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Energy for Earth: The Sun

Suggested Level: Grades 5 through 8

LEARNING OUTCOME

Students describe the production of energy within the sun, citing the process of nuclear fusion; describe the transfer of that energy by convection and radiation to the surface of the sun; and explain how that energy is finally released to space by the process of radiation.

LESSON OVERVIEW

The production of energy within the sun and the transfer of that energy from the sun through space to the earth is explored through modeling and laboratory work. In addition to learning what energy is and how it is transformed, students focus on the production of and the nature of radiation.

MATERIALS

- Hot plate
- Telescope (optional)

Per group:

- A solid steel ball (1/2-inch diameter)
- Sheet of foil-faced insulation (4” x 12”)
- Three metric rulers
- Calculator
- Felt-tip marker
- Balance scale
- Graduated cylinder
- Plastic hand lens
- Two sheets of stiff white paper
- Pin
- Colored pencil

SAFETY

Warn the students not to look directly at the sun at any time due to the danger of eye injury.
Also warn them not to focus the hand lenses on anything that might burn.

TEACHING THE LESSON

This lesson is divided into four parts. Part 1 serves as an introduction to the topic of the sun as an energy (light) source. Pick a sunny day, and have the students make their pinhole sheets and take them outside to safely “view” the sun. You may want to bring a telescope outside when the students try their pinhole cameras. Aim the telescope at the sun and project its image from the eyepiece into a white paper-lined box to show them a larger view of the sun. The questions for Part 1 and Part 2 could be done for homework.

Part 3, Steps 1 through 12, will take another class period, especially for those students who are weaker in mathematics and would benefit from in-class guidance. Steps 1 through 12 could be finished for homework and clarified in the next class period. It might take another class period to gather the data for Steps 13 and 14. The graphs and questions at the end could be started in class and finished for homework.

Part 4 should take another period and homework session to finish after Part 3 is discussed. A class period should be reserved to finish discussion and reinforce learning objectives.

ACCEPTABLE STUDENT RESPONSES

Part 1:

4. Answers will vary depending on the sun's 11-year sunspot cycle.

5. When the hole becomes too large, the image disappears.

6. You get two images.

7. You would get a brighter image.

8. An image of the sky, sun, and clouds.

DEVELOP YOUR UNDERSTANDING SECTION

1. The light is being diffracted by the edge of the pinhole (just like a convex lens).

2. Yes, it too is upside down and backwards because of diffraction of light.

3. Light is composed of electromagnetic waves that change velocity when they enter a medium (glass) of different density or when unevenly slowed by nearby collisions with a solid (the paper).

POST-LAB:

2. No

3. As the hot plate gets hotter, it starts to glow dull red, gradually changing to orange-red.

4. When it got hot

5. Yes.

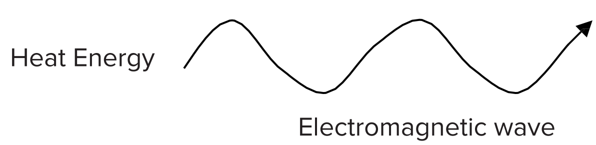
6. The radiation felt has a longer wavelength than the radiation seen.

7. Increased temperature produces radiation of shorter wavelength.

Part 2:

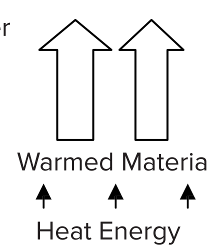
2.

3. Radiation:



Convection:

Rises away from Gravitational Center



DEVELOP YOUR UNDERSTANDING SECTION

1. Sunspots are cooler than the rest of the sun's photosphere (3,500–5,000 vs 6,000 Kelvin). They are relatively darker.

2. Heated plasma expands, becomes less dense, and rises.

3. It is transformed into (1) heat; (2) light; and (3) mechanical.

4. The helium nucleus has less mass than the original four hydrogen protons.

5. The repulsive electrostatic charges are trying to keep the protons apart.

6. It gets absorbed by the plasma within the sun.

7. A change in the density of the fluid material

8. They must be diffuse enough to let the radiation through.

9. Sun: $V = 4/3\ \pi\ r^3 = 4/3\ (3.14)\ (432{,}000 \text{ miles})^3 = 3.377 \times 10^{17} \text{ miles}^3$
   Earth: $V = 4/3\ (\pi)\ (3{,}960 \text{ miles})^3 = 2.601 \times 10^{11} \text{ miles}^3$
   Sun Volume / Earth Volume = $3.377 \times 10^{17} / 2.601 \times 10^{11} = 1.3 \times 10^6$ times larger

Part 3:

Procedure:

2. Answers will vary, mostly from ½ to ¾ inches.

3. Answers will vary.

4. Answers will vary.

5. Answers will vary.

7. a. Yes.   b. Answers will vary.

