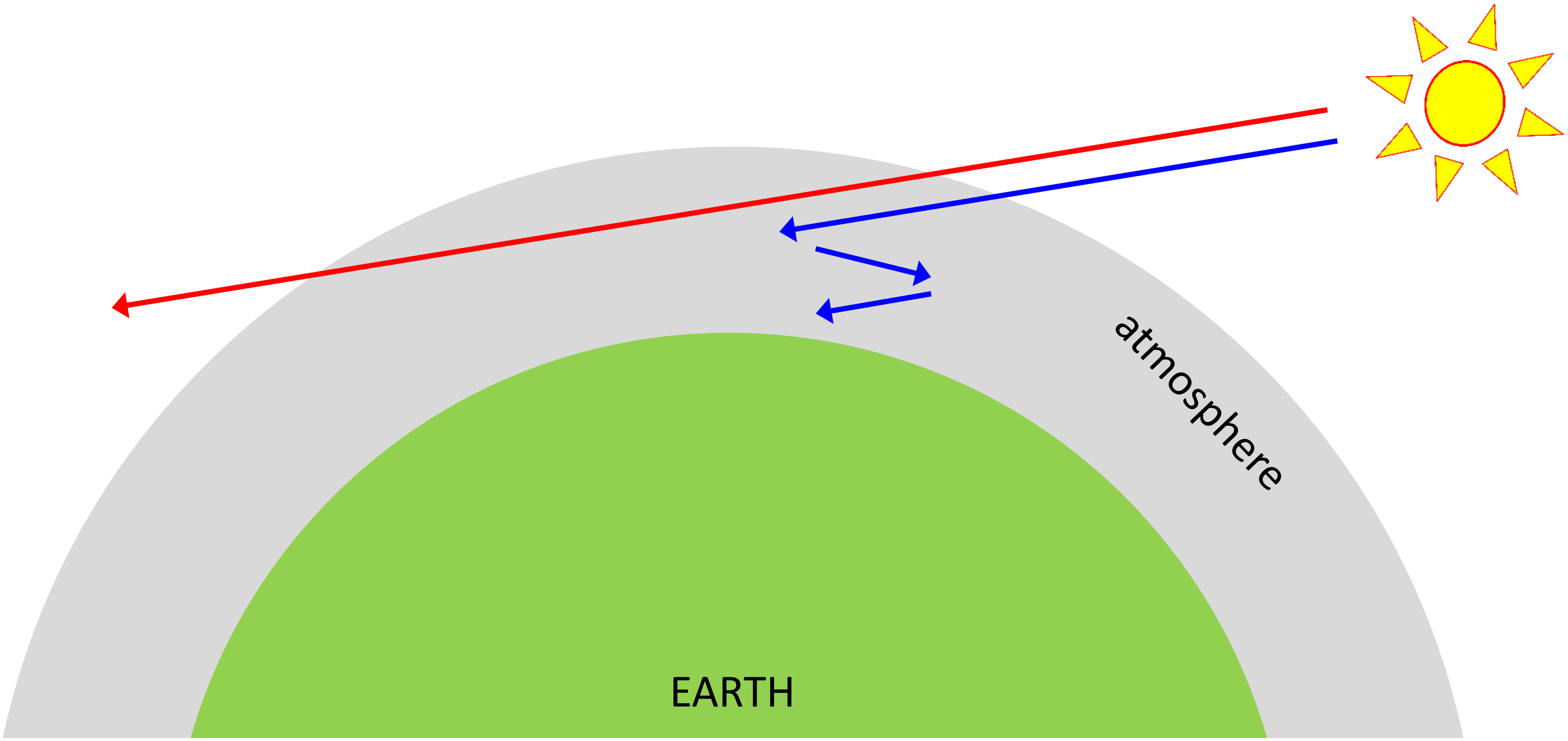




Dipole Radiation Example #2

Blue Sky

Blue light scatters at a higher rate than **red light** → Sky looks blue.



