Today's Topics

Friday, February 13, 2026 (Week 3, lecture 10) – Chapter 5.

A. Dipole radiation: Why is the sky blue?

B. Light particles: photons

C. Electronic structure of atoms & spectroscopy

D. Doppler effect

E. Nuclear particles

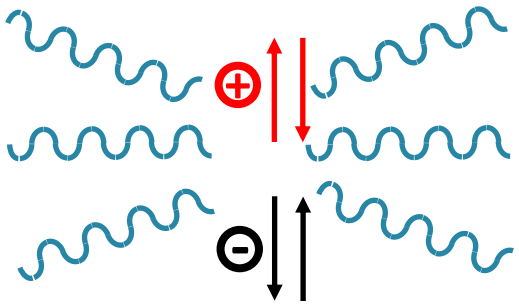
REMINDER #1: ***Problem Set #4*** is due on ExpertTA by Wednesday, February 18, 9:00 AM.

REMINDER #2: **Midterm #1** is on Friday, February 20.

How do you generate light ?

Question: How do you generate an electromagnetic wave?

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



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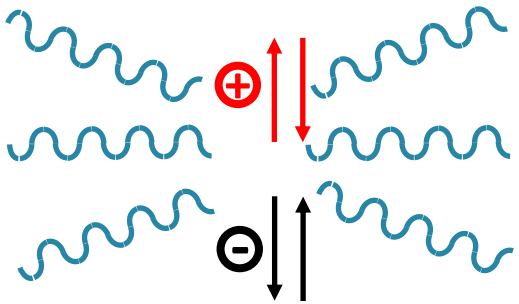
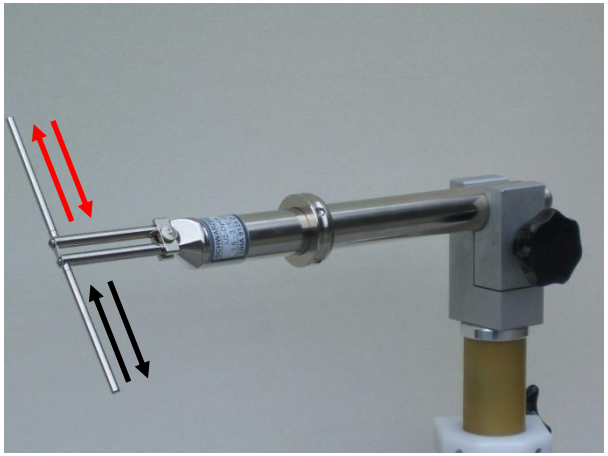
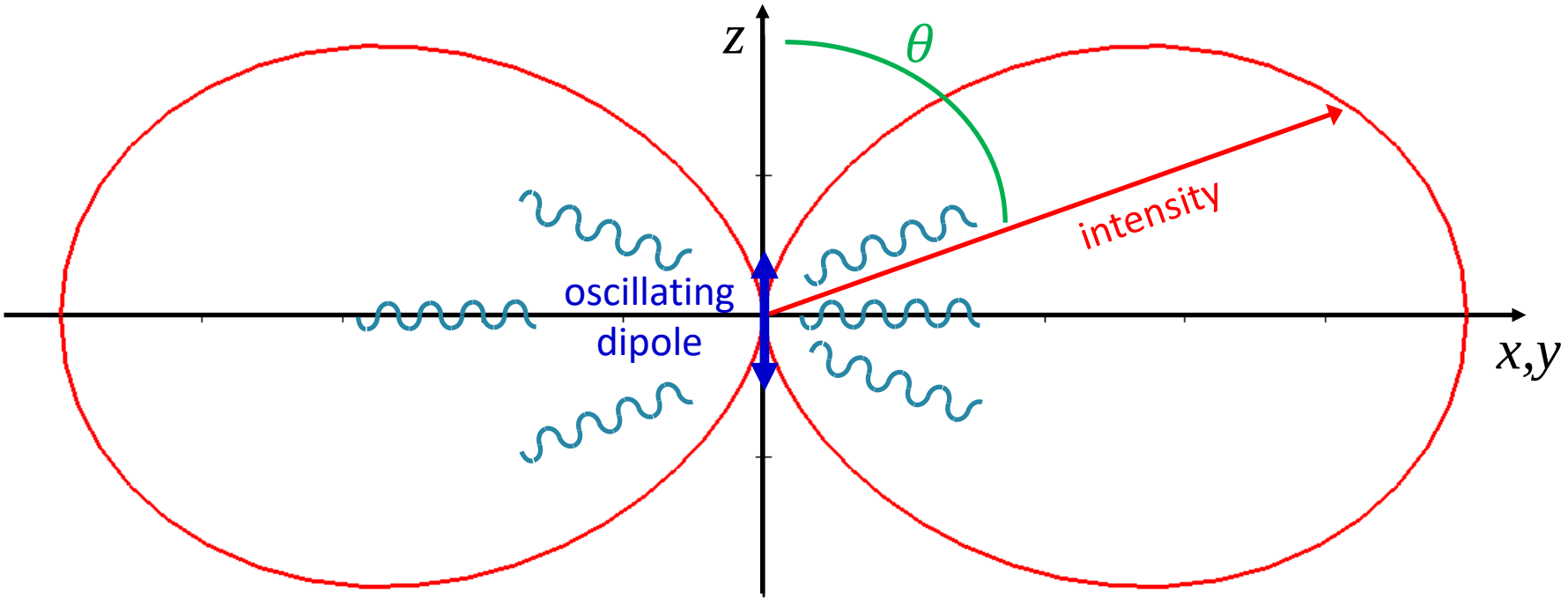




[Schwarzbeck Mess-Elektronik, Wikipedia (2025)]

Dipole Radiation Pattern

dipole moment = p_0 = charge × separation

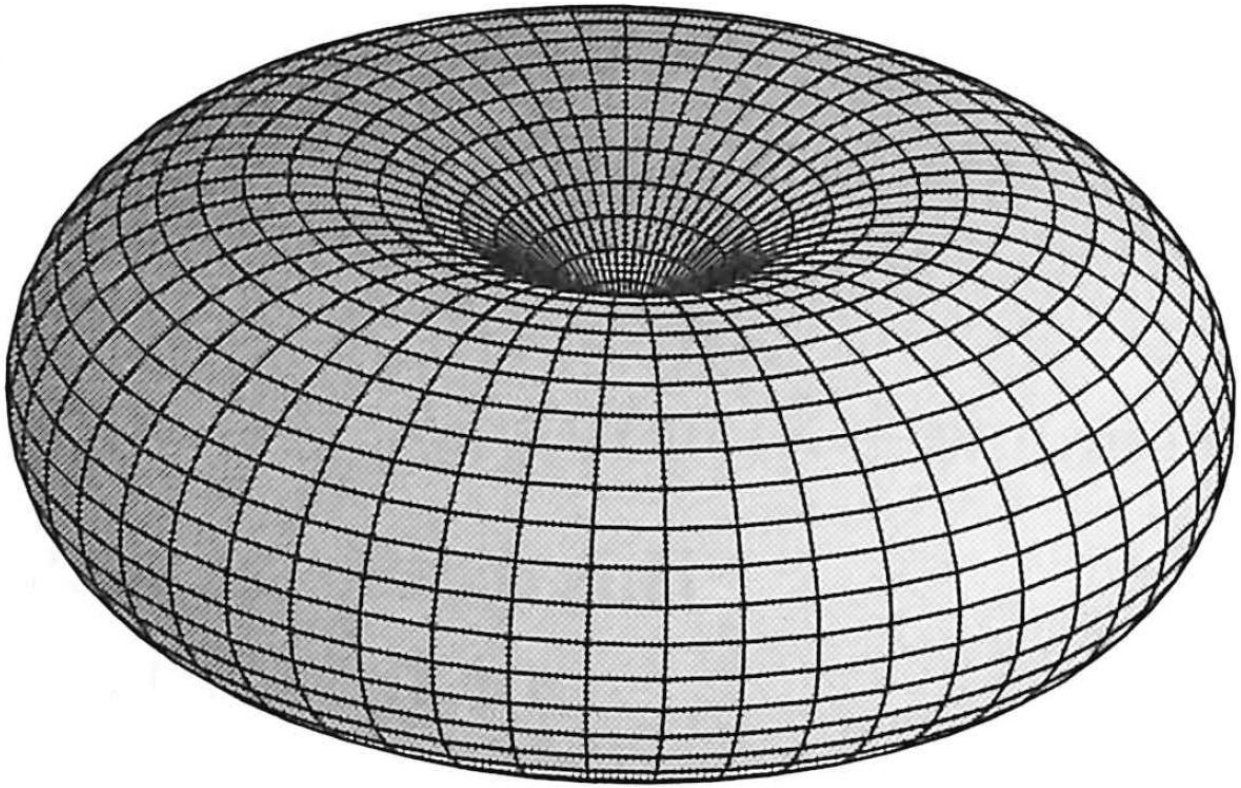


$$Intensity = \frac{\pi^2 p_0^2}{2\epsilon_0 c^3} \cdot f^4 \cdot \frac{\sin^2\theta}{r^2} \qquad \propto f^4 \frac{1}{r^2}$$

r = distance from dipole

f = frequency

Dipole Radiation Pattern



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

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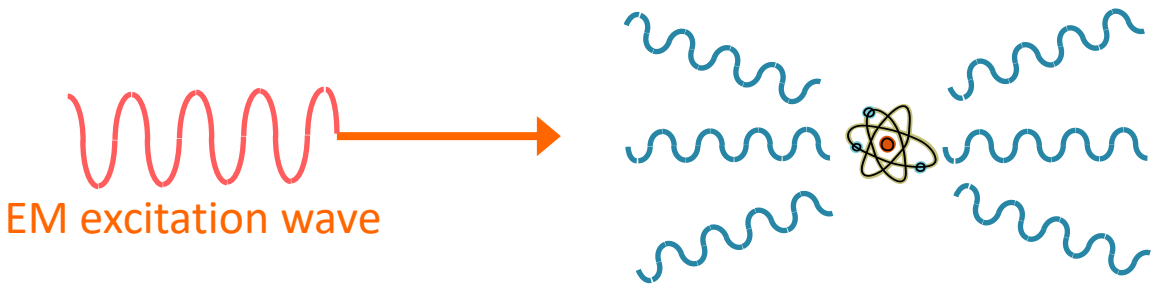
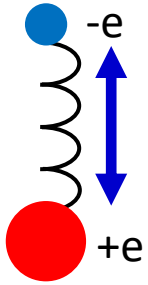
Dipole Radiation Example #1

