Today's Topics

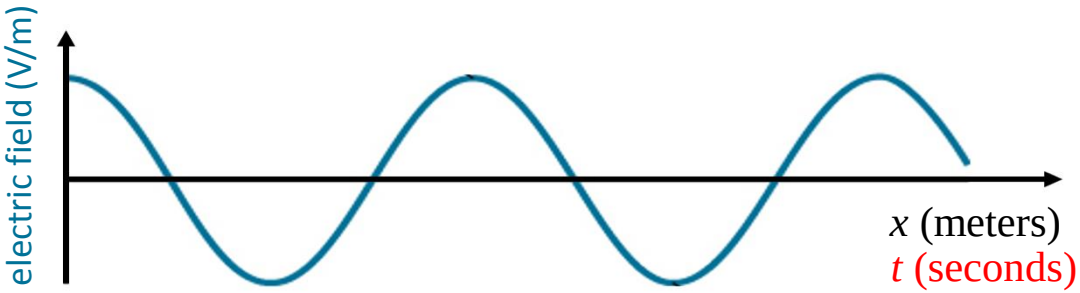
Monday, September 7, 2020 (Week 3, lecture 9) – Chapter 5.

A. Light basics: EM waves & photons

B. Electronic structure of atoms & spectroscopy

D. Doppler effect, part 1

EM Wave Basics



propagation at speed **c**

magnetic field [Tesla] $= \frac{\text{electric field}}{c}$

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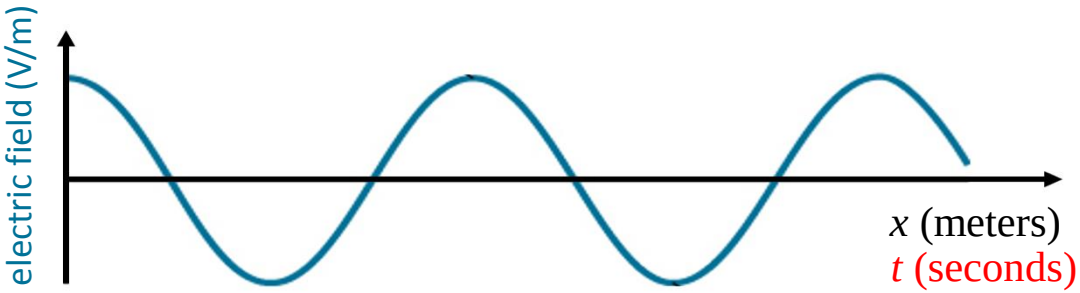

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"brightness" of light (not source)

E = electric field [V/m]

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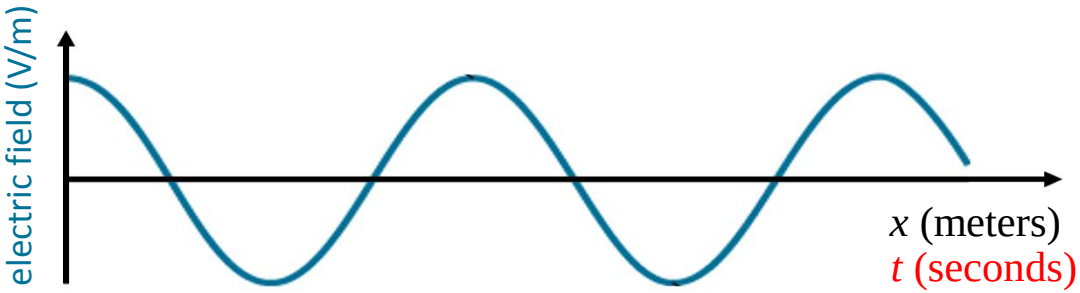

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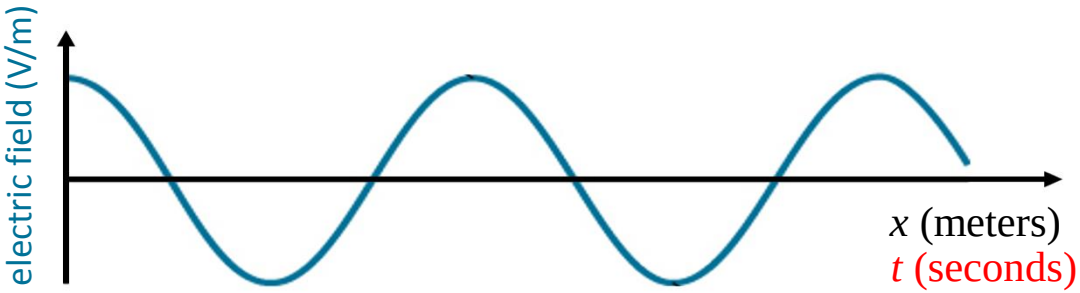

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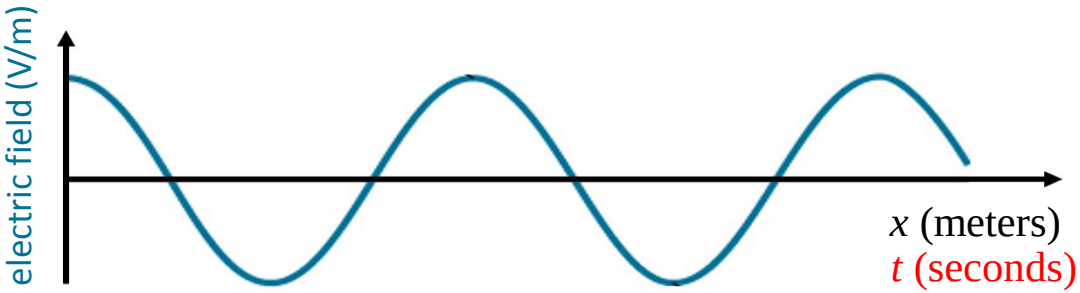

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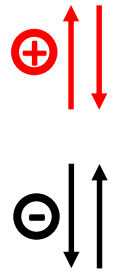
→ generates "dipole radiation."



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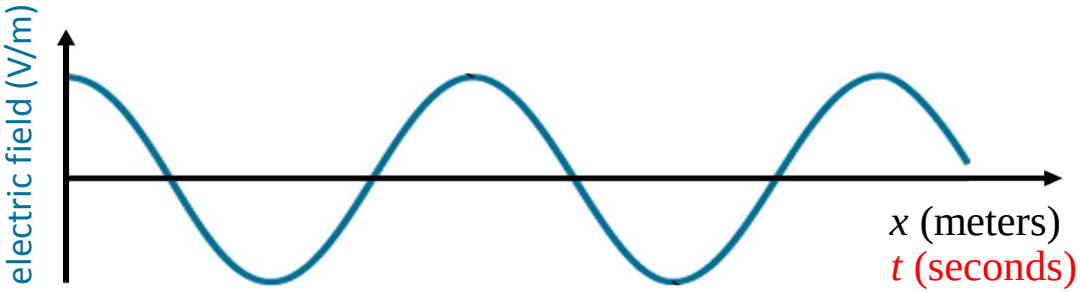