8. There can be many improvised devices here; most will involve projecting a small probe below the level of the foil surface into the depression, then measuring the depth from the probe.

9. The ball had velocity, and therefore force, when it hit the foil.

10. a. Answers should be consistent with #3 above.

    c. $t^2 = 2\ d\ /\ g = [(2)\ (.05 \text{ meters})]\ /\ 10 \text{ meters/second}^2 = .1\ /\ 10 \text{ meters/meter/second}^2$
       $t^2 = .01 \text{ seconds}^2$
       $t = .1$ second

    d. $v = g\ t = (10 \text{ m/s}^2)\ (.1 \text{ sec}) = 1$ meter/second

    e. $KE = ½\ m\ v^2 = (.5)\ (\text{mass})\ (1 \text{ meter/sec})^2 = .5$ the mass kilogram meters/second^2.

11. $PE = (m)\ (10 \text{ meters/sec}^2)\ (.05 \text{ meters}) = .5$ the mass kilogram meters/second^2.

12. They are equal to each other.

13. It should have more energy and make a bigger dent.

14. Answers will vary but should show a trend toward wider and deeper.

15. Answers will vary but should show a trend toward wider and deeper.

16. The higher the ball, the greater the energy.

Part 4:

1. Level 6

2. Level 6

3. A fast-moving electron

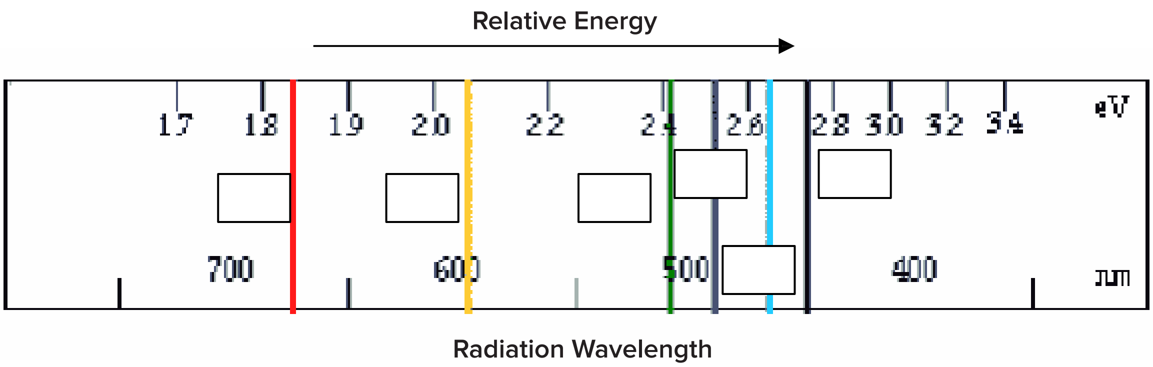
4. It increases also.

5. Purple (right-hand one)

6. The same one

7. The shorter the wavelength, the greater the energy.

8.



DEVELOP YOUR UNDERSTANDING SECTION

1. By electromagnetic radiation

2. Nuclear fusion of hydrogen into helium

3. By radiation and convection (and conduction)

4. Excited electrons in the atoms there absorb energy, become excited, and lose the energy as radiation as they return to a lower energy state.

BACKGROUND INFORMATION

Part 2:

The process of stellar nuclear fusion is a complicated series of nuclear reactions that change with changes in temperature. The sun is essentially a plasma ball in which some electrons have escaped from the atoms with which they are normally associated. At about 4 million degrees Celsius, the elements lithium, beryllium, and boron are involved in the production of helium from hydrogen. At higher temperatures around 15 million degrees Celsius, carbon, nitrogen, and oxygen play critical roles. If 1 gram of matter is converted to energy, $E = mc^2$ gives us a value of energy equal to 1 gram x $(3 \times 1010 \text{ cm/sec})^2$ which equals 9 x 1020 ergs. At this rate, one millionth of the sun's mass will be converted to energy in the next 15 million years.

Students may have a difficult time finding the lost mass in the nuclear fusion reaction. Essentially, we know the mass is missing because we can measure the decreased mass using the mass spectrometer. We know the energy is released because we can observe and measure the released energy. In essence, we recognize that bound nucleons (protons and neutrons) of the nucleus have less mass than when free of nuclear confinement. For example: 6 protons @ 1.00728 atomic mass units (amu), 6 neutrons @ 1.00866 amu, plus 6 electrons @ 0.00055 amu add up to 12.0000 amu when combined in a carbon atom.

