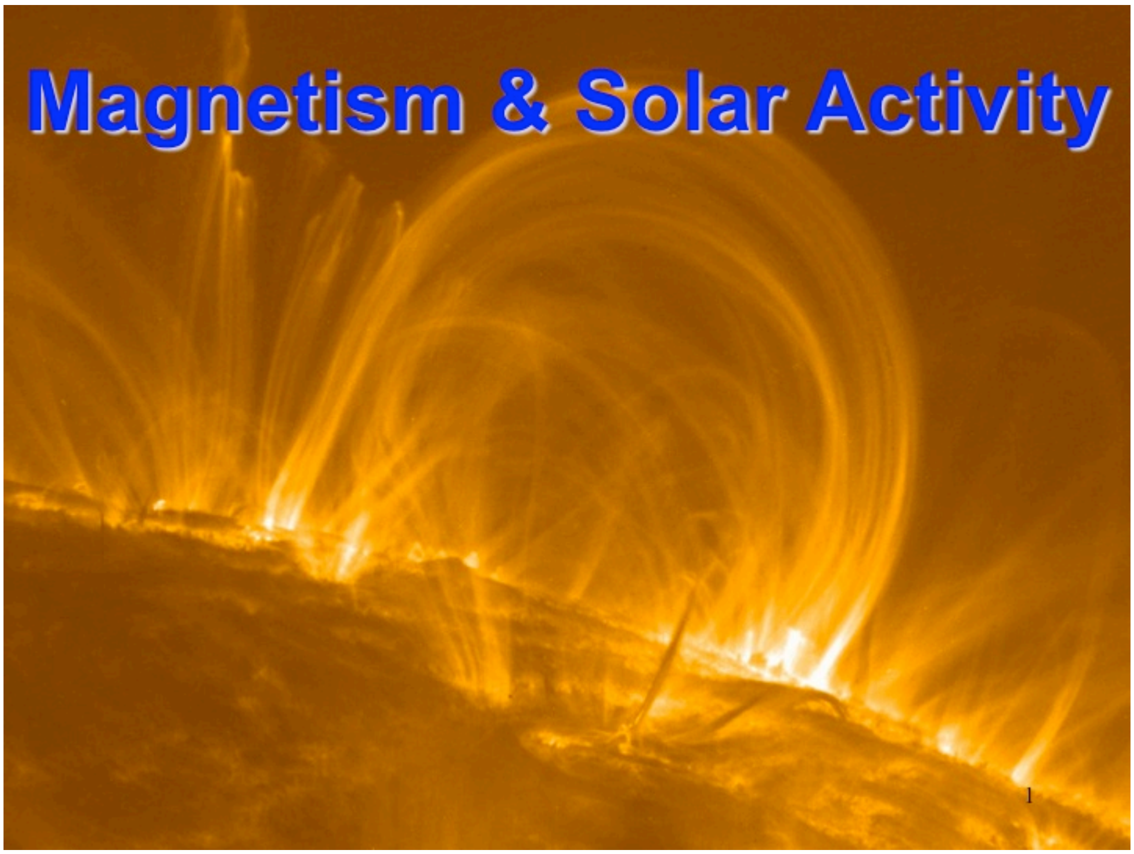
A Teacher's Guide to Magnetism and Solar Activity



NASA's Solar Dynamics Observatory, AIA instrument

Deborah Scherrer
Stanford University Solar Center

Designed to accompany the video-enhanced
"Magnetism and Solar Activity" PowerPoint presentations

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Introduction

This Teacher Guide is designed to accompany the 3 Powerpoint presentations associated with the "Magnetism and Solar Activity":

Section 1 – Magnetism on Earth
Section 2 – Our Magnetic Sun
Section 3 – The Sun-Earth Connection

The presentations include many NASA-developed descriptive videos and animations. Associated activities were developed and initially provided through hands-on high school teacher workshops given in Developing Nations, where resources relating to the Sun were often not available. The Teacher Guide includes information for all 3 sections, although the PowerPoints are separate.

This collection is not expected to be a full introduction to magnetism. Rather, the focus is on aspects of magnetism most relevant to the understanding of the Sun and solar activity. The unit includes 3 sections and 9 exploratory, hands-on activities. A materials list is provided with each activity. Many video illustrations and simulations are designed to make the lessons "come alive". The presenter is welcome to give the sections at different times and/or pick and choose what they need to present. Materials required can often be scrounged or hand-made.

I have provided extensive commentary for most slides. Adapt the amount of information to the age group you are working with.

The presentation draws heavily from the excellent *Exploring Magnetism Lesson Series* developed at UC Berkeley's Center for Science Education:

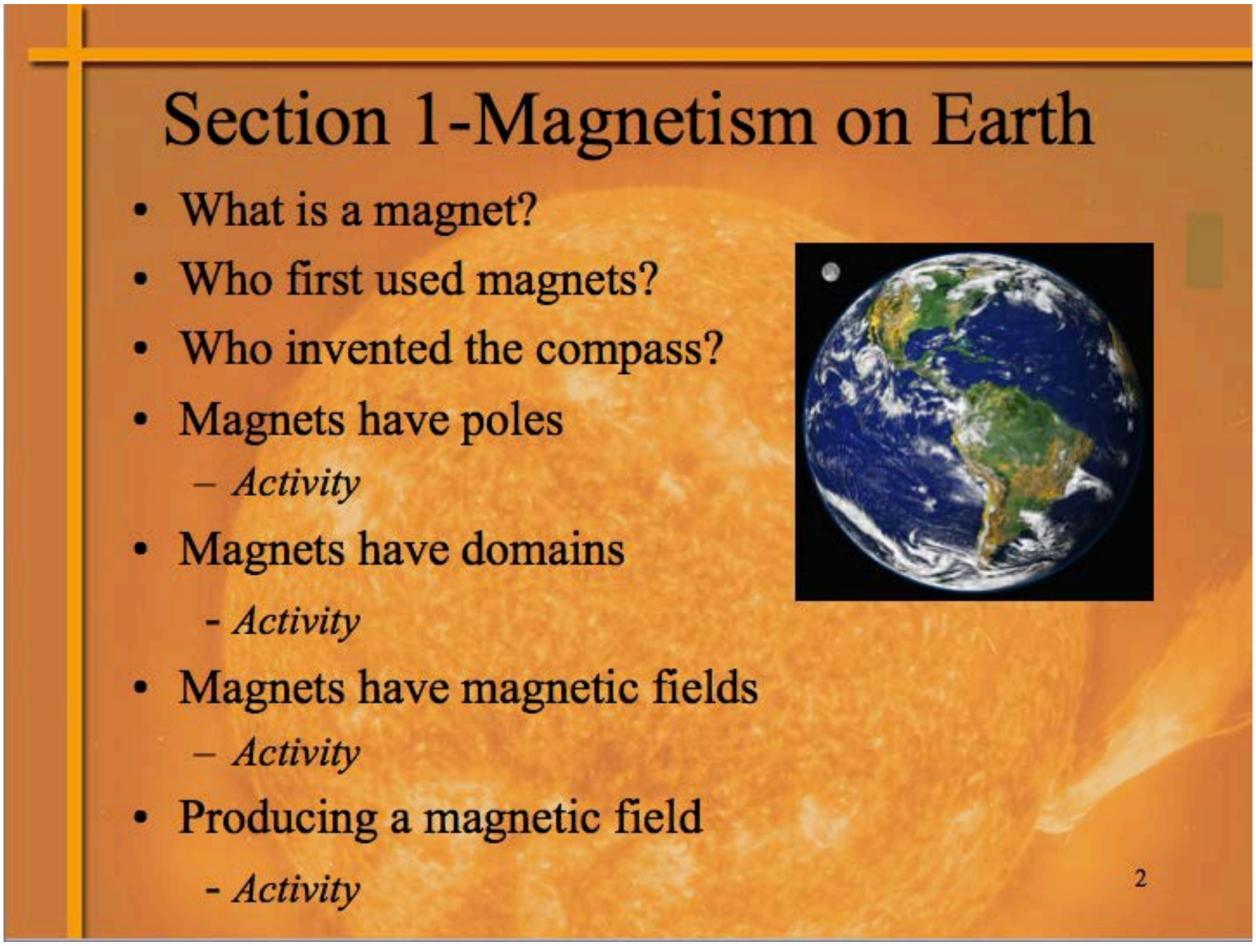
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/

Special thanks to Bryan Mendez and Ruth Paglierani for allowing use of their wonderful work and for constructive comments on the presentations and guide.

Special thanks also to Todd Hoeksema, Leif Svalgaard, and Phil Scherrer of the Solar Observatories Group here at Stanford for their support and very helpful advice on the lessons.

Deborah Scherrer,
Director, Stanford Solar Center
Stanford University

Section 1 – Magnetism on Earth

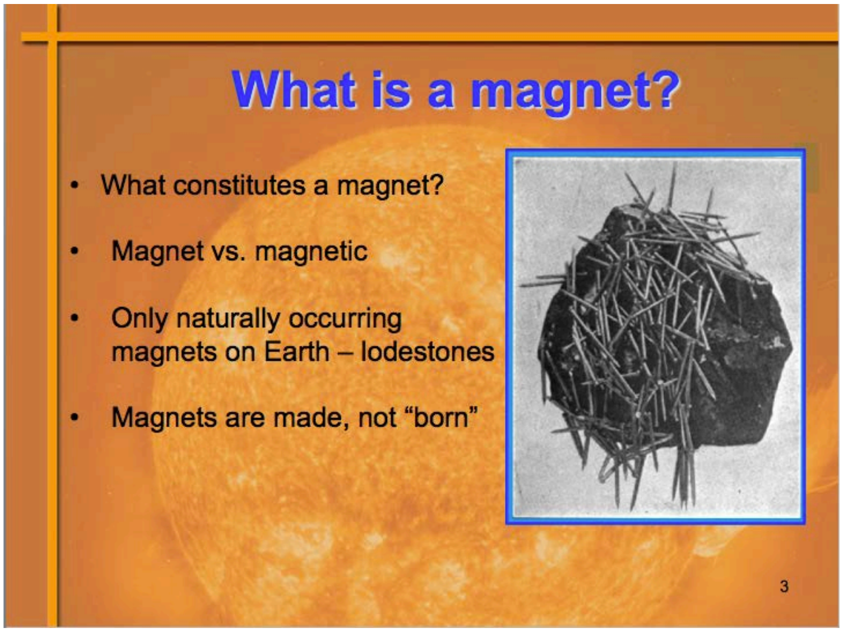


Slide 2

Learning objectives

Students will be introduced to magnets and magnetism on Earth.
They will learn the differences between a magnet and a magnetic object, about magnetic poles, magnetic field lines, and magnetic domains.

