

Light

&

The Sun

BTW: Exam #2 next week. Look for review on website.
Bring a calculator and Pens/Pencil to exam.

Structure of Matter

Atom: consists of electrons orbiting a nucleus which contains protons and neutrons.

FYI:

Protons and neutrons are comprised of quarks.

Electrons orbit in orbits around the nucleus with distinct energy levels.

Structure of Matter

- The number of protons in nucleus determine chemical property of atom, the element.
- # Protons = #Electrons ~ Neutral Atom
- If electrons are lost or gained then the atom is an ion.

Structure of Matter

Isotope: different types of atoms of the same chemical element, each having a different number of neutrons.

Light!!!

- Luminous objects produce light
 - Sun
 - Light bulb
 - Fire

- The moon is not luminous
Why????

What is Light???

- Light is electromagnetic radiation
 - Electromagnetic Radiation:
A self propagating energy from the disturbance of a changing coupled electric field and magnetic field that travels as both a wave and a particle without the need of a medium.

E/M Radiation (Light)

Two forms of Propagation

1. Wave Motion

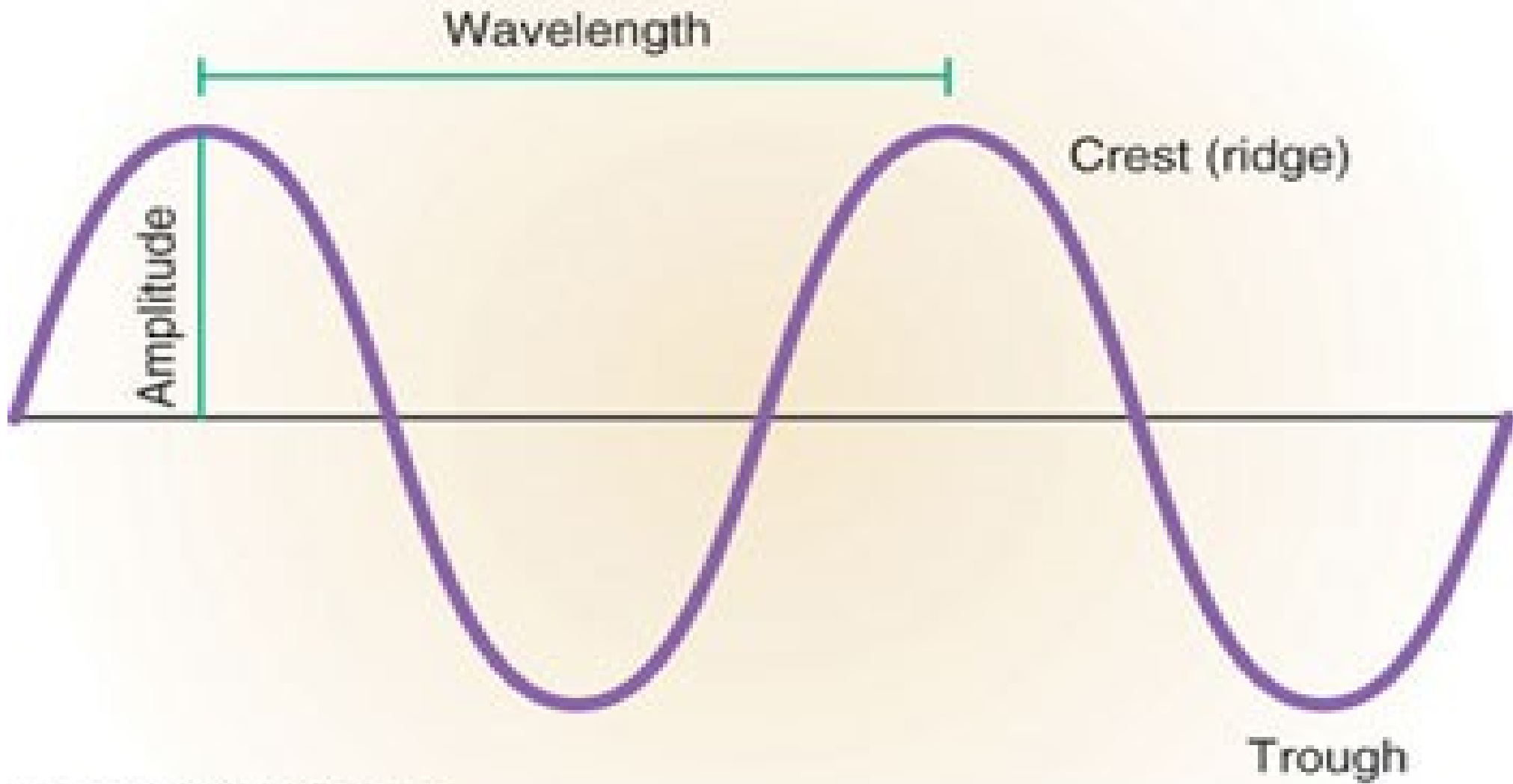
- Wave: any periodic repeating pattern of disturbance.
- Waves carry energy or transmit energy.

- Examples:

Sound Waves: repeated movement of air particles as compressions and rarefactions

Water Waves: energy transmitted through water.

- E/M waves need no medium to transmit energy.



- Wave Properties:

- Speed of propagation

- Wavelength: the distance between crests or troughs of a wave.

- Unit: nanometer (nm)