Part 4:

Energy is lost by rapidly moving electrons surrounding the nucleus of atoms as they "fall" from excited states to lower levels. The model in Parts 3 and 4 has been simplified to make it more readily understandable to students. The basic idea that the greater the fall, the greater the amount of energy released by the electron is valid. Further reading may be warranted if a deeper understanding is desired. Some of the more complicating factors involved include the following:

- Electrons do not always fall all the way back to "base" level in the way that the ball did.
- Each particular change in energy level does produce a set amount of energy release—a quantum—which is unique and consistent for energy level change.
- Some of the radiation wavelengths produced fall outside the visible spectrum.

(STUDENT HANDOUT FOLLOWS)

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Energy for Earth: The Sun

Introduction

The sun is the major source of energy for the earth. In our everyday activities we are well aware of this. We sit on the sunny side of the house in the morning for breakfast; we get out of the sunlight when it's too hot; and we sit on that sunny spot on the floor when we are cold in winter. Your school's solar collector panels are aimed at the sun. But how do we get this energy from the sun? How does the sun produce energy and how does it travel to us? This series of lab activities will help you answer these two questions.

Part 1: Observing the Sun

All of us have "seen" the sun. We see it rise in the eastern sky, not usually directly east, but most people do not notice this. We know it rises higher in the sky during the day and some of us incorrectly think it gets directly overhead here in New York State. Then, it sets on the western horizon, but many of us do not know what the horizon is and once again the direction of sunset is not typically directly west. Naturally, most of us have not looked very closely at the sun. It's too bright, and it hurts our eyes to look at the sun. Actually looking at the sun DOES harm our eyes; you shouldn't look at the sun. So here's a safe way for you to see the source of all of this energy, to see the object we want to study. **Remember: don't EVER look directly at the sun, with or without a telescope (unless you have the proper filters)**.

Projecting the Sun

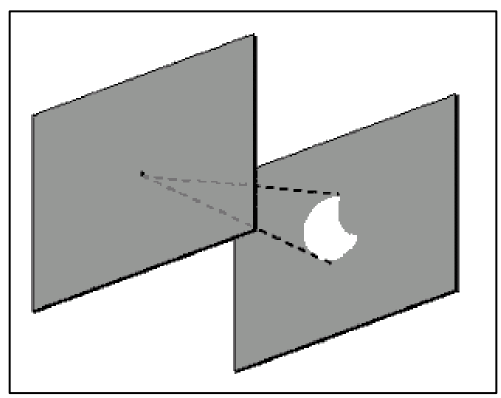
You can easily and safely observe the sun by projecting it through a tiny hole onto a white sheet of paper. This simple device is called a "pinhole camera."

Materials (for 2 students)

- 2 sheets of stiff white paper
- 1 pin
- Hand lens

Procedure

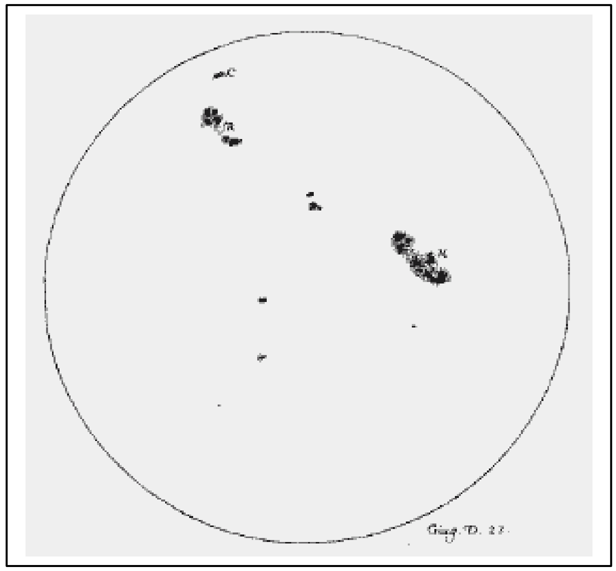
1. With the pin, punch a hole in the center of one of your pieces of paper.
2. Go outside on a partially sunny day, and hold the piece of paper so that the pinhole is between the sun and the plain sheet of paper. (Don't look directly at the sun either through the hole or in any other way!)
3. Move the higher piece of paper up and down until you see the image of the sun on the lower sheet.
4. Make sure the image rests on the paper and is in focus (has a nice, crisp edge) and is not just a dot of light. Does the image of the sun look like the circular graphic to the right?



5. Experiment by making the hole larger or smaller. What happens to the image?

6. What happens after you punch two holes in the piece of paper?

7. Try bending your paper so the images from the two holes lie on top of each other. What do you think would happen if you punched a thousand holes in your paper and were able to bend your paper so all the images lined up on top of each other?



In fact, optical telescopes can be thought of as a collection of millions of “pinhole” images all focused together in one place! You can make your pinhole camera fancier by adding devices to hold up your piece of paper, or a screen, on which to project your sun image. Or you can make your pinhole camera a “real” camera by adding film.

