The Biggest Explosions in the Solar System

presented by ThursdaysClassroom.com

Thursday's Classroom Corner

Would you like to use this story in your 6th to 12th grade classroom? These lessons might help:

- **The Biggest Explosions in the Solar System**: the Science@NASA story.
- **Discussion Questions**: Ignite a discussion in your classroom! [lesson plan] [activity sheet]
- **Electromagnetic Flash Cards**: What's the difference between x-rays and gamma-rays? This fun game will shed light on the mysteries of the electromagnetic spectrum. [lesson plan] [activity sheet] [flash cards]
- **Sunspot Twister**: Students use magnets and iron filings to create magnetic field patterns that foretell the onset of solar explosions. [lesson plan] [activity sheet] [answers]
- **Solar Rubber Bands**: This simple activity examines the rubber band-like behavior of sunspot magnetic fields -- using real rubber bands. [lesson plan]

Explosive Vocabulary:

eV: a tiny parcel of energy called an "electron Volt." 1 eV is the energy gained by an electron when it passes through a one volt battery. An efficient 60 watt light bulb emits about 10^{20} eV/sec.
arcsecond: a unit for measuring very small angles. There are 3600 arcseconds in a degree. The Sun is approximately 1800 arcseconds wide.

The Biggest Explosions in the Solar System

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Marshall Space Flight Center

NASA's HESSI spacecraft is heading for space to unravel an explosive mystery: the origin of solar flares.

Listen to this story (requires any MP3 Player)

June 12, 2001 -- Astronauts love space walks. Floating weightless hundreds of kilometers above Earth, the terrain below racing by at 17,000 mph --no space traveler wants it to end. But it only takes two words to send one of those brave explorers racing back to their craft: "Solar flare!"

"Solar flares are the biggest explosions in the solar system," says Robert Lin of UC Berkeley's Space Science Lab. "They erupt near sunspots with the force of a hundred million hydrogen bombs." Astronauts caught spacewalking during a solar flare or one of their cousins, a coronal mass ejection, can absorb a radiation dose equivalent to 100 chest x-rays -- reason enough to dash for shelter.

Above: Astronaut Steven Smith floats above Earth during shuttle mission STS-103. [more]

Flares pose little direct danger to Earth dwellers because our planet's atmosphere protects us from their deadly radiation. But the unpredictable explosions do affect our lives. They can disable satellites, scramble aircraft navigation, and interrupt high-frequency radio communications for hours.

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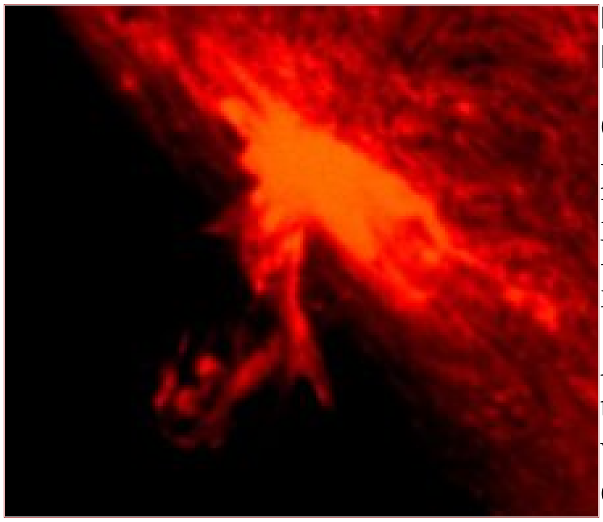
"One of the most amazing things about solar flares," says Brian Dennis of NASA's Goddard Space Flight Center, "is the efficient way they accelerate subatomic particles to energies exceeding 10^9 eV." As much as 50% of the total explosion energy emerges as electrons and atomic nuclei traveling at nearly the speed of light. "Flares operate much more efficiently than any particle accelerator we've been able to build here on Earth."

"How do flares do that?" he asks. We don't know, but terrestrial particle physicists would love to find out.

What ignites solar flares? How do they unleash so much energy so quickly? And is it possible to predict when they will happen?

Such questions have vexed astronomers since 1859 when Lord Carrington spotted a solar flare for the first time. "I was [counting sunspots on a projected image of the Sun]," he recalled, when suddenly "two patches of intensely bright and white light broke out" near a remarkably large sunspot group. "Flurried by the surprise," Carrington rushed from his telescope to call a second witness, but by the time he returned minutes later the outburst had vanished.



