UNIT 4

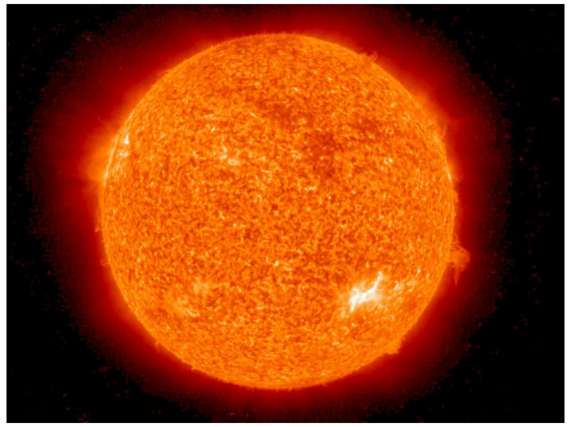
The Sun and Stars

4.1 Energy formation and layers of the Sun

4.2 - Spectral Class & Spectral Analysis

4.3 - Life Cycle & HR Diagram

All about Sol Assignment



Introduction:
The Sun is the star at the center of the Solar System. It is almost perfectly spherical and consists of hot plasma interwoven with magnetic fields. Its diameter of 1,392,000 km, makes it more than 100 times wider than that of Earth and its mass is 330,000 times that of Earth. The Sun accounts for about 99.86% of the total mass of the Solar System! The size of the Sun dwarfs all of the planets combined.

If we were to create a model of the Solar system in which the Earth was the size of a baseball, the Sun would be larger than the entire gymnasium! Our Sun looks relatively small in the sky only because we average more than 93,000,000 miles from it. Our Sun is just one of trillions in space. Compared to other stars, the Sun is an average sized star, categorized as a yellow dwarf.

Question: So why do we study the sun?

Background: *(write a few things that you already know pertaining to about the question above)*

Vocabulary:
Magnetic field-
Nuclear fusion-
Nuclear fission-
Neutrino-
Photon-
Core-
Radiation zone-
Convection zone-
Photosphere-
Chromosphere-
Corona-
Solar wind-
Granulation-
Sunspot-
Solar Prominence-
Solar flare-
Coronal Mass Ejection-

Materials: This reading

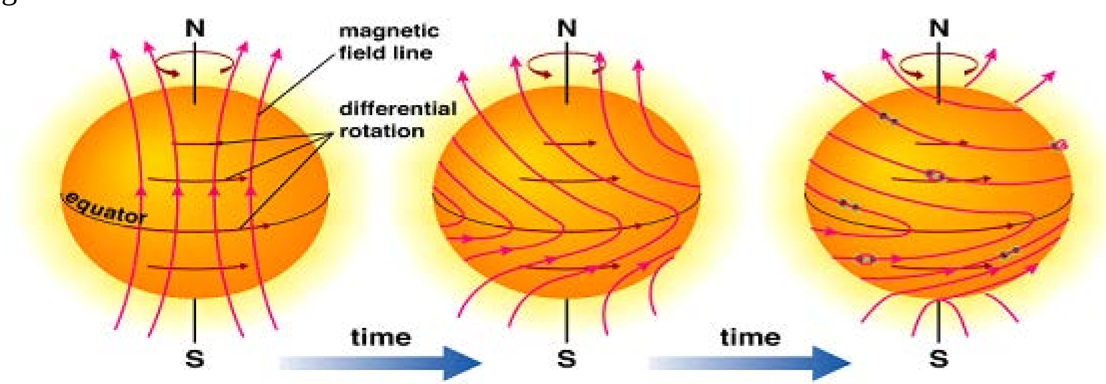
Procedure:
Read through the following passage.

The Sun

The Sun is the star closest to Earth. It provides the heat, light, and energy for all life. Ancient people worshipped the Sun as a life-giving god. Some of the names given to the Sun god were Aton, Apollo, Helios, and Sol. The Sun is very important to earth – without its heat and light, we would not be able to survive. Its gravity keeps us and the other planets in orbit, it gives us our seasons, and it provides Earth with almost all of its energy! Changes in solar activity or surface features effect our climate, atmosphere, weather & even electrical power transmissions.

As we learned earlier, the Sun is located on one of the arms of our Milky Way Galaxy. Relative to Earth, the Sun is "relatively" stationary, at the center of our Solar System. It does rotate around itself but because it is in the plasmatic state, it does not rotate quite like solid objects such as the Earth or Moon. The center latitudes of the Sun take 25 days to rotate, while areas near the poles take 35 days to rotate.

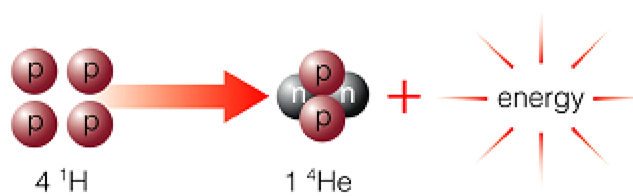
This asynchronous rotation causes the sun to have incredibly large and strong magnetic fields. These magnetic fields cause most of the activity and features on the sun that we will learn about later. At any given time, the Sun can have more than 10,000 magnetic poles (as opposed to Earth's meager 2)! Similarly, because of the uneven rotation of the sun, every 11 years the suns magnetic field flips. This means the solar cycle is 22 years, because it takes that long for the magnetic field to flip-flop back to where it began!



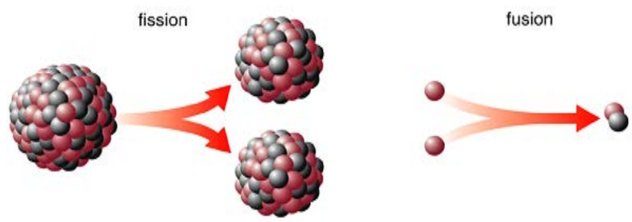
Energy Formation

The Sun is made of 73% Hydrogen, 25% Helium and 2 % other elements. Those other elements consist of 70 different elements.

Energy for the sun is produced in the core of the sun through a process called nuclear fusion. Under the extreme heat and pressure located at the core of the Sun, four hydrogen atoms fuse together to form a helium atom. Also given off in nuclear fusion are neutrinos which have a mass but no charge and photons which you would know as photons of electromagnetic energy (gamma rays, x-rays, visible light, radio waves, etc).



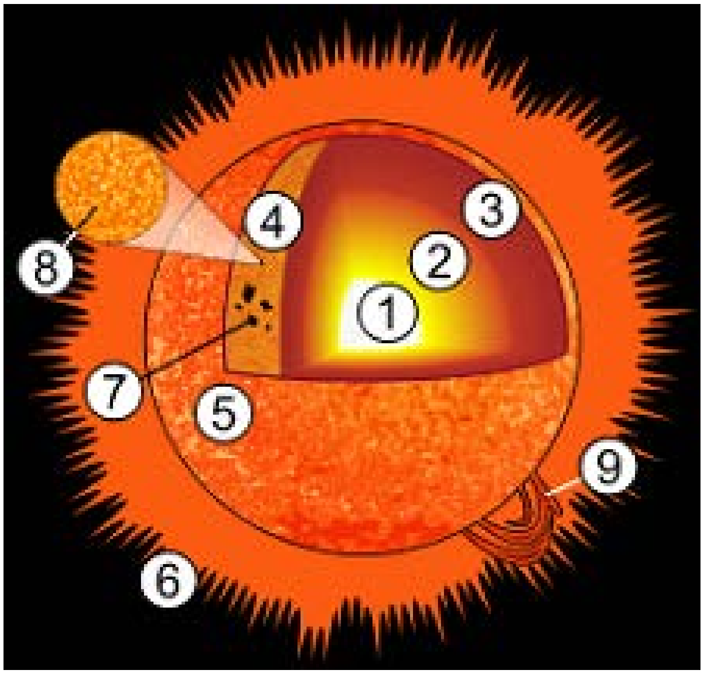
It is important to keep in mind that this process requires such extreme heat and pressure that it cannot be duplicated here on Earth. Nuclear power plants and nuclear bombs here on Earth use nuclear fission or the breaking apart of atoms to give off energy.



Layers of the Sun

Much like the Earth and Moon have layers, the Sun also has layers. In total, the sun is made of six layers: 3 inner layers and 3 outer.

The inner 3 layers are part of the sun's *interior*



1. Core – Where photons of energy are produced through nuclear fusion. Has temperatures of 15,000,000°C and pressures 200,000,000,000 times greater than that which we exist!

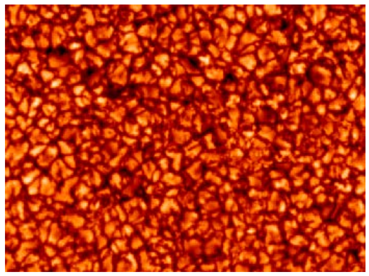
2. Radiation Zone - Where photons of energy are absorbed and readmitted after being produced in the core (this process takes an average of 20,000,000 years!)

3. Convection Zone - Where photons of energy are circulated (in convection currents) to the atmosphere of the sun

The outer 3 layers are part of the sun's *atmosphere*

4. Photosphere - Is the visible layer of the sun. The entire photosphere of the sun is covered in a grainy, rice-like appearance called granulation. This is a result of circulating currents under the photosphere in the convection zone.

Every photon of energy takes a different amount of time to reach the photosphere from the core. On average it takes 20 million years for energy produced in the core to make it all the way to the photosphere of the sun. Once it hits the photosphere, those photons of energy travel at the speed of light and they reach the earth in about 8.5 minutes!



granulation on the Sun's surface

5. <u>Chromosphere – </u>Transparent layer that extends 10,000Km into space. The temperature increases dramatically as photons pass through the chromosphere

6. <u>Corona – </u>from the Latin word for crown, is the outer most layer of sun's atmosphere. It is full of Hot and very tenuous gases.

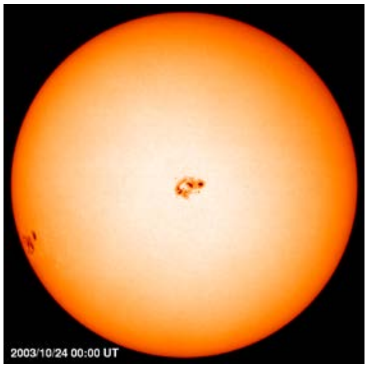
corona visible during a total solar eclipse.