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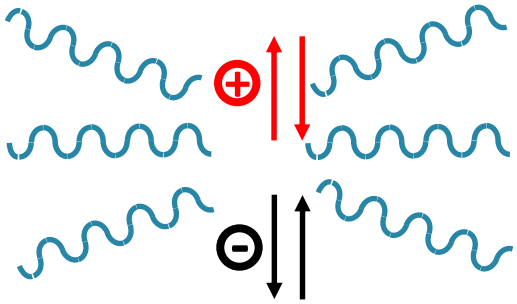
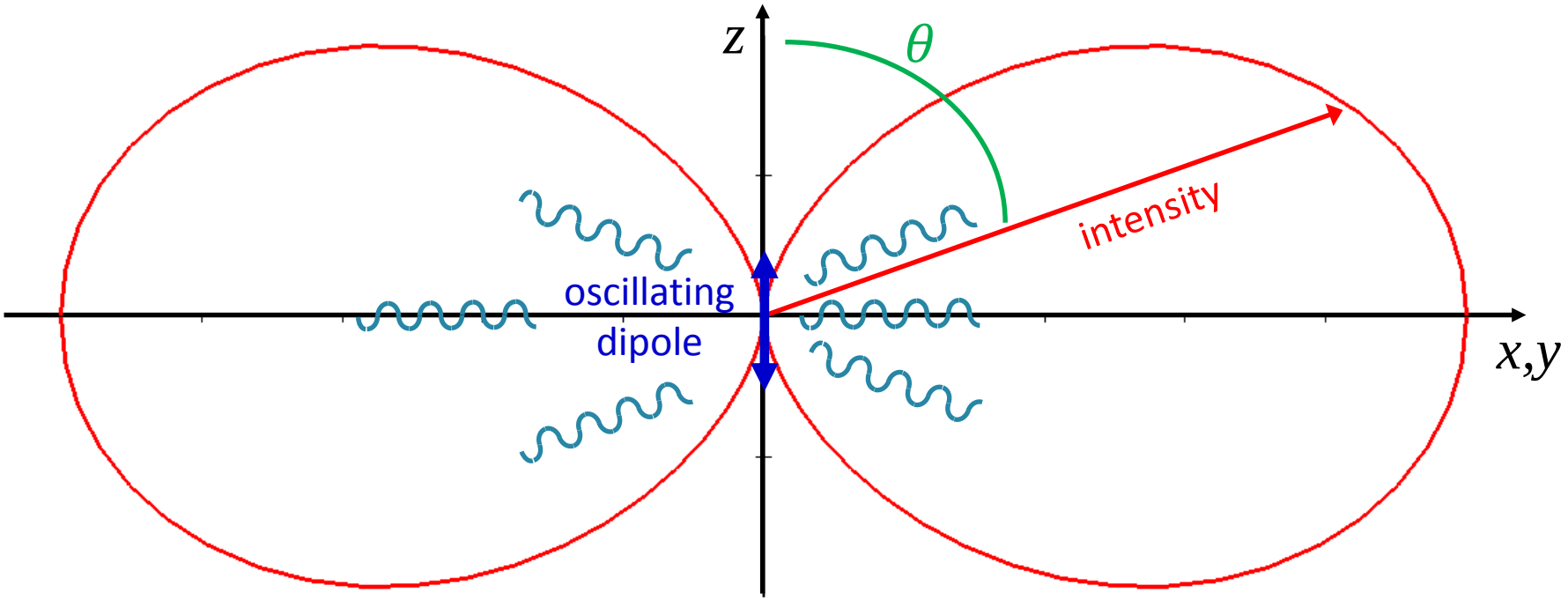


Dipole Radiation Pattern

dipole moment = p_0 = charge × separation



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

r = distance from dipole

f = frequency

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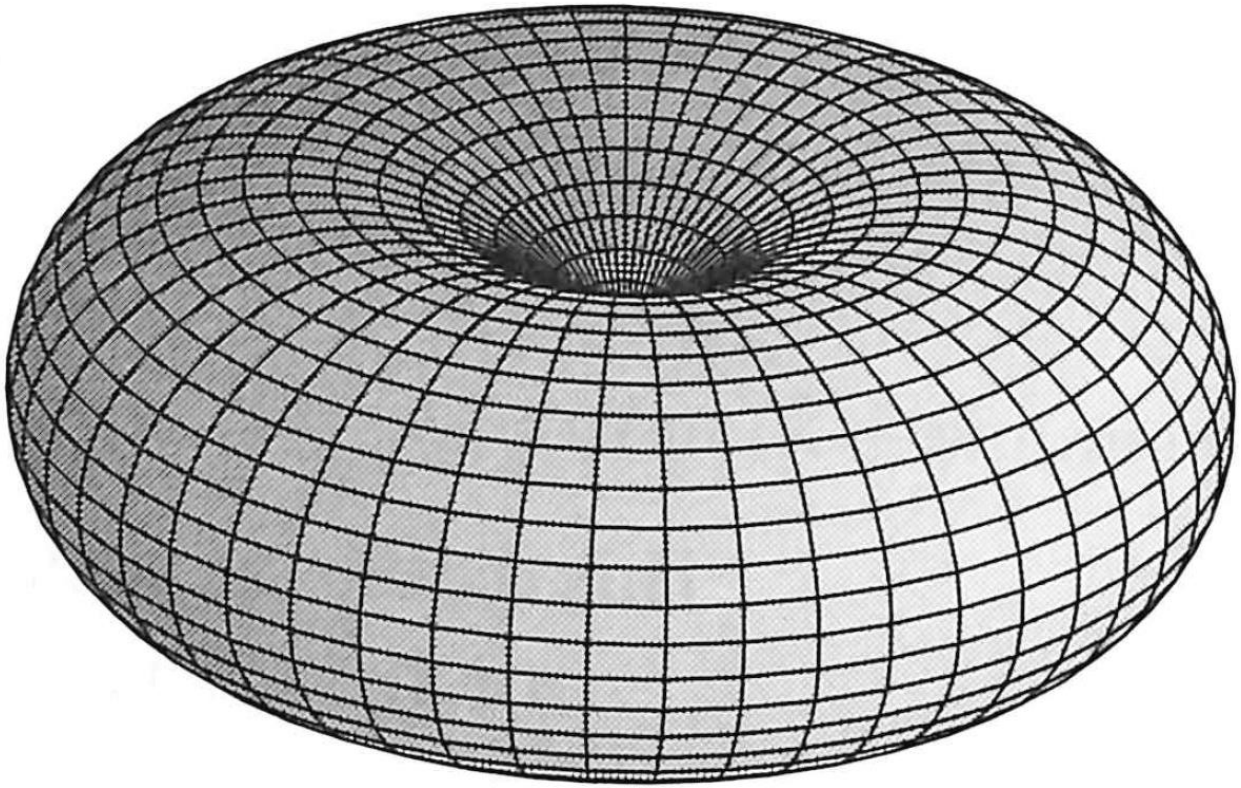

[Figure 11.4, *Introduction to Electrodynamics*, by D. Griffiths, 4th Ed.]

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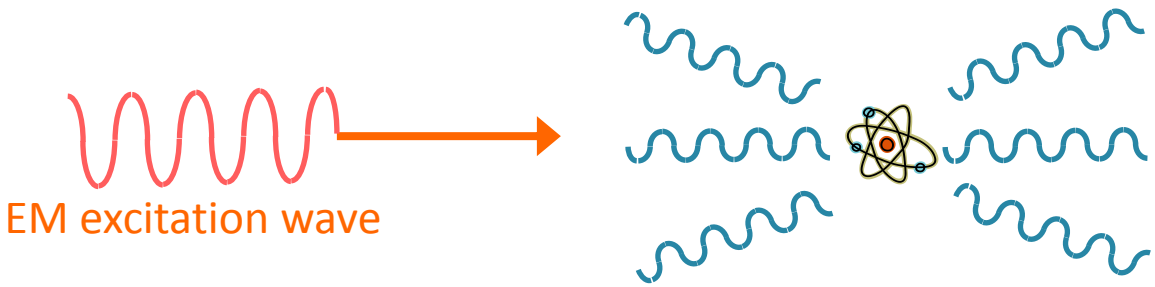
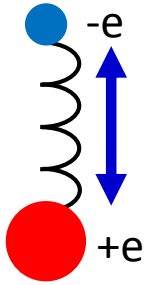
Dipole Radiation Example #1