Through a series of hands-on activities they will explore magnetic poles and a variety of magnet types, learn how to produce a simple temporary magnet, experiment with mapping magnetic fields with a compass, and learn how to produce an electromagnet.



Slide 3

What is a magnet?

In simplest terms, a magnet is an object that attracts iron and some other materials. Magnets do this by generating a magnetic field around themselves. In these lessons we will explore magnets, magnetic fields, domains, magnetic poles, and how magnetism works on the Earth and the Sun.

Make sure your students understand the difference between a magnet and a material that is magnetic:

- A **magnet** is anything that produces a magnetic field.
- A material that is **magnetic** is capable of either being magnetized or being attracted by a magnet. These types of materials include iron, nickel, cobalt and their alloys, some types of rare-earth metals, and some naturally occurring minerals such as lodestone.

Magnets on Earth are made, not "born". The only naturally occurring magnets on Earth are **lodestones,** rocks with the mineral magnetite (Fe3O4). And, only some lodestones are magnets. Scientists are not sure, but they suspect that magnet lodestones were most likely struck by lighting. (Later in the lesson students will experiment with lodestones.) All other magnets on Earth are produced. Permanent magnets are made from "hard" ferromagnetic materials such as alnico and ferrite that are subjected to special processing in a powerful magnetic field during manufacture, to align their internal microcrystalline structure (i.e. their domains), making them very hard to demagnetize. More on this, and domains, later.

For more details on magnetism, see **Appendix J – More Resources.** *Image credit: Wikipedia Commons*

Note: The U.S. five cent coin called a "**nickel**" is made of 75% copper and 25% nickel. Even though it contains a small bit of nickel, a ferromagnetic material, the coins aren't visibly attracted to magnets. In fact, they hardly interact with magnets at all! https://terpconnect.umd.edu/~wbreslyn/magnets/is-nickel-magnetic.html

Slide 4

First use of magnetism

Ancient Chinese alchemists realized that magnetite ore would always point in the same direction, although they didn't know why, nor did they know what a magnetic pole was.

Earliest records show a spoon shaped compass made of lodestone or magnetite ore, referred to as a "South-pointer" dating back to sometime during the Han Dynasty (2nd century BCE to 2nd century CE). The spoon-shaped instrument was placed on a cast bronze plate called a "heaven-plate" or diviner's board that had the eight trigrams (Pa Gua) of the I Ching, as well as the 24 directions (based on the constellations), and the 28 lunar mansions (based on the constellations dividing the Equator). Often, the Big Dipper was drawn within the center disc. The square symbolized Earth and the circular disc symbolized heaven. Upon these were inscribed the azimuthal points relating to the constellations.

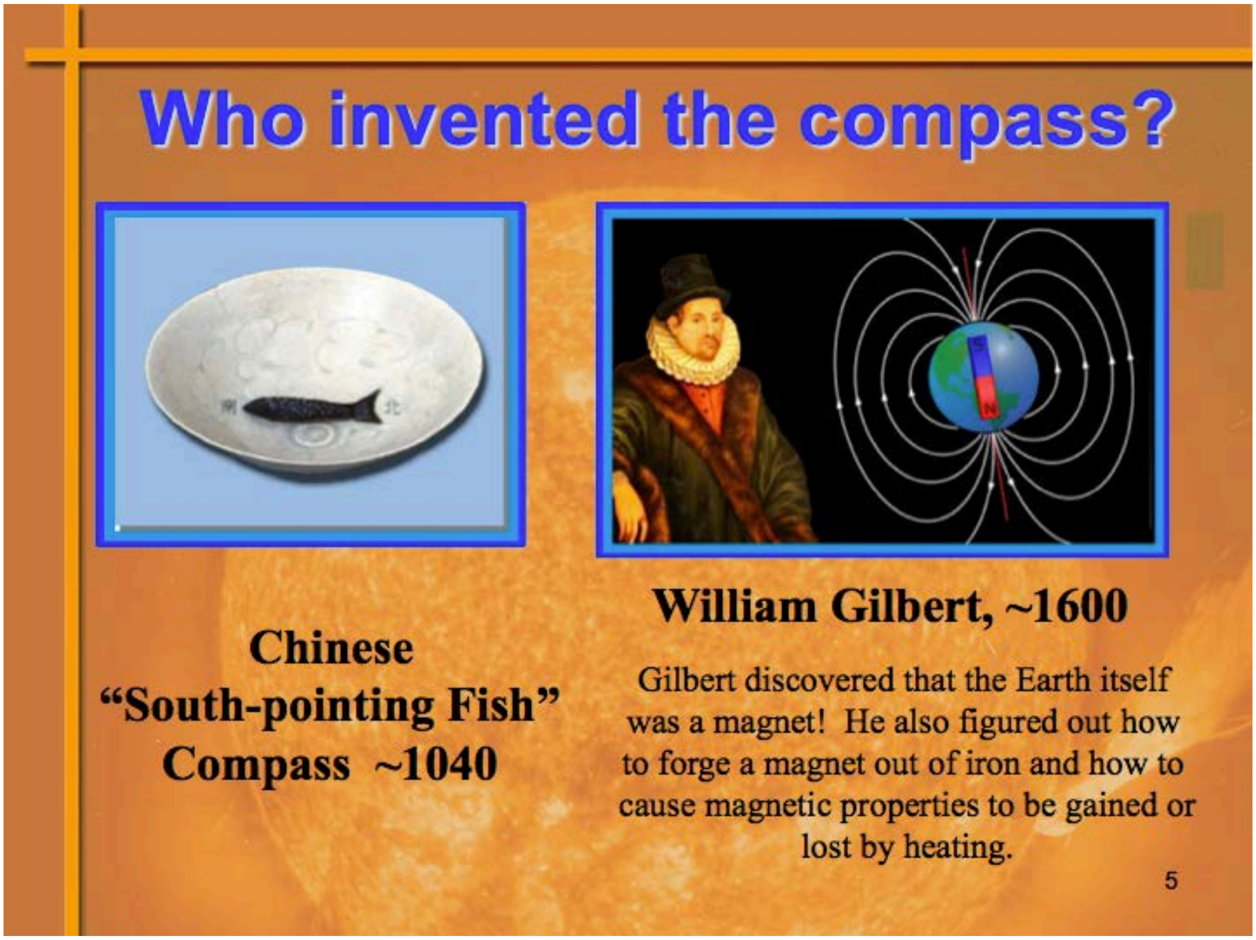
The spoon-compass primary use was that of geomancy (divination) to determine the best location and time for such things as burials. (There is a story that the first Chin emperor used the divining board and compass in court to affirm his right to the throne.) In a culture that placed extreme importance on reverence for ancestors, this remained an important tool well into the 19th century. Even in modern times there are those who use the divination concepts of Feng Shui (literally, of wind and water) for locating buildings or fortuitous times and locations for almost any enterprise.

There is reasonable evidence to suggest that the Olmec of ancient America were aware of magnets and magnetic materials. These have been incorporated into their art. An Olmec hematite artifact in Mesoamerica, radiocarbon dated to 1400-1000 BC, shows that the Olmecs may have also used magnetism for divination. If so, the Olmec use predates the Chinese use by a millennium.
https://curiosmos.com/the-ancient-olmec-incorporated-magnetism-in-their-statues-and-made-use-of-magnetic-anomalies/

In prehistoric times, meteorites were certainly recognized as metallic, though there is no evidence (yet?) that ancient humans recognized them as magnetic.