Atomic fluorescence & photon scattering

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





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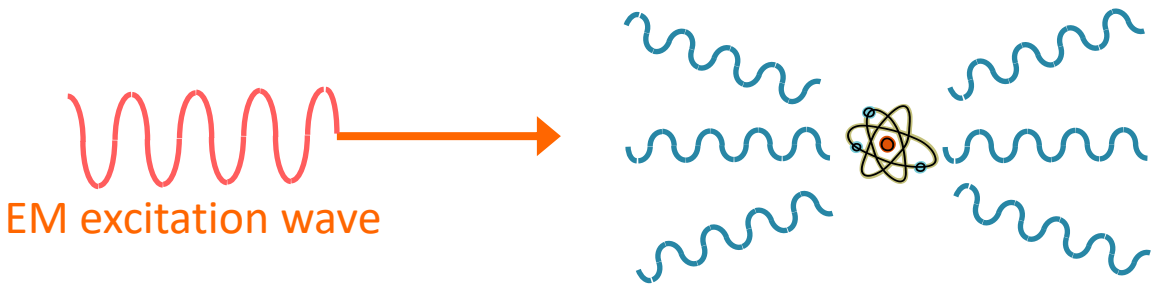
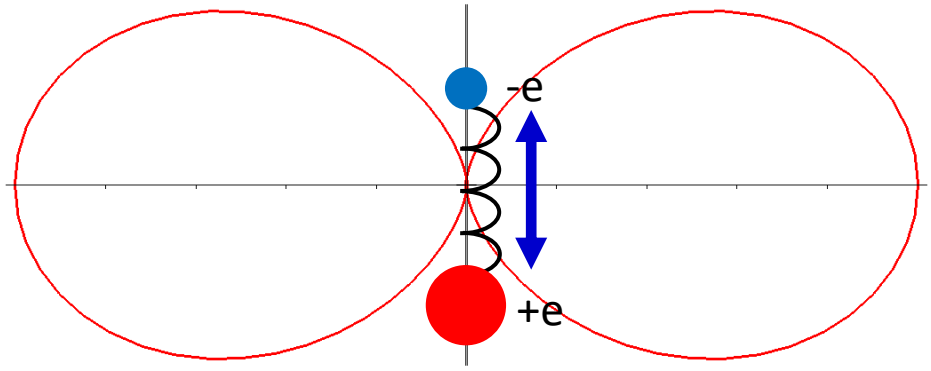


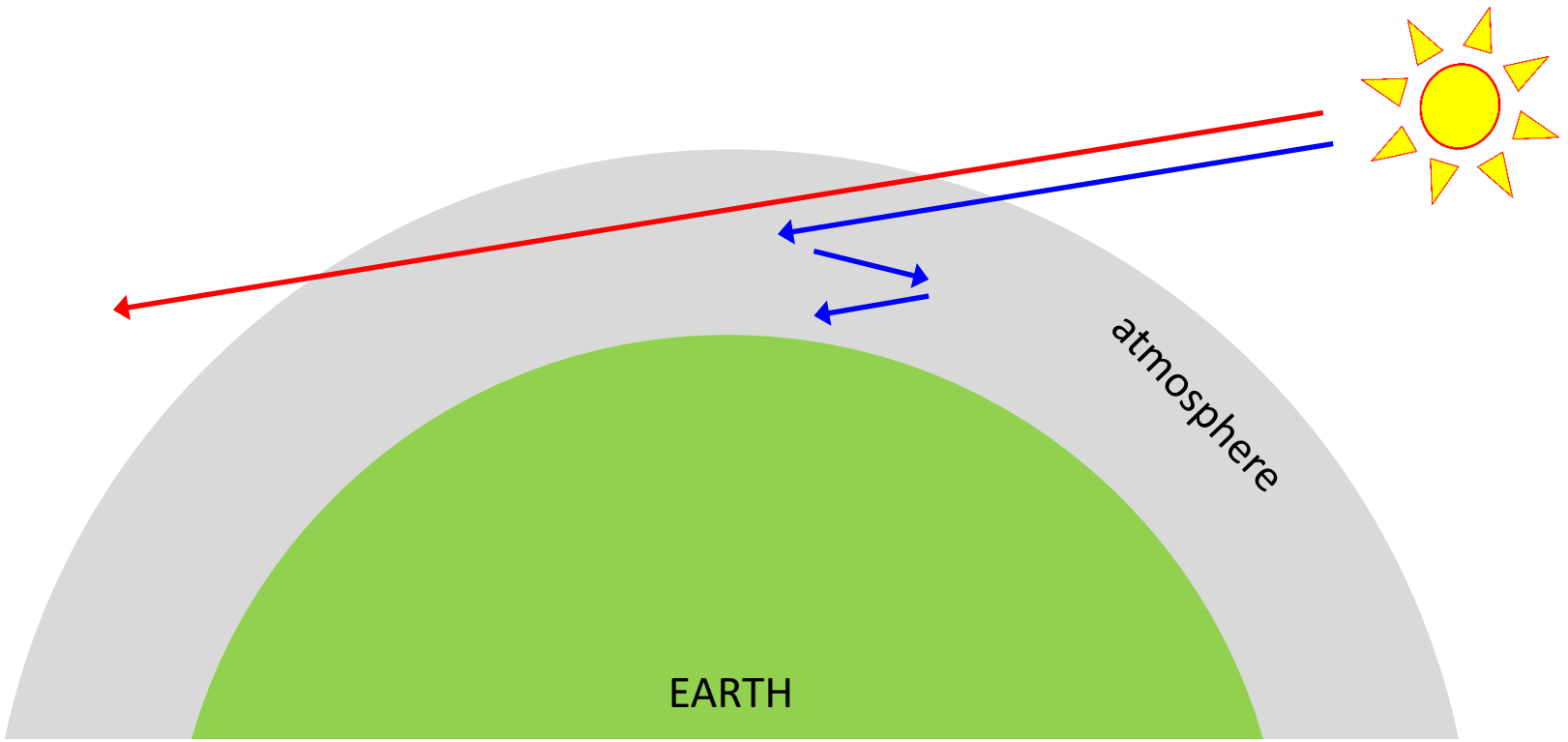
dipole radiation emission pattern



Dipole Radiation Example #2

Blue Sky

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



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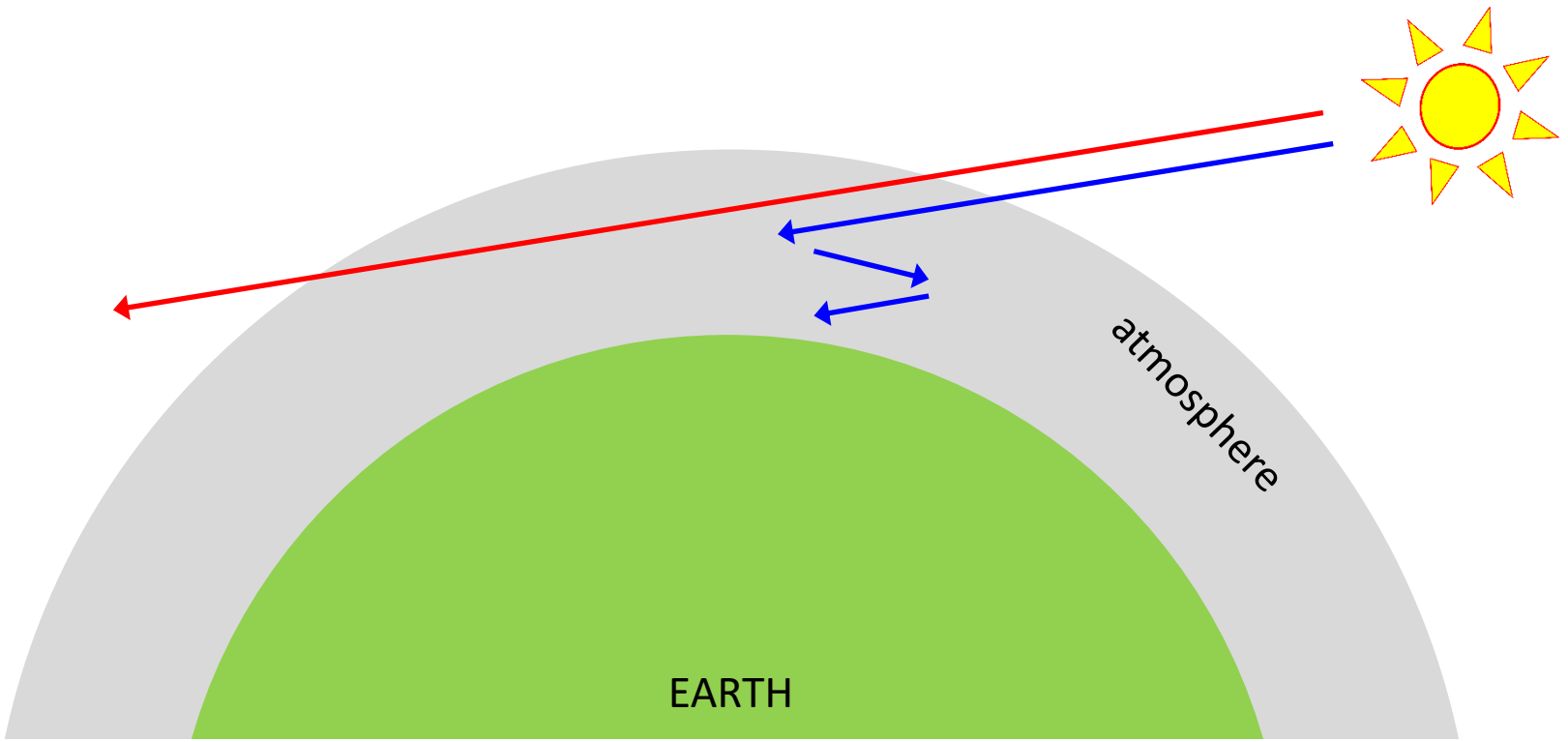