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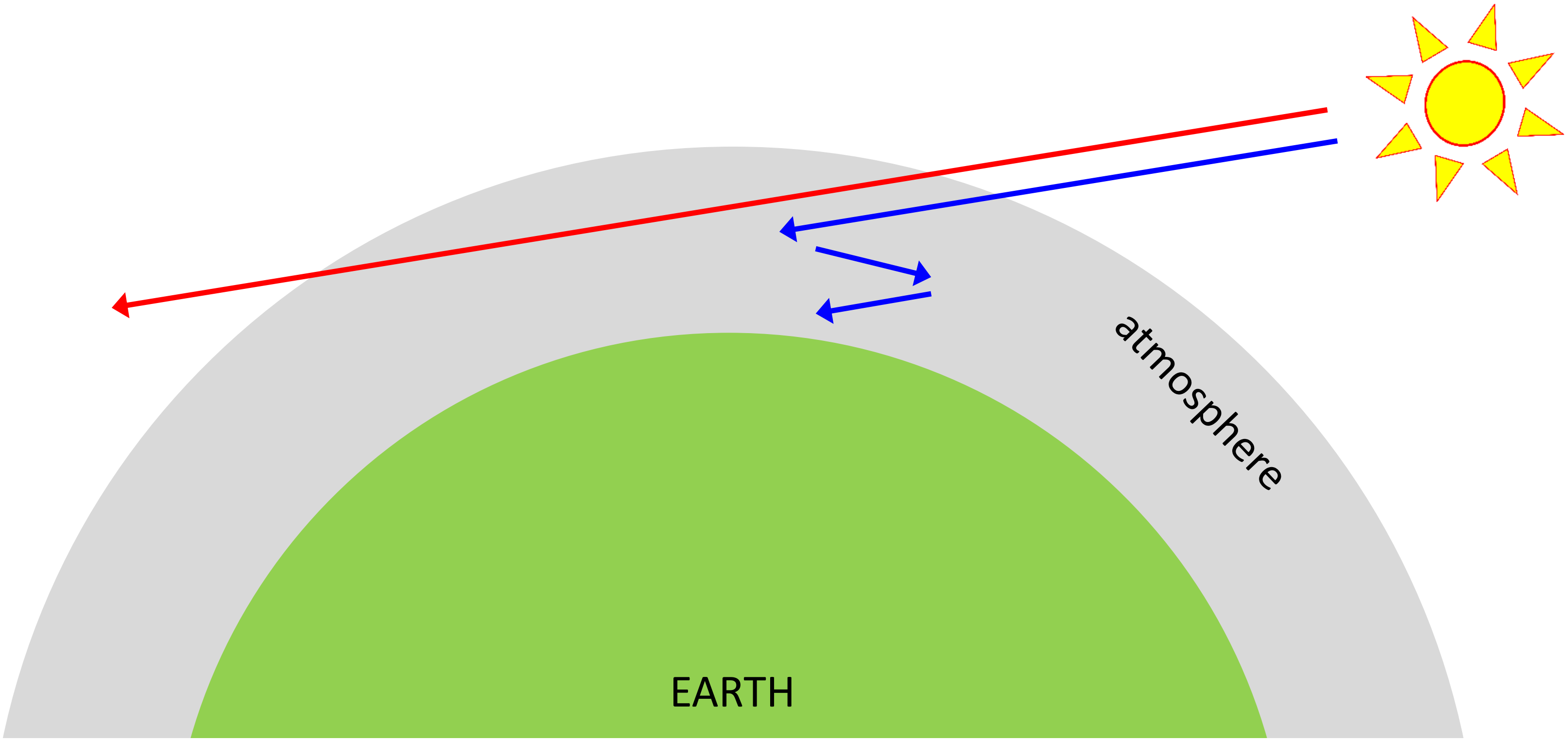

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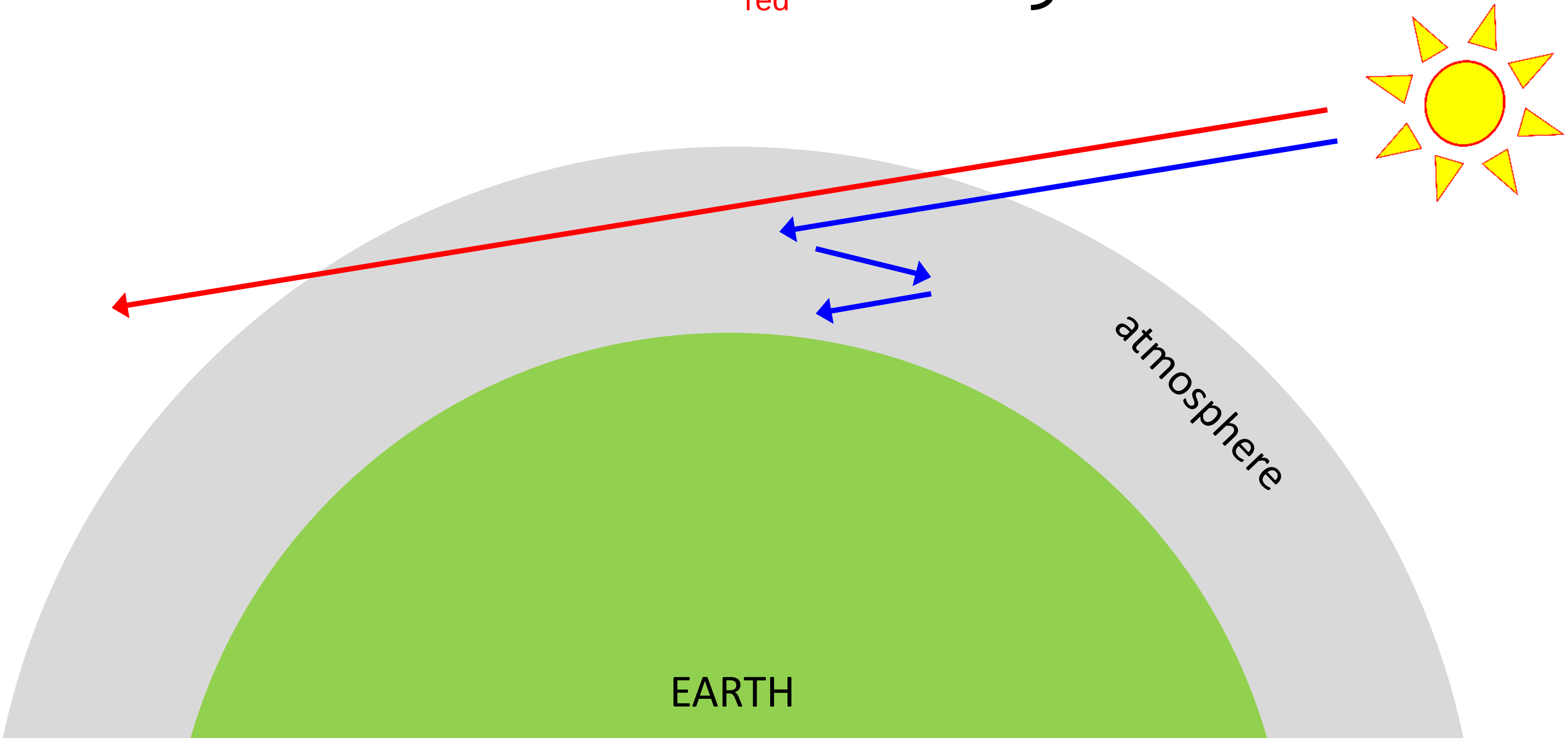
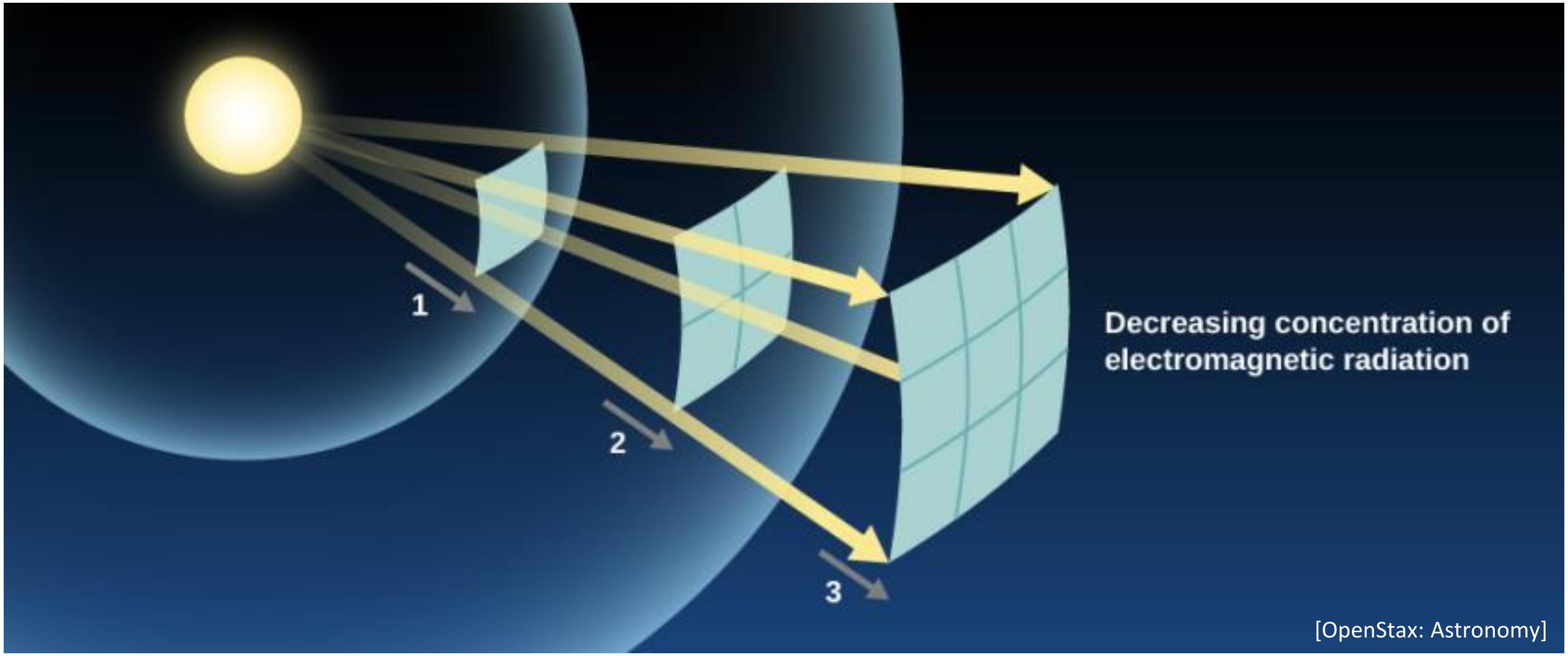
$$\frac{I_{blue}}{I_{red}} = \left(\frac{650}{450}\right)^4 \approx 4.3$$