Left: A 4.2 MB mpeg movie shows a solar flare in action, blasting hot gas away from the limb of the Sun. [more]

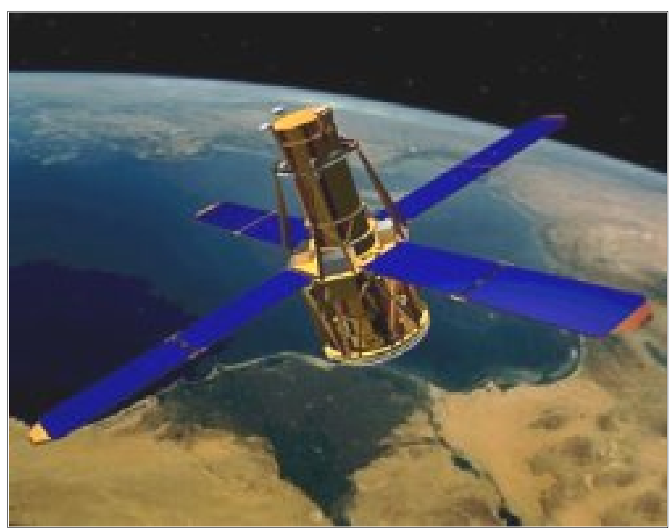
Carrington knew he had glimpsed something enormously powerful, but what he saw was just the tip of the iceberg. Fast-moving particles that emerge from flares radiate mostly high-energy x-rays and gamma-rays. Lower-energy visible light isn't as important.

And therein lies the reason that flares have been able to guard their secrets for so long. The explosions are brightest at wavelengths that Earthbound observers can't see with their eyes. Telescopes are hobbled, too, because our atmosphere is opaque to x-rays and gamma-rays.

Now a new NASA satellite aims to change all that. The High Energy Solar Spectroscopic Imager (HESSI for short) will orbit Earth nearly 600 km above our planet's obscuring atmosphere, where it can record x-ray and gamma-ray emissions from flares. HESSI, which is slated for launch no earlier than June 14th, isn't the first spacecraft capable of detecting such radiation. But it will be the first to capture crisp hard x-ray and gamma-ray images of the violent explosions.

"The angular resolution of HESSI's hard x-ray images will be about 2 arcseconds or about as good as you could get from an optical telescope on the ground." says Lin, the mission's principal investigator. The gamma-ray images will be a little less detailed, with resolutions between 7 and 36 arcseconds. But, Lin notes enthusiastically, "we've never seen *any* gamma-ray image of a solar flare before." HESSI's will be the first.

Right: An artist's rendering of HESSI in orbit 600 kilometers above Earth. [more information]

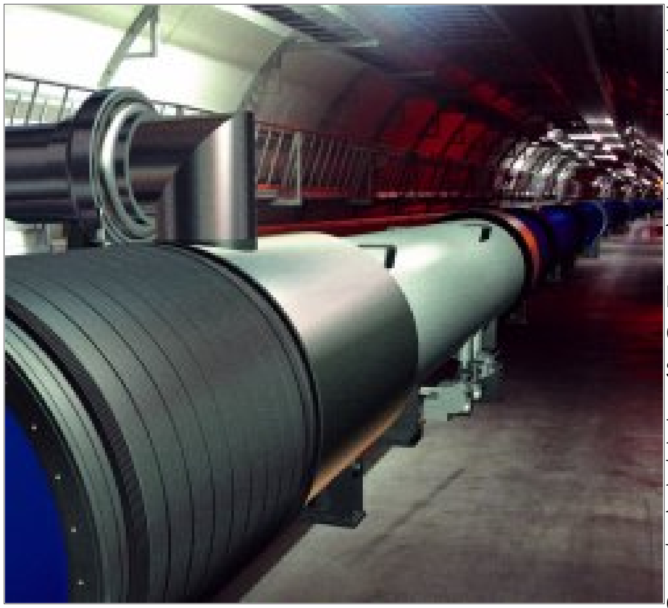


To put these numbers into perspective, consider the following: When a solar flare erupts, it heats a region of the Sun's atmosphere many Earth-diameters across. (What Carrington saw in 1859 was the white light "bloom" from such a flare.) HESSI's hard x-ray images will reveal details only 1700 km wide -- about the distance between Los Angeles and Seattle.

That's amazing because such high-energy x-rays and gamma-rays can't be focused; they fly right through conventional lenses. Instead, HESSI forms images by looking at the Sun through finely-spaced parallel slats --like microscopic Venetian blinds-- that cast shadows across onboard radiation detectors. "We'll rotate the spacecraft every 4 seconds to create a modulation pattern from the shadows that we can analyze to form an image of the Sun," explains Lin. The process is similar to a medical x-ray, except scientists are interested in the source of the rays (the Sun), not the material that blocks them (the slats).

