

Worksheet 4.2 (Answer Key)

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

The Sun *is* a star, but the Sun is very close and the stars are very, very far away.

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

The Sun's diameter is 109 times larger than Earth. The volume is over 1 million times greater than Earth's. The Earth is 150 million km from the Sun (or 93 million miles, or 8.3 light-minutes, or 1 Astronomical Unit, or 11,700 Earth diameters, or 390 times the distance between the Earth and the Moon).

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

The Sun is very dense at its core, and the density steadily decreases out toward its surface, where it is less dense than Earth's atmosphere. It continues to decrease out into the corona where the density is about 1 particle per cubic centimeter. The temperature at the core is 15 million Kelvin and decreases steadily out to about 5,000 K at the photosphere. It then rises again to about 1 million Kelvin in the corona. [Student answers need not be this detailed]

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

It uses nuclear fusion at its core to stay hot.

5. Why does the Sun shine?

The Sun shines because it is hot.

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

The chromosphere is visible using UV and H-Alpha (which is visible). The corona is visible using visible light, extreme ultraviolet, and x-ray light.

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

No, plasma cannot move freely in a magnetic field because it is charged gas. When charged gas moves it creates an electrical current. Electrical currents are constrained to move along magnetic lines of force.

8. What are sunspots?

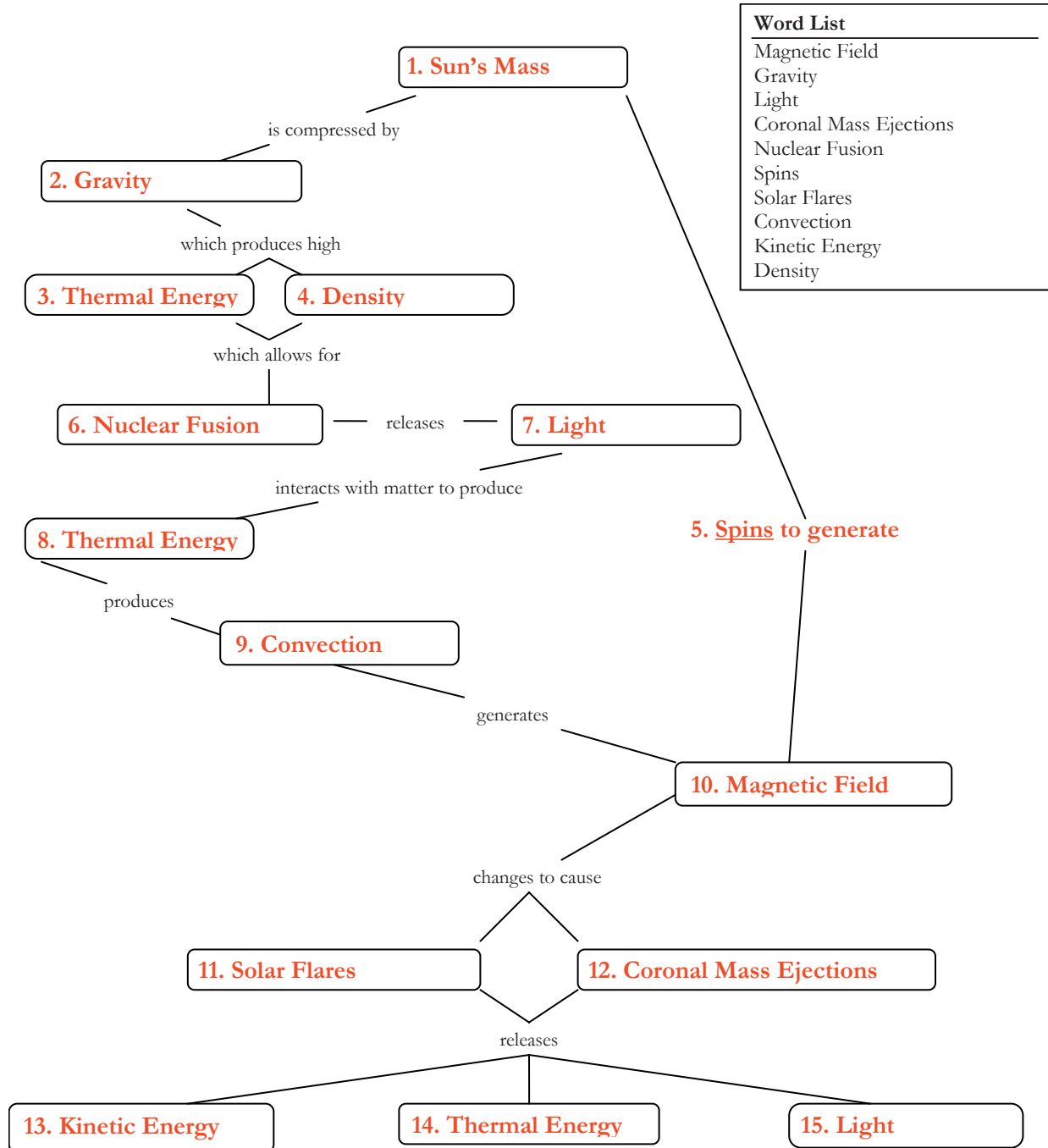
Sunspots are cooler places than average on the Sun's photosphere where strong magnetic fields inhibit convection.

