



## The E-M Spectrum

The Nature of Light:  
Wave-Particle Duality

### Light as a Particle (photon)

$$E = h f$$

$$h = \text{Planck's Constant} \\ = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

### Light as a Wave

$$c = f \lambda$$

$f$  = frequency (Hz = 1/sec)

$\lambda$  = wavelength (meters)

$$c = \text{speed of light} \\ = 300,000,000 \text{ m/s (in vacuum)}$$

light is slower in other materials

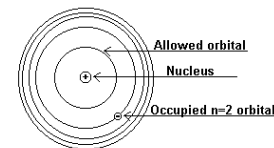
## Matter and Light

To Understand Light,  
We Need To Understand Matter

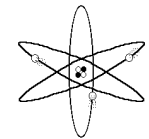
“All Models of the Atom are  
Fundamentally Wrong” – Dr. Phil

### Matter

- protons (+ charge)
- neutrons (neutral)
- electrons (- charge)



Bohr Hydrogen Atom

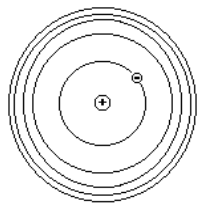


Classic Electrons Whirling Around Nucleus

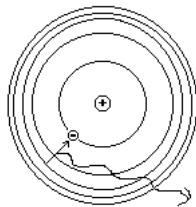
size of a Hydrogen atom  
 $1 \times 10^{-10} \text{ m} = 1/10,000,000,000 \text{ m}$   
size of the nucleus  
 $1/100,000^{\text{th}}$  of an atom

## Light From Electrons Changing Orbits in Atoms and Ions

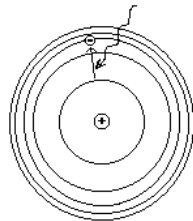
- emission
- absorption



Ground State



Energy Released as Light  
When Dropping to a Lower  
Level



Excited State: Need to Add  
Energy to Ground State

**In Quantum Mechanics**, Physics quantities become *quantized* – they are allowed to have only certain values. Like the seats in this room.

### **In Addition:**

- transmission (goes through)
- reflection & scattering (bounces)

## Spectra

- continuous (rainbow, white)
  - emission
  - absorption

“like fingerprints”

combine with Doppler shift!

## Temperature Scales

°F	°C	K	
212	100	373	B.P. of water
98.6	37	310	Human normal
68	20	293	Room Temp
32	0	273	M.P. of ice
-40	-40	233	only -40°
-110	-79	194	dry ice
-321	-196	77	liq. nitrogen
-460	-273	0	Absolute Zero

## Black Body Radiation

Objects radiate light & energy based on their temperature

For Sun,  $T = 5777$  K blackbody  
(white)

Light Bulb,  $T = 3200$ - $3400$  K (orange)

Candlelight,  $T = 1800$  K (looks red)

Uncorrected Color TV,

$T = 8000$ - $10,000$  K (looks too blue)

## More Definitions

**Atom** – a neutral object with equal numbers of electrons and protons

**Ion** – a charged atomic system with either extra electrons (negative ion) or missing electrons (positive ion)

**Element** – atoms with the same number of protons ( $Z =$  atomic number)

**Isotope** – same element, but different number of neutrons ( $N$ ) (atomic mass  $A \sim Z + N$ )

## Hydrogen: a Unique Case of Isotopes

**H** ( $Z=1$ ,  $N=0$ ) regular old hydrogen, doesn't need a neutron to stabilize the nucleus. The most common material in the universe.

**D** ( $Z=1$ ,  $N=1$ ) heavy hydrogen, has one neutron, also called deuterium. Stable, but uncommon. Twice the mass of regular hydrogen, but still has same chemistry. Heavy water is  $D_2O$ , not  $H_2O$ .

**T** ( $Z=1$ ,  $N=2$ ) super-heavy hydrogen, has two neutrons, also called tritium. Radioactive, so it will eventually decay into another element. Also behaves like H in chemistry.