HESSI's cameras can make pictures of the entire Sun, but researchers will be especially interested in sunspots. "That's where flares erupt -- in the vicinity of sunspots with intense, twisted magnetic fields," says George Fisher, a colleague of Lin's at Berkeley. "Twisted magnetic fields are like rubber bands stretched taut," he explained. "They want to snap back -- violently. Reconnecting fields are probably the power source for flares."

At least that's what most solar physicists believe. The problem is, no one has ever seen it happen. "Before HESSI we couldn't locate the onset of an eruption with sufficient precision to make the connection between flares and kinks in the magnetic field," says Fisher. "I'm dying to know where flare particles are accelerated, and I think HESSI is finally going to show us."



HESSI's job is important fundamental physics, adds NASA's mission scientist Brian Dennis. Understanding how flares work could teach us how to build better particle accelerators on Earth and maybe even advance the cause of fusion power, which also involves superheated gases threaded by magnetic fields.

Left: Inside the CERN high-energy particle accelerator in Geneva. Basic research on solar flares might one day improve such devices on Earth. © CERN Geneva

HESSI's findings will also shed light on mysterious happenings far outside our solar system. "Whatever triggers solar flares could be the same mechanism that blasts jets of particles from the magnetized accretion disks of black holes and neutron stars," says Dennis. "The Sun is comparatively nearby, so it's a natural laboratory for studying such exotic processes."

Meanwhile most astronauts would be satisfied with simple timely predictions of garden-variety solar flares, a potential spinoff of the HESSI mission. If the spacecraft can accomplish that one thing, space will become a safer place ... for everyone.

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Editor's note: Solar flares are closely related to coronal mass ejections (CMEs) -- billion-ton clouds of gas that billow away from the Sun and trigger geomagnetic storms when they strike Earth's magnetosphere. Scientists once thought flares propelled CMEs into space, but we've since learned that flares and CMEs can happen together or separately. Perhaps the two are different aspects of the same kind of explosion triggered by changing magnetic fields on the Sun. No one is sure. "One of HESSI's goals is to understand the relationship between solar flares and CMEs," says Dennis. [**Listen** to Bob Lin discuss CMEs].

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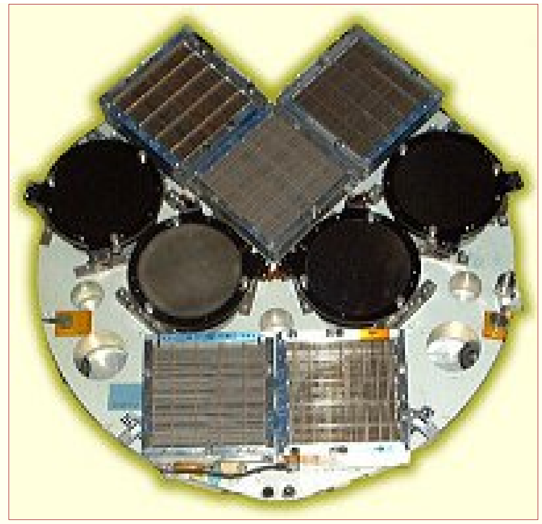
Web Links

HESSI Fact Sheet: The mission at a glance, from NASA's Goddard Space Flight Center.

The High Energy Solar Spectroscopic Imager: education and public outreach site from the University of California Berkeley.

The High Energy Solar Spectroscopic Imager: mission home page from NASA's Goddard Space Flight Center

How does HESSI make x-ray images? It's done with shadows!



Space Spinoff: The manufacture of HESSI's image-forming grids is possible thanks to newly developed microfabrication techniques. Potential applications include x-ray imaging for high-volume baggage inspection, characterization of heavy metal deposits, and radioactive waste assessment. It's another down-to-Earth spinoff of fundamental space research.

Listen: Berkeley astronomer Bob Lin explains how solar activity affects life on Earth.

The First Recorded Solar Flare -- Excerpt from: Description of a Singular Appearance seen in the Sun on September 1, 1859. by Richard C. Carrington, Monthly Notices of the Royal Astronomical Society, vol. 20, 13-15, 1860.

Atmospheric Transmission -- the Good News and the Bad News - Find out why you need to be above Earth's atmosphere to "see" gamma-rays and x-rays.

Why Study Solar Flares? NASA/Goddard's Solar Flare Theory web site offers some answers.