8. While the sun is behind some thin clouds, hold your hand lens at various distances above the paper. What do you see?

DEVELOP YOUR UNDERSTANDING

1. Why does the sunlight coming through the pinhole produce an image of the sun? What must be happening to the light?

2. Does the hand lens produce the same kind of picture of the sun as the pinhole? Explain.

3. What is it about the nature of sunlight, and light in general, that allows these images to be produced and us to see them?

Post-lab Demonstration: Materials

- 1 hot plate

Procedure:

1. Gather close enough to your teacher so that you can see the hot plate clearly. Turn off the lights to darken the room. Turn on the hot plate. Observe the hot plate.
2. When the hot plate is first turned on, is it warm or does it glow?
3. Describe the changes in temperature and color that you observe during this demonstration.
4. When did the hot plate produce visible light?
5. Could you feel radiation before you saw any radiation?
6. What is the difference between the radiation you felt and the radiation you saw?
7. What does this demonstration tell you about the relationship between temperature and the production of radiation?

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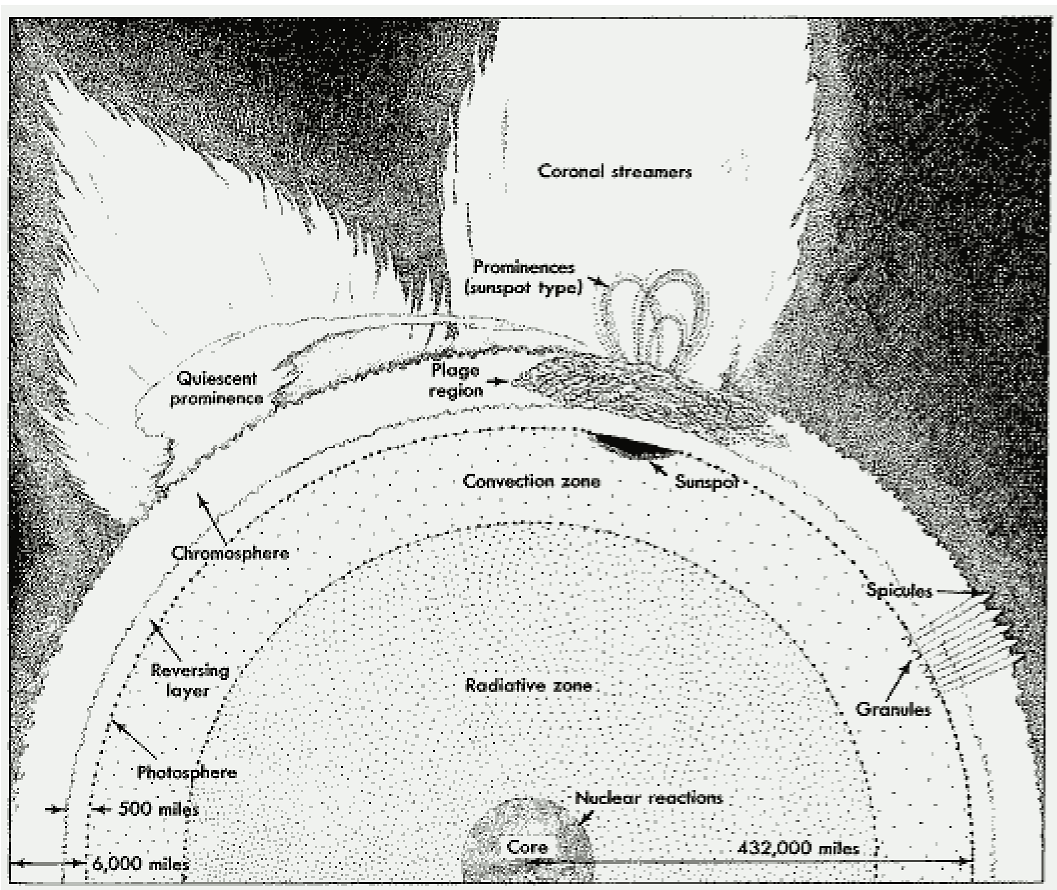
Part 2: The Sun's Structure and Source of Energy

Now that you have actually seen the sun and have some idea about the nature of radiation and where it comes from, what were you looking at when you observed the sun? How is the sun different from the hot plate? What you see when looking at the sun is the photosphere, the light-producing surface of the sun.

1. Find this layer in the diagram of the cross section of the sun below that shows the internal structure of the sun. With a colored pencil, carefully and lightly shade in the internal part of the sun between the sun's core and the photosphere. You divided the sun into three parts. Let's look at these parts one at a time.