Atomic fluorescence & photon scattering

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





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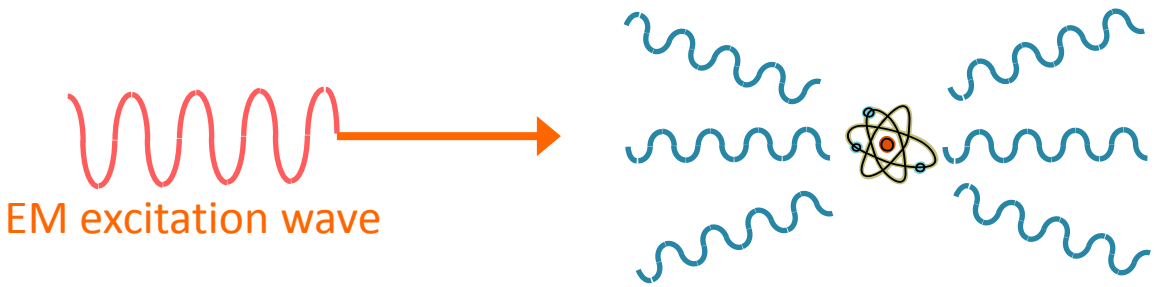
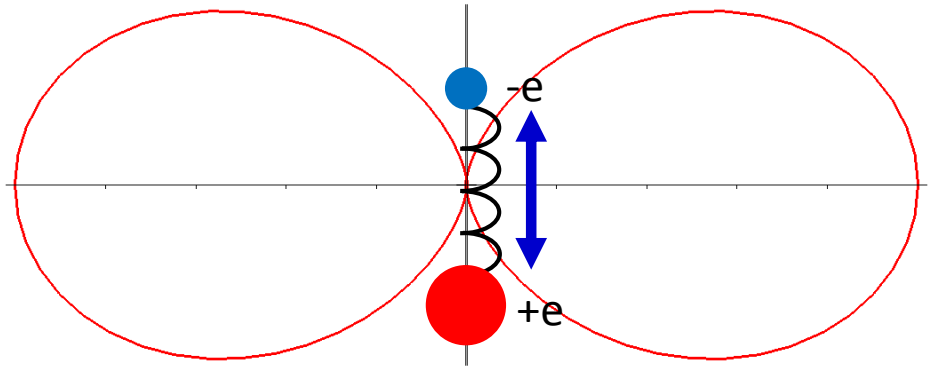


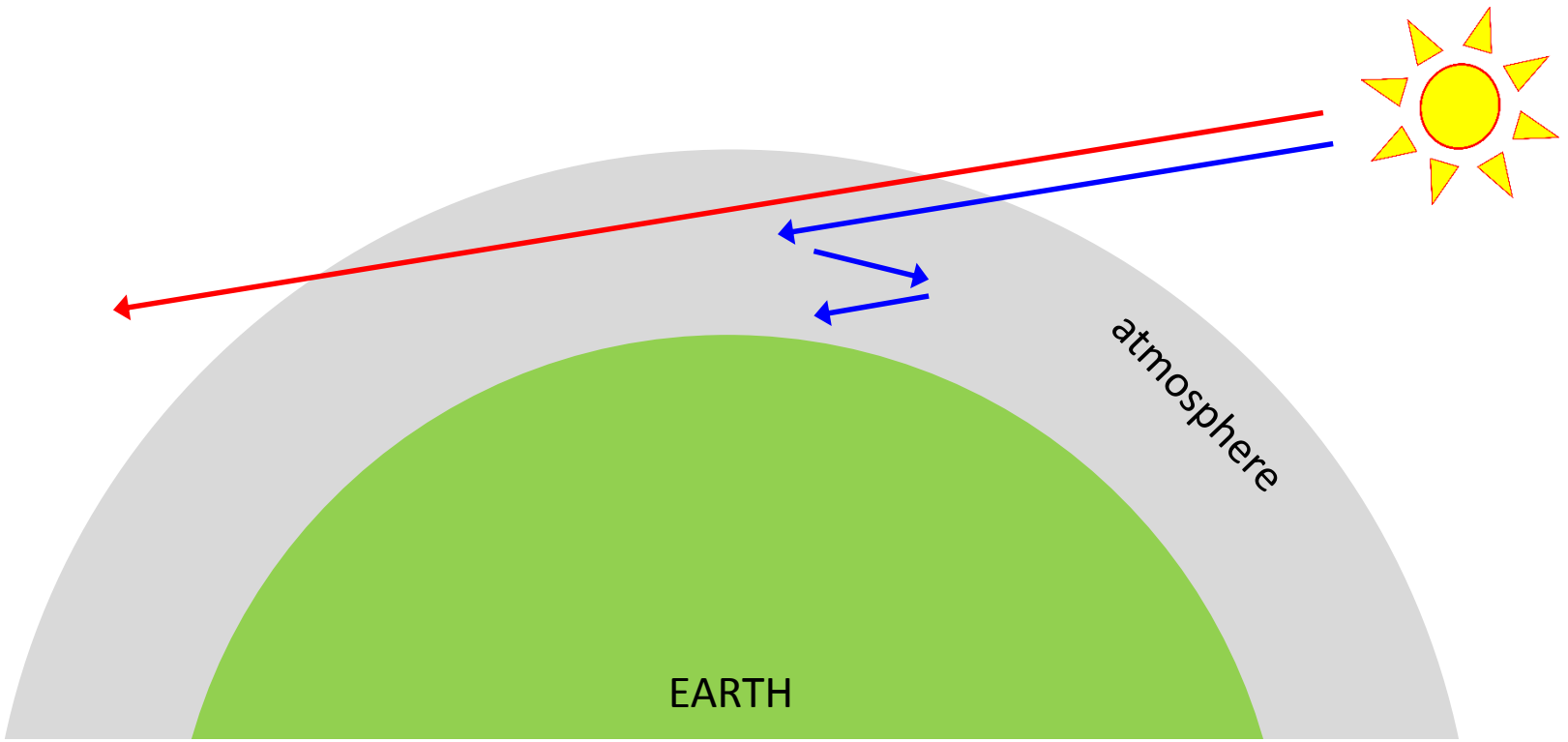
dipole radiation emission pattern



Dipole Radiation Example #2

Blue Sky

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



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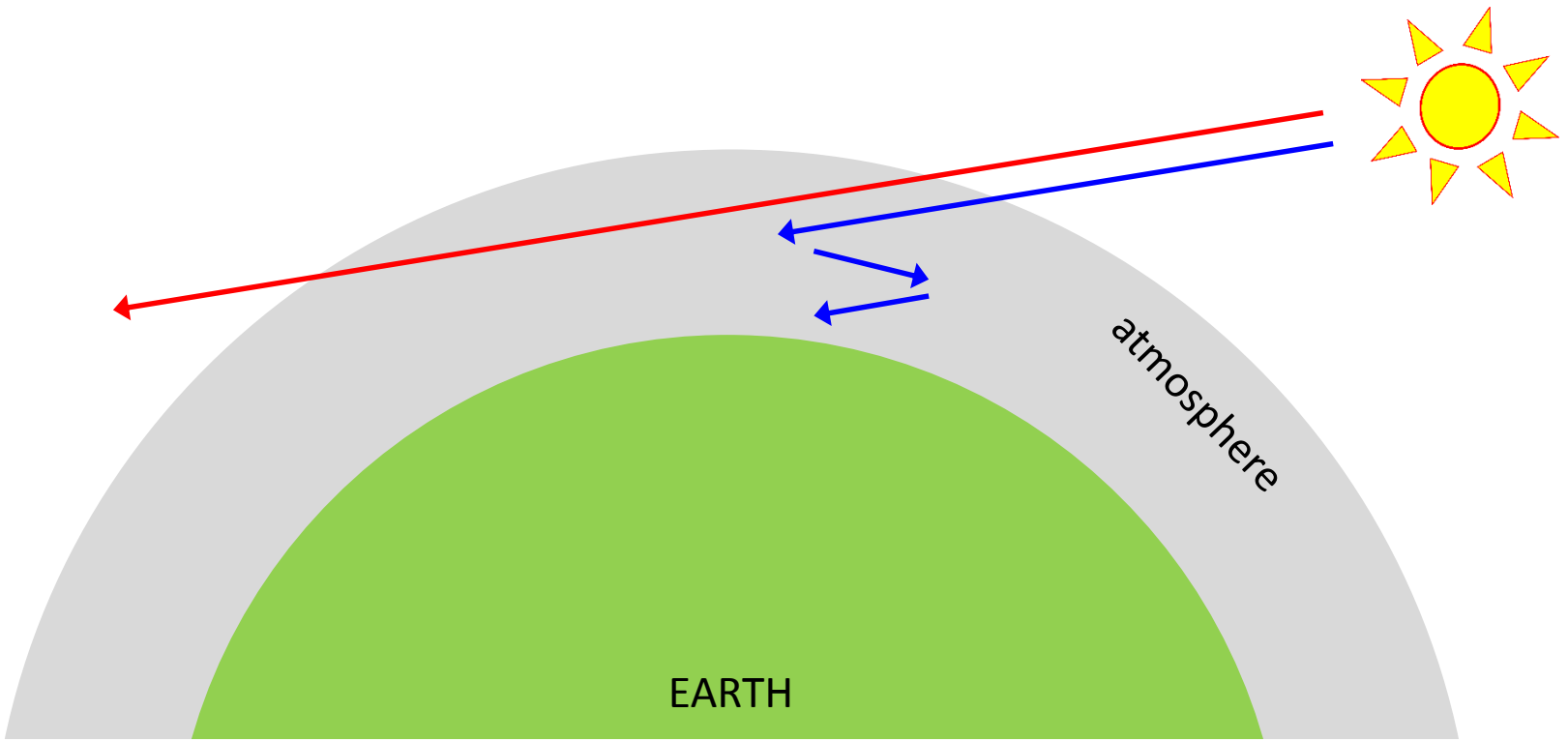

