Today's Topics

Friday, February 14, 2025 (Week 3, lecture 10) – Chapter 5.

A. Light particles: photons

B. Electronic structure of atoms & spectroscopy

C. Doppler effect

D. Nuclear particles

REMINDER #1: ***Problem Set #4*** is due on ExpertTA by Wednesday, February 19, 9:00 AM.

REMINDER #2: **Midterm #1** is on Friday, February 21.

Light is also a particle: the Photon

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

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

➢ Light particle = photon =packet of EM energy

➢ Energy $= hf$ (f is the frequency)
$h =$ Planck's constant = 6.626×10^{-34} J·s
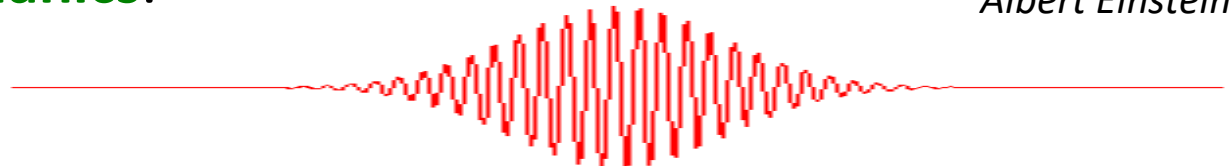
➢ Discovery of the photon helped initiate **Quantum Mechanics**.
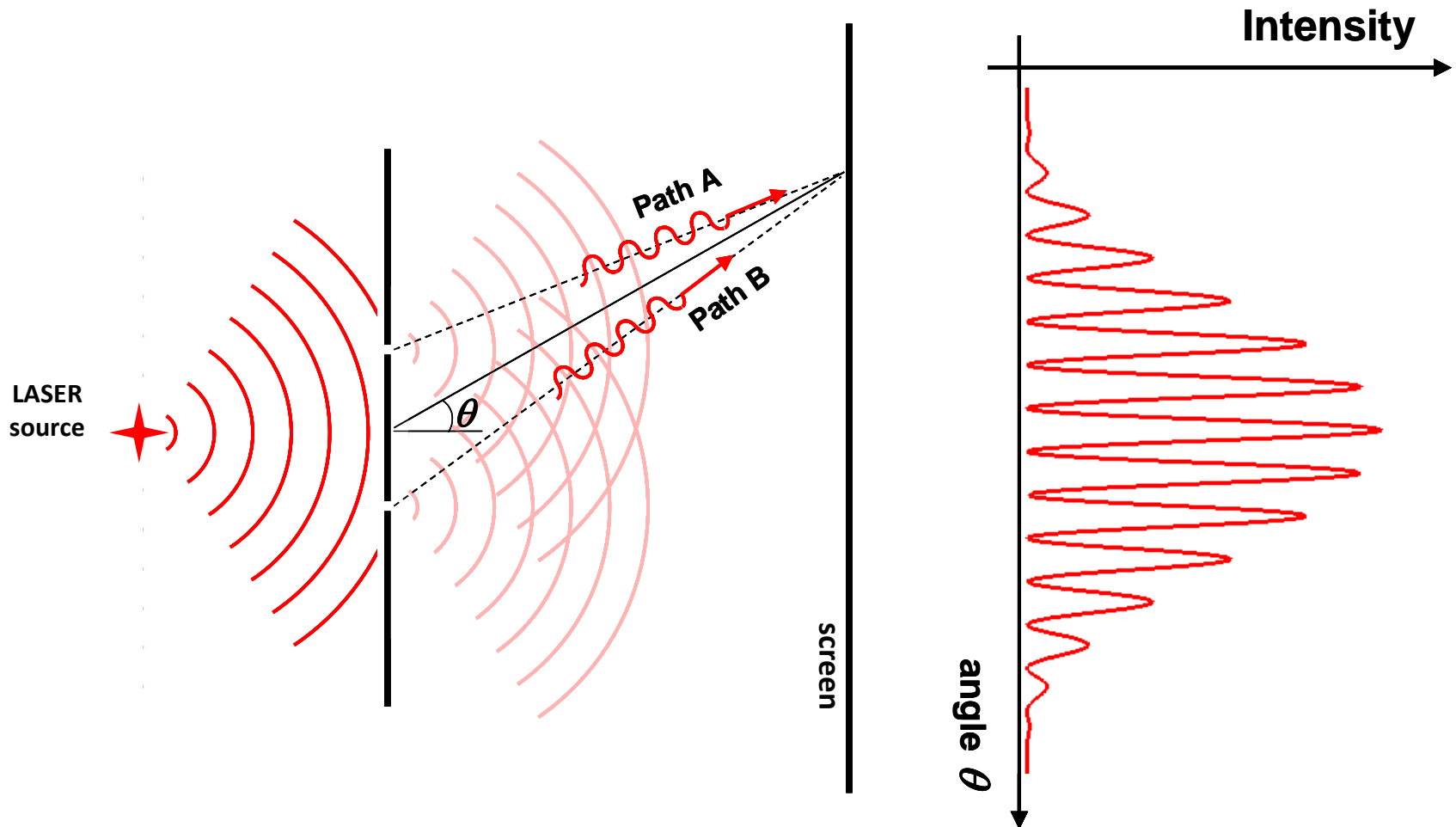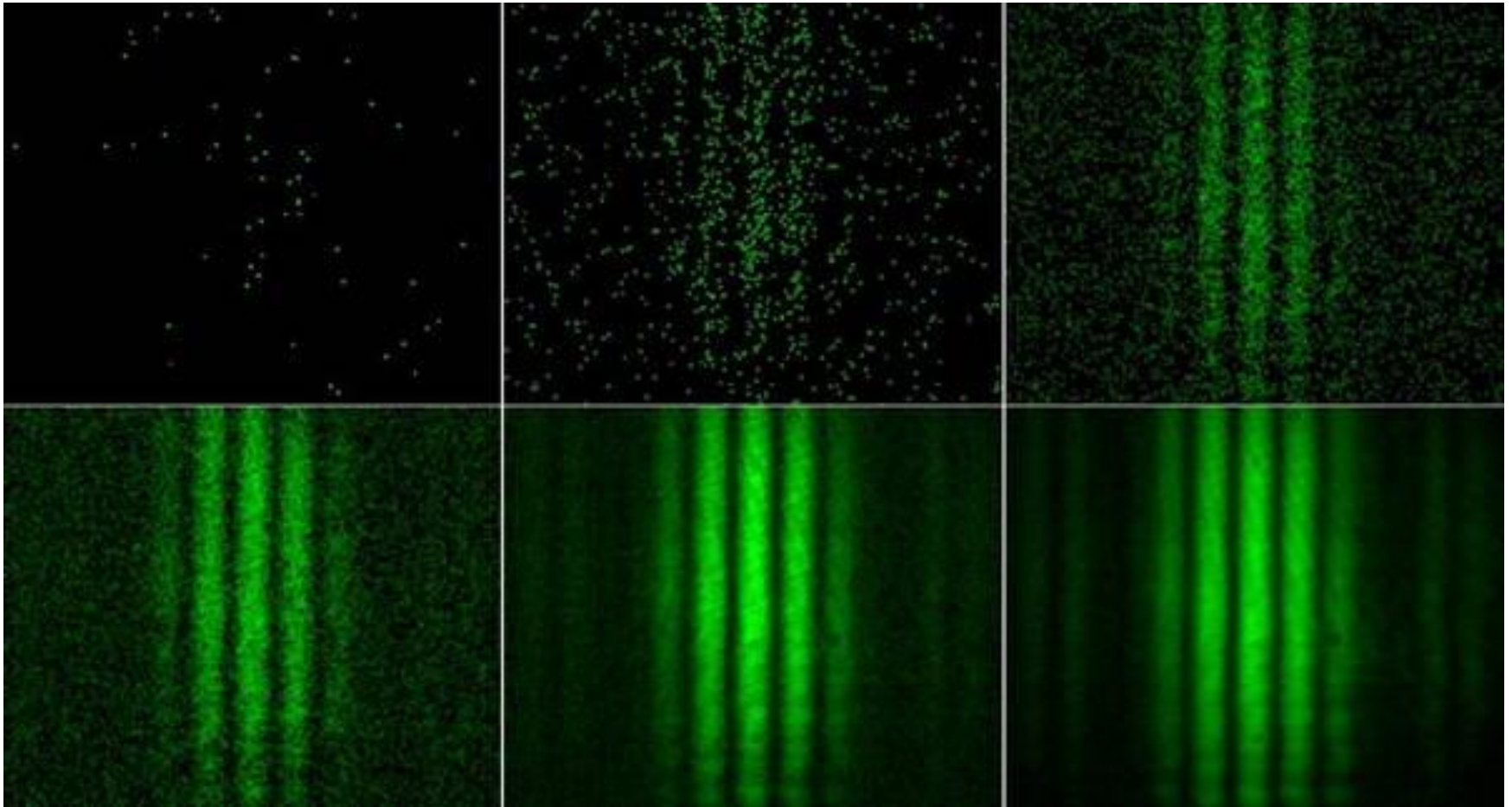
Max Planck
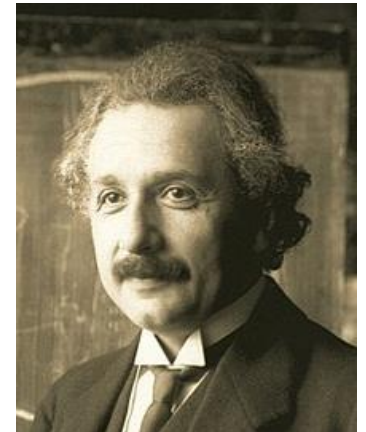
Albert Einstein