Surface Features of the Sun

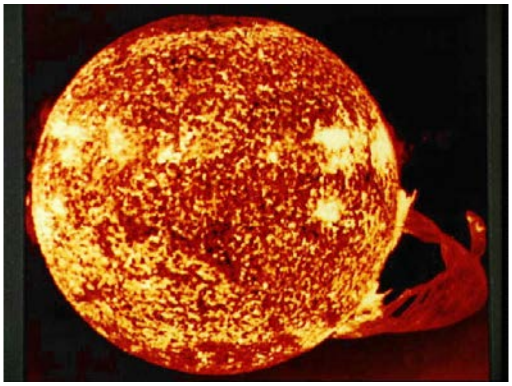
There is a constant flow of photons (energy and radiation) coming off the sun. This is called the Solar Wind. The solar wind travels throughout the solar system and usually does not reach the surface of earth because our atmosphere protects us from too much radiation. It does constantly reshape our magnetosphere, which is the part of earth's magnetic field that is confined by the solar wind.

Another feature of the Sun are dark, coolers areas on the sun's surface called sunspots. Sunspots are cooler than their surroundings, but still about 4,480°C. Sometimes, the interaction of the Sun's magnetic field with the magnetic field of a sunspot causes a small explosion off the sun's surface. It is through these sunspots that the Sun can shoot tremendous amounts of electromagnetic energy in the form of photons from its surface.

The number of sunspots goes through a cycle - sometimes the sun has lots of sunspots, sometimes the sun has very few. This sunspot cycle reaches a maximum, then falls to a minimum and then climbs back to a maximum again! It takes about 11 years to go through this cycle.



Sunspots

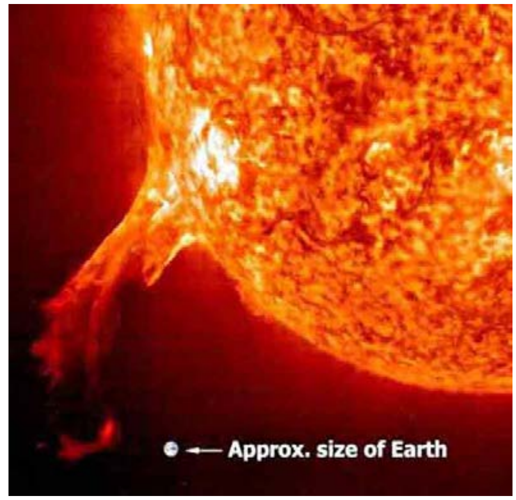


Solar prominence

If the ejecta that is shot out through a sunspot is not traveling fast enough, it loops back around forming a fiery arch that rises off the Sun's surface called a solar prominence. Solar Prominences typically form and last for about a day, however, very stable prominences may last a few months. Sometimes, the interaction of the sun's magnetic field with the magnetic field of a sunspot causes a sudden, tremendous, explosive outburst of light, invisible radiation and material from the sun called a solar flare. This only happens if the ejecta is traveling fast enough to escape the sun's gravitational pull. Solar Flares usually only last a few minutes, but can sometimes last a few hours.

An increase in the amount of sunspots (at sunspot maximums) generally means an increase in Solar Prominences and Solar Flares. It is important for us to follow the Sunspot cycle to know when there is going to be an increase in Sunspots, because they cause Solar Flares and Prominences.

Although the Earth's magnetic field can deflect or pull in much of the energy that is carried in a solar flare, during a coronal mass ejection, large amounts of radiation hit the Earth in what is known as a geomagnetic storm. Geomagnetic storms can knock out satellites, cause havoc with radio signals, cause compasses to point in the wrong direction, and even cause a surge down electrical lines (which absorb the energy much like an antennae would) causing blackouts. As this light is pulled in near the North and South Magnetic Poles, it causes the air in the upper atmosphere to glow much like a florescent tube or neon sign would. In the Northern Hemisphere we call this phenomenon the Northern Lights or Aurora Borealis. In the Southern Hemisphere, we call it the Southern Light or Aurora Australis.

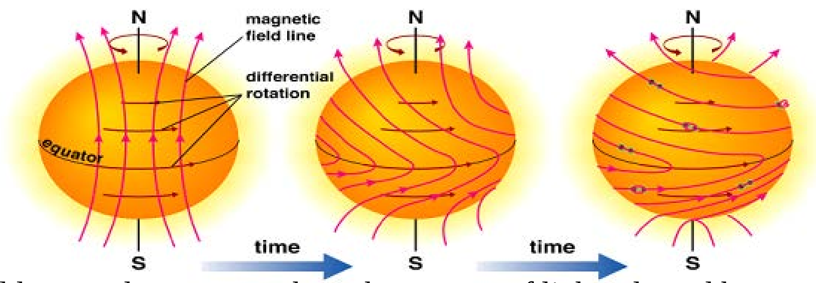


Solar flare

Analysis:
Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. How large is the Sun compared to Earth?
2. Other than the Sun, what is our "other" source of energy (don't think combustion or gravity)?
3. What causes the Sun's magnetic fields?
4. What is the product of nuclear fusion?
5. Draw a Venn diagram comparing and contrasting neutrinos and photons?
6. Draw a Venn Diagram comparing and contrasting fusion and fission.
7. List the interior layers of the Sun and briefly describe what occurs in each layer.
8. List the three atmosphere layers of the Sun and briefly describe what occurs in each layer.
9. What is the solar wind and how is Earth protected from it?
10. What are sunspots and what causes them?
11. What are prominences and what causes them?
12. What are solar flares and what causes them?
13. How do coronal mass ejections cause geomagnetic storms?
14. What are the potential negative effects of a geomagnetic storm?
15. How does the aurora occur?
16. What would you still like to know about our Sun?

Sunspots Graphing Assignment
Introduction:
Sunspots are cooler areas on the Sun that appear as dark spots. These spots are still incredibly bright (one spot can be brighter than entire Moon) but appear dark in comparison to the rest of the bright surface of the Sun. When the Sun rotates, it does not rotate like the Earth or the Moon. The polar regions of the Sun rotate slower than the equatorial regions. This asynchronous rotation causes the sun to have incredibly large and strong magnetic fields. At any given time, the Sun can have more than 10,000 magnetic poles as opposed to Earth's meager 2!



These magnetic fields cause large areas where the amount of light released becomes much less. These areas are called sunspots. Through these spots the sun can eject tremendous amounts of neutrinos, photons, and matter in events called solar flares. Extremely large solar flares known as coronal mass ejections can shoot millions of tons of mass and trillions of joules of energy out into space knocking out satellites and disrupting electrical grids.

Because of the uneven rotation of the sun, every 11 years the suns magnetic field flips. This means the solar cycle is 22 years, because it takes that long for the magnetic field to flip-flop back to where it began. The sunspots tend to occur in cycles that start at the solar minimum (when the fewest spots occur), reach their solar maximum (when the most spots occur) and reduce again in number until the cycle begins again. Recent research shows a correlation between sunspot cycle trends and climate change. Can these spots and their cycles tell us anything? Do this activity to find out.

Question: What can we get from observing the sunspot cycle?

Background: *(write a few things that you already know pertaining to about the question above)*

Vocabulary:
Solar maximum-

Solar minimum-

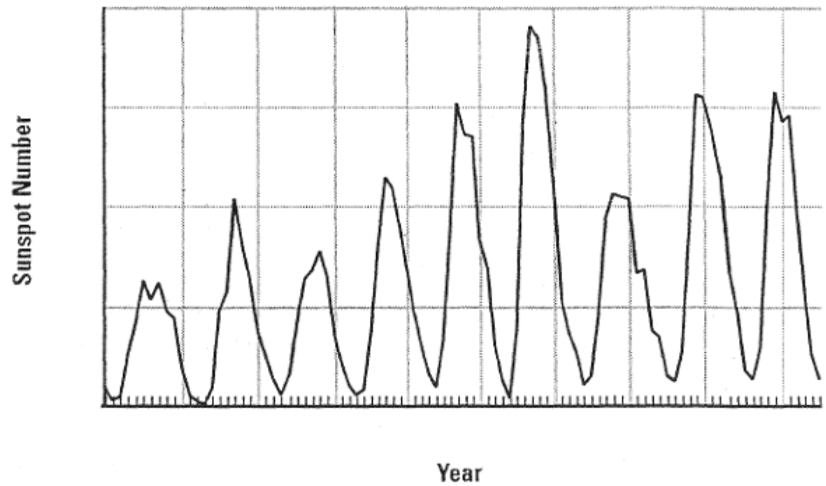
Sunspot cycle-

Materials: This handout

Procedure:
Read through the following passage and answer the questions that follow.

Part I –Sunspot cycles

Sunspot cycles 1900-1995



1. Label the graph with an x for each solar maximum and an m for each solar minimum.

2. What trends do you notice? What are the similarities and differences between cycles?

3. From the graph, estimate the year when each cycle started and when it ended. Calculate the length of each cycle and the average length for the nine cycles shown.

Year of Max									
Year of Min									
Length of cycle									X

4. Scientists think the sunspot minimums are also on an 11-year cycle. Does your data support this theory? Why/why not?

Part II – Within a sunspot cycle

5. Graph the data from Solar Cycle 23 below on the graph that follows.

Solar Cycle 23

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	24.2	29.9	31.1	14.0	14.5	15.6	14.5	14.3	11.8	21.1	9.0	10.0
1996	11.5	4.4	9.2	4.8	5.5	11.8	8.8	14.4	1.6	0.9	17.9	13.3
1997	5.7	7.6	8.7	15.5	18.5	12.7	10.4	24.4	51.3	22.8	39.0	41.2
1998	31.9	40.3	54.8	53.4	56.3	70.7	66.6	92.2	92.9	55.5	74.0	81.9
1999	62.0	66.3	68.8	63.7	106.4	137.7	113.5	93.7	71.5	116.7	133.2	84.6
2000	90.1	112.9	138.5	125.5	121.6	124.9	170.1	130.5	109.7	99.4	106.8	104.4
2001	95.6	80.6	113.5	107.7	96.6	134.0	81.8	106.4	150.7	125.5	106.5	132.2
2002*	114.1	107.4	98.4	120.4	120.8	88.5	88.2	85.7	83.2	80.7	78.1	75.6
2003*	73.0	70.5	67.9	65.4	62.9	60.4	58.0	55.6	53.2	50.9	48.6	46.4

*Years 2002–2003 contain estimated and predicted values.

