SESSION FOURTEEN: THE EVOLUTION OF STARS

Approximate Characteristics of Several Types of
M A I N S E Q U E N C E S T A R S

Class	Mass in Comparison to Sun	Contraction to Zero Age Main Sequence Not well known	Surface Temp. (K)	Luminosity compared to sun	M Absolute Magnitude	Years on Main Sequence	Radius in suns
O6 mid	29.5 blue super g	10 Th	45,000	140,000	-4.0	2 M	6.2
O9 late	22.6 blue super g	100 Th	37,800	55,000	-3.6	4 M	4.7
B2 early	10.0	400 Th	21,000	3,190	-1.9	30 M	4.3
B5 mid	5.46	1 M	15,200	380	-0.4	140 M	2.8
A0 early	2.48	4 M	9,600	24	+1.5	1B	1.8
A7 late	1.86	10 M	7,920	8.8	+2.4	2 B	1.6
F2 early	1.46	15 M	7,050	3.8	+3.8	4 B	1.3
G2 early	1.00 sun	20 M	5,800	1.0	+4.83	10 B	1.0
K7 late	0.53	40 M	4,000	0.11	+8.1	50 B	0.7
M8 late	0.17 minimum	100 M	2,700	0.0020	+14.4	840B	0.2 2 Jupiters

Temperature-Spectral Class-Color Index Relationships for Main-Sequence Stars

Temp	54,000 K	29,200 K	9,600 K	7,350 K	6,050 K	5,240 K	3,750 K
Sp Class	O5	B0	A0	F0	G0	K0	M0
Co Index (UBV)	-0.33	-0.30	-0.02	+0.30	+0.58	+0.81	+1.40

1. Luminosity is proportional to mass$^{3.5}$ (sun = 1)
2. Time on the main sequence = 1/mass $^{2.5}$ x 10BY or mass/lum. x 10BY (sun = 10 billion years)
3. Radius = $R/R_{sun} = (T_{sun}/T)^2(L/L_{sun})^{1/2} = (^1/T_{star})2$ x $(\text{Luminosity}_{star})^{1/2}$ (sun = 1 for temp, luminosity, radius)
4. Stefan-Boltzmann law: Energy per unit area = σ x temp^4 (temp in Kelvin)
   σ = Stefan-Boltzmann constant = 5.67 x 10^{-5} erg cm^{-2} K^{-4} sec^{-1}
5. Wien's law: dominant wavelength of light being emitted by a star, λ_{max} = 0.2898 x 10^8 Å T/T (temp in Kelvin)
6. Planck's Constant: h = 6.626 x 10^{-27} erg sec; energy = h x frequency = higher frequency, shorter wavelength, and greater energy.
7. Supernova candidates: Stars with masses greater than nine solar masses at the time of the supernova
   DIFFERENT TYPES OF STELLAR MAGNITUDE
8. Apparent (m): Measurement of a body's brightness as seen from Earth
9. Absolute (M): Apparent magnitude of an object as seen from a standard distance of 10 parsecs (32.6 light years)
10. Apparent Bolometric (m bol): Measures the total radiation received from the body outside of Earth's atmosphere

A. **Understanding Stellar Distances:** When looking at the sky at night we are confronted with bright and faint stars. It is impossible to tell simply with the unaided eye whether the bright stars are truly bright, or luminous just because they are close to us. Conversely, is a faint star faint because it is not producing much energy, or is it faint because that star is incredibly bright, but extremely far away? Unless it was possible to determine how far away the stars really were and then mathematically move them to a standard distance, astronomers would never be able to compare range of stars and understand their differences.

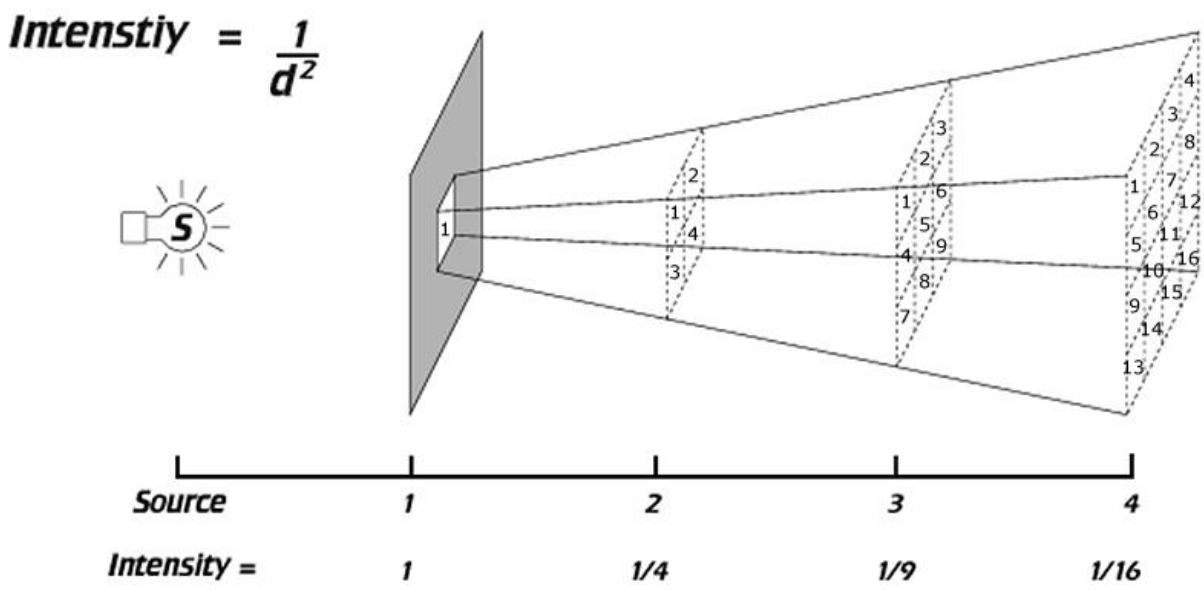
1. **Hipparchus Invented the Stellar Brightness or Magnitude System**: (Greek philosopher, born approx. 190 BC—died 120 BC) Greatest astronomer of the pre-Christian era. Invented or developed trigonometry, systematically observed the heavens creating a star atlas, the magnitude system, discovering parallax (that objects changed position when viewed over a baseline), and developed a geocentric model of the universe using eccentrics and epicycles. Don't get Hipparchus mixed up with Hipparcos the **HI**gh **P**recision **PAR**allax **CO**llecting **S**atellite that measured the distances to 2.5 million stars during its four year lifespan. It is not the same as the Greek philosopher.
2. **Magnitude system according to Hipparchus:** It was a subjective system in which the limits of magnitude were designated as the brightest which was the least positive number of the system (+1), and the faintest stars had the greatest positive number (+6). A first magnitude star was twice as bright as a second magnitude star in the Greek system.
3. **Modern magnitude system:** In 1856, English astronomer, Norman R. Pogson formalized the magnitude system as follows:
   a. **Maintained the Greek concept** that the brighter stars are less positive.
   b. **Quantified** that a difference of five magnitudes would correspond to an intensity change of 100 times. A +1 magnitude star is 100 times brighter than a +6 magnitude star. A change of one magnitude equals an intensity change of 2.51. $(2.51)^5 = 100$.
   c. **Used Polaris as the standard** from which all magnitudes would be calculated. This was later changed to Vega, because Polaris was found to be a variable star.
   d. **Extended the scale** into the negative numbers for the brighter stars/moon/planets.

1) Sun	-26.7
2) Moon	-12.6
3) Venus	-4.6
4) Sirius	-1.4
5) Vega	+0.03
6) North Star	+1.99
7) Faintest visible to human eye	+6.0 to +7.5 under optimal condition
8) Hubble Space Telescope	+31
9) James Webb Telescope	+32 to +35

I. **Inverse Square Law:** Discovered by Johannes Kepler (German astronomer, 1571-1630)

1. Brightness = $1/d^2$
2. A small change in the distance gives a huge change in the brightness.
3. The inverse square law applies to electromagnetic radiation, magnetism, gravity, and some types of sound propagation.

Inverse Square Law



B. **Intensity vs. Magnitude:**
$I = 2.51^x$ where x = the difference in magnitude

What is the intensity difference between a star of magnitude +3.5 and the planet Venus which can be as bright as -4.6?
Difference in magnitude = 3.5 – (-4.6) = 8.1 magnitudes

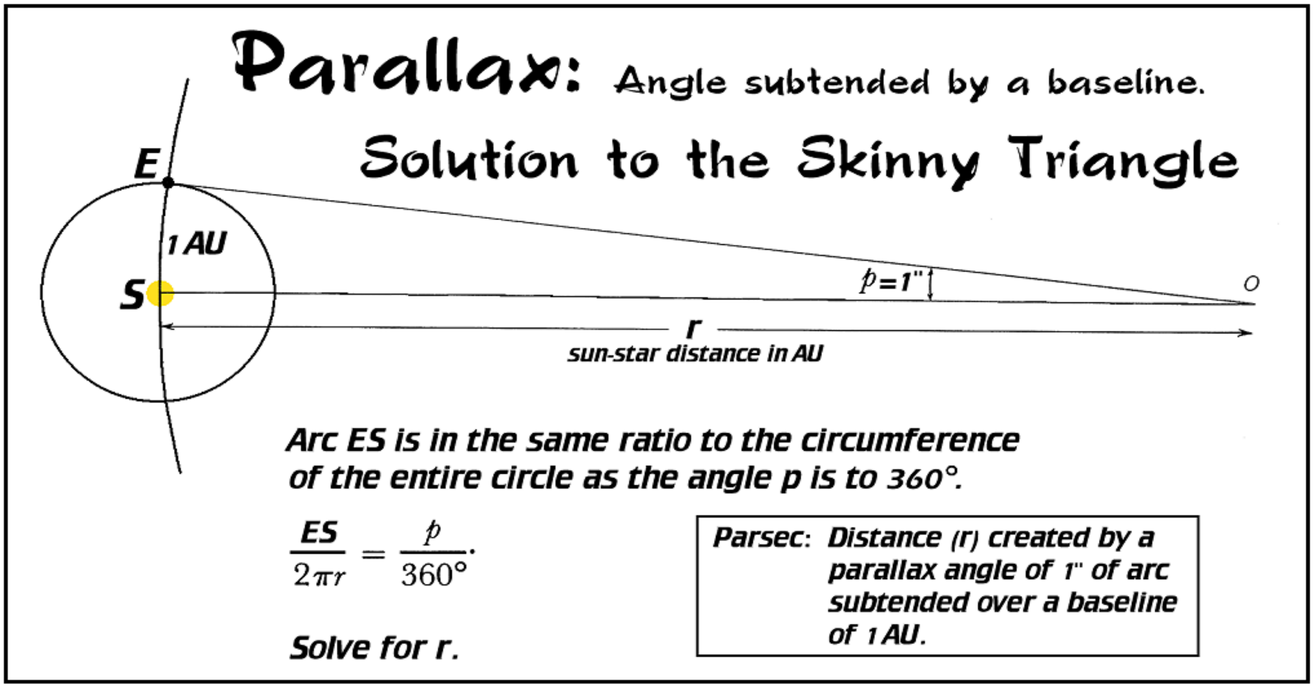
$I = 2.51^x$; $I = 2.51^{8.1}$; I = 1727 Since 2.51 has three significant numbers the final answer would be 1730.

Two stars have an intensity difference of 573 times. What is their difference in magnitude?

$573 = 2.51^x$; to normalize the differences between intensity and magnitude, both sides are converted to logarithms.

$\log 573 = \log 2.51^x$; $\log 573 = x \log 2.51$; $2.76 = x\,(0.400)$; $x = \dfrac{2.76}{0.400}$; x = 6.90 **magnitudes**

C. **Parallax:** The angle subtended by a baseline.



ES = 1 AU (Earth-sun distance)
p = 1" (one second of arc)
2π = 2 x 3.141593 = 6.283185
360° This must be converted into seconds of arc to keep the units consistent.

Not to Scale: The distance ES as measured in the book was about 9/16-inch. If this drawing were to scale, O would be approximately 1.83 miles distant.

$$\frac{360^o}{} \times \frac{60'}{1^o} \times \frac{60''}{1'} = 3.60 \times 10^2 \times 3.600 \times 10^3 = 1.296000 \times 10^6 \text{ sec}$$

1,296,000 sec = "

$$r = \frac{1 \text{ AU} \times 1.296000 \times 10^{6''}}{6.283185 \times 1''} \qquad r = \frac{1.296000 \times 10^6 \text{ AU}}{6.283185} \qquad r = 2.062648 \times 10^5 \text{ AU}$$

Considering the number of significant figures (7) in 2π r = 206,264.8 AU

An object with displays a parallactic angle of one second of arc, subtended over a baseline of 1 AU, will have a distance of 206,264.8 AU.

How many light years are there in 206,264.8 AU? Solving this problem with English Units

$$\text{Speed of light} = 186{,}282.4 \frac{\text{mi}}{\text{sec}} = 1.862824 \times 10^5 \frac{\text{mi}}{\text{sec}}$$

One Astronomical Unit = 1 AU = 92,955,807 mi or 9.2955807×10^7 mi

In order to know how many AUs there are in one light year, we need to find the distance that light travels in one year by multiplying the speed of light by the number of seconds in one year, and then divide by the number of miles in 1AU.

Speed of light: $186{,}282.4 \frac{\text{mi}}{\text{sec}}$ **1 AU** = 92,955,807 mi **Tropical Year** = 365.24220 days

Distance that light travels in one year

$186{,}282.4 \frac{\text{mi}}{\text{sec}} \times 60 \frac{\text{sec}}{\text{min}} \times 60 \frac{\text{min}}{\text{hr}} \times 24 \frac{\text{hr}}{\text{day}} \times 365.24220 \frac{\text{days}}{\text{yr}}$ The Tropical Year is used as a reference (Vernal Equinox).

$$1.862824 \times 10^5 \times 3.600 \times 10^3 \times 2.4 \times 10^1 \times 3.6524220 \times 10^2 = 5.878500 \times 10^{12} \frac{\text{mi}}{\text{yr}}$$

$$5.878500 \times 10^{12} \frac{\text{mi}}{\text{ly}} \times \frac{1\text{AU}}{9.2955807 \times 10^7 \text{ mi}} = \frac{5.878500 \times 10^{12} \frac{\text{mi}}{\text{ly}}}{9.2955807 \times 10^7 \frac{\text{mi}}{\text{AU}}} = 6.323973 \times 10^4 \frac{\text{AU}}{\text{ly}} \text{ or } 63{,}239.73 \frac{\text{AU}}{\text{ly}}$$

FINAL SOLUTION TO THE PROBLEM

$$r = 206{,}264.8\text{AU} = 2.062648 \times 10^5 \text{ AU} \times \frac{1 \text{ ly}}{6.323973 \times 10^4 \text{ AU}} = (3.2616)33 \text{ ly}$$

Accepted value = 3.2616 ly

3.2616 ly = 1 parsec (1pc), the distance created by a **par**allax angle of 1 **sec**ond of arc, subtended over a baseline of 1 astronomical unit.

Within 100 pc of the sun there are about 300,000 stars. Prior to 1989, astronomers had parallactic measurements for about 6800 of them. The **E**uropean **S**pace **A**gency's Hipparcos satellite (**HI**gh **P**recision **PAR**allax **CO**llecting **S**atellite—operational 1989–93) catalogue of more than 100,000 stars with high-precision measurements was published in 1997. The lower precision Tycho Catalogue of more than a million stars, was published at the same time. The enhanced Tycho-2 Catalogue containing 2.5 million stars was published in 2000. The ESA's Gaia satellite, launched in 2013, is currently on target to catalog high-precision parallaxes of approximately 1 billion astronomical objects through 2022, mainly stars, but also planets, comets, asteroids and quasars among others.

Parallax angles are no longer measured in seconds of arc. Refinement of angle measuring techniques allows astronomers to measure parallactic angles in milliarcseconds (mas). A milliarcsecond is a unit of angular measurement equal to 1/1000th of an arcsecond. Convert milliarcseconds into seconds of arc by dividing the milliarcsecond (mas) value by 1000 as demonstrated in the problem below. A star has a parallax measured at 27.22 mas. What is the parallax angle of that star in seconds of arc and what is the distance to that star?

$$\text{Stellar Distance in parsecs} = \frac{1}{\text{Parallax angle in seconds of arc}} \qquad d_{pc} = \frac{1}{p''}$$

Parallax with respect to distance represents an inverse relationship. The smaller the parallax angle, the greater the distance to the star.

$27.22 \text{ mas} \times \frac{1''}{1000 \text{ mas}} = 0.02722''$; $\frac{1}{0.02722''} = 36.74 \text{ pc} \times 3.2616 \frac{\text{ly}}{\text{pc}} = 119.8 \text{ ly}$

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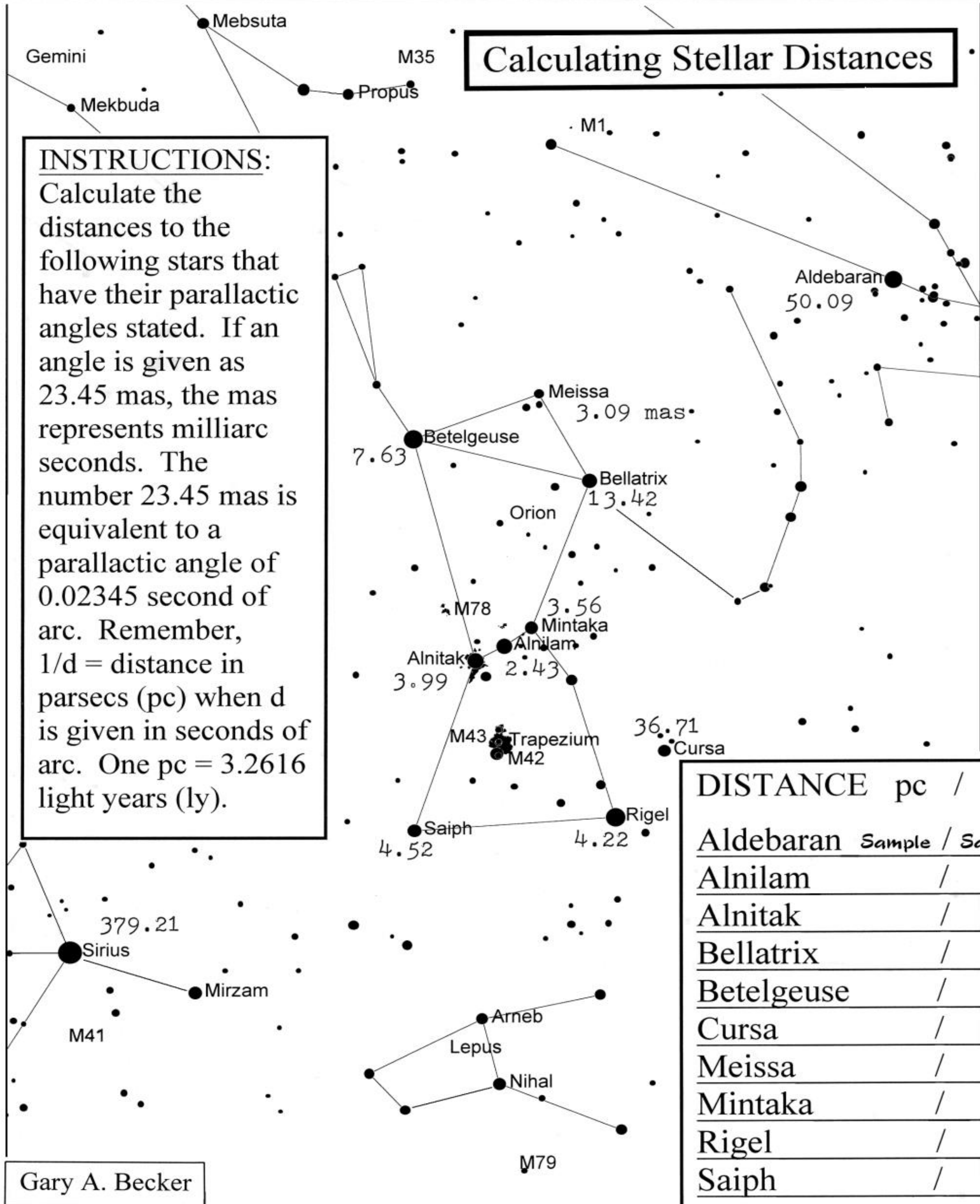
or $\dfrac{27.22 \text{ mas}}{\frac{1000 \text{ mas}}{1''}} = \dfrac{\frac{27.22 \text{ mas}}{1}}{\frac{1000 \text{ mas}}{1''}} = \frac{27.22 \text{ mas}}{1} \; \frac{1''}{1000 \text{ mas}} = 0.027.22''$

Distance = 1/parallax in seconds of arc 0.02722''; $\frac{1}{0.02722''} = 36.74 \text{ pc} \times 3.2616 \frac{\text{ly}}{\text{pc}} = 119.8 \text{ ly}$

conversion to seconds of arc, 1/parallax'' = distance in parsecs, conversion to light years

Name ______________________________________ Date _______________

Calculating Stellar Distances



INSTRUCTIONS: Calculate the distances to the following stars that have their parallactic angles stated. If an angle is given as 23.45 mas, the mas represents milliarc seconds. The number 23.45 mas is equivalent to a parallactic angle of 0.02345 second of arc. Remember, 1/d = distance in parsecs (pc) when d is given in seconds of arc. One pc = 3.2616 light years (ly).

DISTANCE	pc / ly
Aldebaran	Sample / Sample
Alnilam	/
Alnitak	/
Bellatrix	/
Betelgeuse	/
Cursa	/
Meissa	/
Mintaka	/
Rigel	/
Saiph	/
Sirius	/

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CALCULATIONS

(Significant numbers are necessary)

1. Alnilam:

2. Alnitak:

3. Bellatrix:

4. Betelgeuse:

5. Cursa:

6. Meissa:

7. Mintaka:

8. Rigel:

9. Saiph:

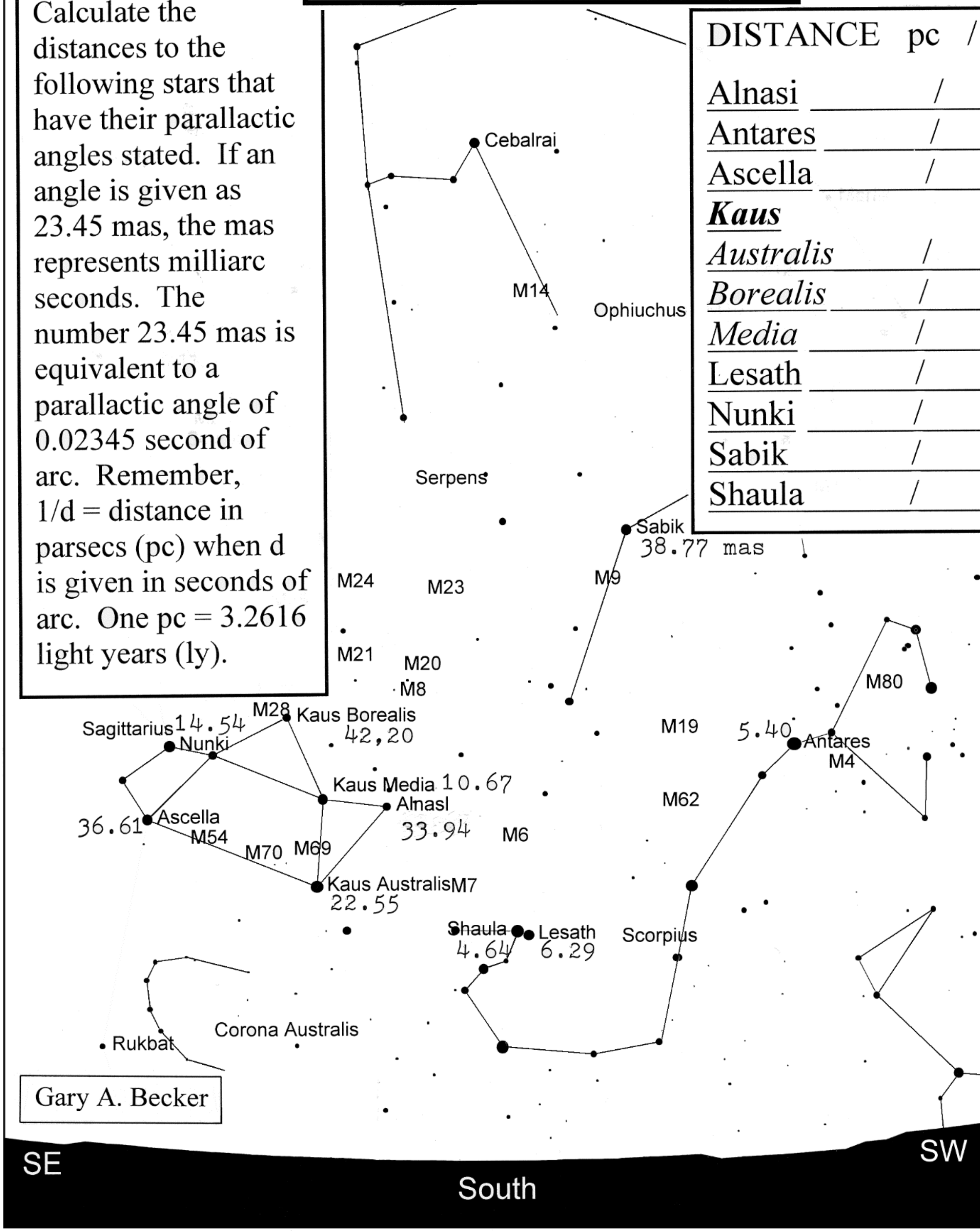
10. Sirius:

Name ______________________________ Date ______________

Calculating Stellar Distances

INSTRUCTIONS: Calculate the distances to the following stars that have their parallactic angles stated. If an angle is given as 23.45 mas, the mas represents milliarc seconds. The number 23.45 mas is equivalent to a parallactic angle of 0.02345 second of arc. Remember, 1/d = distance in parsecs (pc) when d is given in seconds of arc. One pc = 3.2616 light years (ly).