## More On Continuous Spectra

### Temperature Influences The Light

- Black Body Radiation
  - peak intensity goes towards higher energy/ shorter wavelengths (blue) with higher T
- Stefan-Boltzman law
  - more photons of all wavelengths than lower T (and new photons at higher energies/shorter wavelengths than from lower T)
- Wein's law
  - higher T means higher average energy/shorter wavelengths

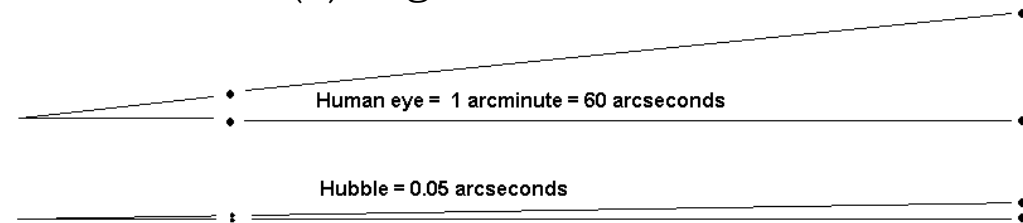
## Telescopes

### (1) Light Gathering Area

Telescope size generally given in diameter D

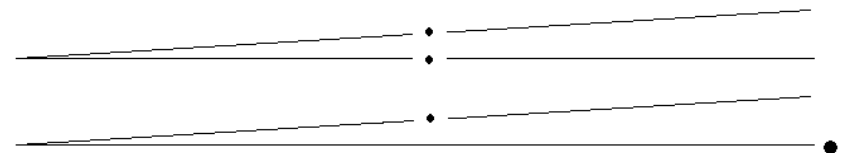
$$A = \pi r^2 = \pi D^2 / 4$$

### (2) Angular Resolution

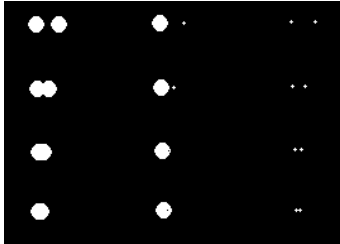


### Remember the 3<sup>rd</sup> Dimension!

Similar angular size...  
could be larger star further away.



## More aspects of angular resolution



The Angular Size of One Object  
May Make It Harder to See  
Another Object

## The Sun

93,000,000 miles away  
(~150,000,000 km)

### Main Sequence Stars

O B A F G K M  
“Oh Be A Fine Guy, Kick Me”

Our Sun is a G-type star  
(actually a G2 star)

Little tiny red dwarfs are M-types,

So O-types must be really large...  
... and hot!

## The Sun

R = 695,000 km

M = 330,000 M<sub>E</sub>

98% H and He

## The Earth

R<sub>E</sub> = 6378 km

M<sub>E</sub> = 5.94 × 10<sup>24</sup> kg

= 5,940,000,000,000,000,000,000 kg

## 11 year Sunspot Cycle

The Butterfly Pattern

1645 – 1715

## The Maunder Minimum

“The Little Ice Age”

## Types of Telescopes

### Refracting

Long tubes, large lenses

Problems with different wavelengths focusing differently

### Reflecting

Use mirrors to shorten tubes

Don't get problem with wavelengths focusing differently, at least not from the mirror parts

Problems with large heavy mirrors – have to remove material to make lighter

### Adaptive

Compensate for atmosphere (remove twinkle from stars) or...

Simulate larger mirror with group of smaller, steerable mirrors

### Radio Telescopes

Reflect radio waves from large dish

Can work in daylight

Detected cosmic background radiation from the Big Bang

### Interferometry

Use two or more telescopes in conjunction

Analyze what the waves are doing to project larger telescope, etc.

## Regarding Quiz 5

Because we are looking at copies of copies, the lines are a little hard to tell. You've got 3 different line widths and 3 different line spacings. (grin)

This is not going to be graded "exactly", but more in the spirit of trying to analyze it.

The idea is that interpreting the lines can be quite difficult – in other words, spectra ain't easy. (grin)

## Chapter 11.1

### Apparent Brightness vs. Stellar Luminosity

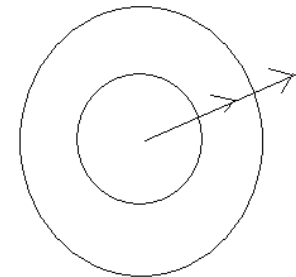
Luminosity = Power Output

Power = Energy / Time  
(Watts)

100 W = 100 J/sec

Apparent Brightness = Luminosity /  $4\pi d^2$

Double the distance, the area of the spherical shell of expanding light is 4 times as big, so the apparent brightness is  $\frac{1}{4}$ .