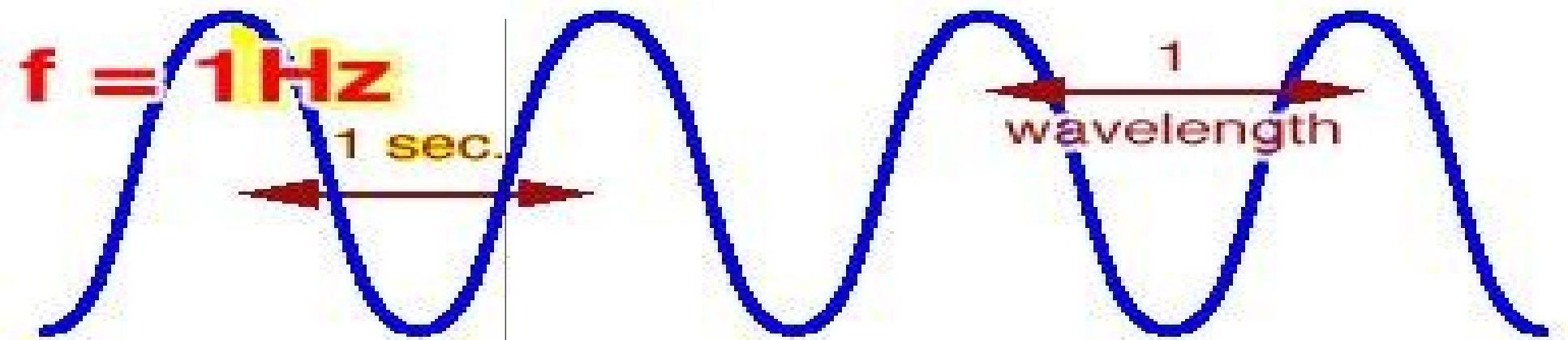
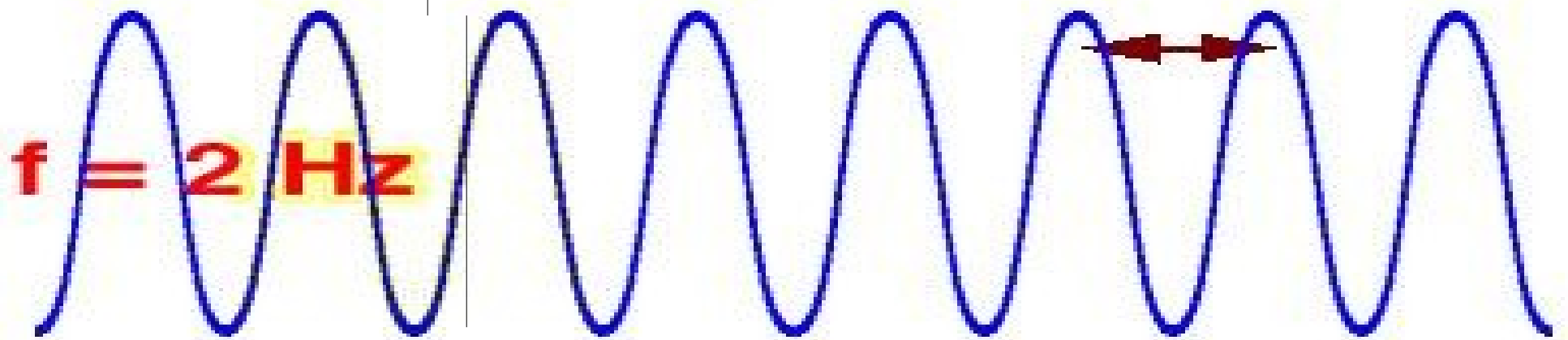
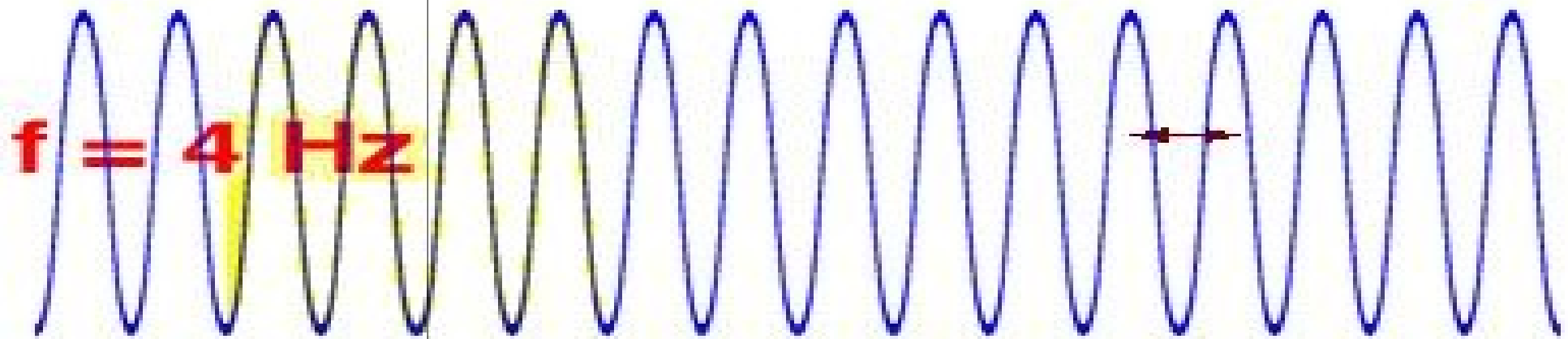
- $$\text{nm} = 1 \times 10^{-9}$$

- Or meter (m)

- Frequency:

- Number of oscillations per second.

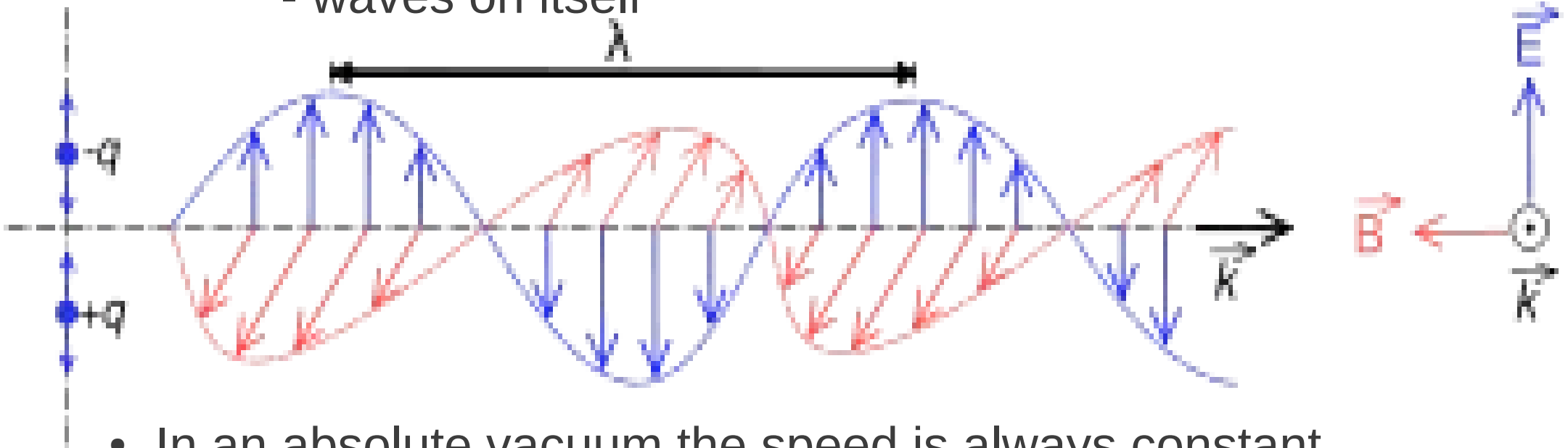
- Unit: Hertz (hz)



E/M Radiation (Light)

Two forms of Propagation

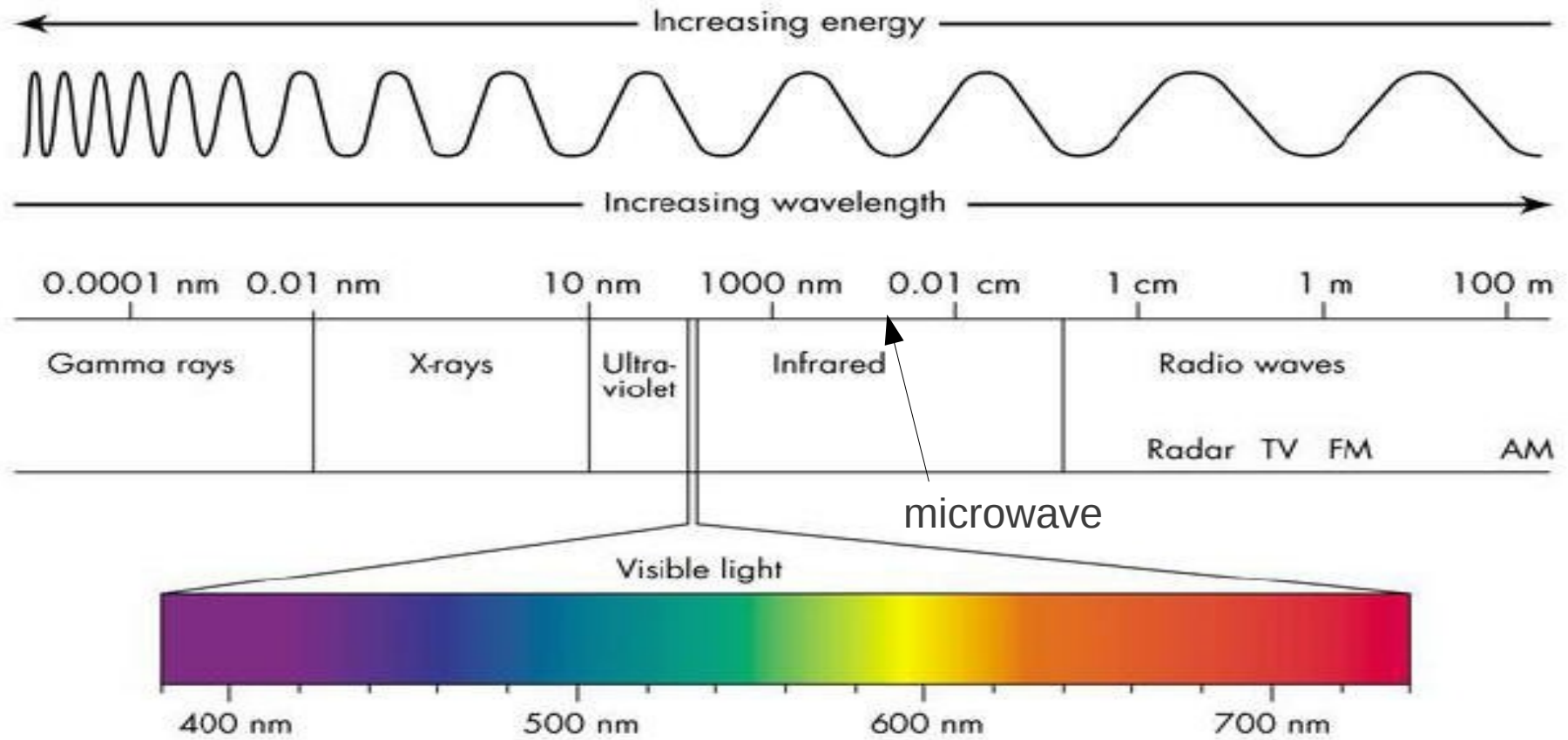
- E/M Radiation (light):
 - needs no medium
 - waves on itself