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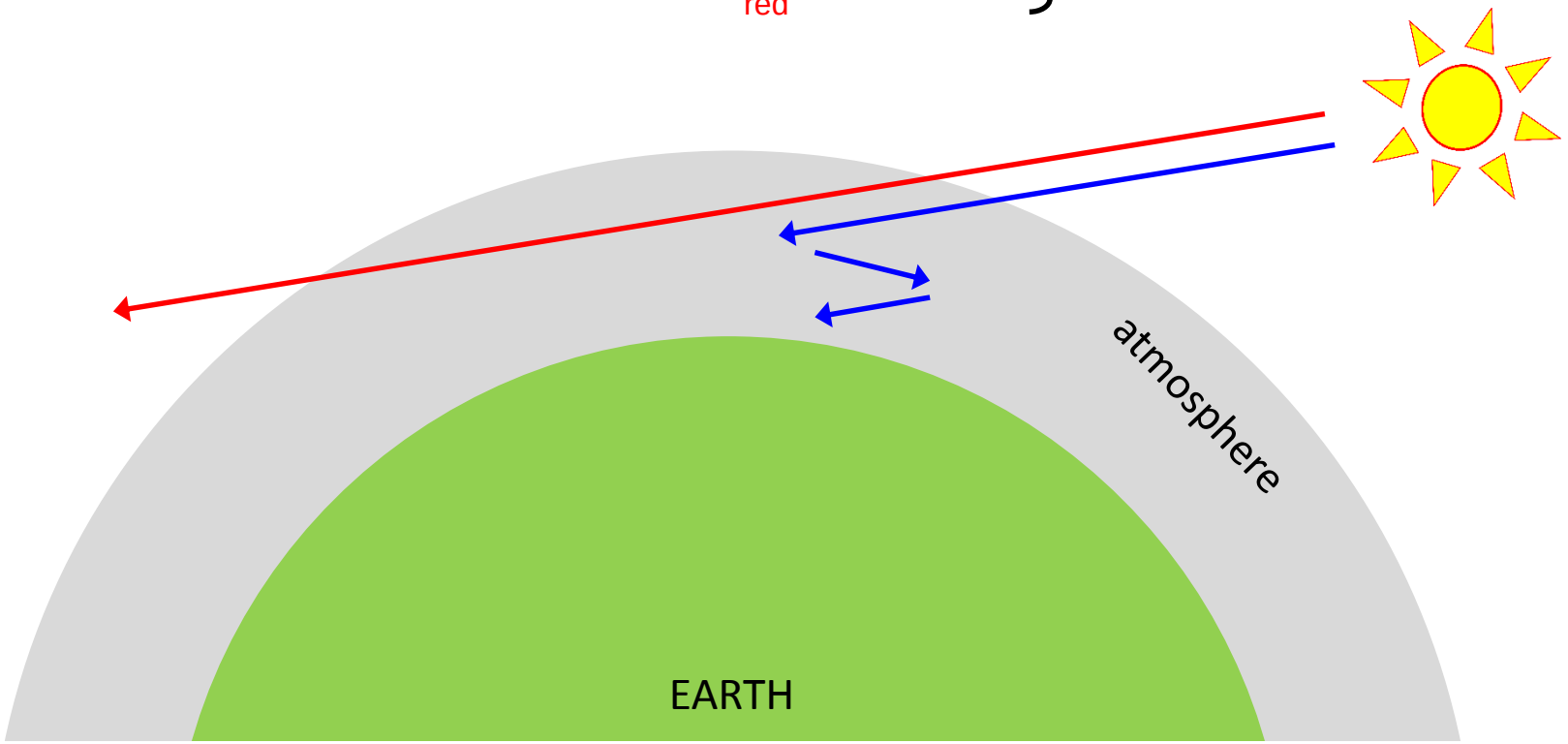
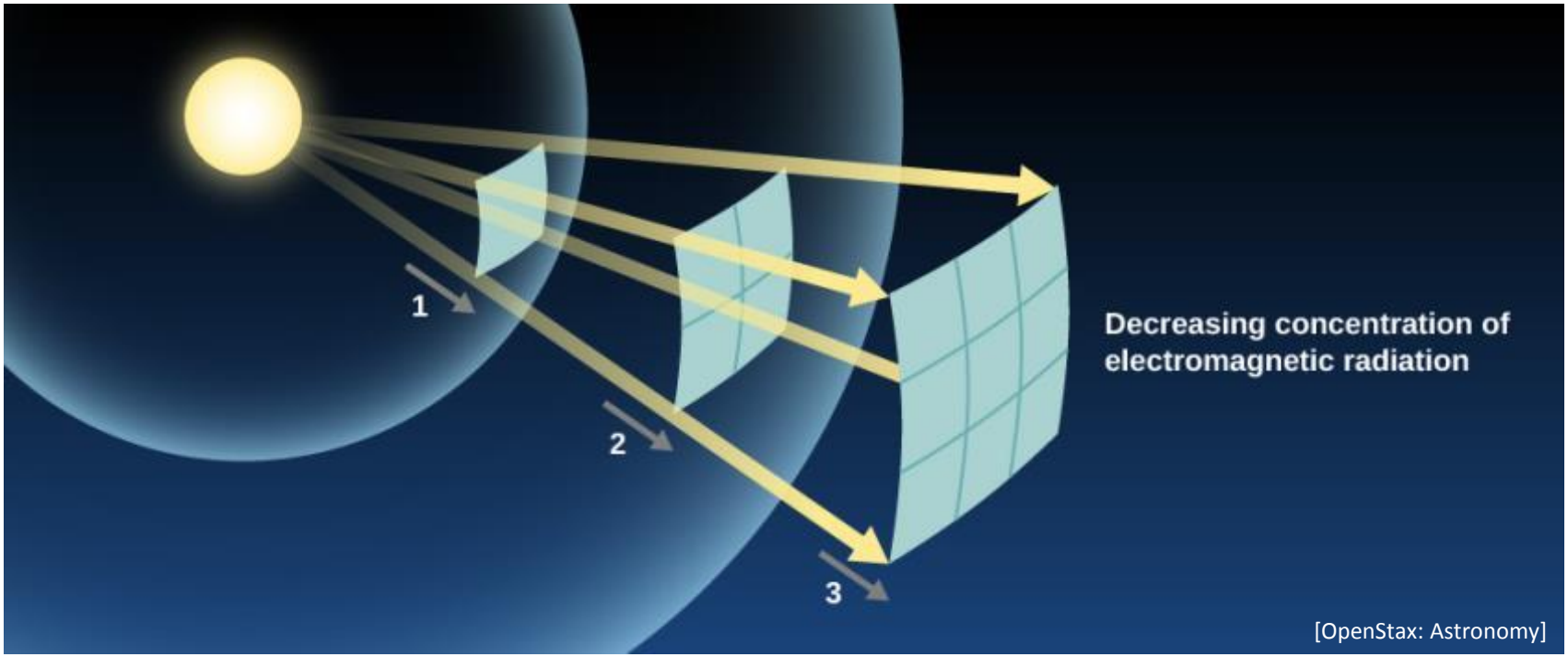
$$Intensity \propto f^4 \propto \frac{1}{\lambda^4} \Rightarrow \left\{ \begin{array}{l} \lambda_{blue} = 450\ nm \\ \lambda_{red} = 650\ nm \end{array} \right. \quad \frac{I_{blue}}{I_{red}} = \left(\frac{650}{450}\right)^4 \approx 4.3$$