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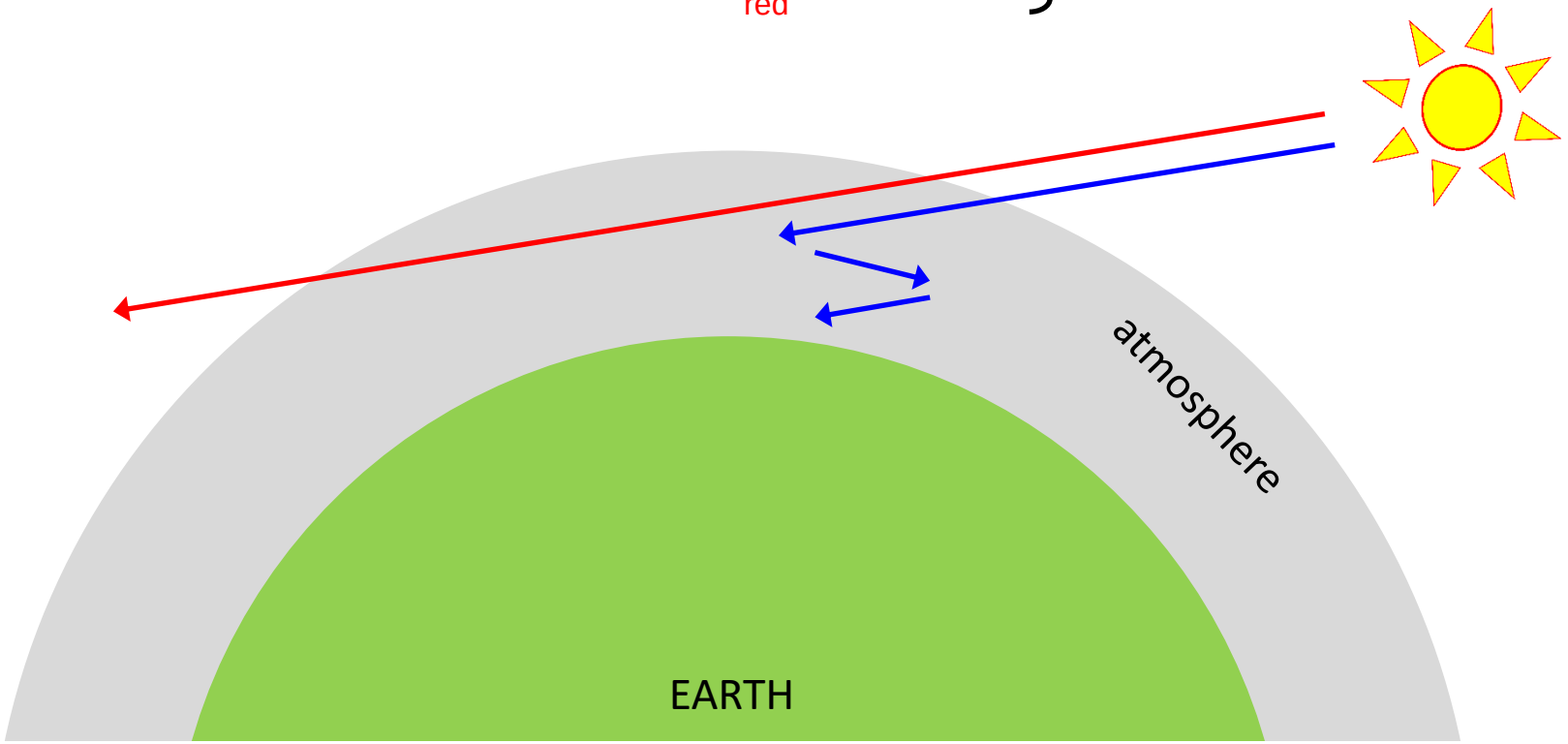
$$Intensity \propto f^4 \propto \frac{1}{\lambda^4} \Rightarrow \left\{ \begin{array}{l} \lambda_{blue} = 450\ nm \\ \lambda_{red} = 650\ nm \end{array} \right. \quad \frac{I_{blue}}{I_{red}} = \left(\frac{650}{450}\right)^4 \approx 4.3$$

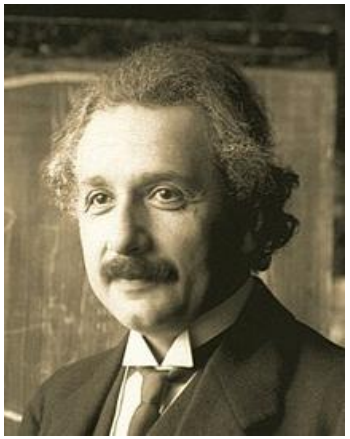


Light is also a particle: the Photon

- **Max Planck** (1858-1947) figured out that light also behaves as a ***particle*** using **blackbody radiation**.

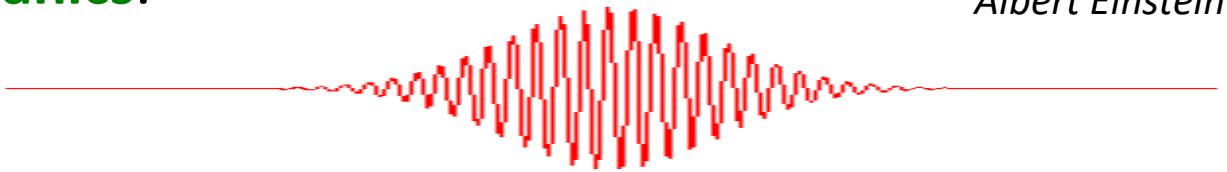
Max Planck

- Albert Einstein (1879-1955) also figured out that light behaves as a **particle** based on the **photo-electric effect**.



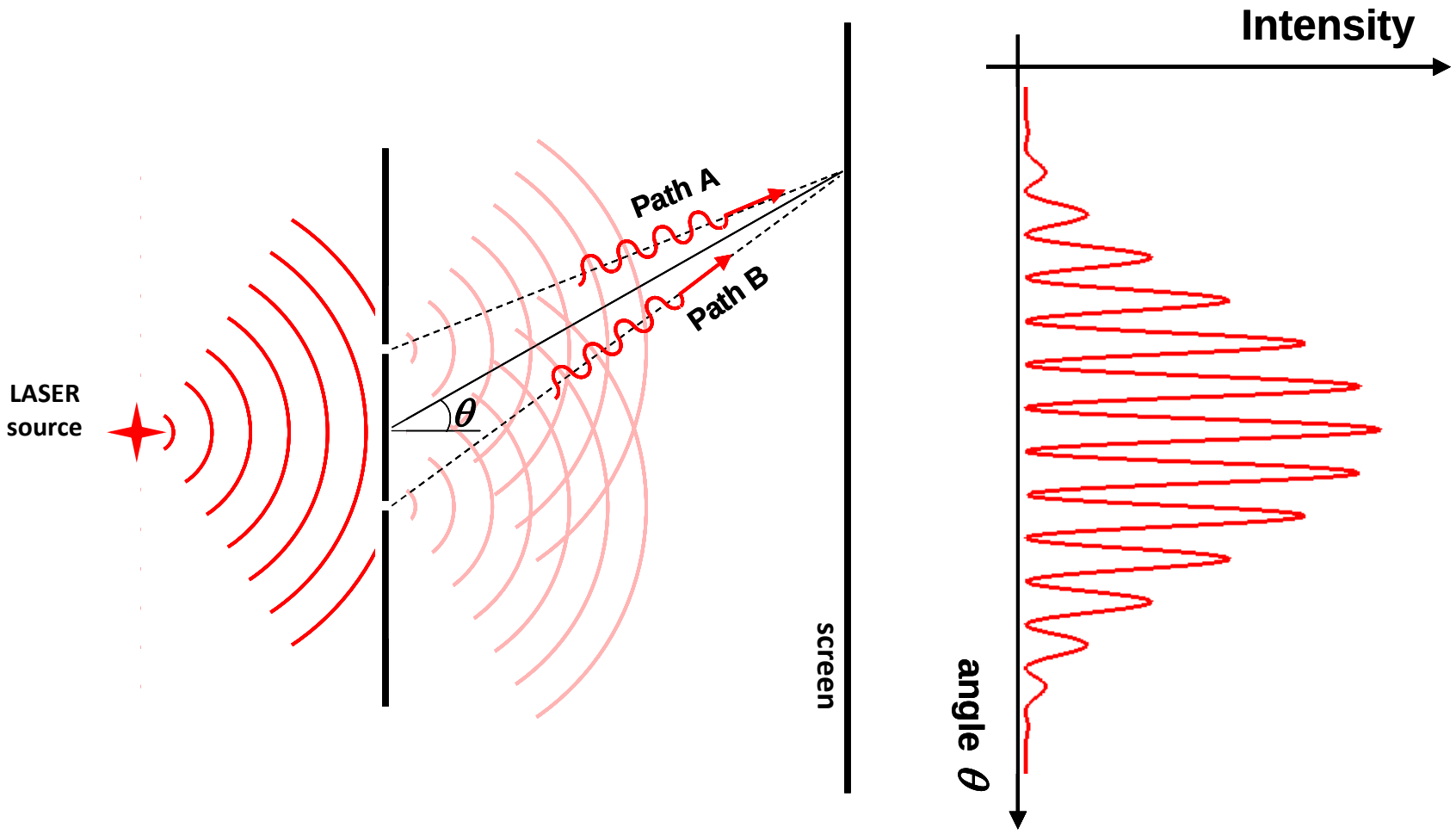
Albert Einstein

- Light particle = photon =packet of EM energy
- Energy $= hf$ (f is the frequency)
  h = Planck's constant = 6.626×10^{-34} J·s
- Discovery of the photon helped initiate **Quantum Mechanics**.