- In an absolute vacuum the speed is always constant regardless of the the energy being transmitted.

$$c = 299,297,458 \text{ m/s}$$

Electromagnetic Spectrum



E/M Radiation (Light)

Two forms of propagation

2. Particle Motion:

- Photon: a elementary particle that carries a packet of energy.
- Massless particles that can be deflected and stopped (absorbed).
- How much energy does a photon carry???

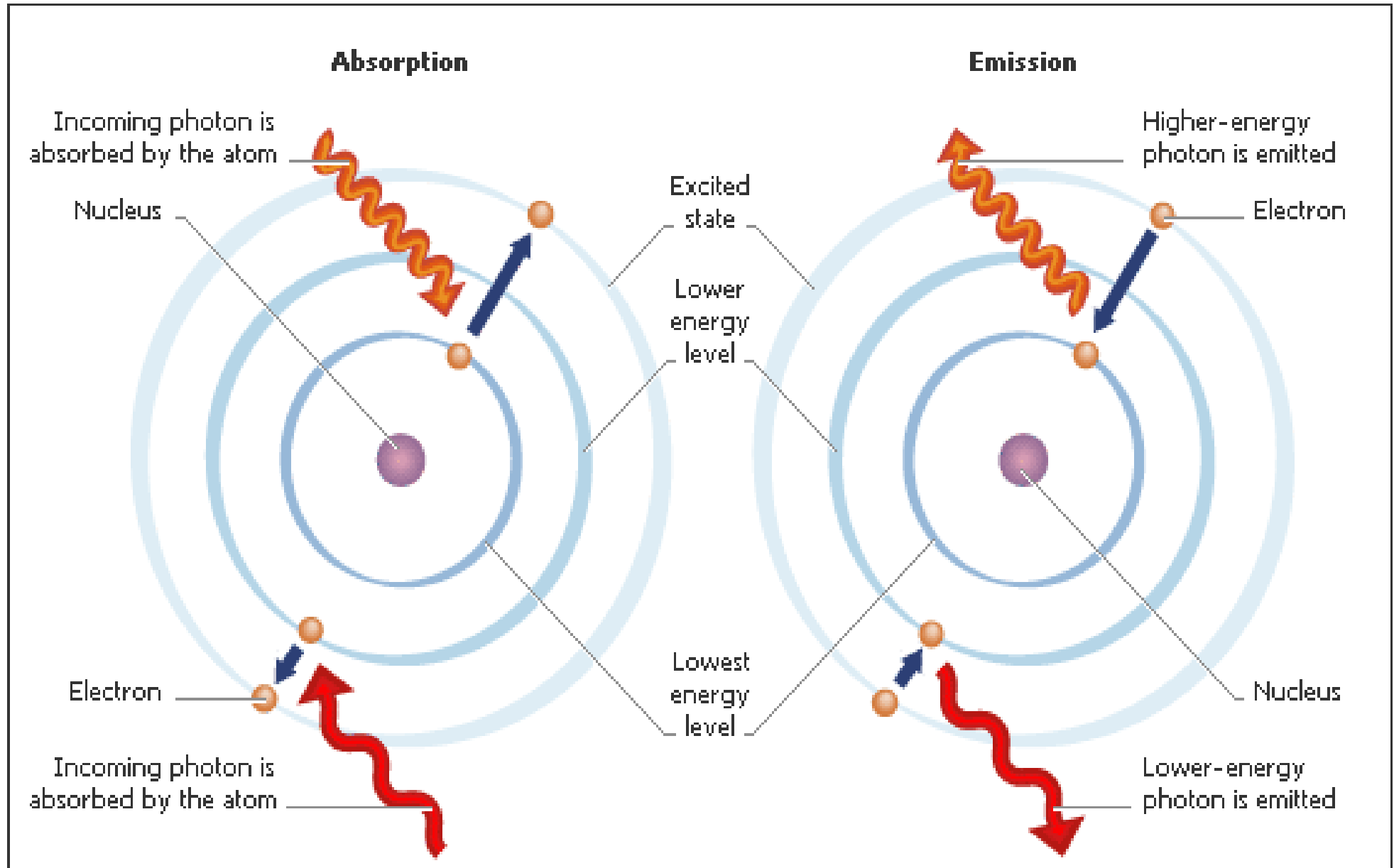
$$\text{Energy} = h \times \text{frequency}$$

$$h = \text{Planck's constant} = 6.62606896 \times 10^{-34} \text{ J.s}$$

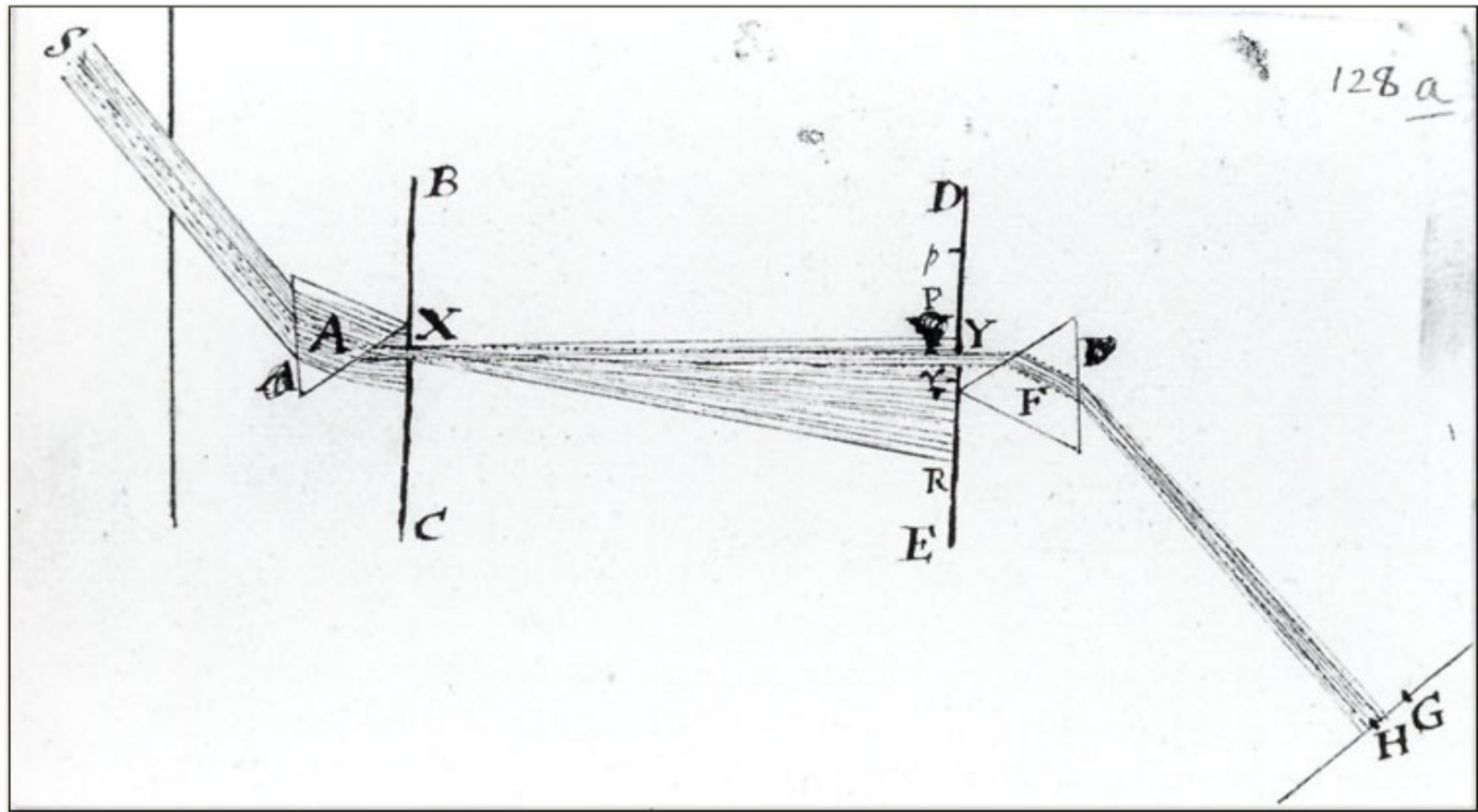
- This is where the wave nature and the particle nature are related to one another