DISTANCE	pc / ly
Alnasi	______ / ______
Antares	______ / ______
Ascella	______ / ______
Kaus	
Australis	______ / ______
Borealis	______ / ______
Media	______ / ______
Lesath	______ / ______
Nunki	______ / ______
Sabik	______ / ______
Shaula	______ / ______



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CALCULATIONS

(Significant numbers are necessary)

1. Alnasi:

2. Antares:

3. Ascella:

4. Kaus Australis:

5. Kaus Borealis:

6. Kaus Media:

7. Lesath:

8. Nunki:

9. Sabik:

10. Shaula:

D. **Distance Modulus:** $M = m + 5 - 5\log r$, where

M = absolute magnitude the brightness of star at 10 pc or 32.616 ly
m = apparent magnitude the brightness of a star as it appears in the sky
r = distance to the star in parsecs (pc)

The Distance Modulus allows astronomers to move a star mathematically to the standard candle distance of 10 pc to ascertain its absolute magnitude and compare it to the absolute magnitude of other stars. Furthermore, this formula can be used to find the distance to a star when only its absolute magnitude is known, by employing the spectral classification system and luminosity classification of the star as plotted on the Hertzsprung-Russell diagram.

The $\log_{10}$ (log to the base 10) of a number represents the exponent to which 10 must be raised to obtain the number. In its written form, the log is followed by the number, i.e., log 100 = 2 and the base 10 is simply assumed. See below.

Number	Scientific Notation	Log of that Number
0.001	$1 \times 10^{-3} = 10^{-3}$	-3
0.01	$1 \times 10^{-2} = 10^{-2}$	-2
0.1	$1 \times 10^{-1} = 10^{-1}$	-1
1.0	$1 \times 10^{0} = 10^{0}$	0
10.0	$1 \times 10^{1} = 10^{1}$	1
100.0	$1 \times 10^{2} = 10^{2}$	2
1000.0	$1 \times 10^{3} = 10^{3}$	3

Three stars appear to be very faint to the human eye—apparent magnitude = +6. Their absolute magnitudes vary by five magnitudes or 100 times the intensity and 10 magnitudes or 10,000 times the intensity respectively. What are their absolute magnitudes (M) of these stars using the Distance Modulus and the distances (r) noted below?

Star Name	**Distance**	**Apparent Magnitude**	**Absolute Magnitude**
A	1 pc	+6	+11
B	10 pc	+6	+6
C	100 pc	+6	+1

M of Star A

$M = m + 5 - 5\log r$

$M = +6 + 5 - 5\log 1$

$M = +6 + 5 - 5\,(0)$

$M = +11 - 0$

$M = +11$

A = one unit of intensity
$1/(1)^2 = 1$

M of Star B

$M = m + 5 - 5\log r$

$M = +6 + 5 - 5\log 10$

$M = +6 + 5 - 5\,(1)$

$M = +11 - 5$

$M = +6$

B is 100 times brighter than A
$1/(10)^2 = 100$ or 5 magnitudes brighter.

M of Star C

$M = m + 5 - 5\log r$

$M = +6 + 5 - 5\log 100$

$M = +6 + 5 - 5\,(2)$

$M = +11 - 10$

$M = +1$

C is 10,000 times brighter than A, $1/(100)^2 = 10{,}000$ or 10 magnitudes brighter.

NOTES

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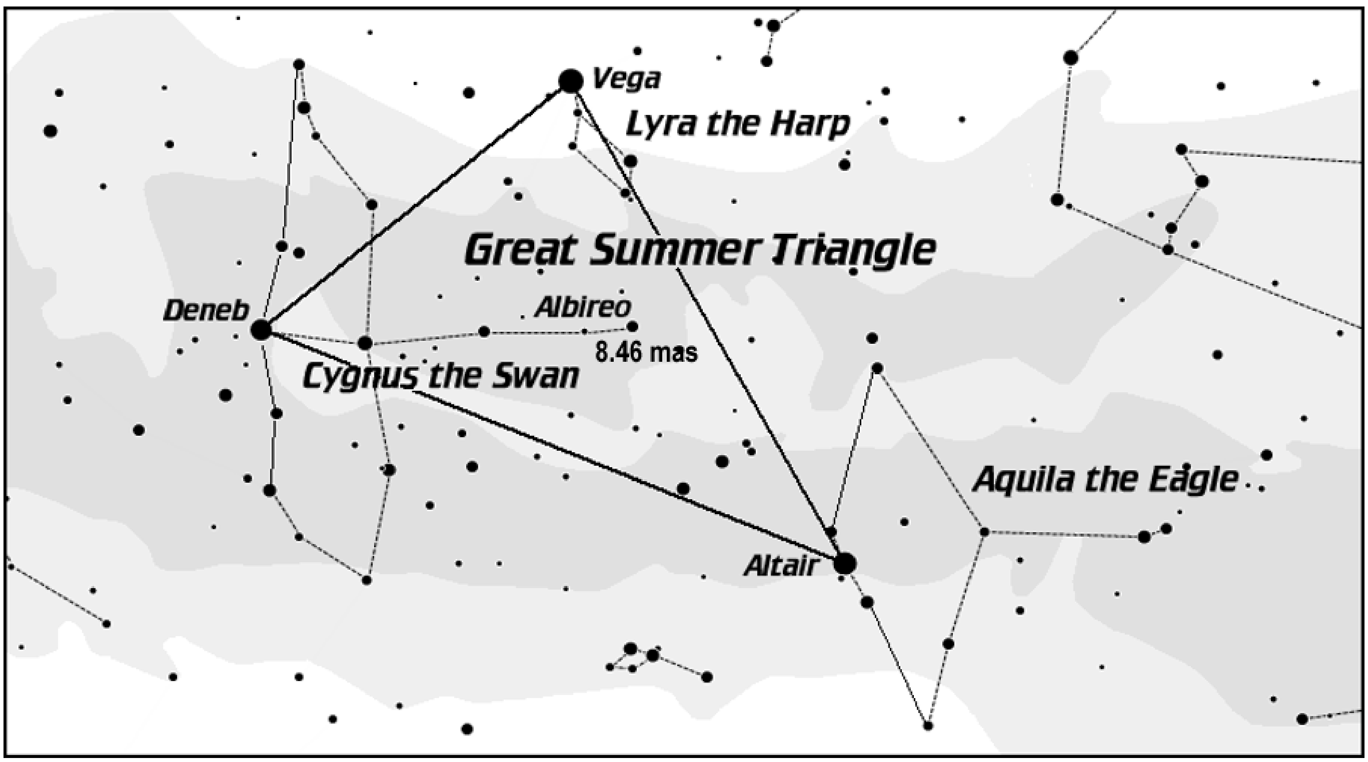
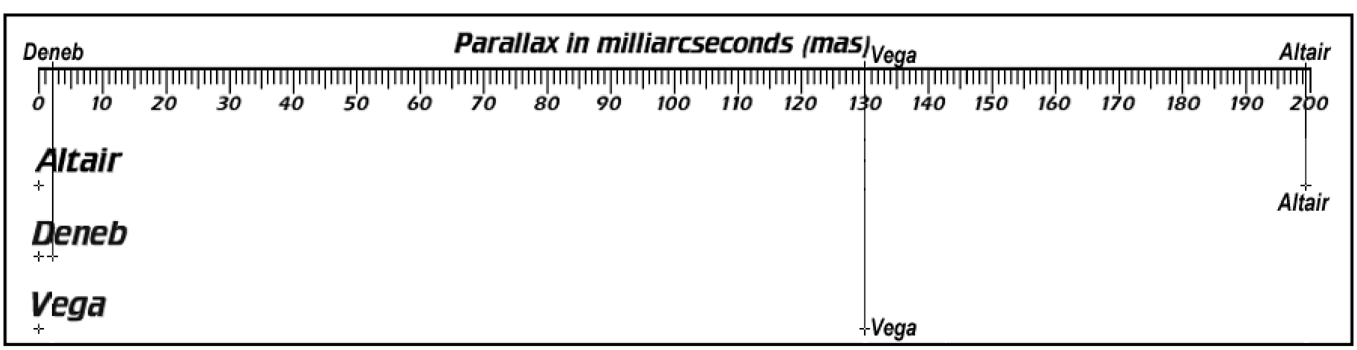
FINDING THE MOST LUMINOUS STAR IN THE GREAT SUMMER TRIANGLE

(10 points)

Instructions: The Great Summer Triangle is one of the hallmark asterisms of the summer and fall sky. It is not really a constellation, but composed of the first magnitude stars of three constellations, Altair of Aquila the Eagle, Deneb of Cygnus the Swan, and Vega of Lyra the Lyre (harp). In the table on the next page, the apparent magnitudes (m) of these three stars are given. Using the scale below, find the parallaxes of the stars of the Great Summer Triangle in milliarcseconds and calculate their distances. Afterwards, use the Distance Modulus to find the absolute magnitudes (M) of these stars and compare M with the sun's absolute magnitude to discover which star is really the most luminous. Finally, discover how much brighter or dimmer the stars of the Great Summer Triangle are to our sun. The sun has an absolute magnitude of **+4.83**.



Use this Scale to measure the parallax angles of the three stars of the Great Summer Triangle.



Procedure for comparing the stars of the Great Summer Triangle with each other and the sun.

Find the distance to the star by converting the parallactic angle given in milliarcseconds **(MAS)** into seconds of arc. Take the inverse of the parallax in seconds of arc to find the distance to the star in parsecs (**D_{pc} = 1/p"**). Finally, multiply the distance in parsecs by the number of light years in one parsec (**3.2616 ly/pc**) to find the star's distance in light years. Enter the calculated values into the table below.

Find the absolute magnitude (M) of the star by using the Distance Modulus, **M = m + 5 – 5log r,** where **M** = the absolute magnitude of the star at 10 parsecs, **m** = the apparent magnitude of the star as seen from the Earth, and **r** = the distance to the star in parsecs. Enter these values into the table below.

Examine how much brighter or dimmer these stars are to the sun by finding the difference in magnitude compared to the sun and converting this number into an intensity. Enter these values into the table below.
Difference in magnitude between the sun and star = **$\Delta M = M_{sun} - M_{star}$**
$I = 2.51^x$, where **I** is the light intensity of the star and the exponent **"x"** represents the difference in magnitudes between the star and the sun. **The absolute magnitude of the sun (M_{sun}) is +4.83.**

PRACTICE WITH THE DOUBLE STAR ALBIREO: Significant numbers are a requirement.

First, find the Distance to Albireo. Parallax of Albireo = 8.46 mas (three significant figures)

$$8.46 \text{ mas} \times \frac{1''}{1000 \text{ mas}} = 0.00846''; \quad D = \frac{1}{p''}; \quad \frac{1}{0.00846''} = \mathbf{118\ pc} \times 3.2616 \frac{ly}{pc} = \mathbf{386\ ly}$$

Then, find the absolute magnitude of Albireo. Apparent magnitude of Albireo = +2.90 (given)
M = m + 5 – 5log r; M = +2.90 + 5 – 5log 118; M = +2.90 + 5 – 5(2.072); M = +7.90 – 10.36

M = -2.46

Finally, find the intensity difference between the sun and Albireo. Which star is brighter, the sun or Albireo?
Difference in magnitude = $\Delta M = M_{sun} - M_{star}$; $\Delta M = +4.83 - (-2.46)$ = **7.29 magnitudes**.
Since Albireo has the brighter (more negative) absolute magnitude, it is the more luminous star.
What is the actual intensity difference?
$I = 2.51^{\Delta M}$; $I = 2.51^{7.29}$; **I = 820**, taking into account significant figures Albireo is brighter than the sun by an intensity difference of 820 times.

Data Table for the Great Summer Triangle Lab
(Correct Significant Figures Required)

Name of Star	Parallax (mas) (Number of Significant Figures to be used is in parentheses)	Apparent Magnitude (given) (m)	Distance in Parsecs/ Light Years $D_{pc} = 1/p''$ pc / ly	Absolute Magnitude $M = m + 5 - 5\log r$ Distance Modulus (M)	Change in Magnitude $M_{sun} - M_{star}$ (ΔM)	Intensity in Comparison to the Sun $I = 2.51^{\Delta M}$ (I)	Which Star is Brighter, the Sun or the Other Star? (Star's Name)
Albireo	(3) 8.46	+2.90	118 / 386	-2.46	7.29	820	Albireo
Altair	(3)	**+0.77**	/				
Deneb	(1)	**+1.24**	/				
Vega	(2)	**+0.03**	/				

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Show all work, i.e., steps in the problem's solution, including the correct usage of significant figures.

Altair

Distance to Altair in parsecs/light years:
D_{pc} = 1/p"; 3.2616 ly/pc

Absolute magnitude of Altair:
M = m + 5 – 5log r

Difference in intensity compared to the sun:
Difference in M: $\Delta M = M_{sun} - M_{Altair}$; $M_{sun} = +4.83$ Intensity = I = $2.51^{\Delta M}$

Deneb

Distance to Deneb in parsecs/light years:
D_{pc} = 1/p"; 3.2616 ly/pc

Absolute magnitude of Deneb:
M = m + 5 – 5log r

Difference in intensity compared to the sun:
Difference in M: $\Delta M = M_{sun} - M_{Deneb}$; $M_{sun} = +4.83$ Intensity = I = $2.51^{\Delta M}$

Vega

Distance to Vega in parsecs/light years:
$D_{pc} = 1/p''$; 3.2616 ly/pc

Absolute magnitude of Vega:
$M = m + 5 - 5\log r$

Difference in intensity to the sun:
Difference in M: $\Delta M = M_{sun} - M_{Vega}$; $M_{sun} = +4.83$ Intensity = $I = 2.51^{\Delta M}$

The most luminous star of the Great Summer Triangle is _____________.

THE NATURE OF LIGHT

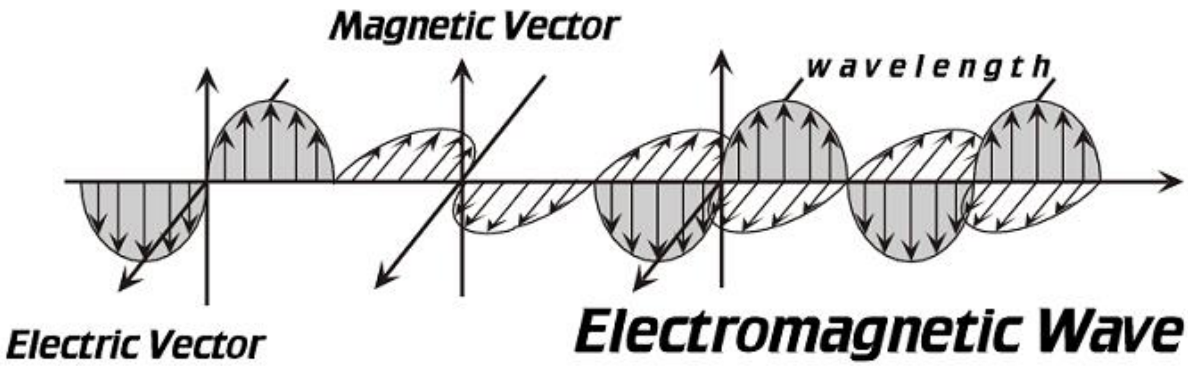
A. **Light has wave properties and particle properties** which allow it to be it to be reflected, refracted, dispersed, diffracted, undergo interference, scattered and Doppler shifted. As a particle, light can act as ping pong balls dislodging electrons in direct proportion to the number of impacting photons.

1. **Synonyms for Light:** electromagnetic waves, waves, electromagnetic radiation, photons, corpuscles, quanta, energy packets, ping pong balls.
    a. **Reflection:** The change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated.
    b. **Refraction:** The change in direction of a wave front passing from one medium to another caused by its change in speed, slowing in denser mediums (Snell's law).
    c. **Dispersion:** A particular property of refraction in which the angle and of a wave front passing through a (dispersive) medium depend upon their frequency. White light passing through a prism is dispersed in the rainbow.
    d. **Diffraction:** The various phenomena which occur when a wave front encounters an opaque obstacle.
    e. **Interference:** A phenomenon in which two waves superimpose to form a resultant wave of greater amplitude (additive) or lower amplitude (subtractive).
    f. **Scattering:** The dispersal of a beam of particles or wave fronts into a range of directions.
    g. **Doppler Shift:** A phenomenon of increased or decreased frequency of the wave front observed whenever the source of waves is moving with respect to the observer. See Doppler shift after the spectroscopy section.
2. A Visual illustration of electromagnetic energy is shown below.
    a. **Lambda (λ):** Lambda represents the wavelength of light, the distance between energy crests. Electromagnetic radiation of longer wavelengths has greater distances between their wave crests than shorter wavelengths of energy.
    b. **Frequency (f):** The number of wave crests passing a detector per unit interval of time, normally one second.
    c. **Speed of light in a vacuum is a constant:** C = the speed of light in a vacuum. $c = 3 \times 10^5$ km/sec $\times 10^3$ m/km $\times 10^2$ cm/m $= 3 \times 10^{10}$ cm/sec.

    $c = \lambda f$; speed of light = wave length x frequency

    $\lambda = \frac{f}{c}$; wave length = $\frac{\text{frequency}}{\text{speed of light}}$

    $f = \frac{c}{\lambda}$; frequency = $\frac{\text{speed of light}}{\text{wave length}}$



3. **Particle (mass) properties:** Light pressure can move micron sized particles in space which means that light has momentum which is equal to mass x velocity. All photons have a mass equivalency.
4. **The speed of light cannot be treated as a vector quantity** with respect to motion. In our normal world of experiences, two cars striking each other head on at 90 mph would have an impact velocity relative to each other of 180 mph. Two beams of light striking each other at the speed of light (c) would have an "impact speed" of only c, and not 2c.
5. **LIGHT—Electromagnetic radiation does not need a medium for transmission**. Think of the electric wave inventing the magnetic wave which invents the electric wave, which allows the entire electromagnetic wave to just keep moving along.

B. **Spectroscopy:** The science that allows energy from the electromagnetic spectrum to be dispersed and analyzed. Spectroscopy allows us to understand the composition, temperature, atmospheric structure, rotation, line of sight motion (radial velocity) and many other characteristics of astronomical bodies.

C. **Kirchhoff's Three Laws of Spectroscopy:** Gustav Kirchhoff (German-1824-1887) developed three fundamental laws dealing with how spectra are formed.
1. **First Law: Continuous Spectrum**—A solid, liquid, or gas (under high pressure/partially ionized under high pressure) emits a continuous spectrum in which all colors (wavelengths) are represented.
2. **Second Law: Emission Spectrum**—A gas under low pressure (rarefied) when made to fluoresce (glow) will emit energy at certain discrete wavelengths which are specific to its composition/atomic structure.
3. **Third Law: Absorption Spectrum**—A rarefied gas lying between a continuous source and an observer will produce a continuous spectrum with discrete wavelengths of light missing. These missing wavelengths are absorbed by the intervening gas and are specific to the composition/atomic structure of the gas through which the light from the continuous source is passing.
4. The spectral lines emitted in a continuous spectrum are exactly the same as those which are absorbed in the creation of an absorption spectrum. Laboratory experiments dealing with emission spectra allow astronomers to understand the absorption spectra of stars.

D. **<u>Wien's Law</u>** (Wilhelm Wien, pronounced Veen)—German 1864-1928): The black-body radiation curve for different temperatures will peak at different wavelengths that are inversely proportional to the temperature. The higher the temperature, the shorter or smaller the wavelength of the thermal radiation.

1. **Black bodies** are perfect absorbers of all radiation incident upon them.
2. **Equation:** λ_{max} T = 0.2898 x 10^8 Å T or λ_{max} = 0.2898 x 10^8 Å T/T, where λ (lambda) equals the wavelength of the greatest amount of energy being emitted in Ångstroms by the black body, and T is the temperature in Kelvin.
3. **Hotter Temps./Shorter λ_{max}:** The hotter the star, the more λ_{max} is shifted towards the blue.
4. **Lower Temps./Longer λ_{max}:** The cooler the star, the more λ_{max} is shifted towards the red.
5. **Example:** The sun's temperature is 5778K. What is λ_{max}?
   $\lambda_{max} = \frac{0.2898 \times 10^8 \text{ Å T}}{T_{sun}}$; $\lambda_{max} = \frac{0.2898 \times 10^8 \text{ Å T}}{5778\text{K}}$; λ_{max} = 5016 Å; = $\frac{5016\text{Å}}{\frac{1\text{nm}}{10\text{ Å}}}$ = 501.6 nm

E. **<u>Stephan's Law</u>** (Josef Stefan—Austrian 1835-1893): See illustration, next page.

1. The total energy emitted from a black body is proportional to the temperature in Kelvin to the fourth power (K^4). If the temperature doubles, the radiation increases by 16-fold.
   $E = \rho T^4$ where ρ (rho), a constant, equals 5.67 x 10^{-5} $\frac{\text{erg}}{\text{cm}^2 \text{ sec } T^4}$
   where temperature is measured in Kelvin (K). T = K

   $E = \frac{\text{ergs}}{\text{cm}^2 \text{ sec}}$ One erg = the force of a dyne acting over a distance of 1 cm

   1 dyne = the force necessary to accelerate $\frac{1 \text{ gm } 1 \text{ cm}}{\text{sec}^2} = \frac{\text{gm cm}}{\text{sec}^2}$
2. Let's look at the units only
   $E = \frac{\text{ergs} \times K^4}{\text{cm}^2 \text{ sec } K^4}$ $E = \frac{\text{ergs}}{\text{cm}^2 \text{ sec}}$ E = ergs per cm square per second

3. The sun has a temperature of 5778K. What is its energy production?
   $E = \rho T^4$; $E = 5.67 \times 10^{-5} \frac{\text{erg} \times (5778\text{K})^4}{\text{cm}^2 K^4 \text{ sec}}$

   $E = 5.67 \times 10^{-5} \frac{\text{erg}}{\text{cm}^2 \text{ sec } K^4} \times 1.11 \times 10^{15} K^4$

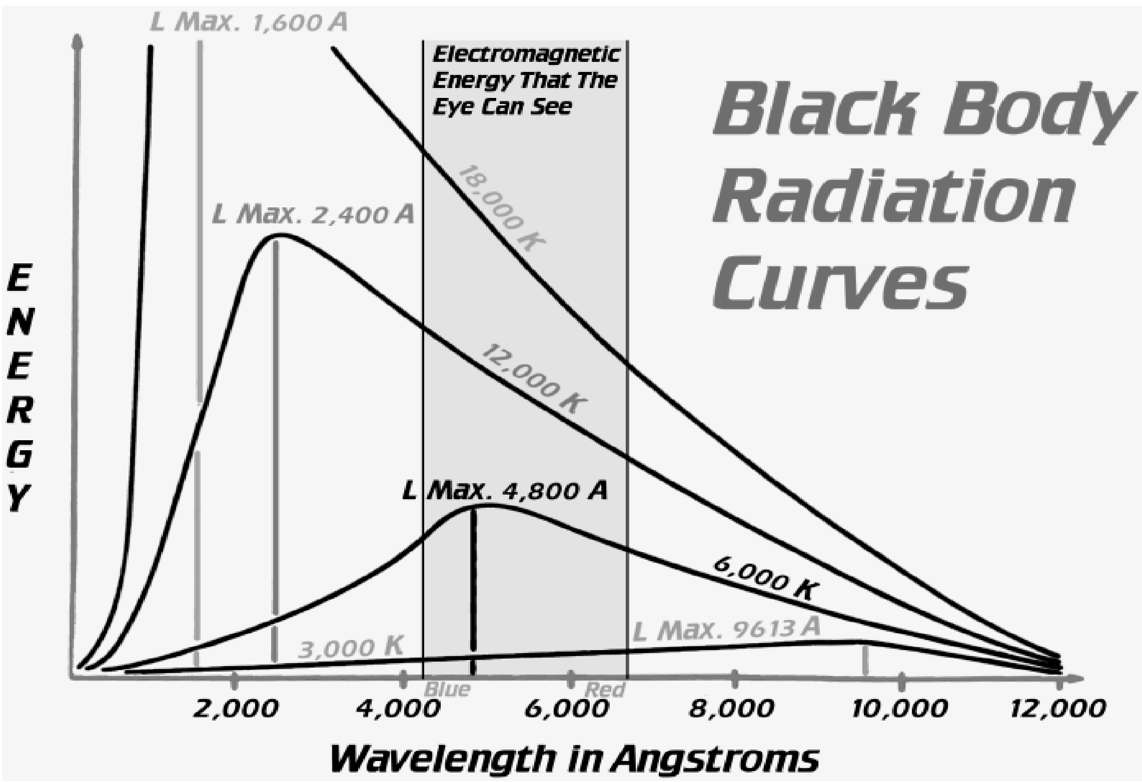
   $E = 6.29 \times 10^{10} \frac{\text{ergs}}{\text{cm}^2 \text{ sec}}$ area of the sun = 6.088 x 10^{22} cm^2

   $E = 6.29 \times 10^{10} \frac{\text{ergs}}{\text{cm}^2 \text{ sec}} \times 6.088 \times 10^{22} \text{ cm}^2 = 38.3 \times 10^{32} \frac{\text{ergs}}{\text{sec}}$

   $E = 3.83 \times 10^{33} \frac{\text{ergs}}{\text{sec}}$ accepted value = 3.846 x 10^{33} $\frac{\text{ergs}}{\text{sec}}$

F. **Planck's Law** (Max Planck—German 1858-1947): The higher the frequency, the higher the energy. The shorter the wavelength the higher the energy.