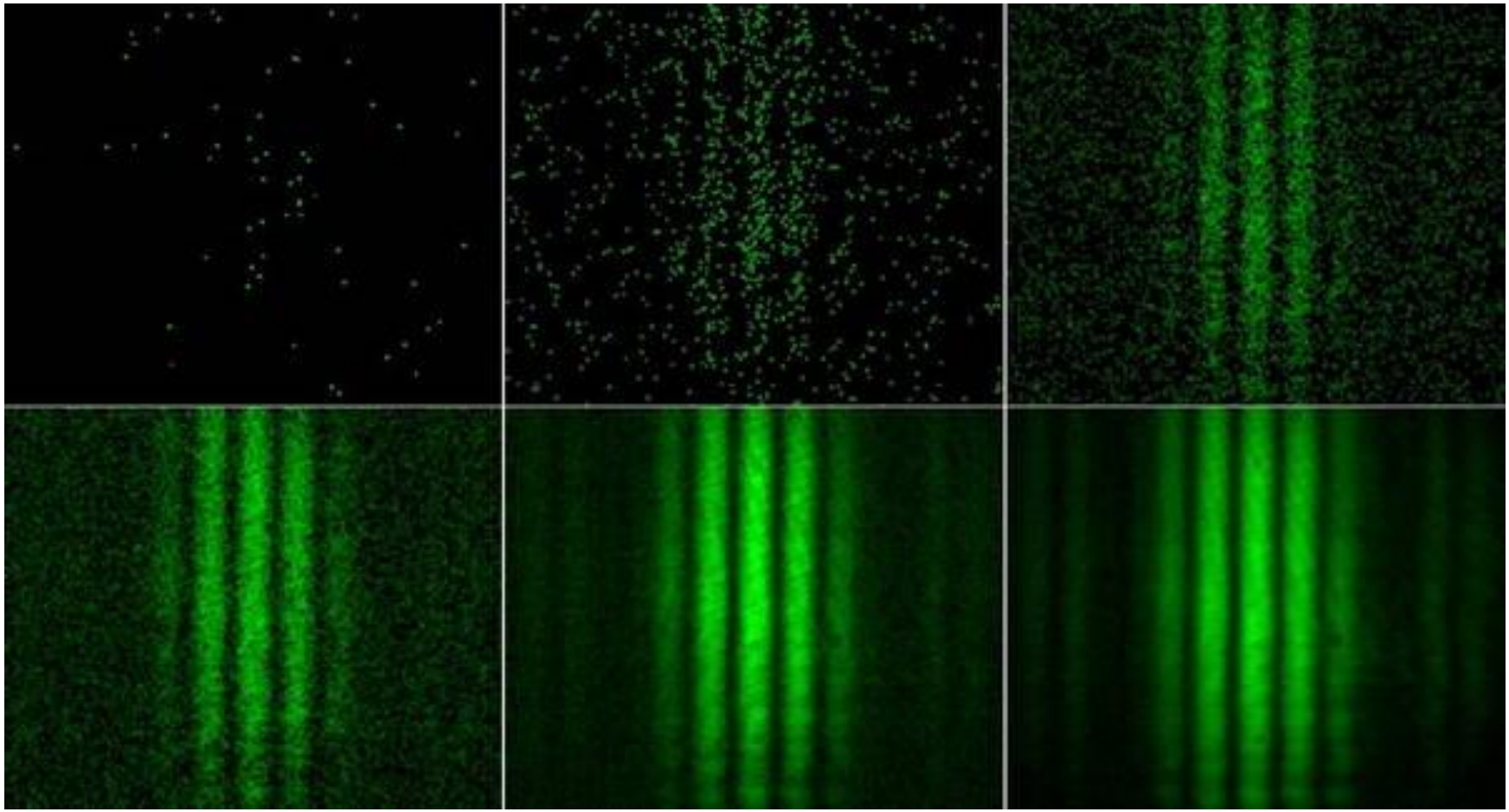


2-slit Interference Experiment

(proof that light is a wave)



Repeat Interference Experiment one photon at a time



[A. L. Weiss and T. L. Dimitrova, Swiss Physics Society, 2009.]

LIGHT IS A

Photon Basics

Photon energy = $E_\gamma = hf$

Important: Photon is massless

$M_\gamma = 0$

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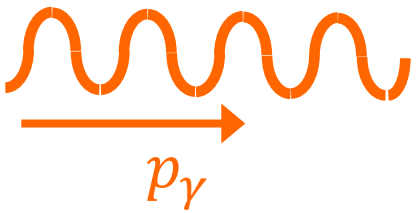
Shine light on an atom



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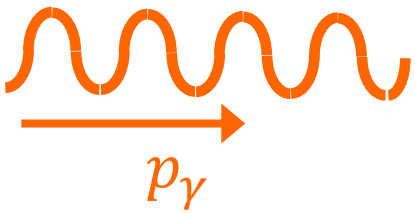

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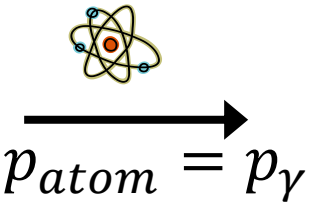
Atom after absorption of 1 photon

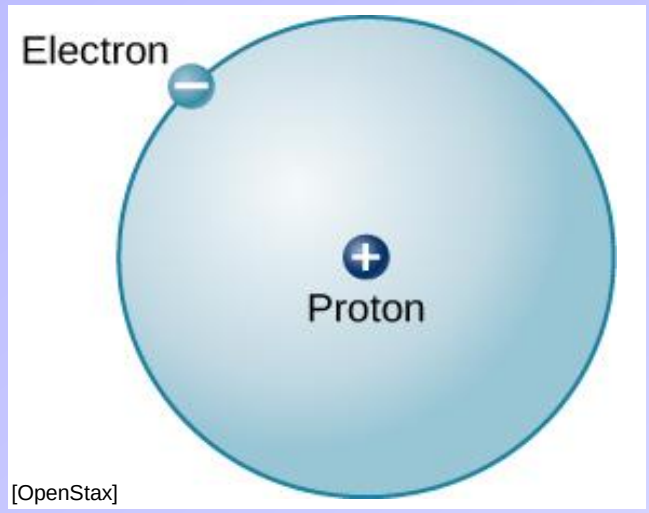


(conservation of momentum)

Basic

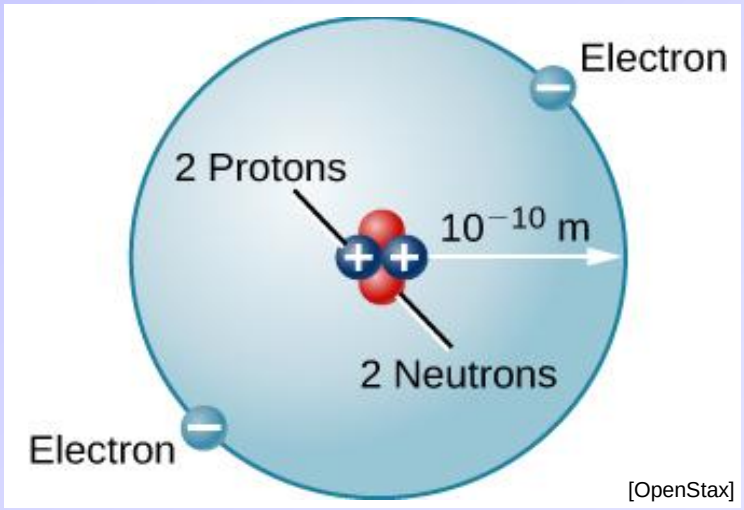
Structure of Atoms

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.

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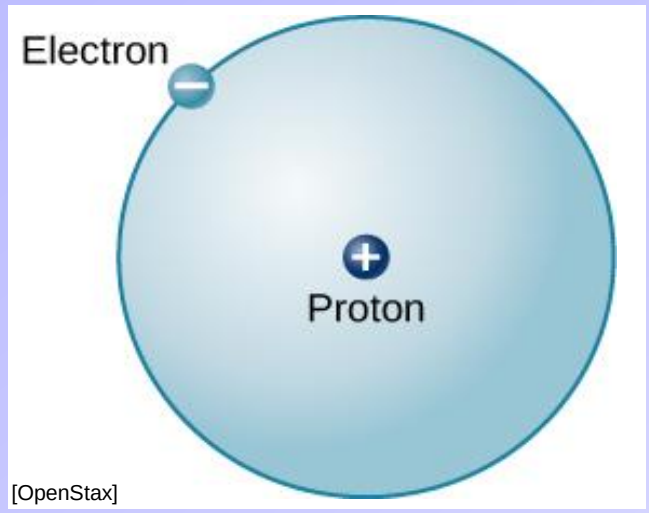

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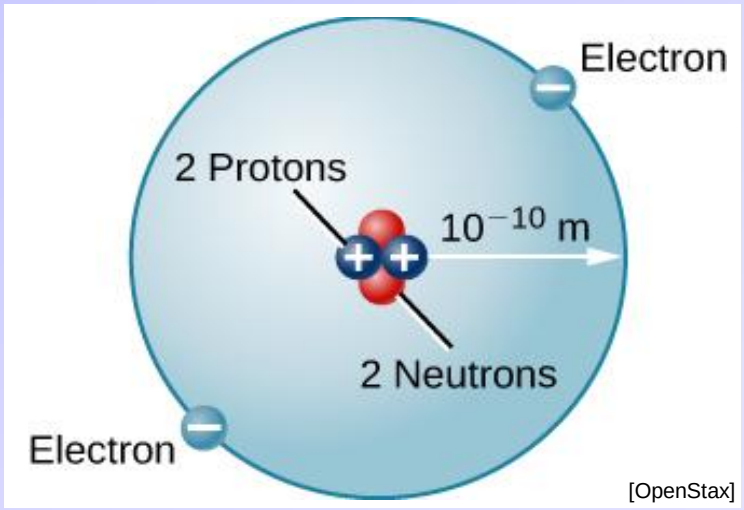