## Comparing One Star To Another

**Luminosities** of the stars seems to range from  $10^{-4} L_{\text{Sun}}$  to  $10^6 L_{\text{Sun}}$ , or about 0.0001 of the Sun's Luminosity to 1,000,000 times the Sun's Luminosity

## The Spectral Sequence

Table 11.1 p. 312

O B A F G K M  
Hotter.....Cooler

Further subdivided:

F9 G0 G1 **G2** G3 G4 G5 G6 G7 G8 G9 K0  
Hotter.....Cooler

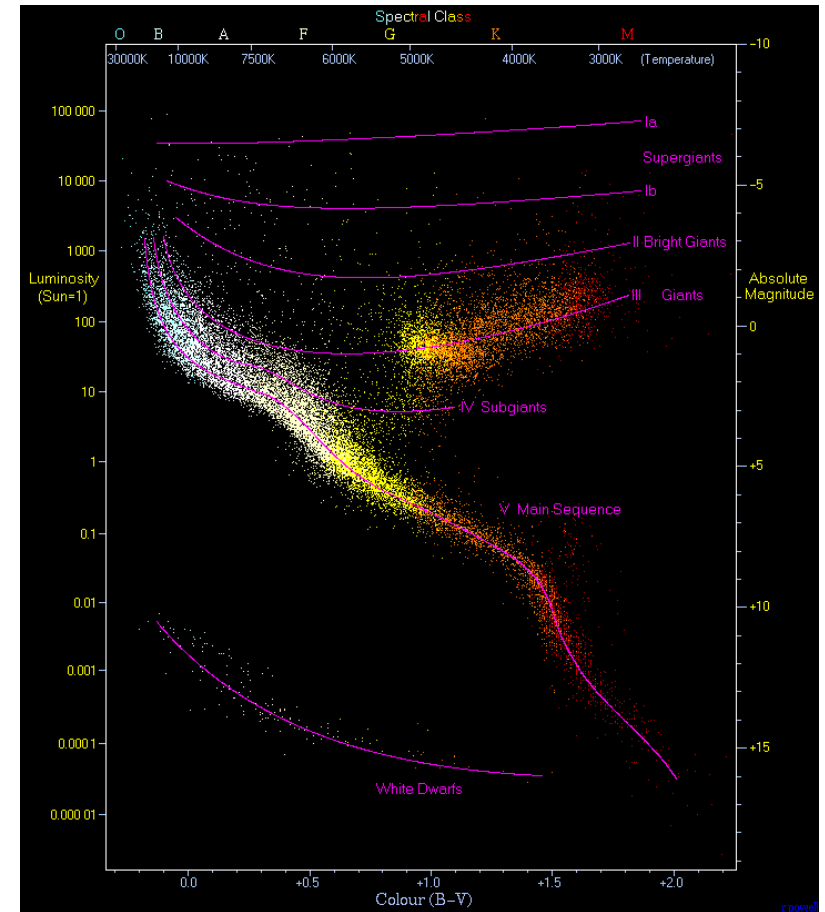
**Main Sequence Stars** Fall Along the Line of Luminosity Class V (LC V)

So our Sun is a **G2 V** star.

Luminosity Classes > V are brighter

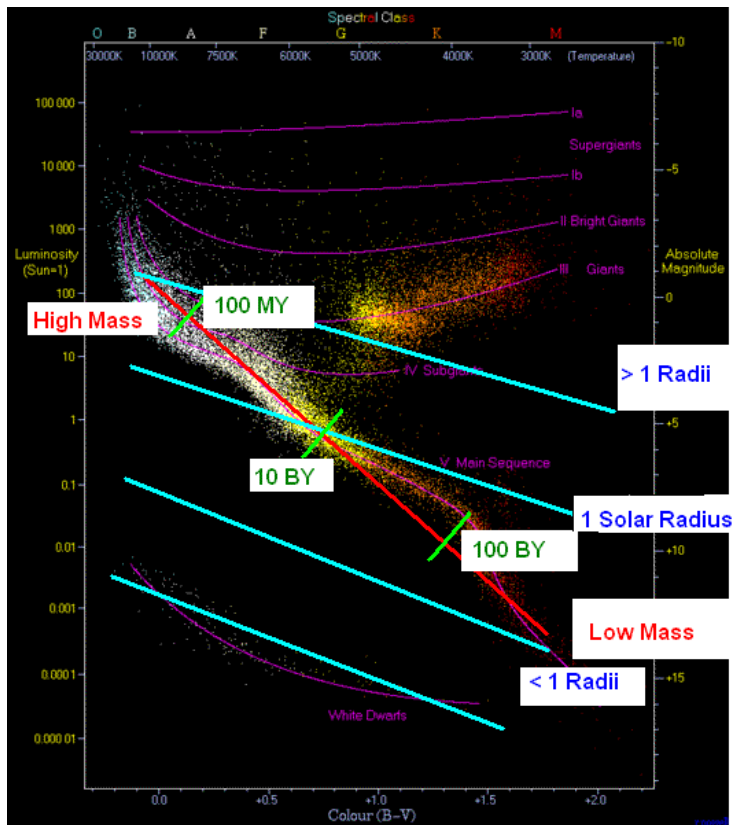
I II III IV V  
Brighter.....Dimmer

## Hertzsprung-Russell diagram (pp. 318-319) The Main Sequence



Things We Can Learn From The H-R Diagram:

