Worksheet 4.1

1. Below is a drawing of a pair of sunspots on the surface of the Sun. Scientists have found that sunspots are like magnetic poles of a bar magnet. Draw what you predict the magnetic field above the surface of the Sun looks like in the region around the sunspots.

Worksheet 4.2

1. How are the stars we see at night related to the Sun? How are they different?

2. How big is the Sun relative to Earth? How far away is it?

3. How do the density and temperature of the Sun vary from the center outward?

4. How does the Sun produce the energy it needs to stay hot?

5. Why does the Sun shine?

6. What parts of the Sun are revealed by using invisible forms of light to observe it?

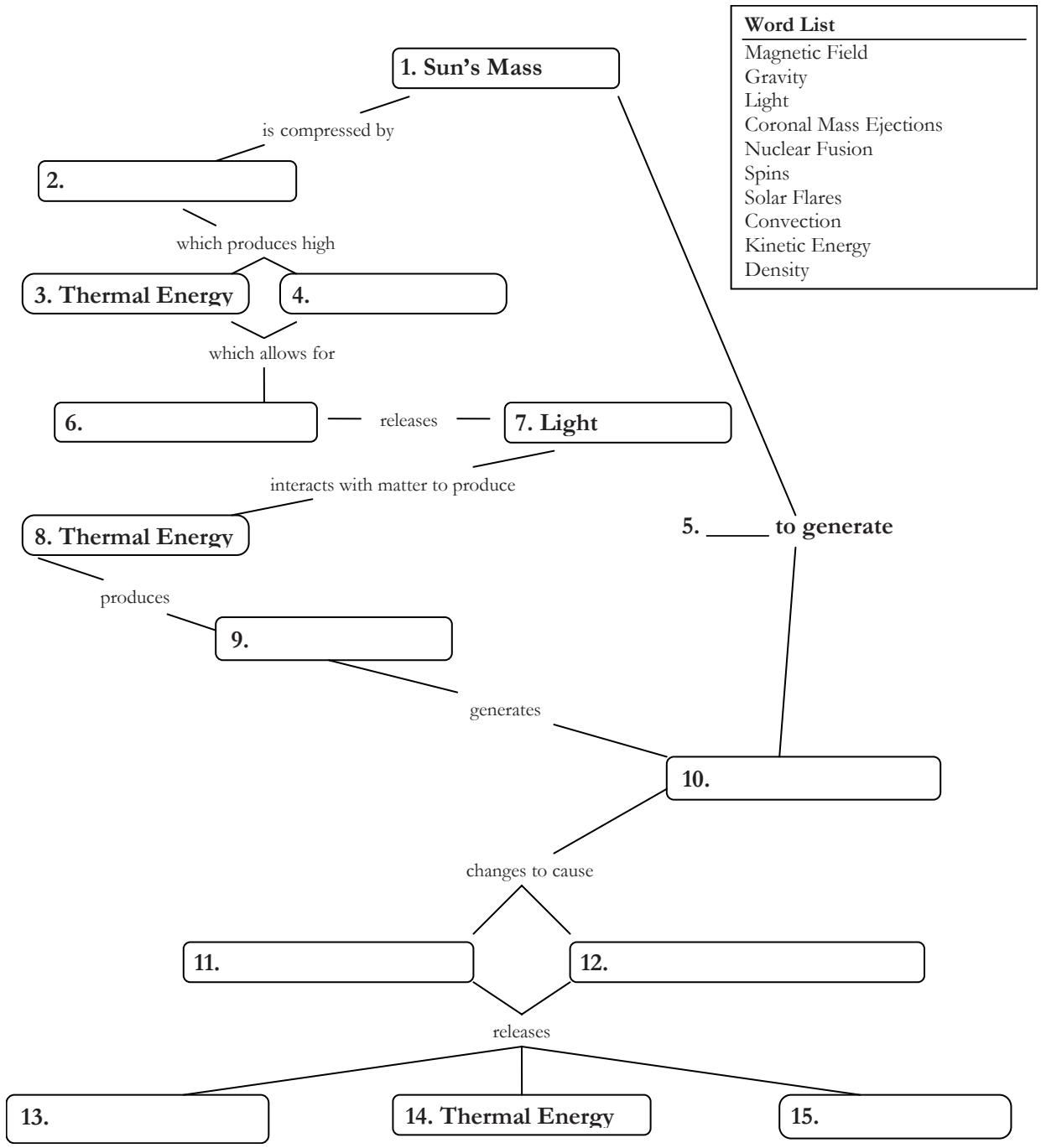
7. Can plasma move freely in the presence of a magnetic field? Why not?