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

WAVE!

Photon Basics

Photon energy = $E_\gamma = hf$

Important: Photon is massless
$$M_\gamma = 0$$

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Photon momentum = $p_\gamma = \dfrac{h}{\lambda} = \dfrac{E_\gamma}{c}$

Note: $p_\gamma \neq M_\gamma c \ (= 0)$

Photon Basics
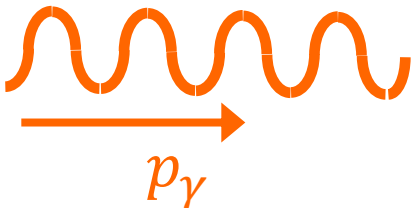
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Shine light on an atom

p_γ

$p_{atom} = 0$

Photon Basics
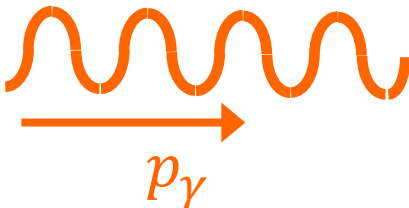
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Shine light on an atom

Atom after absorption of 1 photon

p_γ
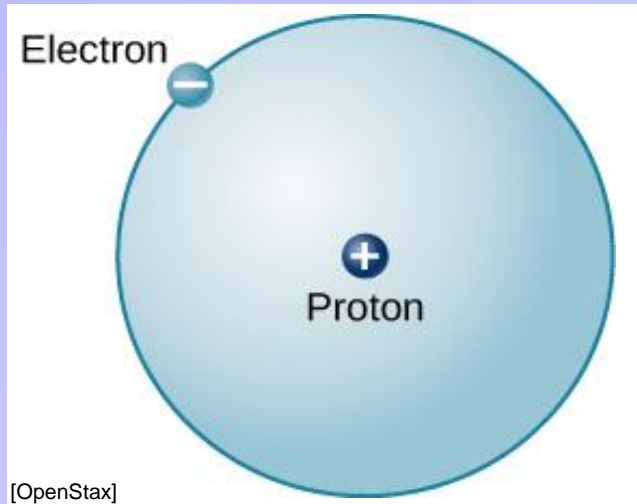
$p_{atom} = 0$

$p_{atom} = p_\gamma$

(conservation of momentum)

Basic Structure of Atoms
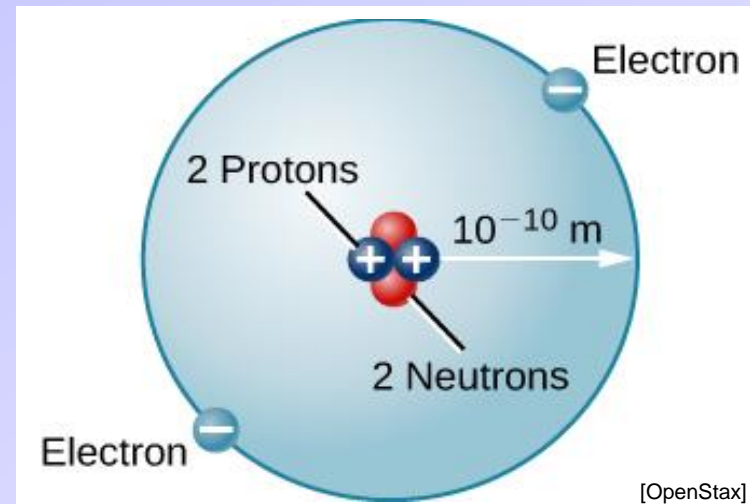
Hydrogen: ^{1}H

Helium: ^{4}He

$4 = $ *2 protons*
+ 2 neutrons

Electron
Proton

Electron
2 Protons
10^{-10} m
2 Neutrons
Electron

[OpenStax]

[OpenStax]

➢ Atom consist of **positively charged nucleus** orbited by **negatively charged electrons** (for neutral atoms: total charge = zero).

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

Basic Structure of Atoms
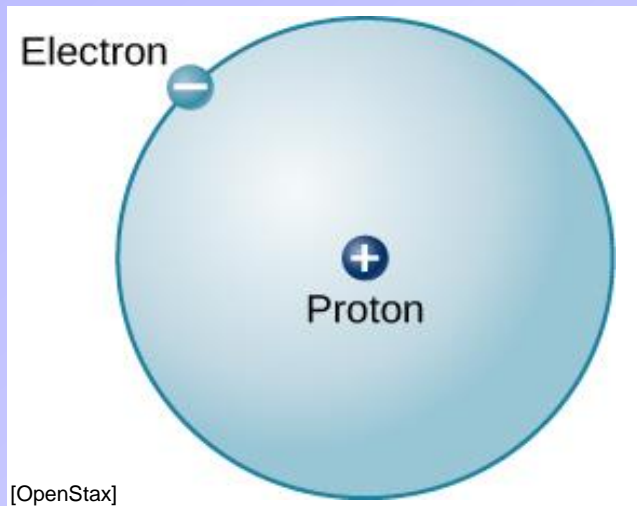
Hydrogen: ^{1}H

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Electron — Proton
[OpenStax]