Coronal Mass Ejections -- learn more about these cousins of solar flares from NASA/Goddard's Solar Flare Theory web site.

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THE END

Teacher Lesson Plans
Discussion Questions

Objective:

The student will read or listen to the article and participate in a three-level discussion of the information.

Materials:

The student could have a copy of the article and the questions, or the activity may be done orally.

Estimated Time: The article and the discussion will probably take about 25 minutes.

Procedure:

1. Introduce the topic by talking about explosions. What explosions have the students witnessed? Created? What other explosions do they know about. Explain that they are going to read about the biggest explosions in our solar system.

2. As a class, read the article. Stop to explain what a solar flare is, note the common questions of modern astronomers and Lord Carrington, define an arcsecond as 1/3600th of a degree in the sky (a degree being about the width of a thumb held at arm's length), and discuss magnetic fields.

3. After reading the article, discuss the questions. Answers follow.

Discussion Questions

1. How much energy is unleashed in a solar flare explosion? As much as a hundred million hydrogen bombs.

2. What do scientists think might be the power source of solar flares? Twisted magnetic fields on the Sun.

3. What is the real name of the new NASA satellite called HESSI? The High Energy Solar Spectroscopic Imager.

4. What is an electron volt or "eV"? A tiny parcel of energy equal to the energy gained by a single electron as it passes through a 1 volt battery. Scientists often measure particle energies in eV. Particles accelerated by solar flares carry billions of electron volt's worth of energy.

5. Why do solar flares pose little danger to Earthlings? We are protected by our planet's atmosphere.

6. Where do flares usually erupt? Above sunspots

7. How do solar flares affect human life? They disable satellites, scramble aircraft navigation, and interrupt high-frequency radio communications

8. Why is radiation a problem for humans? Too much radiation can cause nausea, radiation sickness, and cancer

9. What ignites solar flares? Scientists do not know yet. They hope HESSI will reveal the answer.

10. Why are astronauts interested in solar flares? When they are in space, they are unprotected by Earth's atmosphere. Solar flares can release dangerous amounts of radiation.

11. Why do we know so little about solar flares? The explosions are brightest at wavelengths of light, called x-rays and gamma-rays, that we can't see.

12. Why are physicists interested in solar flares? Basic research about solar flares could reveal how to predict the explosions, how to build better particle accelerators, and perhaps even tell us what accelerates particles away from black holes and neutron stars.

13. Are you interested in anything that you can not see? Make a list. Answers will vary.

14. Do you think solar flares will affect human life more or less in the future? Why? Answers will vary. Increases in telecommunications and satellites in general will make us more vulnerable.

Rationale:

Discussion will promote long term retention and comprehension of the information.

The Biggest Explosions in the Solar System
Discussion Questions

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2. What do scientists think might be the power source of solar flares?

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12. Why are physicists interested in solar flares?

13. Are you interested in anything that you can not see?

14. Do you think solar flares will affect human life more or less in the future? Why?

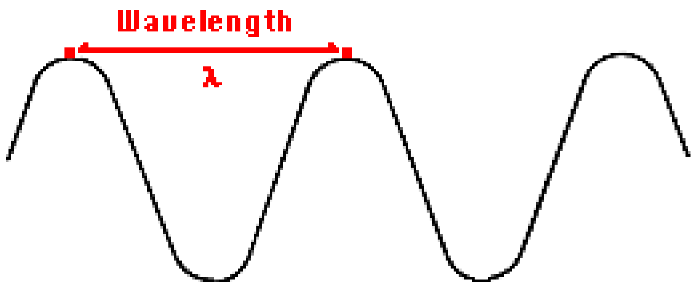
Teacher Lesson Plans
"Electromagnetic Flash" Cards

Objective:

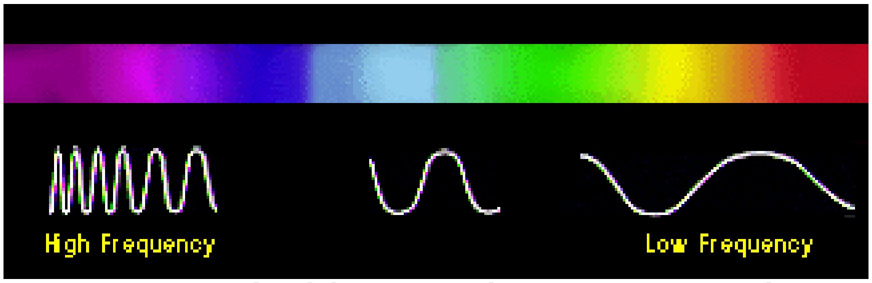
By playing a simple card game, students will learn that gamma rays, x-rays, ultraviolet radiation and radio waves are all parts of the electromagnetic spectrum -- just like light.