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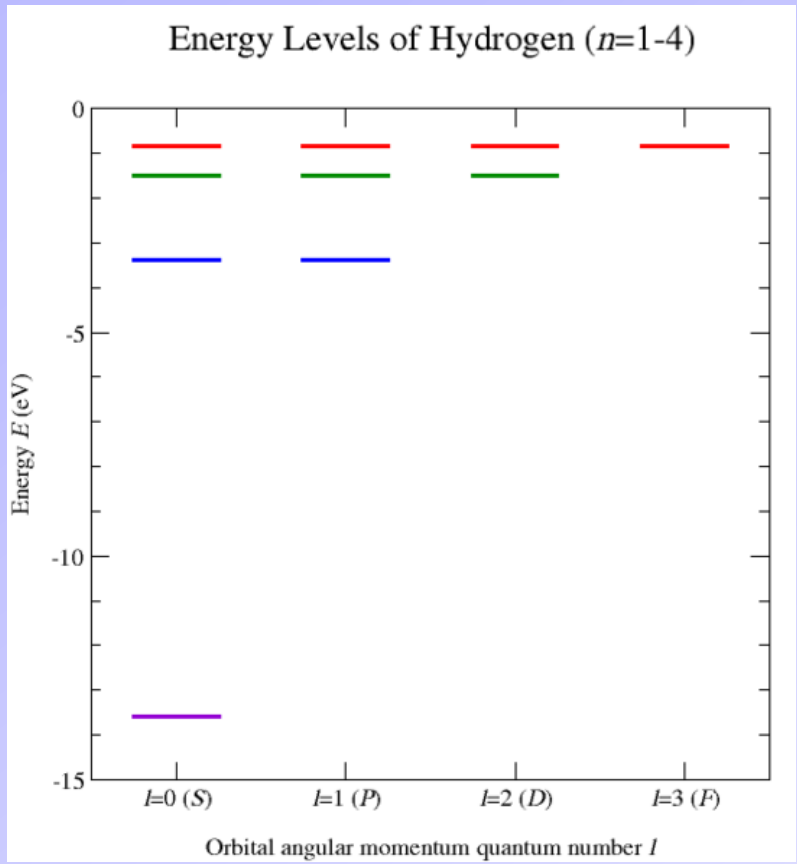
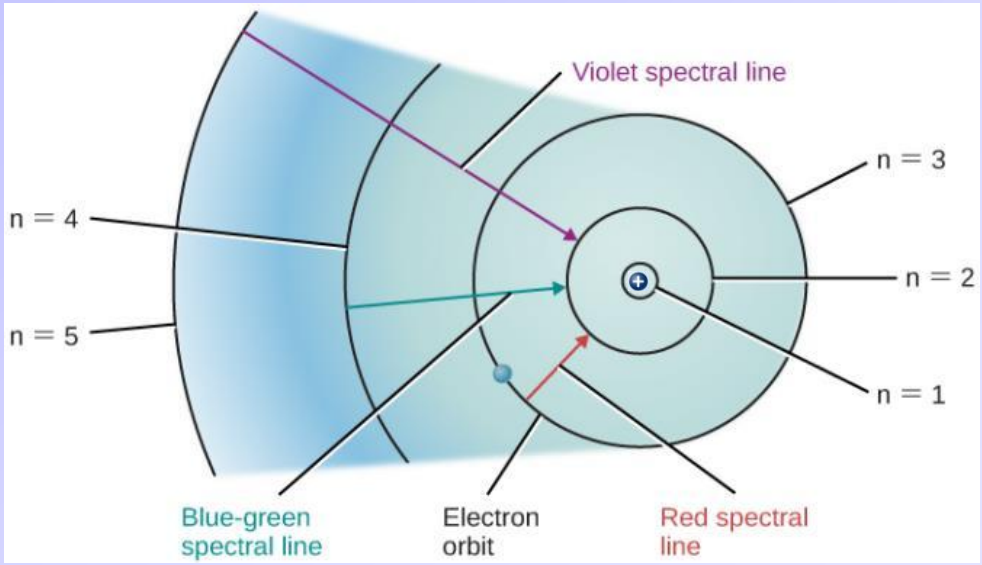
- Electron number, orbits, and properties determine the **chemistry** of the atom.
- **Nucleus** consists of positively charged **protons** and **neutral neutrons**.
- For neutral atoms: ***Number of protons = number of electrons***.
- Neutrons help bind protons together. **Number of neutrons $\gtrsim$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

Electronic Structure of Atoms



[Figure from wikimedia.org]

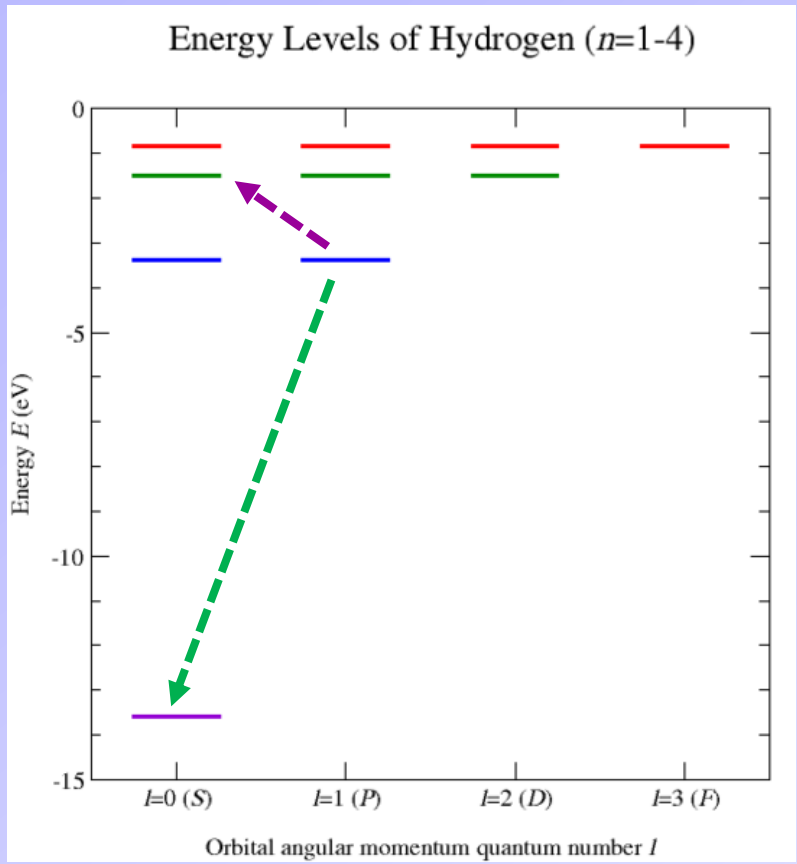


[OpenStax]

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

Note: 1 eV = 1.602×10^{-19} J

Electronic Structure of Atoms



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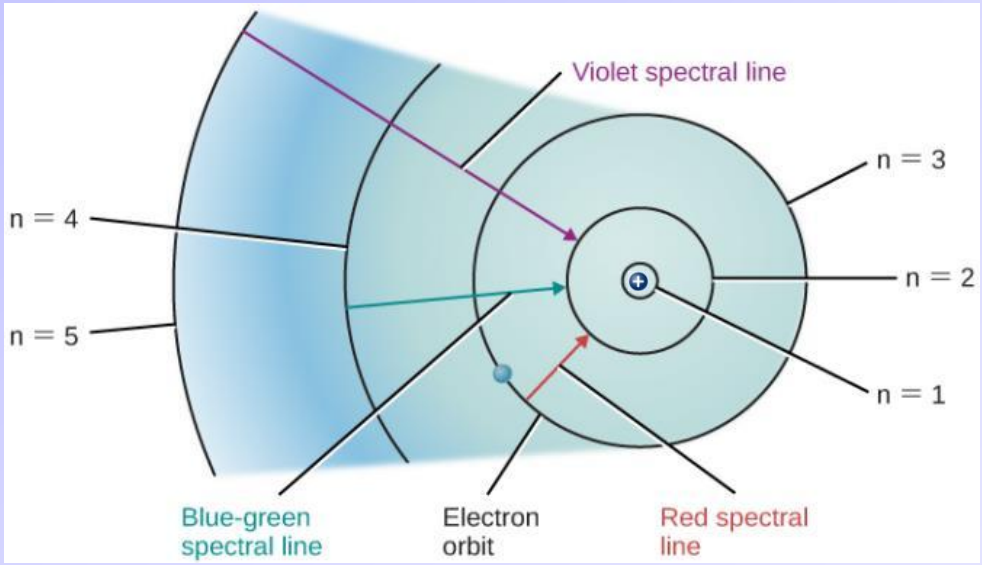
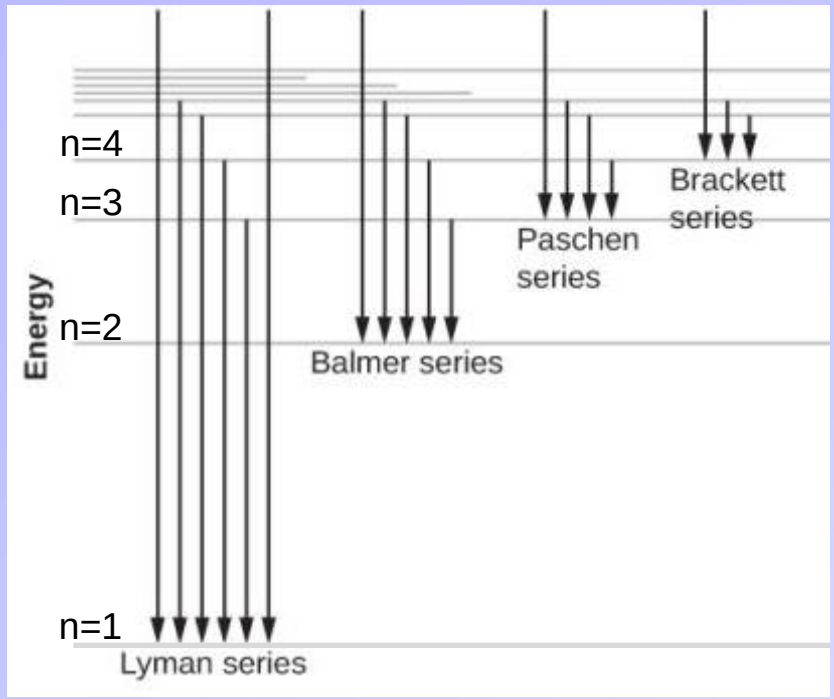
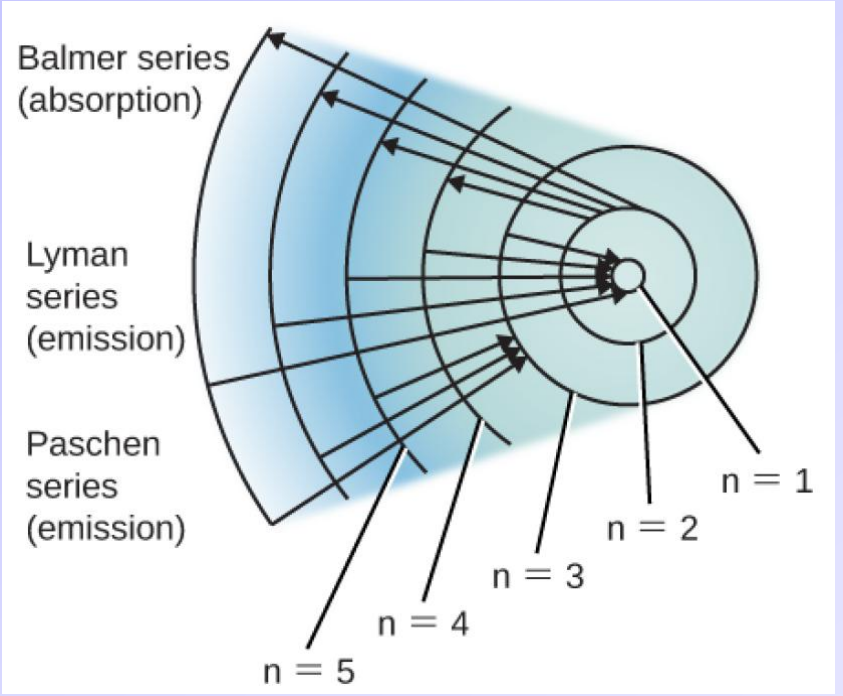


[OpenStax]

- 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**.