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

The Sun's magnetic field gets twisted up due to the differential rotation of the Sun. As it gets twisted, parts of it poke through the surface, forming sunspots and causing solar flares. The magnetic field gets the most twisted every 11 years and flips polarity.

Worksheet 4.3 (Answer Key)

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 4.6 (Answer Key)

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.

(Note: v is used for velocity, which is speed and direction, but in this formula there is no direction, so speed and velocity are the same.)

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.

Diameter of blob = 1 cm

$$1 \text{ cm} \times 11 \text{ arcsec/cm} = 11 \text{ arcsec}$$

$$11 \text{ arcsec} \times 725 \text{ km/arcsec} = \mathbf{7,975 \text{ km}}$$

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

$$V = \frac{4}{3} \pi r^3$$

$$r = D/2 = 7975 \text{ km}/2 = 3988 \text{ km}$$

$$V = \frac{4}{3} \times \pi \times (3988 \text{ km})^3 = \mathbf{2.66 \times 10^{11} \text{ km}^3}$$

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

$$m = \rho V$$

$$V = 2.66 \times 10^{11} \text{ km}^3 \times (10^5 \text{ cm/km})^3 = 2.66 \times 10^{26} \text{ cm}^3$$

$$m = 2 \times 10^{-14} \text{ g/cm}^3 \times 2.66 \times 10^{26} \text{ cm}^3 = \mathbf{5.32 \times 10^{12} \text{ g}}$$

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

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

$$m = (5.32 \times 10^{12} \text{ g}) \times 1 \text{ kg}/10^3 \text{ g} = 5.32 \times 10^9 \text{ kg}$$

$$v = 240 \text{ km/s} \times 10^3 \text{ m/km} = 2.4 \times 10^5 \text{ m/s}$$

$$KE = 0.5 \times (5.32 \times 10^9 \text{ kg}) \times (2.4 \times 10^5 \text{ m/s})^2 = 1.53 \times 10^{20} \text{ kg m}^2/\text{s}^2 \\ = \mathbf{1.53 \times 10^{20} \text{ Joules}}$$

5. The actual amount of mass that was ejected from the Sun was 10 times larger than just that seen in the X-ray image. 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.

$$m = (5 \times 10^{13} \text{ g}) \times 1 \text{ kg}/10^3\text{g} = 5 \times 10^{10} \text{ kg}$$

$$v = 2.4 \times 10^5 \text{ m/s}$$

$$\text{KE} = 0.5 \times (5 \times 10^{10} \text{ kg}) \times (2.4 \times 10^5 \text{ m/s})^2 = 1.44 \times 10^{21} \text{ kg m}^2/\text{s}^2 \\ = \mathbf{1.44 \times 10^{21} \text{ Joules.}}$$