Background:

Although we can't see them, gamma rays are simply another form of light. Gamma rays, light rays, x-rays and radio waves are all part of the electromagnetic spectrum. For an overview of the electromagnetic spectrum and the differences between light and gamma rays, please visit this excellent web site from NASA/Goddard.



Electromagnetic waves oscillate. How fast they oscillate is called their frequency. For example, AM radio waves oscillate (move back and forth) about one million times per second, or 1 MegaHertz. (Hertz is a unit physicists use. It means "once per second.") The wavelength of an electromagnetic wave is the distance *between wave crests. For an AM radio wave that distance is about 300 meters.*



The energy carried by an electromagnetic wave is proportional to its frequency. Radio waves have a relatively low frequency; they are low energy waves. Gamma rays have a very high frequency; they are high energy waves. A typical gamma ray carries 3,000,000,000,000 times more energy than an AM radio wave.

On the playing cards, the "Power Points" are proportional to the energy carried by a wave of the type indicated on the card. All of the power points are relative to the power carried by a 1 Megahertz AM radio wave.

Materials:

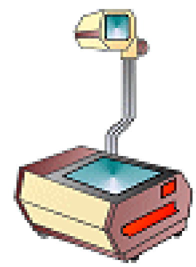
The student will need a copy of the activity sheet, the card sheet, and some scissors. You should also copy a diagram of the electromagnetic spectrum onto transparency paper for display on your overhead projector, or simply distribute a copy of the diagram to each member of the class.

Estimated Time:

The cutting is what takes the time here. You can save ten minutes of instructional time if you can get someone to cut out the cards on a paper cutter for the kids. Remind them to only cut one page at a time so that each student receives a complete set. The lesson take about ten minutes to teach and about 15 minutes of play time.

Procedure:

1. Distribute the activity sheet and read the description of the activity. They will be excited so try to get the questions answered now.



2. On a overhead projector, show the diagram of the electromagnetic spectrum. Be sure to mention that gamma rays and light are the same thing, it's just that gamma rays carry more energy than light and our eyes cannot see them. Both are waves, but gamma rays have a shorter wavelength and they oscillate faster than the type of light our eyes can see. Radio waves are also a form of light. They have a longer wavelength and oscillate slower than the type of light our eyes can see.

Someone is bound to ask if gamma rays move faster than light. NO. All forms of electromagnetic radiation move at the same maximum speed -- 186,000 miles per second.

3. Pass out the cards. Either have them cut the cards out or have them check to make sure that they have a complete set. Review the values on the cards and go through a couple of examples of which would be brighter scenarios. Model the game.

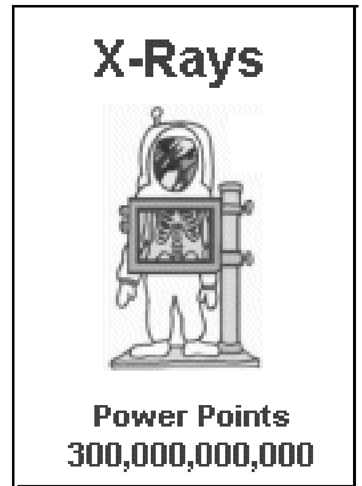
4. Let them play!

Rationale:

This is a highly motivational means of familiarizing students with an intrinsically confusing but important scale.

Name: ____________
Date: ____________

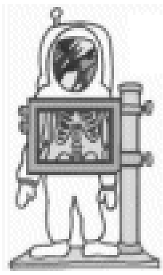
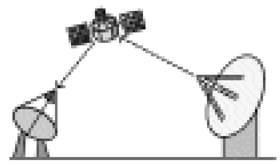
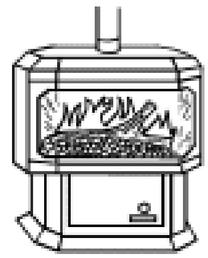
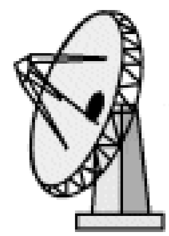
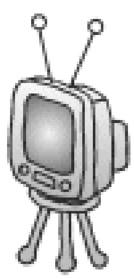
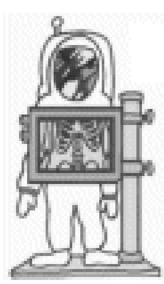
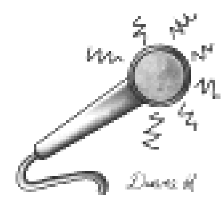
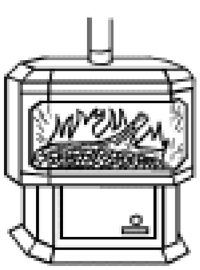
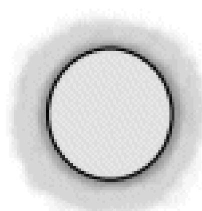
Electromagnetic Flash Cards