Inverse Square Law for Light



- As light radiates away from its source, it spreads out such that its intensity decreases as the **square** of the **distance *d*** from its source.
- *Intensity* $\propto 1/d^2$.

Photon Basics

Photon energy = $E_\gamma = hf$

Important: Photon is massless

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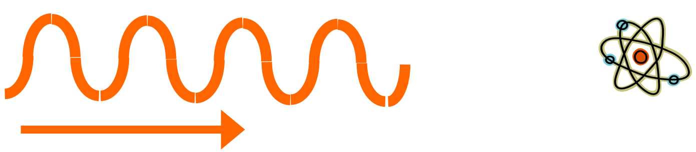
Shine light on an atom



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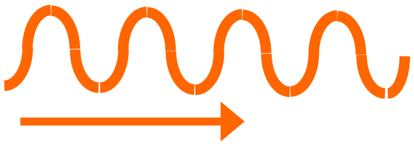

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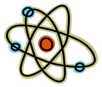

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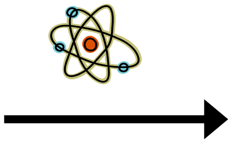
Atom after absorption of 1 photon

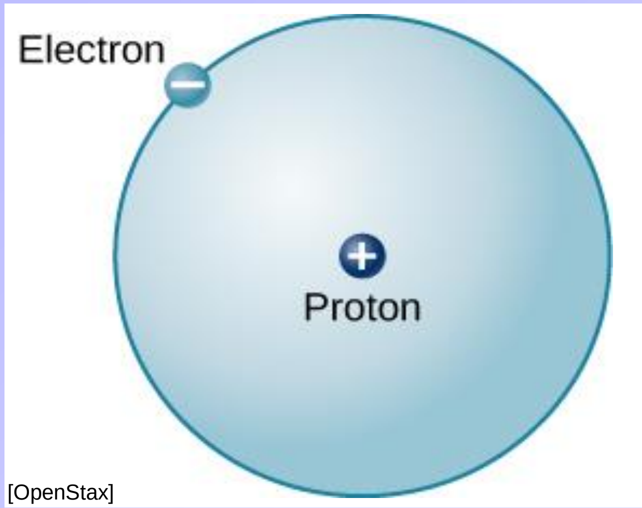


$p_{atom} = p_\gamma$

(conservation of momentum)