Structure of Matter

How can E/M Radiation be produced??



1672: Isaac Newton publishes first paper to understand the nature of white light



Prism: transparent optical element with flat surfaces that refract light

Each wavelength of light corresponds to a different speed and therefore a different angle inside the more dense medium.

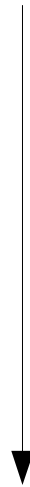
Primary Additive Colors: the colors red, blue, and green when added together will give white light.

$$W = R + B + G$$

Visible spectrum is a continuous spectrum.

| | | | |
|--------|------|---|--------|
| Violet | (V), | = | 400 nm |
| Indigo | (I), | = | 445 nm |
| Blue | (B), | = | 475 nm |
| Green | (G), | = | 510 nm |
| Yellow | (Y), | = | 570 nm |
| Orange | (O), | = | 590 nm |
| Red | (R), | = | 650 nm |

Shortest to longest wavelength



Spectra of Stars

- A spectrum typically depicts the energy a star (gas) emits at each wavelength.
- Spectral Analysis is a way in which using the stars spectrum we can determine the composition and effective temperature.
- There are three types of spectra a gas can produce:
 - 1) Continuous Spectrum
 - 2) Emission Spectrum
 - 3) Absorption Spectrum

Types of Spectra

- Continuous Spectrum: energy at all wavelengths.

Types of Spectra

- Absorption Spectrum: results when radiation passes through cooler gas and that gas absorbs certain wavelengths of light creating dark bands in a continuous spectrum.

- This spectrum will occur when analyzing a star directly toward the light source.

Types of Spectra

- Emission Spectrum: particular wavelengths that are emitted when electrons transition back down to their ground state.

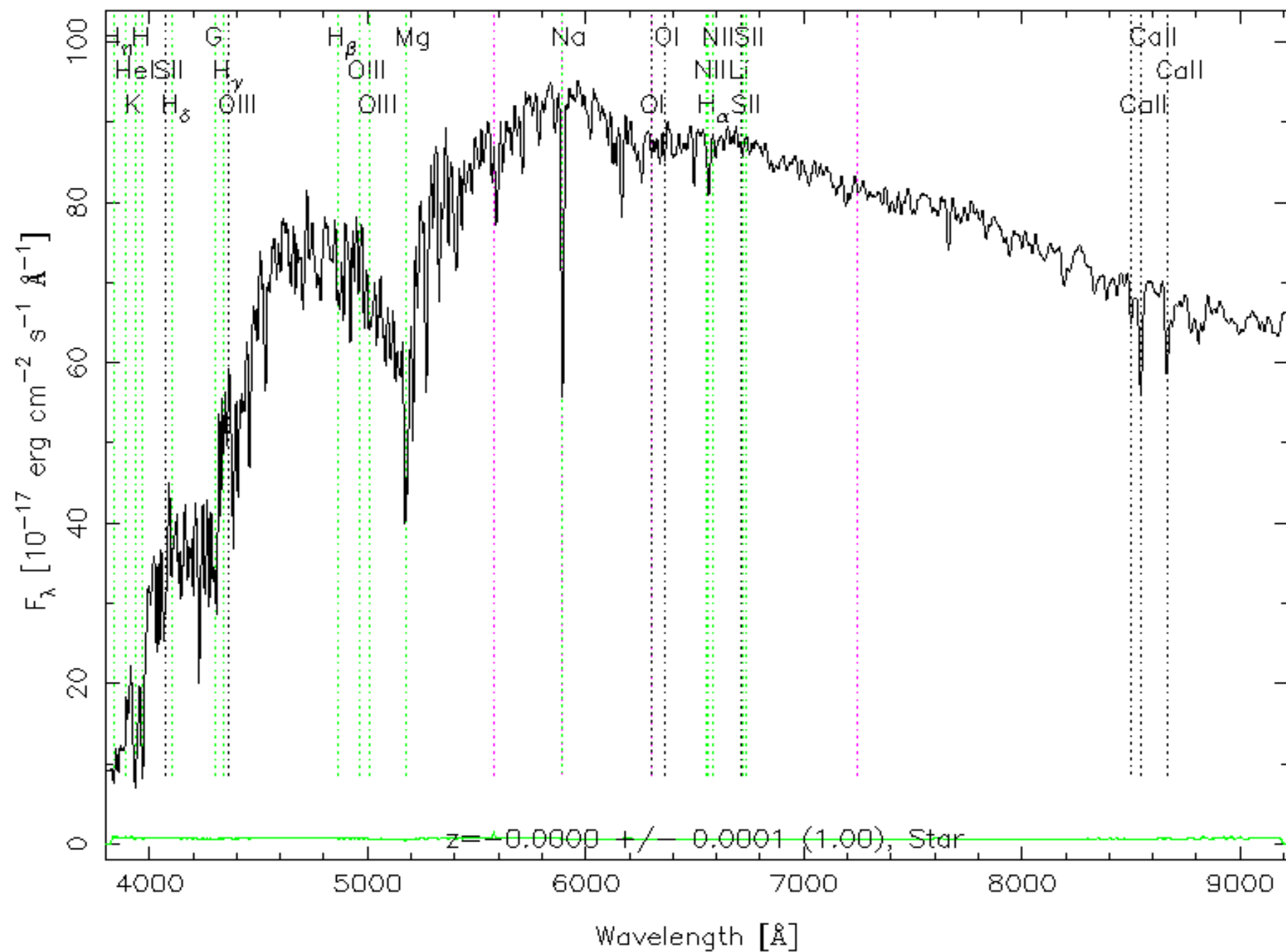
Iron

- This can be observed when looking directly at the cooler gases around a star and not directly at the star.

Spectral Analysis

- Each element when excited will have a unique absorption/emission spectrum. Think of it as the elements fingerprint.
- Use this to determine the composition of gases in a star.

RA=200.20903, DEC=-0.07525, MJD=51959, Plate= 297, Fiber=316



Temperature and Electromagnetic Radiation

- Temperature:
the average amount of internal motional energy.
 - Do not define this as how “hot” or “cold” an object feels. Why??
- Units for temperature in Astronomy:

Kelvin (K): based on the point where all molecular motion almost halts, absolute zero.

Temperature and Electromagnetic Radiation

- Wein's Law:

the wavelength at which an object radiates most strongly is inversely proportional to the objects temperature.

$$T = \frac{2.9 \times 10^6}{\lambda_{\max}}$$

11, 600 K

5800 K

$$T = \frac{2.9 \times 10^6}{250} = 11,600 \text{ K}$$

For the Sun

$$\lambda = 500$$

$$T = 5800 \text{ K}$$

What about infrared?

$$\lambda = 1000$$

Temperature and Electromagnetic Radiation

- Wein's Law:
the wavelength at which an object radiates most strongly is inversely proportional to the objects temperature.