Image credits: Both from Wikipedia
Related resources:

- https://link.springer.com/referenceworkentry/10.1007%2F978-1-4020-4425-0_8712
- https://en.wikipedia.org/wiki/History_of_the_compass
- https://www.dartmouth.edu/~izapa/CS-MM-Chap.%203.htm
- https://www.jstor.org/stable/1740186?seq=1
- https://nationalmaglab.org/education/magnet-academy/history-of-electricity-magnetism/museum/early-chinese-compass
- https://link.springer.com/referenceworkentry/10.1007%2F978-1-4020-4425-0_8712



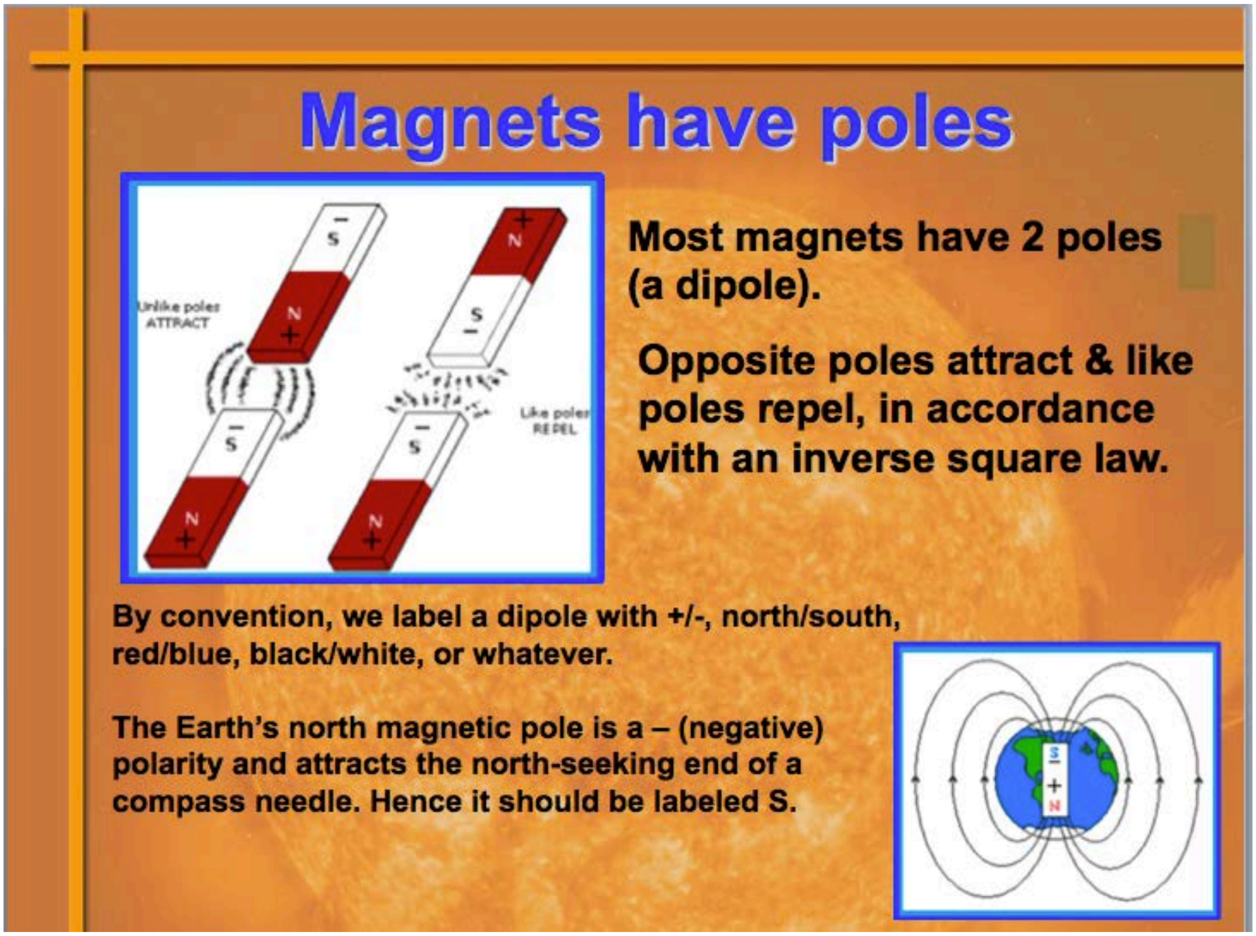
Slide 5

Who invented the compass?

The Chinese eventually figured out that magnetite would point North-South and, by around 1040, they invented the "south pointing fish" compass. The "south pointing fish" was made out of an iron or steel sheet cut out in the shape of a fish. By heating up the fish and soaking it in water, one was able to produce a weak state of magnetization (derived from the Earth's magnetic field). As the fish was placed on calm water, its head pointed toward the south.

The first western scientist to create a magnet was William Gilbert, in 1600. He discovered that magnets could be forged out of iron and that their magnetic properties could be lost if they were heated. He also discovered that the Earth itself was a magnet!

South-pointing fish credit: https://tech114ckl27.wordpress.com
Gilbert image from: https://www.famousscientists.org/william-gilbert/
See also: https://www.shenyunperformingarts.org/blog/view/article/e/vsCaJlGyWY0/chinese-inventions
https://www.dowlingmagnets.com/blog/2016/who-discovered-the-very-first-magnet/



Slide 6

Magnets have poles

Your students probably know that most common magnets have 2 poles (a dipole) and that opposite poles attract and like poles repel. If not, they should be allowed to experiment with this before going further.

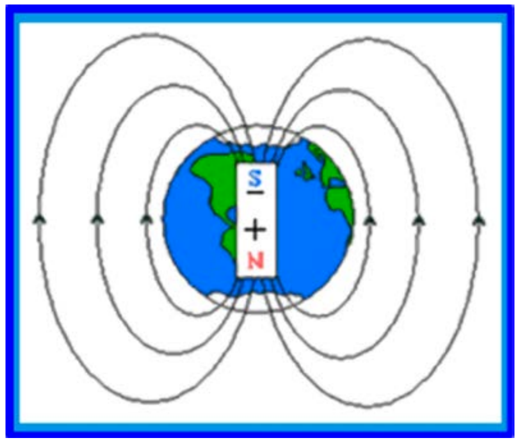
Most students are not aware that magnetic fields have a direction. Point out to your students that the direction of a magnetic field is from + (north) to – (south), as shown in the arrows around the Earth's magnetic field on the slide. Students will also discover this for themselves later on in the unit.

Common conventions used in labeling magnets:

- N/North + positive red north pole
- S/South - negative blue/white/green south pole
- Earth's southern magnetic pole is +, a north magnetic pole
- Earth's northern pole is -, a south magnetic pole

To avoid confusion scientists prefer to use "+" and "-". However most magnets students will be working with are labeled N/S, so both are used in this unit.

Going further:
The magnetic field near Earth's north geographic pole is a negative or “south” magnetic pole. The magnetic field lines at the north pole point downward into the Earth. A north-seeking pole (usually labeled N) is pulled northward. So the field lines from Earth’s south geographic pole point out of the Earth, bending around towards the magnetic pole near Earth’s north geographic pole.

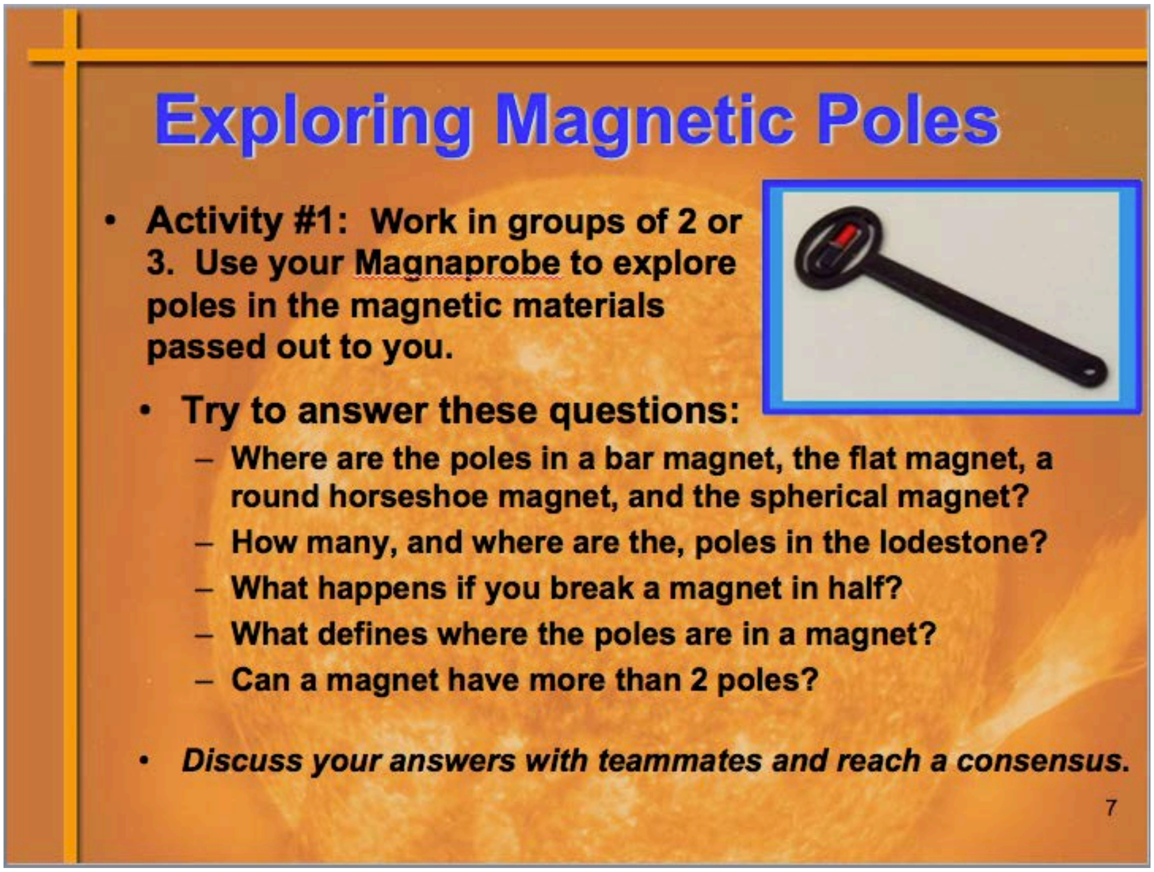


Modern compasses are north-pointing, meaning they point to what would be a “South” (negative) pole. So a typical commercial bar magnet’s “North” pole is really a north-seeking pole, and vice versa. Nowadays, we tend to think of and label things that are “north-seeking” as North, much to the consternation of scientists and confusion of the rest of us.

This usually confuses students too, since the conventions are somewhat arbitrary. The point to make is that the Earth’s north magnetic pole is equivalent to the negative end of a bar magnet (usually labeled South), and vice versa. Look at the bar magnet in the Earth above.