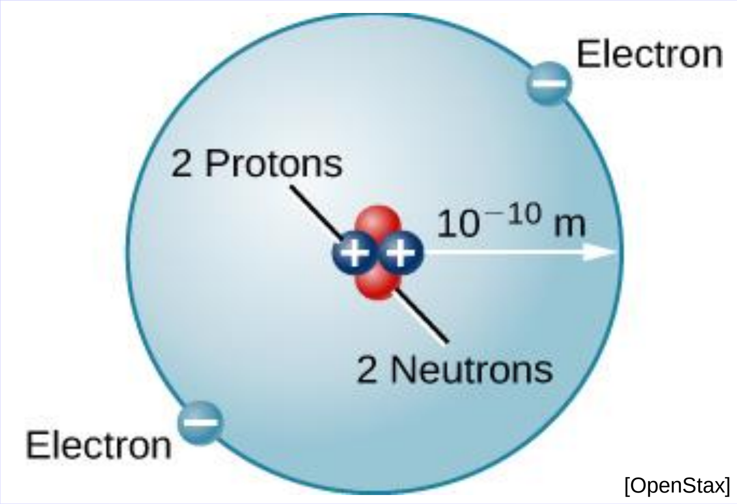
Basic
Structure of Atoms

Hydrogen: ^{1}H



Helium: ^{4}He

4 = 2 protons
+ 2 neutrons



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- Electron number, orbits, and properties determine the **chemistry** of the atom.

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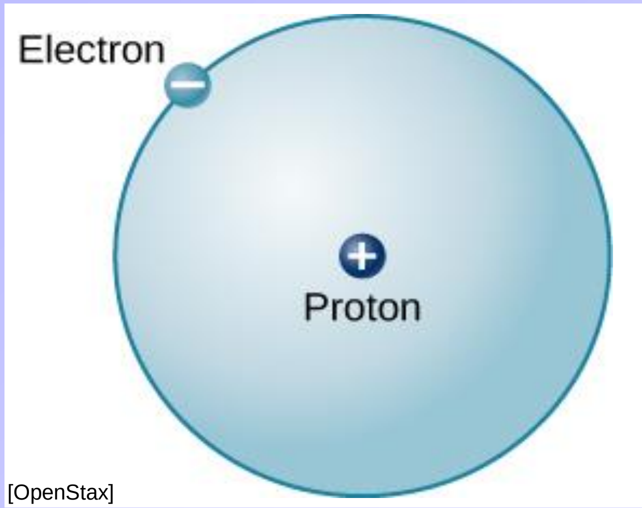