Source: National Geophysical Data Center/Solar Terrestrial Physics at: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/

6. When did Solar Cycle 23 begin?

7. Did Solar Cycle 23 reach its solar maximum or minimum? If so, when did this occur?

8. Based on the average you calculated for the other solar cycles, when do you predict this cycle will end?

9. Can you predict when the next solar maximum might occur? Explain your prediction.

Part III – Historic sunspot cycles

Use the information about sunspot activity to answer the questions.

Year	Number of observed sunspots	Year	Number of observed sunspots
1728	135	1766	20
1732	7	1770	130
1739	125	1775	5
1743	6	1778	165
1750	90	1784	18
1756	15	1788	140
1761	80	1797	6

10. List all the entries that include at least 80 sunspots. These are the years of sunspot maximum.

11. List all the entries that include less than 20 sunspots. These are the years of sunspot minimum.

12. From the data chart of 18th centruy sunspots, estimate the year when each cycle started and when it ended. Calculate the length of each cycle and the average length for the nine cycles shown.

Year of Max							
Year of Min							
Length of cycle							X

13. Do sunspot maximums always occur every 11 years? If not, is there a general pattern?

14. If the last sunspot maximum was in 1990, when will the next two maximums most likely occur?

The Universe: Secrets of the Sun  *(This video can also be watched on Netflix Streaming)*

Answer the following questions on a separate sheet of paper. You do not need to answer them in complete sentences. Questions are spaced out with enough time for you to answer each (1-3 minutes apart).

1. How far away is Earth from the sun?

2. What type of star is our sun?

3. How many other stars are there in our solar system?

4. When did scientists discover nuclear fusion?

5. Due to the tremendous amount of heat, the sun's core is not a solid, but a:

6. What are the particles of light and heat that carry energy out of the sun called?

7. How long does it take for a photon to travel from the sun to our planet?

8. What is the massive explosion that spawned our sun called?

9. What drives all outbursts of solar violence?

10. What are the dark blemishes on the sun's surface called?

11. What are the most colossal explosions in the solar system?

12. When was there a sunquake that would've measured 11.3 on the Richter scale?

13. When waves of plasma rocket out from a flare, it's like what phenomenon on Earth?

14. Coronal Mass Ejections (the most dangerous threat you've never heard of) are also known as:

15. The NOAA is home to what organization?

16. Why doesn't Mars have an atmosphere?

17. Energy from solar storms has easy access to what regions?

18. What causes the Auroras?

19. When was the "perfect solar storm"?

20. What is the length of the sun spot cycle?

21. What do scientists call the spike in solar activity associated with the sun spot cycle?

22. When is the next solar maximum?

23. What is the sun's outer atmosphere called?

24. When can you see the corona from Earth?

25. How often do we get a total eclipse?

26. If you stayed in one place on Earth, how often would a solar eclipse occur?

27. When will the Sun die?

28. What will the Sun expand to?

29. What will happen to Earth's orbit?

30. About what size will the Sun be once it has cast off its outer shell?

Photon Radiation Rates Lab

Introduction:
When looking up at night, we are often met with thousands of distant stars shining in the surrounding blackness of space. The light we see travels at a rate called the "speed of light." This speed varies depending on what light is traveling through but in the vacuum of space, it travels as 300,000 km per (186,000 miles) per second. Light is very fast, but space is really, really big and the speed of light is finite.

Technology has not advanced far enough for us to travel even close to the speed of light. Nor has anything been identified that can travel at this speed other than the photons of light energy. Though it is easy to believe that the light from stars reaches us "instantaneously," like that of a light bulb being turned on, it is only with very distant luminescent objects that we can notice that light takes time to travel. The more distant the star, the longer it will take the light to reach Earth. For most stars, light travels years, if not decades or even centuries before it has covered the vast distances to reach us on Earth. In comparison, it takes only eight minutes for the light to travel through the vacuum of space from Sol to reach the Earth.

Stars are made primarily of hydrogen and helium with trace amounts of other elements. The gravity and heat of the sun cause all of those atoms to be very hot, so hot they are continuously in the plasma phase. Atoms in the plasma are also known as ions and they behave differently that those that are liquids, solids, or gases.

Fusion occurs at a star's core producing photons, neutrinos, heat energy, and heavier elements. All materials formed in the core either convect or radiate outward until they are far enough away from the core to escape the inward pull of the sun’s gravity and magnetic pull. Photons do not take a straight-line path out of the star. However, as they move outward, they collide with existing plasma and are absorbed. This creates extra energy in the plasma and that extra energy must be given off again. When it is, the photon is re-radiated in a totally different and random direction. A single photon may be a absorbed and readmitted (given off) trillions of times on this journey outward. Because of this, photons may take hundreds of thousands or even millions of years to eventually reach the photosphere of the star. Once they reach the photosphere they zip away from the sun, through the vacuum of space, at 300,000 km/sec!

Question: Why do photons take so long to get out of the Sun?

Background: (write a few things that you already know pertaining to about the question above)

Vocabulary:
Luminescent
Photon
Ions

Materials:
2 Dice

Procedure:
Read through the following passage and label the appropriate items as you continue.

1. Label the Average Size Star Diagram (Figure 4a) with the following terms in the appropriate locations; Core, Photosphere, Plasma

2. Roll both dice, and tally (add up) their values.
3. Enter this value on a handwritten table on a separate piece of paper (it should resemble Figure 1). This value will correspond to a direction on the Stellar Profile Diagram (Figure 2) that the Photon A has moved in its path out of the star.
4. Determine which direction (of the six possible choices) a line can be drawn on the Stellar Profile Diagram (see Figure 2).
5. Place your pencil on the center dot (circled) on the Average-sized Diagram (Figure 4a). Draw a line to the closest dot in the direction you determined based upon the roll of your die. Example: If the tally of your two dice was "2," then starting with the center circle, draw a line to the dot in the upper right section of the nearest circle of dots. (See Figure 3.) All even values will be used for movement in this activity, however, if the tally creates an odd value, still count it as a "throw" and record the information in the chart (See Figure 1).
6. Repeat steps 2-5 until you are able to draw your line outside of the outer ring of dots.
7. **Repeat steps 2-6 for four more photons (four more times). Color each path in a different color pencil.**
8. Enter the total number of throws from your tables onto Figure 5.
9. Average the total number of throws your five photons required to escape this "averaged" size star.
10. The number of layers in your star = (average number of throws)
11. Once you have completed the photon path for the averaged-sized star, do one photon path for the dwarf star.
12. Once you have completed the photon path for the dwarf-sized star, do one photon path for the giant star.

Throw No.	Dice Tally
1	2
2	**11**
3	10
4	6

Figure 1. How to use the dice to determine the path of your photon.

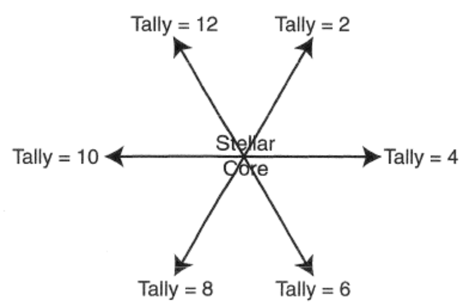


Figure 2. How to draw the path of your photon on the star diagram.

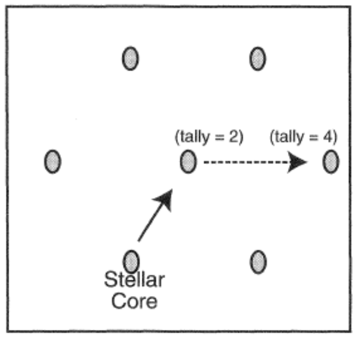


Figure 3. How to continue the path of your photon after it leaves the core of the star.

Example/ Your group first rolled a tallied score of 2. Your photon left your stellar core and moved to the dot to the upper right of the (tally = 2) starting position. Your group then rolled a tallied score of 4 (tally = 4). From the last position of the photon, it will now move to another dot in the direction of a "4". Remember, a photon can return to a dot it has already visited. Be certain to show this with arrows.