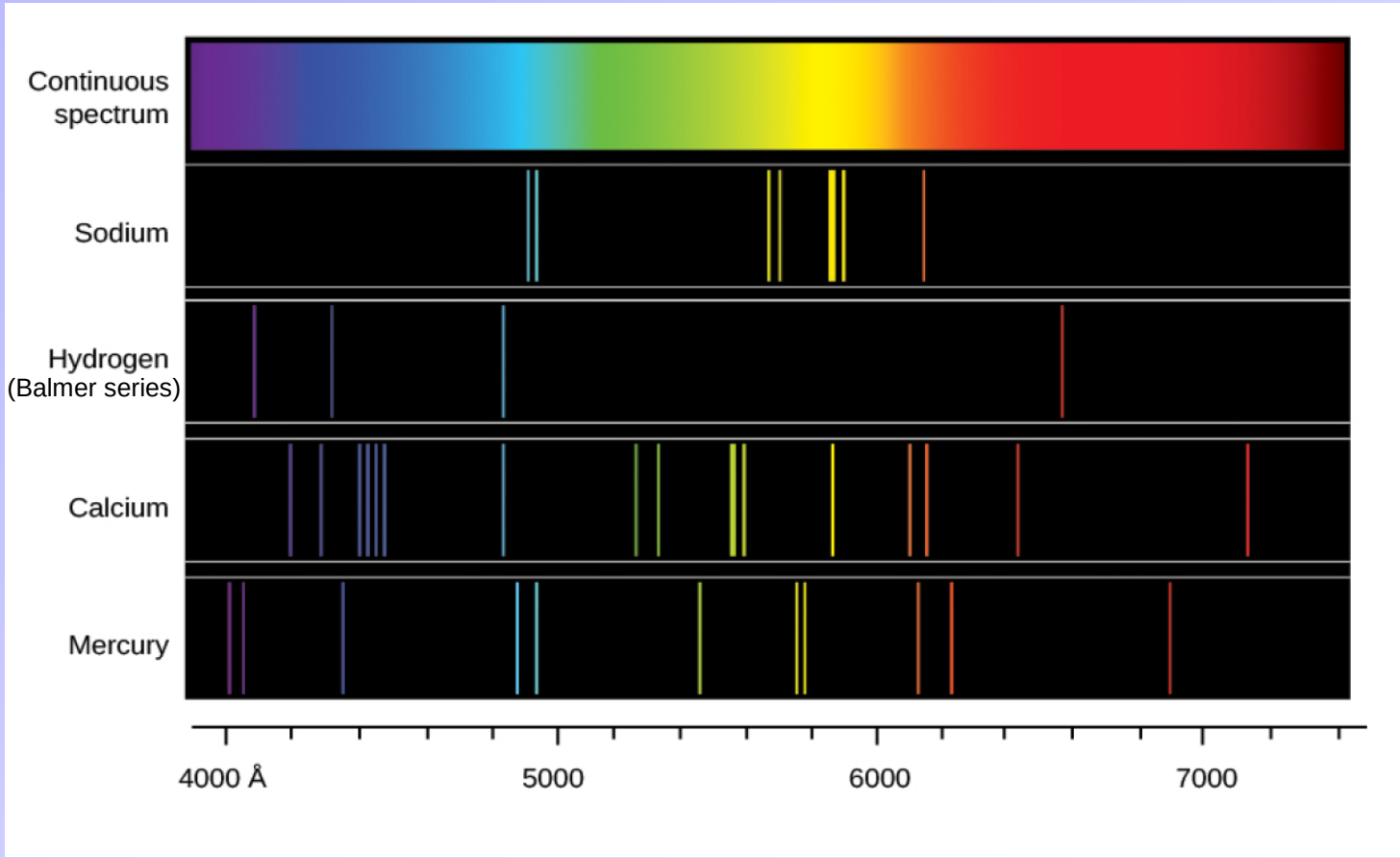
Emission Spectrum of Hydrogen





- 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.

PollEv Quiz: PollEv.com/sethaubin

Identify the element in the lamp:

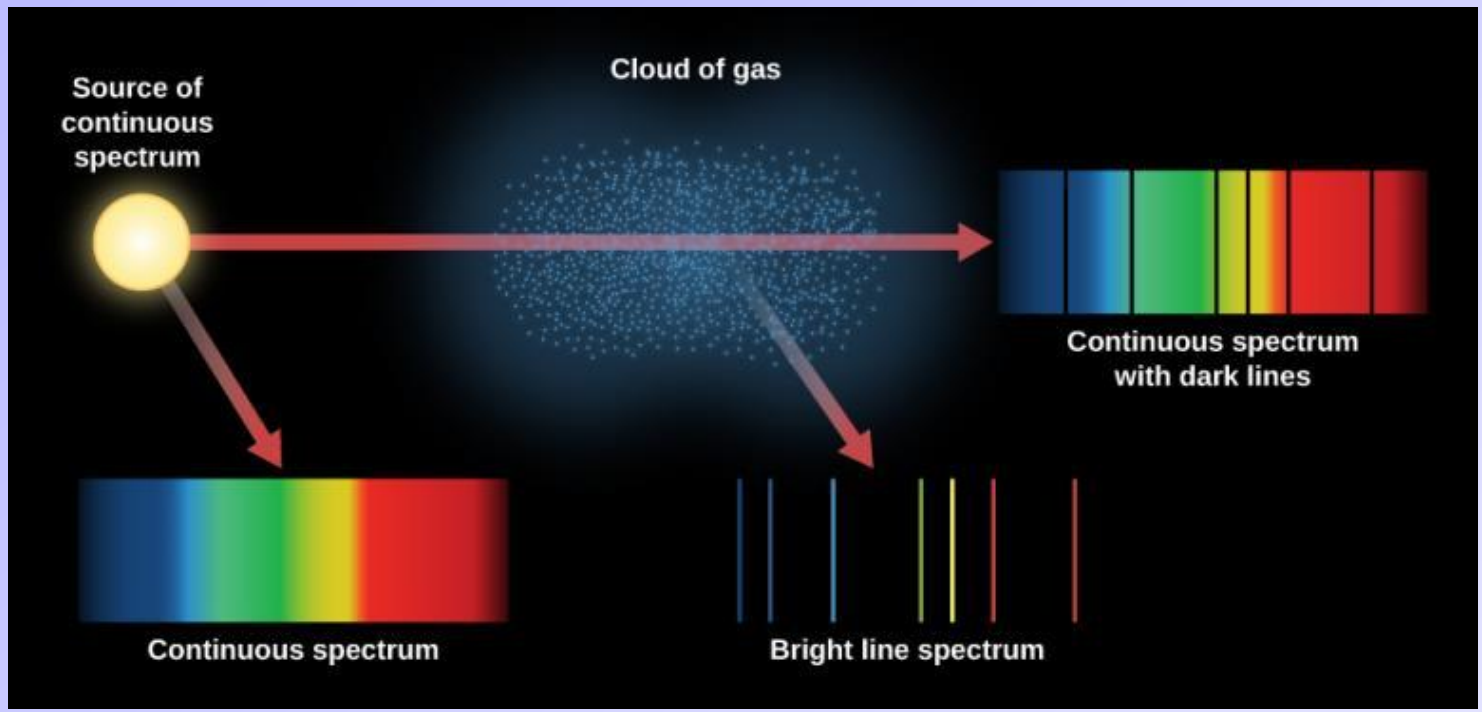
A. Sodium.

B. Hydrogen.

C. Calcium.

D. Mercury.

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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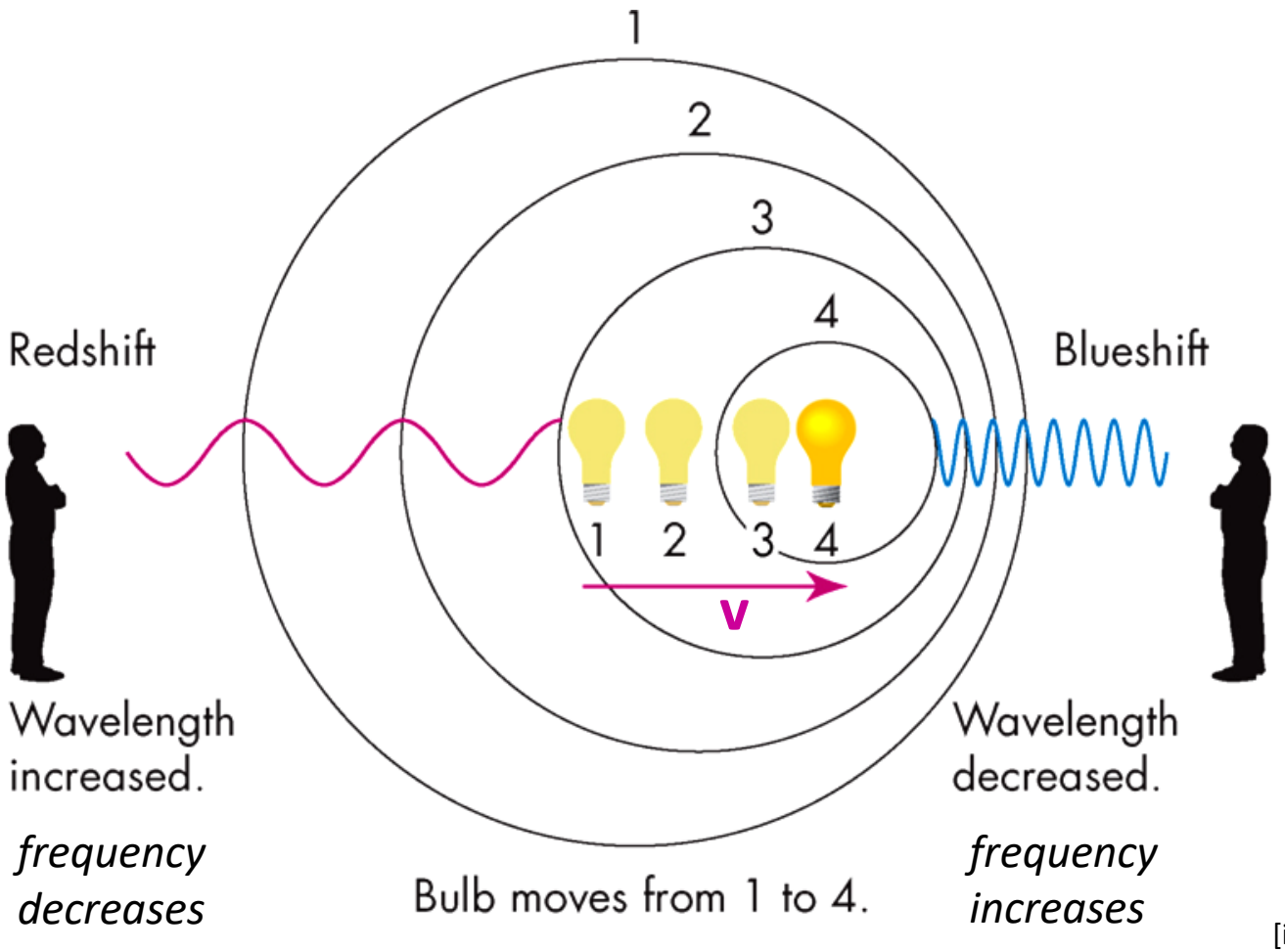