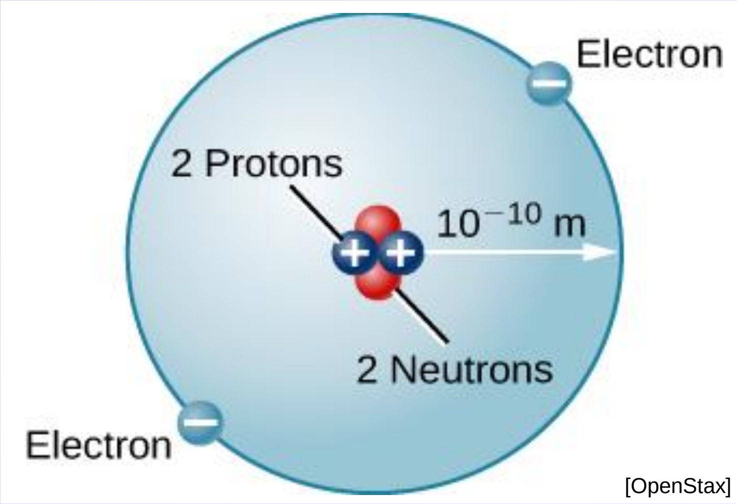

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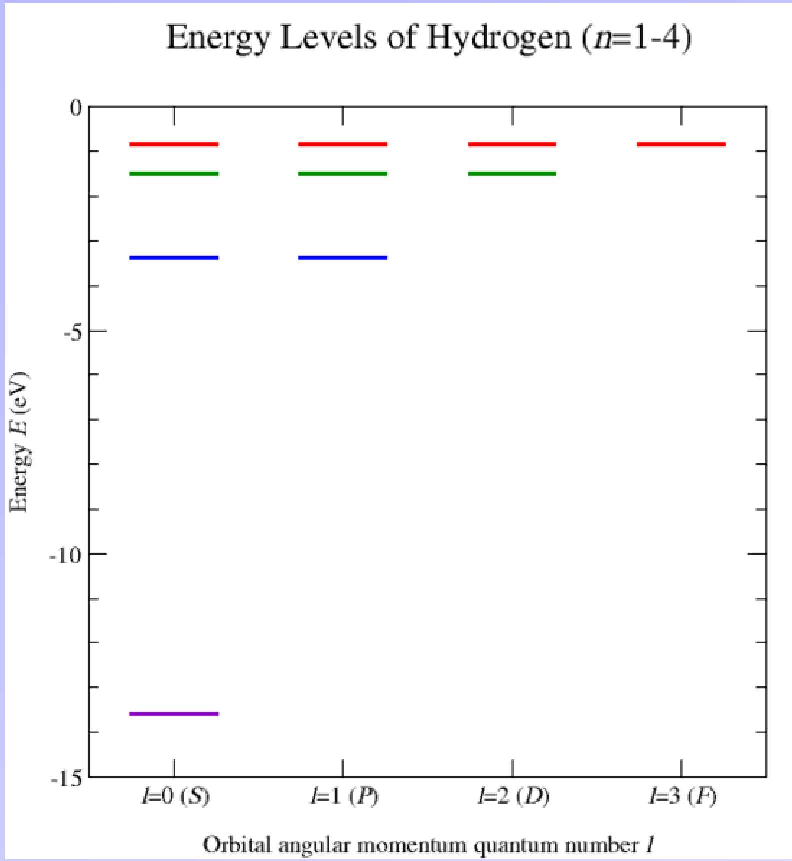
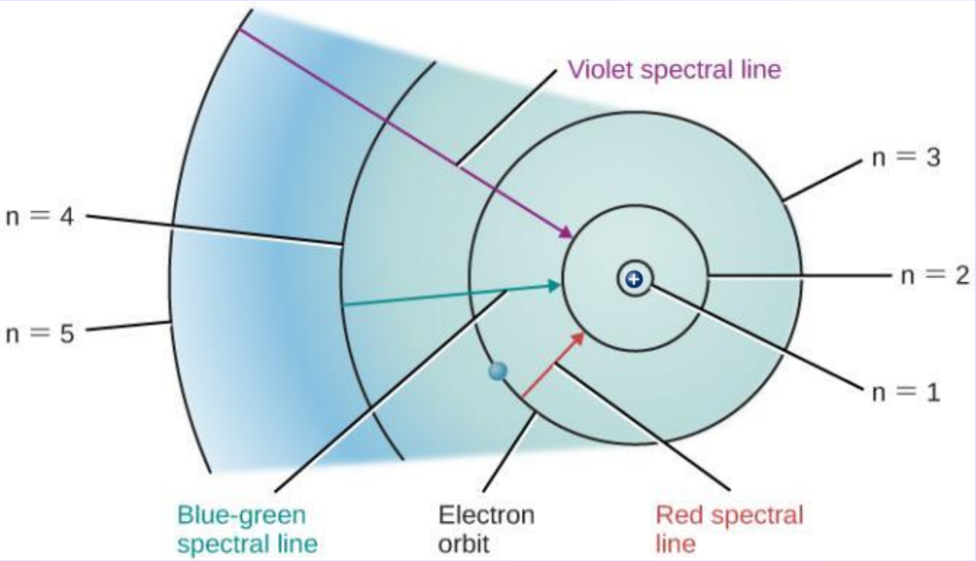
- Electron number, orbits, and properties determine the **chemistry** of the atom.
- **Nucleus** consists of positively charged **protons** and **neutral neutrons**.
- For neutral atoms: ***Number of protons = number of electrons***.
- Neutrons help bind protons together. **Number of neutrons $\gtrsim$ number of protons.**

Electronic

Structure of Atoms



[Figure from wikimedia.org]



[OpenStax]

- Electrons have **discrete allowed energies and orbits**.

Note: 1 eV = 1.602 × 10^{-19} J

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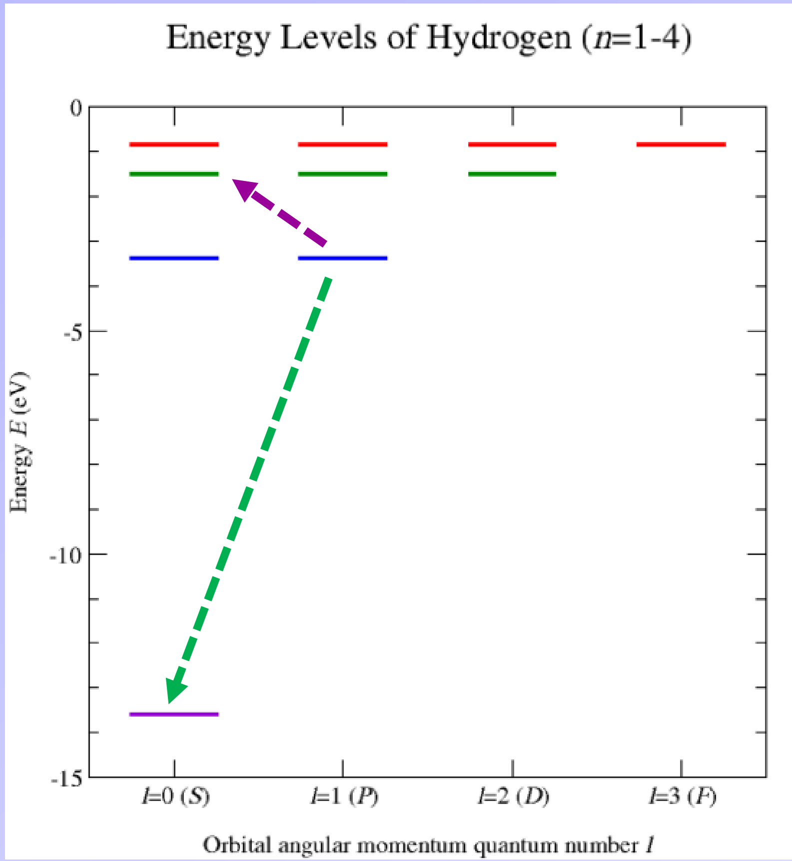