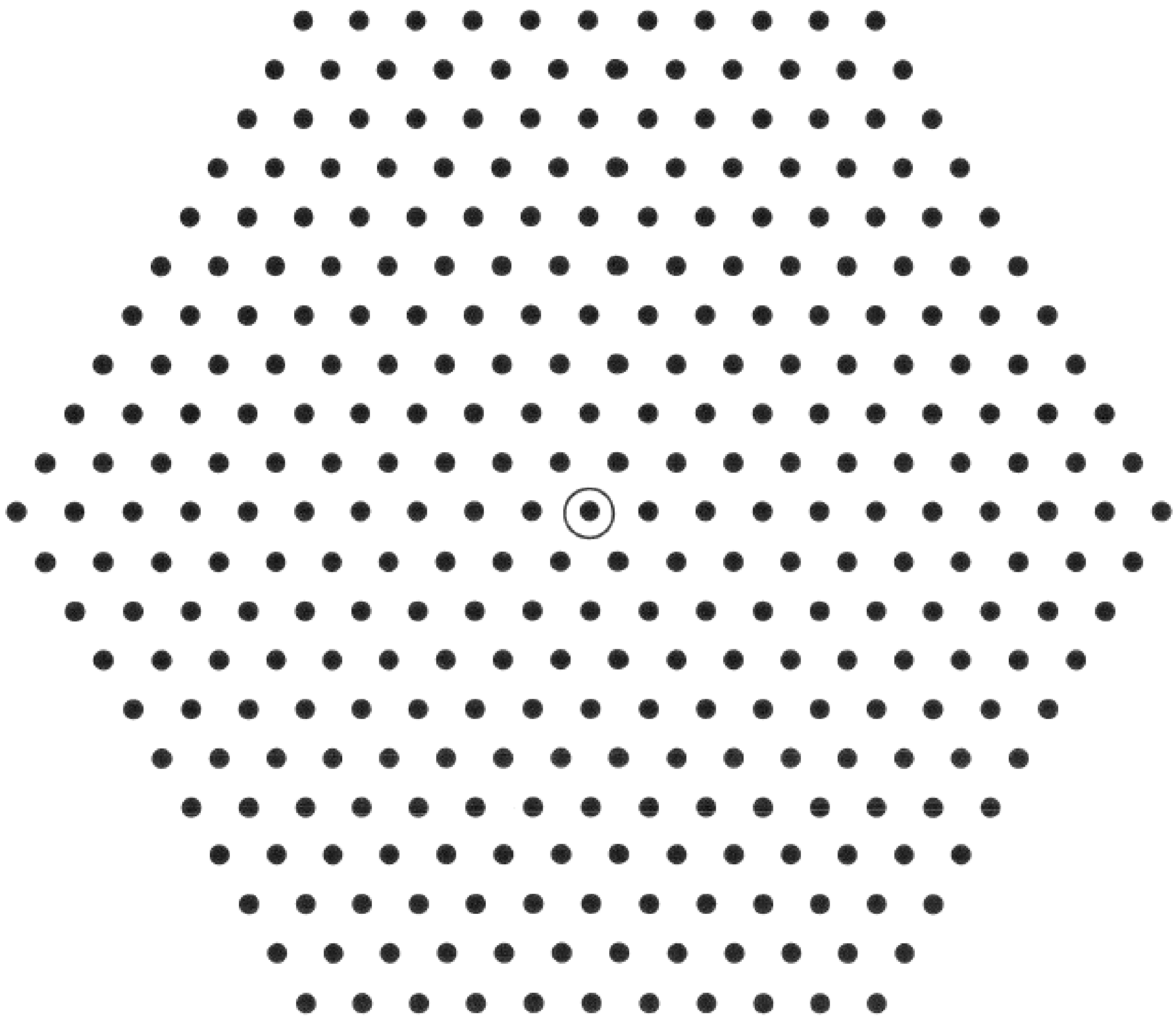


Figure 4a. Average Size Star Diagram

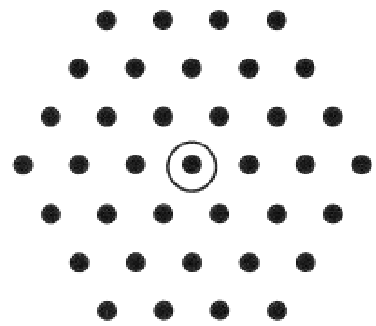


Figure 4b. Dwarf Size Star Diagram

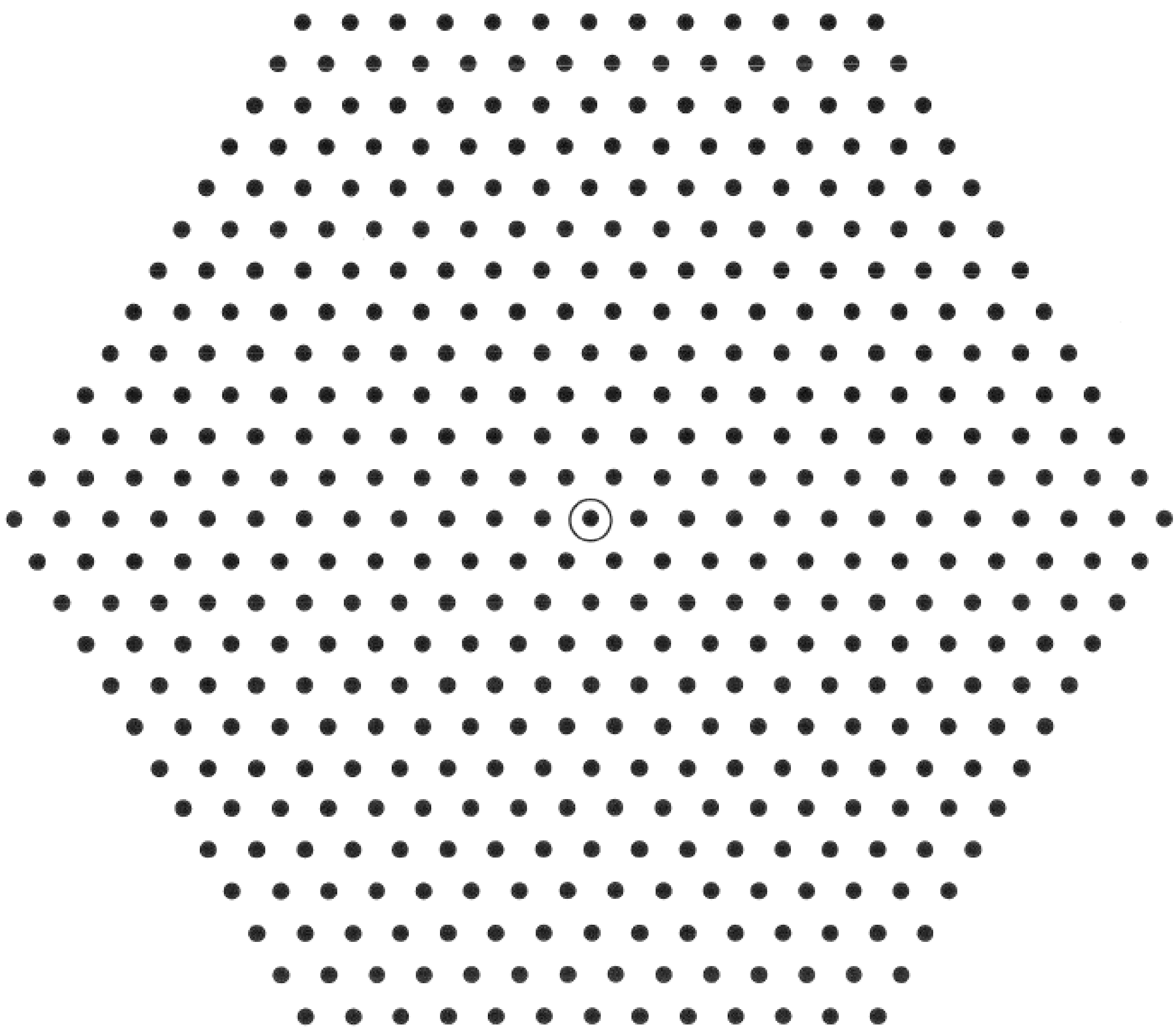


Figure 4c. Giant Size

This diagram represents the ionized atoms (dots) in a star. There are a particular number of layers of this plasma, and the number of layers represents the size of the star.

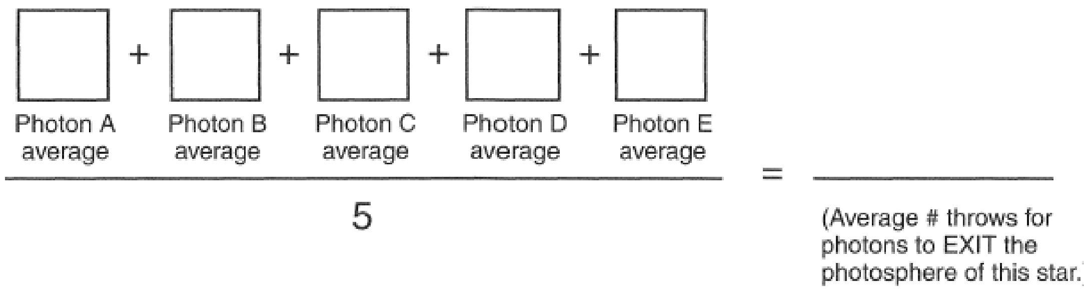


Figure 5. Averaging the total number of throws from all groups. Each group's data represents the random path of one photon in the star.

Analysis:

Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. How fast does light travel?
2. If you traveled in a car at 62 miles per hour, how long would it take to drive the distance that light travels in one second?
3. If the speed of light is so fast, why does it take light so long for light from other stars to reach us?
4. Why do photons in the core of the sun take so long to reach the photosphere?
5. Why do you think the photons of light travel so quickly once they make it to the photosphere?
6. Describe the path that photons of light take to get out of the sun.
7. How can the diagram be changed to represent smaller stars?
8. How can the diagram be changed to represent larger stars?
9. Why can't humans travel to the nearest star from our Solar System?
10. The closest star to Earth is Proxima Centauri in the constellation Centaurus and is 4.24 light years away. How many kilometers away is Proxima Centauri? (Note – it is a very large number)!
11. The fastest space sprobe ever created traveled 72 km/sec. How many years would it take for a space probe to travel to Proxima Centauri if it traveled at that speed?
12. In Avatar, humans travel to the planet Pandora in 6 months. If Pandora were a planet of Proxima Centauri, how fast would we have to travel to get there in that amount of time?

Star Spectrometer Activity

Introduction:
How do we study stars? How do we know the things we know about them? We can't travel near them, but yet we still know about stars that are located in other galaxies? How does this work?????

All stars give off electromagnetic waves including visible light. Visible light is rarely a perfect mix of all of the colors of the spectrum and by measuring what wavelengths are missing from a spectrum, astronomers can tell a lot about a star's chemical make-up as well as other properties such as temperature, age, and even whether or not the star is moving towards or away from us!

Astronomers use a device known as a spectrometer to break down visible light into its spectrum and measure
spectra, or different properties of light waves. A spectroscope is a spectrometer equipped with scales for measuring wavelengths or indexes of refraction.

Sometimes scientists see spectral lines that do not fit the usual pattern. The lines might shifted from their usual positions. This may suggest that the star is moving either toward the observer (shift toward the blue) or away from the observer (shift toward the red).

Question: How do we know so much about stars if we haven't been there?

Background: (write a few things that you already know pertaining to about the question above)

Vocabulary:
Spectroscope
Spectrometer

Materials:
Incandescent Light
Fluorescent Light
Natural Light
Element lamp tubes

Procedure:
You are going to do this 3 times, aimed at:

1. Hold the viewing end (not the end with the slit) to your eye and aim the opposite end at the light source. When we view the sun DO NOT aim it directly at the sun, just aim it toward the sky (NOT AT THE SUN)!!!!

2. Adjust the spectroscope (rotate it) until the spectrum appears on the side walls of the tube. Once the spectrum is on the side, turn the slit portion until the widest band is achieved.