Or, you can skip this issue to provide more continuity to your presentation.

https://www.ucl.ac.uk/EarthSci/people/lidunka/GEOL2014/Geophysics9%20-Magnetism/Useful%20papers/Magnetism.htm



Slide 7

Activity 1: Exploring Magnetic Poles – See Appendix A

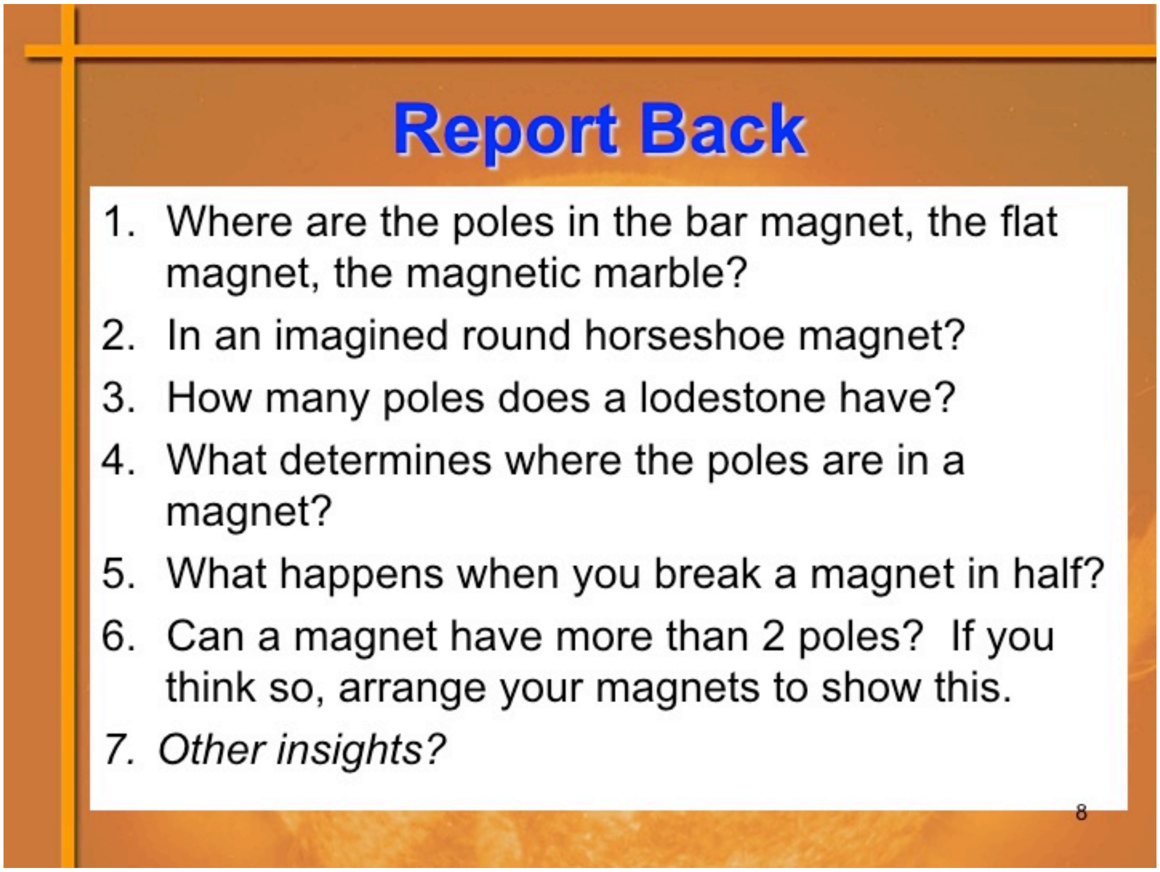
1. Complete directions are in Appendix A.

2. Divide participants into teams of 2-3 and pass out:
    a. Magnaprobe (magnetic pole finder), as described in Appendix B.
    b. Bar magnet and/or cow magnet
    c. Flat or disk magnet (e.g. refrigerator magnet)
    d. Magnetic marble
    e. Horseshoe magnet(s)
    f. Lodestone
    g. Other interesting magnets, if available
    h. Magnetic Pole Worksheet (see Appendix A)

    Directions for making or obtaining Magnaprobes (magnetic pole finders) are in Appendix B. Sources for obtaining magnetic materials are given in Appendix C.

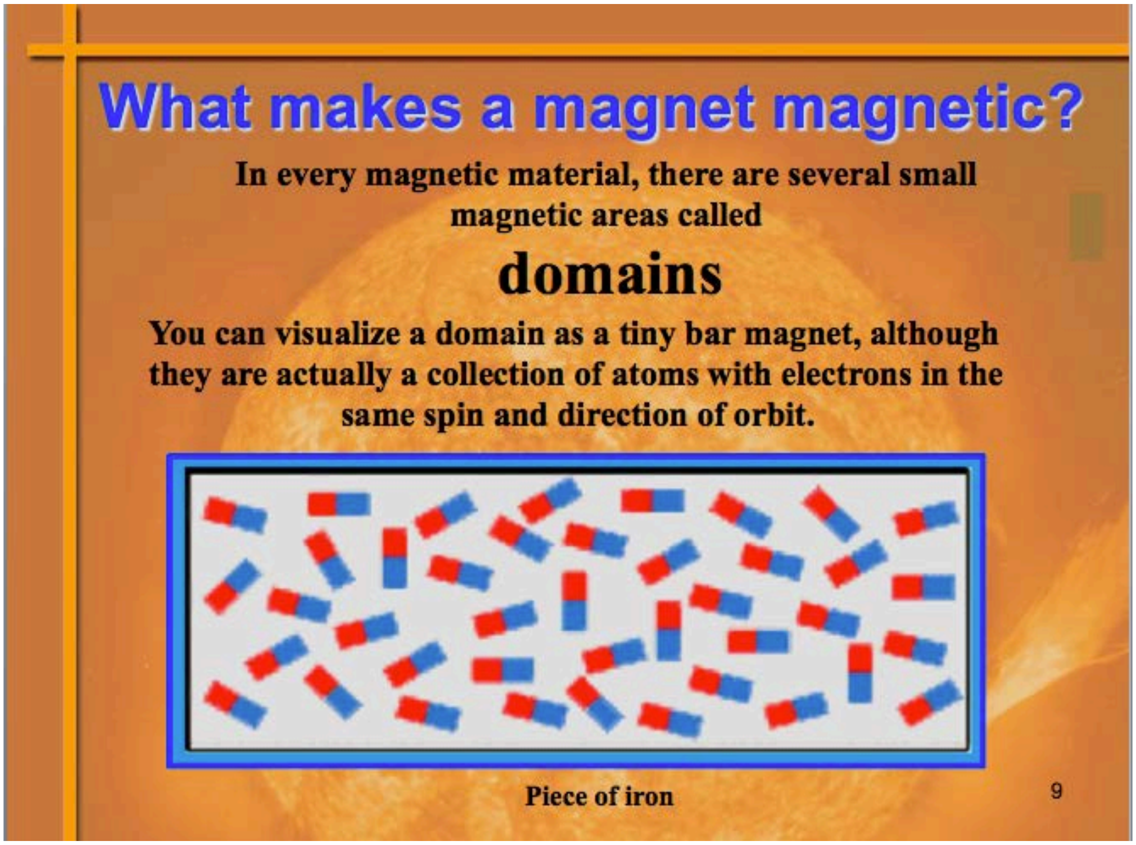
3. Ask students to explore the poles as per the instructions on their worksheets.

Activity developed by Deborah Scherrer, Stanford Solar Center.



Slide 8

4. Have teams report back on their findings. Answers are given on your worksheet as well as here:
    a. Poles in a bar magnet & a horseshoe magnet are at each end. The magnetic fields will point from **North to South**.
    b. Poles on a flat magnet are on each flat side. Fields will point from one side of the magnet to the other.
    c. A sphere will have a North and a South pole, just as the Earth does.
    d. A lodestone will also have 2 poles - a North and a South pole, usually found opposite each other at odd positions in the rock.
    e. A horseshoe magnet formed into a circle (and sealed) will have no (zero) poles. i.e. there is no way for the magnetic field to "escape". The field lines will point around the circle.
    f. The direction of the field lines determines where the poles are in a magnet.
    g. When you break a magnet in half, the 2 halves will each have a North and a South pole.
    h. Yes, complex magnetic systems can have multiple poles. Magnets can have 0, 2, or more poles, but never one. The answer worksheet gives examples. When a magnet appears to have an odd number of poles, it is usually because 2 poles have been forced against each other, hence really having an even number of poles.



Slide 9

What makes a magnet magnetic?

In every material there are many small magnetic areas called domains[1]. A magnetic domain is essentially a region within a magnetic material in which the magnetization is in a uniform direction[2]. You can visualize these as tiny bar magnets, although they are actually a collection of atoms with the electrons in the same spin and direction of the orbit.