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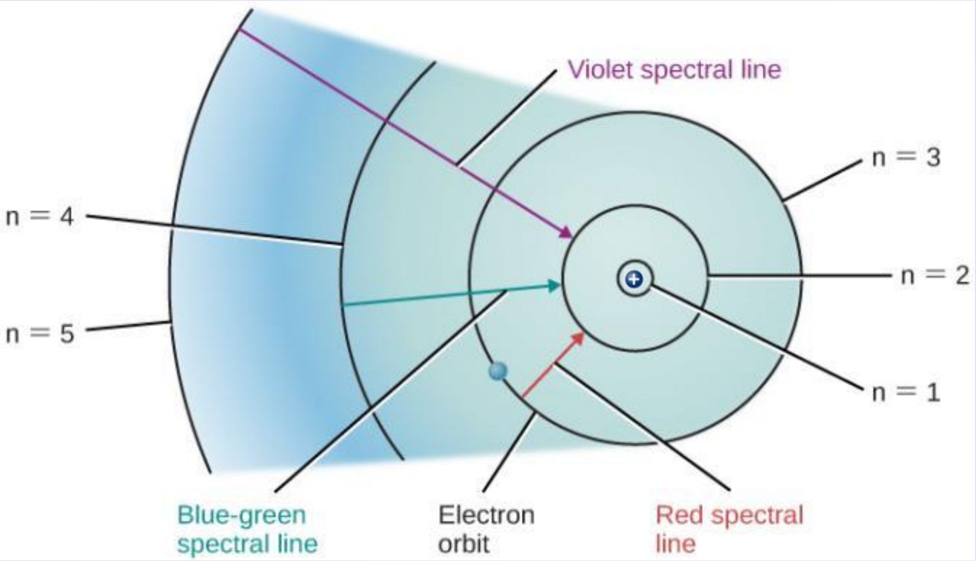
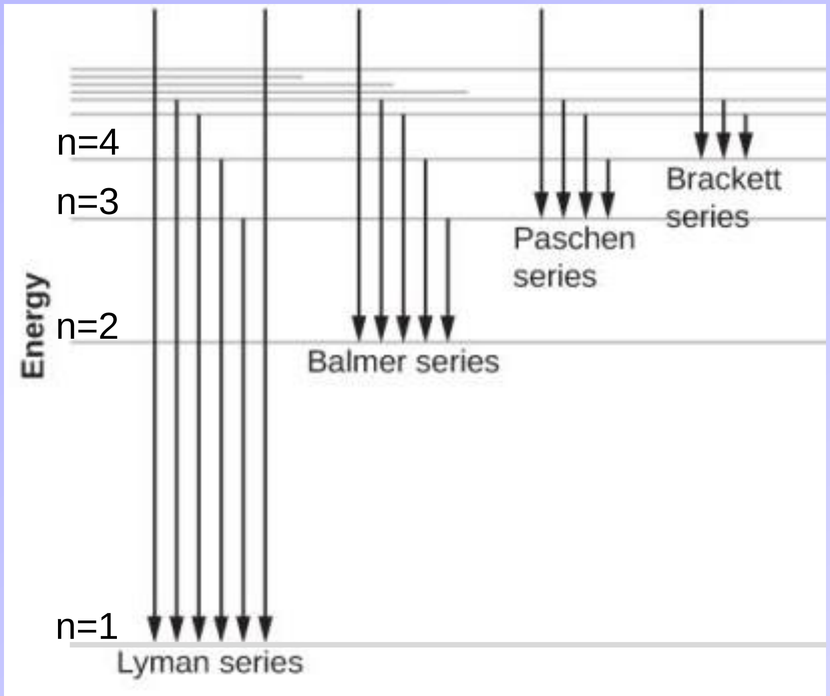
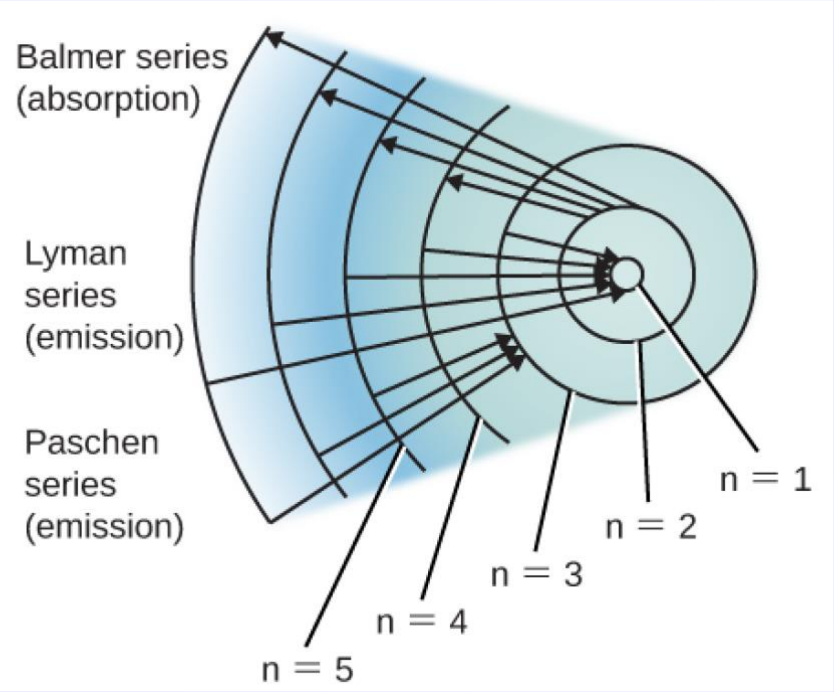


[OpenStax]

- Electrons have **discrete allowed energies and orbits**.
- Transitions between two energy levels requires **emission** or **absorption** of a photon that bridges the energy gap.
- **Discrete** emission and absorption **spectra**.