7. 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.

$$1.44 \times 10^{21} \text{ Joules} / 2 \times 10^{23} \text{ Joules} = 0.0072 = \mathbf{0.7\% \text{ of total flare}} \\ \mathbf{(rather small)}$$

$$1 \text{ candy bar} = 250 \text{ Calories}$$

$$250 \text{ Cal} \times 4,186.8 \text{ Joules/Cal} = 1.05 \times 10^6 \text{ Joules}$$

$$2 \times 10^{23} \text{ Joules} \times (1 \text{ Candy Bar}) / (1.05 \times 10^6 \text{ Joules}) = \mathbf{1.9 \times 10^{17} \text{ candy bars}}$$

That's **190 quadrillion candy bars**. Whew!

Worksheet 4.7 (Answer Key)

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:

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

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

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

$$B^2/(2\mu_0) = E/V$$

$$B^2 = 2\mu_0(E/V)$$

$$B = [2\mu_0(E/V)]^{1/2} \text{ or } B = \text{SQRT}[2\mu_0(E/V)]$$

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 $V = \pi R^2 l$, 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

$$l = \pi/2 \times d.$$

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.

The coordinates of the footprints are: (840, 372) & (864, 348) arc-seconds, so using the formula for the distance between two points gives

$$d = \text{SQRT}[(864 - 840)^2 + (348 - 372)^2] = \text{SQRT}(1152 \text{ arc-sec}) = 34 \text{ arc-sec}$$

$$d = 34 \text{ arc-sec} \times 725 \text{ km/arc-sec} = 2.5 \times 10^4 \text{ km}$$

For students who measure the distance with a ruler they should find that the distance is approximately 2.5 cm. The scale of that image is 13.3 arc-sec/cm.

$$2.5 \text{ cm} \times 13.3 \text{ arc-sec/cm} \times 725 \text{ km/arc-sec} = 2.4 \times 10^4 \text{ km}$$

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.

Using the contours near the top footprint they should find that the width of the loop is about 1 cm.

$$1 \text{ cm} \times 13.3 \text{ arc-sec/cm} \times 725 \text{ km/arc-sec} = 9.6 \times 10^3 \text{ km}$$

$$R = \frac{1}{2} \times 9.6 \times 10^3 \text{ km} = 4.8 \times 10^3 \text{ km}$$

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

$$V = \pi R^2 l \text{ and } l = \pi/2 \times d$$

$$V = \pi R^2 (\pi/2 \times d) = (\pi^2/2) \times R^2 d$$

$$V = (\pi^2/2) \times (4.8 \times 10^3 \text{ km})^2 \times 2.5 \times 10^4 \text{ km} = \mathbf{2.8 \times 10^{12} \text{ km}^3}$$

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).

$$B = [2\mu_0(E/V)]^{1/2}$$

$$V = 2.8 \times 10^{12} \text{ km}^3 \times (10^3 \text{ m/km})^3 = 2.8 \times 10^{18} \text{ m}^3$$

$$E = 2 \times 10^{23} \text{ Joules} = 2 \times 10^{23} \text{ kg}\cdot\text{m}^2/\text{s}^2$$

$$B = [2 \times 4\pi \times 10^{-7} \text{ kg}\cdot\text{m}/\text{Coulomb}^2 \times 2 \times 10^{23} \text{ kg}\cdot\text{m}^2/\text{s}^2 / (2.8 \times 10^{18} \text{ m}^3)]^{1/2}$$

$$\mathbf{B = 4.2 \times 10^{-1} \text{ kg}/(\text{Coulomb}\cdot\text{s}) = 4.2 \times 10^{-1} \text{ Tesla} \times 10^4 \text{ Gauss/Tesla}}$$

$$\mathbf{B = 4.2 \times 10^3 \text{ Gauss}}$$