Main Sequence Distribution  
and  
Those bands NOT Main Sequence



**The H-R Diagram plots Luminosity vs. Temperature (Color)**

But we can also see patterns in:

- Size (Solar radii)
- Mass (Solar masses)
- Lifetimes (Millions or Billions of Year)

The Most Luminous Stars in the Main Sequence are also the largest and have the most mass, but also the shortest lifetime.

Their mass means more gravity to compress them which means higher temperatures which means ultimately they burn their fuel faster.

All of the properties we see on the H-R Diagram can be boiled down to: MASS

Our Sun is:  
Spectral Type G2  
Luminosity Class V

(G2 LC-V)

## **Reminder:**

Work that is NOT turned in to Dr. Phil  
Should be turned in at the Physics Dept. Office  
1<sup>st</sup> Floor Everett Tower

Do NOT put papers under Dr. Phil's door

or

Pin them to the door or bulletin board.

## **All Is Not Hydrogen**

- But It Started Out That Way
- The Universe is Still Mostly Hydrogen
- And Everything Else Came From Hydrogen



## **In Our Solar System**

- Helium From Another Star – In Our Sun – In Large Planets Like Jupiter and Saturn
- Helium Made By Fusion Inside Our Sun
- Helium On Earth Comes From Radioactive Decay of Uranium in Earth's Crust

### **On Earth, Helium is a gas.**

It's mass-to-volume ratio (density) is so low,  
any Helium gas in the air rises up quickly  
through the atmosphere.

Collisions result in its gaining speed.  
Reaches escape velocity and leaves the Earth.  
Forever.

## Giants, Supergiants and White Dwarfs

### **Giants**

Aldebaran K5 III, 350  $L_{\text{sun}}$ , 30  $R_{\text{sun}}$   
not nearly as large as even the orbit of Mercury

### **Supergiants**

B-G

M2 I, 38,000  $L_{\text{sun}}$ , 500  $R_{\text{sun}}$   
past the orbit of Mars – Mercury, Venus, Earth  
and Mars would all be inside this star.

Since these giants and supergiants are NOT hot,  
but very luminous, their brightness comes from  
SIZE, large surface area.

Old stars. Stars which used to be on the Main  
Sequence, and have gotten old. “Mid-life crisis?”

Really, really big ones – “deviant” stars?

### **White Dwarfs**

are essentially the exposed cores of stars.

“The Old Retirement Home?”

## **Reminder:**

**Tuesday 27 October 2009**  
**is**  
**PHYS-1060 Exam 2**

We will *not* have additional class  
after this exam. You’ll be free to go  
when you are done.

Exam may have 30 or 50 questions.

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## Unit 3 Readings

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Also – I added tags to the HTML  
Book and Movie Assignment pages  
so you can jump right to the Book  
or Movie Lists...

## Star Clusters

### **Open and “Closed” Globular Clusters**

#### **Star clusters are Localized:**

The stars are all about the same distance from Earth and all about the same age.

**Open clusters** in the flat plane of the galaxy, where the dust and gasses are.

Up to a few thousand stars,  
loosely held together by gravity.

**Globular clusters** are in the “halo” or sphere around the galaxy – and are very old.

Up to a hundred thousand stars,  
tightly bound by gravity.  
No dust or gas. Low metal stars.

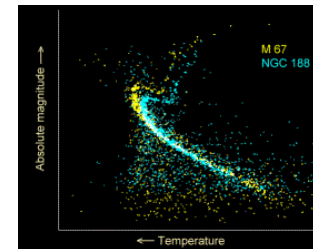
### **Stellar nurseries**

The H-R Diagram for an Open Cluster is cut off at the high mass end (O B A), and though it has a strong Main Sequence line, there is some spread outward.

#### **Age of Star Clusters**

The Main Sequence Turn-Off... occurs because the stars in a cluster are roughly of the same age and the high mass stars have shorter lifetimes. So as the star cluster ages, any high mass stars will end their hydrogen burning life and leave the Main Sequence.

H-R Diagram for two clusters (M67 and NGC 188):



Recall that the Main Sequence stars have age estimates based on their mass...

So NGC 188 is older than M67.