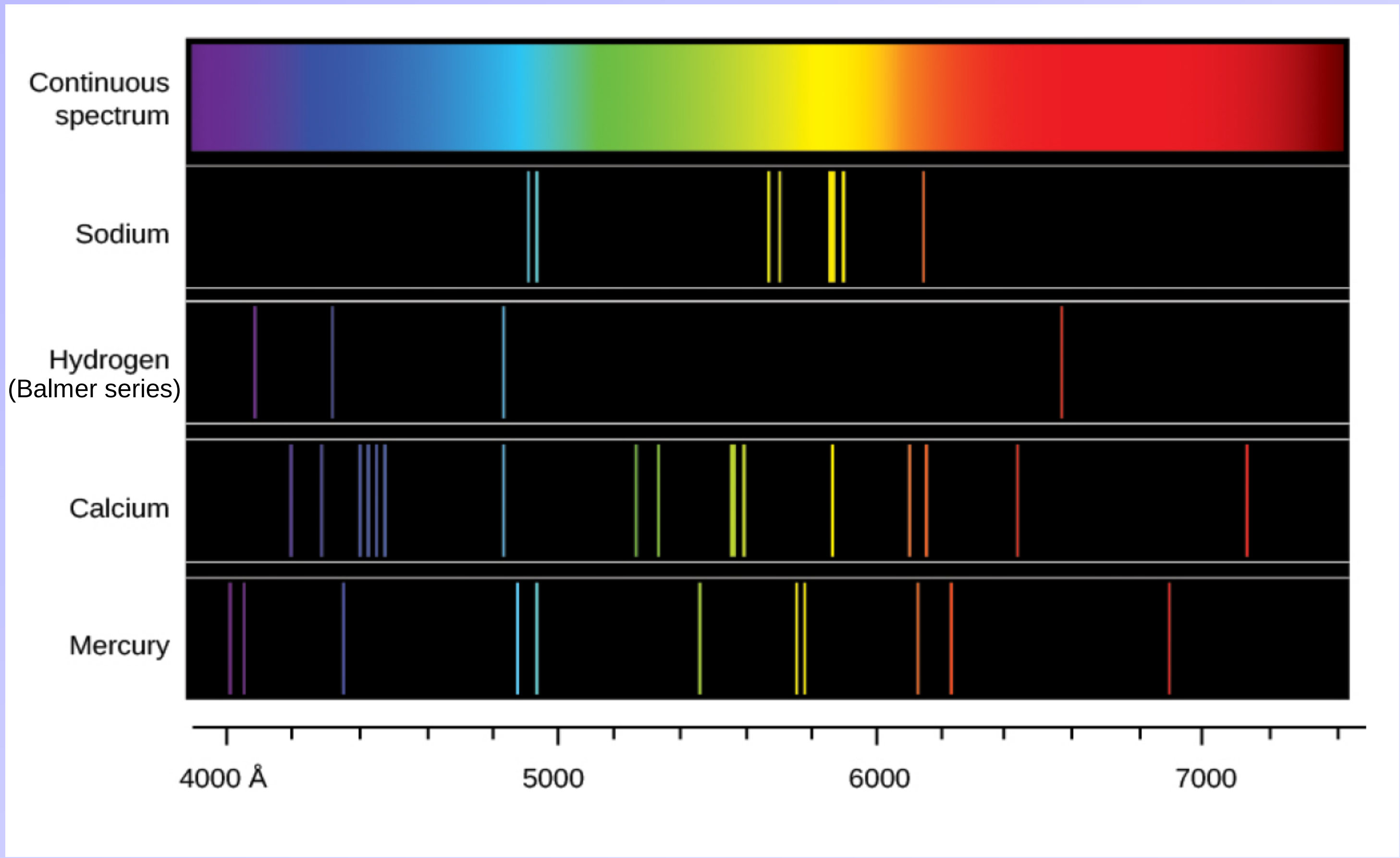
Emission Spectrum of Hydrogen





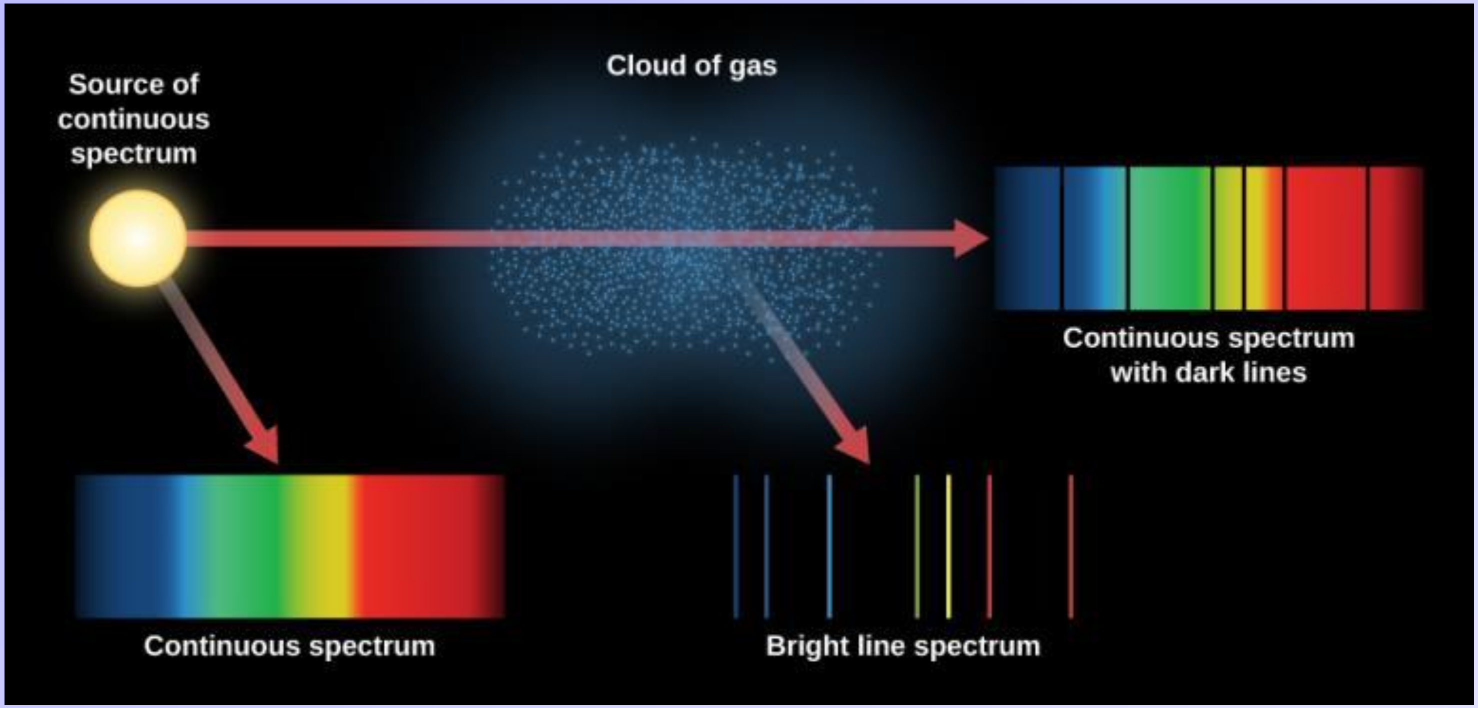
- Hydrogen has a number of emission and absorption spectral series that depend on the start/end point of the transition.
- Other elements are qualitatively similar.
- Also true for molecules, but their spectra are more complicated.