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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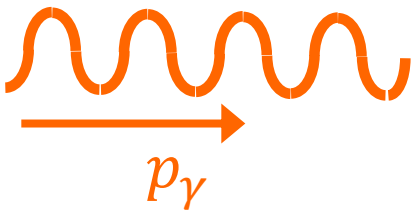

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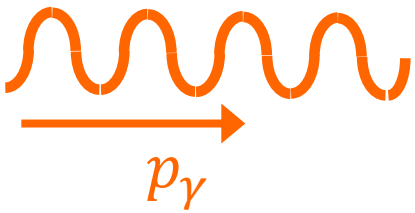

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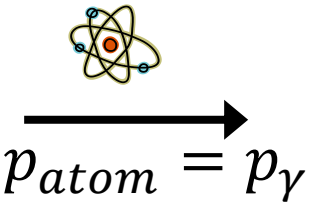
Atom after absorption of 1 photon

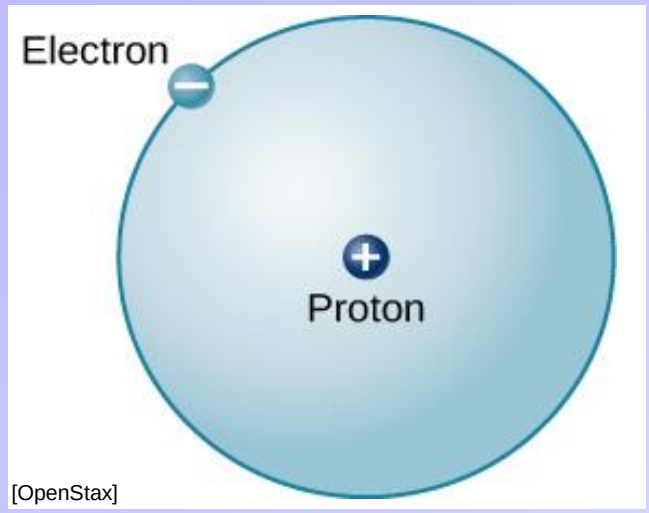


(conservation of momentum)

Basic

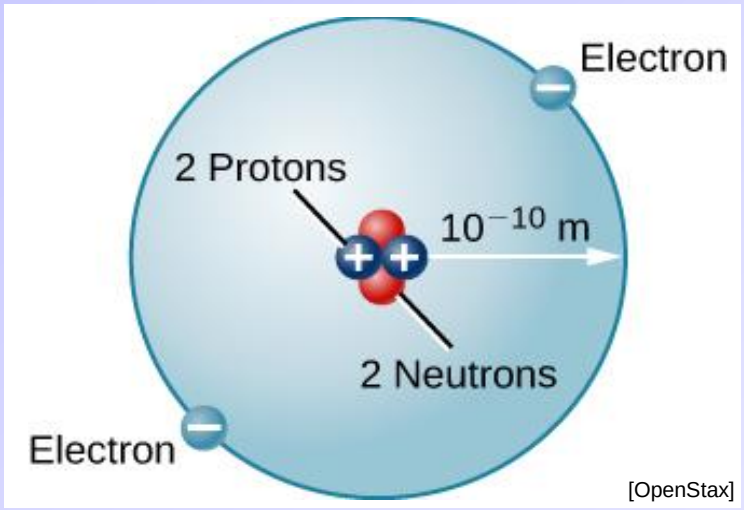
Structure of Atoms

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.

Basic

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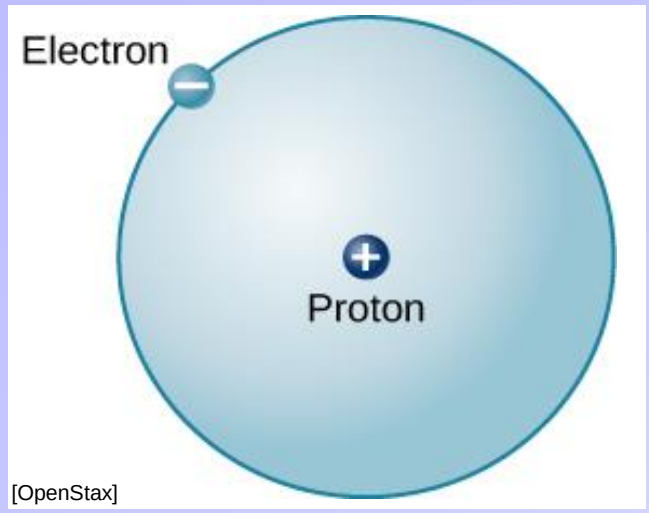

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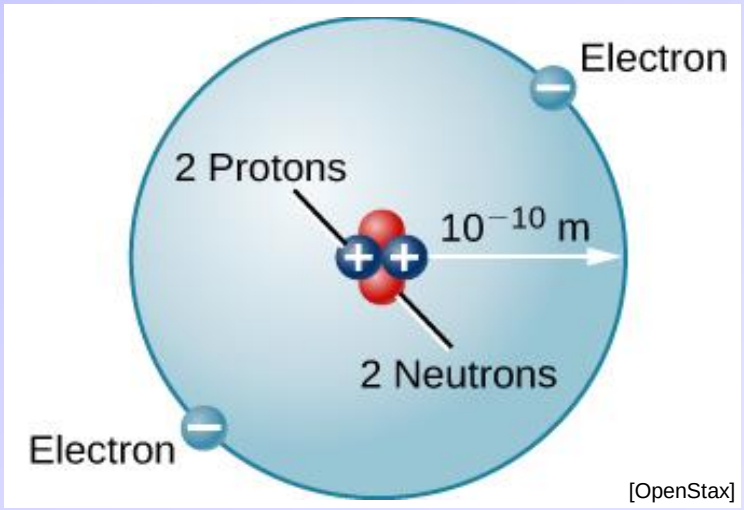