Ferromagnetic materials, such as iron, nickel, cobalt and their alloys, contain unpaired electrons, each with a small magnetic field of its own. These align readily with each other in response to an external magnetic field. So ferromagnetic materials can be readily magnetized. The main way that permanent magnets are created is by heating a ferromagnetic material to a key high temperature then exposing the material to a strong magnetic field as it cools. The key temperature is specific to each kind of metal but it has the effect of aligning and "fixing" the domains of the magnet in a permanent position.

https://www.universetoday.com/85002/permanent-magnet/
http://www.madehow.com/Volume-2/Magnet.html
https://www.electronics-tutorials.ws/electromagnetism/magnetism.html

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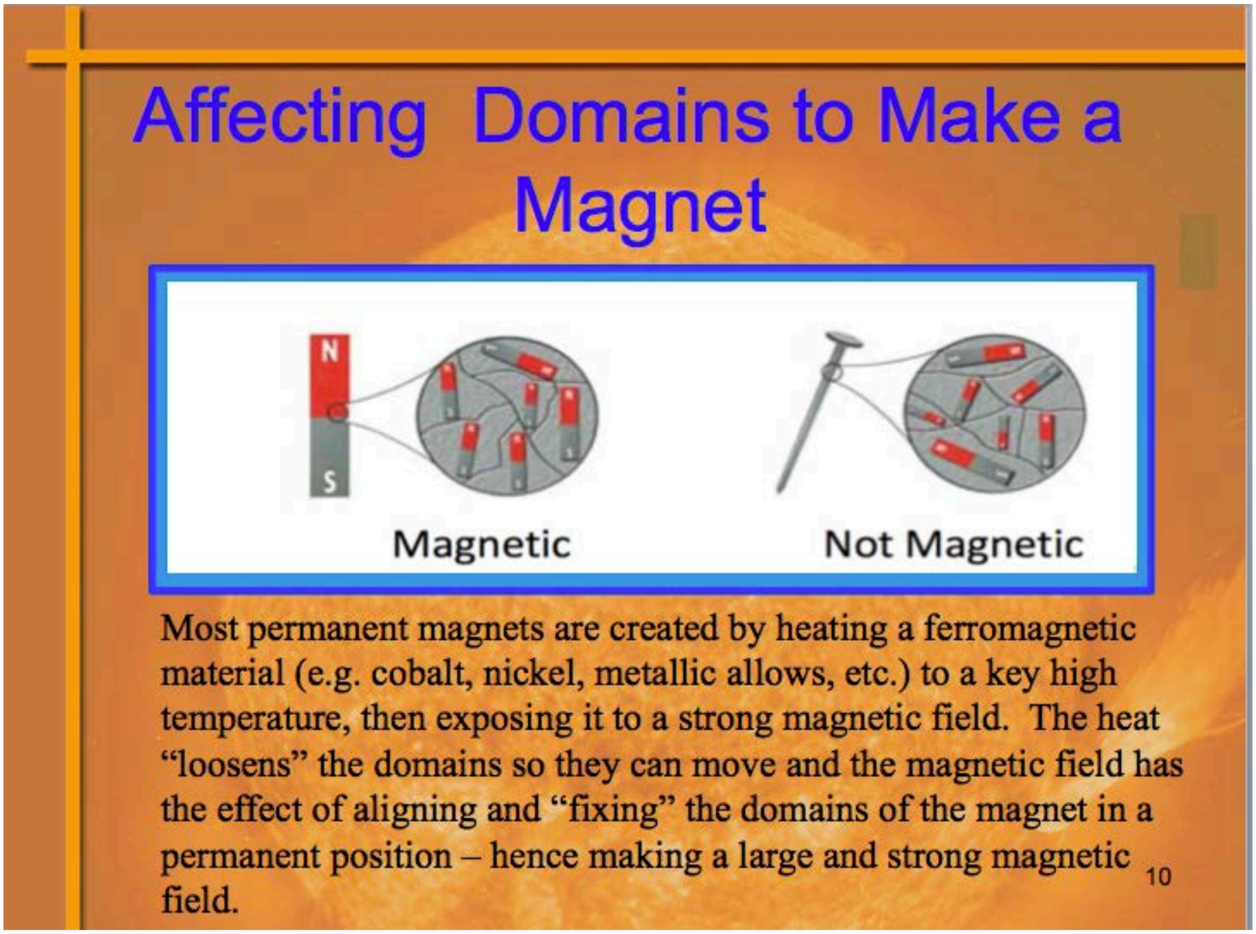
1 https://www.nde-ed.org/EducationResources/HighSchool/Magnetism/magneticdomain.htm

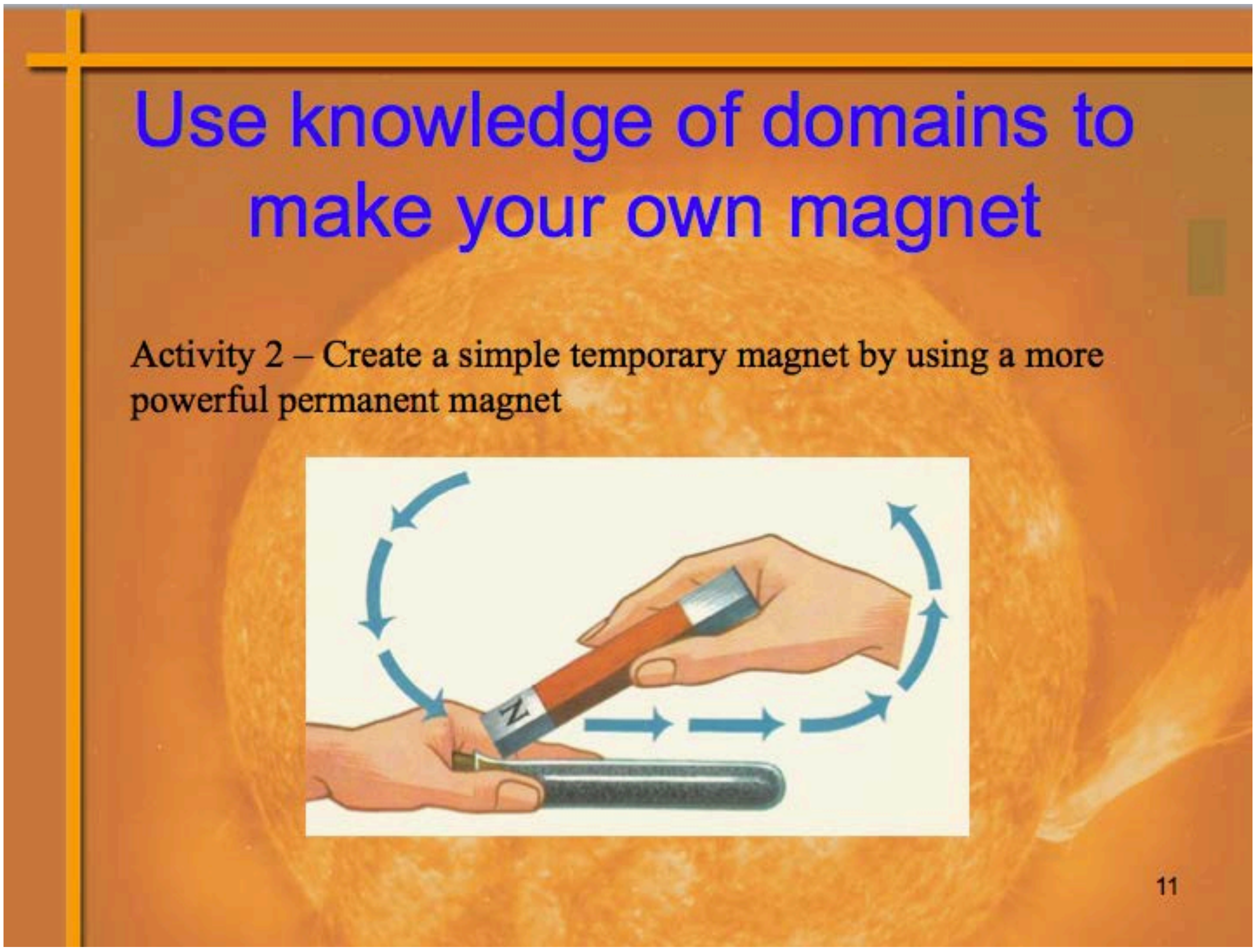
2 Wiki – article on magnetic domains



Slide 10

Affecting Domains to Make a Magnet

Most of the time domains are independent of each other and face different directions. However, a strong magnetic field can arrange the domains of any ferromagnetic metal so that they align to make a larger and stronger magnetic field. This is how most magnets are made. The regions separating magnetic domains are called domain walls, where the magnetization rotates coherently from the direction in one domain to that in the next domain.