1. **Equation:** $E = hf$; but $f = \frac{c}{\lambda}$; $E = \frac{hc}{\lambda}$
   where, h = Planck's constant 6.626×10^{-27} erg sec, f = frequency (wavelengths/sec), and λ = the wavelength of the energy.
2. **The higher the frequency**, the shorter the wavelength, the greater the energy of the photon.
3. **The lower the frequency**, longer the wavelength, the smaller the energy of the photon.
4. **Electromagnetic spectrum:** All of the various forms of energy that travel at the speed of light. From highest energies to lowest energies, they range from gamma, X-rays, ultraviolet, visible, infrared, microwaves, and radio.

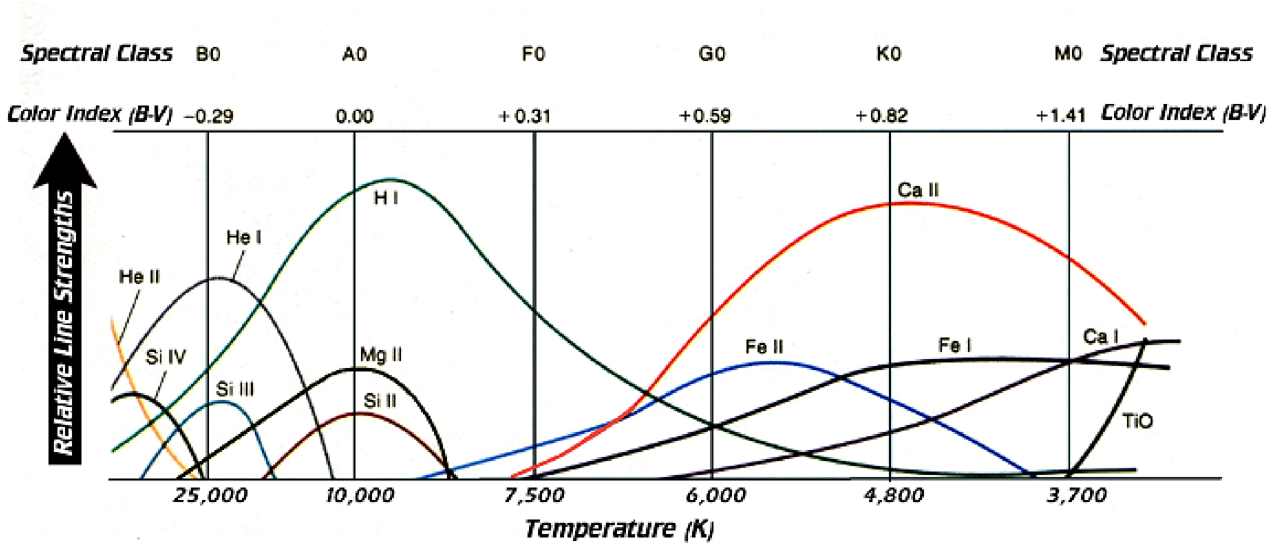


G. **Black Body Radiation Curves:**

1. Black bodies are perfect absorbers of all incident radiation.
2. As a black body heats, the wavelength of energy which is most commonly emitted, λ max, shifts towards the blue (**Wien's Law)**.
3. The total energy emitted under the curve of a black body is proportional to the temperature in K^4 (**Stephan's Law)**. If the temperature doubles, the radiation increases by 2^4 or 16-fold.
4. The radiation curve of two or more black bodies at different temperature will never intersect. In other words, a black body at a higher temperature will emit a greater amount of energy per unit area at all wavelengths than another black body emits at a lower temperature.

5. **<u>Levels of Ionization in Emission Spectra are Dependent Upon Temperature</u>:**
   a. **<u>Ionization</u>:** Any process where an atom or molecule which is electrically neutral, loses or gains electrons, and thereby is converted to an atom or molecule which is electrically charged.
   b. An atom that is neutral is designated as Atomic Symbol I, i.e., Li I
   c. A singly ionized atom is designated as Atomic Symbol II, i.e., Li II
   d. A doubly ionized atom is designated as Atomic Symbol III, i.e., Li III
   e. As more and more electrons are stripped from an atom, its absorption and emission spectrums are shifted towards the blue because the remaining electrons are more tightly bound to the nucleus. To excite these more tightly bound positive ions, higher energy levels are required. Generally, shorter wavelengths of energy will be emitted when these electrons return to the ground state or lowest energy level.

Line Intensity is Dependent Upon Temperature



Different atoms, ions, and molecules produce their spectra at different temperatures. Molecules are abundant only in M stars. Neutral metals are present in lower temperature stars. Toward higher temperatures, more highly ionized species (atoms) are created.

PRINCIPLES OF SPECTROSCOPY

(You'll be happier if you read this several times.)

Most of our knowledge of the physical characteristics of stars comes from their emission and absorption spectrums. Each element gives its own characteristic spectrum: the position, pattern, and intensities of the lines of each element differing from the position and patterns of every other element. The intensity of an absorption spectrum of a particular element will also change based upon the temperature of its continuous source. Although all stars are composed principally of hydrogen, the hydrogen (Balmer) absorption lines in a star may be weak because most of the hydrogen is ionized or neutral. The ideal temperature for revealing the hydrogen Balmer series is about 10,000 K.

Compounds (molecules) give a particular type of spectra called band spectra. Each band consists of individual lines crowding closer and closer together until they merge at a limit, the head of the band. For some compounds the band head is towards the violet; while for others, it is toward the red. Molecular spectra are as individual as atomic spectra, but because they form at lower temperatures, they are found only in cooler stars.

Matter in the visible universe is composed of three basic units: protons, neutrons, and electrons. The proton is distinguished from the electron in at least two ways. First, its mass is 1836 times greater than the electron's mass. Second, the proton possesses one unit of positive electrical charge, whereas the electron possesses an equal amount of negative charge. Atoms which contain equal amounts of protons and electrons are electrically neutral. Protons may also absorb electrons in such a way that the resulting combination acts like a single particle. The resulting neutral particle is called a neutron. Neutrons act as a buffer in the nuclei of atoms, keeping the strong nuclear force at just the right distance (strength) so the atom's nucleus does not fly apart.

Element	Symbol	Atomic Number	Atomic Weight	Protons	Neutrons	Electrons
Hydrogen	H	1	1	1	0	1
Helium	He	2	4	2	2	2
Lithium	Li	3	7	3	3	3
Uranium	U	92	238	92	146	92

Utilizing these building blocks, Ernest Rutherford (New Zealand/England, 1871-1937) and Niels Bohr (Danish, 1885-1962) formed a convenient working model of the atom. For the simplest atom, hydrogen, the model consists of one proton and one electron, the electron revolving in an orbit around the proton. Hydrogen has an atomic weight of 1 and an atomic number of 1. The next simplest element is helium with an atomic weight of 4 and an atomic number of 2. Since its atomic number is 2, it must have 2 protons in the nucleus and two electrons in orbit around the nucleus. Since its atomic weight is 4, it must also have 2 neutrons in its nucleus. The two electrons are orbiting the nucleus at different inclinations to each other. Lithium has an atomic number of 3 and an atomic weight of 7. Its nucleus contains three protons and 4 neutrons. The most complex atom occurring in nature, uranium has an atomic number of 92 and an atomic weight of 238. It has 92 protons, 238–92 or 146 neutrons in its nucleus along with 92 electrons in various orbital paths around the nucleus.

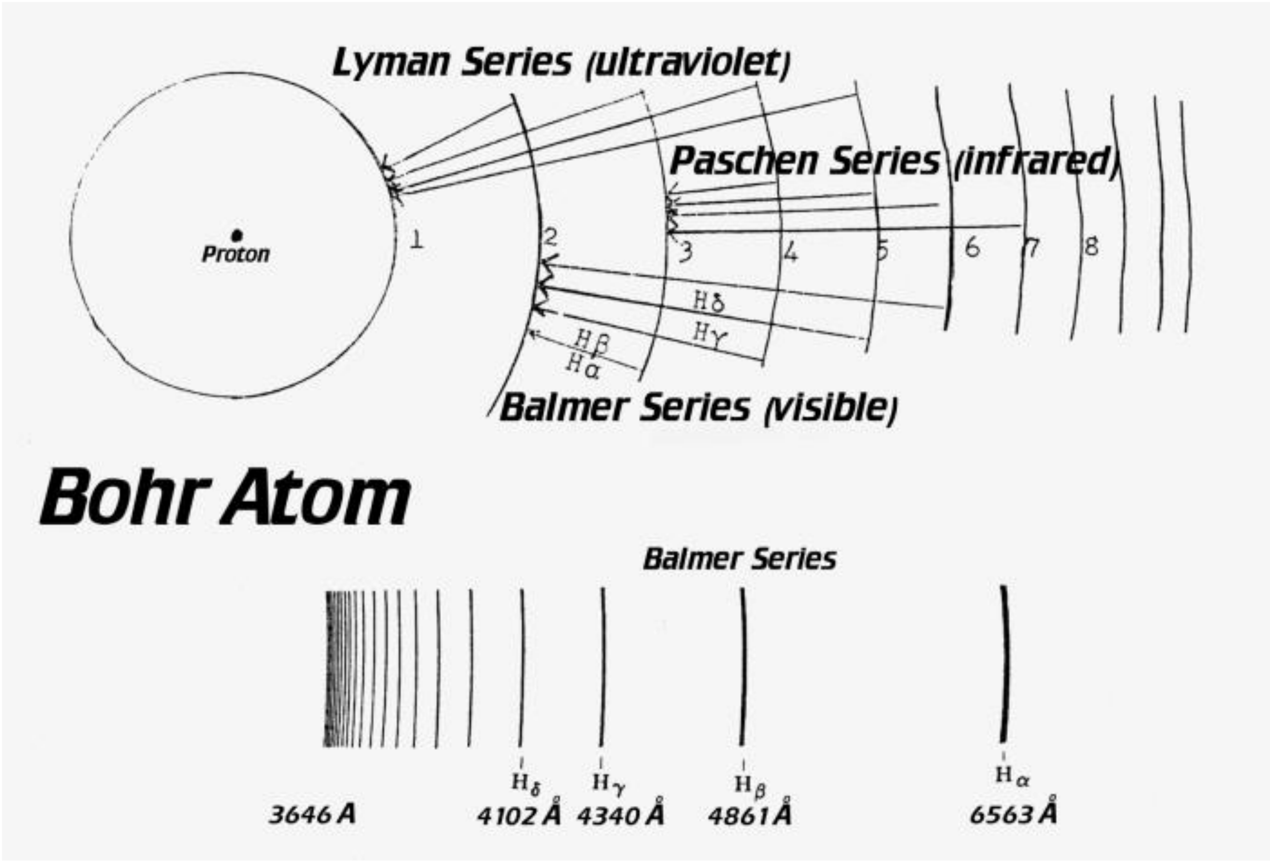
The proton in a hydrogen atom is about 1.6 to 1.7 x 10^{-15} m in diameter (1.6-1.7 femtometers), while the electron orbits the proton at an approximate distance of 5.29 x 10^{-11} m from the nucleus. Put in a different way, if the proton were the diameter of the sun, the electron would be orbiting the proton at nearly 300 AU from the proton. Neptune orbits the sun at 30 AU. Clearly the atom is a much more vacuous structure than the solar system.

While this picture of atomic structure is simplified, it nevertheless forms a convenient means of visualizing the way in which a spectrum is formed. Light is a form of electromagnetic energy. The amount of energy which is involved in the emission of a certain wavelength is given by Planck's law, where $E = hf$, where h = Planck's constant (6.62606957 x 10^{-27} erg sec), and f is equal to the frequency or number of wave crests passing per unit time interval. The shorter the wavelength, the higher the frequency becomes, and the greater the energy of the photon. For an atom to radiate at a certain line (wavelength), it must lose a certain amount of energy. Thus, an atom acquires energy from some source at a shorter wavelength or through the kinetic energy of a collision, before it can be lifted to a higher energy state. Later, when the electron comes down the energy ladder, it will emit radiation with a wavelength proportional to its jump. Some of this energy may be in the form of visible light, while other transitions will produce energy that we cannot see.

Niels Bohr suggested that the process of emission which produces a series of related lines consists of changes of energy of the atom from certain excited, discrete (specific) energy levels to some specific lower energy level. There are no half, third, or quarter levels. In terms of the atom, these energy levels may be pictured as various possible orbits for the electrons, possessing greater and greater radii at increasingly greater energy levels. A jump of the electron from one of the outer orbits to any inner orbit would then result in a loss of energy of the atom and the emission of a spectral line with a frequency given of $hf = E_1 – E_2$ where E_1 = the higher energy level and E_2 is the lower energy level. If energy levels of all intensities were represented, emissions of an infinite variety of frequencies would be possible, and the spectrum would become continuous.

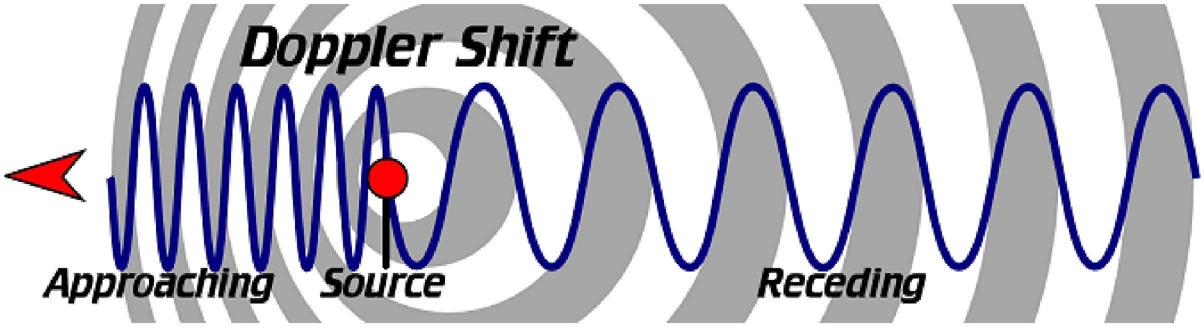
An analogy to this idea would be to imagine a one-legged painter. He would have to hop up a ladder one, two, three, etc. rung(s) at a time. There would be no existence of any intermediate levels. Now at the top of the ladder, the painter encounters an active wasp nest. As the wasps swarm out and begin to sting him, the painter has a number of options as to how he might come down the ladder. He might jump one whole step at a time, or take several steps at a time, or throw all caution to the wind, and simply jump off the ladder to get to the ground. Likewise, an electron can climb the energy ladder one step or multiple steps at a time, or even be ionized. Coming down the energy ladder can be just as complicated with varying amounts of energy given off along the way. However, one concept is constant. The total amount of energy absorbed will always be equal to the total amount of energy which is released when the atom becomes neutral.

Take hydrogen as an example. Suppose the various possible energy levels of a hydrogen atom are represented by a series of energy orbits 1, 2, 3, etc. Orbit 1 is the lowest energy state, where the electron “feels” most comfortable in its orbital pattern around the proton. This electron absorbs a photon of energy and is lifted to a higher energy state. The tendency of the electron will be to return to its ground state (least energy level). When the electron jumps from orbital 2 to orbital 1 or from orbital 3 to orbital 1, it gives rise to the lines of the Lyman series which can be found in the ultraviolet. Jumps from orbit 3 to 2, 4 to 2, and 5 to 2 give rise to the visible red, aqua, and deep blue lines of the Balmer series called Hα (hydrogen alpha), Hβ (hydrogen beta), and Hγ (hydrogen gamma). Each successive member of the series is positioned farther toward the violet, but closer to the preceding line, since these jumps represent successively larger energy losses, but smaller changes in distance from the nucleus, and therefore, smaller total changes in energy. Jumps from higher orbitals then back to 3 and still higher energy levels where the electron jumps back to orbit 4 will result in the Paschen and Brackett series which emits electromagnetic radiation in the infrared. In Helium with two electrons, the number of possible jumps is increased, and the spectrum becomes more complex. For more massive atoms, the descriptions of orbital jumps become hopelessly complicated. See the diagram on the next page for hydrogen.



Dr. Joseph Gerencher (including drawing), Moravian University, revised Gary A. Becker (2009/13).

H. **Doppler Effect** (Christian Doppler—Austrian 1803-1853): A phenomenon of increased or decreased frequency of the wave front observed whenever the source of waves is moving with respect to the observer, or the observer is moving with respect to the emitted wave fronts. A sound source moving towards an observer is of a higher frequency or higher pitch because its wavelengths are compressed in the direction of motion. A sound source moving away from an observer (lower frequency) has its wavelengths lengthened which results in a lower pitch. The frequency of a source represents the number of wave fronts passing a position per unit time interval. With regards to electromagnetic energy, an approaching source has its wavelength shortened or shifted towards the blue, while a receding source has its wavelength shifted towards the red.



1. **Red Shift:** Net radial motion puts the source moving away from the observer. Although the radiation is still traveling at the speed of light, its wavelength is increased and its frequency decreased. The light appears redder, hence the term red shift. Absorption spectral lines are shifted towards the red.
2. **Blue Shift:** The net radial motion of the source is towards the observer and the emitted electromagnetic radiation is compressed in the line of sight of the observer. The frequencies become higher, with more wave crests passing the observer per unit time interval. The light is shifted towards the blue. Absorption spectral lines are shifted towards the blue.
3. **Radial Velocity:** Motion of an object towards or away from an observer. The shift of the wavelength of the spectral lines is proportional to the radial velocity of the source.
4. The fraction of the rest wavelength that the wavelength of light is shifted is in the same proportion as the fraction of the speed of light at which the body is traveling.

$$\frac{\Delta\lambda}{\lambda_0} = \frac{v_r}{c} \qquad \frac{\text{change in wavelength}}{\text{rest wavelength}} = \frac{\text{radial velocity}}{\text{speed of light}}$$

$$v_r = \frac{c\,\Delta\lambda}{\lambda_0} = \text{ the formula for the Doppler shift.}$$

5. The rest wavelength of an emission line in a laboratory experiment lies at 5000Å. When the same line is seen in absorption in a star, the wavelength is measured to be at 4500Å. What is the radial velocity of the star? The speed of light in a vacuum is 299,792 $\frac{\text{km}}{\text{sec}}$

Radial velocity = speed of light $\frac{\text{(measured wavelength – rest wavelength)}}{\text{Rest wavelength}}$

$$v_r = 299{,}792\,\frac{\text{km}}{\text{sec}}\,\frac{(4500\text{Å} - 5000\text{Å})}{5000\text{Å}}\ ;\ v_r = 299{,}792\,\frac{\text{km}}{\text{sec}}\,\frac{-500\text{Å}}{5000\text{Å}}\ ;\ v_r = -29{,}979.2\,\frac{\text{km}}{\text{sec}}$$

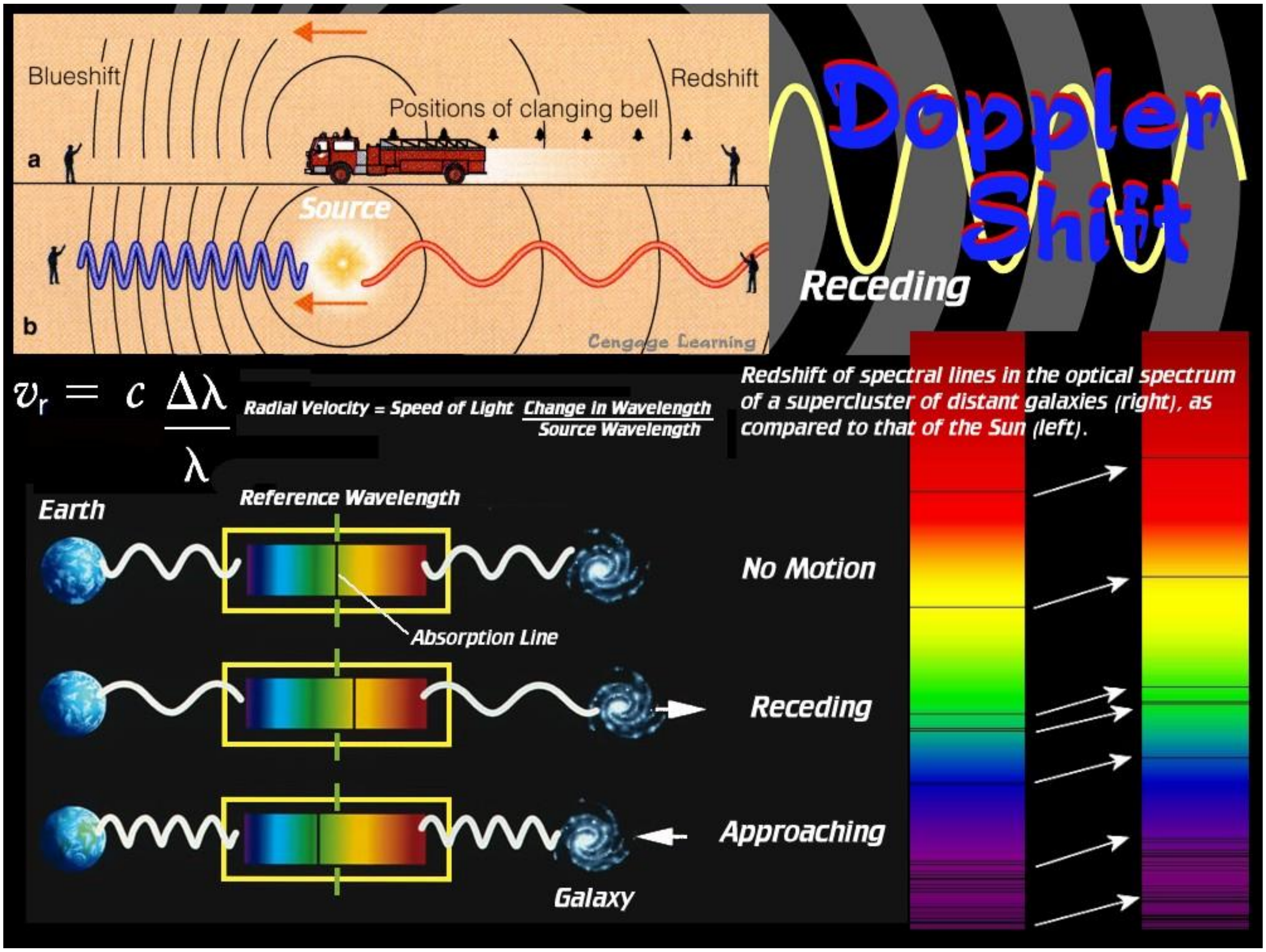
$v_r = -30{,}000\,\frac{\text{km}}{\text{sec}}$ (with the correct number of significant figures)

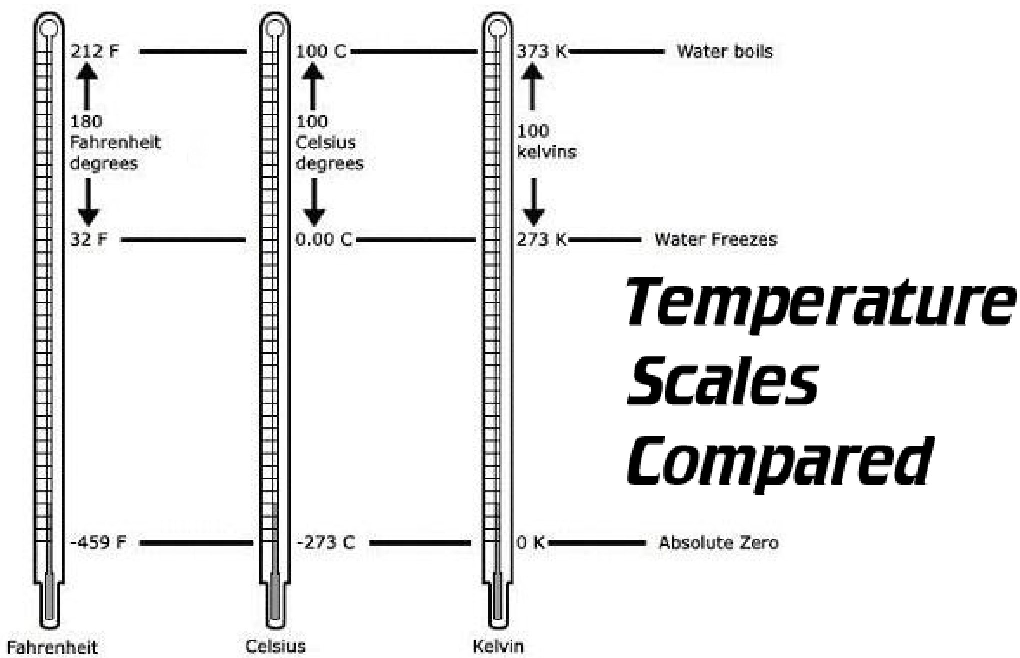
6. The rest wavelength of an emission line in a laboratory experiment lies at 5000Å. When the same line is seen in absorption in a star, the wavelength is measured to be at 5500Å. What is the radial velocity of the star? The speed of light in a vacuum is 299,792 $\frac{\text{km}}{\text{sec}}$

Radial velocity = speed of light $\frac{\text{(measured wavelength – rest wavelength)}}{\text{Rest wavelength}}$

$$v_r = 299{,}792\,\frac{\text{km}}{\text{sec}}\,\frac{(5500\text{Å} - 5000\text{Å})}{5000\text{Å}}\ ;\ v_r = 299{,}792\,\frac{\text{km}}{\text{sec}}\,\frac{500\text{Å}}{5000\text{Å}}\ ;\ v_r = 29{,}979.2\,\frac{\text{km}}{\text{sec}}$$

$v_r = 30{,}000\,\frac{\text{km}}{\text{sec}}$ (with the correct number of significant figures)


Blueshift
Redshift
Positions of clanging bell
a
b
Source
Cengage Learning
Doppler Shift
Receding
$v_r = c \frac{\Delta\lambda}{\lambda}$
Radial Velocity = Speed of Light Change in Wavelength / Source Wavelength
Redshift of spectral lines in the optical spectrum of a supercluster of distant galaxies (right), as compared to that of the Sun (left).
Earth
Reference Wavelength
No Motion
Absorption Line
Receding
Approaching
Galaxy


212 F
180 Fahrenheit degrees
32 F
-459 F
Fahrenheit
100 C
100 Celsius degrees
0.00 C
-273 C
Celsius
373 K
100 kelvins
273 K
0 K
Kelvin
Water boils
Water Freezes
Absolute Zero
Temperature Scales Compared

I. **<u>Temperature Scales are compared</u>:** What makes the Kelvin system so desirable is that it is a ratio scale since it starts at absolute zero. If the temperature doubles, the radiation increases by 16-fold. Heating an object from 1 K to 2 K will cause it to become 16 times brighter as Stephan's law predicts. Stephan's law states that the total energy emitted from a black body is proportional to the temperature in Kelvin to the fourth power (K^4).