8. What are sunspots?

9. What happens to the Sun's magnetic field with time, and how does that affect the number of sunspots and solar flares?

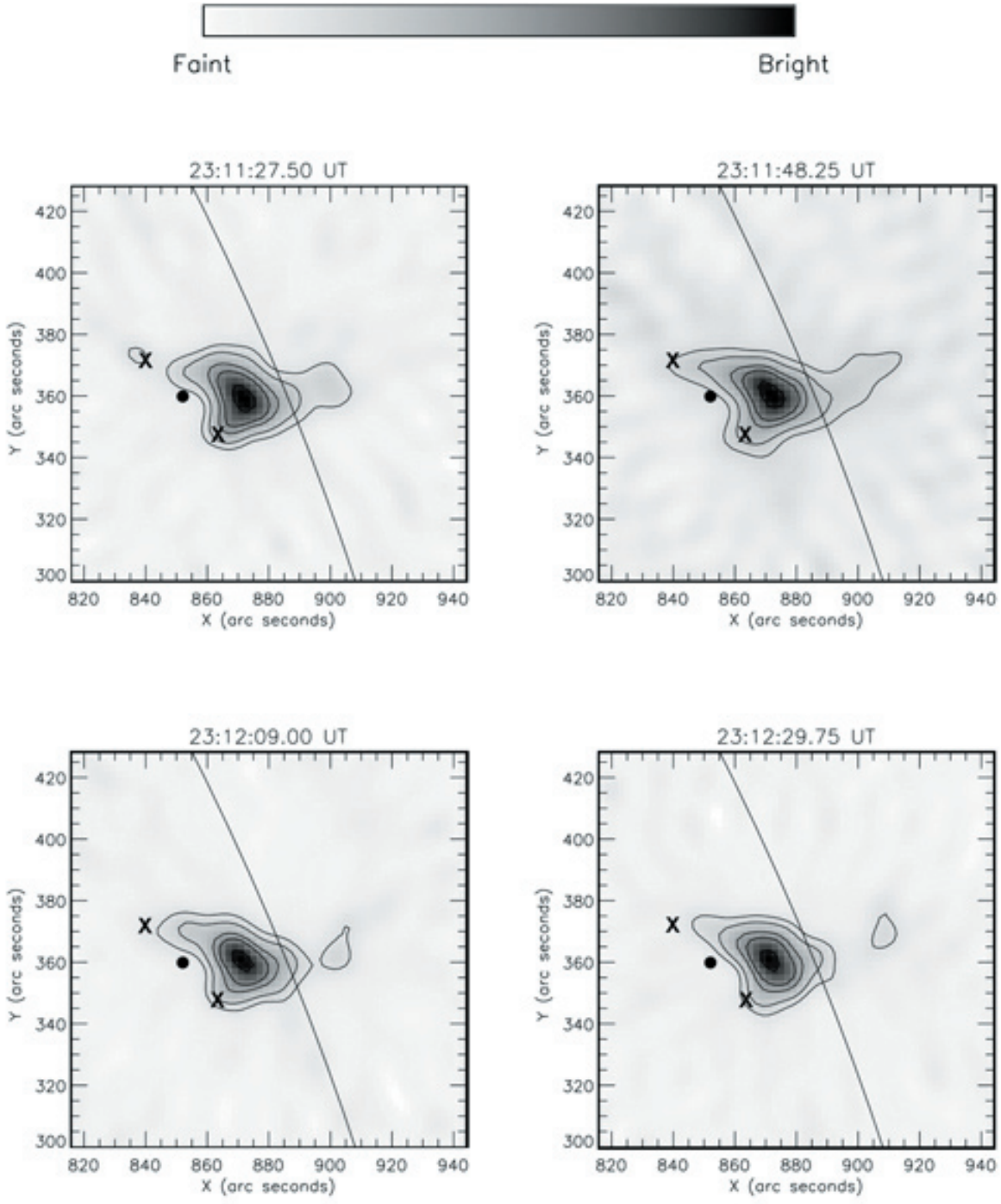
Worksheet 4.3

Now that you have read the essay about solar flares, and where the energy comes from that produces them, examine the concept map below and fill in the boxes with the appropriate words from the following list.



Worksheet 4.4

1. Below is a sequence of images of a solar flare, which occurred on April 15th, 2002, as observed in X-rays by the RHESSI spacecraft. In each of the images, predict what you think the shape of the magnetic field will look like and draw it on top of the image. The X's in the image indicate the location of the "footprints" of the coronal loop.



Worksheet 4.5

1. Your teacher will hand out a sequence of nine images from the RHESSI spacecraft as well as some graph paper. Examine each image and determine the location of the brightest spot in the coronal X-ray source (a.k.a. "the blob"), which is above the coronal loop.

2. Using a ruler, draw one horizontal and one vertical line through that spot (cross hairs) reaching the axes so that you can read off the coordinates of the spot. Record the data in the table provided below.

3. Determine the height of the blob above the surface of the Sun (in arc seconds). This can be done a number of ways. Discuss which ways are possible with your Science Team (and possibly your teacher) and decide how you will make this measurement. Describe your method below and show all calculations. Record the data in the table.

4. Convert the height that you calculated above from units of arc-seconds to kilometers. In all the images, the scale is 725 km/arc-sec. Show your calculations below and record the data in the table.