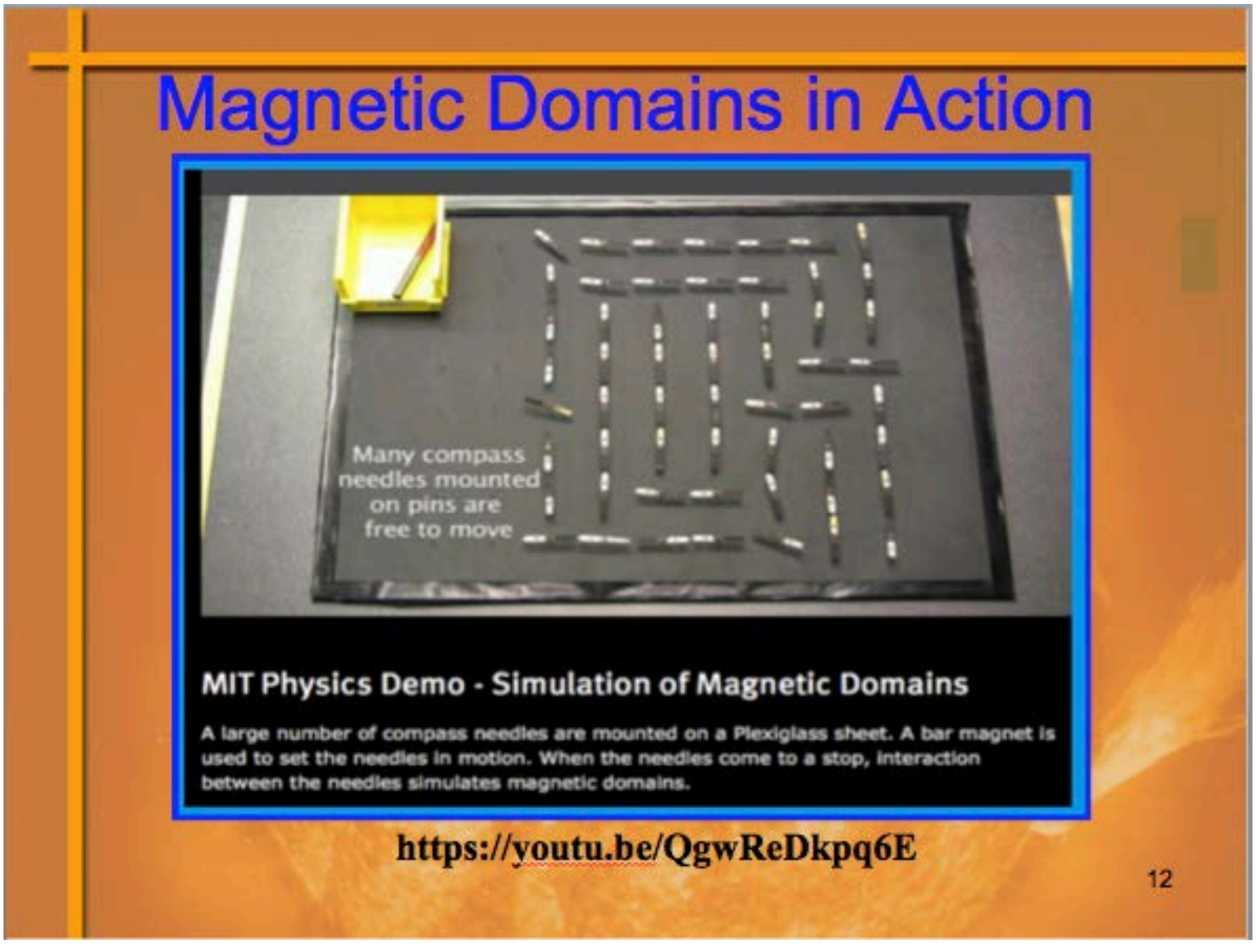


Slide 11

A *Brief Activity* –

Activity 2 in Appendix D: Creating a simple magnet by understanding domains
Students will create a simple, temporary magnet by rubbing an iron nail with a permanent magnet.

Image from
https://www.google.com/search?hl=en&tbm=isch&source=hp&biw=938&bih=739&ei=2S3DXrgBitj7BLWqhbgI&q=magnetizing+a+nail&oq=magnetizing+a+nail&gs_lcp=CgNpbWcQAzICCAAyBAgAEBgyBAgAEBgyBAgAEBhQDVjXHmDkIGgAcAB4AYAB8gOIAYoKkgEJMC4zLjAuMS4xmAEAoAEBqgELZ3dzLXdpei1pbWc&sclient=img&ved=0ahUKEwj40dGS277pAhUK7J4KHTVVAYcQ4dUDCAY&uact=5#imgrc=eTAj21eSjcWBvM



Slide 12

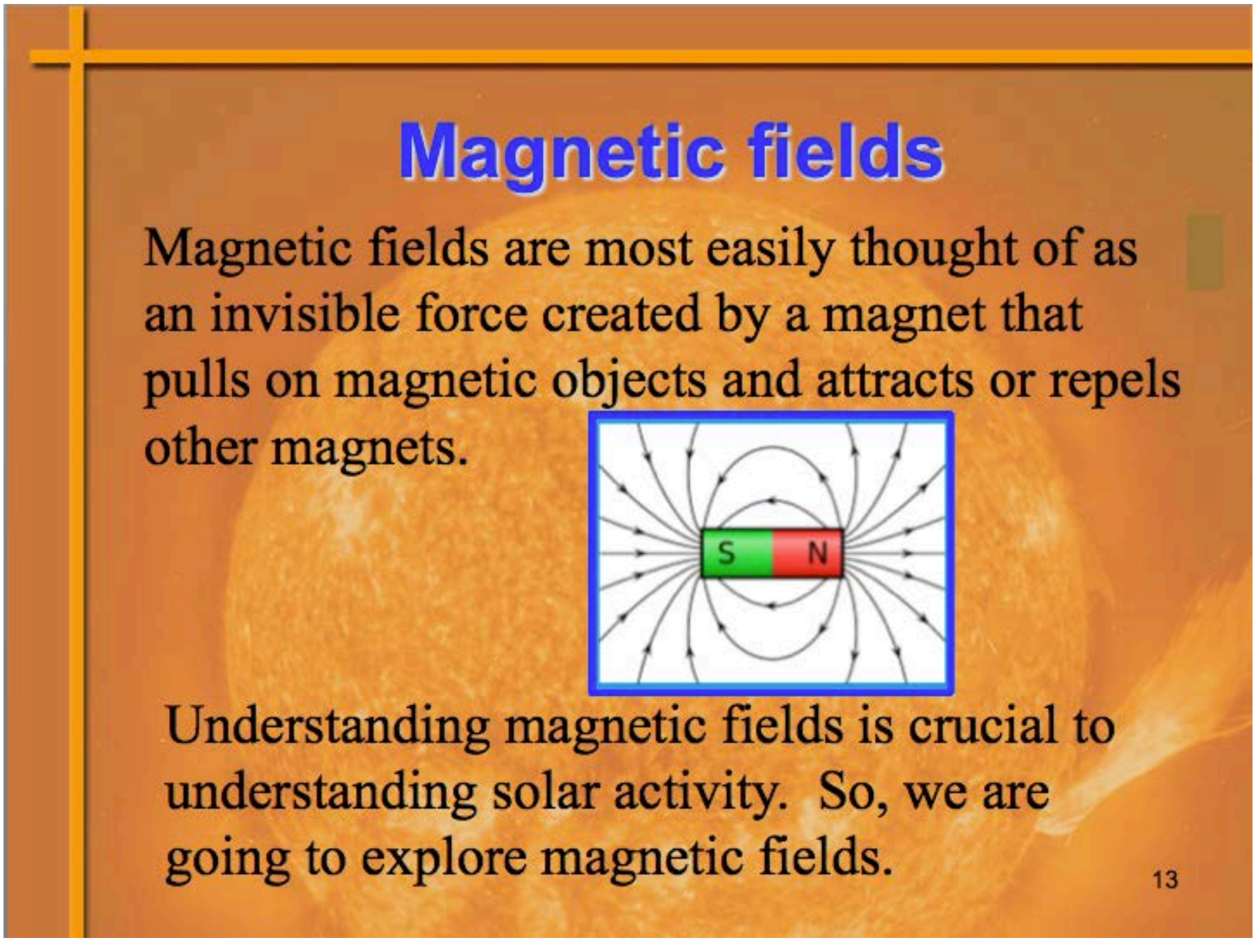
Visualization – Magnetic Domains in Action

Video

This is an excellent visualization of magnetic domains, originally available at: https://youtu.be/QgwReDkpq6E

The visualization shows that magnetic fields pull on ferromagnetic materials such as iron, cobalt, or nickel, and attract or repel other magnets. Ferromagnetic materials have domains that are sensitive to magnetic fields and tend to line up with the nearby fields. The domains then act like a magnet and are pulled to the poles that are the source of the field.