J. The equations to convert one temperature into another are found below:

a. Fahrenheit to Centigrade: C = (F – 32) x 5/9

b. Centigrade to Fahrenheit: F = (C x 9/5) + 32

c. Kelvin to Centigrade: C = K - 273

d. Centigrade to Kelvin: K = C + 273

NOTES

Name ___________________________________ Date_________________ Moravian University

Name ___________________________________

EMISSION SPECTRUM LAB

Name of Plasma Gas	Important Characteristics such as brightness, tube color, line intensity	Line Colors and Positions Blue…..G…...Y…...O…..Red
Hydrogen		
Neon		
Oxygen		
Chlorine		
Mercury		
Nitrogen		
Argon		
Xenon		
Carbon Dioxide		
Helium		

IDENTIFY THE GASES FROM THEIR EMISSION SPECTRUMS
(10 points)

1. ______________________________ **6.** ______________________________

2. ______________________________ **7.** ______________________________

3. ______________________________ **8.** ______________________________

4. ______________________________ **9.** ______________________________

5. ______________________________ **10.** ______________________________

Signature of the person correcting this quiz: ____

NOTES

CLASSIFYING ABSORPTION SPECTRA LAB

Instructions: This laboratory exercise consists of classifying the absorption spectra of 30 stars. Examine the key on the right of the exercise sheet (or online), where the stars are placed top to bottom in order of decreasing surface temperature. In the absorption spectrums, the colors blue and violet are to the left; longer wavelengths are to the right. Since the image was taken using a blue-sensitive photographic plate, the red, orange, and yellow spectral regions have not been recorded.

Note that the hotter stars tend to be relatively more intense in the violet than the cooler stars. These stars will have longer trailing "tails" in the blue. In cooler stars where there is little energy emitted in the blue part of the spectrum, the light will seem to bunch to the right where the greatest amounts of energy are being produced. However, it is the dark absorption lines in each spectrum that will generally give the most information for you to successfully classify the stars in this lab. The classification will also involve assigning a decimal subscript, between $_0$ and $_9$ within each of the major letter types by interpolating the information between the provided reference spectra. The number is assigned as a subscript, A_0, F_6, K_4, etc.

The spectral lines are dark because light in the star's atmosphere is absorbing energy at specific wavelengths. At the top of the key is one Wolf-Rayet star. These stars are emitting energy in such great abundance that they drag their own atmospheres into space forming a shell of gas around the star which fluoresces and produces bright emission lines against a fainter continuum.

In spectral types B, A, and F, the pattern of hydrogen (Balmer) lines plays the dominant role in classifying the star, distinguishing these early (hotter) type stars from the later (cooler) ones. The secret for determining B and early A stars from late A and F stars is the relative strength of the Balmer series of hydrogen as well as the K line of signally ionized Calcium (Ca II). The H and K lines of singly ionized calcium (Ca II) become prominent in F, G, and K spectra. Important secondary information is given by the strength of the G band at 4307 Ångstroms (430.7 nm) with respect to hydrogen gamma or the neutral calcium line at 4227 Ångstroms (422.7 nm).

O: Temperatures are so high that helium is singly ionized and other elements are at least doubly ionized. In the visual region these spectra are almost featureless with long tails that are blue and violet.

B_0: The Balmer series is faintly visible. If the spectrum is well exposed, a few helium lines may be seen. Neutral helium is strongest at B_2 and fades rapidly towards A_0.

A_0: Hydrogen lines of the Balmer series are strong (strongest at A_3). Helium lines are no longer present. In this photograph, the singly ionized K line of Calcium becomes visible at A_2.

F_0: The Balmer lines are still conspicuous, although only half as strong as in the A_0. However, the K line of singly ionized calcium is as strong as the blend of hydrogen-epsilon (Hε) and the H line of calcium.

G_0: In this solar type spectrum, the H and K lines of singly ionized calcium (Ca II) are the strongest features visible with the Balmer lines no longer conspicuous. The continuum shows through between the numerous metal lines that are just at the limit of visibility. In G, K, and M stars, the light of the star's spectrum is brightest in the longer wavelengths (to the right) and appears bunched in these locations.

K_0: The energy maximum of the continuous spectrum lies far to the red (right) of the singly ionized calcium H and K lines which reach their greatest intensity in this class. Many metal lines are easily visible. The strongest is that of neutral calcium at 4227 Ångstroms (422.7 nm). Even stronger is the G band to the right of the calcium line.

M_0: The wide bands of the molecule TiO, shaded towards the violet, mark the spectra of the M class. The 4227 Ångstrom line of calcium (422.7 nm) is very strong, and the G band is also conspicuous. There are no M stars present in this laboratory exercise.

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Look at the full-page absorption spectrum photograph online or given to you. Here are some hints. As a trial, sort the first six numbered spectra near the top into some rough order. Notice that 1 and 5 have similar, almost featureless continua; 2 and 6 are also related, both exhibiting many hydrogen lines; 3 is an emission line star; and 4 belongs in yet another category. The intense part of 4 is bunched to the right on the longer wavelength end. This indicates a much cooler star than 5, whose spectrum is very strong in the ultraviolet light. It is evident that spectra with longer blue tails, such as 5, arise from hot early type stars, whereas 4 represent a later (cooler) type star. Compare 2 and 6 more carefully. The hydrogen lines are comparatively stronger in 2, but the most striking difference is the appearance of the H and K lines of singly ionized calcium which spoils the regular Balmer line pattern. Comparison with the key shows that 2 is an A star and 6 is an F star. You pick the decimal number which goes with each star. In star 4 the H and K lines are clearly visible, but the hydrogen series has vanished, thus ruling out type G and earlier (hotter). The dark line some distance to the right of the H and K pair is the G band. Since the 4227Å calcium line is not visible, this must be a K star. You pick the decimal. It is instructive to compare this spectrum with 26, 27, and 28, as well as with the key. Examples 1 and 5 are clearly much earlier than A_0, and 3 shows emission lines. Use these hints to help with the other stars that need identification.

NOW IT IS YOUR TURN TO CLASSIFY THE STARS

1. ______	11. ______	21. _____
2. ______	12. ______	22. _____
3. ______	13. ______	23. _____
4. ______	14. ______	24. _____
5. ______	15. ______	25. _____
6. ______	16. ______	26. _____
7. ______	17. ______	27. _____
8. ______	18. ______	28. _____
9. ______	19. ______	29. _____
10. ______	20. ______	30. _____

The written material was revised from the original exercise, "Laboratory Exercises in Astronomy-Spectral Classification," reprinted from *Sky and Telescope* magazine, written by Owen Gingerich of the Smithsonian Astrophysical Observatory and Harvard University. "Laboratory Exercises in Astronomy" are no longer in print.

CONSTRUCTION OF A HERTZSPRUNG-RUSSELL DIAGRAM

Introduction: The spectral classification of stars began in the mid-19th century with two major efforts. One was to obtain a large sampling of low-resolution spectra, while the other was to image the spectra of a select number of stars to a high degree of resolution. At the same time, laboratory work made it abundantly clear that there was a relationship between the bright emission lines being produced under controlled laboratory experiments and with the absorption spectra of the stars being imaged. Astronomers speculated about the key to understanding the variety of lines which filled these spectrograms. Various classification schemes were proposed, but it was not until the early years of the 20th century, with the development of quantum theory, that it became clear that the distribution and intensity of the lines were mainly a function of the temperature of the stars being observed. The electrons of the various atoms making up the chemical components of a star were able to change their orbital positions in relationship to the temperature of the star. The Harvard classification system was eventually perfected by Annie Jump Cannon and Edward Charles Pickering. It consisted of O, B, A, F, G, K, and M stars, taken from the more orderly attempts of earlier classification schemes, but now arranged into a temperature sequence from hottest to coolest.

Concurrent with the investigation of stellar spectra were efforts to determine the distances (parallaxes) to the stars. The first successful measurements was achieved by the German, Friedrich Wilhelm Bessel, in 1838 with the faint star 61 Cygni. Knowing the distance to a star and its apparent magnitude as observed from Earth, allowed astronomers to calculate mathematically (using the Distance Modulus $M = m + 5 - 5\log r$) the star's absolute magnitude (M) or its apparent brightness from a standardized distance of 10 parsecs or 32.6 light years from the sun.

The absolute magnitudes (parallaxes) and the temperatures (spectral classification) of the stars could now be determined with some precision, but was there a relationship connecting these two parameters, or did all luminosities fit randomly into all temperature ranges? The problem was solved by two astronomers between 1910 and 1913, an American, Henry Norris Russell (1877-1957) and a Dane, Ejnar Hertzsprung (1873-1967). Together they constructed with much less accurate data than is available today, a two-dimensional representation of the stars (absolute magnitude vs. spectral type). This Hertzsprung-Russell diagram would in future years be expanded into a working model of stellar evolution whereby the life histories of stars and star clusters could be determined with confidence.

Purpose: Your task will be to create and analyze an H-R diagram constructed from two different groupings of stars: the brightest stars in the sky, many of which are easily seen from a city environment and some of the closest stars to our sun. Several stars, including the sun, can be found in both groupings.

Materials Needed: Graph paper (1/4-inch squares), ruler, lead pencil, colored pencils, preferably a blue, yellow, and red pencil for plotting points.

Procedure: Create the framework for your H-R diagram by plotting spectral types along the X-axis and absolute magnitudes (M) along the Y-axis. Make sure that both axes are properly labeled and that your graph is titled.

Follow these instructions:

1. Data for your Hertzsprung-Russell diagram can be found in the brightest and nearest star tables found with this lab.
2. Spectral types will be plotted along the horizonal x-axis. Start with O_6 stars at the origin and continue to M_8 in increments for each square as follows: $O_{4, 6, 8}$, $B_{0, 2, 4, 6, 8}$, $A_{0, 2, 4, 6, 8}$, $F_{0, 2, 4}$, etc., to M_8
3. Plot absolute magnitude along the vertical y-axis. Start at the origin with an absolute magnitude of +18 and continue upward in increments of one magnitude per square until an absolute magnitude of -9 is reached.
4. Use a <u>BLUE</u> pencil to color star plots of spectral types 0_6-A_9.
5. Use a <u>YELLOW</u> pencil to color star plots of spectral types F_0-G_9.
6. Use a <u>RED</u> pencil to color star plots of spectral types K_0-M_9.
7. Stars contained in the <u>BRIGHTEST</u> Stars Table should have a short <u>VERTICAL</u> line segment drawn through them.
8. Stars of the <u>NEAREST</u> Stars Table should have a short <u>HORIZONTAL</u> line segment drawn through them.
9. A few stars can be found in both tables. These are indicated with a double asterisk in the "Thirty Brightest Stars Table." These stars should appear on your graph as small dots with crosses through them. Label these stars with their name on your graph.
10. In the NEAREST star table, you will notice a "wd" in front of several spectral types. These stars are white dwarfs. Plot the spectral type as if they were a zero (wdA = A_0).
11. The data in the BRIGHTEST star table that have a double asterisk are a compilation of the brightnesses if the system has multiple components.
12. One star, Aldebaran, in the BRIGHTEST star table has a "v" next to the absolute magnitude to indicate that it is a variable star.
13. Create a key by showing in tabular form what the colors and line segments represent on your graph. Your graphing grade will be determined by its accuracy (60%), neatness (20%), and labeling (20%).
14. After completion of your Hertzsprung-Russell diagram, answer the questions found at the end of this exercise.
15. <u>Note</u>: If a star's absolute magnitude is -2.5, the plot occurs above the -2 <u>position</u> on your H-R Diagram, but if the absolute magnitude is positive, like +4.3, the plot would occur below the line that indicates +4.

THIRTY OF THE BRIGHTEST STARS

From the Hipparcos Star Catalog
Mark these stars with a vertical line segment.

Star	Rank	Name	MAGNITUDE apparent m	MAGNITUDE absolute M	DISTANCE light years	Spectral Type w/o luminosity
**Sun			-26.7	+4.8	8.3 light min.	G_2
**Alpha CMa	(1)	Sirius	-1.46	+1.43	8.6	A_1
Alpha Car	(2)	Canopus	-0.73	-5.64	310	F_0
**Alpha Cen	(3)	**Rigil Kentaurus**	-0.29	+4.06	4.39	G_2*/K_1
Alpha Boo	(4)	Arcturus	-0.05	-0.31	37	K_2
Alpha Lyr	(5)	Vega	+0.03	+0.58	25	A_0
Alpha Aur	(6)	Capella	+0.07	-0.49	42	G_0*/G_5
Beta Ori	(7)	Rigel	+0.15	-6.72	770	B_8
**Alpha CMi	(8)	Procyon	+0.36	+2.64	11	F_5
Alpha Eri	(9)	Achernar	+0.45	-2.77	144	B_3
Alpha Ori	(10)	Betelgeuse	+0.55var	-5.05	430	M_2
Beta Cen	(11)	Hadar	+0.61	-5.42	530	B_1
**Alpha Aql	(12)	Altair	+0.77	+2.20	16.77	A_7
Alpha Tau	(14)	Aldebaran	+ 0.86v	- 0.64v	65	K_5
Alpha Sco	(15)	Antares	+0.95	-5.39	600	M_1*/B_4
Alpha Vir	(16)	Spica	+0.97	-3.56	260	B_1*/B_2
Beta Gem	(17)	Pollux	+1.14	+1.07	34	K_0
Alpha PsA	(18)	Fomalhaut	+1.15	+1.72	25	A_3
Alpha Cyg	(19)	Deneb	+1.24	-8.74	3000	A_2
Alpha Leo	(21)	Regulus	+1.36	-0.52	78	B_7
Epsilon CMa	(22)	Adhara	+1.50	-4.10	430	B_2
Alpha Gem	(23)	Castor	+1.58	+0.59	52	A_1*/A_2
Gamma Ori	(26)	Bellatrix	+1.64	-2.72	240	B_2
Alpha UMa	(34)	Dubhe	+1.79	-1.09	124	K_0*/F_0
Delta CMa	(36)	Wezen	+1.83	-6.87	1800	F_8
Alpha UMi	(48)	Polaris	+1.99v	-3.63v	430	F_7
Alpha And	(54)	Alpheratz	+2.07	-0.30	97	B_9
Kappa Ori	(56)	Saiph	+2.07	-4.65	720	$B_{0.5}$
Beta UMi	(57)	Kochab	+2.07	-0.87	127	K_4
Beta Leo	(62)	Denebola	+2.14	+1.92	36	A_3

Key: M = absolute magnitude, m = apparent magnitude, and r is the distance to the star measured in parsecs (1 pc = 3.2616 ly).
Where * = binary or multiple star system in which the component with the asterisk contributes most of the light of the system. Plot only the star with the asterisk.
** = stars that are both bright and near.

THIRTY OF THE NEAREST STARS

From the Hipparcos Star Catalog*
Mark these stars with a horizontal line segment.

Star Name		MAGNITUDE apparent m	absolute M	DISTANCE light years	Spectral Type
Sun		-26.7	+4.8	8.3 light min.	G_2
Alpha Cen	C **Proxima**	+11.01	+15.45	4.22	M_5
	B	+1.35	+5.70	4.39	K_0
	A **brightest**	-0.01	+4.34	4.39	G_2
Barnard's star		+9.54	+13.24	5.94	M_5
Wolf 359		+13.5	+16.5	7.5	M_8
Lalande 21185		+7.5	+10.7	8.1	M_2
Sirius	A **brightest**	-1.44	+1.45	8.60	A_1
	B	+8.7	+11.6	8.6	wdA
UV Ceti	A	+12.5	+15.3	8.8	M_6
	B	+13.0	+15.8	8.8	M_6
Ross 154		+10.6	+13.3	9.5	M_5
Epsilon Eridani		+3.72	+6.18	9.69	K_2
61 Cygni	A	+5.20	+7.49	11.36	K_5
Alpha CMi	**Procyon A**	+0.36	+2.64	11.41	F_5
	B	+10.7	+13.0	11.41	wdF
61 Cygni	B	+6.05	+8.33	11.43	K_7
Epsilon Indi		+4.69	+6.89	11.83	K_5
Tau Ceti		+3.49	+5.68	11.89	G_8
Lacaille 8760		+7.4	+9.5	12.4	M_1
Kapteyn's star		+8.86	+10.89	12.77	M_0
Kruger 60	A	+9.59	+11.58	13.07	M_4
	B	+11.3	+13.4	13.07	M_5
Van Maanen's star		+12.37	+14.15	14.37	wdG
40 Eridani	A	+4.43	+5.92	16.45	K_1
	B	+9.5	+11.1	16.45	wdA
	C	+11.2	+12.8	16.45	M_4
70 Ophiuchi	A	+4.03	+5.50	16.59	K_0
	B	+6.0	+7.5	16.59	K_5
Altair		+0.76	+2.20	16.77	A_7

Key: where M = absolute magnitude, m = apparent magnitude, and r is the distance to the star measured in parsecs (1 pc = 3.2616 ly).
* Visual and absolute magnitudes taken to the hundredth decimal place are from the Hipparcos Star Catalog..

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MAKING SENSE OF THE HERTZSPRUNG-RUSSELL DIAGRAM

Instructions: Answer the following questions about the Hertzsprung-Russell Diagram. You can refer back to the completed graph, noting the representations given by the symbols or working with the two tables which contain information about the 30 nearest and the 30 brightest stars in the sky. **Your answers go at the top of each numbered problem.**

1. ____________________, ____________________ Most of the stars which are near to the Earth (stars with horizonal bars on the graph) are of HIGH/LOW luminosity and HIGH/LOW temperature.

2. ____________________, ____________________ Most of the stars which appear bright in the sky (stars with vertical bars) actually have HIGH/LOW luminosities and HIGH/LOW temperatures. Do you recognize any of the names in the "Thirty of the Brightest Stars" table?

   Statement: The stars on your H-R diagram appear to congregate in three different groupings which are called luminosity classifications.

3. **Main Sequence:** ____________________, __________________ A propeller-shaped band of stars moves from the upper left to the lower right on your H-R diagram. It is known as the main sequence. The location of the sun along this curve sits near the __________, demonstrating why we call the sun an ___________ star.

4. ____________________, __________________ All of stars along the main sequence are powering themselves just like the sun by converting __________ into __________ through thermonuclear fusion.

5. ____________________, __________________ The stars along the upper left of the main sequence are millions of times more __________ than the stars along the lower right of the main sequence. The most common category among main sequence stars is the O, B, A, F, G, K, M classification. Pick only one and enter it in the second space.

6. ____________________, ____________________ The rate at which a star consumes its fuel is directly related to the __________ of that star, and therefore, the position of that star along the main sequence. Luminosity will not be accepted, but it is directly related to the correct word. Stars in the upper left corner of the main sequence have greater compression in their cores and higher core temperatures, causing these blue supergiants to burn hydrogen at a much FASTER/SLOWER pace. Just the opposite is true for the cool, red main sequence stars.

7. ____________________, ____________________ High mass stars found in the upper left of the H-R diagram's main sequence have LONG/SHORT lives, while low mass stars found along the main sequence along the bottom right have LONG/SHORT lives.

8. **<u>Giants</u>:** ____________________ Stars which are generally positioned to the upper right of the H-R diagram are extremely luminous, but according to their spectral characteristics (temperatures), they are very __________.

9. ____________________, ______________________________ Since the energy emitted per unit area is a function of temperature, and the temperatures of these stars are cool, in size they must be extremely __________ in order to compensate for their lower surface luminosities. These stars are known as __________ (two words).

10. ____________________, ____________________, ____________________ The cores of such stars have run out of the basic element that normally powers them, __________, and they have made thermonuclear adjustments to keep themselves from collapsing. The cores of solar mass stars are probably not undergoing thermonuclear fusion, but hydrogen burning still continues in a thin shell which surrounds them. The more massive stars in this group are burning helium or even heavier elements in their cores. Because of their hotter interiors, they are producing energy MORE/LESS rapidly, and this has caused the outer layers of the star to EXPAND/CONTRACT in size.

11. **<u>Dwarfs</u>:** ____________________, ____________________ In an opposite sense, there appears to be several stars on your Hertzsprung-Russell diagram (lower left) which are, with respect to temperature, very __________, but are not very bright. The matter present in these stars is inert, nonreacting helium or carbon-oxygen, leftover material from the cores and shells of stars that were at one time undergoing thermonuclear fusion. Because these stars are radiating a great deal of energy per unit area, but are not very luminous, their sizes must be very __________.

12. ______________________________ Stars with high surface temperatures, but low luminosities are called __________ stars (two words).

13. ____________________ From main sequence to red giant to white dwarf suggests a sequence of __________ from core hydrogen burning to other types of fusion processes, and eventually death.

14. Predict why the population densities, the number of stars in the various luminosity classifications, are lower than the number of stars found in the same spectral classifications along the main sequence.

    Red Giants (cool, but big): ____

    White Dwarfs (hot, but faint): ____

15. Mark areas of the main sequence, red giant, and white dwarf regions of your H-R diagram.

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16. **The Hertzsprung-Russell diagram is a powerful tool for calculating the distances to stars when their parallax angles are too small to measure**. A star is photographed in a nearby galaxy, and it is determined to have an apparent magnitude of +14.55. When a spectrogram is obtained, it is found to be a main sequence star similar to Kappa Orionis (absolute magnitude = -4.65) which you plotted on your graph. Use the distance modulus, to find how far away the galaxy is from us.

M = m + 5 – 5 log r **Distance Modulus**

solving for r

M = absolute magnitude (consult brightest star table)
m = apparent magnitude (given in problem)
r = distance in parsecs (pc), the variable to be solved

$$M - m - 5 = -5 \log r$$

$$\frac{M - m - 5}{-5} = \log r$$

$$\text{antilog} \ \frac{M - m - 5}{-5} = \text{antilog} (\log r)$$

The log of a number is the exponent to which 10 must be raised.
The antilog is the number created when 10 is raised to the "x" power = 10^x.

$$10^x = 10^{\frac{M - m - 5}{-5}} = r$$

Show all work for problem 16 here.

17. A star with an apparent magnitude of +15.78 has a parallax of 282.85 mas. Predict its location on the Hertzsprung-Russell diagram. Below, first make a qualitative prediction in ink, then complete the mathematical calculations below.

    What is your hunch? ____

    Was your hunch correct? _______________

18. Quantify your answer to question 17 mathematically and state one precise location on the H-R diagram where this star could be located and then proceed to the last two questions on the sheet.
    Compute the distance to the star: $d_{pc} = \frac{1}{P''}$

    Use the Distance Modulus to calculate the absolute magnitude of the star:
    M = m + 5 – 5 log r

19. ___________________________ If this star had a spectral classification of F_6, its luminosity classification would make it (a) an __________.

20. ___________________________ If this star had a luminosity classification of M_8, its luminosity classification would make it (a) an __________.