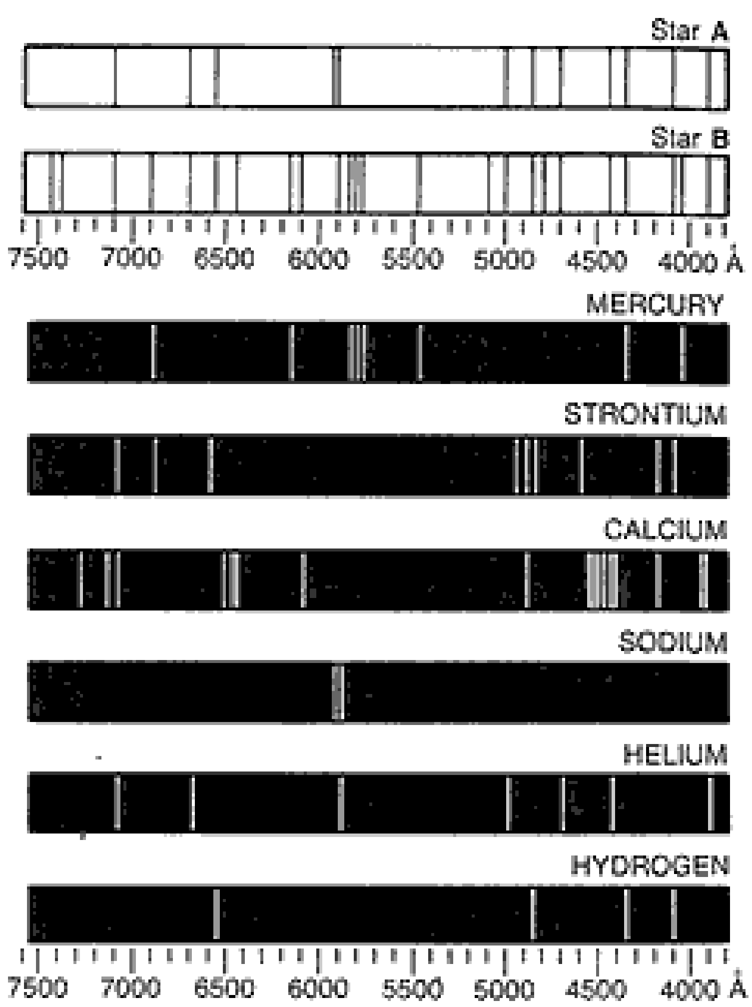
3. If available, do the same with the light samples provided to you via the element lamp tubes.

Analysis:

Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. When viewing the incandescent bulb, what did you see? Draw it using colored pencils.
   *the technical name for this is the continuous spectrum
2. In the continuous spectrum, what is the order of the colors from shortest wavelength to longest wavelength.
3. When viewing the florescent light, what did you see? Draw it with colored pencils.
4. When viewing the natural light, what did you see? Draw it with colored pencils.
5. How is the spectrum of the incandescent light different the spectrum from the florescent light? Are there any brighter or darker spots on the florescent, than there were on the incandescent?
6. What colors were missing when looking at the natural light? Using this information, what wavelengths were missing?
7. Use the Spectral Analysis of Elements in the chart below to answer this question.
   You observe a star with bright lines at 4100, 4350, 4850 and 6550. What element would you assume that star has in it?

Below is the Spectral Analysis of 2 stars, Star A & Star B. Below that, you can find the spectral analysis of the elements Mercury, Strontium, Calcium, Sodium, Helium and Hydrogen.



8. What wavelengths are found in the hydrogen spectrum?
9. Does Hydrogen occur in Star A?
10. Does Hydrogen occur in Star B?
11. What is in the atmospheric composition of Star A?
12. What is in the atmosphere composition of Star B?
13. Which element(s) do not occur in the atmosphere of either star?

If the element tube lamps are available…

14. When you hear someone say that neon lights look beautiful, what color comes to mind? What color is suggested by the "fingerprints" of neon?

Spectrometry lab

Introduction:
The light of celestial objects contains much information hidden in its detailed color structure. In this lab we will separate the light from some sources into constituent colors and use spectrometry to find out which chemicals are present. The same procedure is used for starlight, telling us what its source is composed of. The baseline is a laboratory experiment with known materials, and later we can compare the unknown to what we already know.

Hot, glowing bodies like a light bulb or the Sun, glow in all the colors of the spectrum. All these colors together appear as white light. When such white light hits a prism, or a raindrop, or a diffraction grating, colors get separated according to their wavelength. Red, with its wavelength of 600 nm to 700 nm, is deflected least and ends up on one edge of the spectrum – or the rainbow when sunlight hits a raindrop after a storm. Blue, wavelength around *400 nm*, is the other end of the visible spectrum. An infinite number of colors are located between these two edges, each corresponding to its own wavelength.

An incandescent light bulb radiates a continuous spectrum. All colors are present in this “thermal glow,” and it is impossible to tell what the chemical composition of the source is. However, other physical processes produce different spectra. A fluorescent light tube works, crudely speaking, on the principle of lightening. Electrons rush from the negative pole to the positive pole inside, and hit gas atoms in the tube, making them emit light. This sort of light contains only a few colors, and is called “emission spectrum”. When we separate the colors of such light, only a few bright “emission” lines appear, each in its own color (and wavelength).

Each sort of an atom will emit light at its own particular set of wavelengths. When we analyze the emission spectrum of an unknown source, we can compare the colors of its spectral lines to known spectral lines we see in a laboratory, and tell which substance matches.

Challenge: How do we use the spectrometry of a substance to determine what elements are present?

Background: (write what you already know about the challenge question)

Vocabulary:
Spectrometry
Bunsen burner
Wire loop
Spectrum
Spectroscope
Spectrogram

Materials:

Spectroscope	colored pencils	strontium chloride
Wire loop	potassium chloride	calcium chloride
Butane burner	sodium chloride	lithium chloride

Procedure:

*Examine your spectroscope and identify its parts***:**

1. Find the opening where light enters. Find the grating and find out how to turn it around. Find out how to aim the spectroscope at a light source.
2. Look into the spectroscope. You'll need to use your glasses or contacts (if any) to see the scales clearly. You will use the wavelength scale (the one that goes from 400 nm to 700 nm) to read off the wavelength of spectral lines.
3. Hold the spectroscope in your hands and aim at a fluorescent light. You'll see the input slit light up on the right or left side. The spectral lines you see should be exactly vertical. If the grating is positioned at the wrong angle, you may not see any spectrum at all.

How to Do the Flame Test

1. First, you need put on your safety goggles.
2. Second, you will need to clean your wire loop. They may be cleaned by dipping in hydrochloric or nitric acid, followed by rinsing with distilled or deionized water.
3. Make sure your hair and sleeves and tied up and secured with hair ties, clips, or rubber bands.
4. Test the cleanliness of the loop by inserting it into a gas flame. If a burst of color is produced, the loop is not sufficiently clean. The loop **must** be cleaned between tests.
5. Dip the clean loop into powder or solution of an ionic (metal) salt.
6. While one person is putting the powder onto the loop, their partner should ignite the butane burner as demonstrated by the teacher.
7. Place the loop into the solution using care not to touch the loop against any part of the burner. The lab partners are to use their spectroscopes to view the spectrum.
8. Record the substance name and draw the spectrum on the lab sheet using colored pencils.
9. Repeat steps 1 through 6 for the remaining substances.

Analysis:

Answer these questions in complete sentences on a separate piece of paper.

1. Why did each of the different substances give off different wavelengths of light?
2. Which substance emitted primarily red and orange wavelengths of light?
3. Why was it important to use a clean the loop in between tests? What do you think would have happened if you did not clean the loop?
4. If someone were to burn a large amount of one of the substances used in this lab on the moon, would you be able to tell that what chemical it was from here on Earth? Explain your answer. (Why/ why not?)
5. Would you be able to determine the identity of an unknown substance by burning it in the manner we did in this lab? Explain your answer. (Why/ why not?)
6. How might you be able to do this experiment on a substance, such as iron, that has a very high melting temperature?
7. How do we use the spectrometry of a substance to determine what elements are present?

Apparent and Absolute Magnitudes Lab

Introduction:
The apparent magnitude of a star, or how much light is received on Earth, can be confusing to an astronomer trying to measure the distance a star is from Earth. Apparent magnitude is much different from the absolute magnitude, which is the true measure of how much light the star emits. These two variables control the brightness of the stars we see in our night sky. The absolute magnitude is not the same for every star. It is determined by the amount of light it gives off. The second variable is the amount of light received on Earth. The mixing of these two variables can lead to misunderstanding about the size and distance of a star. That is why it is important to understand the characteristics of stars and light to be able to correctly determine what we see in the night sky.

Question: How do the apparent magnitude and absolute magnitudes of a star differ?

Background: *(write a few things that you already know pertaining to about the question above)*

Vocabulary:
Apparent magnitude
Absolute magnitude

Materials:

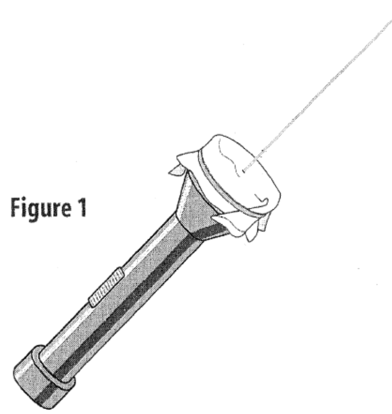
construction paper	small flashlight	scissors	nail
rubber bands	meter stick	tape	dry erase marker

Part I: How light disperses
Procedure:
Read through the following directions and complete the lab as described.

1. Use your scissors to cut a piece of black construction paper large enough to comfortably cover the light end of the flashlight.

2. Cover the end of the flashlight with the paper and secure it in place with a rubber band. Take the sharp end of the nail and carefully poke a single hole in the center of the paper covering. The smaller the hole the better.

Figure 1



3. Find a wall or hard surface on which you can tape a background of construction paper. An area about one meter square would be best for the experiment. An alternate choice would be to use the white-board in the classroom. If you do use a wall, write only with the appropriate materials, such as chalk or erasable marker.

4. At a distance of 2 meters from the wall, mark a spot with tape on the ground. Then mark the next interval at 1 meters. The last mark is at 0.5 meters.

5. Draw the table on the following page on your sheet.

6. Darken the room as much as possible. Stand at the 2 meter mark and turn on the flashlight. The other students will mark the edges of the diameter of the circle of light made by the flashlight with pencil or dry erase markers. Be sure to notice the intensity of the inner and outer regions of the circle of light. You will record this in the data table provided.

7. Repeat this procedure at the closer interval. Then repeat one more time at the closest interval. Look at the intensity of the light instead. When is it most intense and where is it very diffuse? Record these observations in your table.