Video credit: MIT Physics Demo – Simulation of Magnetic Domains

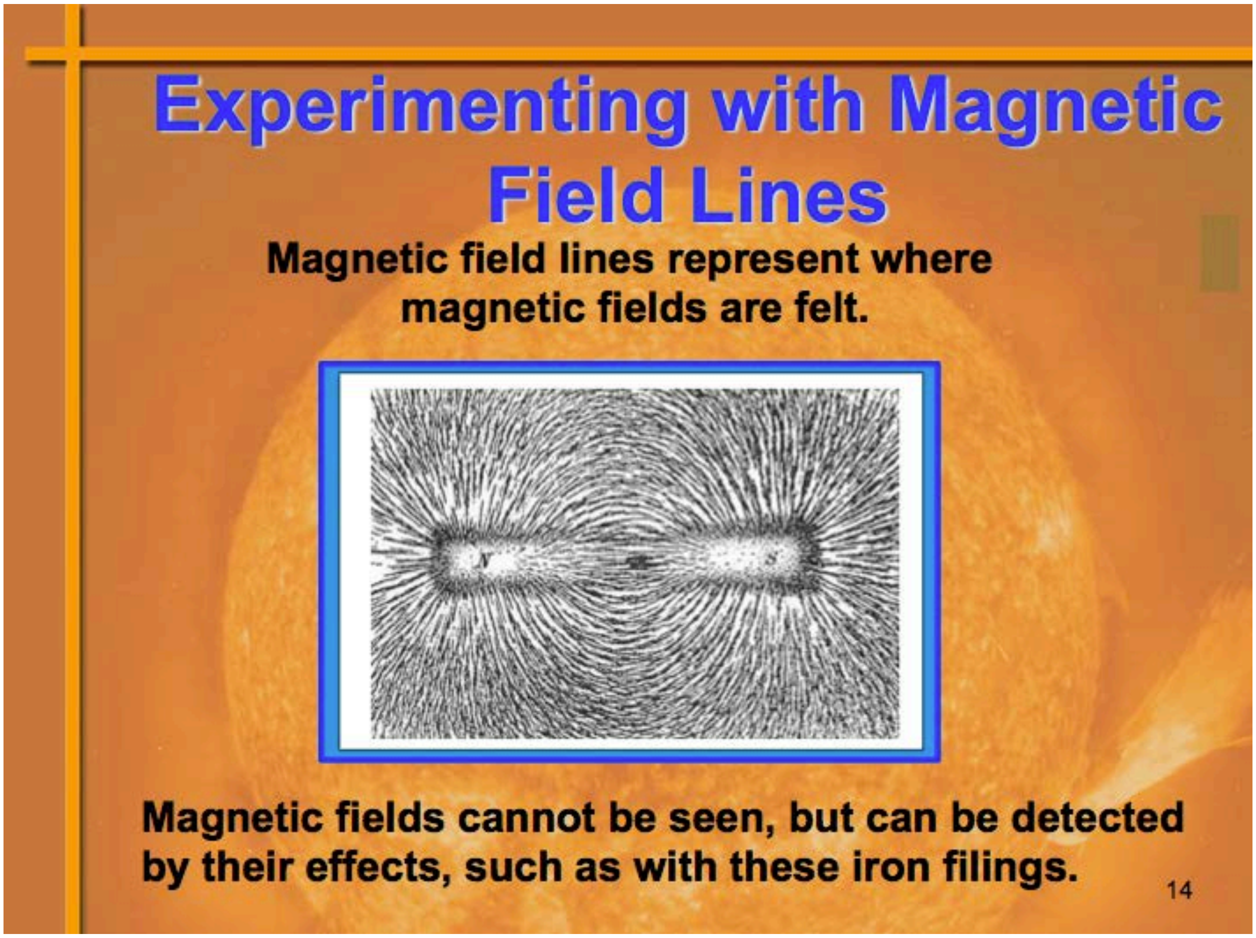


Slide 13

Magnetic Fields

Magnetic fields are a region of space near a magnet, electric current, or moving charged particle in which a magnetic force acts on any other magnet, electric current, or moving charged particle. As noted before, magnetic fields pull on ferromagnetic materials such as iron, cobalt, or nickel, and attract or repel other magnets. Ferromagnetic materials have domains that are sensitive to magnetic fields and tend to line up with the nearby fields. The domains then act like a magnet and are pulled to the poles that are the source of the field.

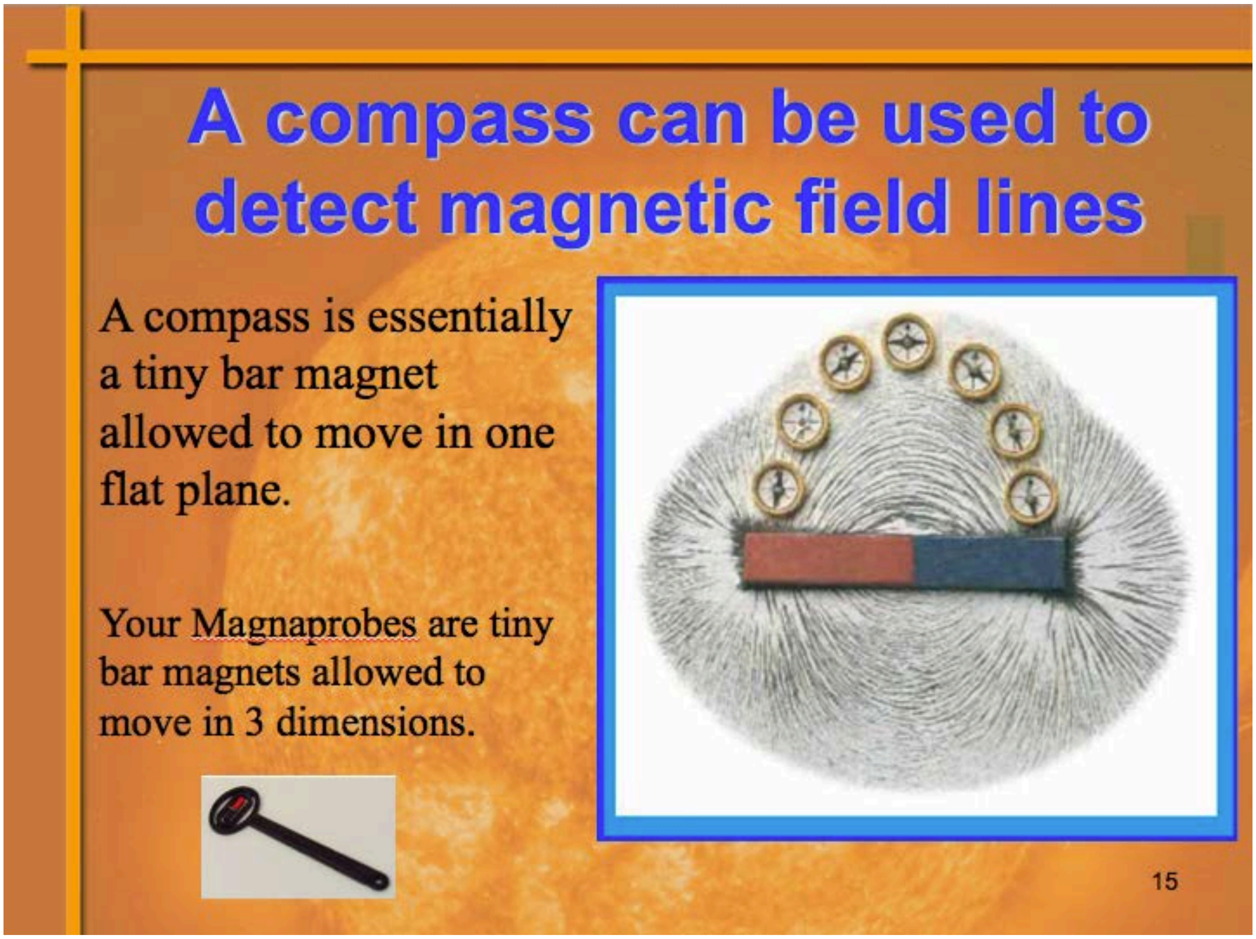
The Earth produces its own magnetic field, which is not only important in navigation, but it shields the Earth's atmosphere from the solar wind and geomagnetic storms. (More about this later.) Most solar activity is produced by the behavior of magnetic fields on the Sun. And this activity has a dramatic effect on Earth. More in Section 3.



Slide 14

Explain to the students that we are going to experiment with finding magnetic field lines. Most students have already seen iron filings align to a magnetic field. If they have not, you should either provide bar magnets and iron filings for them to experiment with or provide imagery of iron filings interacting with magnetic fields.

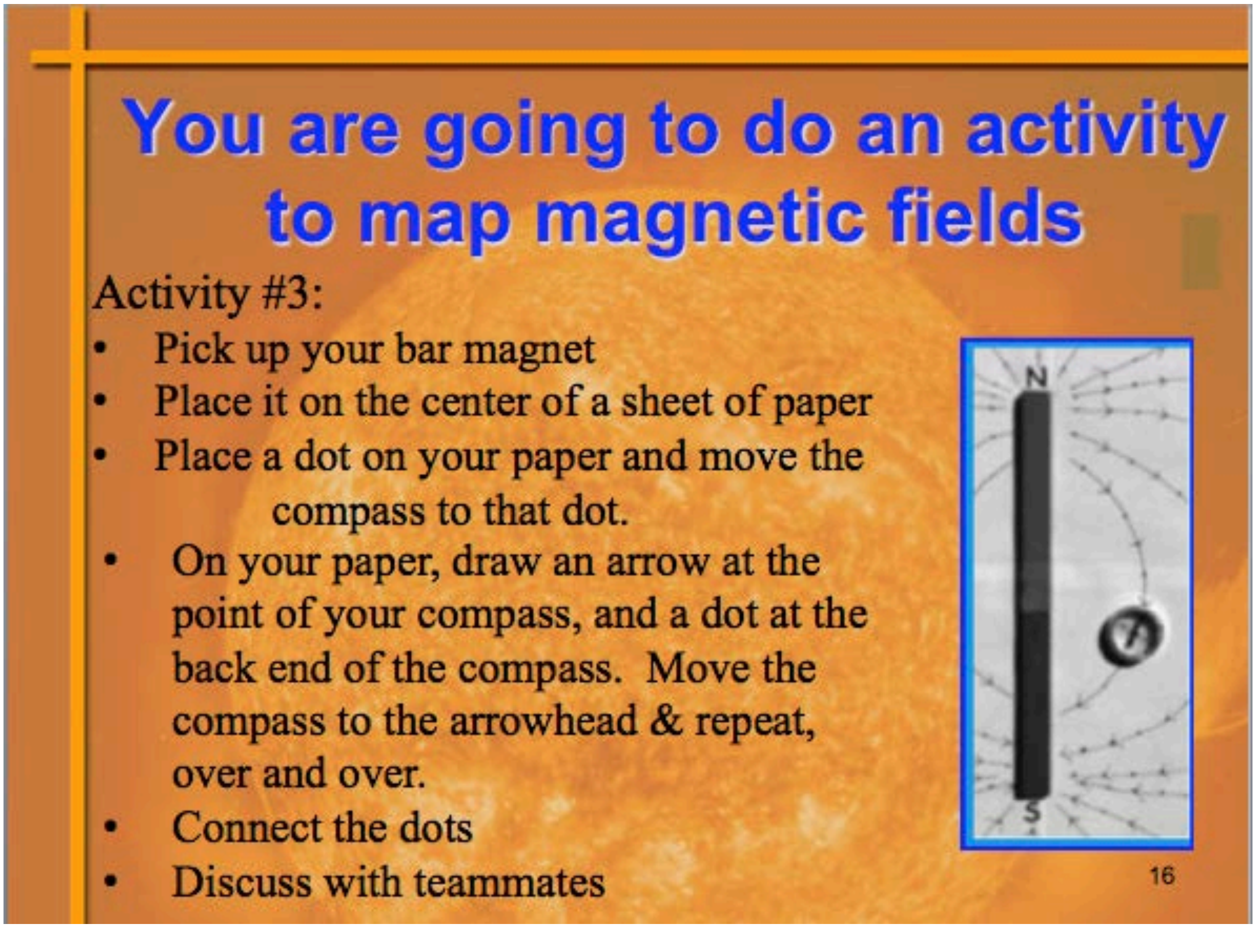
Imagery from UC Berkeley's Exploring Magnetism series:
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/



Slide 15

Explain to students that a compass is essentially a tiny bar magnet allowed to spin in one flat plane.   Their magnaprobes are also tiny bar magnets, but they are allowed to move in 3 dimensions.