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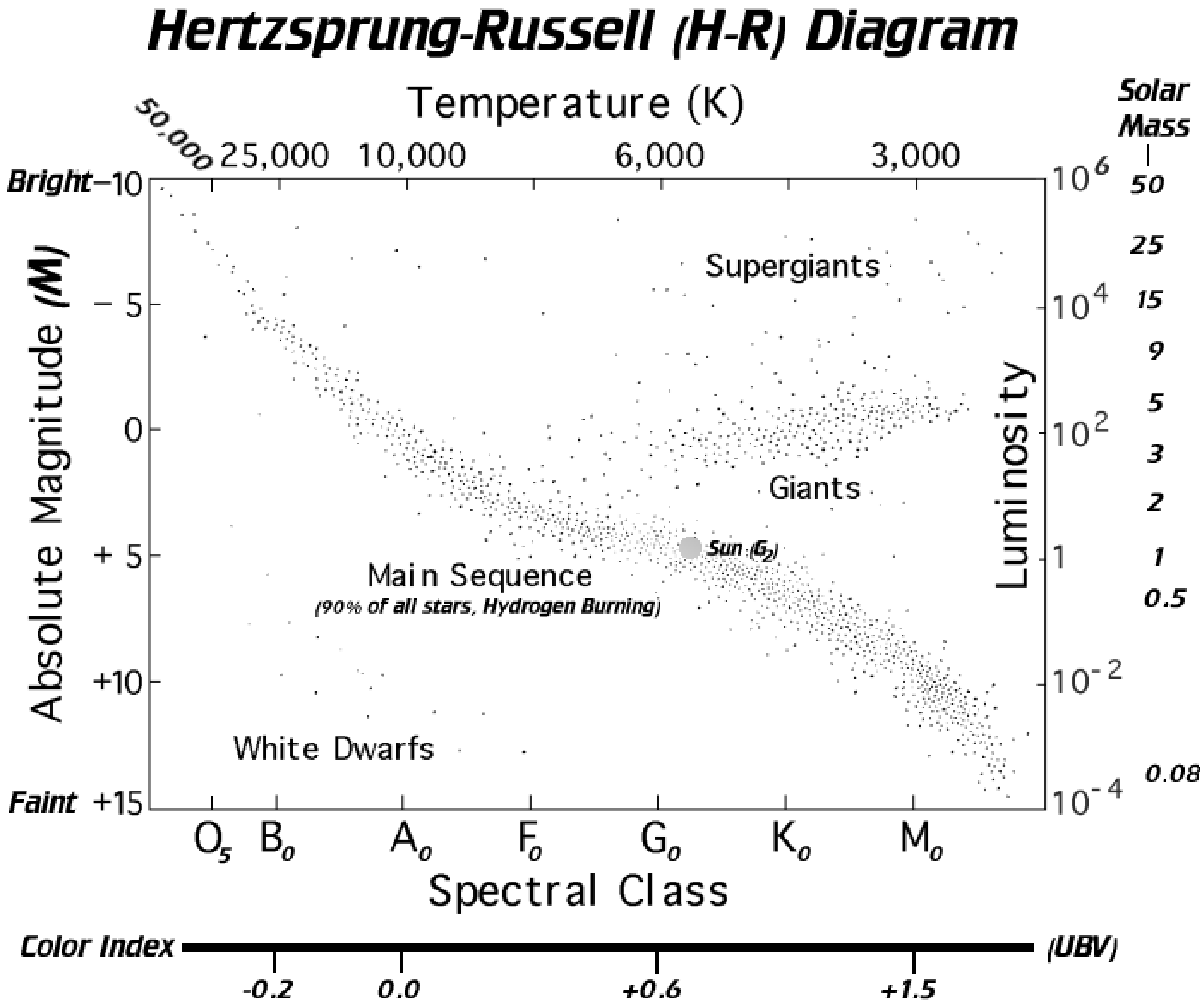
NOTES



E. **<u>Hertzsprung-Russell Diagram</u>:** It is a two dimensional scatter graph showing the relationship of a star's actual brightness against its temperature. It was developed by Ejnar Hertzsprung, a Danish astronomer (1873-1967) and Henry Norris Russell, an American astronomer (1877-1957). Without a doubt, it is the most powerful tool for understanding the evolution of stars.

a. **<u>The spectral sequence was originally classified in alphabetical order</u>**, according to the strength of the hydrogen Balmer lines. The letters went from A-P. When the line intensities were discovered to be attributable to temperature, the letters were rearranged in order of the temperature sequence without any consideration to the original sequencing order.

b. **<u>The apparent magnitude of a star</u>** is its brightness as viewed from the Earth. It is a function of its distance and luminosity. The luminosity of a star is a function of its temperature and the size of the star.

c. **<u>The absolute magnitude of a star</u>** is how bright the star would appear if it was mathematically moved to a distance of 10 parsecs from the sun.

d. **The location of a star on the Main Sequence**, the propeller shaped curve which dominates the H-R diagram, is a function of that star's mass. High mass stars are found to the upper left of the graph, while low mass stars are found near the bottom right.

e. **Edward C. Pickering** (American 1846-1919) and **Annie J. Cannon** (American 1863-1941) are often given credit for the present spectral sequence which is based upon temperature. Cannon was a member of a group of women mathematicians known as the Harvard Computers (less respectfully, "Pickering's Harem.").

f. Harvard Classification Scheme—O B A F G K M:

1) O to M: From hottest (O) to coolest (M)…
   a) O stars: Singly ionized He
   b) B stars: Neutral He
   c) A stars: Balmer lines of H
   d) F stars: Balmer lines of H, singly ionized metals
   e) G stars: Singly ionized metals
   f) K stars: Neutral metals
   g) M stars: Molecules like Ti0 begin to form
2) Mnemonic: Oh, Be A Fine Girl Kiss Me. (A. J. Cannon)
3) Mnemonic: Oh Boy, A Fine Girl/Guy Kissed Me (Becker)
4) Mnemonic: Oh, Becker's Astronomy Field Guide Kills Me (PSU student)
5) Mnemonic: Only Boys Accepting Feminism Get Kissed Meaningfully
6) Each letter is further subdivided into values from zero through nine.
7) The hottest stars in the sky are classified as O_3 or O_4. There are no O_0 stars.
8) The thickness of the spectral lines led to an understanding of luminosity differences which led to a luminosity classification. In its simplest form, identified stars were classified as super giants Ia, Ib, II), giants (III, IV), and main-sequence stars (V). These stars had similar line ratio intensities, but their absorption line thicknesses differed from luminosity class to class.

g. Luminosity Obtained with only Spectral Identification: With the introduction of the Harvard spectral classification scheme, it was now possible to know the true luminosities of stars that were too far away to have their parallax angles measured accurately. Knowing the apparent and absolute magnitudes of the star allowed its distance to be known using the distance modulus.

h. Distance Modulus and Spectroscopic Distance Measurements:

1) Measure the apparent magnitude (m) of a star.
2) Record the spectrum of the star and its luminosity classification.
3) Read the absolute magnitude (M) from the H-R diagram.
4) Solve for r (distance in pc) using the Distance Modulus.
5) **Suppose a G_2 main sequence star has an apparent magnitude (m) of +10, what is its distance from the sun? From the H-R diagram the absolute magnitude of the star (M) is equal to +5.**

$$M = m + 5 - 5\log r$$

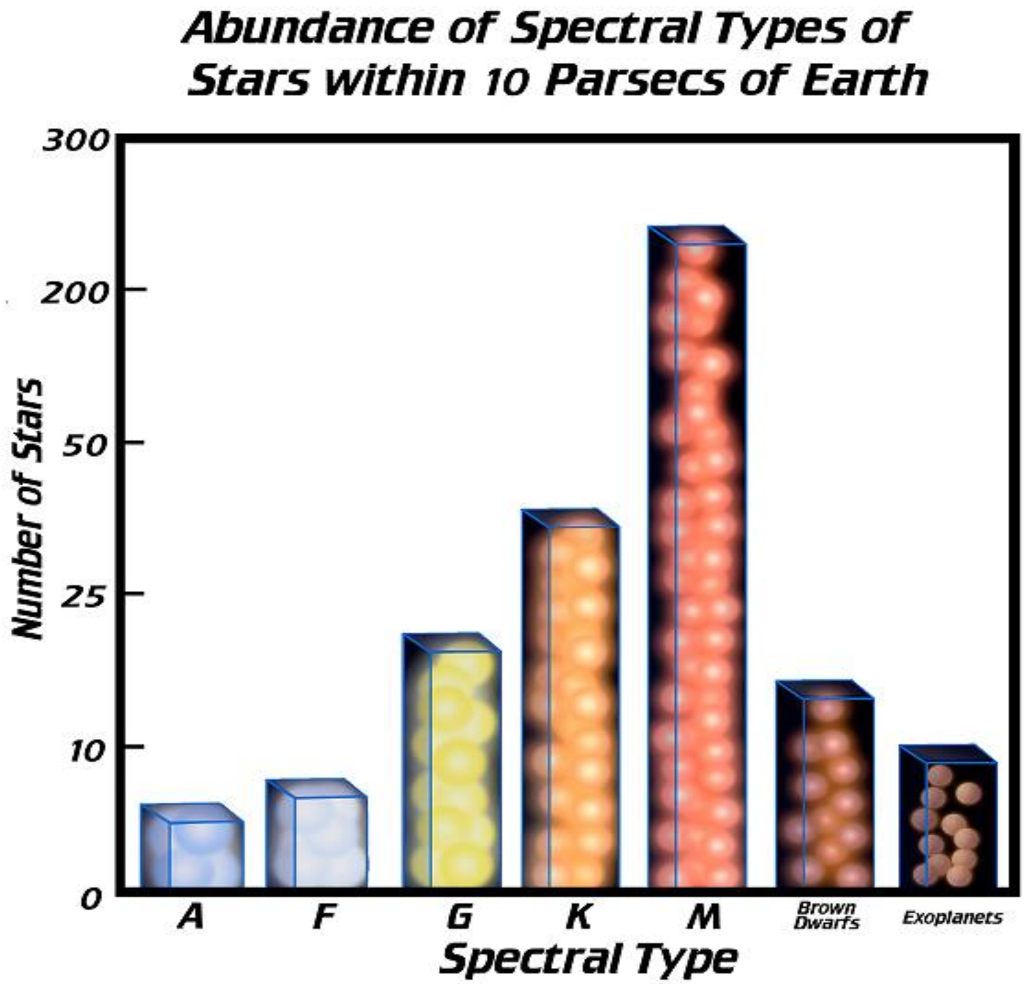
$$+5 = +10 + 5 - 5\log r$$

$$-10 = -5\log r$$

$$\frac{-10}{-5} = \log r$$

$2 = \log r$ (take the antilog of 2 which equals the exponent to which 10 must be raised)

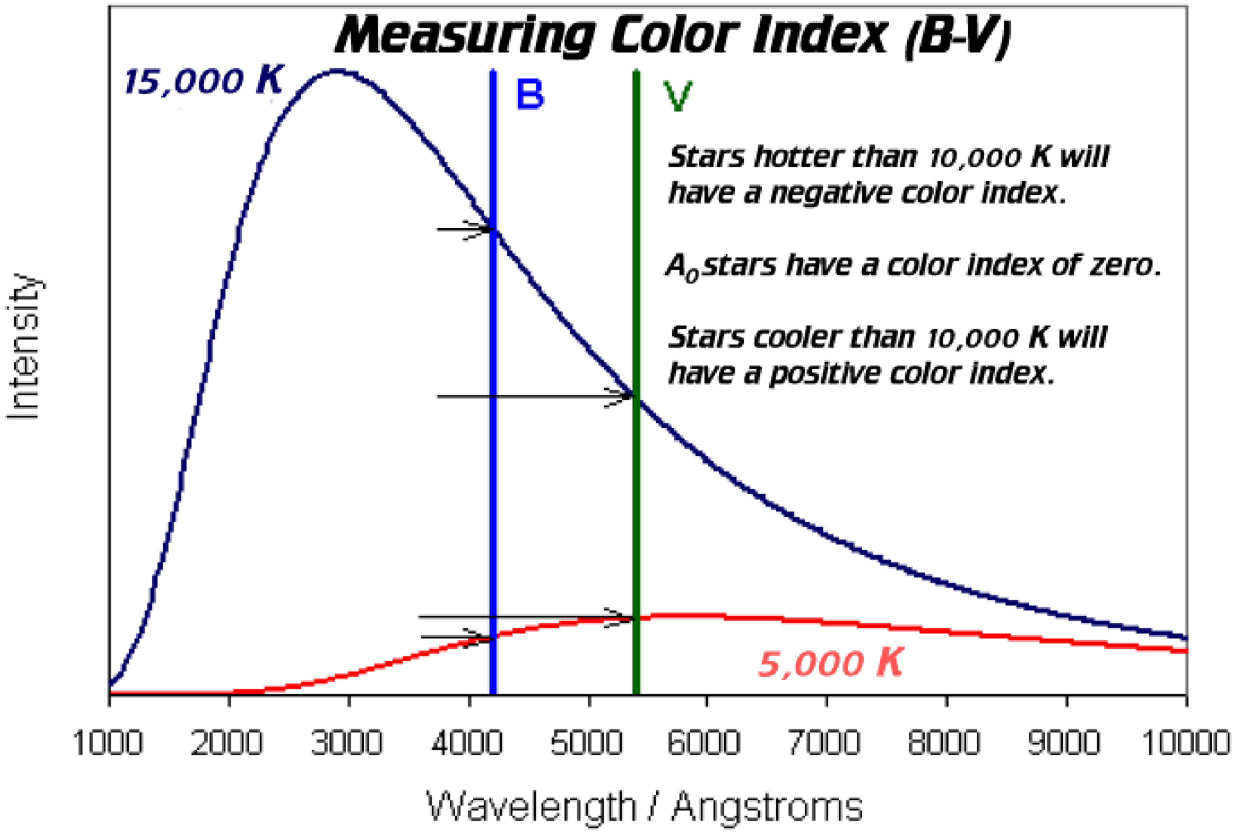
$$r = 100 \text{ pc} \times 3.26 \frac{\text{ly}}{\text{pc}} = 326 \text{ ly distance}$$



Although red (M) stars dominate the stellar "landscape," in number, it is the O and B stars that dominate in the luminosity category (see the H-R Diagram) and influence the way the spiral arms of a galaxy look. One O star with a luminosity of 100,000 suns is the equivalent of hundreds of millions to as many as one billion M stars. This disparity in luminosity causes the rare O and B stars to dominate in the light producing capabilities of Population I stars. The warmer hues which come from the center of a galaxy like the Milky Way are an indication of a more advanced developmental age of that region in the form of giant and supergiant stars.

Temperature-Spectral Class-Color Index Relationships for Main-Sequence Stars

Temp	50,000 K	25,000 K	10,000 K	7,500 K	6,000 K	4,800 K	3,700 K
Sp Class	O5	B0	A0	F0	G0	K0	M0
Co Index (UBV)		-0.2	0.0		+0.6		+1.5

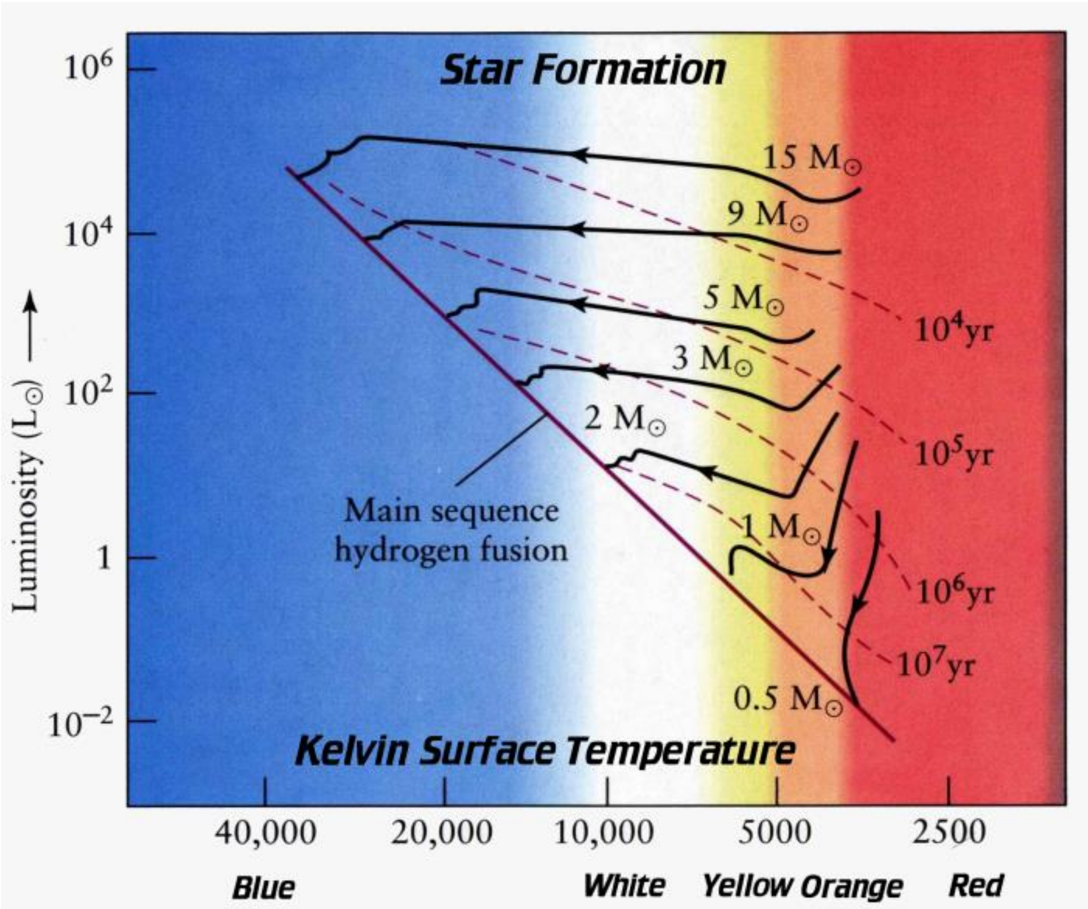


F. **Color Index (CI):** A means of assigning a numerical value to the spectral classification of a star.

1. E_{total} is proportional to T^4 (Stefan's law)
2. λ_{max} is proportional to $0.29/T$ (Wien's law)
3. By measuring the brightness or magnitude of a star, using filters, in two different wavelengths, say in the visual and in the blue, it is possible to subtract one color from the other (B-V) to obtain the color excess. The color excess gives a good approximation of that star's spectral type. Astronomers can create an H-R diagram of a cluster of stars by simply noting the apparent magnitudes of the stars and looking at the photographic brightnesses of stars in the visual and in the blue and subtracting the visual magnitude from the blue magnitude.
   a. **Cool stars:** positive color index because these stars are brighter (less positive) in the red and fainter (more positive) in the blue. When B-V is calculated, the resulting number will be positive.
   b. **A stars**: They have a color index of approximately 0.0.

c. **Hot stars:** They have negative color indices because blue stars are brighter (less positive) in the blue and fainter (more positive) in the red. B-V will be negative.

4. **Practical Reasons for using Color Index:** It is less accurate than spectral identification of stars.
   a. It can give an indication of the amount of dust between the source and the observer. As an example, if a B_2 star has a positive color index, then there must be a substantial amount of dust between the observer and the star. Dust scatters shorter wavelengths more effectively than longer wavelength energy.
   b. The approximate spectral types of many stars can be gleaned at the same time.
   c. H-R diagrams of clusters can be easily created by using the color index of the stars and plotting these against the apparent magnitude of the stars because cluster stars are assumed to be about the same distance from Earth.



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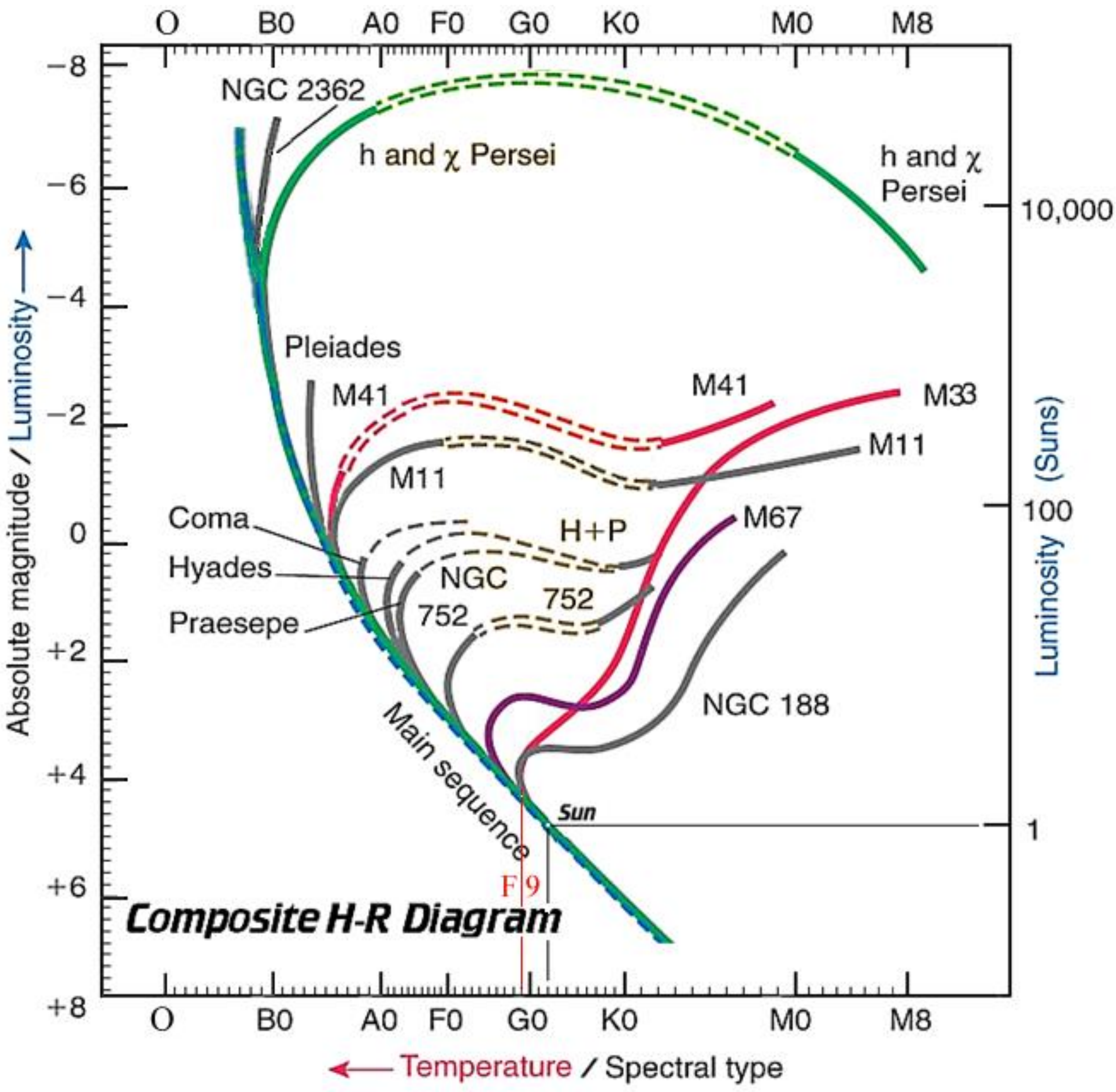
USING THE H-R DIAGRAM TO DETERMINE THE AGE OF STAR CLUSTERS

(10 points)

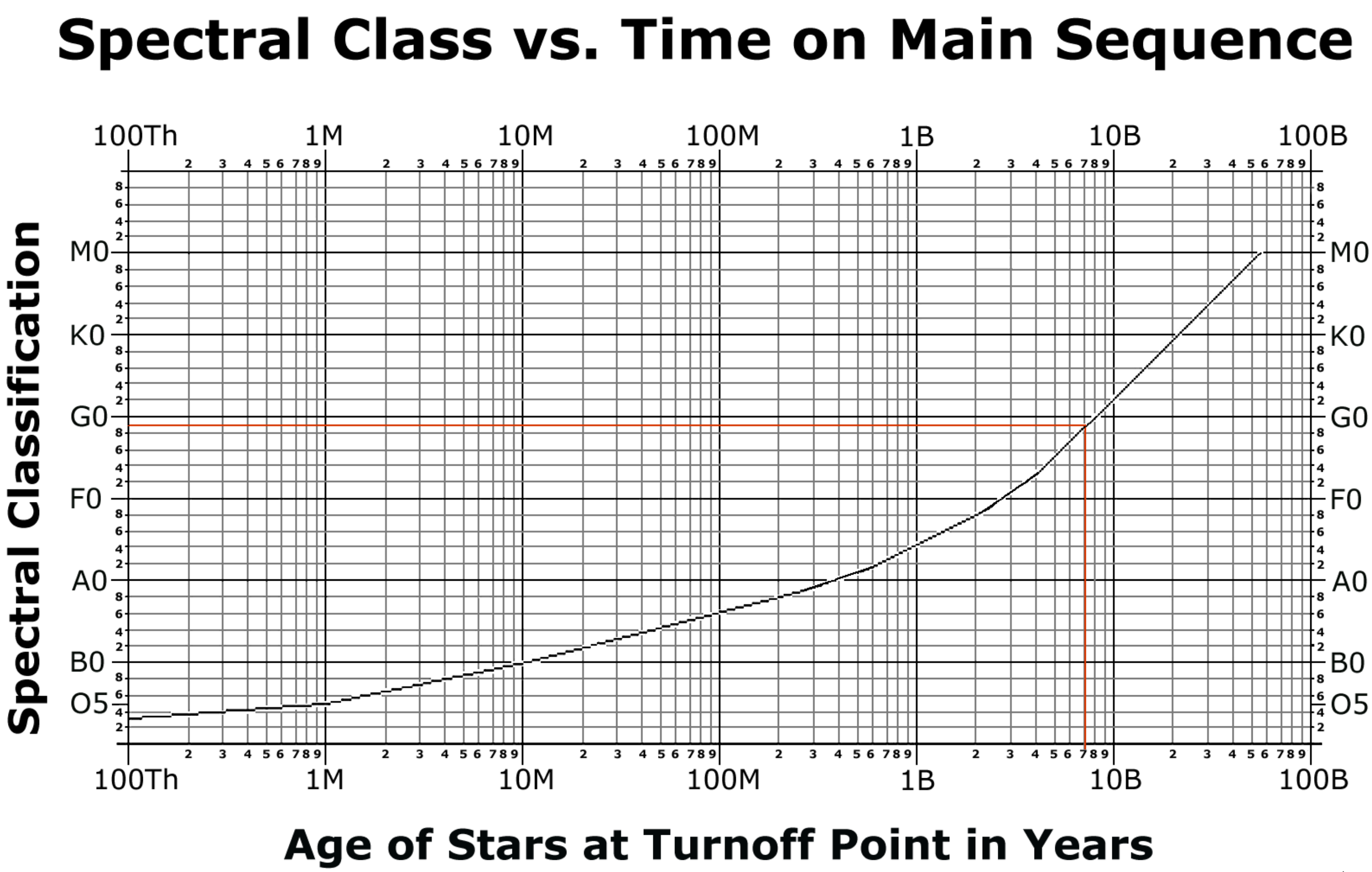
Instructions: Below is a composite **H**ertzsprung-**R**ussell diagram showing numerous clusters of stars on the same graph. The Y-axis on the left shows the absolute magnitude of the stars, while the Y-axis on the right depicts the luminosity (brightness) of the stars compared to the sun, which equals one. The X-axis represents the spectral classifications or temperatures of the stars. Note the turnoff points for the clusters. This location on the H-R diagram illustrates where the cluster leaves the main sequence after its primary fuel, hydrogen, has been exhausted. Using the turnoff points of the various clusters along the main sequence, suggest an approximate age of that cluster. As an example, the age of NGC 188 is 7.3 billion years, according to the graph on the following page.