8. Observe the behavior of light at different intervals. Try to account for what you observe by what you know. For instance, you know the amount of light exiting the flashlight has not changed at all during the experiment.

Diameter of Light Circle (cm)			Observations about Intensity of Light (cm)
Trial 1	Trial 2	Trial 3	

Analysis:

Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. According to your experiment, your circle of light changed in size as you got closer to the wall. The intensity, or brightness, also changed. How would you account for this? Write your hypothesis in the space below.

2. The circle of light produced by your flashlight on the wall was larger when you were farther away from the wall. Was the light more or less intense? How do you account for this?

3. The circle of light got smaller as you approached the wall. Was the light more or less intense? How do you account for this?

4. As a result of your experiment, would you expect a star to appear brighter when closer to or farther from the Earth? Why so?

5. If you used a bigger and brighter flashlight and repeated the same experiment, what would you expect your results to be like? Explain your answer.

6. Suppose you were going to perform the experiment with two students: One holds a weak flashlight; the other a strong flashlight. How would you place the students so that the circles of light on the wall were exactly the same size? Explain your answer in terms of magnitude.

7. How would you model the difference in absolute magnitude between the two flashlights?

8. Predict what an astronomer would look for if or she wanted to determine the size and heat of a star and its distance from the Earth.

Part II: Comparing Apparent Magnitudes
Procedure:
Study the following tables and then answer the questions that follow.

Table 1 identifies the apparent magnitude of select objects that can be see in the sky. The naked-eye limit and the telescope limit indicate the minimum magnitude of sky objects that can be seen. Table 2 identifies the different in apparent magnitude and the ratio of light emitted based on the differences.

9. What is the apparent magnitude of the Sun?
10. What is the apparent magnitude of Sirius?
11. What is difference in the magnitudes the Sun and Sirius?
12. How much more light does the Sun provide than Sirius?
13. What is the difference in the Sun's apparent magnitude from that of full Moon?
14. About how much more light does the Sun provide than the full Moon?
15. What is greatest apparent magnitude that can be viewed by the naked eye?
16. How much more light does Sun give off than an object with least apparent magnitude that can be viewed by the naked eye?
17. What is the difference in the magnitudes between Venus and Mars at their brightest?
18. What is the ratio of light of Venus and Mars at their brightest?

Table 1

Object	Apparent Magnitude
Sun	-26.5
Full Moon	-12.5
Venus (at brightest)	-4.0
Jupiter, Mars (at brightest)	-2.0
Sirius	-1.5
Naked-eye limit	6.5
15cm telescope limit	13.0

Table 2

Difference in Apparent Magnitude	Ratio of Light
0.0	1:1
1.0	2.5:1
2.0	6.3:1
3.0	16:1
4.0	40:1
5.0	100:1
10.0	10,000
15.0	1,000,000:1
20.0	100,000,000:1
25.0	10,000,000,000:1
30.0	1,000,000,000,000:1

Part III: How a star's magnitude and distance are related.
Procedure:
Study the following tables and then answer the questions that follow.

You can compare a star's apparent magnitude to its absolute magnitude and use that to determine whether a star is close to earth, or far away from earth. If a star is "actually" brighter than it "appears," the star is going to be far away. If a star "appears" brighter than it "actually" is, the star is going to be close. It is important to keep in mind that the smaller the magnitude number, the brighter the star is. For example, Barnard's Star has absolute magnitude 13.24 and apparent magnitude 9.7. It's apparent magnitude is brighter than it's absolute magnitude, because 9.7 is lower than 13.24. That means the star appears brighter than it is actually is, which makes it close to us.

Before beginning, write "actual" above the absolute magnitude column on your star data table. Now write "appears" above the apparent magnitude column. *Keep in mind the lower the number is the brighter the star.*

19. Which star appears the brightest? Why does it appear so bright?
20. Which star is actually the brightest? Does this star appear bright to us? Why or why not?
21. How might a star appear brighter to us on earth, even though it isn't actually very bright?
22. How might a star be actually very bright, but not appear very bright to us on earth?
23. Re-explain, in your own words, how to determine whether a star is close or far away from earth using the stars apparent and absolute magnitude.
24. Translate this to stars. What does that tell us about the parallax, or shift, of stars that are close to us vs. the parallax, or shift, of stars that are far away?

Star Data Table

Star	Absolute Magnitude	Apparent Mag.	Far Away or Close to us? (F or C)	Star	Absolute Magnitude	Apparent Mag.	Far Away or Close to us? (F or C)
Barnard's Star	13.24	9.7		Aludra	-7	2.44	
Epsilon Indi	7.0	4.7		Furud	-1.7	3.02	
Lalande 21185	10.5	7.6		Sun	4.74	-26.7	
Ross 128	13.5	11.1		Canopus	-4.4	-0.6	
Ross 248	14.8	12.2		Arcturus	-0.3	1.17	
Tau Ceti	5.68	3.6		Vega	0.5	0.04	
Capella	0.09	0.08		Altair	2.3	1.02	
Sirius	1.42	-1.5		Pollux	1.0	2.17	
Procyon	2.64	0.38		Deneb	-4.8	1.35	
Wolf 359	16.6	13.5		Regulus	-0.7	1.25	
Almaaz	-8.5	3		Spica	-2.4	0.77	
Hoedus	-2.3	3.75		Rigel	-6.4	0.11	
Mirzam	-4.8	2		Archernar	-2.7	0.37	
Wezen	-8	1.86		Fomalhaut	2.0	1.25	
Adhara	-4.4	1.5					

Main Sequence Star Properties

Color	**Class**	**solar masses**	**solar diameters**	**Temperature**	**Prominent Lines**
bluest	O	20 - 100	12 - 25	40,000	ionized helium
bluish	B	4 - 20	4 - 12	18,000	neutral helium, neutral hydrogen
blue-white	A	2 - 4	1.5 - 4	10,000	neutral hydrogen
white	F	1.05 - 2	1.1 - 1.5	7,000	neutral hydrogen, ionized calcium
yellow-white	G	0.8 - 1.05	0.85 - 1.1	5,500	neutral hydrogen, strongest ionized calcium
orange	K	0.5 - 0.8	0.6 - 0.85	4,000	neutral metals (calcium, iron), ionized calcium
red	M	0.08 - 0.5	0.1 - 0.6	3,000	molecules and neutral metals

The Brightest Stars

Name	Spectral Class	Apparent Magnitude	Absolute Magnitude	Distance (LY)
Sirius	A1	-1.47	1.4	8.7
Canopus	F0	-0.72	-3.1	98
Rigil Kentaurus	G2	-0.01	4.4	4.3
Arcturus	K2	-0.06	-0.3	36
Vega	A0	0.04	0.5	26.5
Capella	G8	0.05	-0.6	45
Rigel	B8	0.14	-7.1	900
Procyon	F5	0.37	2.7	11.3
Betelgeuse	M2	0.41	-5.6	520
Achernar	B3	0.51	-2.3	118
Hadar	B1	0.63	-5.2	490
Altair	A7	0.77	2.2	16.5
Aldebaran	K5	0.86	-0.7	68
Acryx	B2	0.86	-3.5	260
Spica	B1	0.90	-3.3	220
Antares	M1	0.91	-5.1	520
Fomalhaut	A3	0.92	2.0	22.6
Pollux	K0	1.15	1.0	35
Deneb	A2	1.16	-7.1	1600
Beta Crucis	B0.5	1.26	-4.6	490

The Nearest Stars

Name	Spectral Class	Apparent Magnitude	Absolute Magnitude	Distance (LY)
Sun	G2	-26.7	4.83	
Proxima Century	M5	11.05	15.45	4.28
α Cen A	G2	0.1	4.38	4.3
α Cen B	K5	1.5	5.76	4.3
Barnard's Star	M5	9.5	13.21	5.9
Wolf 359	M6	13.5	16.80	7.6
Lalande 21185	M2	7.5	10.42	8.1
Sirius A	A1	-1.5	1.41	8.6
Sirius B	White Dwarf	7.2	11.54	8.6
Luyten 726-8A	M5	12.5	15.27	8.9
Luyten 726-8B (UV Cet)	M6	13.0	15.8	8.9
Ross 154	M5	10.6	13.3	9.4
Ross 248	M6	12.2	14.8	10.3
ε Eri	K2	3.7	6.13	10.7
Luyten 789-6	M7	12.2	14.6	10.8
Ross 128	M5	11.1	13.5	10.8
61 Cyg A	K5	5.2	7.58	11.2
61 Cyg B	K7	6.0	8.39	11.2
ε Ind	K5	4.7	7.0	11.2
Procyon A	F5	0.3	2.64	11.4
Procyon B	White Dwarf	10.8	13.1	11.4
∑ 2398 A	M4	8.9	11.15	11.5
∑ 2398 B	M5	9.7	11.94	11.5
Groombridge 34 A	M1	8.1	10.32	11.6
Groombridge 34 B	M6	11.0	13.29	11.6
Lacaille 9352	M2	7.4	9.59	11.7
τ Ceti	G8	3.5	5.72	11.9
BD + 5° 1668	M5	9.8	11.98	12.2
L 752-32	M5	11.5	15.27	12.4
Lacaille 8760	M0	6.7	8.75	12.5
Kapteyn's Star	M0	8.8	10.85	12.7
Kruger 60 A	M3	9.7	11.87	12.8
Kruger 60 B	M4	11.2	13.3	12.8

Life cycle of a Star Reading
Introduction:
A star is an extremely hot sphere of gas and dust. Stars come in all different sizes, colors, temperatures, brightness, luminosities, etc. Most stars aren't actually one star but rather are two stars that orbit each other in a very close orbit. These double stars (and even triple and quadruple stars) can make it difficult to determine the exact characteristics of certain stars.

The size of the star is one of the most important factors in that it determines what it’s life will be like, and what the end holds in store for that star. The size of a star determines whether that star is going to become a black dwarf, a neutron star, a supernova, or even a black hole.

In order to understand the life of a star we must first understand how the star gets it's energy. A star's energy is constantly created in a star’s core through hydrogen Fusion. Hydrogen fusion is the process where four Hydrogen atoms bond together to form one Helium and also, give off energy. In a star’s core, hydrogen atoms can be found in abundance but eventually, all stars will run out of hydrogen and begin burning other atoms for energy. This is when the star begins to move onto other parts of it’s life.