Electron — 2 Protons — 10^{-10} m — 2 Neutrons — Electron
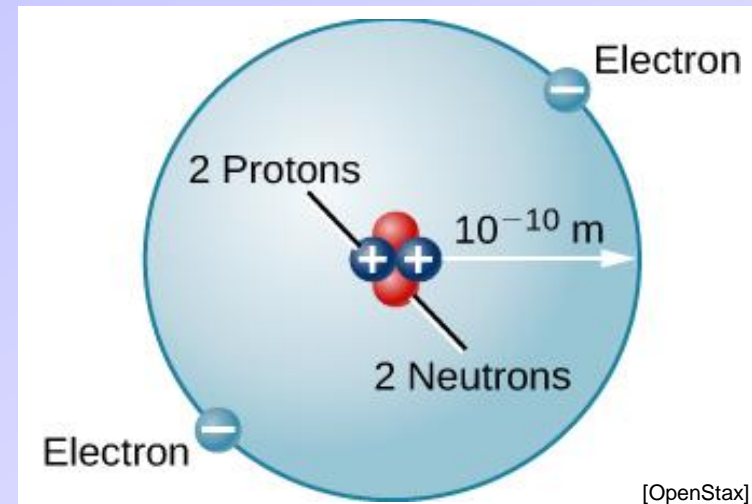[OpenStax]

- ➢ Atom consist of **positively charged nucleus** orbited by **negatively charged electrons** (for neutral atoms: total charge = zero).

- ➢ 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 ≳ number of protons.**

Electronic Structure of Atoms

Energy Levels of Hydrogen (n=1-4)
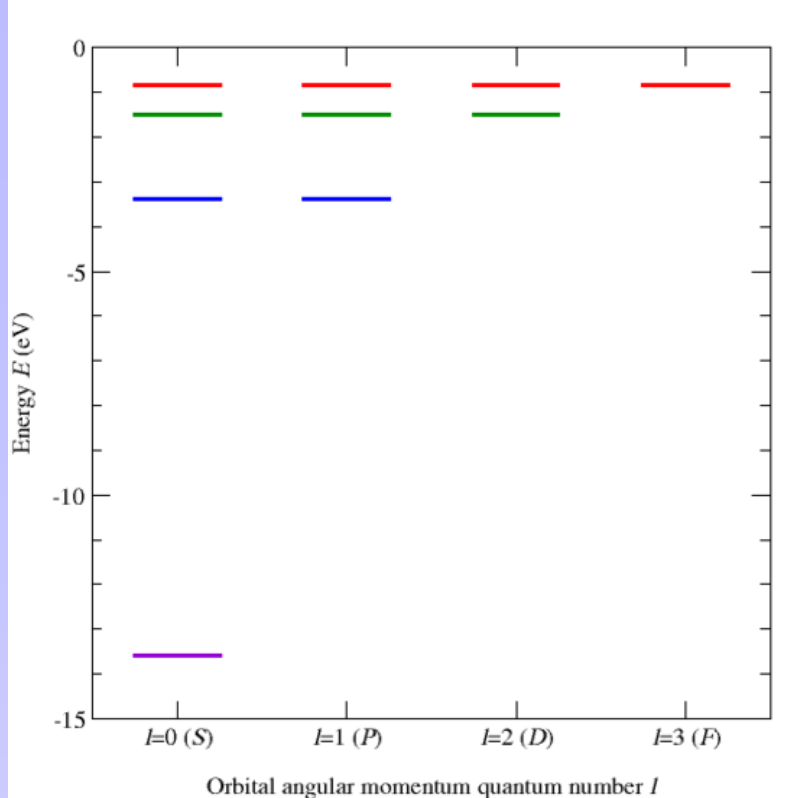
[Figure from wikimedia.org]
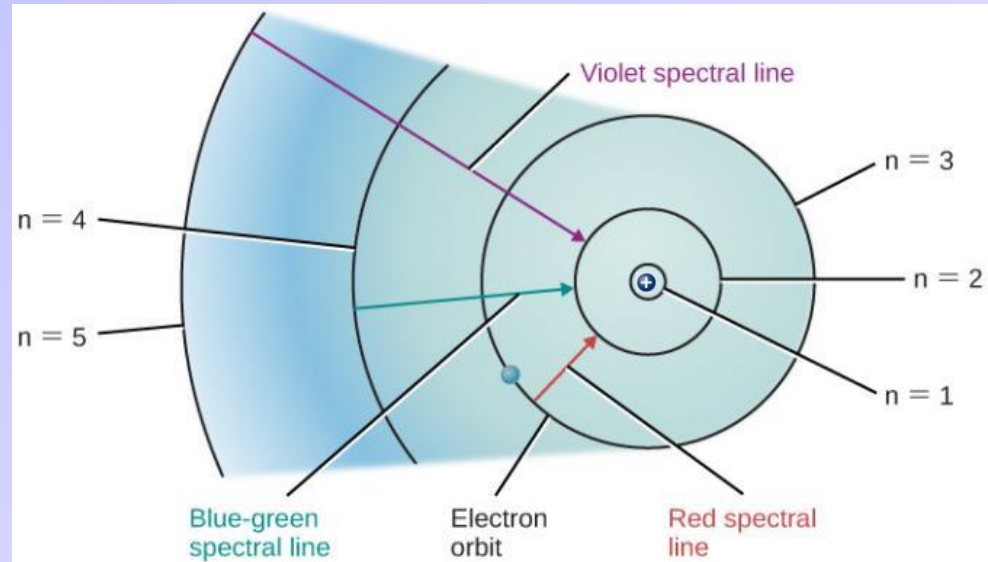
[OpenStax]

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

Note: 1 eV = 1.602 × 10^{-19} J

Electronic Structure of Atoms

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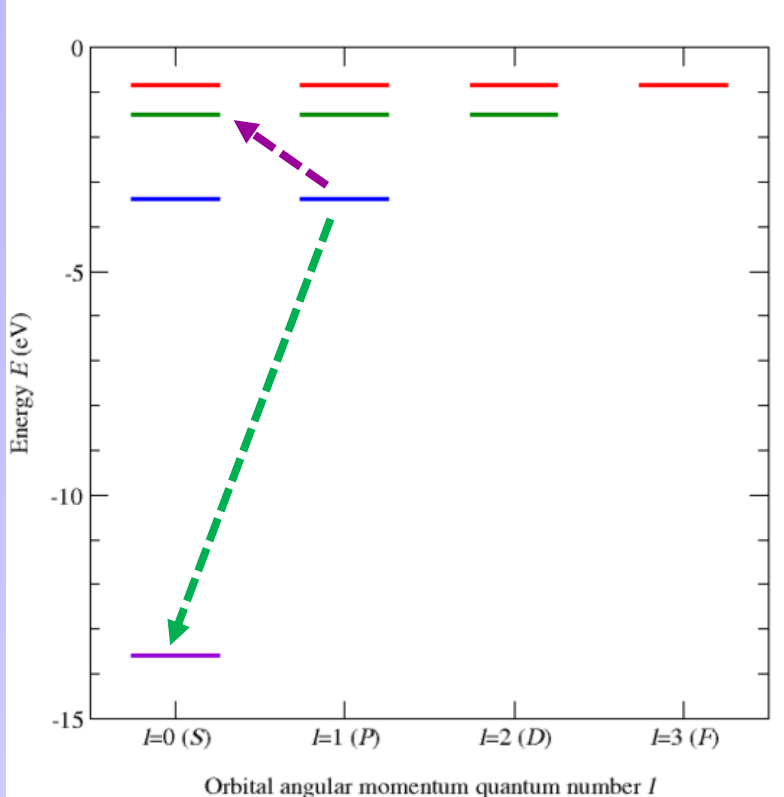
[Figure from wikimedia.org]