2. **The Core:** Scientific evidence indicates that the nuclear fusion of hydrogen to helium occurs within the core of the sun. Because the end product, helium, has approximately .7% less mass than the ingredients that it was created from, energy is released. While this is a relatively small amount of mass lost, it is converted into a tremendous amount of energy in the form of heat and radiation. [Einstein correctly predicted that the energy released (E) is equal to the mass lost times the speed of light squared, or $E = mc^2$. Since c is such a large number, a little value for m is BIG.] Draw this nuclear reaction using symbols in the space below. Four hydrogen nuclei combine to form one helium nucleus. Use different symbols for the protons and the neutrons.

3 **The Region You Colored:** This region consists of the radiative zone and the convection zone. Each zone is named for the dominant energy transfer process occurring there. Show how each of these processes transfers energy by drawing a labeled diagram of each process in the space provided below.

Radiation:

Convection:

4. **The Outer Region:** The photosphere is the surface we see as the source of sunlight, the sun's radiative surface. Sometimes the sunspots, which you may have been able to see while observing the sun, are present on this surface, creating solar prominences in the sun's atmosphere above them.

Circle the sunspot and its prominence on the diagram on page S-4.

DEVELOP YOUR UNDERSTANDING

1. Why do sunspots look darker than the rest of the sun's surface?

2. Describe how the sun's energy is transferred within the convective layer.

3. Identify three other forms of energy into which the sun's nuclear energy is transformed.

(1)

(2)

(3)

4. Where is the mass lost in the hydrogen fusion reaction?

5. What forces have to be overcome in order for the protons of the hydrogen nuclei to join together to form a helium nucleus?

6. What stops the radiation found in the sun's radiation layer from being the earth's direct source of solar radiation?

7. What physical change allows heat energy to be transported by the process of convection?

8. What must be true about the layers above the sun's photosphere to make the photosphere the direct source of solar radiation?

9. If the earth's radius is 3,960 miles, how much greater than the earth's volume is the sun's? [Use the formula V = 4/3π r3 and show your work in the boxes below.]

Sun's Volume =	Earth's Volume =	Sun's Volume / Earth's Volume =

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Energy for Earth: The Sun

Part 3: Potential and Kinetic Energy

Through lab work, we learn how the nuclear reaction energy from the sun's interior is changed to light energy received by the earth.

Materials per group:

- A solid steel ball (1/2-inch diameter)
- Sheet of foil-faced insulation (4" x 12")
- 3 metric rulers
- Calculator
- Felt-tip marker
- Balance scale
- Graduated cylinder (plastic)

Procedure

1. Collect the necessary lab equipment for your group of three or four and bring it to your workstation.
2. Measure the thickness of your piece of foil-faced insulation.

   Thickness = ___________________________ centimeters

3. Measure the mass of the steel ball.

   Mass = ___________________________ grams

4. Measure the volume of the steel ball, using the graduated cylinder and the water displacement technique.

   Volume = ___________________________ cm^3

5. What is the density of the steel ball?

   Density = M/V = Volume = ___________________________

6. Place the foil-faced insulation on your lab station surface and position the rulers as shown in the diagram to the right. Set the horizontal ruler so the lower edge is exactly 5 centimeters above the surface of the foil insulation.

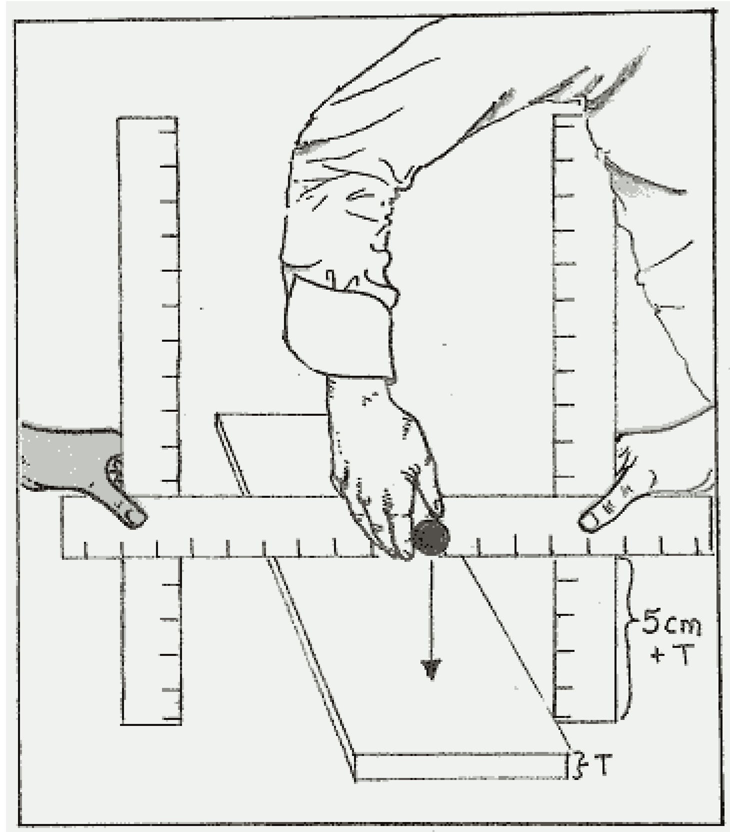
7. While two students hold the rulers as shown in the diagram, a third student should drop the steel ball from the bottom edge of the horizontal ruler so that it lands on the foil insulation.

   a. Did the ball leave a dent in the surface of the foil?

   b. How big is the dent?