Question: How does the mass of a star determine what the star's life cycle will be?

Background: (write a few things that you already know pertaining to about the question above)

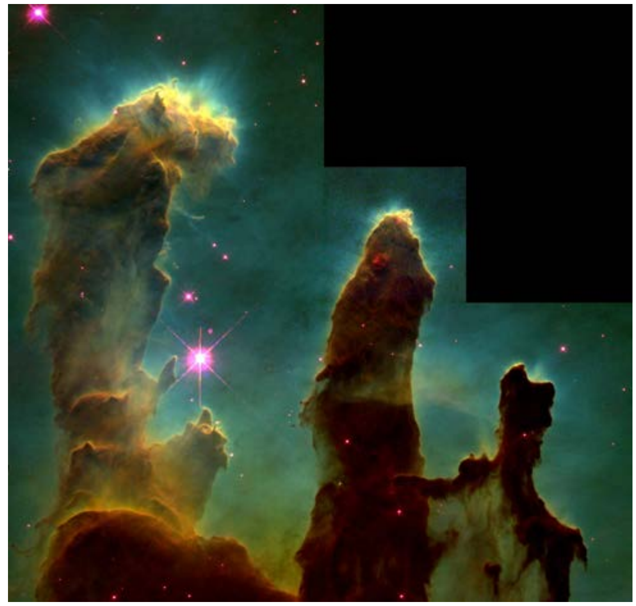
Vocabulary:
Nebula
Protostar
Brown Dwarf
Main Sequence
Giant
Planetary Nebula
White Dwarf
Black Dwarf
Supergiant
Supernova
Neutron Star
Black Hole
HR Diagram

Materials:
This reading packet

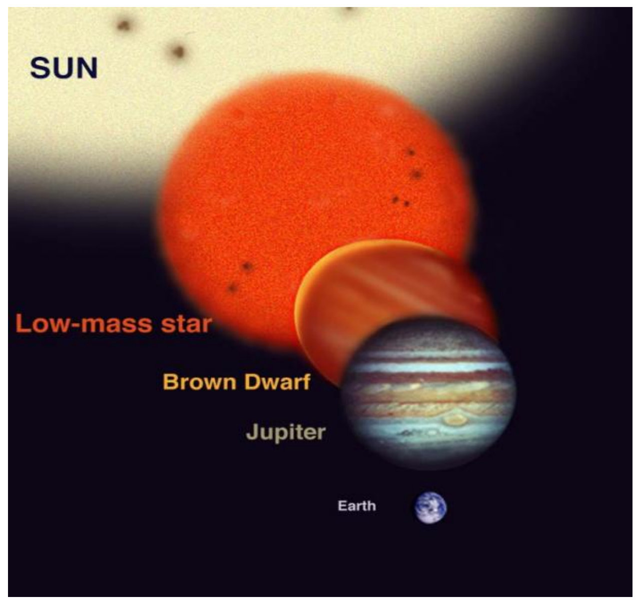
Procedure:
Read through the following passage.

Life cycle of a star
Every star begins its life in a collapsing cloud of dust and gas (almost entirely hydrogen) called a nebula. Nebulas have the distinction of being called a “stellar nursery” because out of this humungous expanse of dust and gas, stars form. Some large nebulas may have enough dust and gas to form into thousands if not millions of stars.

Protostars
As the dust and gases started to accrete, the nebula *(see picture on right)* develops a gravitational center called a protostar. A protostar is the gravitational center of a nebula, which may form into a star. As a protostar collects more and more material, it gets larger and hotter. At this point, however, it is not hot enough and there is not enough pressure to create nuclear fusion. Some protostars never get hot enough or are not large enough for hydrogen fusion to begin. If this is the case, that protostar never becomes an actual star and instead becomes a large planet-sized object called a brown dwarf.



Main sequence stars
If the protostar is hot enough and large enough for fusion to begin the star goes into the Main Sequence of its life. Once in the main sequence, a star is going to remain very stable and have a consistent temperature and luminosity. For these reasons, our sun is currently in the main sequence phase of its life.



Because all stars spend 90+% of their up to 10 billion years in the main sequence phase, it is not surprising that most stars in space are main sequence stars. While in this phase, a star will continue to fuse hydrogen into helium and energy until it begins to run out of hydrogen. If there is enough gravity, when stars begin to run out of hydrogen to fuse they begin to fuse Helium into Carbon and other heavier elements (up to #26 on the Periodic Table).

Life after the main sequence
All stars start off in the same way but how they end depends on it's mass. The final product of star's life is determined when the star is first formed. A star may either end its life as a black dwarf, a neutron star, supernova, or a black hole but this is dependent on the mass or size of the star. Astronomers classify stars into one of three mass categories; Sun-like Stars – up to 1.5 times the mass of the sun, Huge Stars – from 1.5 to 3 times the mass of the sun, and Massive Stars – more than 3 times the mass of the sun.

*End of a Sun-Sized Star (*up to 1.5 times the mass of the sun).
As a sun-sized star runs out of hydrogen is left with only helium in its core. The star will move into Giant phase and begin fusing the left over helium. Fusing helium gives off less heat and therefore causes Giant stars to be cooler than other stars, but bright.

Helium is a heavier element to fuse and in order to compensate for this, the outer layers of the star's atmosphere begin expanding. This causes the star to come less and less stable. Eventually the star will become so unstable and begin to run out of helium. This point all of those outer, expanded layers will be shed in a stellar wind burst called a planetary nebula.

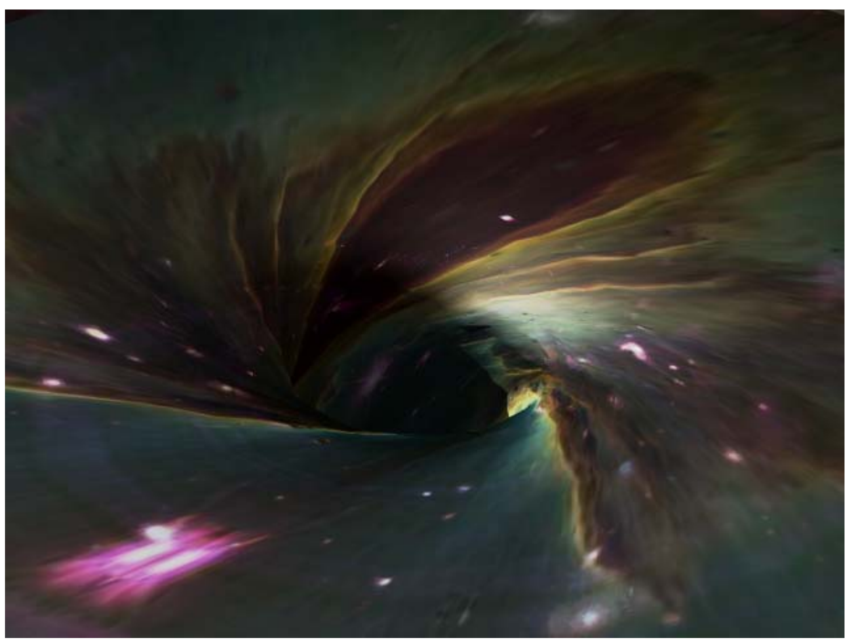
Once the outer layers have been shed, we are left with just the remnants of the core of the star. This core is composed mainly of carbon at this point because it has run out of helium to fuse. The star is now in White Dwarf phase.

This is the group of stars that is hot, but not very bright. The star is not large enough to fuse carbon so it stops producing its own energy and begins to cool down. It eventually cools down to a Black Dwarf, which is the cooled down remnants of a white dwarf. This is the final stage of a Sun-Sized star's life and is how our Sun will one day end up.

End of a Huge Star (from 1.5 to 3 times the mass of the sun)
Just like the sun-sized star, as a huge star runs out of hydrogen in its core, it begins to fuse the left over helium. It now enters the Supergiant phase of its life. A Supergiant is a star that is cool, but very bright. Helium is a heavier element to fuse and in order to compensate for this, the outer layers of the star's atmosphere begin expanding. This star is larger, so it expands more than the sun-sized star.
This causes the star to become less and less stable.

Eventually the star will begin to run out of helium and become so unstable that it will continue to expand until it explodes as a Supernova. The picture of a Supernova to the left shows that this large stellar explosion causes the of space to temporarily be brighter than its surroundings. After the star explodes, the only material left behind is a whirling ball of neutrons known as a Neutron Star. This is the final stage of Huge Star's life!

End of a Massive Star (more than 3 times the mass of the sun)
The end of a massive star's life is exactly the same as a huge star with one difference; the supernova is much larger than that of a huge star. Once the very large supernova occurs, there is no radiation pressure to push outwards against gravity. The star begins to collapse and under this intense pressure continues to collapse until it becomes a black hole. A black hole is an area of space where gravity is so intense, nothing, not even light, can escape. *Light can be seen swirling and being pulled into a black hole in the picture on the right.* This is the final stage of a Massive Star's Life!



Analysis:
Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. Why are nebulas referred to as stellar nurseries?
2. How are protostars formed?
3. How does a protostar become a main sequence star?
4. Based on your knowledge of chemistry, what are the only two (simplest) elements thought to have come out of the big bang? Where did all of the rest of the elements come formed?
5. Draw a flow chart showing the sequence of changes that a sun-like star goes through (starting with nebula).
6. Draw a flow chart showing the sequence of changes that a huge star goes through (starting with nebula).
7. Draw a flow chart showing the sequence of changes that a massive star goes through (starting with nebula).
8. If you were to look into space and see a neutron star, what could you tell about its history as a star?
9. Draw a Venn Diagram comparing and contrasting a sun-sized star and a huge star.
10. Draw a Venn Diagram comparing and contrasting a huge star and a massive star.
11. It is agreed upon by most astronomers that Jupiter probably should have been a brown dwarf. Explain how this could be so.
12. Astronomer s believe that the fusion process can only fuse atoms as large at iron together. Based on you know of the star life cycle, where did all of the elements heavier than iron come from?
13. What did you find most interesting about the life cycle of stars?
14. What would you still like to know about the life cycle of stars?

The Hertzsprung-Russell Diagram Assignment

Introduction:
The development of the H-R Diagram began with Danish astronomer Ejnar Hertzsprung who began plotting the stars around 1911. American astronomer Henry Norris Russell independently developed his own diagram. These two scientists independently discovered that comparing absolute magnitudes and spectral class (color) of stars yielded a lot of information about them. Together, they created a diagram on which they mapped stars by magnitude and spectral class.