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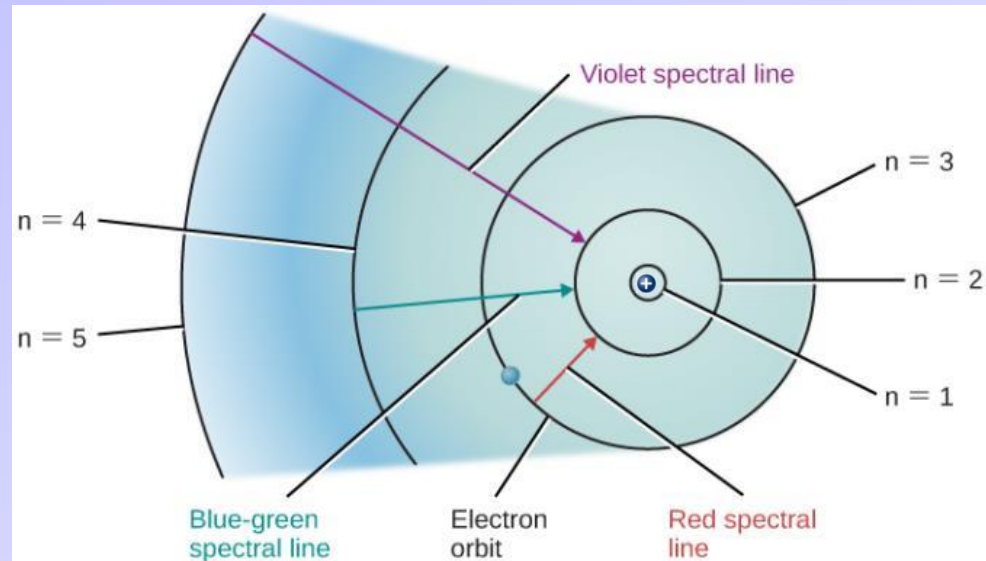
[OpenStax]

> 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
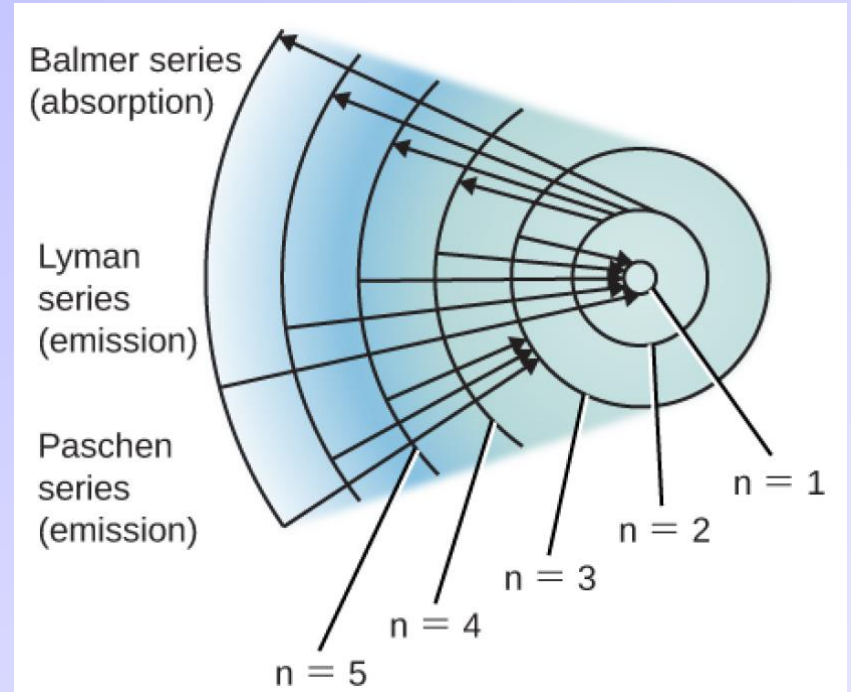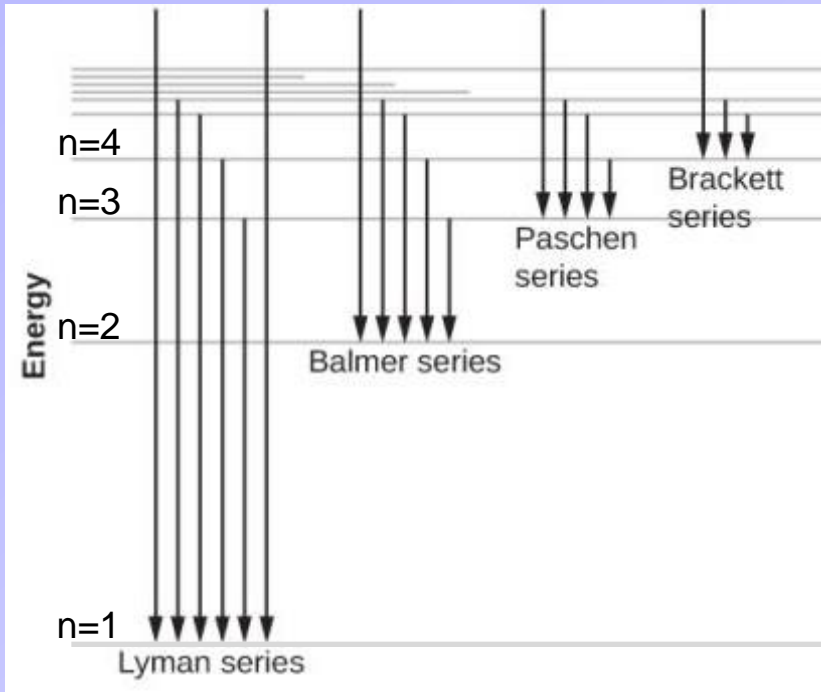
➤ Hydrogen has a number of emission and absorption spectral series that depend on the start/end point of the transition.

➤ Other elements are qualitatively similar.

➤ Also true for molecules, but their spectra are more complicated.