      1) Distance across = ________________ cm

      2) Depth = ________________ cm



8. You may not have a specific tool to measure this depth. See if your lab group can figure out a method to answer this question. Describe your group's method.

9. How did the ball make this dent?

10. That's right. The ball is moving or falling because of the force of the earth's gravity pulling down on it and when it strikes the foil, it exerts a mechanical force on the foil. Another way to say this is to say that the ball, since it has mass and is moving, has **kinetic energy**. Fortunately for us, mathematicians have developed a formula to help determine exactly how much energy this is: **KE = ½ m v^2**. So all we have to find out is the mass of the ball and how fast it was moving (v for velocity) when it hit the foil! So…

a. What is the mass of the steel ball in kilograms? Mass = ______________________________ grams

b. Did you happen to measure the velocity of the ball as it hit the foil? Was your radar gun broken? That's too bad. Mathematics comes to the rescue again! The ball is being accelerated by the force of gravity, an acceleration (g) of approximately 10 meters/second^2. Therefore, the velocity of the ball = the acceleration due to gravity (g) x the length of time the ball was falling (t). As long as the ball falls, it increases in speed by 10 meters/second for each second it falls. This formula gives you the ball's instantaneous velocity: **$velocity_{instantaneous}$ = gt**.

c. But wait, I bet you didn't time how long the ball was falling, either! That's OK. As long as we know how far the ball fell, we can calculate how long that fall took. That's right, mathematics again! The formula is: **d = ½ gt^2**. So, let's find the time so we can determine the velocity. If you algebraically rearrange this formula, you get: **t^2 = 2d/g**. In the box below, plug the numbers and units into this formula and solve first for t^2, then t. [Show how the units cancel to give the correct units for your answer. Also, remember that the distance has to be measured in meters. How many meters did the steel ball fall?

___________________ [meters]

t^2 = 2 d / g

t = ____________________ [Show the correct units.]

d. Now that you know **t**, you can calculate the velocity of the ball when it hit the foil by substituting in equation (b) above. Show your work again.

v = g t

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v = ____________________ [Show correct units]

e. Find the kinetic energy of the ball as it hit the foil using the equation in Step 5 above.

$KE = \frac{1}{2} m v^2$

KE = ____________________ [Show correct units]

11. But where did the ball get this energy? Do steel balls always have energy inside just waiting to get out? In this case only if **someone put it there**. If you are all looking at lab partner #3, good. You have found the guilty party! By lifting the ball 5 cm above the foil, partner #3 stored energy in the ball equal to the mass of the ball times the acceleration due to gravity times the height lifted: this is called **potential energy**. In a formula form: **PE = mgh**. Applying this formula, does the amount of stored energy (PE) equal the amount of kinetic energy measured at the end of the fall? [Remember to write height in meters and the mass in kilograms.]

$PE = m\,g\,h$

PE = ____________________ [Show correct units]

12. You might have noticed that the units for potential and kinetic energy became complicated and a lot of baggage to carry around. Scientists realized this too, so to simplify their (and our) lives, they gave these energy units for work or the name **joules**. [1 joule = 1 gram-meter^2/second^2] State the relationship in joules between the amount of potential energy used to lift the ball and the amount of kinetic energy present in the ball as it returns to its original height.

13. Now that you have some understanding of the energy relationships involved, let's collect some more data. What do you predict will happen to the PE and KE amounts if you lift the ball to a higher level and drop it on the foil?

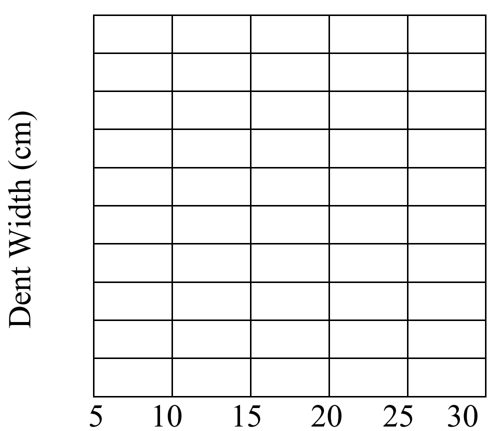
Let's see if you have it right.