Infrared:

$$\lambda = 1000$$

$$11,600 \text{ K}$$

$$5800 \text{ K}$$

$$2900 \text{ K}$$

$$T = \frac{2.9 \times 10^6}{\lambda_{\max}}$$

$$T = \frac{2.9 \times 10^6}{1000} = 2900 \text{ K}$$

Temperature

- The color of a star indicates its relative temperature – blue stars are hotter than red stars
- More precisely, a star's effective temperature (in Kelvin) is given by the wavelength in nanometers (nm) at which the star radiates most strongly

Luminosity vs. Brightness

A) Which is brighter?

Traffic Light A: $1/4^{\text{th}}$ mile away

Traffic Light B: 2.0 miles away

B) Which is brighter?

Traffic Light A: 1.0 mile away

Traffic Light B: 1.0 mile away

The Magnitude Scale

- About 150 B.C., the Greek astronomer Hipparchus measured apparent brightness of stars using units called *magnitudes*
 - Brightest stars had magnitude 1 and dimmest had magnitude 6
- Two modern magnitude scales:
 - Apparent Magnitude
 - Absolute Magnitude

Apparent Magnitude Scale

- Scale based on the apparent brightness of object.
 - Scale runs “backward”: high magnitude = low brightness
 - Modern calibrations setting Vega as $m_v = +0.0$ of the scale create negative magnitudes.
 - Magnitude differences equate to brightness ratios:
 - 1 magnitude difference = 2.512
 - A difference of 5 magnitudes = a brightness ratio of 100

Each Magnitude is 2.512 brighter/dimmer than the next. Therefore, every 5 magnitudes is $2.512^5 = 100$ x brighter/dimmer

Magnitude

Factor brighter than Vega

-20

1000000000

-15

10000000

-10

10000

-5

100

0

+5

100

+10

10000

+15

1000000

+20

100000000

+25

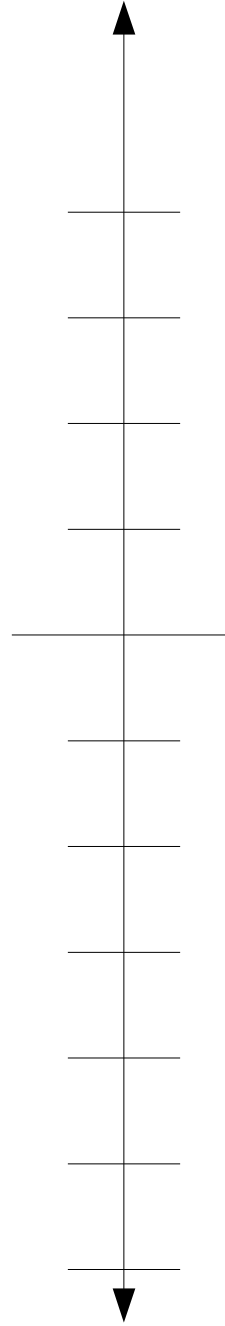
10000000000

+30

10000000000000

brighter

dimmer



Apparent Magnitude Scales

| Object | m_v |
|--------------------------------------|-------|
| Sun | -26.8 |
| Moon | -12.6 |
| Sirius | -1.47 |
| Vega | +0.0 |
| Polaris | +1.97 |
| Faintest star the naked eye can see: | +6.0 |
| Faintest star with Hubble Telescope: | +30.0 |

Apparent Magnitude Scale

How much brighter is one star than another????

$$\text{Star A: } m_v = +5.0$$

$$\text{Star B: } m_v = +30.0$$

1) Find the difference between the two stars:

Dimmer Star – Brighter Star:

$$+30 - +5 = 25$$

2) Use the answer to step #1 as your exponent on 2.512

$$2.512^{25} = 1.0 \times 10^{10}$$

This tells us that Star A is 1.0×10^{10} brighter than Star B

Apparent Magnitude Scale

How much brighter is one star than another????

Star A: $m_v = -15.0$

Star B: $m_v = +5.0$

1) Find the difference between the two stars:

Dimmer Star – Brighter Star:

$$+5.0 - -15 = 20$$

2) Use the answer to step #1 as your exponent on 2.512

$$2.512^{20} = 1.0 \times 10^8$$

This tells us that Star A is 1.0×10^8 brighter than Star B

Apparent Magnitude Scale

How much brighter is one star than another????

Star A: $m_v = +6.0$

Star B: $m_v = -26.8$

1) Find the difference between the two stars:

Dimmer Star – Brighter Star:

$$+6.0 - -26.8 = 32.8$$

2) Use the positive answer to step #1 as your exponent on 2.512

$$2.512^{32.8} = 1.0 \times 10^{13}$$

This tells us that Star A is 1.0×10^{13} dimmer than Star B

The Magnitude Scale

- Astronomers use ***absolute magnitude*** to measure a star's luminosity
 - The absolute magnitude of a star is the apparent magnitude that same star would have at 10 parsecs
 - A comparison of absolute magnitudes is now a comparison of luminosities, no distance dependence
 - An absolute magnitude of 0 approximately equates to a luminosity of $100L_0$

The Magnitude Scale

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Magnitude Scales

Absolute Magnitude, M_v :

| Object | m_v | M_v |
|---------|-------|-------|
| Sun | -26.8 | 4.85 |
| Sirius | -1.47 | 1.40 |
| Vega | 0.0 | 0.60 |
| Polaris | 1.97 | -3.20 |

Magnitude Scales

- Distance Modulus formula:

$$m_v - M_v = -5 + 5 \log (\text{distance})$$

- Rearrange formula:

$$\text{distance} = 10^{(m_v - M_v + 5) / 5}$$

Example:

Polaris: $m_v = 1.99$ $M_v = -3.2$

$$\begin{aligned} \text{distance} &= 10^{(1.99 - (-3.2) + 5) / 5} \\ &= 10^{(5.19 + 5) / 5} \\ &= 10^{(2.038)} = 109 \text{ pc} \end{aligned}$$

How much brighter is one star than another????

Star A: $m_v = -1.0$

Star B: $m_v = +3.5$

Star A: $m_v = +9.2$

Star B: $m_v = +0.8$

Solar Size/Composition/Temperature

Radius: $1R_{\odot} = 7 \times 10^8 \text{ m}$ (434,960 miles)

Mass: $1 M_{\odot} = 1.989 \times 10^{30} \text{ kg}$

Temperature: 5780 K (9,980 F) - surface
3,000 X's surface temp -core

Compositions: (by mass*)

74% Hydrogen

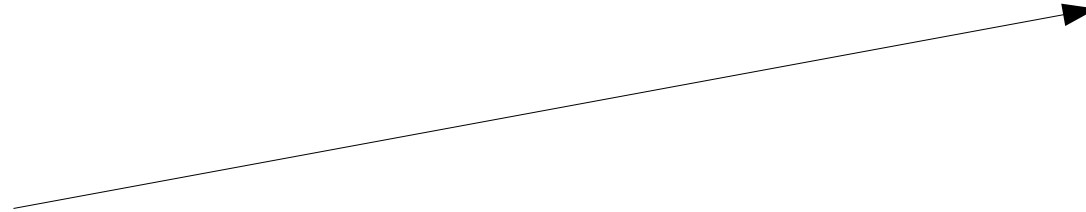
25% Helium

1.3% Metals

Distance from Earth: $1.0 \text{ AU} = 93,000,000 \text{ miles}$

* Rounded numbers taken from *The Chemical Composition of the Sun*, Asplund et al 2009

The Core



- Central Region:

- $0 R_{\odot} - 0.25 R_{\odot}$

- Thermonuclear Fusion converting hydrogen to helium

- 9.1×10^{10} megatons of TNT a second.