[image source: J. Nelson]

Doppler Effect

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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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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

$\Delta \lambda < 0$

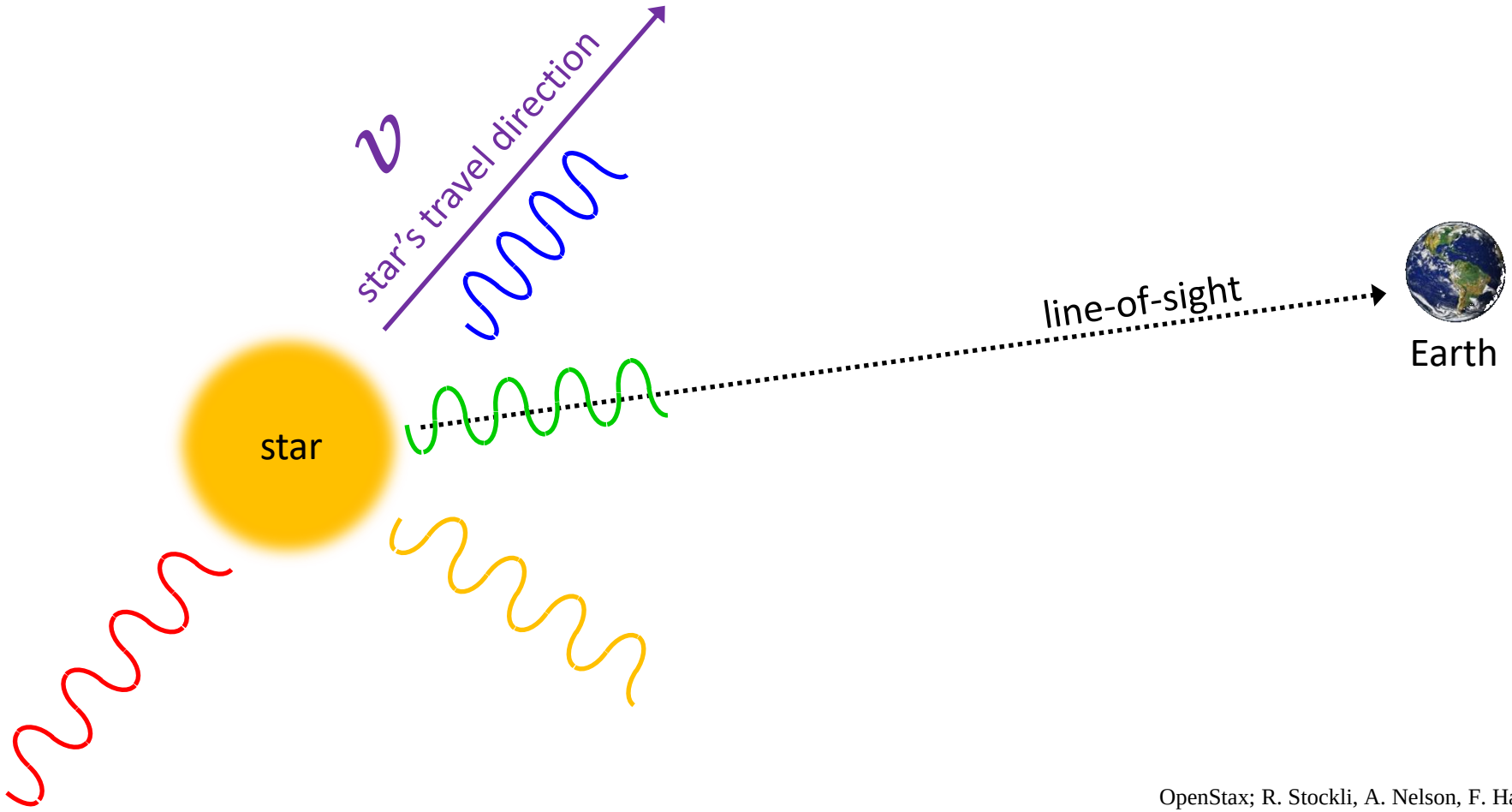
If source is moving away from you, then light is red shifted.

$v < 0$

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

$\Delta \lambda > 0$

Doppler Shift
is for
Line-of Sight Velocity Component



OpenStax; R. Stockli, A. Nelson, F. Hasler, NASA/GSFC/NOAA/USGS)

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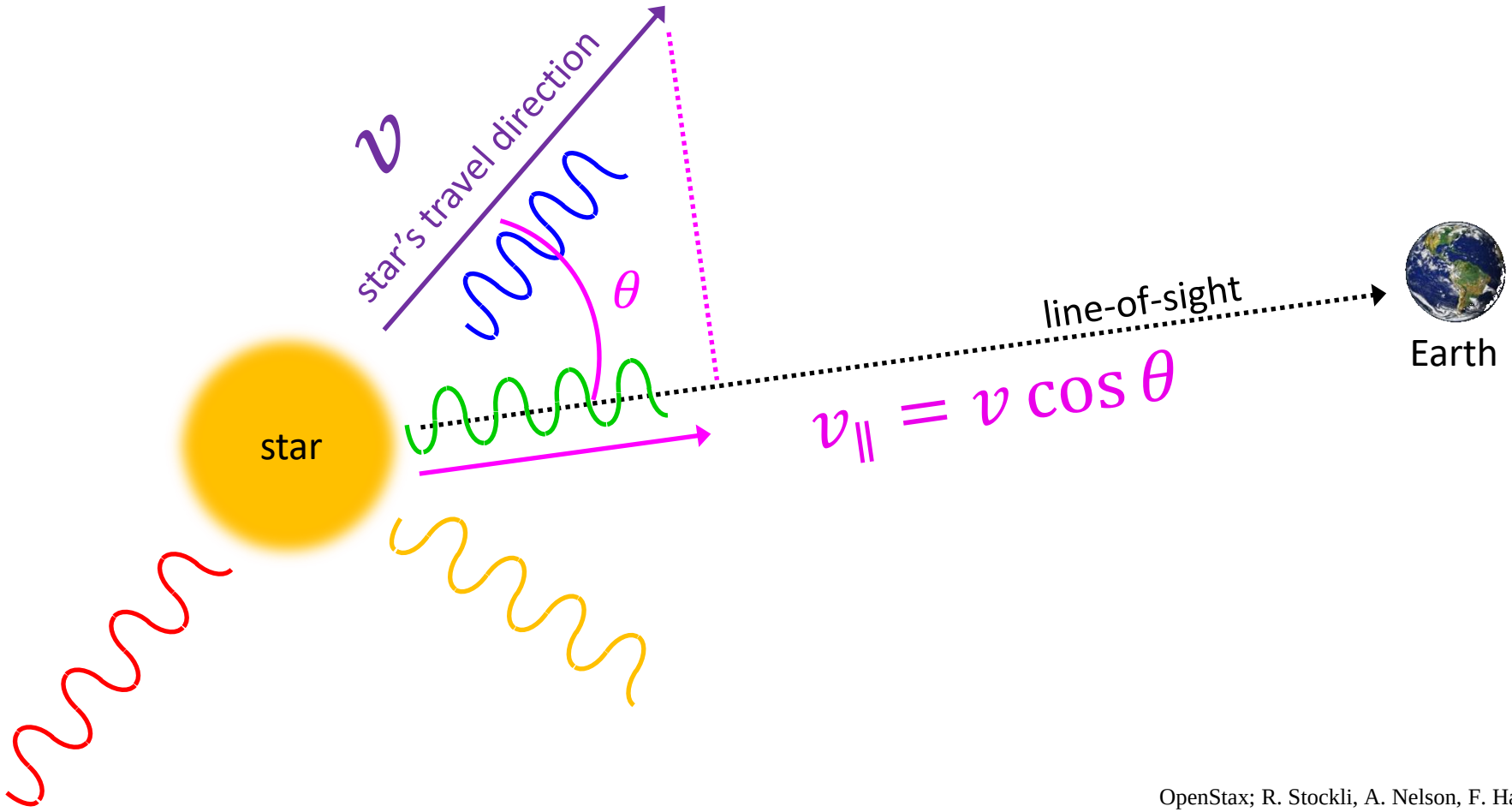

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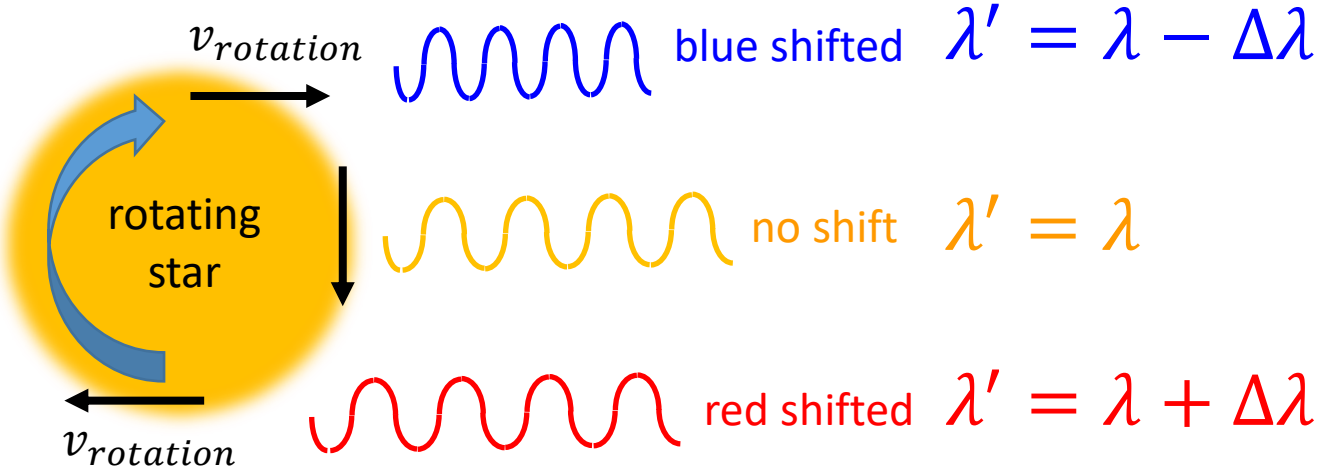
Doppler Shifts for Rotating Sources