14. Using the felt-tip marker, label the dent that you've already made in the foil at 5 cm. Raise the horizontal ruler to a height of 10 cm + T. Drop the steel ball onto the foil from this height. Label the dent in the foil by the height from which the ball was dropped. Measure the dent width and depth. Record these values in the chart to the right. Repeat this procedure every 5 cm to a drop height of 30 cm + T.

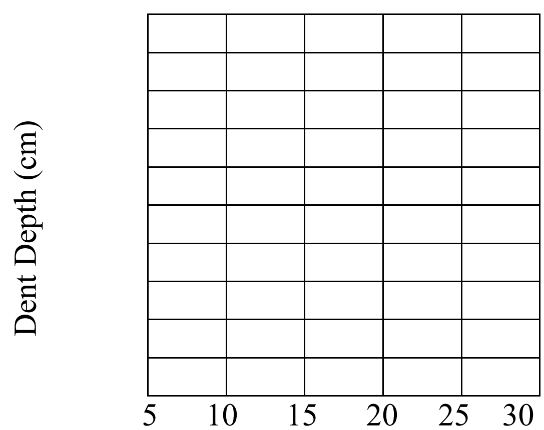
Ball Height Above Foil (cm)	Dent Width (cm)	Dent Depth (cm)
5		
10		
15		
20		
25		
30		

15. Plot this data on the graphs below. Be sure to enter an appropriate scale so as to fit your data on the vertical axis of each graph.

Ball Height versus Dent Width



Ball Height versus Dent Depth



16. Summarize the relationship between the height of the ball drop and the energy indicated by the dent made by the ball in the foil insulation.

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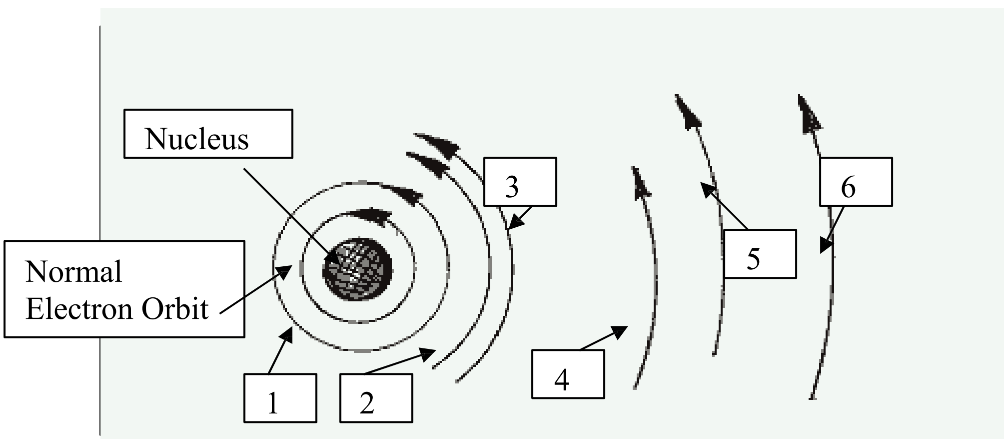
Energy for Earth: The Sun

Part 4: Potential Energy, Kinetic Energy, and Radiation from the Sun

What does the “ball drop activity” have to do with the earth’s receiving radiation energy from the sun? If you understand the energy changes from potential to kinetic energy that occurred, you can use it as a model for the production of radiation within a star such as our sun. The steel ball represents an electron rapidly orbiting the nucleus of an atom. When the huge amounts of energy are released during the nuclear fusion of hydrogen atoms into helium atoms within the sun’s core, the heat and motion of matter within the sun cause collisions among the atoms. This energy, when absorbed by the electrons of these atoms, lifts the electron [stored potential energy] from its normal orbit in the circular pathway closest to the nucleus into one of the higher excited states farther from the atomic nucleus [shown by curving arrows 1, 2, 3, 4, 5, and 6 below]. These are like the higher levels to which you lifted the steel ball.



The electron remains at the higher energy level only momentarily, and then falls back toward its original normal level just like the steel ball falling to the foil.

