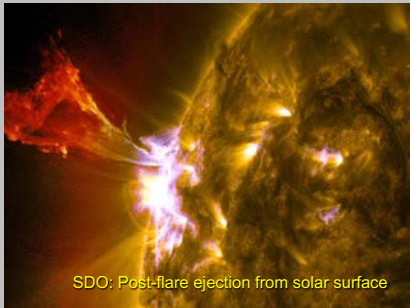


**ASTR 1040
Stars &
Galaxies**



SDO: Post-flare ejection from solar surface

Prof. Juri Toomre TAs: Ryan Horton, Loren Matilsky
Lecture 3 Tues 4 Sept 2018
zeus.colorado.edu/astr1040-toomre

Reading for today's and Thur class:

- Read Chap 5, carefully (Light and Matter)
- This chapter covers a lot – read it at least twice!
- Start reading Chap 6, telescopes

Continuing Topics for Today

- Electromagnetism: Light as waves and photons
- Coupling of atoms and light
- Yields “spectral lines” that are fingerprints unique to each atom
- How gas can emit or absorb light
- Observatory Night # 1 (tonight Tues 4 Sept) by signup (8:30pm; 9:00pm; 9:30pm)
- Hope you completed HW #0 on MA, now well underway with HW #1 (due Thur classtime)
- Recitations / AHR office hours can help

Light: The Cosmic Messenger

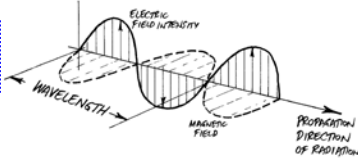
CONTINUING TOPIC



Barred Spiral Galaxy NGC 1672

E-M (LIGHT) AS WAVES

ELECTROMAGNETIC RADIATION AS A WAVE



$\lambda \times f = c$

WAVELENGTH \times FREQUENCY = SPEED OF “LIGHT”

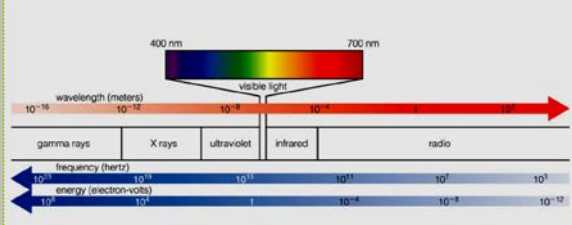
$\lambda = c/f$, $f = c/\lambda$

PROPAGATION SPEED OF ALL EM WAVES IS THE SAME!

C IS A CONSTANT $\approx 300,000$ km/sec
 $= 3 \times 10^{10}$ cm/sec

Speed of light SAME for all wavelengths

Electromagnetic Spectrum



400 nm 700 nm

wavelength (meters)

frequency (hertz)

energy (electron-volts)

gamma rays X rays ultraviolet infrared radio

gamma-rays x-rays ultraviolet visible infrared radio

$c = \lambda \cdot f$

ATOMS
 protons, neutrons, electrons
 (and quarks ..)
 Building blocks for everything

ATOMS

NUCLEUS: POSITIVELY CHARGED PROTONS AND UNCHARGED NEUTRONS
OUTER SHELL(S) OF NEGATIVELY CHARGED ELECTRONS

HYDROGEN
 ONE PROTON, NO NEUTRONS ONE ELECTRON
 BUT ELECTRONS CAN BE IN ONE OF MANY DIFFERENT "ORBITALS" WITH DIFFERENT ENERGIES

HELIUM
 TWO OF EACH (ALSO ISOTOPES WITH ADDITIONAL NEUTRONS)

CARBON
 SIX OF EACH
 NUCLEI RELATIVELY SMALL (10^{-8} Å)

Nucleus and its electron cloud ...

atomic number = number of protons
 atomic mass number = number of protons + neutrons

Hydrogen (¹H) **Helium (⁴He)** **Carbon (¹²C)**

atomic number = 1 atomic number = 2 atomic number = 6
 atomic mass number = 1 atomic mass number = 4 atomic mass number = 12
 (1 electron) (2 electrons) (6 electrons)

The number of electrons in a neutral atom equals its atomic number.