Did you know that radio waves, infrared radiation, and x-rays are really the same things ? They are all different forms of light. They may not look like light (hey, you can't even see them!), but that's what they are. Light, radio waves, gamma rays, x-rays, infrared waves and ultraviolet radiation all all parts of the **electromagnetic spectrum**.

Believe it or not, you can learn about the electromagnetic spectrum by playing cards. Each of the playing cards your teacher gives you represents a different form of light -- from radios waves to gamma rays. The number of "Power Points" at the bottom of the card shows how powerful that form of radiation is. The weakest is AM Radio with 1 power point. The strongest is gamma rays with 3,000,000,000,000 power points (count the zeros!).

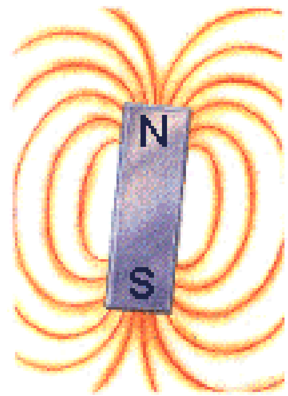
Play the same way that "War" is played. If you have trouble with a partner who is trying to wait until you flip your card before he/she flips hers, try this; both of you chant "One, Two, Peekaboo!" and both flip the cards as you say "peekaboo." The person who flips the most powerful card takes possession of both cards. If you both flip the same type of radiation, each person lays one card face down and then flips another face up; the winner takes all six cards. Have fun!

X-Rays  **Power Points** **300,000,000,000**	**UltraViolet**  **Power Points** **30,000,000,000**	**Microwaves**  Microwaves are used to communicate with satellites. **Power Points** **2400**	**Gamma Rays**  **Power Points** **3,000,000,000,000**
Visible Light  **Power Points** **600,000,000**	**Shortwave Radio**  **Power Points** **10**	**Infrared**  **Power Points** **10,000,000**	**FM Radio**  **Power Points** **100**
Television  **Power Points** **250**	**X-Rays**  **Power Points** **300,000,000,000**	**Gamma Rays**  **Power Points** **3,000,000,000,000**	**AM Radio**  **Power Points** **1**
Infrared  **Power Points** **10,000,000**	**Microwaves**  People use microwave ovens to cook popcorn! **Power Points** **2400**	**Visible Light**  **Power Points** **600,000,000**	**UltraViolet**  **Power Points** **30,000,000,000**

Teacher Lesson Plans
Sunspot Twister

Background:

Electric and magnetic fields are two different manifestations of electromagnetism. Electric force fields are caused by positive and negative charges carried by particles like protons and electrons. Magnetic force fields are caused by charges in motion.



Sunspots have strong magnetic fields. More often than not, sunspots come in pairs. One spot is the North magnetic pole, the other is the South. The magnetic field looks like that of a bar magnet (pictured right). Scientists can trace the magnetic fields of sunspots using a device called a magnetograph.

Sunspot magnetic fields store a lot of energy -- especially when they become tangled and sheared. Magnetic fields act a bit like rubber bands. When you stretch or twist them they can snap back violently. With a rubber band all you get is a hurt finger. With a sunspot magnetic field you can end up with a tremendous solar flare.

Scientists predict when flares are going to happen by looking at sunspot magnetic fields. When the fields are simple and untangled, like a bar magnet's, flares are unlikely. When field lines are twisted and complicated, get ready for an explosion!