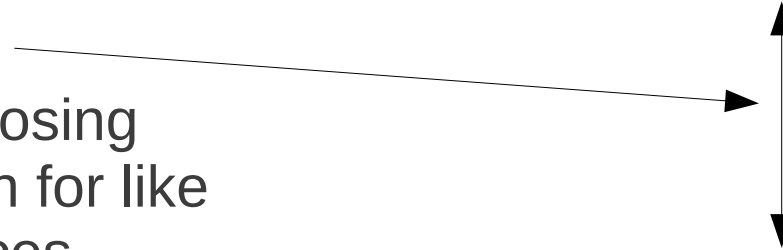
- releases photons of gamma rays.

- Density 150 times that of water: $150,000 \text{ kg/m}^3$

Engine of the Sun: Thermonuclear Fusion

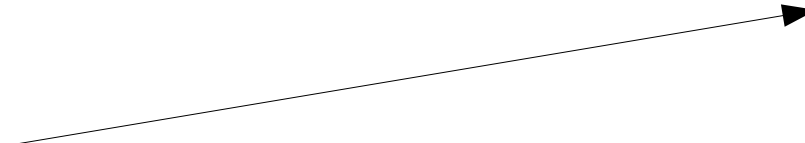
Electromagnetic Force:

Force of attraction for opposing charges and force of repulsion for like charges that acts over distances greater than 10^{-15} m.



Strong Nuclear Force:

Force of attraction between protons and neutrons that acts over distances less than 10^{-15} m.



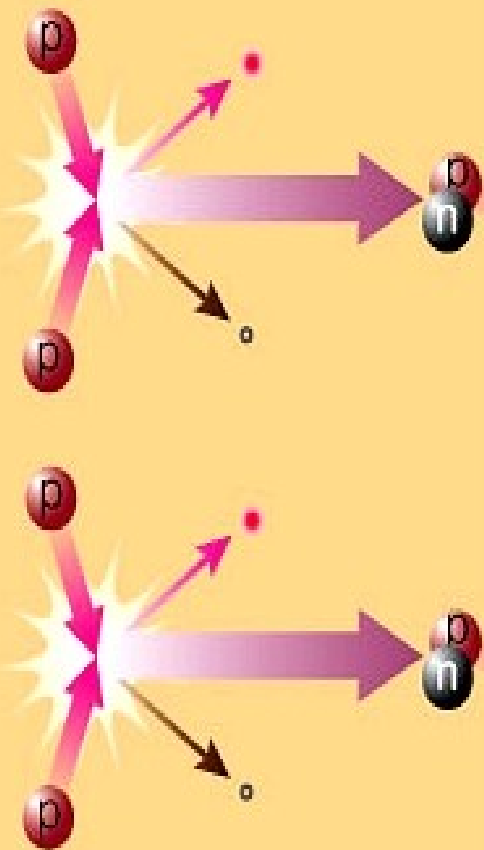
Engine of the Sun: Thermonuclear Fusion

- Under normal conditions two Hydrogen nuclei would repel.
- due to speed and temperature of nuclei at core of the Sun the strong nuclear force is severe and cancels out the electromagnetic force.
- Nuclei tunnel into one another and fuse together.
- converts hydrogen to helium via proton-proton chain in core of Sun.

Hydrogen Fusion by the Proton-Proton Chain

Step 1

Two protons fuse to make a deuterium nucleus (1 proton and 1 neutron). This step occurs twice in the overall reaction.



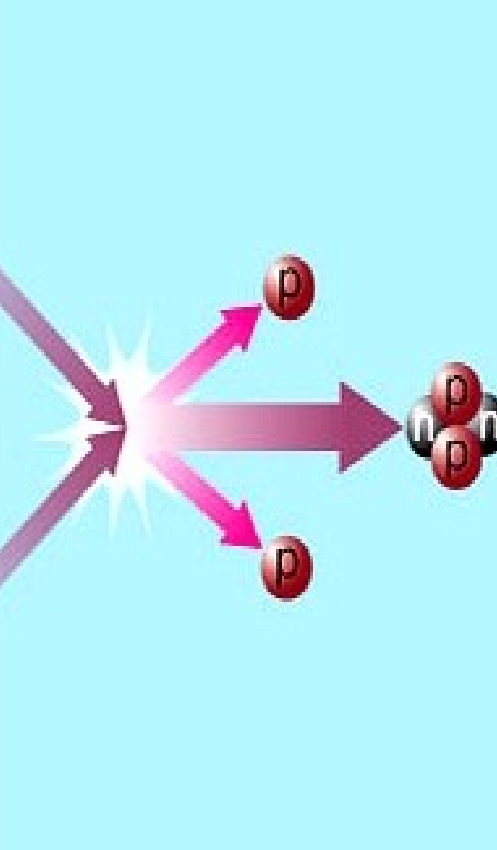
Step 2

The deuterium nucleus and a proton fuse to make a nucleus of helium-3 (2 protons, 1 neutron). This step also occurs twice in the overall reaction.



Step 3

Two helium-3 nuclei fuse to form helium-4 (2 protons, 2 neutrons), releasing two excess protons in the process.



Key:

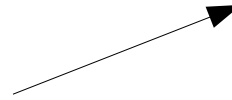
-  neutron
-  proton
-  gamma ray
-  neutrino
-  positron

The Radiative Zone

- Next Layer:

 - $0.25 R_{\odot}$ - $.70 R_{\odot}$

- Photons randomly bounce off of particles or become absorbed to create new photons at lower energy.



- It will take about 16 million years for photons to make it to the next layer.

Credit: Ziad Ganim

The Convection Zone

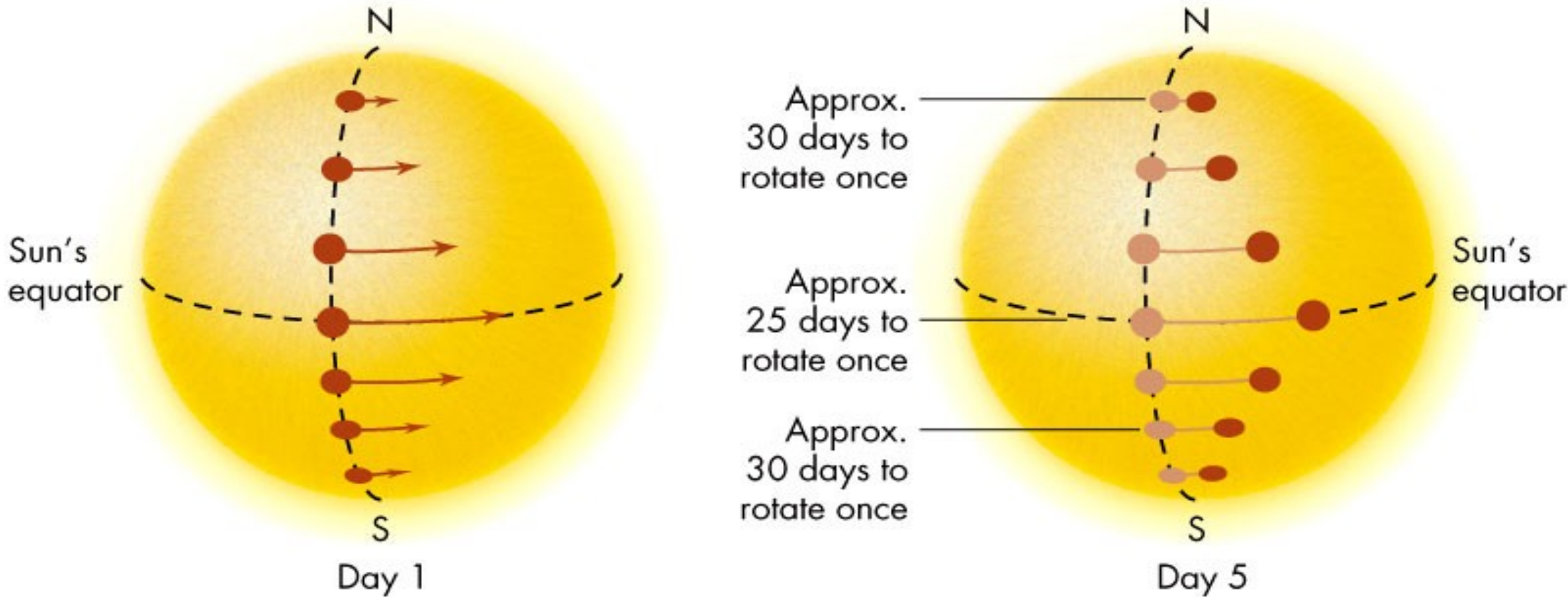
- Outer most layer:
- packets of gas begins to “boil” or convect.
- “hottest” escape toward surface
- “coolest” sinks back into Sun.
- Granules show convection on surface.