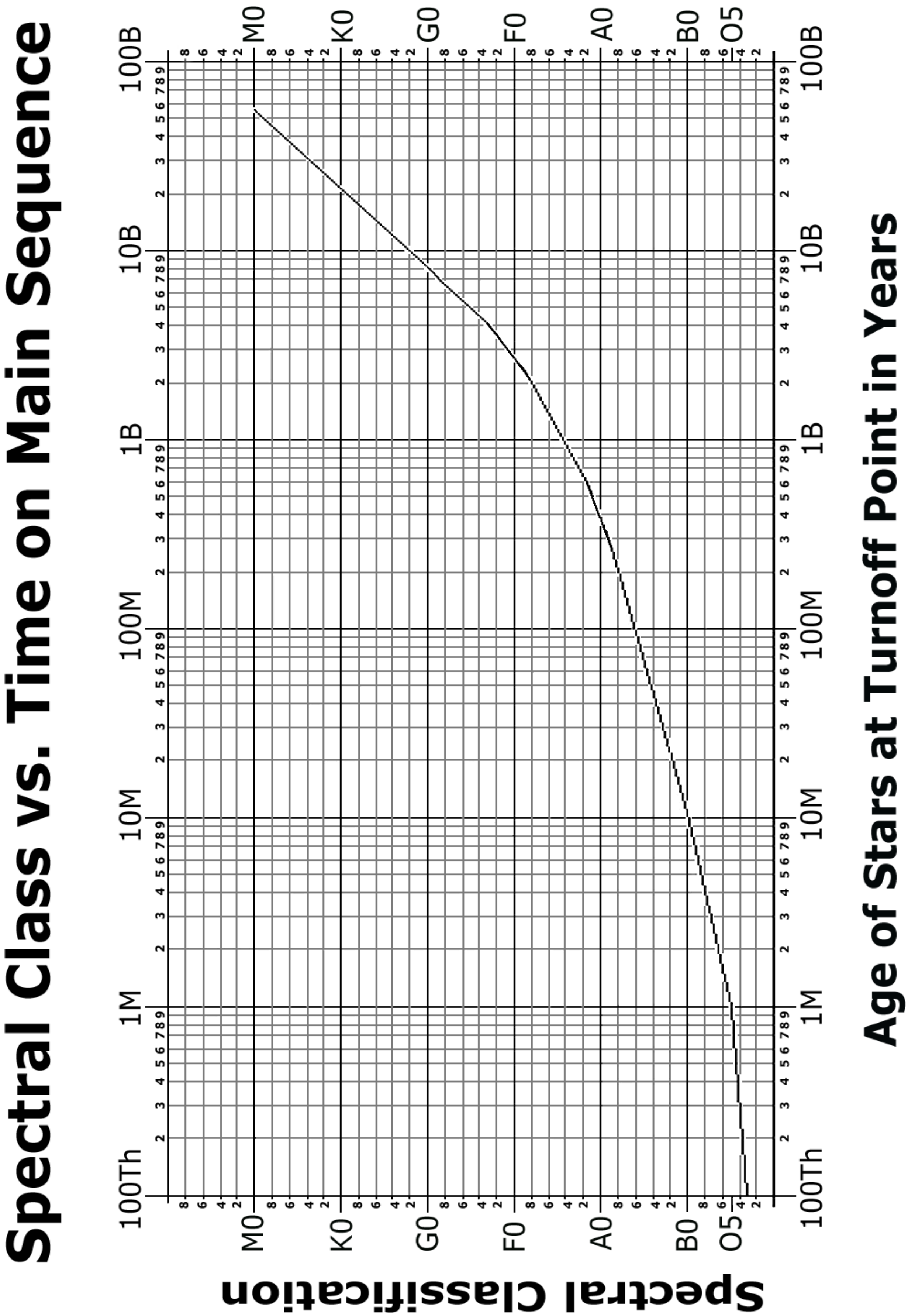
Procedure: Find the ages of the clusters in the H-R diagram by matching the turnoff position of the cluster on the main sequence of the composite H-R diagram with its spectral type. Then, compare the spectral type with the age of the stars on the graph on page three to establish an approximate age for the cluster. The graph is logarithmic.

Show how you determined the ages of the various clusters using the information and graph contained in this exercise.

1. Show how you determined the turnoff positions. See the example found on the first page of the exercise.
2. Show how you used the turnoff positions of the clusters to find their ages using the graph on the next page.
3. Submit all pages of the laboratory exercise for examination.



	Cluster	Turnoff Point /	Age In Years
Example:	NGC 188	F9 /	7.1 billion years


Spectral Class vs. Time on Main Sequence
Age of Stars at Turnoff Point in Years
Spectral Classification
100Th
1M
10M
100M
1B
10B
100B
M0
K0
G0
F0
A0
B0
O5

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Cluster	**Turnoff Point /Age In Years**
1. NGC 2362:	____________/____________
2. h and χ Persei:	____________/____________
3. Pleiades:	____________/____________
4. M41:	____________/____________
5. M11:	____________/____________
6. Coma Berenices:	____________/____________
7. Hyades:	____________/____________
8. Praesepe, M44:	____________/____________
9. NGC 752:	____________/____________
10. M67:	____________/____________

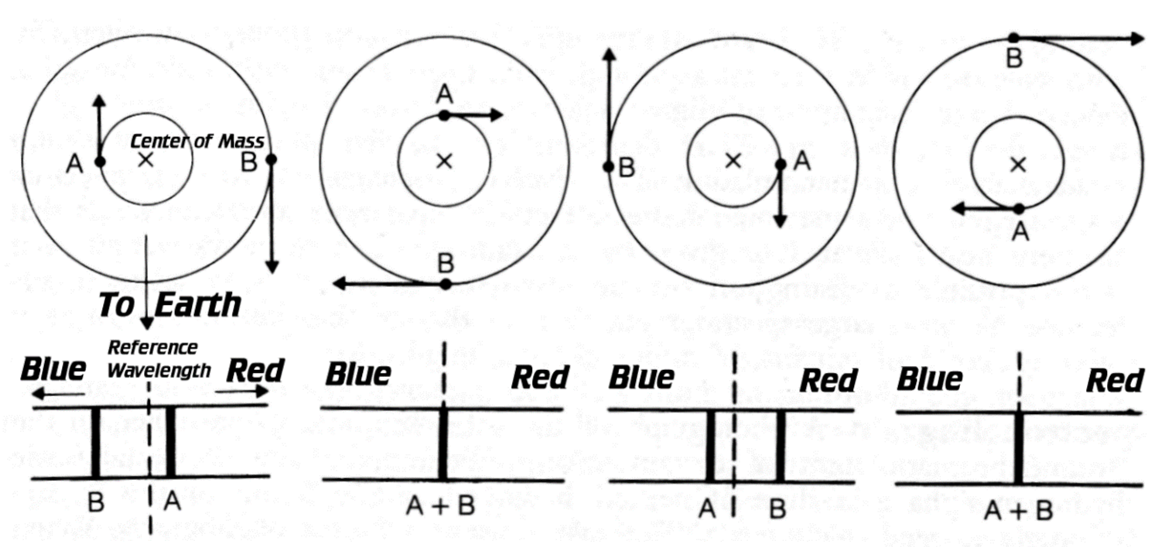
1. Show how you determined the turnoff positions.
2. Show how you used the turnoff positions of the clusters to find their ages using the graph on the previous page.
3. Submit all pages of the laboratory exercise for examination.

BINARY/VARIABLE STARS

A. **Two different identified populations of stars:**
   1. **Population I:** Located in irregular galaxies and in the arms of spiral galaxies like the Milky Way. They have a higher metal content, elements heavier than hydrogen and helium.
   2. **Population II:** Older, metal deficient stars found in elliptical galaxies, the bulge of spiral galaxies, and in globular clusters.
   3. **Population III:** A hypothetical class of stars which contain virtually no metals.

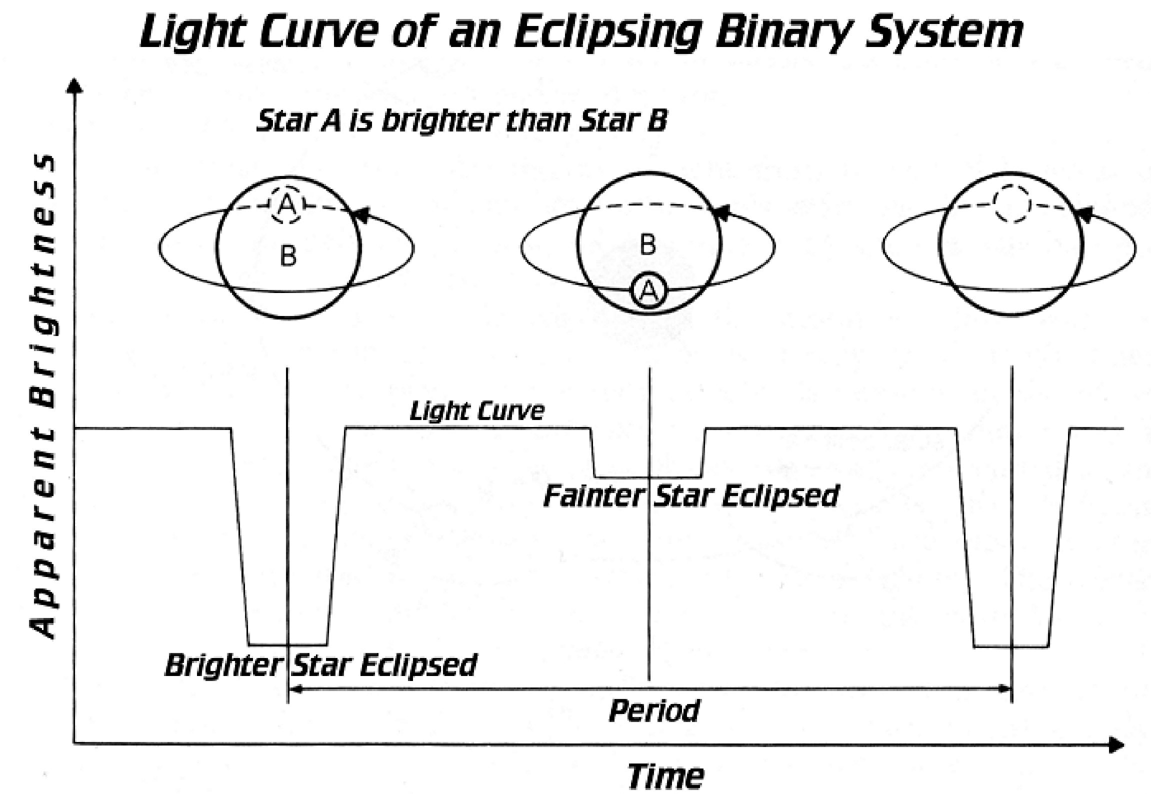
B. **Binary Stars:** Two or more stars which revolve around a common center of mass called a barycenter. They are not to be confused with optical doubles, two stars which appear close to each other because they are found along the same line of sight. About one third of the stars in the Milky Way Galaxy are physical doubles.
   1. **Visual Binaries:** Systems which can be separated through telescopic observations. They generally have very long periods because their components must be separated by large distances in order for them to be seen.
   2. **Astrometric Binaries:** One companion is too faint to be seen, but its gravitational influence perturbs the motion of the star which can be seen in a cyclical fashion as its proper motion carries it across the sky.
   3. **Spectroscopic Binaries:** A close binary system in which the components are revealed by the change in the radial velocities of the spectral lines as the stars approach or recede from the observer.

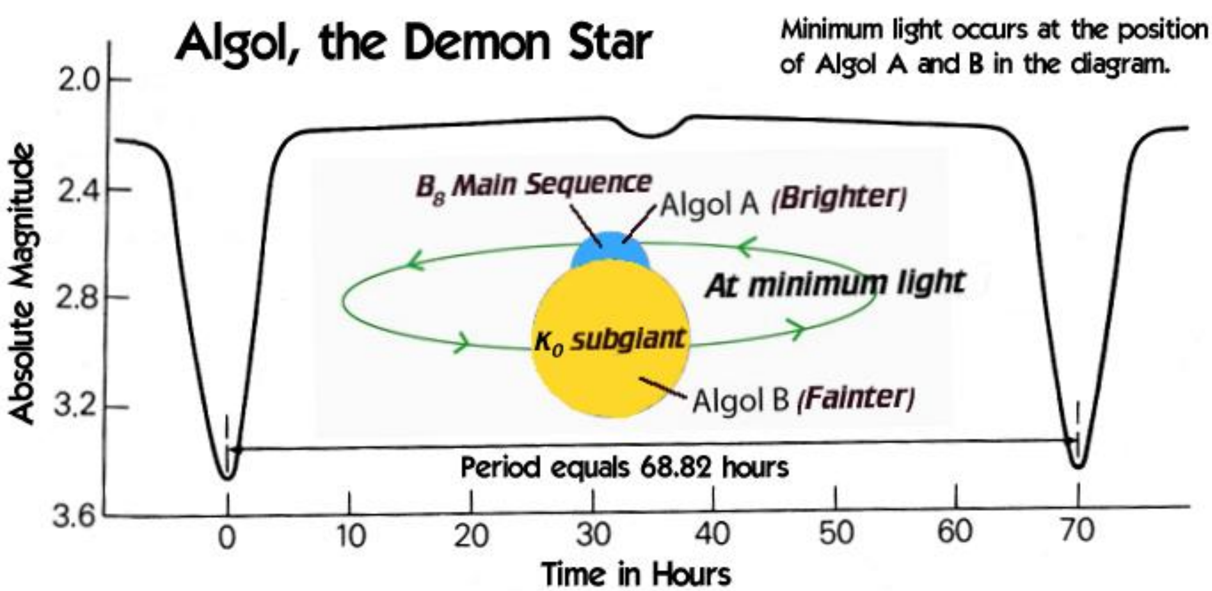
Spectroscopic Binary



Doppler shifts of spectral lines at various orbital positions of a spectroscopic binary star.

4. **Eclipsing Binaries:** A binary star that has its orbital plane near the plane of the Earth's orbit allowing the stars to totally or partially eclipse one another. The stars are normally close together with very short periods. If they were farther apart, chances are they would not eclipse each other.





5. **Algol, the Demon Star:** If the distance between the stars is equal to 6.4 x 10^6 miles and the period of revolution of the system is 2.86739 days, what is the mass of the system?

Kepler's Third Law: $P^2 = ka^3$. The square of the sidereal period of a planet is equal to a constant multiplied by the cube of its semi-major axis (average distance from the sun). If "P" is given in years and "a" in astronomical units, then solving this problem for the Earth, $k = \frac{P^2}{a^3}$, or $k = \frac{1^2}{1^3} = 1$

Newton's derivation of Kepler's Third Law states:
$(m_1 + m_2)P^2 = (4\pi^2/G)a^3$, where $G = 6.67 \times 10^{-8}$ dynes cm^2/gm^2

If relative units are used then the constant drops out, and $m_1 + m_2$ are in solar masses, if "P" is in years, and "a" is in astronomical units.

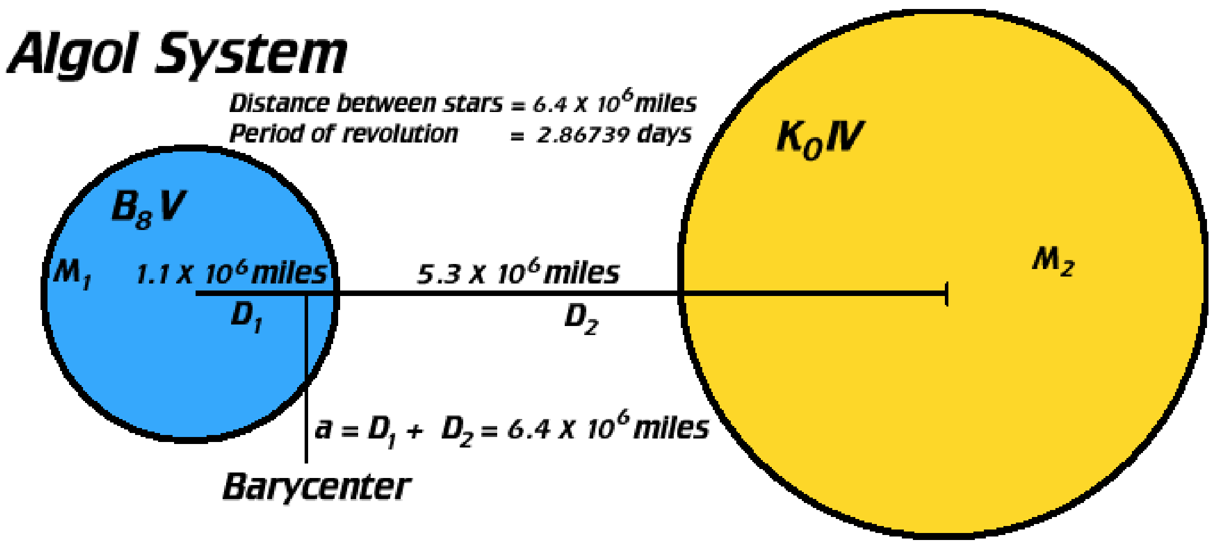
$(m_B + m_G)\ p^2 = a^3 \quad a = \frac{6.40 \times 10^6 \text{ miles}}{92.8 \times 10^6 \text{ miles}} \quad a = 0.0690 \quad p = \frac{2.88 \text{ days}}{365 \text{ days}} \quad p = 0.00789$

$M_{total} = \frac{a^3}{P^2} \quad a = 6.90 \times 10^{-2} \quad a^3 = 3.28 \times 10^{-4} \qquad p = 7.89 \times 10^{-3} \quad p^2 = 6.23 \times 10^{-5}$

$M_{total} = \frac{3.26 \times 10^{-4}}{6.20 \times 10^{-5}}$

$M_{total} = 0.526 \times 10^1$

M_{total} = 5.26 solar masses   Actual M_{total} is 5.8 solar masses



The ratio of the distances to the barycenter is 1.1×10^6 miles and 5.3×10^6 miles respectively over a total distance of 6.4×10^6 miles.

$\frac{1.1 \times 10^6 \text{ miles}}{6.4 \times 10^6 \text{ miles}} = 0.172 = 17\ \% \qquad \frac{5.3 \times 10^6 \text{ miles}}{6.4 \times 10^6 \text{ miles}} = 0.828 = 83\ \%$

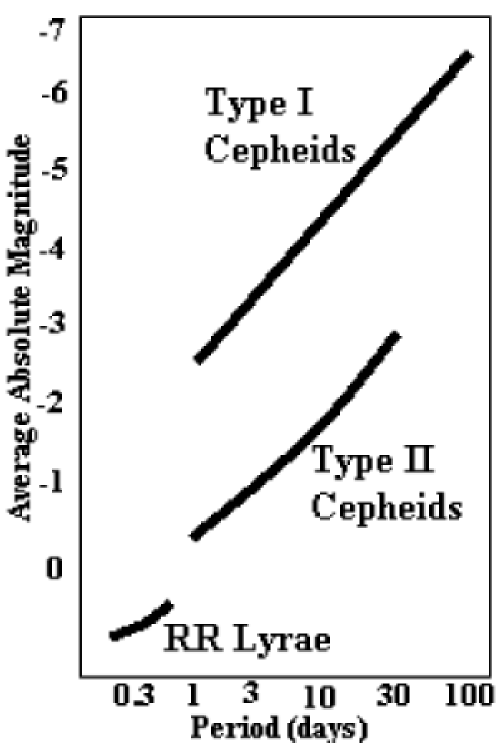
Ratio of the masses will be the inverse of the distances to the barycenter.

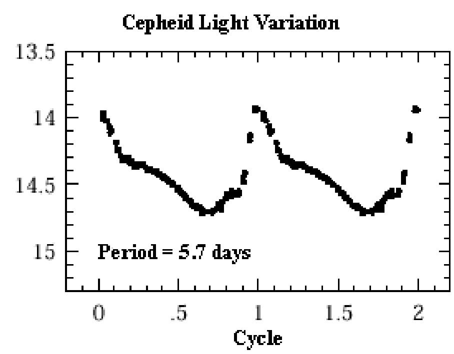
$$M_1 D_1 = M_2 D_2 = \frac{M_1}{M_2} = \frac{D_2}{D_1} \qquad M_1 = \frac{D_2}{D_1} \times T_{mass} \qquad M_2 = \frac{D_1}{D_2} \times T_{mass}$$

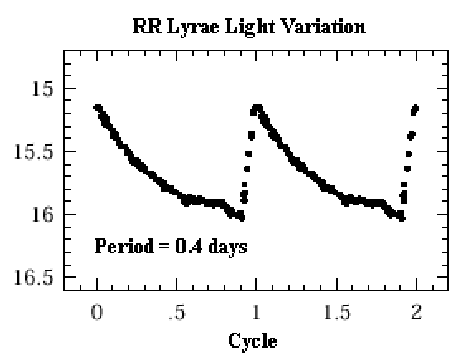
$$M_1 = \frac{5.3 \times 10^6 \text{ miles}}{6.4 \times 10^6 \text{ miles}} \times 5.26_{\text{solar masses}} = 4.36 \text{ solar masses}$$

$$M_2 = \frac{1.1 \times 10^6 \text{ miles}}{6.4 \times 10^6 \text{ miles}} \times 5.26_{\text{solar masses}} = 0.904 \text{ solar masses}$$

6. **Cepheid Variables:** Old stars that vary in their light output due to intrinsic changes in their thermonuclear output which induce the star to pulsate. There are no Cepheid variables within 100 parsecs of the sun. Of the nearly 12,000 entries in the Hipparcos Catalog, 273 were Cepheids and 186 RR Lyrae variables.
   a. **Period Luminosity Relationship:** The longer the period of the Cepheid, the brighter the star. Know the period of a Cepheid variable after identifying its light curve and its luminosity (absolute magnitude) will be known. Then using the distance modulus, the distance to the star and cluster can be calculated. The only problem with Cepheid variables is that there are two types; Type I Cepheids are more luminous than Type II Cepheids.
   b. **RR Lyrae stars:** Pulsating variables which are old halo and disk Population II stars. They are found primarily in globular clusters and are identified by their light curves which have period of a day or less. They all have an absolute magnitude of about +0.5.

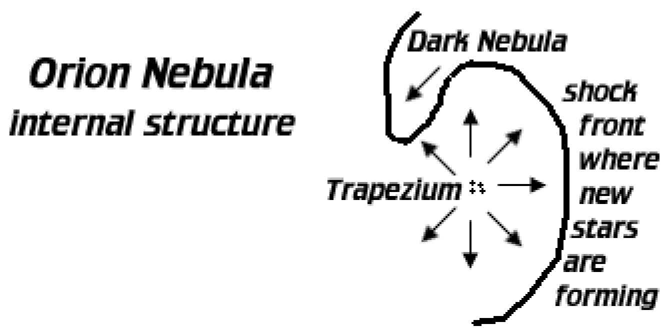






NEBULAE AND CLUSTERS

A. **Nebulae:** clouds of dust and gas contained within the galaxy.
   1. **Dark Nebulae:** The dust component of a large cloud of gas and dust. Starlight passing through a dark nebula will appear to be fainter and redder. The blue light is scattered.
   2. **Bok Globules:** (Bart Jan Bok, Dutch-American astronomer 1906-1983): A dark usually circular region where a gas and dust cloud may be contracting to form a star.
   3. **Bright Nebulae:**
      a. **Reflection:** A star or a group of stars illuminate a dust nebula through the process of scattering. The nebulosity appears blue. The Pleiades or Seven Sisters are the best example, but the reflection nebula is not contained within the cluster.
      b. **Emission:** Hot stars (B_1 or earlier) excite gasses with their ultraviolet radiation and cause the gasses to fluoresce. The best example of an emission nebula is the Orion Nebula located as the middle fuzzy object in the sword of Orion the Hunter.



      c. **Planetary:** Results from the fluorescence of gasses by a white dwarf star when it precursor giant star sheds between 30 to 70 percent of its mass.
   4. **Emission Nebulae, Dark Nebulae, and Reflection Nebulae in the same area:** A good example of this is the Trifid Nebula, M20, where a bright emission area is seen trisected against a dark nebula which appears in front. Below this is a reflection nebula which is glowing due to a star, HD 164514. This star is not hot enough, however, to cause the gas in its vicinity to glow, indicating that gas and dust are mixed within the same structure.