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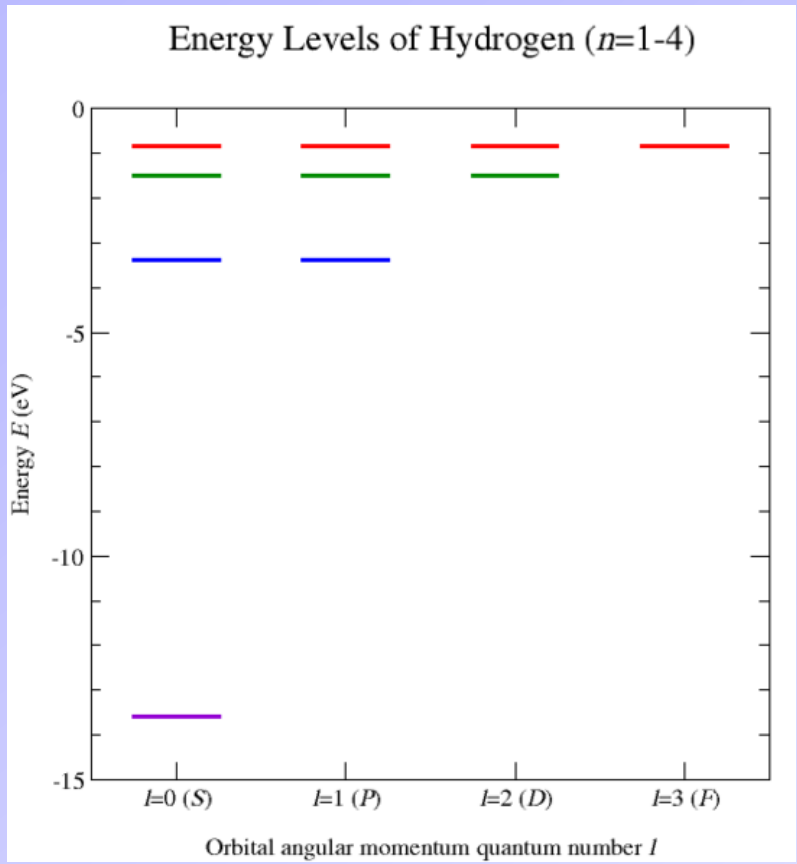
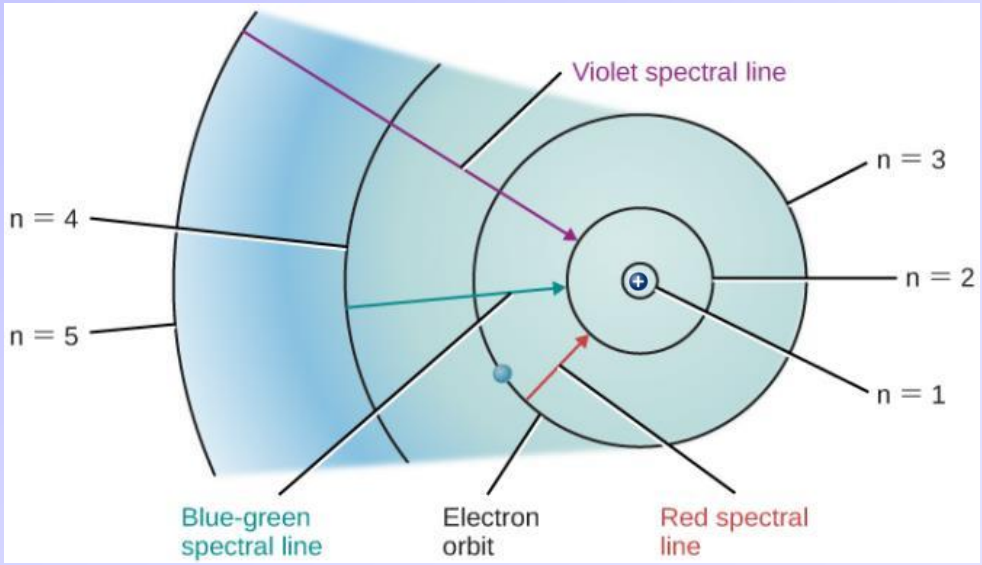
- Electron number, orbits, and properties determine the **chemistry** of the atom.
- **Nucleus** consists of positively charged **protons** and **neutral neutrons**.
- For neutral atoms: ***Number of protons = number of electrons***.
- Neutrons help bind protons together. **Number of neutrons $\gtrsim$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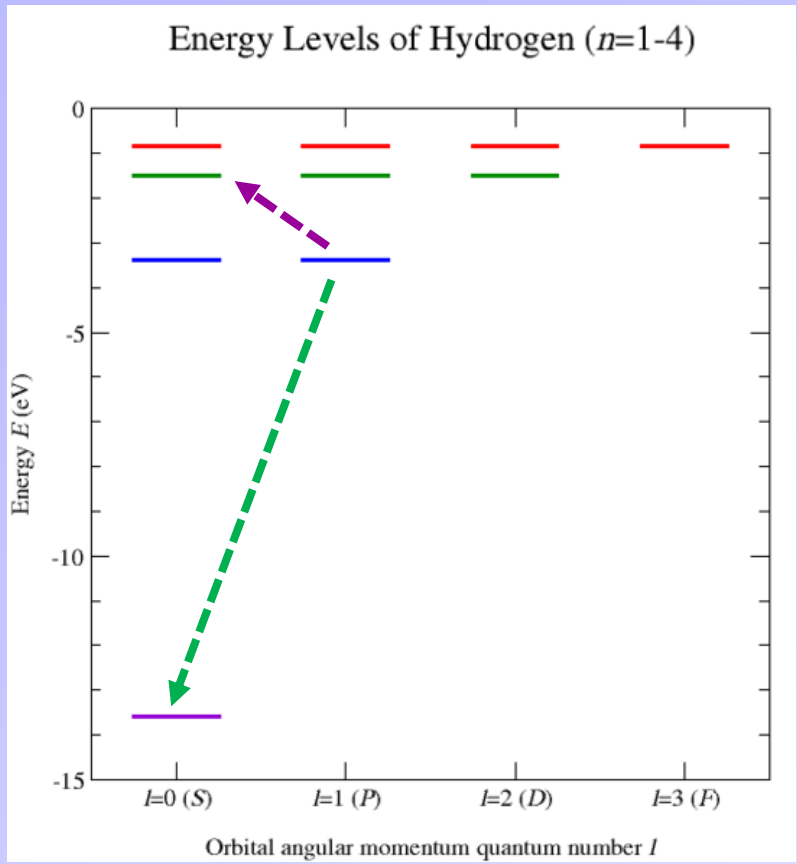