The Photosphere

- Visible layer of the Sun (surface).
- Features visible:
 - Granules
 - Sunspots
- Rotational period of Surface:
 - 25 days at equator
 - 36 days at the poles.

Differential Rotation

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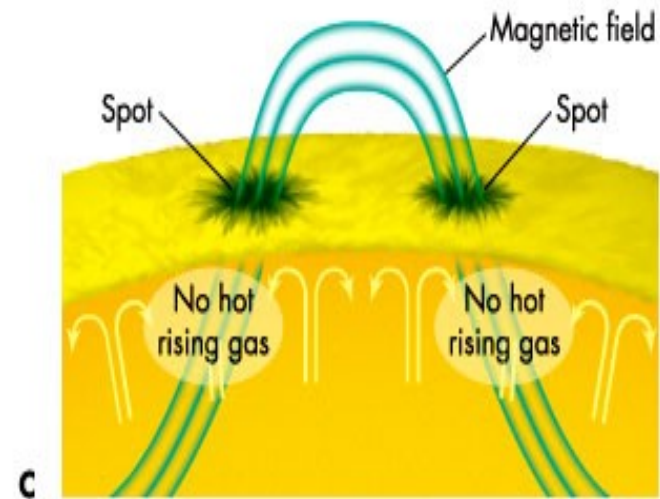
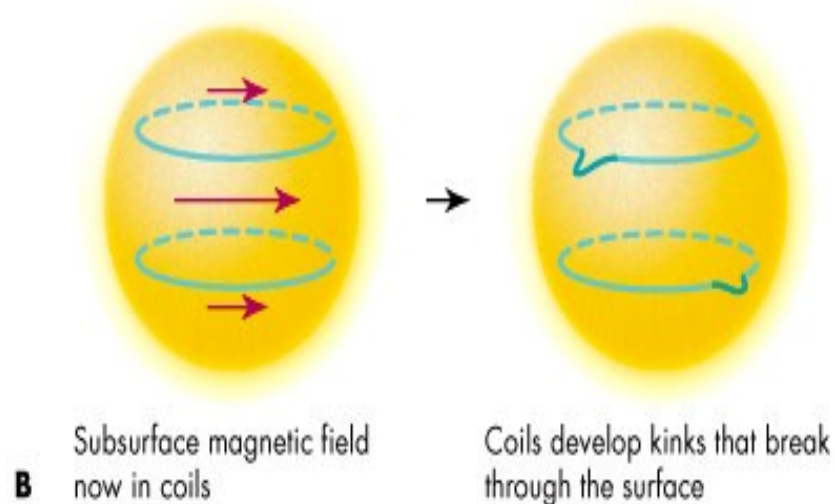
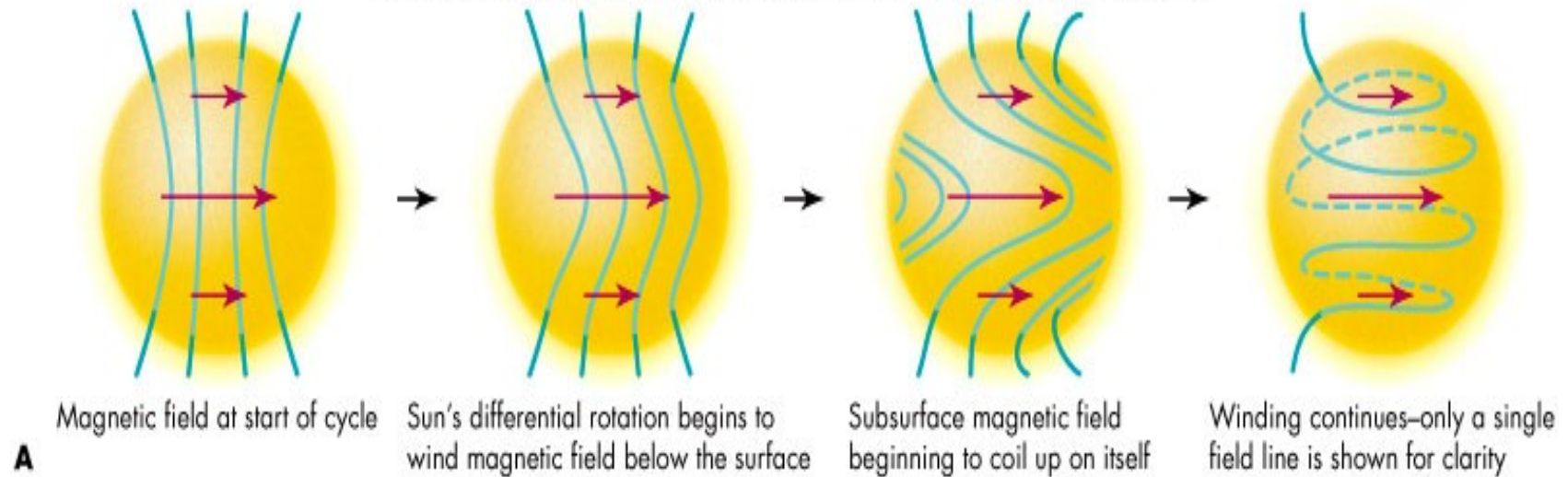
- The Sun undergoes differential rotation, 25 days at the equator and 36 days at the poles

Sunspots

- Appear as dark spots on the surface of the Sun.
- Magnetic regions on the Sun with field strengths thousands of times stronger than the Earth.
- Usually occur in groups of two one positive and one negative.
- Field strongest where darkest.

Cause of the Solar Cycle

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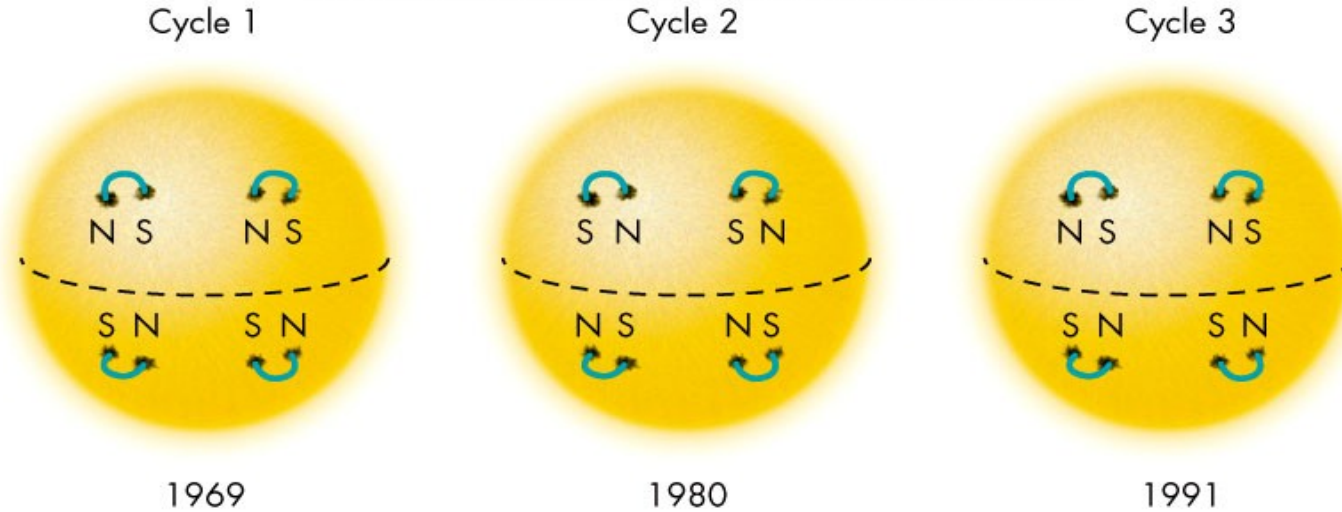