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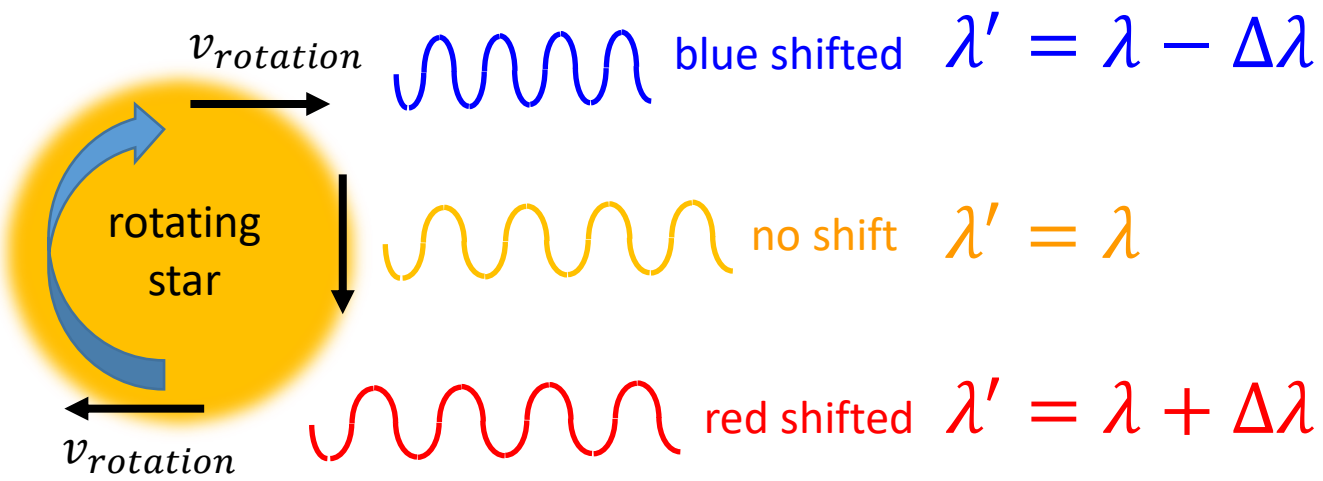

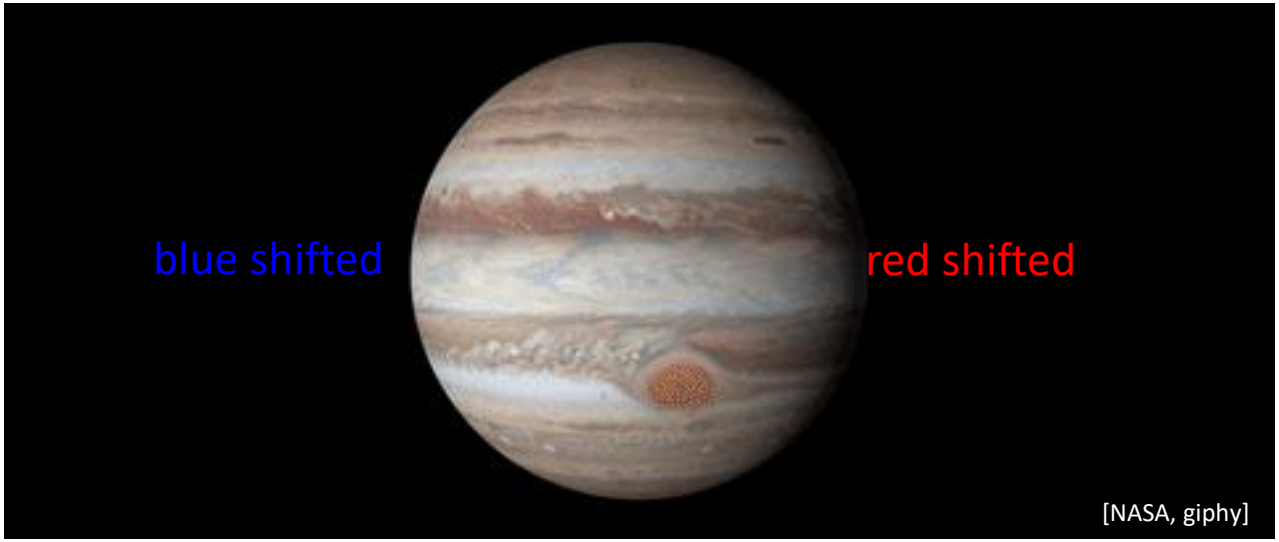

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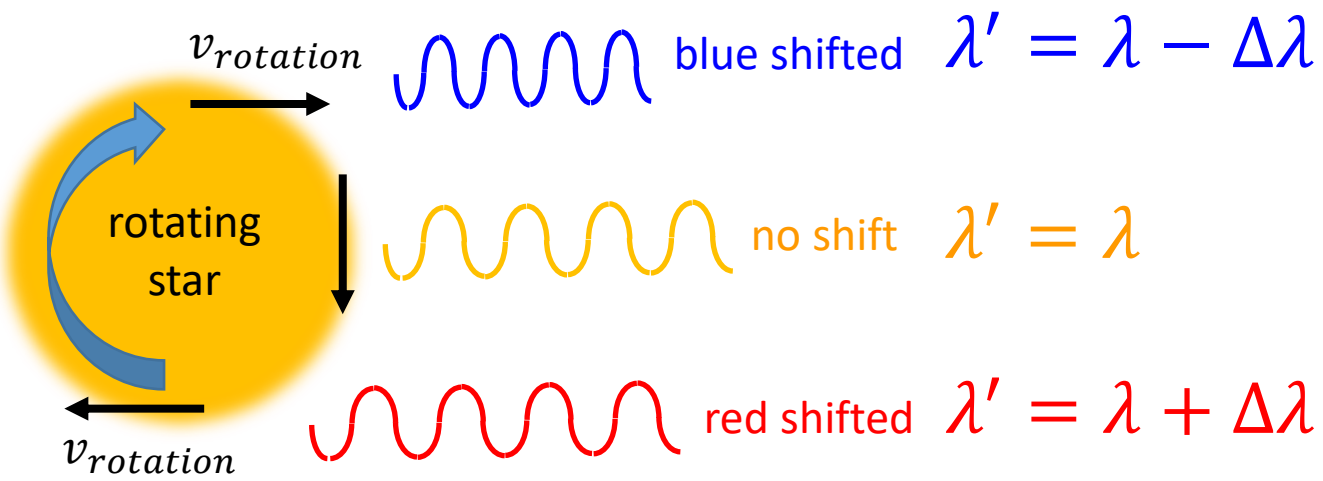

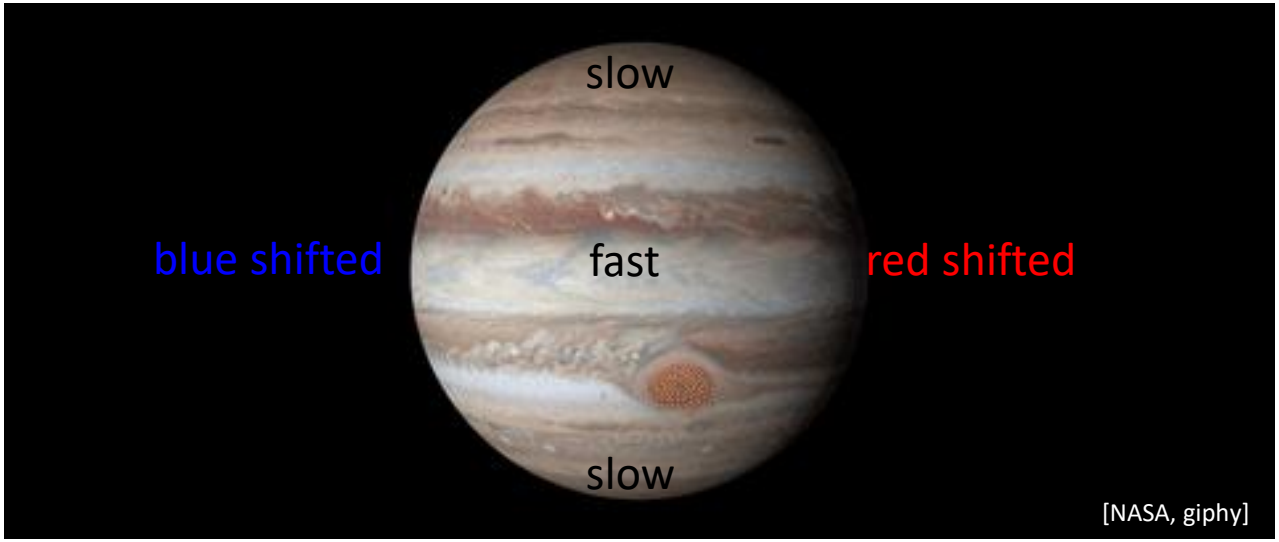

Nuclear Particles

Photons are the easiest particles with which to view space, but they are not the only ones

- Protons (p or p^+), electrons (e or e^-), neutrons (n)
- Alpha particles (α)
- Neutrinos (ν)
- Anti-particles: Positrons (e^+) & anti-protons (p^-)
- Cosmic rays (high energy p^+, p^-, e^+, e^-, α, etc)

Particle Properties

Particle	Mass (kg)	Electric charge	Forces
Proton	1.67265×10^{-27}	+1	Strong, EM, weak, gravity
Neutron	1.67495×10^{-27} $m_n \sim m_p$	0	Strong, weak, gravity
Electron	9.11×10^{-31} $m_e \sim 1/2000\ of\ m_p$	-1	EM, weak, gravity
Neutrino	$< 2 \times 10^{-36}$	0	weak, gravity

barely interacts with anything !!! (very hard to detect)

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Fundamental forces

There are only 4 fundamental forces that we know of:

Strong nuclear force, electromagnetic force, weak nuclear force, gravity.

(holds nucleus together) [short range]

(generates radioactive decay) [short range]

(very very weak)