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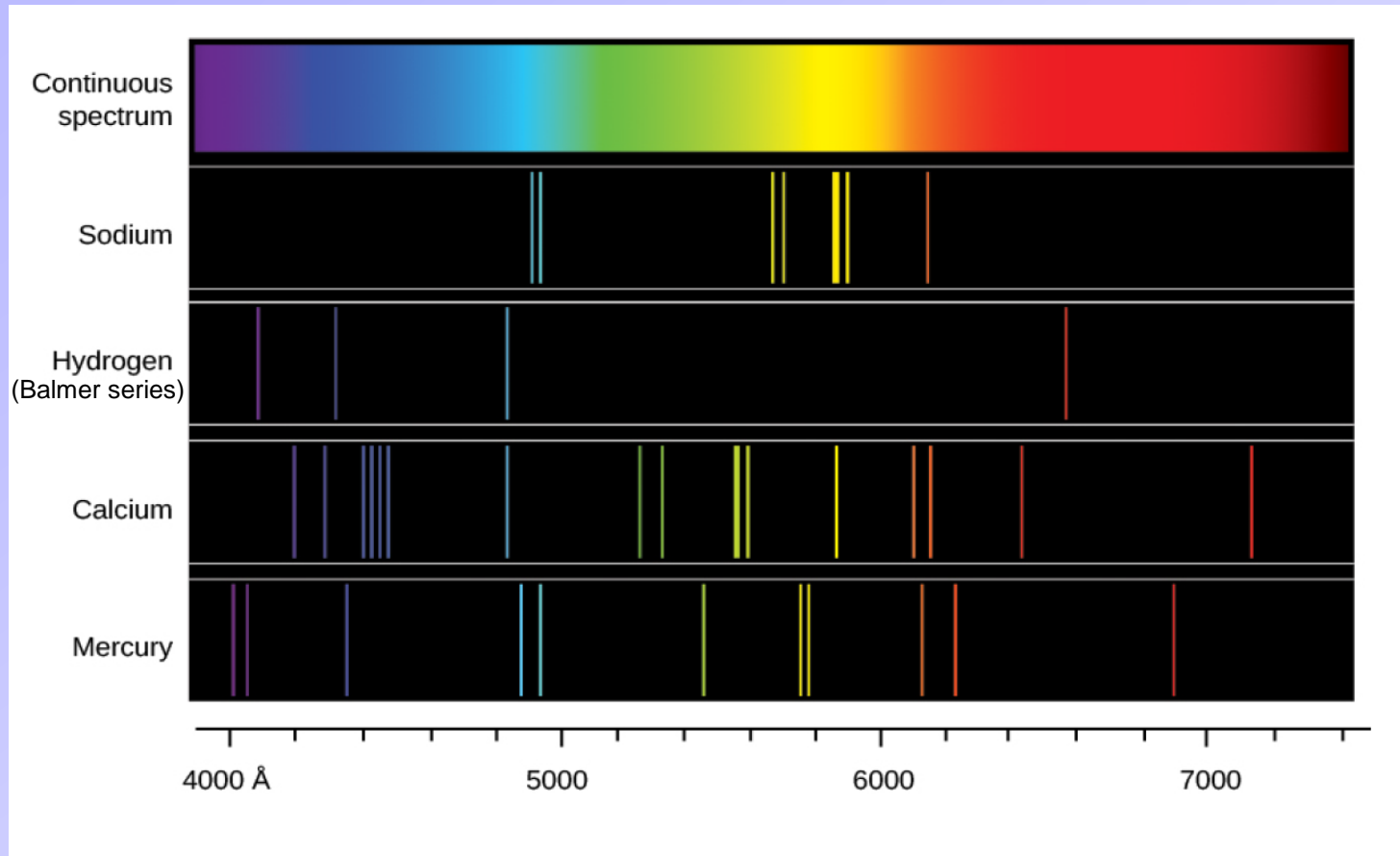
If you build a **catalog of spectral lines**, then you can **determine the elements** that are present from the spectrum.

Identify the element in the lamp:

A. Sodium.

B. Hydrogen.

C. Calcium.

D. Mercury

Emission & Absorption Processes
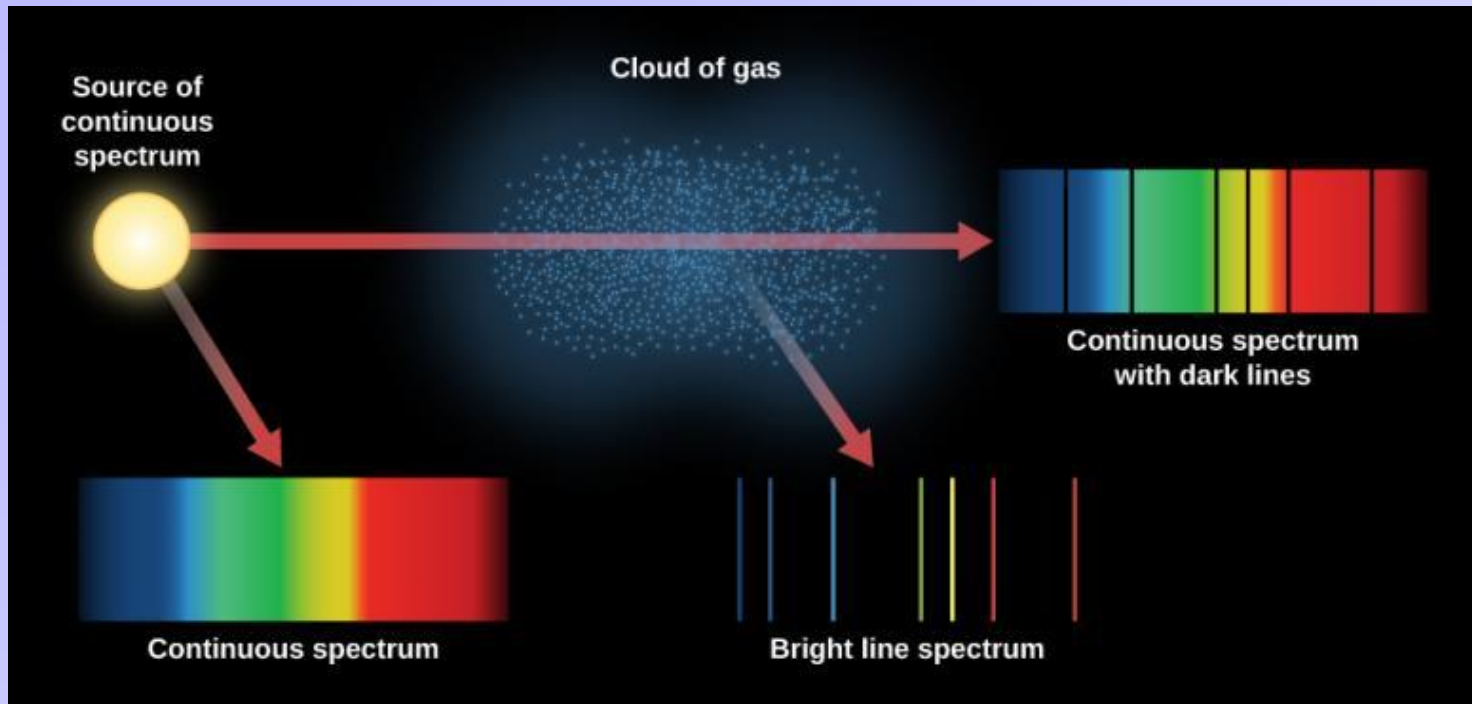
Three types of spectra

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**.

Doppler Effect

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

Redshift

Blueshift

Wavelength increased.

frequency decreases

Bulb moves from 1 to 4.

Wavelength decreased.