Isotopes of Carbon

carbon-12 carbon-13 carbon-14

(6 protons + 6 neutrons) (6 protons + 7 neutrons) (6 protons + 8 neutrons)

Different isotopes of a given element contain the same number of protons but different numbers of neutrons.

Atoms Involve Big Empty Spaces

Ten million atoms could fit end to end across this dot.

The nucleus is nearly 100,000 times smaller than the atom but contains nearly all of its mass.

(or 1 Angstrom)

10⁻¹⁰ meter

Atom: Electrons are "smeared out" in a cloud around the nucleus.

Nucleus: Contains positively charged protons (red) and neutral neutrons (gray).

Clicker: How much time does it take light to travel one Astronomical Unit (1 AU)?

- A. Speed of light x 1 AU
- B. Speed of light / 1 AU
- C. 1 AU / speed of light
- D. 1 light-year

"ORBITS" OF ELECTRONS

Popping from one orbit to another involves particular PHOTONS
 (like DNA prints)

POSSIBLE ORBITS FOR ELECTRON (ORBITS)
 IN HYDROGEN ATOM

TRANSITIONS (USUALLY) EMIT OR ABSORB PHOTON

PROTON (NUCLEUS)

1, 2, 3, 4, 5, 6

ELECTRON ON ORBIT

BLUER SHORTER

LONGER LONGER

EMITTED

PHOTON

PHOTON

PHOTON

PHOTON

SPECTRAL LINES

ONLY LIGHT OF CERTAIN COLORS (ENERGIES) CAN BE ABSORBED OR EMITTED

EACH CHEMICAL ELEMENT HAS ITS OWN UNIQUE NUMBER AND PATTERN OF ELECTRON ORBITS
 => UNIQUE PATTERN OF COLORS (SPECTRAL LINES ARE LIKE A FINGERPRINT!)

Revolution of "Quantum Mechanics"

- Discrete spectral lines and electron energy levels go hand in hand, but WHY?
- Classical physics had no real explanations, even if Bohr's model of electron orbits for H looked good
- A new mathematics/physics had to be invented in the 1920s, with solutions of the "Schroedinger wave equation" giving probabilities (orbitals) of where electrons could be located
- Such "quantum mechanics" also explained why light (photons) act both like waves and particles, and so too electrons!

Electron in Hydrogen Atom (S4.3)

Orbital solutions from Schrodinger wave equation

- In **quantum mechanics**, an electron in an atom does not orbit in the usual sense
- We can know only the **probability** of finding an electron at a particular spot (orbital)

ENERGY LEVELS (of electrons) IN HYDROGEN

Each transition involves photons of specific color (like fingerprints)

ENERGY LEVELS AND SPECTRAL LINES IN HYDROGEN ATOM

Each transition of electron in energy produces one spectral line (emission/absorption of photon)

Hydrogen's Energy Diagram

Emission

Absorption

Each atom has a different set of energy levels

- Just like no two people have the same fingerprints, no two elements have the same emission spectrum

As in our emission tube demo last Thur

Hydrogen

Sodium

Helium

Neon

Mercury

Wavelength (nm)


Very important Idea #2

$$E = h \times f$$

Photon's **Energy** = Planck's constant x Photon's **Frequency**

Idea #1 $c = \lambda \cdot f$

Colors of Light



• *Newton showed: White light is made up of many different colors*

Clicker Question




Infrared light can have a wavelength of 3 microns ($3 \times 10^{-6} \text{ m}$) and a frequency of $1.0 \times 10^{14} \text{ Hz}$. What is the wavelength of light that has a frequency of $0.5 \times 10^{14} \text{ Hz}$? (Hint: What is the relationship between wavelength and frequency?)