B. **Star Clusters:** Associations of stars that have been formed essentially at the same time from the same pocket of gas or dust. These stars, in some cases, share the same space motion. Clusters of stars which do not share the same space motion, like the Pleiades, are probably very young and will one day dissipate (evaporate).
   1. **Galactic or Open Clusters:** They are found in the plane of the galaxy in dirty space (regions of gas and dust). They have no distinct shape, and number from several dozen stars to perhaps several thousand stars. There are thousands of open clusters. Galactic (open) clusters are composed of Population I stars, luminaries which have a higher metal content than Population II stars which are metal deficient and found near the center of the Milky Way Galaxy and in globular clusters.

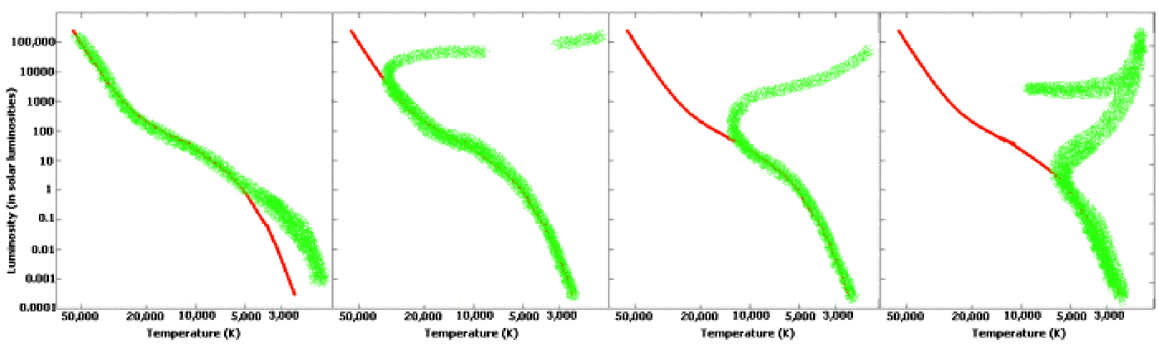
2. **Globular Clusters:** A larger more structured assemblage of stars which can number from 10,000 to one million members. In larger cases like Omega Centauri, they may be small galaxies captured by the Milky Way or other external galaxies. Some astronomers believe that globular clusters may have been the assemblages of stars of galaxies that were cannibalized into larger structure, i.e., the galaxies that we see today. They are found in a spherical distribution around the Milky Way, and many orbit the galaxy at high inclinations to the galactic plane. They are composed of older Population II stars.

C. **H-R Diagrams of Clusters:**

1. Since both globular and galactic (open) clusters were formed at the same time and their members are essentially at the same distances from the sun, astronomers do not have to know the distances to the clusters in order to create meaningful H-R diagrams. Instead of the absolute magnitude of the star, the apparent magnitude of the stars can be plotted against their spectral types or color indices.
2. If a cluster H-R diagrams shows few stars in a particular area of the graph, it is an indication that the stars spend a very little time at that location. The positions on the graph where stars transition off the main sequence will give an excellent approximation of the developmental stage of the cluster—youth, maturity, or old age. This can also be quantified as a chronological age.
   a. **Chronological Age:** The number of years that an object has been present.
   b. **Developmental Age:** Youth, maturity, or old age

Age Chronological	Human, Developmental	Dog, Developmental	Frog, Developmental
1 year	Baby	Puppy	Maturity
5 years	Young Child	Maturity	Old Age
10 years	Child	Old Age	Dead

H-R Diagrams: Age of Clusters Increases L to R



3. The location of the turnoff point of a star cluster gives astronomers a good idea of the age of the cluster.
4. The farther down the main sequence the cluster turns off, the longer the cluster has been in existence.

LIFE AND DEATH OF THE SUN

A. **Gas and Dust Nebula Collapses:**
1. **Time:** Began about five billion years ago
2. **Duration:** 10-20 million years
3. An interstellar cloud of gas and dust, approximately 50,000 AU in diameter, began to collapse gravitationally. Its mass may have been a few thousand solar masses. The cloud fragmented, and one area with at least 1.1 to 2.0 solar masses continued to collapse. Several mechanisms could have initiated such an event.
   a. **O B Associations:** Hot luminous blue supergiant stars create interstellar winds from their tremendous outpourings of radiation. This radiation has the ability to collect matter to form new stars. This occurs in large, interstellar clouds of hydrogen.
   b. **Collection of Mass from the Explosion of a Supernova:** As a shock wave from a supernova event moves through space, a region of higher density is generated immediately in back of the wave front.
   c. **Magnetic fields/Gravity Waves** which originate in the center of a galaxy give rise to shock fronts which move through the medium. With respect to magnetic fields, as charged particles come in contact with the field lines, they are slowed, collecting matter which creates the necessary densities that generate stars.

B. **Pressure and Density Increased. Rotation of the Nebula Increased.** The cloud formed a disk about 60 AU across and about one AU thick. Temperatures rose more rapidly near the center where the density and opacity were greatest. The center of the cloud may have been about 2000 K (3500 °F), while the edge remained cold at about 100 K (-300 °F). Dust near the center becomes vaporized, and atoms of gas became ionized, creating a magnetic field which permeated throughout the contracting mass.

C. **Transfer of Angular Momentum:**
1. **Duration:** Perhaps as short as a few thousand years
2. **Magnetohydrodynamic effect transfers the sun's spin** away from the inner to the outer solar system [Hannes Alfvén-1954, Swedish plasma physicist (1908-1995)].
   a. Early contracting sun had a strong magnetic field.
   b. Area immediately surrounding the sun was composed of ionized particles. Charged particles interacted with the magnetic field so that they spiraled outward along the magnetic lines of force. These magnetic lines returned to the sun, trapping the ions.
   c. The sun was rotating faster than the ions in its vicinity.
   d. The magnetic field lines of the sun, sweeping through the plasma tended to accelerate the cloud, increasing its rotational velocity at the expense of the sun's spin. Angular momentum was transferred away from the sun.
   e. The drag effect of the cloud against the sun also tended to decrease the rotational velocity of the sun.
   f. Differences in composition between the inner and outer planets can be accounted for.
      1) The magnetic field of the sun tended to accelerate the more positively charged ions (which were mostly volatile substances) away from the sun, while the more refractory materials condensed in the cooling solar nebula. These refractory substances, such as iron, nickel, and silicate grains would no longer have been affected by the solar magnetic field because they would have been

electrically neutral. This matter would have collected into the more refractory terrestrial planets of the inner solar system.

2) The volatiles would have remained charged, and thus affected by the sun's magnetic field for a longer period of time. These materials would have spiraled away from the sun accelerated by the sun's magnetic field lines and condensed much farther away in the cooler regions where the Jovian planets orbit the sun today.

g. The basic problem of the Magnetohydrodynamic Effect lies with the assumption that the sun's magnetic field strength would have had to have been 150,000 times stronger than it is today. Presently, the field strength of the sun is approximately two Gauss, four to six times that of the Earth's field strength.

D. **Formation of Grains and Planetesimals:**

1. **Grains condensed** with their composition dependent upon the temperature of the immediate environment. Generally, the denser terrestrial materials formed nearer to the sun, while icy materials condensed farther away.
2. **Grains collided to form planetesimals,** small bodies ranging in size from millimeters to 10 kilometers. They grew through direct physical collisions with each other.

E. **Evolution of the Planets from Protoplanets:**

1. **Planetesimals became protoplanets** once their masses became great enough to possess an effective gravitational field. The ability of protoplanets to obtain more mass was not limited strictly to their size, as it was for planetesimals. At this point the protoplanet population rapidly assembled into the solar system that we know today.
2. **The sun initiates thermonuclear fusion.** Solar wind (particles) and solar radiation (energy) swept out the remaining gaseous materials from the nebular disk.
3. **The inner planets became heated and then melted from the material accreting onto their surfaces.** Their primordial atmospheres were lost. Outgassing from these bodies through volcanic eruptions eventually created secondary atmospheres. The Jovian planets because of their great masses retained their primeval atmospheres which are similar to the composition of the present-day sun.

F. **Demonstrations:**

1. Conservation of angular momentum wheel
2. Conservation of angular momentum, using a ball, string, and spool
3. Fahrenheit 451 demonstration (tube and plunger)
4. Size of the solar system modeled from a sun 84 inches in diameter. **If a hydrogen atom were enlarged to the same size as the sun, the electron would be in orbit around the nucleus 3.3 times the distance from the sun to Neptune.** There is more empty space in an atom than there is in the solar system.
5. Solar system is demonstrated using a roll of paper towels. Each towel square equals one AU.

STELLAR EVOLUTION WORD LIST

1. **Absorption Spectrum:** The dark lines superimposed over a continuum when intervening rarefied gases absorb radiation at specific wavelengths.
2. **Absolute Magnitude:** The brightness of a star when viewed from a standard distance of 10 parsecs or 32.6 light years.
3. **Angstrom:** **(**Å) A unit of measurement in the metric system equal to one hundred billionth of a centimeter. (10^{-8} cm).
4. **Apparent Magnitude:** The brightness of an object in the night sky.
5. **(Name of Atom) I:** neutral form of an atom such as Na I, N I, etc… It is the atomic symbol and the Roman numeral one. Keep in mind that Roman numerals did not include a zero.
6. **(Name of Atom) Atom II:** singly ionized form of an atom such as He II, Ca II, etc…
7. **(Name of Atom) Atom III:** doubly ionized form of an atom such as Fe III, Si III, etc…
8. **Balmer Series:** A related series of absorptions and emissions in the Bohr model of the hydrogen atom. These transitions take place in the visible part of the spectrum. N=2 is the pivotal energy state from which the Balmer series originates.
9. **Base Line:** The separation between observing locations when determining distances trigonometrically. In determining the parallax of a star, the base line is one AU.
10. **Black Body:** An object which absorbs all of the energy which falls upon it. It is a perfect absorber and emitter of energy. The emitted radiation is a function of temperature.
11. **Black Body Radiation Curve:** The energy distribution coming from an object that is a perfect absorber/emitter of electromagnetic radiation.
12. **Blue Stragglers:** These stars have a later turnoff point from the main sequence than would be expected because of their mass. Better mixing of a star's interior with its outer layers, caused by a binary system in which one of its stars is spilling hydrogen onto the other component, may be the reason for these stars.
13. **Bohr Model:** A theory which proposes that electrons can only move between specified energy states. These energy quanta give an atom its specific spectral characteristics.
14. **Color Index:** A method of determining a star's temperature or spectral type by accurately measuring its magnitude at standardized wavelengths (UBV).
15. **Continuous Source:** A source of electromagnetic radiation in which all wavelengths of energy are represented.
16. **Continuous Spectrum:** The type of electromagnetic radiation which is being produced when a solid, liquid, or gas (under pressure) is made to incandesce. All wavelengths are represented.
17. **Continuum:** A synonym for a continuous spectrum. All wavelengths are represented.
18. **Core Burning:** All thermonuclear fusion is occurring in the center of a star. Stars which have this structure belong to the main sequence.
19. **Diffraction:** The various phenomena which occur when a wave front encounters an opaque obstacle and amplification and cancellation of wave fronts result.
20. **Dispersion:** A particular property of refraction in which the angle and velocity of a wave front passing through a (dispersive) medium depend upon their frequency.
21. **Doppler Shift:** A phenomenon of increased or decreased frequency of the wave front observed whenever the source of waves is moving with respect to the observer. See Doppler shift after the spectroscopy section.
22. **Dwarfs:** The luminosity characteristics of main sequence stars which are about the mass of the sun or less.

23. **Electromagnetic Spectrum:** The array of the various energies which are found in nature and include, gamma, X-rays, ultraviolet, visible, infrared, microwave, and radio wavelengths.
24. **Emission Spectrum:** The type of spectrum which is produced when a rarefied gas is made to incandesce. The light is being emitted at specific wavelengths, which is a result of the electron structures of the atoms which are producing it.
25. **Energy (associated with wavelength):** capable of doing work… As the wavelength of electromagnetic radiation decreases, the energy inherent in that wavelength increases. Put in another way, as the frequency of electromagnetic radiation increases, so too does the energy.
26. **Frequency:** The number of wave crests of sound or electromagnetic radiation passing a given location in a (unit) time interval.
27. **Giants:** The luminosity classification of low mass stars, such as the sun, after they have initiated shell hydrogen burning and moved away from the main sequence.
28. **H II Region:** A large cloud composed mostly of ionized hydrogen. The region surrounding an OB Association would be ionized due to the ultraviolet radiation coming from the young, luminous stars which compose it.
29. **Hertzsprung-Russell Diagram:** A two-dimensional representation highlighting the relationship between a star's absolute magnitude and its temperature. It is probably the best visual tool for understanding the evolution of stars.
30. **Horizontal Branch:** A region to the left of the red giant locale of an H-R diagram where low mass stars have lost mass during their red giant phase. The horizontal branch is seen in globular clusters, large aggregates of stars which are almost like miniature galaxies in our Milky Way.
31. **Horsehead Nebula:** One of the most famous dark nebulae in the heavens. It is located near the bottom belt star, Alnitak, of Orion the Hunter and looks like a chess piece called a Knight.
32. **Hyades:** An old, open cluster which forms the head of Taurus the Bull, minus the bright star Aldebaran.
33. **Interference:** A phenomenon in which two waves superimpose to form a resultant wave of greater amplitude (additive) or lower amplitude (subtractive).
34. **Ion:** An atom (or molecule) which is not electrically neutral.
35. **Kirchhoff's First Law of Spectroscopy:** A solid, liquid, or gas (under pressure) when made to incandesce will produce a continuous spectrum in which all of the energies of the spectrum are represented.
36. **Kirchhoff's Second Law of Spectroscopy:** A rarefied gas when made to incandesce will produce an emission spectrum unique to the gas creating it.
37. **Kirchhoff's Third Law of Spectroscopy:** A rarefied gas found between a continuous source and an observer will produce an absorption spectrum. The dark lines of the absorption spectrum are created when specific wavelengths of energy from the continuous source are filtered by the intervening rarefied gas.
38. **Line Strength:** The blackness and thickness of a dark line in an absorption spectrum.
39. **Lyman Series:** A related series of absorptions and emissions in the Bohr model of the hydrogen atom which take place in the ultraviolet. All of these transitions take place in the ultraviolet part of the spectrum. N=1 is the pivotal energy state from which the Lyman series is created.
40. **Luminosity:** The total brightness of a star represented by all of the electromagnetic radiation radiated from that body.
41. **Magnitude:** A quantitative method for accurately measuring the intensity differences among stars. The more negative the magnitude of a star, the brighter it becomes. The intensity difference between one whole magnitude equals 2.51

42. **Main Sequence:** It is the dominant S-shaped or propeller-shaped structure in a Hertzsprung-Russell diagram where stars are converting hydrogen into helium within their cores.
43. **Metals:** All elements heavier than hydrogen and helium which are contained within a star.
44. **Molecular Cloud:** A large volume of space within a galaxy where temperatures are low enough and densities high enough to support the formation of molecules, such as H_2.
45. **n = 1:** Lowest energy level or ground state of an electron in the Bohr model of the atom.
46. **Nanometer:** A unit of measurement in the metric system equal to one billionth of a meter (10^{-9} meter).
47. **OB Associations:** A method of star formation by which hot, young OB stars in molecular clouds create shock fronts from their radiant energy. These shock fronts gravitationally collapse, forming new OB clusters which ripple through the cloud until most of the hydrogen has been used.
48. **Orion Nebula:** Found as the center star-like object in the sword of Orion the Hunter, it is the best example in the sky of an emission nebula and stellar nursery.
49. **Parallax:** The angular displacement of an astronomical body created by viewing it across a baseline. It is the same as obtaining the distance to a terrestrial object by viewing it from two different positions (the baseline).
50. **Parsec:** 3.2616 light years… A parallax angle of one second of arc, created by a baseline of one astronomical unit.
51. **Paschen Series:** A related sequence of absorptions and emissions in the Bohr model of the hydrogen atom which take place in the infrared. N=3 is the pivotal energy state from which these transition occur.
52. **Pillars of Creation:** A star-generating area in the Eagle Nebula being ripped apart by energy radiated from a new star cluster, also part of the Eagle. The young star cluster is blowing dust away from numerous contracting protostars, creating the light year sized columns made famous by the Hubble Space Telescope.
53. **Planck's Constant**: A numerical device which allows for the relationship of wavelength (frequency) and energy to be quantified.
54. **Planck's Law:** $E = hf = hc/\lambda$ where h = Planck's constant 6.626×10^{-27} erg sec, f = frequency, λ = wavelength of the energy, and c is the speed of light.
55. **Pleiades:** The brightest and best example of an open or galactic star cluster in the heavens. The Pleiades are 425 light years distant, contain no more than 500 stars, and are found on the shoulder of Taurus the Bull. They are also called the Seven Sisters.
56. **Prancing Horse:** A dark nebula in the shape of its namesake found between the summer constellations of Scorpius and Sagittarius. Its ability to be photographed or seen visually is an indication of minimal light pollution.
57. **Proplyds:** A cloud of gas and dust surrounding a protostar in a stellar nursery like the Orion Nebula.
58. **Quanta:** An energy unit or energy packet in the Bohr model of the atom. In quantum physics, it is the messenger particle for the electromagnetic force.
59. **Quantum Physics:** The physics which governs the interactions of atoms and the nuclei of atoms. It is the physics of the very small.
60. **Radial Motion:** Line of sight motion towards or away from an observer.
61. **Red Dwarfs:** The luminosity characteristics of main-sequence stars of the lowest masses.
62. **Reflection:** The change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated.

63. **Refraction:** The change in direction of a wave front passing from one medium into a second medium caused by the wave front's change in speed induced by the second medium.
64. **Roche Lobe:** Imaginary surfaces surrounding a binary system over which the gravitational field is constant. At the point between the binary system where the gravitational potential is equal, matter from a star filling its Roche lobe can spill over onto its component.
65. **Scattering:** The dispersal of a beam of particles or wave fronts into a range of directions.
66. **Spectral Classification:** A temperature dependent method of classifying stars based upon a comparison of the strengths of lines in absorption spectra.
67. **Shell Burning:** Thermonuclear fusion is occurring in a layer or numerous layers surrounding the core of a star. The star is no longer on the main sequence.
68. **Shock Front:** A region of higher density moving through a medium.
69. **Stephan's Law:** The total energy emitted from a black body is proportional to the temperature in K^4.
70. **Supergiants:** Stars of the highest luminosity classification, Ia, Ib, or II… Blue Supergiants are found along the main sequence in the upper left of the H-R Diagram. Red Supergiants are found in the upper right of the H-R Diagram.
71. **Supernova:** A stellar explosion… The manner in which highly evolved stars, nine solar masses or greater, end their existence.
72. **Temperature:** A quantitative measurement which determines the kinetic energy of the matter being measured.
73. **Trapezium:** The name of the star cluster at the center of the Orion Nebula. It causes the nebulosity to fluoresce.
74. **Turnoff Point:** Location along the main sequence where a star switches from core hydrogen to shell hydrogen burning.
75. **Type I Supernova:** A stellar explosion precipitated by a star in a binary system in its later stages of evolution, filling its Roche lobe and dumping hydrogen onto a white dwarf. The extra mass causes compression, heating, and eventual thermonuclear fusion. If the fusion rips through the star at a speed greater than the speed of sound for that medium, the star explodes.
76. **Type II Supernova:** A stellar explosion precipitated by the halting of thermonuclear fusion inside the iron core of a red supergiant. The core implodes (0.2 second) sending temperatures "off the scale" and initiating fusion which produces all of the 92 naturally occurring elements. The star explodes seeding the regions with these new elements. Depending upon the remaining mass, what remains is a white dwarf, neutron star, or black hole.
77. **Wavelength:** Distance between energy wave crests in the electromagnetic spectrum.
78. **White Dwarf:** A luminosity classification on an H-R diagram conducive to the characteristics of cooling cores of fully evolved stars. The core of an evolved star is no longer undergoing thermonuclear fusion. Its mass must be less than 1.44 solar masses.
79. **Wien's Law:** $\lambda_{max} T = 0.29 \times 10^{-8}$ A or $T = 0.29/\lambda_{max}$ where λ (lambda) equals the wavelength of greatest energy emission in centimeters, and T is the temperature in absolute degrees Kelvin.
80. **Zero Age Main Sequence:** The position of a star on the main sequence when core hydrogen burning begins.

CAN YOU ANSWER THE FOLLOWING QUESTIONS/STATEMENTS ABOUT THE EVOLUTION OF STARS?

ATOMS

1. The smallest quantity of matter which retains the chemical properties of that material is called an _______________.

2. An atom is composed of three basic subatomic particles. They are called the _______________, _______________, and the _______________.

3. Both the protons and the neutrons are located in the center of the atom which is called the _______________.

4. _______________ orbit the nucleus of an atom, but are not attracted to it by the force of gravity.

5. Rather, protons have a _______________ charge and electrons have a _______________ charge. This difference in **electrostatic charges** called the **electromagnetic force** holds the atom together.

6. In matter which is neutral, atoms or molecules contain an _______________ number of electrons and protons.

7. Atoms or molecules that are not balanced with respect to the number of protons or electrons which they contain are c_____________. These atoms or molecules are now called _______________.

   Two hydrogen atoms meet. One says, "I've lost my electron." The other hydrogen atom says, "Are you sure?" The first replies, "Yes, I'm POSITIVE!" (Jordan Brown, LED—2007)

   A neutron walks into a bar and orders a drink. The barkeep looks at "her" and says, "For you babe, there's NO CHARGE" (Richard Feynman).

8. When ions and electrons are mixed together, they are called a _______________. The physical state of this material is a SOLID, LIQUID, GAS (circle one). The temperature is HOT/COLD (circle one).

9. E_____________ absorbed by an electron is one way that it can become detached from the nucleus. An atom or molecule which loses an electron is said to be _______________.

ENERGY

10. The whole array of different energies, of which light is just one component, is called the ________________ spectrum.

11. The different components of this energy spectrum in their correct order from the most intense to the least intense are as follows:
________________ less than 1 Angstrom (Å) in length
________________ 1 to 100 Å in length
________________ 100 to 4000 Å in length
__Visible Light _ 4000 to 7000 Å in length
________________ 7000 A to 1 mm in length
________________ 1 mm to 1 meter in length
________________ greater than 1 meter

One Angstrom equals 0.00000001 cm or 10^{-8} cm. Another way of describing the smallness of an Angstrom is to say that there are 254,000,000 or 2.54 x 10^{8} Å/$_{\text{inch}}$.

12. All forms of electromagnetic energy travel at the speed of ________________.

13. Electromagnetic energy can be described as a ________________ or a ________________. Each description helps us to visualize certain characteristics of this energy as it applies to its encounters with matter.

14. For example, if a quanta of energy knocks an electron of an atom out of its orbit, it is best to imagine the energy to be in the form or a ________________. Synonyms for this description might be a bullet, quanta, or energy packet.

15. However, if a person is describing the size of the electromagnetic energy, or how refraction occurs, the description of a ________________ might be more appropriate.

THE ELECTROMAGNETIC SPECTRUM:

16. When electromagnetic energy is described as a wave, the distance between wave crests is designated as the ________________ of that radiation.

17. List the following portions of the electromagnetic spectrum, given below, in correct order with respect to wavelength, proceeding from longest to shortest.
visible, infrared, gamma rays, x-rays, microwaves, radio, ultraviolet
________________ longest...
____
____
____
____
____
________________ shortest...

18. Since all electromagnetic radiation travels at the velocity of _______________, the number of wave crests passing a given point per second will be HIGHER/LOWER (circle one) for radiation of a shorter wavelength.

19. The number of wave crests passing a given point per second is termed the _______________ of the radiation.

20. Give the name of a portion of the electromagnetic spectrum which has a high frequency, a medium frequency, and low frequency.

    high _______________, medium _______________, low _______________

21. The electromagnetic spectrum represents a band of energy of different intensities. The shorter the wavelength, the HIGHER/LOWER (circle one) the energy. The higher the frequency, the HIGHER/LOWER (circle one) the energy.

22. The visible spectrum, which represents that portion of the electromagnetic spectrum which can be seen by the _______________, contains the colors which are given by the famous acronym ROY G. BIV. These colors, in their correct order from longest to shortest wavelength are : _______________, _______________, _______________, _______________, _______________, _______________, _______________.

23. The color visible to the human eye with the longest wavelength, _______________, is the color with the HIGHEST/LOWEST (circle one) frequency. The color with the shortest wavelength has the HIGHEST/LOWEST (circle one) frequency.