frequency increases

[image source: J. Nelson]
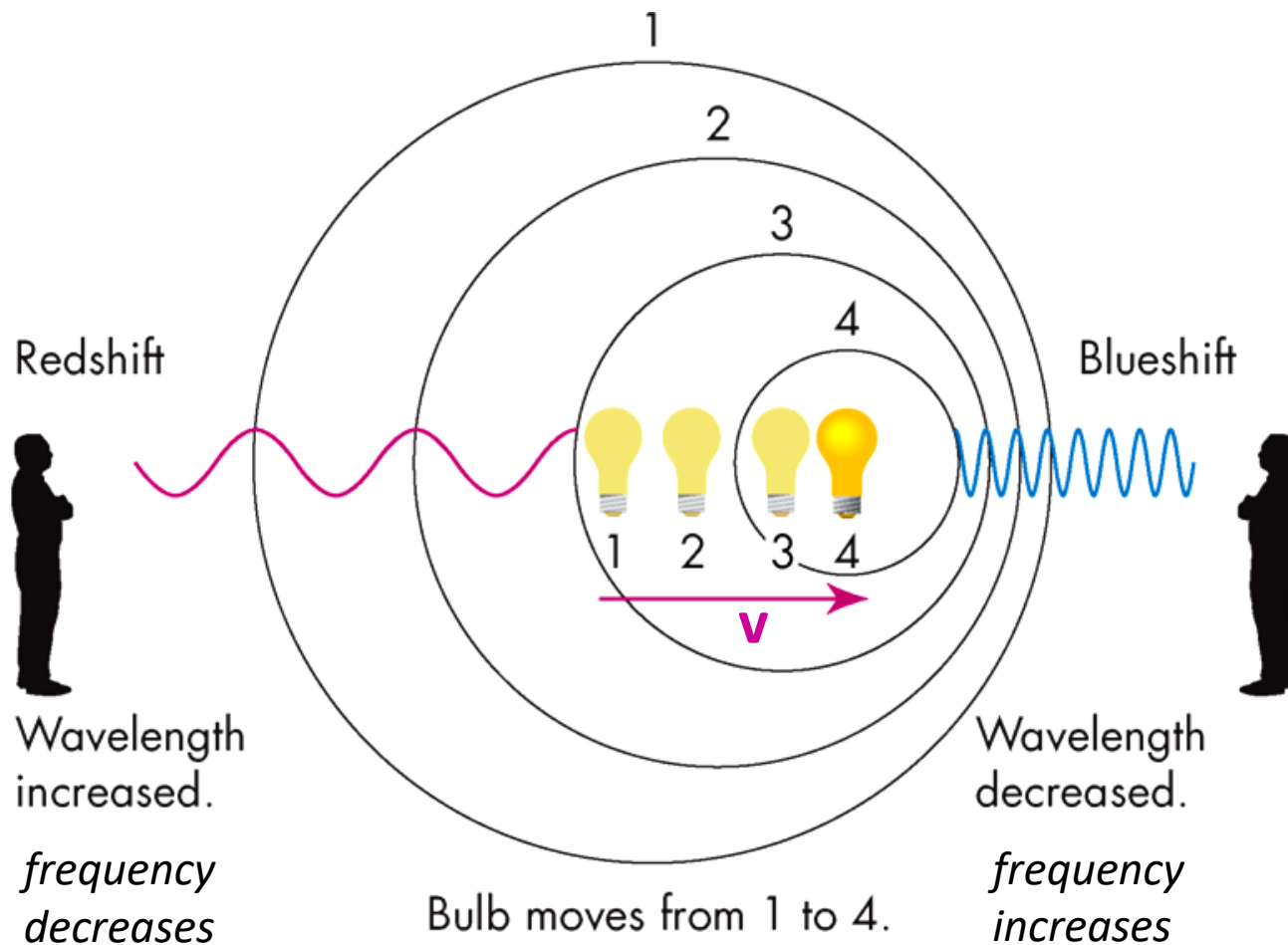
Doppler Effect

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

Works for sound too !!!

Doppler Shift Calculation

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

frequency of
stationary source

perceived frequency
of moving source

Doppler Shift Calculation

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frequency of
stationary source

perceived frequency
of moving source

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

$\boxed{v > 0}$ $\boxed{\Delta f > 0 \,, f' \text{ goes up}}$

$\Delta \lambda < 0$

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

$\boxed{v < 0}$ $\boxed{\Delta f < 0 \,, f' \text{ goes down}}$

$\Delta \lambda > 0$

Doppler Shift is for Line-of Sight Velocity Component
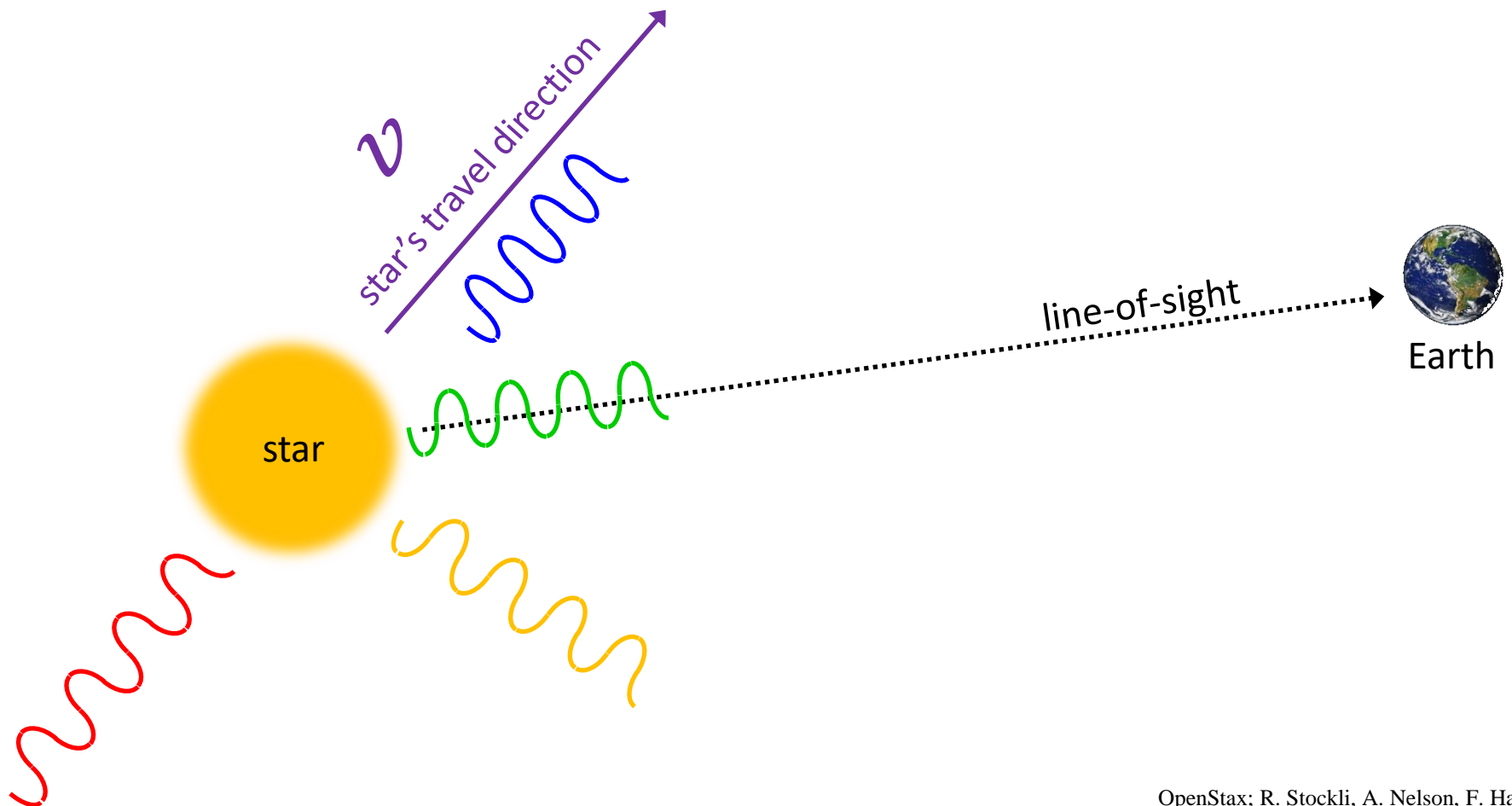
v

star's travel direction

line-of-sight

Earth

star

Doppler Shift
is for
Line-of Sight Velocity Component

v

star's travel direction

θ

line-of-sight

Earth

star

$v_{\parallel} = v \cos \theta$

Doppler Shifts for Rotating Sources

$v_{rotation}$ blue shifted $\lambda' = \lambda - \Delta\lambda$

rotating star

no shift $\lambda' = \lambda$

red shifted $\lambda' = \lambda + \Delta\lambda$

$v_{rotation}$

Doppler Shifts for Rotating Sources

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rotating star   no shift $\lambda' = \lambda$

$v_{rotation}$ red shifted $\lambda' = \lambda + \Delta\lambda$

blue shifted   red shifted

[NASA, giphy]