- A. 1.5 microns
- B. 2.0 microns
- C. 2.5 microns
- D. 3.5 microns
- E. 6.0 microns

SPECTRA (KIRCHOFF'S LAWS)

NATURE OF SPECTRA

Kirchoff's laws

- A.  **RADIATING SOLID, LIQUID, OR HIGH-PRESSURE GAS (OFTEN THICK)**
⇒ CONTINUOUS SPECTRUM
- B.  **RADIATING RARIFIED GAS (LOW DENSITY)**
⇒ BRIGHT-LINE SPECTRUM (EMISSION) Emission
- C.  **LIGHT OF CONTINUOUS SPECTRUM VIEWED THROUGH A COOLER GAS**
⇒ DARK-LINE (ABSORPTION) SPECTRUM Absorption

LIGHT **THIN CLOUD**

hot light source thin cloud of gas

CONTINUOUS

Continuous Spectrum

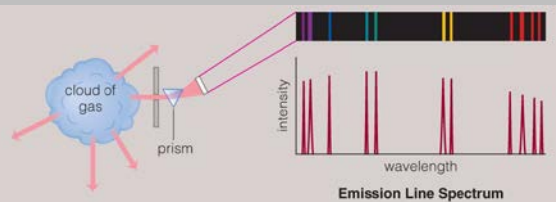
EMISSION LINE

Emission Line Spectrum

ABSORPTION LINE

Absorption Line Spectrum

Emission Spectra

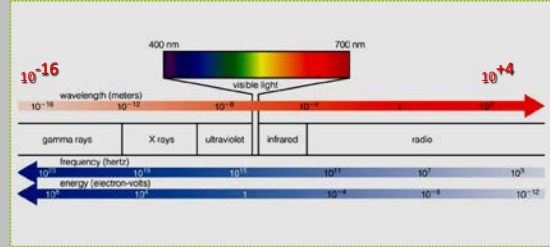


• *Emission for thin, hot gas: Gas glows in specific colors.*

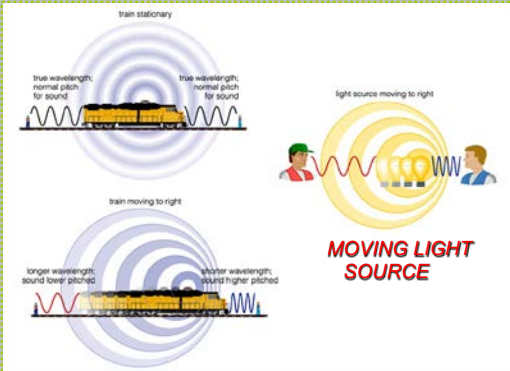
Clicker Q – EM Waves

- From shortest to longest wavelength, what is the correct sequence of EM radiation?
- A. gamma-rays, x-rays, UV, visible, IR, radio
- B. gamma-rays, x-rays, visible, UV, IR, radio
- C. IR, visible, UV, x-rays, gamma-rays, radio
- D. radio, IR, visible, UV, x-rays, gamma-rays

A. gamma-rays,x-rays,UV,visible,IR,radio



Doppler Effect: Trains and Light



DOPPLER EFFECT

Applied to positions of spectral lines

Doppler Demo

DOPPLER EFFECT

LIGHT FROM RECEDING SOURCE IS RED SHIFTED
 LIGHT FROM APPROACHING SOURCE IS BLUE SHIFTED

CRESTS FURTHER APART → LONGER WAVELENGTH
 WAVECRESTS CLOSER TOGETHER → SHORTER WAVELENGTH λ
 HIGHER FREQUENCY f

$$\text{CHANGE IN WAVELENGTH} = \frac{\Delta \lambda}{\lambda} = \frac{v}{c} = \frac{\text{VELOCITY OF SOURCE}}{\text{SPEED OF LIGHT}}$$

CAN USE TO CALCULATE LINE-OF-SIGHT VELOCITY OF SOURCE:
 "DOPPLER VELOCITY" v

$$v = \frac{\Delta \lambda}{\lambda} c$$

IF ABSORPTION LINE AT SKY 5000 Å REDSHIFTED BY 0.5 Å

$$v = \frac{(+0.5 \text{ \AA}) (300,000 \text{ Km/sec})}{5,000 \text{ \AA}} = +30 \text{ Km/sec}$$