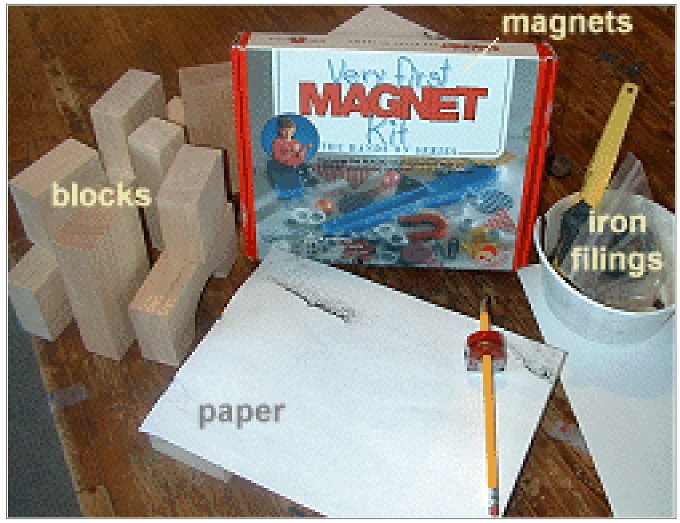
Objective:

Students will use magnets and iron filings to visualize magnetic fields that are simple, and ones that are complicated

Students will learn that twisted fields lead to solar flares.

Materials:

For each team of students you will need:



1. 1 activity sheet
2. about 1 teaspoon of iron filings. (Iron filings are easy to find. In most places you can extract them right from the dirt outside. How do they get there? That's a good topic for classroom discussion. Some are bits of construction debris and some are tiny meteorites -- no kidding! Send an adventurous student to the playground with a container and a magnet. They will love sifting their magnet through the dirt for tiny bits of iron. It takes a few recesses to get a cup. Some kids love to put water in the container to rinse off the stuff; be sure they collect the wet iron filings with the magnet before pouring it down the drain.)
3. 2 to 4 children's blocks
4. a few small pieces of scotch tape
5. at least one bar magnet, plus two or three additional magnets of any sort

6. one piece of white paper
7. a pencil

Time:

This lesson takes about 40 minutes.

Procedure:

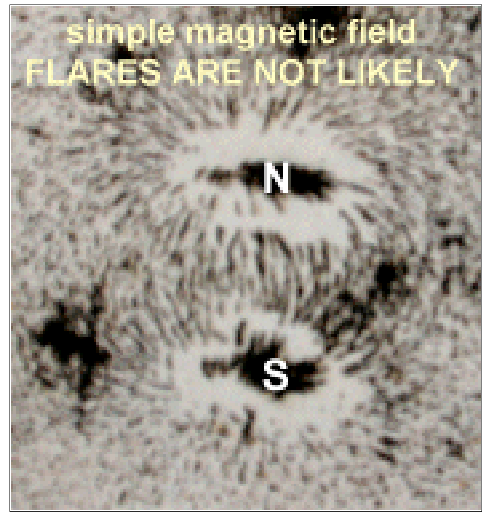
1. Divide your class into groups of 2 to 4 students. Distribute a set of materials and activity sheets to each group.

2. Show the students the iron filings. Point out the messy nature of the iron filings. Also, if they get vacuumed up they are lost.

3. Show the students how to make a paper and block work bench for their experiments. Lay several blocks flat on the table to make a 3-sided frame. Tape the paper across the top. There should be a 1 or 2 inch gap between the table and the paper. This gap is where students will insert their magnets through the missing 4th side of the frame. Iron filings will be dusted across the paper. The paper is the surface of the Sun!

4. Next, ask your students to tape a simple bar magnet to the end of a pencil. This will serve as a simple sunspot pair.

5. Using about half of their supply of iron filings, students should dust the top of their paper. A thin layer works best!

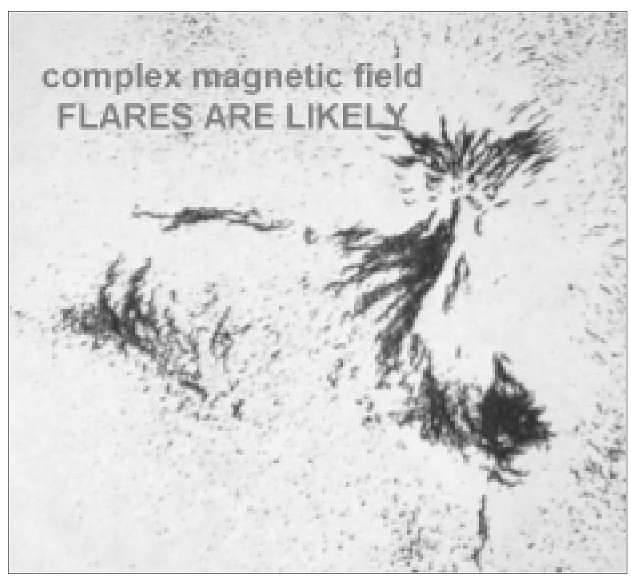


6. Insert the bar magnet underneath the paper. The iron filings will align themselves with the magnetic field. If all goes well, the iron filings will make a pattern this the one pictured right. Explain to students that these are the lines of force of a classic bipolar magnetic field. Sunspot pairs with magnetic fields like this don't often produce solar flares.