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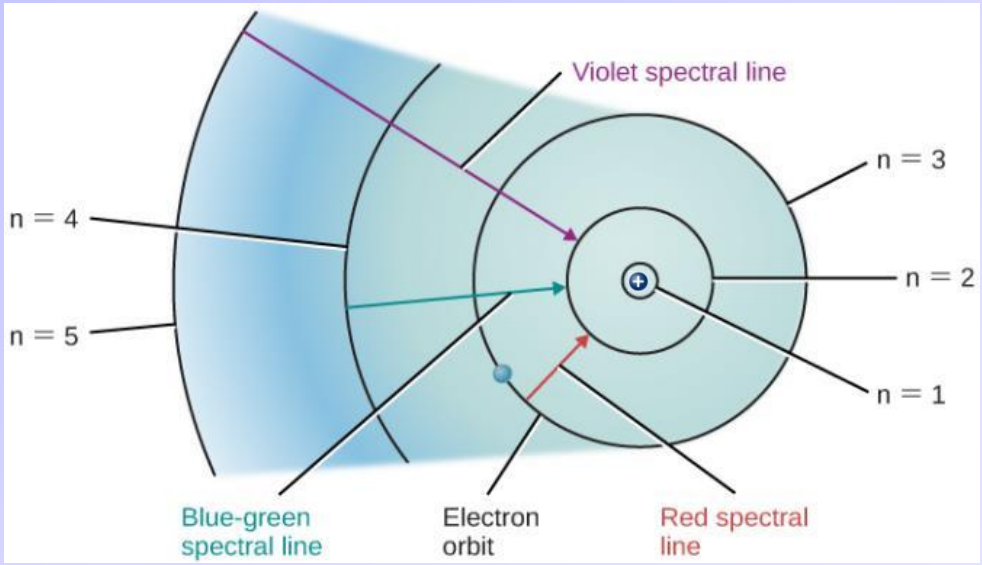
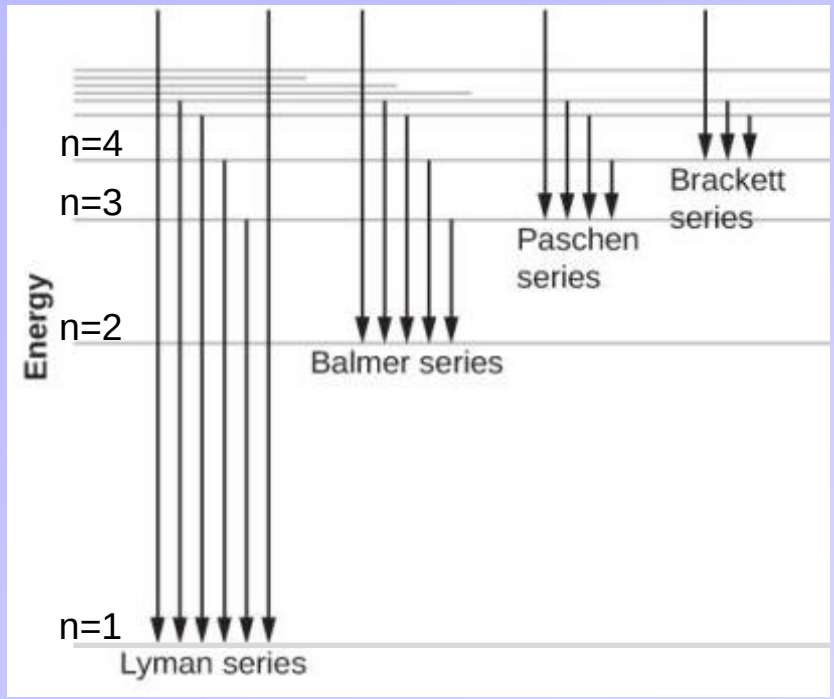
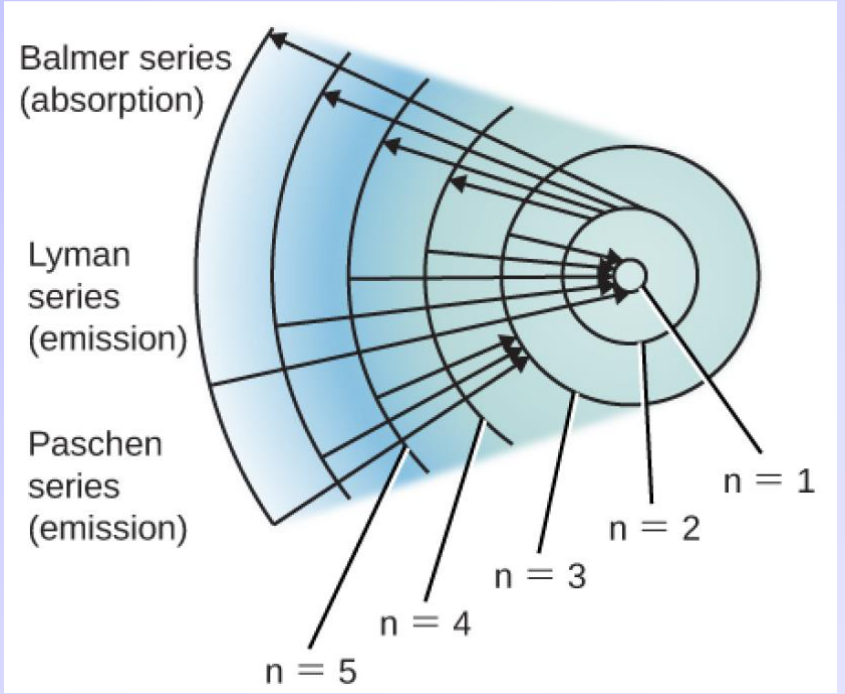


[OpenStax]

- 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**.