Doppler Shifts for Rotating Sources

$v_{rotation}$

blue shifted $\lambda' = \lambda - \Delta\lambda$

rotating star

no shift $\lambda' = \lambda$

$v_{rotation}$

red shifted $\lambda' = \lambda + \Delta\lambda$

slow

blue shifted

fast

red shifted

slow

[NASA, giphy]
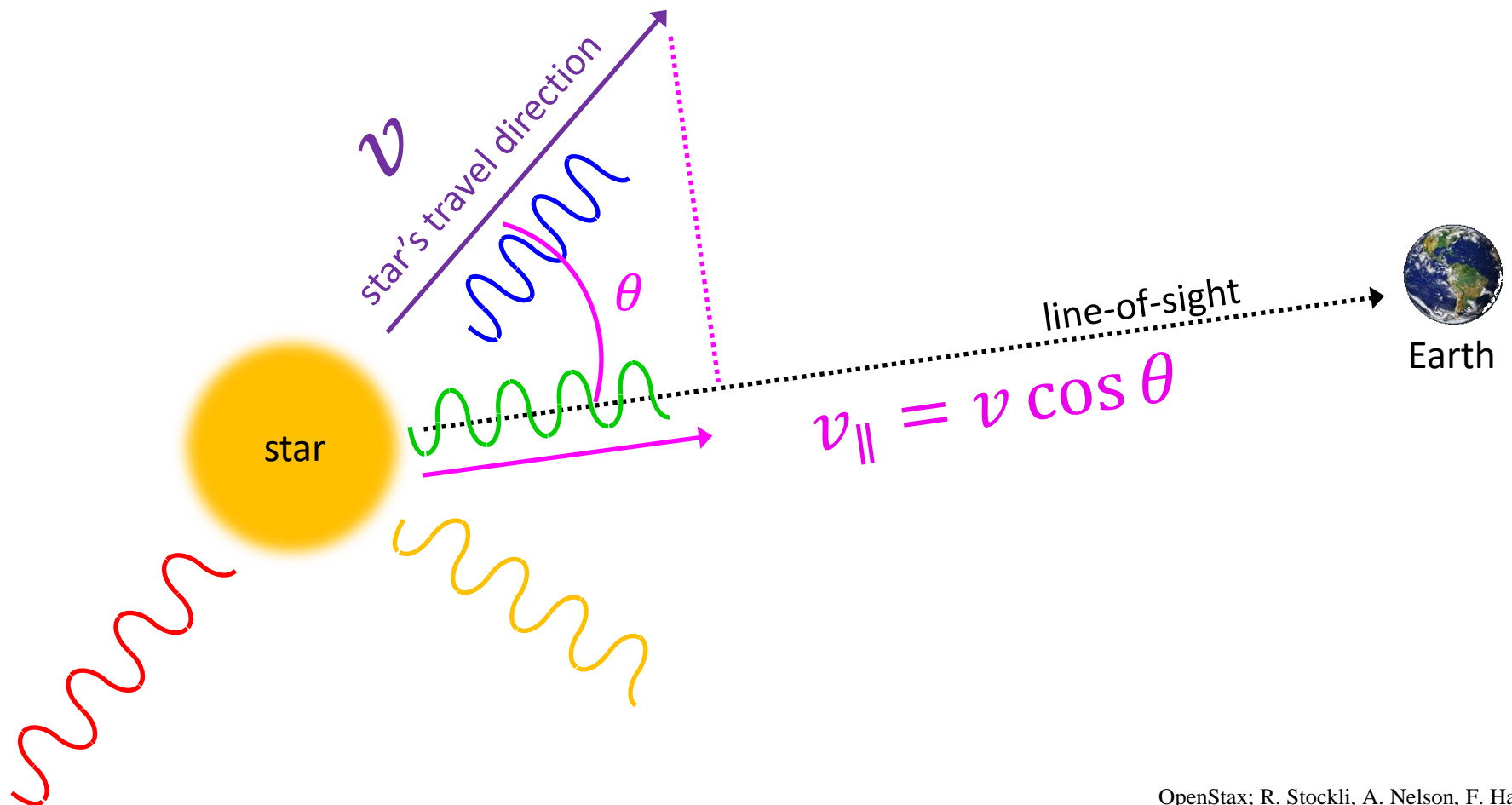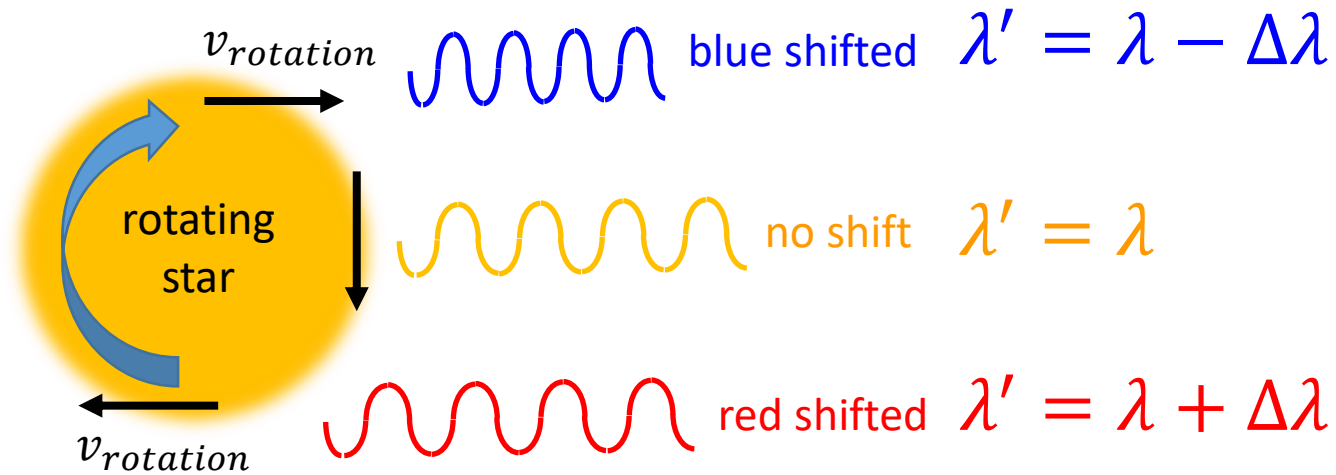