24. Multiplying the frequency (f) of the electromagnetic radiation by a constant, called Planck's Constant ($h = 6.625 \times 10^{-27}$ erg sec) yields the actual amount of _______________ that each frequency will deliver. The shorter the wavelength, the MORE/LESS (circle one) energetic the radiation.

THE NATURE OF LIGHT AND MATTER

25. The energy curve for an object which is a perfect absorber and emitter of energy is referred to as a _______________ energy distribution. Stars are basically perfect emitters and absorbers of energy. Their energy distribution is very consistent with blackbody radiation curves.

26. Two stars at different temperatures are emitting energy spectrums of various wavelengths of visible and nonvisible light. The star which is cooler will have its energy distribution curve shifted towards the RED/BLUE (circle one) with respect to the hotter star (Wien's law). At all points along the energy curve, the hotter star will be radiating MORE/LESS (circle one) energy than the cooler star. The temperature of a stars in K = 0.29/dominant wavelength measured in centimeters.

27. The energy being radiated per unit area at a star's surface is a direct function of the _______________ of that star (Stefan-Boltzmann law).

28. A hotter star will radiate MORE/LESS (circle one) energy at all wavelengths than a cooler star. Besides this, the hotter star will radiate its maximum energy at a SHORTER/LONGER (circle one) wavelength. Therefore, the hotter the star, the BLUER/REDDER (circle one) its light will become.

29. What is found is that stars which are cool radiate most of their energy in the _______________, whereas stars like our sun, have their peak radiation areas in the _______________. Hot stars radiate most of their energy in the _______________. The location of the peak of the energy curve, with respect to the eye's color perception, is why the temperature of a star can be understood through a <u>qualitative</u> observation of its _______________.

30. Knowing the precise energy peak of a star gives astronomers a good <u>quantitative</u> measurement of the _______________ of a star; however, color is difficult to perceive with just the human eye because most of the stars in the sky are very faint. Two of the best examples for detecting color with the eye, or with binoculars, are Rigel, a _______________ (color) star which forms the right knee of Orion the Hunter, and Betelgeuse, the _______________ (color) star, which defines the left shoulder of the Hunter.

31. However, just describing a star's color is a very <u>qualitative</u> method. The instrument which allows astronomers to gain a numerical understanding of a star's color is a _______________. Such an instrument uses the light gathered by a telescope and splits it into its component colors, called a _______________. A diffraction grating, such as "Lazar Shades," can be used to view the spectrum of fluorescing gases. Fine, closely spaced lines embedded with the membrane of the transparent Lazar Shade material bend light of different colors through different angles to produce a spectrum.

32. The solar spectrum peaks at about _______________ Angstroms (Å). Blue stars like Rigel peak at LONGER/SHORTER (circle one) wavelengths than red stars like Betelgeuse. The solar peak falls about midway between these two stars.

33. The farther towards the blue the peak of the spectral curve appears, the HOTTER/COOLER (circle one) the star becomes. In fact, the precise location of the spectral peak will determine the exact _______________ of the star.

34. All stars are essentially composed of _______________ and _______________. Elements which are heavier than the two most common constituents of the universe, are called _______________.

THREE LAWS OF SPECTROSCOPY

35. A solid, liquid, or gas (under high pressure) when heated and made to incandesce (glow) produces a _______________ (Kirchhoff's first law).

36. A rarefied gas when made to glow produces bright spectral lines at wavelengths distinctive only to that gas. This type of spectrum is called an ________________ (Kirchhoff's second law).

37. A cool, rarefied gas found between a continuous source and an observer will produce an ________________ (Kirchhoff's third law).

38. The name of the German physicist who formulated the three laws of spectroscopy mentioned above was Gustav K________________ (1824-1887).

THE MESSAGE OF STARLIGHT

39. The elements which compose a star can be revealed through the analysis of that star's ________________ spectrum. However, the spectra of various stars appear to emphasize different elements in their chemical makeup. This is not so much the result of a variation in composition between the stars, but rather a difference in the ________________ of the various luminaries.

40. The difference in a star's temperature will be revealed by which particular absorption lines in the spectrum attain the greatest ________________. This factor by itself DOES/DOES NOT (circle one) indicate the **quantitative** composition of that star. The differences in the spectra of the stars has allowed astronomers to attempt a ________________ system.

41. Because the atoms of "metals" are more complex than hydrogen and helium, electrons will be found CLOSER TO/FARTHER FROM (circle one) the nucleus of the atom. It will require MORE/LESS (circle one) energy to ionize a metal than it will a hydrogen or helium atom. This translates into a HIGHER/LOWER (circle one) temperature. To break the bonds between atoms in a molecule requires MORE/LESS (circle one) energy (temperature) than to ionize a metal.

42. Very cool stars display the spectral absorption bands (fingerprints) of ________________ in their spectra because temperatures are low enough for atoms to combine. Warmer stars like the sun display prominent absorption lines of various ________________, such as calcium, sodium, and iron. The hottest stars have spectra which display prominent lines of ________________, ________________, and multiple lines of ionized metals.

43. Classify the spectral types listed below into hot, medium, and cool temperature catagories.

O B A F G K M

______________________, ________________, ________________

44. Write a mnemonic device which will allow you to remember the spectral classification of the stars in order of decreasing temperatures.

____

45. Neutral helium is labeled He I, while singly ionized He is written He II. Doubly ionized calcium is noted as Ca III. Please write the correct representations for the following elements:
    a. Iron (Fe) with nine electrons missing ________________
    b. Silicon (Si) with two electrons missing ________________
    c. Silicon (Si) with three electrons missing ________________
    d. Neutral hydrogen (H) ________________

46. The greater the ionization of the elements which compose a star's atmosphere, the HOTTER/COOLER (circle one) that star will be.

THE BRIGHTNESS OF STARS

47. The scheme for classifying stars according to their brightness or ________________ originated from the ancient ________________.

48. They called the brightest stars ________________ magnitude stars, while the dimmest stars were said to be of the ________________ magnitude.

49. Today astronomers have quantified the magnitude system. The key to its understanding is to realize that the brighter the object, the MORE/LESS (circle one) positive its magnitude, and that the intensity difference between magnitudes is equivalent to ________________, not 2.0. The intensity difference between five whole magnitudes, i.e., from a 1st to a 6th magnitude star is equal to ________________ times in intensity.

50. The brightness of a star in the night sky as seen from the Earth is designated by that star's ________________ magnitude.

51. The brightness and color of stars are two major characteristics of these objects which can be measured with a large telescope. The amount of light gathered by a telescope from a star depends upon the actual brightness of the luminary and its ________________ from the observer.

52. A casual glance into the night sky reveals that some stars appear to be brighter than other stars. Just because one star looks brighter than another does not mean it is giving off more light. A star might look bright because it is very ________________ to us, or because it is exceedingly ________________. If we knew the ________________ to the star, we could determine the actual energy output, since we know that the brightness of a light source varies as the inverse ________________________________.

53. If the distance to a star is known, then it is possible to obtain mathematically a QUALITATIVE/QUANTITATIVE (circle one) measurement of the actual amount of energy which the star is emitting. This is known as a star’s ________________ magnitude.

54. The problem has been solved by accurately measuring the p_______________ of nearby stars created by the Earth's yearly circuit around the sun. When the distance to a star is known, as well as its apparent magnitude, it is possible to manipulate its distance mathematically from the Earth to see how its brightness compares with other stars of known distance. If the brightnesses of many stars can be compared to each other at a standard distance, then it will become possible to see which ones are really the bright luminaries, and which stars appear bright only because of their closeness to the Earth. The formula for accomplishing this is $m - M = 5 \log (^{d}/_{10})$, where m and M are the apparent and absolute magnitudes respectively, and d is the distance to the object in parsecs. One parsec equals a distance of _______________ light years.

55. A star which shifts through a PARallax angle of one SECond of arc is at a distance of ____________________ from Earth.

56. The standard distance to which stars are mathematically moved for comparison purposes is equivalent to ____________________. This distance equals _______________ light years. This is represented by the 10 in the formula $m - M = 5 \log (^{d}/_{10})$.

57. The luminosity of a star, standardized for a distance of 10 parsecs from the sun, is known as that star's _______________ magnitude.

58. One might think that stars of every spectral classification would fall into every category of absolute magnitude. This is, however, untrue. Early in the 20th century, the Danish astronomer, Ejnar _______________, and the American, Henry Norris _______________, independently combined the concepts of absolute luminosity (absolute magnitude) and temperature (spectral classification) into a graphical analysis for several dozen stars. Their efforts resulted in the foundation for our modern understanding of the life cycles of stars. These two individuals discovered that stars of a particular spectral classification could only possess a specific luminosity. In other words, a star's spectral classification predestined its _______________ magnitude. Color-luminosity plots of stars are collectively known as Hertzsprung-Russell diagrams, also abbreviated as _______________ diagrams.

THE CLASSIFICATION OF STARS: UNDERSTANDING THE H-R DIAGRAM

59. When the absolute magnitude is plotted against the spectral classification for a large sampling of stars, the result is known as a ____________________ diagram.

60. The vertical axis of the diagram represents the brightness or ____________________ of the stars standardized for a distance of 10 parsecs from the sun.

61. The horizontal axis of the diagram represents the spectral classification of the star which is really another way of describing the _______________ of the stars being plotted.

62. On this diagram, most stars are located along a curved track which is called the ____________________. Stars throughout this location have much the same internal structure and composition and are existing through much the same processes. They are fusing _______________ into _______________ to create the energy which powers their existence. Stars spend most of their ________________ at this location. **DO NOT THINK** of the curve as a sliding board, where stars start at the upper left and work their way down to the lower right as the evolve.

63. The feature about the stars which leads to the correlation of the pattern which we term the main sequence on an H-R diagram is a direct result of that star's _______________.

64. Along the main sequence, low luminosity stars are COOL/HOT (circle one) stars, while high luminosity objects on the main sequence are COOL/HOT (circle one).

65. Stars which lie at the lower right of the main sequence are low luminosity, and therefore, have HIGH/LOW (circle one) masses. Stars which lie at the upper left of the main sequence are of high luminosity. These object have HIGH/LOW (circle one) masses.

66. A star is a balancing act between the mass of the object which wants to _______________ the star due to gravitational forces, and the outward _______________ created by the thermonuclear fusion processes which are generated by a star's internal temperatures pushing against this force of gravity. Low mass/low luminosity stars have less internal compression and have lower temperatures. Their lives must be extremely _______________ for they consume themselves very slowly. High mass/high luminosity stars have tremendous internal compressions and extremely high temperatures. They consume hydrogen at a prodigious rate. Their longevity on the main sequence must be extremely _______________.

67. Since stars which fall along the main sequence are believed to have the same internal _______________, it can be inferred that stars which are positioned off the main sequence must have internal structures which are quite different. One of these classifications is represented by stars which are very luminous. Their spectra indicate that they are very cool. Since cooler stars emit MORE/LESS (circle one) energy per unit area, the only way that they can be very luminous is if they are very _______________. These types of stars are called ____________________.

68. On the other hand, there are stars which according to their spectra are extremely hot, emitting a lot of energy per unit area. However, these objects are not very luminous. In size, these stars must be very _______________. Stars which fall into this category are labeled ____________________.

69. Supergiants, giants, main sequence, and white dwarf stars represent four different types of _______________ classifications found on the H-R diagram. These regions represent different ________________ stages that a star may pass through during its lifetime.

70. Stars not found along the main sequence are utilizing different processes other than core hydrogen burning to sustain their existence. Giants are converting hydrogen into helium in a thin _______________ surrounding their cores. Eventually, temperatures may become hot enough to initiate helium burning in the star's interior. Some supergiants have gone through core helium burning, and they are now converting _______________ into carbon and oxygen in a thin shell surrounding their carbon-oxygen rich cores.

71. White dwarfs are really the hot, inert helium or carbon-oxygen _______________ from dead, low mass stars which have shed their outer envelopes of hydrogen and helium. The mass of the "star" is sustained from further collapse due to the pressure of _______________. Matter in this particular condition is said to be _______________.

72. On the H-R diagram the sun is placed in the middle of the main sequence because it is considered to be an _______________ star. Stars which are at the upper left of the main sequence are very ________________ and ________________. Their core temperatures and pressures must be much higher than the sun's. Their sizes in comparison to the sun's size must also be LARGER/SMALLER (circle one). The only way that these conditions can be generated is if these stars possess greater internal compression created by more _______________. Because a star's luminosity varies approximately to the 3.5 power of its mass, these stars have LONG/SHORT (circle one) lives.

73. Stars at the lower right hand corner of the main sequence of the H-R diagram are cool and not very luminous. Their internal _______________ and _______________ are less because their masses are less. Glowing with a cool, red color, these stars consume their nuclear fuel so slowly that their lives will be very _______________ indeed.

74. With respect to solar masses, the numbers ________ to ________ represent the lower and upper limits of all stars found in the sky. This translates into a luminosity of less than $^{1}/_{7000}$th to more than 1,000,000 times that of the sun's brightness.

75. In addition to allowing stars to be classified with respect to luminosity, mass, and size, an H-R diagram allows astronomers to trace the e_______________ tracks of these objects as well.

STELLAR BIRTH

76. Stars are born when large masses of gas and dust gravitationally _______________. The greater the mass, the FASTER/SLOWER (circle one) this process takes place. The range in time can be from tens of thousands to nearly 100 million years.

77. When contraction begins, these protostars are cool, but very _______________. This indicates that they are very (size) _______________. On the H-R diagram low mass stars move _______________ (direction) and then to the _______________ (direction) as they are formed.

78. As contraction proceeds in the early stages of the formation of a low mass star, the surface brightness remains constant while the size _______________. These stars become less luminous. Energy is released as gravity pulls the material which will form the star closer together and temperatures and pressures increase. Energy is transported to the surface via _______________ currents (turbulence). During contraction low mass stars are immersed in a cocoon of _______________.

79. Once the low mass star moves to the left, a different mode of energy transportation, called _______________ transfer becomes dominant in its interior. The cocoon of dust is shed, revealing the true protostar as an optical object. Internal temperatures and pressures approach the level where full _______________ burning can be sustained. Luminosity remains fairly constant.

80. In the formative processes, the most massive stars basically move to the _______________ (direction), on the H-R diagram, maintaining their luminosities at the expense of a decrease in size. T_______________ must be going up very rapidly to sustain this constant energy output despite a smaller surface area. In the end when hydrogen burning commences, these stars are substantially larger than our sun due to the enormous pressures which are generated in their cores through the accelerated burning of hydrogen. These stars are often called ____________________.

81. Once a star initiates hydrogen burning, it is positioned somewhere along the ____________________ at a position called its ________________ age location. A star's specific position along this curve is essentially determined by its ________________.

82. Since a random sampling of stars in the sky will show that most stars fall along the main sequence, it can be said that stars spend the greatest portion of their lives converting ________________ into _________________.

STELLAR DEATH

83. As thermonuclear fusion proceeds _______________, ash builds up in the star's core. The core becomes smaller as gravity squeezes this inert material into ever higher densities.

84. Contraction of the core causes core temperatures to INCREASE/DECREASE (circle one), ACCELERATING/DECELERATING (circle one) hydrogen burning in the core. The star becomes slightly MORE/LESS (circle one) luminous, but is still considered to be on the main sequence.

85. Eventually, all hydrogen burning ceases in the core. Hydrogen begins to fuse in a thin ______________ surrounding the core, adding more helium ash into the system. Because no fusion is occurring in the core, it continues to contract under the force of gravity, eventually reaching a fraction of its original size. Temperatures in this region INCREASE/DECREASE (circle one) dramatically, causing an acceleration in the star’s shell hydrogen burning, lifting the star's outer layers.

86. Temperatures in the outer layers of the star INCREASE/DECREASE (circle one), but because the size of the star has become so much larger, the actual _______________ has increased. At this point the star rapidly moves away from the main sequence to become a _______________.

87. When the core of the star reaches 100 million K, _______________ nuclei begin to fuse. In higher mass stars this begins gradually, but in less massive stars, the onset is explosive, and it is known as the ____________________. The fusion of helium atoms into carbon is called the _______________ process.

88. When the helium flash occurs in low mass stars, the core expands and WARMS/COOLS (circle one), reducing the amount of fusion in the hydrogen burning shell. This causes the bloated outer layers to contract because they are no longer being supported by as much pressure from the hydrogen burning shell. The star backs away from its high point in luminosity on the H-R diagram and moves to the left. *Low mass stars in this region of the H-R diagram are known as h_______________-branch stars.

89. A post helium flash, low mass star is a WARMER/COOLER (circle one) and BIGGER/SMALLER (circle one) object than when it was a red giant.

90. As helium burning occurs in the core of low mass stars, the ash which results is chemically known as _______________ and oxygen. Eventually, most of the helium in the star's core is consumed. The ash compresses and is further heated, triggering helium burning in a _______________ surrounding the core. Since conditions in the core are hotter than ever before, the star ascends to the giant branch once again, but not merely as a red giant. This time the star becomes a _______________ red giant star. Astronomers do not believe the sun will reach this final stage in its evolutionary cycle or whether the sun will ever initiate helium fusion within its core.

91. In low mass stars, instabilities can develop in the helium burning shell that will lift the outer layers of the star from its core. The expanding sphere of luminous gas is called a _____________________ nebula. The remaining hot, compact core is called a _____________________. Over billions of years, this object will eventually cool to become a _____________________.

92. The evolution of more massive stars follows a sequence of core and shell burning which produces heavier and heavier _______________. Like a low mass star, hydrogen is changed into helium and helium into carbon and oxygen, but because high mass stars have higher internal pressures and temperatures, the energy production can continue to more interesting later stages where carbon and oxygen are converted into silicon, sulfur, argon, calcium, and finally, _______________.

93. By this time the massive star's life is almost over. Its interior is segregated into ________________, where successive elements are burning, each producing less energy than the last, and each reaction taking a LONGER/SHORTER (circle one) amount of time to occur over the previous stage.

94. All fusion reactions up to iron have been ________________, meaning that energy is given off during the fusion reaction. To produce heavier atoms beyond iron necessitates the input of energy. These nuclear reactions are ________________.

95. At the heart of the star, an iron core rapidly begins to grow as the process of nuclear fusion can go no further. When enough iron has been produced in the innermost regions of the star, gravity takes over, fusion abruptly stops and the core ________________ almost instantaneously (about $^{2}/_{10}$ of a second). This produces temperatures and pressures found nowhere else in the universe.

96. During the collapse, complex iron nuclei in the core are broken down into simpler elements, and electrons are forced into protons to form neutrons with the subsequent release of ________________. A shock wave is produced as the imploding material bounces off the core and is lifted by the pressure of the neutrinos passing through the incredible nuclear densities which have been created by the collapse. This whole event takes place in SECONDS/DAYS/YEARS (circle one).

97. The result of this action is a prodigious outburst of energy known as a ________________. During the explosion, elements ________________ than iron are synthesized.

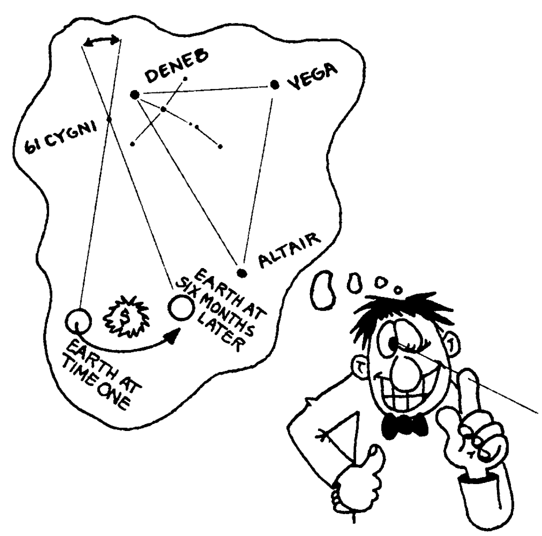
98. What is left after the detonation is a core of nuclear material about 10 miles in diameter known as a ________________ star It is surrounded by an expanding cloud of gas containing the elements that can make other planetary systems, stars, or even, if given enough time, human beings.

99. The event mentioned in the previous statement is termed a TYPE I/TYPE II (circle one) supernova. The spectrum is dominated by ________________ lines because that gas is still very abundant in the star's outer layers.

100. In a TYPE I/TYPE II (circle one) supernova, hydrogen from a ________________ star in a binary system accretes on a white dwarf composed of carbon and oxygen. Eventually, the increase in mass, with its resulting increase in pressure, nearly forces the dwarf to become a neutron star; however, before this can occur, carbon burning is initiated.

101. Because the material of the white dwarf is in a state of d_______________, there is no increase in pressure as carbon burning ensues. Because of this, there is no expansion of the gases as a result of the energy being released. The carbon burning accelerates, eventually producing so much energy that the material in the star can no longer remain in a state of degeneracy. However, by this time it is too late. Now obeying the perfect gas laws, this plasma rapidly ________________, causing the star to blow apart or consume itself in a rapid thermonuclear outburst.

102. Among the billions of galaxies contained within the universe, it is hypothesized that supernovas occur with a frequency approximating one event each _______________. However, very few of these stellar deaths are observed from Earth each year because of intervening dust, distance, and the lack of adequate search patrols to locate these objects.



NOTES

ANSWERS TO SESSION FOURTEEN QUESTIONS

ATOMS

1. atom
2. proton, neutron, electron
3. nucleus
4. electrons
5. positive, negative
6. equal
7. charged (not neutral, ionized), ions
8. plasma, GAS, HOT
9. Energy, ionized

ENERGY

10. electromagnetic
11. gamma rays, X rays, ultraviolet, <u>visible light</u>, infrared, microwaves, radio waves
12. light (186, 000 $^{\text{miles}}/_{\text{second}}$ or 300,000 $^{\text{km}}/_{\text{sec}}$)
13. bullet (photon, quanta, energy packet, ray), wave
14. photon
15. wave
16. wavelength
17. radio waves, microwaves, infrared, visible light, ultraviolet, X rays, gamma rays
18. light, HIGHER
19. frequency
20. HIGH--gamma rays, or X rays, or short ultraviolet
    MEDIUM--long ultraviolet, or visible light, or short infrared
    LOW--long infrared, or microwaves, or radio waves
21. HIGHER, HIGHER
22. eye, ROY G. BIV = red, orange, yellow, green, blue, indigo, violet (This simple mnemonic device gives an approximate feeling for the colors of the visible spectrum.)
23. red, LOWEST, HIGHEST
24. energy, MORE

THE NATURE OF LIGHT AND MATTER

25. black body
26. RED, MORE
27. temperature (to the fourth power)
28. MORE, SHORTER, BLUER
29. infrared, visible, ultraviolet, color
30. temperature, blue, red
31. spectrograph, spectrum
32. 5000, SHORTER
33. HOTTER, temperature (Wien’s law)
34. hydrogen, helium, metals (Remember, this is astrophysical jargon.)

THREE LAWS OF SPECTROSCOPY

35. continuous
36. emission
37. absorption
38. Kirchhoff

THE MESSAGE OF STARLIGHT

39. absorption, temperatures
40. intensity, DOES NOT, classification
41. FARTHER FROM, LESS, LOWER, LESS
42. molecules, metals, hydrogen, helium
43. hot, medium, cool
44. Oh Boy, A Fine Girl/Guy Kissed Me (I know that's sexist. So let me know if you have had a more creative success.) Oh, Becker's Astronomical Field Guide Kills Me (Words of despair from a former PSU student who failed the course)
45. a) Fe X, b) Si III, c) Si IV, d) H I, but normally written as just H
46. HOTTER

THE BRIGHTNESS OF STARS

47. magnitude, Greeks
48. first, sixth
49. LESS, 2.51, 100
50. apparent
51. distance
52. close, luminous (bright), distance, square of its distance
53. QUANTITATIVE, absolute
54. parallaxes, 3.26
55. one parsec
56. 10 parsecs, 32.6
57. absolute
58. Hertzsprung, Russell, absolute, H-R

THE CLASSIFICATION OF STARS: UNDERSTANDING THE H-R DIAGRAM

59. Hertzsprung-Russell
60. absolute magnitude (luminosity)
61. temperature
62. main sequence, hydrogen, helium, lives (existence, time)
63. mass
64. COOL, HOT
65. LOW, HIGH
66. collapse, pressures, long, short
67. structure, LESS, large, red giants
68. small, white dwarfs
69. luminosity, evolutionary
70. shell, helium
71. cores, electrons, degenerate

72. average, hot, luminous, LARGER, mass, SHORT
73. pressures, temperatures, long
74. 0.08 ($^{8}/_{100}$), 60 (A star of 150 solar masses has been discovered)
75. evolutionary

STELLAR BIRTH

76. contract, FASTER
77. luminous, huge, downward, left
78. decreases, convection, dust
79. radiative, hydrogen (thermonuclear)
80. left, temperatures, blue supergiants
81. main sequence, zero, mass
82. hydrogen, helium

STELLAR DEATH

83. helium
84. INCREASE, ACCELERATING, MORE
85. shell, INCREASE
86. DECREASE, luminosity, red giant
87. helium, helium flash, triple-alpha
88. COOLS, horizontal
89. WARMER, SMALLER
90. carbon, shell, super
91. planetary, white dwarf, black dwarf
92. elements (metals or atoms), iron
93. shells (layers), SHORTER
94. exothermic, endothermic
95. collapses
96. neutrinos, SECONDS
97. supernova, heavier
98. neutron (Rapidly rotating neutron stars are called pulsars.)
99. TYPE II, hydrogen
100. TYPE I, red giant
101. degeneracy, expands
102. second

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