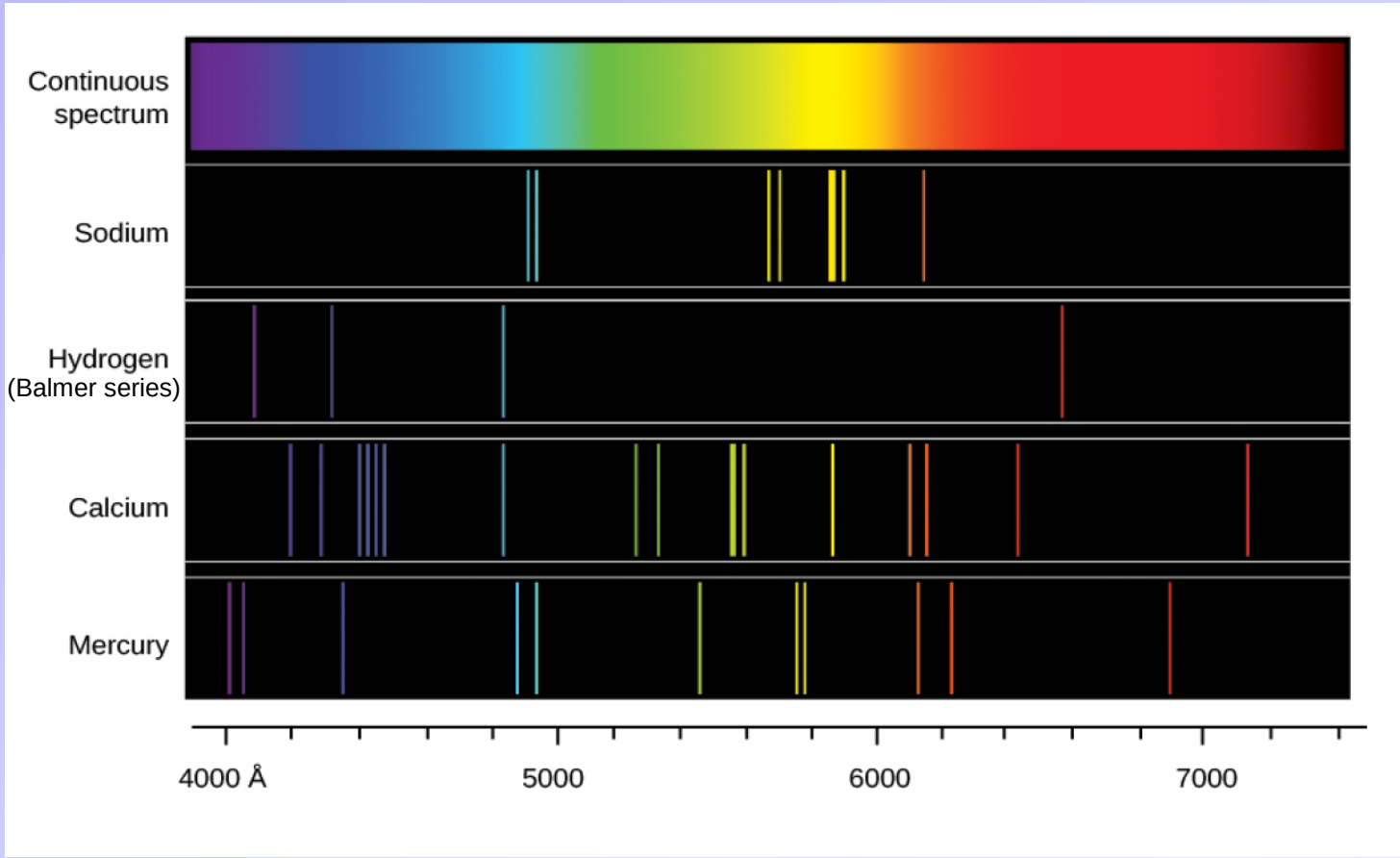
Emission Spectrum of Hydrogen





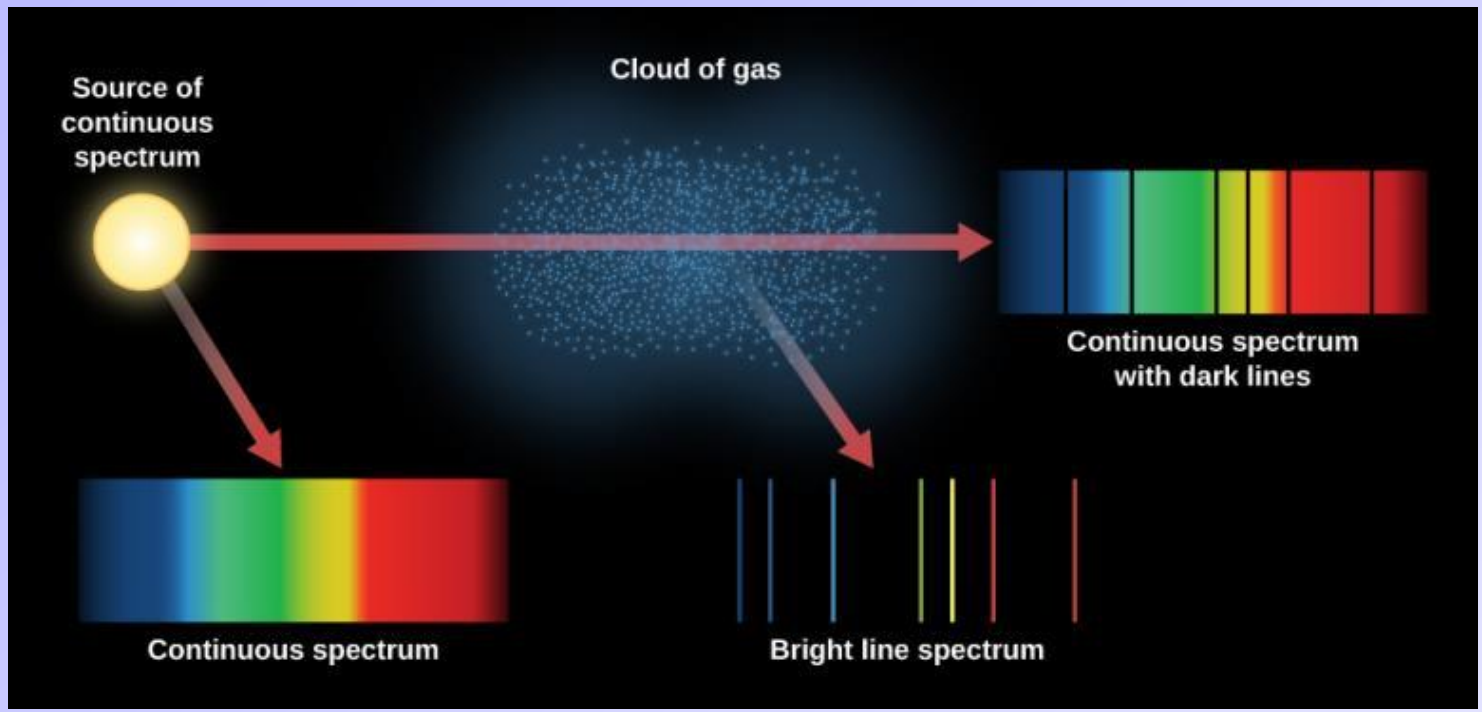
- Hydrogen has a number of emission and absorption spectral series that depend on the start/end point of the transition.
- Other elements are qualitatively similar.
- Also true for molecules, but their spectra are more complicated.

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

A **moving source** cannot change the speed of its emitted light, but it does change its **frequency & wavelength**.

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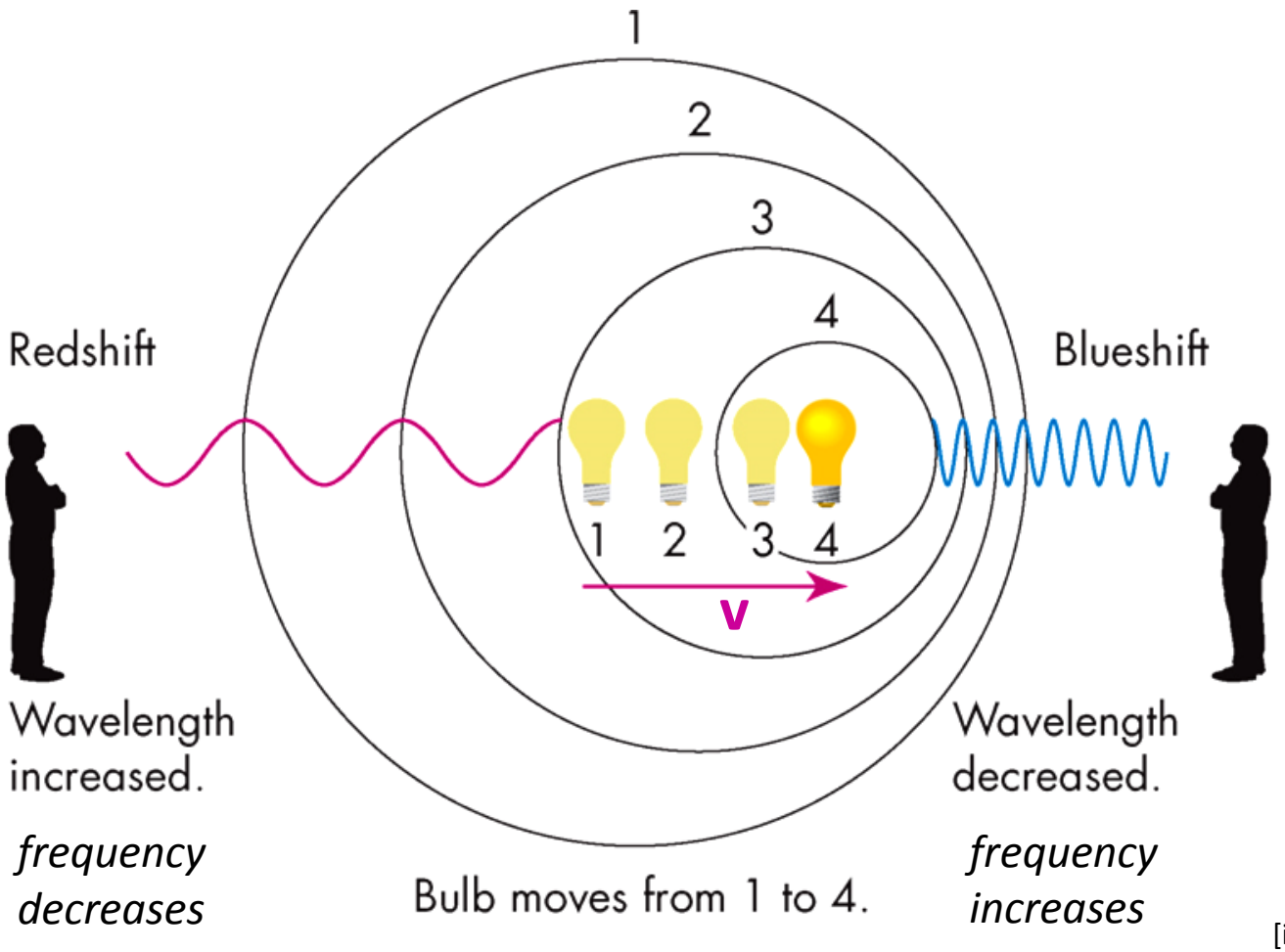

[image source: J. Nelson]

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Works for sound too !!!

Doppler Shift Calculation

Doppler frequency shift: $\frac{\Delta f}{f} = -\frac{\Delta \lambda}{\lambda} = \frac{v}{c}$ with $f' = f + \Delta f$

frequency of stationary source

perceived frequency of moving source

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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

$\Delta \lambda > 0$