1. Which excited electron level in the diagram above represents the greatest input of stored or potential energy?

2. The most energy will be released when the electron falls from which excited electron level?

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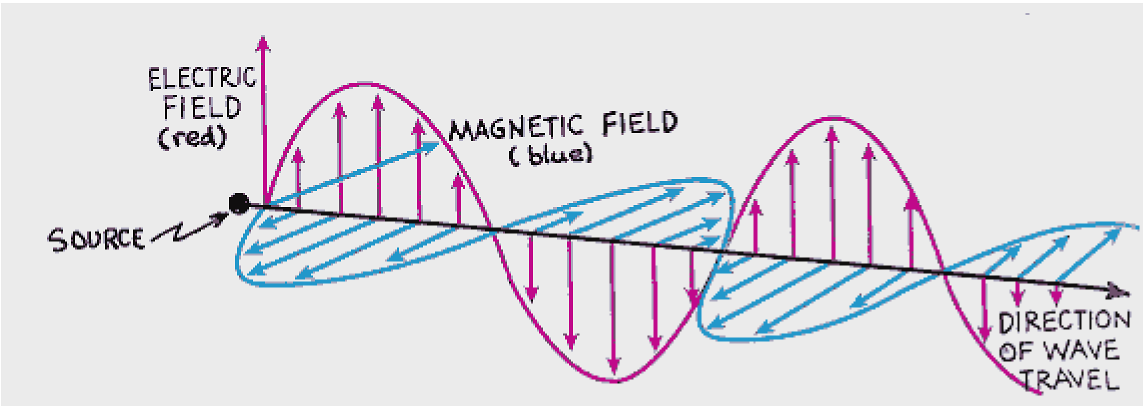
Each drop distance of the electron represents a unique amount of energy. The energy is released in the form of electromagnetic radiation shown in the diagram below. Notice that there are two waves traveling together, an electric wave and a magnetic wave—thus the name.

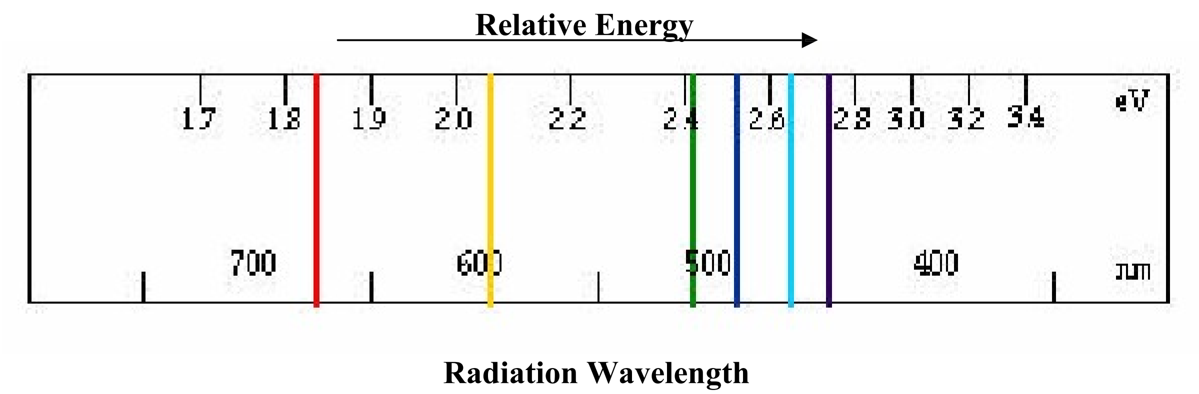


You probably know that a moving electric current always produces a magnetic field: an effect that creates the electromagnet. You may also know that the reverse is true. A moving magnetic field can produce an electric current, which is the basis for pieces of technology such as the electric generator. The physicist James Maxwell discovered in the mid-1800s that the radiation from the sun behaves as a changing electric field that generates a changing magnetic field, which in turn regenerates the changing electric field and so on.... This occurs only if the electromagnetic radiation is moving at a speed of 300,000 meters per second, the speed of light—a value that Maxwell was able to calculate (not measure) from his mathematical equations!

3. That radiation has the properties of a fast-moving electric current makes sense given the "source" of the radiation in the diagram above. What is the source?

4. As the amplitude (the height) of the electric wave increases, what happens to the height of the magnetic wave?

When the electromagnetic radiation from the electrons of the atoms of one chemical element in the gaseous phase is refracted through a prism, a distinctive fingerprint of bright lines is seen as shown in the example below. Each line has a particular wavelength (the bottom scale in 10^{-7} centimeters) and relative energy (the top scale).



5. Which line has the shortest wavelength?

6. Which line has the greatest amount of energy?

7. State the general relationship between wavelength and energy content of these six electromagnetic waves.

8. If these six spectral lines were produced by the fall of our model electron (the steel ball) from the "model electron levels" shown in the first diagram above, which excited orbital state produced which spectral line? To answer this question, place the number of the orbital state next to the line produced on the bright line spectrum above.

DEVELOP YOUR UNDERSTANDING

1. How is energy transferred from the sun to the earth?

2. Describe the original source of that energy within the sun's core.

3. Describe how that energy is transferred from the middle of the sun to the photosphere.

4. Describe what happens within the photosphere that releases the sun's energy to space (and the earth).