7. Now we can make a magnetic field configuration that might lead to a solar flare. Explain to the students that complicated magnetic fields store lots of energy. Use the analogy of the twisted rubber band. When a stretched or twisted rubber band snaps back, energy is released. The same thing happens to sunspot magnetic fields. When they get twisted and tangled they want to snap back to look like the field of a simple bipolar sunspot group. The energy that's released when this happens triggers a solar flare or a coronal mass ejection.

8. Ask your students to tape several magnets to their pencil in a random arrangement.

9. Dust the paper with a fresh thin layer of iron filings.



10. Insert the collection of magnets under the paper and see what happens. The iron filings will line up again, but this time they won't look like a simple bipolar magnetic field. They will more likely appear tangled and weird. This is the signature of a sunspot group that's about to produce a solar flare.

11. Now that the students have seen both types of magnetic configurations, explain that this is how space weather forecasters predict solar flares. They look at the shape of magnetic fields above sunspots. If they are

simple, like a bar magnet, flares are unlikely. If they are complex, like the field lines pictured above, an explosion is likely to happen!

Rationale:

This activity will help students understand how scientists predict solar explosion. The hands-on element will promote retention of otherwise abstract concepts.

Name: __________
Date: __________

Sunspot Twister

Sunspots are areas on the Sun where magnetic energy is concentrated. Magnetic lines of force act like rubber bands. If you twist them around and stretch them, they are likely to snap back violently. When a rubber band snaps back it hurts your finger. When a sunspot magnetic field snaps back there is a tremendous explosion called a solar flare.

You and your classmates are going to use blocks, paper, iron filings, and magnets to create your own sunspot magnetic fields. Your teacher will show you how.

After you've finished experimenting with your iron filings and magnets, come back here and answer these questions:

1. Suppose you're an astronaut in the middle of a space walk to repair the Mir space station. Ground control calls you on your radio to say that there is a sunspot group on the sun with a magnetic field like a bar magnet. What should you do? Head back for Earth? Take an aspirin and call mission control in the morning? Or simply keep working like there's no danger?

2. Later, while you're drinking coffee inside Mir, mission control calls again. One of the solar panels has fallen off! They want to know if you'll go back out for a few more repairs. They also mention that the sunspot they called about earlier now has a very twisty contorted magnetic field. What should you do?

Name: __________
Date: __________

Sunspot Twister -- With Answers

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1. Suppose you're an astronaut in the middle of a space walk to repair the Mir space station. Ground control calls you on your radio to say that there is a sunspot group on the sun with a magnetic field like a bar magnet. What should you do? Head back for Earth? Take an aspirin and call mission control in the morning? Or simply keep working like there's no danger?

Sunspots with magnetic fields like a bar magnet are usually not in danger of erupting. Keep working!

2. Later, while you're drinking coffee inside Mir, mission control calls again. One of the solar panels has fallen off! They want to know if you'll go back out for a few more repairs. They also mention that the sunspot they called about earlier now has a very twisty contorted magnetic field. What should you do?

Don't go outside! Twisty contorted magnetic fields contain lots of stored energy for explosions. Sounds like there's about to be a solar flare!

Teacher Lesson Plans
Solar Rubber Bands

Objective:

Students will compare stretched rubber bands to twisted magnetic fields.

Materials:

The teacher will want to demonstrate this activity rather than arm the students with large rubber bands. Two big rubber bands are needed. Since you are demonstrating, the bigger the better. Sometimes Physical Education teachers have those arm length rubber bands or those so-called Chinese jump ropes.

Estimated time: This demonstration will take about 5 - 10 minutes.

Procedure:

1. Refer to the rubber band section of the article - "Twisted magnetic fields are like rubber bands stretched taut," George Fischer explained. "They want to snap back -- violently. Reconnecting fields are probably the power source for flares."

2. Ask students about their experiences with snapping rubber bands.

3. Pull out your big bands and get a super dependable assistant. Pull the bands apart or twist them. Discuss how a twisted rubber band has stored energy. Twisted magnetic fields have stored energy, too. What does a twisted rubber band want to do? Unleash its energy and return to a relaxed state ... snap! What do you think twisted magnetic fields will do when they are twisted by turbulent motions on the Sun?

Rationale:

This hands-on demonstration will help students to understand the abstract concept of magnetic fields as well as provide motivation.