5. Plot the data on a graph above the surface of the sun. The x-axis should be **Time** and the y-axis should be **Height** in kilometers. Be sure to label the axes and include units. Do not draw lines through the points in the graph, just plot the points.

6. Return to the data table and calculate the distance moved between each pair of consecutive points. Show all work and record the data in the Table.

7. Use the distance moved between each pair of points and divide it by the time interval between each image to calculate the average speed of the blob at each point. Show all work and record the data in the Table.

8. Finally, use a ruler to draw a line through the last 3 points in your graph. If you cannot get a straight line to go through all three points, draw the line such that it comes as close to all three points as possible. Now, measure the slope of the line, displacement in the y-direction divided by the displacement in the x-direction ("rise over run"). The slope of this line is the average speed of the blob as it was ejected from the Sun. Show all work and record your result below.

9. At what time did the blob finally separate from the coronal loop and eject away from the Sun?

10. When did the blob experience the greatest acceleration (change in speed with time)? Explain.

11. When did the blob experience the greatest net force, and what was the source of the force? Explain.

Time	Time Interval (sec)	X-Ray Source Position		Height (arc sec)	Height (km)	Distance Moved (km)	Speed (km/s)
		X	Y				

Worksheet 4.6

The blob that was ejected from the solar flare later moved completely away from the Sun as a Coronal Mass Ejection (CME) moving with the same speed that you calculated in Worksheet 4.5. This blob has mass and a speed, so we can calculate its kinetic energy. The formula for kinetic energy is:

$$KE = \frac{1}{2}mv^2$$

where m is mass and v is speed.

1. The mass of the blob can be estimated by first estimating its volume and using the typical density of plasma in a coronal loop. Examine the 9th flare image in the series (23:12:50.50 UT) and estimate the diameter of the blob in kilometers. Show your work and record the number below.

2. Assume that the blob is a sphere and calculate its volume. Show all work.

3. The typical density of plasma in a coronal loop is 2×10^{-14} g/cm^3. Use this value to calculate the mass of the blob. Show all work.

4. Now, calculate the kinetic energy of the blob in Joules. Show all work, and be mindful of units.

5. The actual amount of mass that was ejected from the Sun was 10 times larger than what the X-ray image shows. The total amount of mass ejected from the Sun was estimated by NASA scientists to be 5×10^{13} g. Calculate the kinetic energy of the CME in Joules. Show all work and be mindful of units.

6. The total amount of energy released by the flare that went into heating and accelerating matter was estimated by NASA scientists to be 2×10^{23} Joules. How does this compare to the amount of kinetic energy given to the CME? How many candy bars would you have to eat to equal the total amount of energy? Show all work and be mindful of units.

Worksheet 4.7

1. Now that you have found out how much energy was released by the Solar flare, you will estimate how strong the magnetic field was inside the coronal loop. To do this you will use the following equation that relates the amount of magnetic energy contained within a region of space where a magnetic field is present:

$$\mathbf{E = B^2/(2\mu_0) \times V}$$

where **B** is the magnetic field strength, **E** is energy, **V** is volume of the coronal loop, and $\mu_0 = 4\pi \times 10^{-7}$ kg•m/Coulomb^2 which is called the permeability of free space. Algebraically solve the equation for **B**. Show your work.

2. Now you need to estimate the volume of the coronal loop. To make the estimate simple, assume that the loop is a cylinder that has been bent into a semicircle. The volume of a cylinder is $\mathbf{V = \pi R^2 l}$, where **R** is the radius of the cylinder and **l** is its length. Because, you are assuming that the shape of a coronal loop is a semicircle, then the length of the cylinder is half of the circumference of a full circle. The diameter of the full circle would be the distance, **d**, between the footprints of the coronal loops. So the length of the cylinder is

$$\mathbf{l = \pi/2 \times d.}$$

Examine the 9th flare image in the series (23:12:50.50 UT) and find the distance, **d**, between the footprints in kilometers. You can do this by either measuring the distance with a ruler or using the coordinates of the footprints. Show all work and be mindful of units.

3. Now examine the same image and use a ruler to measure the diameter of the coronal loop, use the contours as a guide. The radius of the cylinder, **R**, will be half of that diameter. Calculate the radius in kilometers. Show all work and be mindful of units.

4. Now calculate the volume, **V**, of the cylinder in cubic kilometers. Show all work and be mindful of units.

5. Return to your equation for the magnetic field strength in part 1. We are hoping to estimate the strength of the magnetic field that produced the solar flare and CME from this equation. If you use the amount of energy that the NASA scientists found as the total energy released by the flare in **Worksheet 4.6** in this equation, then that will mean that all of the energy contained in the coronal loop would have been transformed from magnetic energy into heat, kinetic, and light energy. Since the loop still exists after the flare, clearly not all of the energy within it was used. So, using this method will actually calculate the minimum magnetic strength of the coronal loop. Set **E** equal to 2×10^{23} Joules and calculate **B** in units of Gauss. Show all work and be mindful of units. Note on units: 1 Gauss = 10^{-4} Tesla, and 1 Tesla = 1 kg/(Coulomb•seconds).