Question: How do we use a Hertzsprung-Russell Diagram to explain star characteristics?

Background: (write a few things that you already know pertaining to about the question above)

Vocabulary:
Absolute magnitude
Spectral class
H-R Diagram
Giants
Supergiants
Main Sequence
Dwarfs

Materials:
Pencil
Highlighter
Colored pencils (red, orange, yellow and blue)
Blank Hertzsprung-Russell Diagram

Procedure:
Read through the following passage and complete the activity that follows, answering questions on a separate sheet of paper.

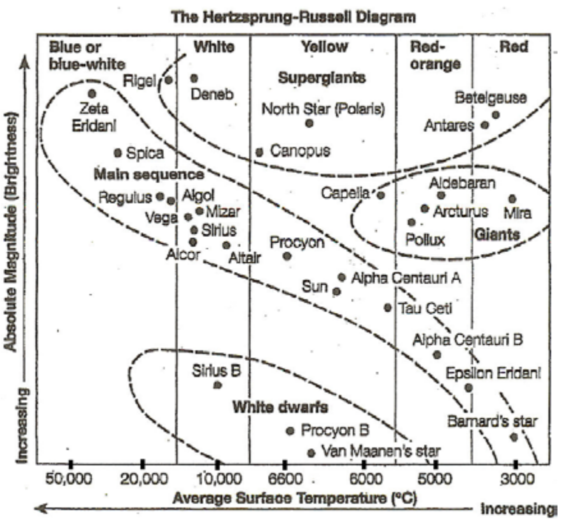
Luminosity
The Luminosity of a star is the amount of energy coming out of star. That has an effect on the Absolute Magnitude of a star, which is the actual magnitude of a star. This is different than Apparent Magnitude, which is the magnitude of a star as we see it on earth. The difference between the two, is that even if a star has a very bright absolute magnitude, it might have a very dim apparent magnitude because it is really far away. We learned this when we discussed Parallax, which was the apparent shift of a star due the position we are viewing it from. We had to use absolute magnitude and apparent magnitude to determine if the star we were talking about was far or close, and in turn determine that star's parallax.

Spectral Class
Stars are classified in many different ways. One way is by something called their Spectral Class. Spectral class is a one letter description that tells us the color and temperature of a star. Just like with heating elements or compounds here on Earth, the temperature of an object can often be determined by the color that it glows at. Similarly, a star's color is determined by its temperature. The hottest stars are blue in color, and called "O" type stars. The coldest stars are red in color, and called "M" type stars. In order for hottest to coldest stars we have "O" type, "B" type, "A" type, "F" type, "G" type, "K" type, and "M" type stars.

Spectral class and the color of stars is just one way of classifying stars. We will begin talking about HR Diagrams, which takes spectral class and plots that along the X-axis of a graph, and then compares that to the luminosity and magnitude of a star, along the Y-axis of a graph. This is the graph that tells us where the star is in its life cycle.

The HR Diagram: comparing absolute magnitudes and spectral class
After the astronomers had completed graphing the stars, they noticed that several patterns appeared. First, they noticed that ninety per cent of the stars fell along a diagonal line from the top-left corner to the bottom-right corner. These are called main sequence stars, of which our Sun is a member. Three other distinct groupings of stars appeared; red giants, super-giants, and dwarfs. The white dwarfs were on the bottom-left; the red super-giants were in the upper-right; red giants were on the diagonal that those two made. Astronomers further break down those regions to include blue giants, red dwarfs, sub-giants, Cepheid's, neutron stars and more. For the purposes of this lesson, we are going to focus on the four major categories on the HR Diagram.

The categories on the HR Diagram also tell us something about where a star is in its life cycle, or the evolution of the star. You can clearly see the giants, supergiants, main sequence stars and white dwarfs on the diagram. We defined those words using the group's brightness and temperature, and you can see how that correlates to where they are located on the diagram.



The HR Diagram is sometimes called an evolutionary diagram of the stars because it has the different phases of the star's lives on it. Please note that it does not include all of the stages of all of the different types of star's lives.

Creating the Hertzsprung-Russell Diagram - Plotting Stellar Temperatures.

1. Temperature is the independent variable and is therefore plotted along the x-axis. Temperatures increase from RIGHT to LEFT. The x-axis is not divided equal in temperatures differences. Start with 2,000 ºC at the right corner of the x-axis. Place the following temperatures on the x-axis from right to left: 3,000 ºC; 4,000ºC; 5,000ºC; 6,000ºC; 7,500ºC; 10,000ºC; 25,000ºC; 35,000ºC; 45,000ºC; and 50,000ºC.

2. Stellar color is related to the surface temperature of the star. Using colored pencils, lightly shade in the x-axis (where the surface temperature is represented) with the following colors. Temperatures from 2,000 ºC to 3,500 ºC will be red stars.

3. Temperatures between 3,500ºC and 5,000ºC will be orange stars. Temperatures from 5,000ºC to 6,500ºC will b 1yellow stars. From 6,500ºC to 7,500ºC are blue-white stars. Blue stars will be from 7,500ºC to 11,000ºC. Use a dark-blue color for the stars with temperatures greater than 11,000ºC.

Creating the Hertzsprung-Russell Diagram Plotting Luminosity

4. Luminosity is plotted along the y-axis and values increase from bottom to top on the diagram. Luminosity represents the relative brightness of a star compared to the brightness of Sol (that has a luminosity of 1). Values on this scale increase and decrease by factors of ten.

5. At the top of the chart write the words "Bright, high energy output." and down toward the bottom, write "Dim, low energy output."

6. For each mark made on the y-axis, complete the appropriate scale for luminosity with the luminosity values. Note Sol has a value of "1."

Drawing Stellar Size

7. Use the Stellar Luminosities and Temperature Table to determine the position for each star in your list. Place a dot at each location.

8. Determine the most appropriate size for each star based upon its position in the diagram. (Supergiants should be about 20mm in diameter and dwarfs should remain the size of a dot). When stars overlap due to sizes, draw them as if one were behind the other. That way the center point of each circle will still represent the most accurate position of the star. You do not need to label your stars.
9. Connect the "X's" on the diagram to show the location of the Main Sequence stars. Label this line.

10. Give Sol a special symbol and provide a legend on the right border of the diagram.

11. Lightly color in each star based on the star's temperature using the appropriate colors previously mapped on the x and y axis.

Stellar Luminosities and Temperatures Table

Star Name	Luminosity	Temperature (°C)
61 Cygnus B	.04	3,600
AA star	.36	3,900
Aldebaran	90	3,900
Alpha Centauri A	1.3	5,500
Alpha Centauri C	.00006	2,500
Alpha Crucis	2,700	20,700
Antares	4,400	4,600
Arcturus	90	4,200
Bernard's Star	.004	2,600
Beta Centauri	.6	20,700
Beta Crucis	3,000	21,700
Betelgeuse	17,000	2,900
C33 Star	.3	8,500
Canopus	1,500	7,700
Capella	150	5,600
Deneb	40,000	9,600
E546 Star	50,000	37,000
Epsilon Eridani	.3	4,200
Epsilon Indi	.13	3,900
F11 Star	850,000	7,000
Fomalhaut	14	9,200
J5T Star	8,500	6,600
K900 Star	900,000	14,000
Lalande 21185	.005	2,900
Luyten 789-8A	.00006	2,400
Mimosa	30,000	26,200
Mira	2,600	2,650
P78 Star	.8	6,500
P98C Star	25	6,000
Polaris	8,000	6,000
Pollux	3,300	4,600
Procyon A	7.6	6,200
Procyon B	.0005	7,100
R34 Star	250,000	5,400
Regulus	250	11,900
Rigel	40,000	11,500
S344 Star	250,000	8,000
Sirius A	19	10,100
Sirius B	.008	10,400
Sol	1	5,300
Spica	1,900	20,700
V89 Star	.08	6,400
Vega	60	10,400
W78 Star	75,000	6,800
Wolf	.00001	2,400
Y211 Star	140,000	45,000

Mapping Stellar Evolution

12. *High Massed Stars*- Using a highlighter, draw an arrow from the Blue Supergiants across the diagram to the Red Supergiants. These most massive stars live the shortest periods-on the scale of only millions of years.

13. *Intermediate Massed Stars* - Using your highlighter, draw an arrow from the Giant stars on the Main Sequence to the Red Giants.

14. *Low Massed Stars* - (Though Sol is technically an intermediate massed star it is likely that it will follow this death sequence.) Using a highlighter, draw an arrow along the Main Sequence from Orange to Yellow. Continue this arrow off the main sequence to the Red Giant Stars. Now, change the direction of the arrow by drawing it to the White Dwarfs. These least massive stars live the longest periods of time-on the scale of billions of years.

Analysis:

Answer the following questions on lined paper in complete sentences which restate the question in your answer.

1. On the H-R Diagram;
   a. where are the larger stars are found?
   b. where are the brightest stars are found?
   c. where are the hottest stars are found?
   d. what color are the stars with the coolest temperature?
   e. what color is Sol?
2. How do you think the Main Sequence got its name?
3. What two major uses does the diagram have for astronomers?
4. Why do you think there no Novas or Black Holes shown on the HR diagram?
5. Briefly describe the death sequence of a high massed star once it leaves the H-R Diagram.
6. Briefly describe the death sequence of an intermediate massed star once it leaves the H-R Diagram.
7. Briefly describe the death sequence of a low massed star once it leaves the H-R Diagram.
8. Describe two changes a star undergoes once it leaves the Main Sequence.
9. Once a star changes color, what does that tell astronomers about the fusion process occurring in the stellar core?
10. What one variable will determine the death-sequence a star will take at the end of its life?
11. Summarize the history and probable future of our sun (a main sequence star). How did it begin and how will it end its life cycle? Be sure to include the following terms in your discussion: nebula; fusion; gravity; giant; white dwarf.
12. Why is the process of nuclear fusion important?
13. What would you tell someone who thinks that all stars are very similar (be sure to discuss temperature and brightness)?
14. Are the stars scattered randomly on the graph, or is there a pattern? Explain.
15. Would you expect hotter stars to be dim or bright? Does the graph agree with this answer? (Give a specific example to support your answer).