Emission Spectra "Fingerprints"



If you build a **catalog of spectral lines**, then you can **determine the elements** that are present from the spectrum.

Emission & Absorption Processes



Three types of spectra

1. **Continuous** spectrum, e.g. a thermal **blackbody** source.
2. **Emission** spectrum (discrete): if light excites atoms, then the atomic emission will be at discrete frequencies.
3. **Absorption** spectrum (discrete): if a continuous spectrum excites atoms, then the absorption of photons will remove light at discrete frequencies (“shadow lines”).

Doppler Effect

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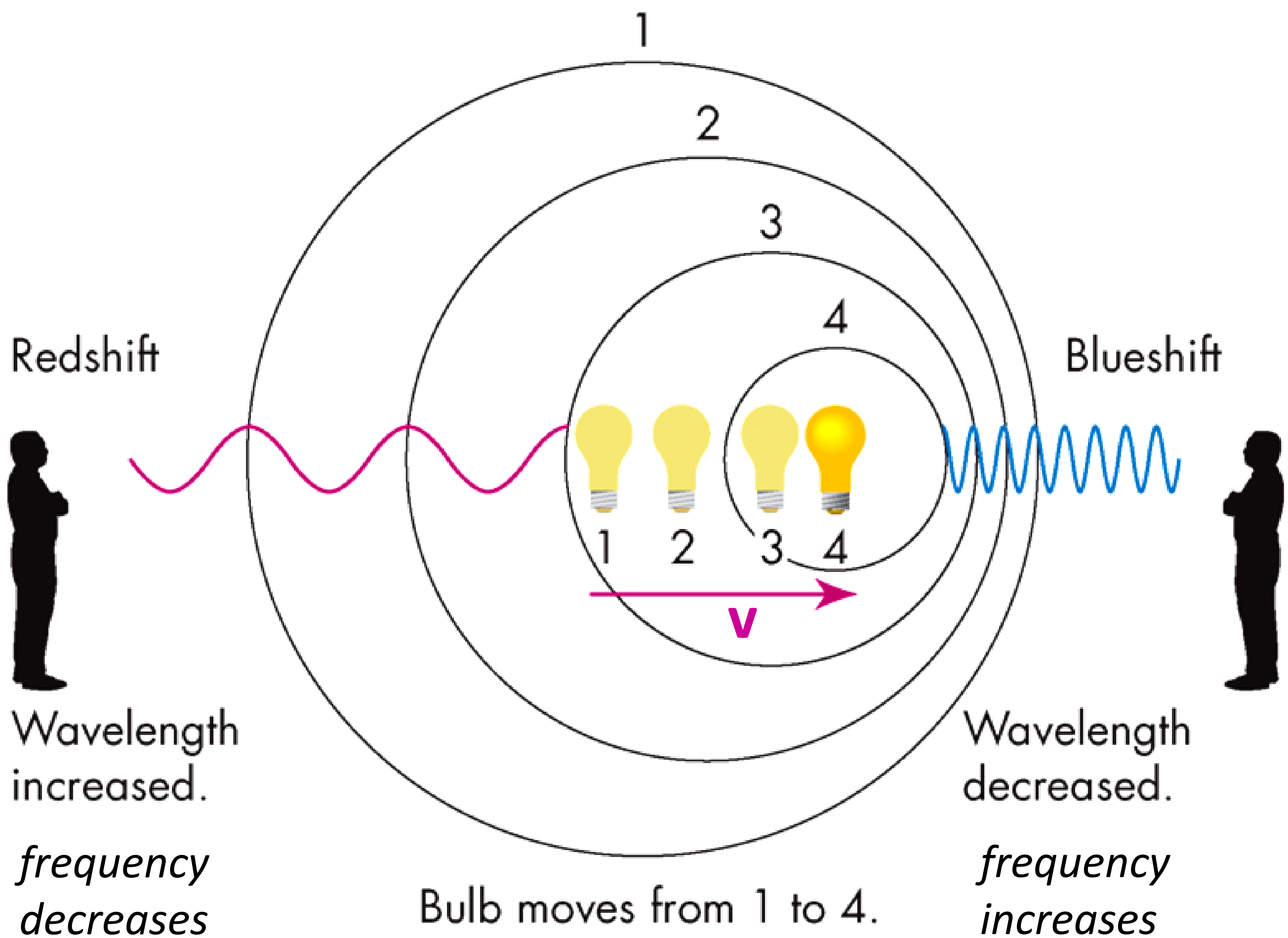

[image source: J. Nelson]

Doppler Effect

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Works for sound too !!!

Doppler Shift Calculation

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frequency of stationary source

perceived frequency of moving source

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frequency of stationary source

perceived frequency of moving source

If source is moving towards you, then light is blue shifted.

$v > 0$ | $\Delta f > 0$, f' goes up

$\Delta\lambda < 0$

If source is moving away from you, then light is red shifted.

$v < 0$ | $\Delta f < 0$, f' goes down

$\Delta\lambda > 0$