Origin of Sunspots

- Starved of heat from below, the surface cools where the magnetic fields breach the surface creating a dark sunspot

Changes in the Solar Cycle

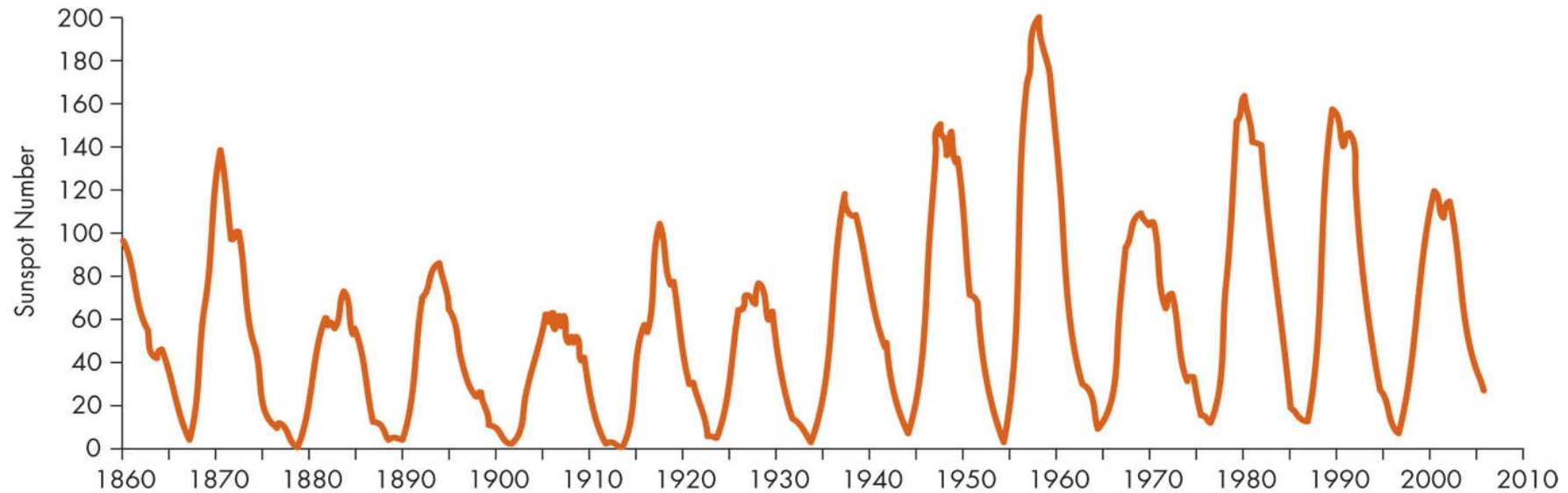
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- Leading spots in one hemisphere have the same polarity, while in the other hemisphere, the opposite polarity leads
- Cycle breaks when magnetic field lines from both hemispheres meet and cancel each other out.

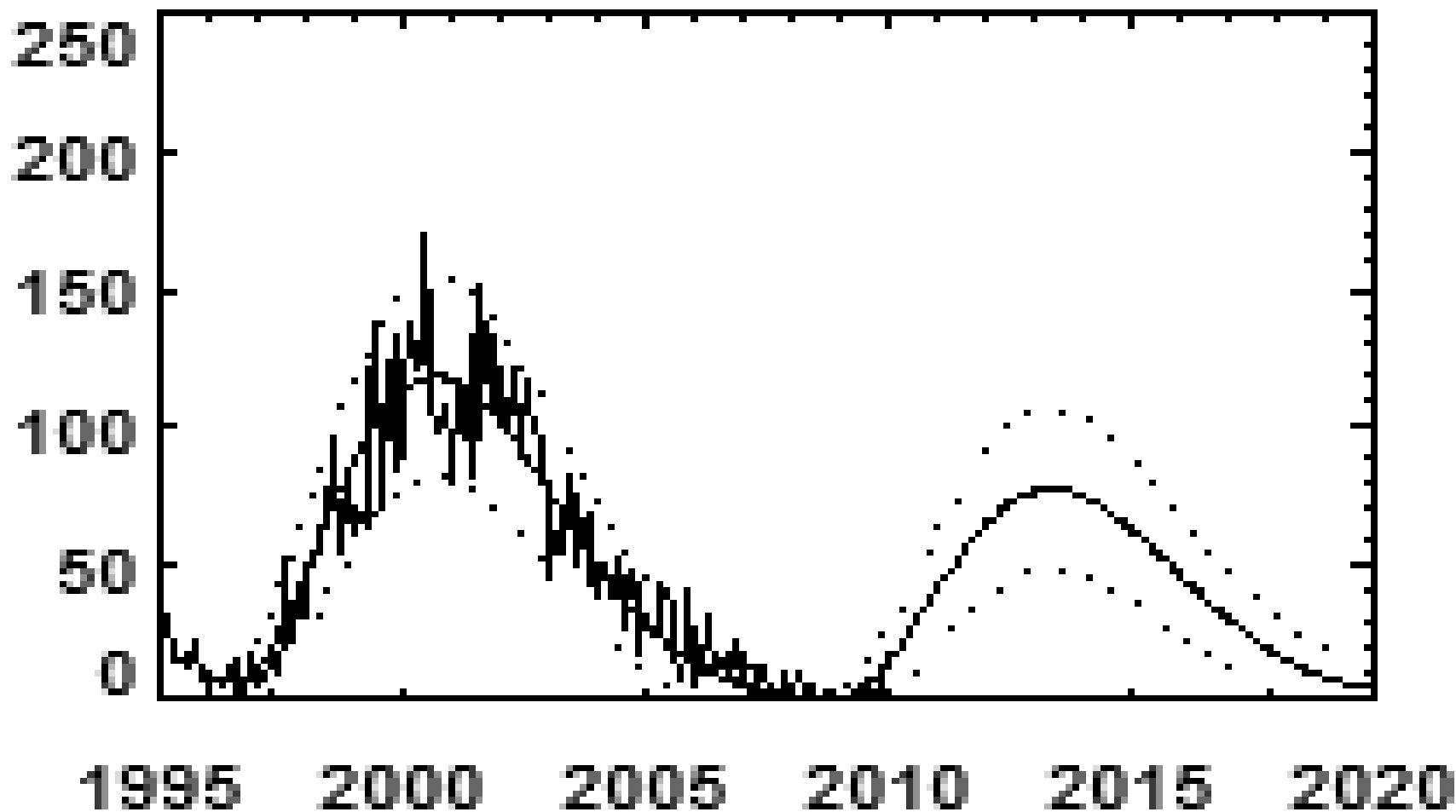
The Solar Cycle

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- Sunspot activity change yearly in a pattern called the ***solar cycle***
- Over the last 140 years or so, sunspots peak in number about every 11 years
- Climate patterns on Earth may also follow the solar cycle

Cycle 24 Sunspot Number Prediction



Predicted below average.

<http://spaceweather.com/>

The Chromosphere

- Lowest layer of Sun's atmosphere.
- Easiest visible during a total solar eclipse.
- Spicules: thin columns of gas thousands of kilometers long.

The Corona

- Outer most part of Sun's atmosphere.
- Visible during a solar eclipse as a white crown surrounding Sun.
- Low density cloud of plasma
- Features include: Flares
 Plumes

The Solar Wind

- due to high temperature particles are able to break away from Corona in large streams.
- Takes 4.5 days to reach Earth.
- Effects whole Solar System.

Solar Flares

- Tremendous explosions on the surface of the Sun.
- Release as much energy as a billion megatons of TNT.
- Occur near Sunspots.