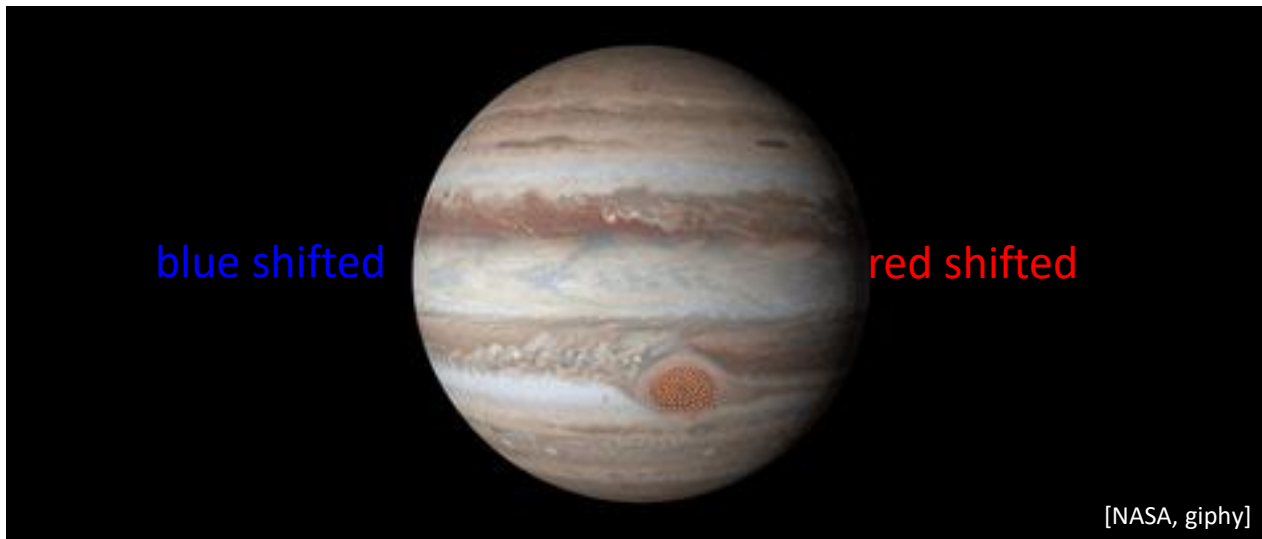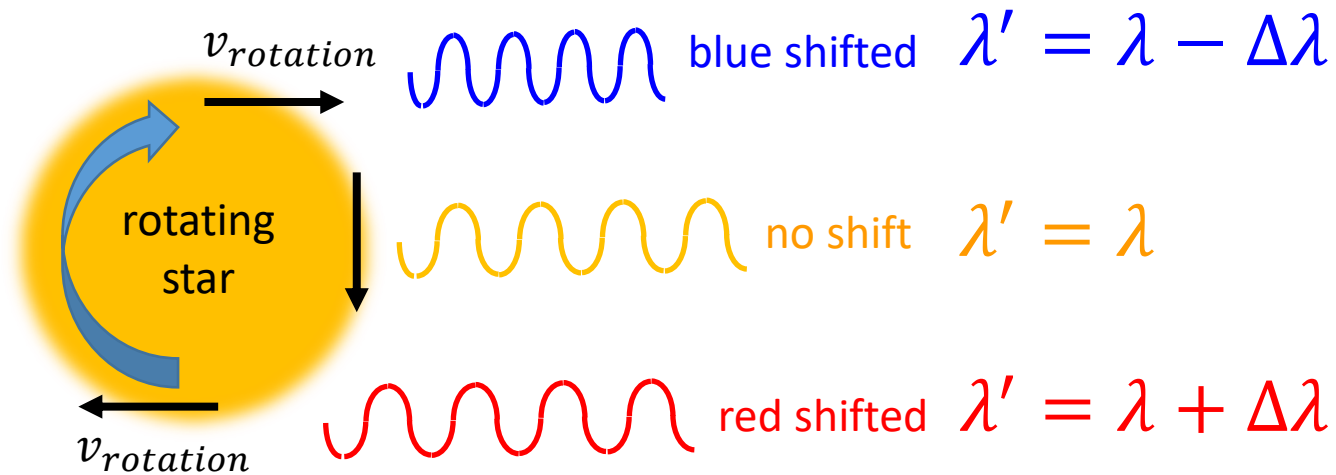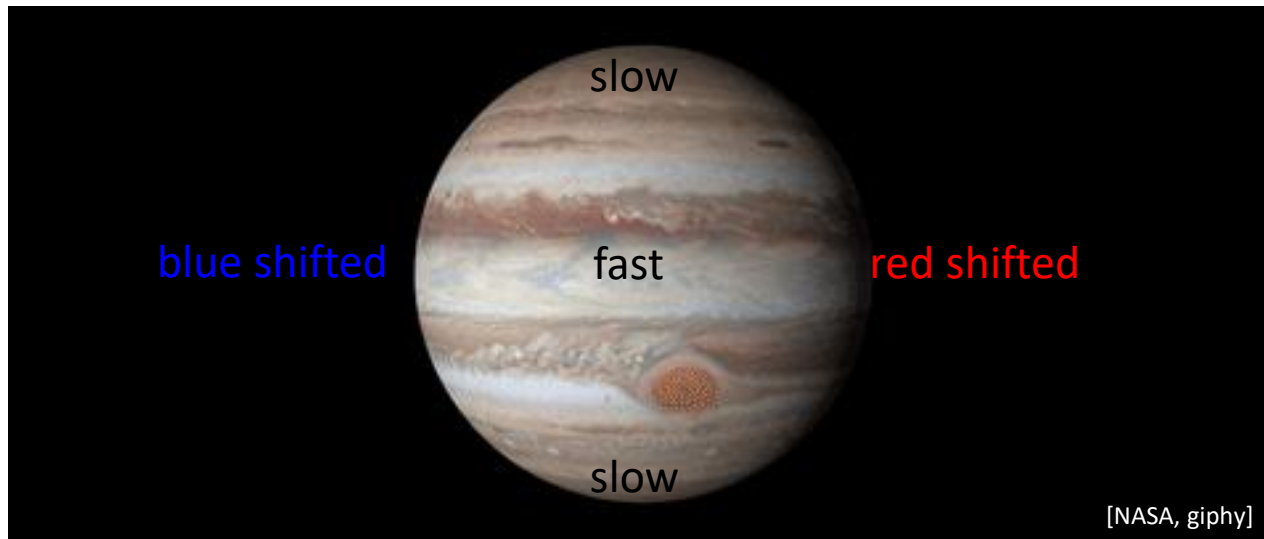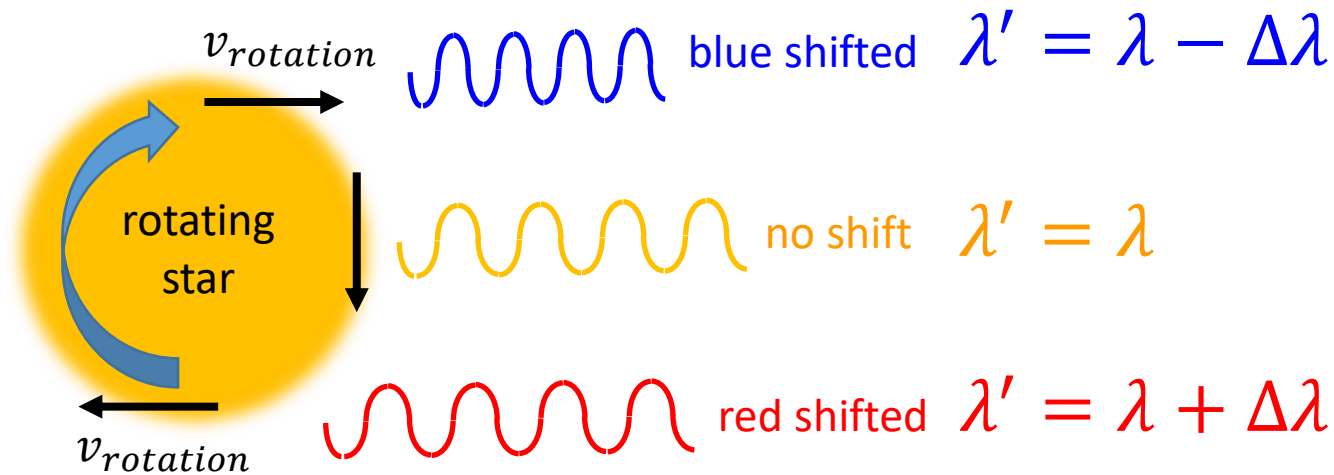
Nuclear Particles

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)   (generates radioactive decay)   (very very weak)

[short range]   [short range]