Bar magnet imagery from UC Berkeley's Exploring Magnetism series:
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/

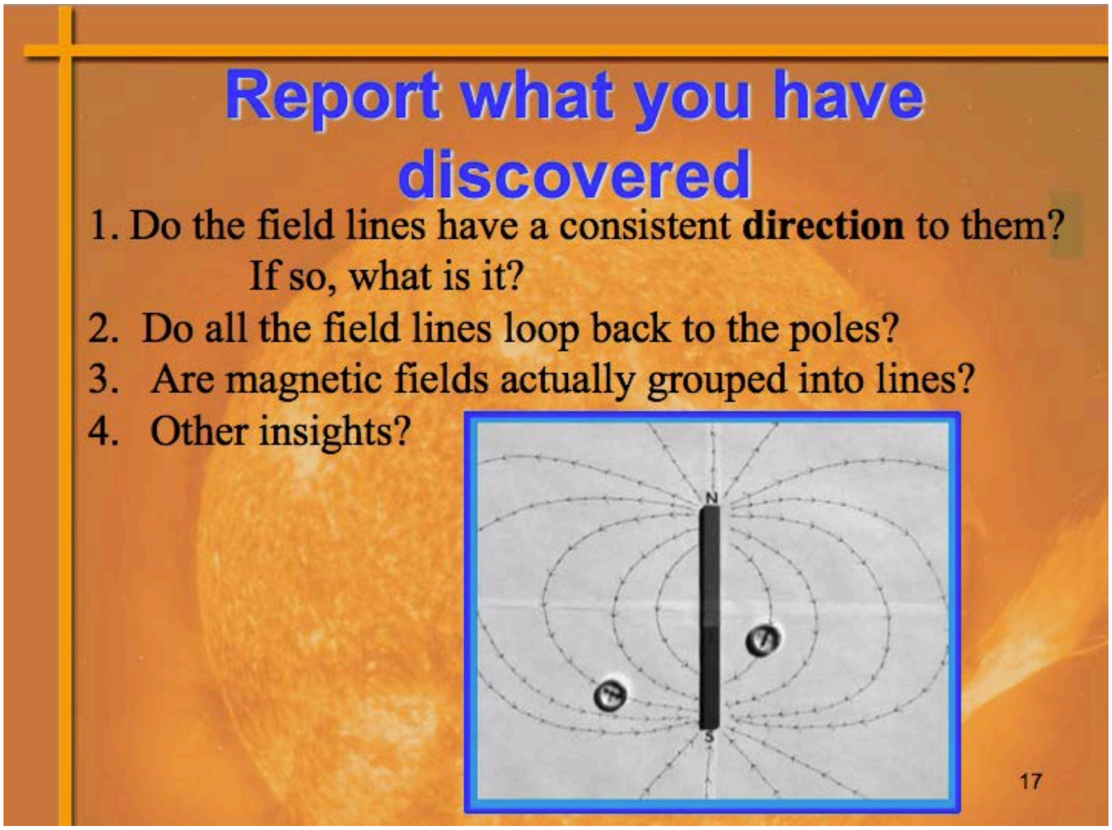


Slide 16

Activity 3 - Mapping magnetic field lines – See Appendix E

1. Pass out:
    - Magnetic compasses
    - Bar or cow magnets (if they don't already have them)
    - Plain piece of paper
    - Pencils
    - Adhesive tape
    - Worksheet in Appendix D
2. Warn participants to put their other magnets out of the way
3. Ask the participants to learn how to use the compass by placing it in front of them on a flat surface. Make sure the compasses are kept away from the magnets. Rotate the entire compass so that the red or pointed end is pointing toward the "N" (north). This is the direction of magnetic north.
3. Have the participants place the bar magnet in the center of a sheet of paper and tape it down. Tell them they will now trace the magnetic force field shape around the magnet. Ask them to hypothesize what they think the field will look like and share their thoughts with a neighbor.
4. Have participants move the compass around the magnet to get a feel for how the arrow moves. Have them draw a dot at some point near the magnet and place the center of the compass over the dot

5. Draw an arrow head at the location of the arrow head of the compass.
6. Move the compass center to this new arrow and again draw an arrow at the location of the compass needle head.   Repeat.
7. Continue steps 4-6 until the line meets the magnet (or edge of paper). Remove the compass from the paper and draw lines connecting the dots with arrows indicating the direction that the compass points.
8. Pick another spot near the magnet and repeat the process.
9. Ask students to report on what they have discovered to a neighbor.



Slide 17

Ask the participants to discuss their findings:

1. Do the field lines have a consistent direction to them? [*yes*] The direction of a magnetic field is from + (north) to – (south)

Remind participants that compasses "seek Earth's north pole" and hence point to what would be the South pole of a bar magnet, as above.

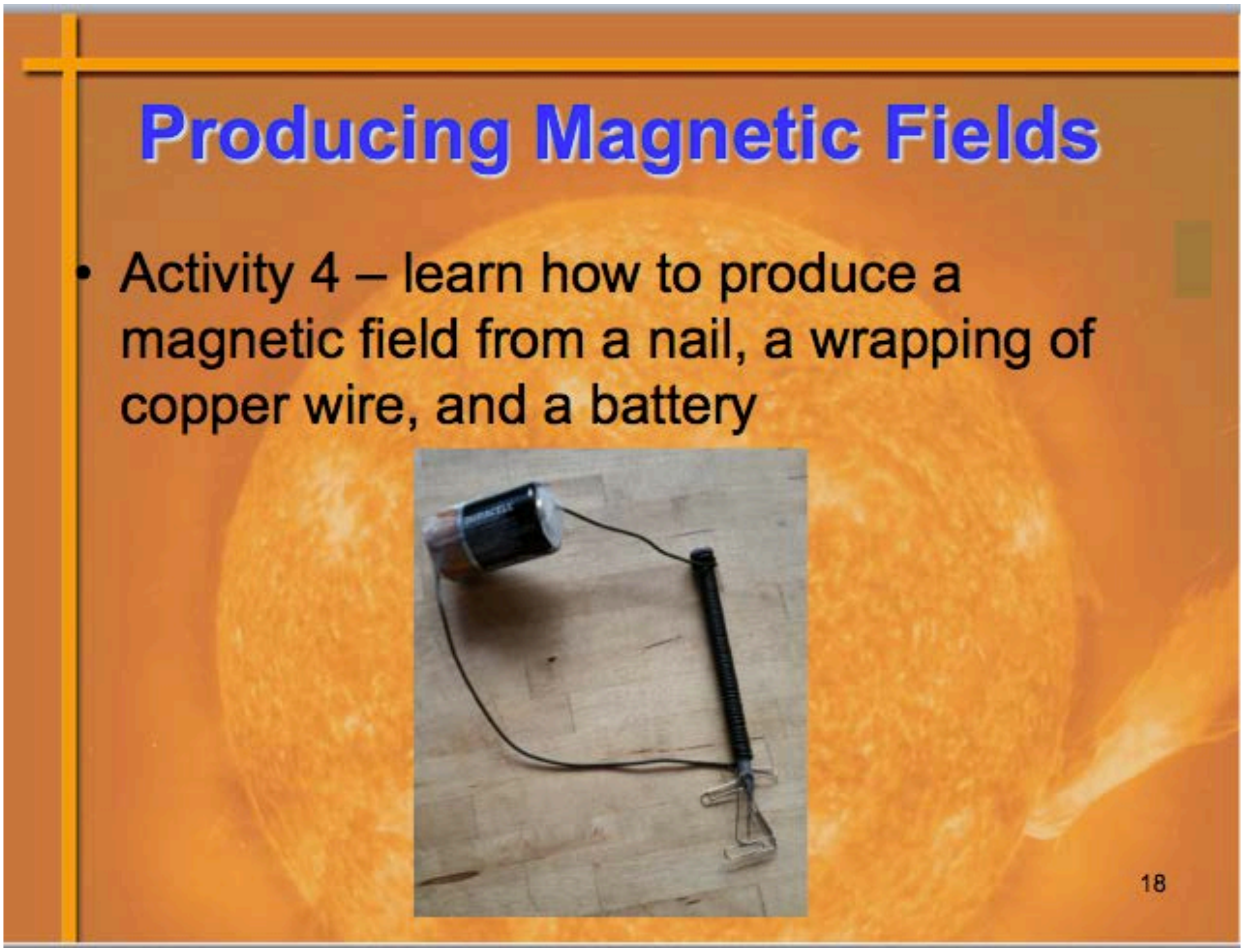
2. Do all the field lines loop back to the poles? [*yes, even though we can't see them]*

3. Are magnetic fields actually grouped into specific lines. [*no*]

4. Ask students to explain other insights they might have had.

This activity was excerpted from UC Berkeley's Exploring Magnetism guide. Bryan Mendez, of UC Berkeley, adapted it from a lesson by his 8th grade science teacher, Mr. Halbert. Thank you, Mr. Halbert!

The more extensive activity is available at:
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/exploring_magnetism/index.html



Slide 18

Activity 4: How to Create an Electromagnet – See Appendix F

The most common way that magnets are produced is by heating them above their Curie temperature[3] and exposing them to a strong magnetic field as they cool. The Curie temperature is the temperature at which ferromagnetic metals lose their magnetic moments (i.e. their domains are able to change direction).

Ferromagnetic materials can also be categorized into soft and hard metals. Soft metals lose their magnetic field over time after being magnetized. Hence they are termed temporary magnets. The student-produced nail magnet is such an entity. On the other hand, hard metals are likely candidates for becoming permanent magnets.

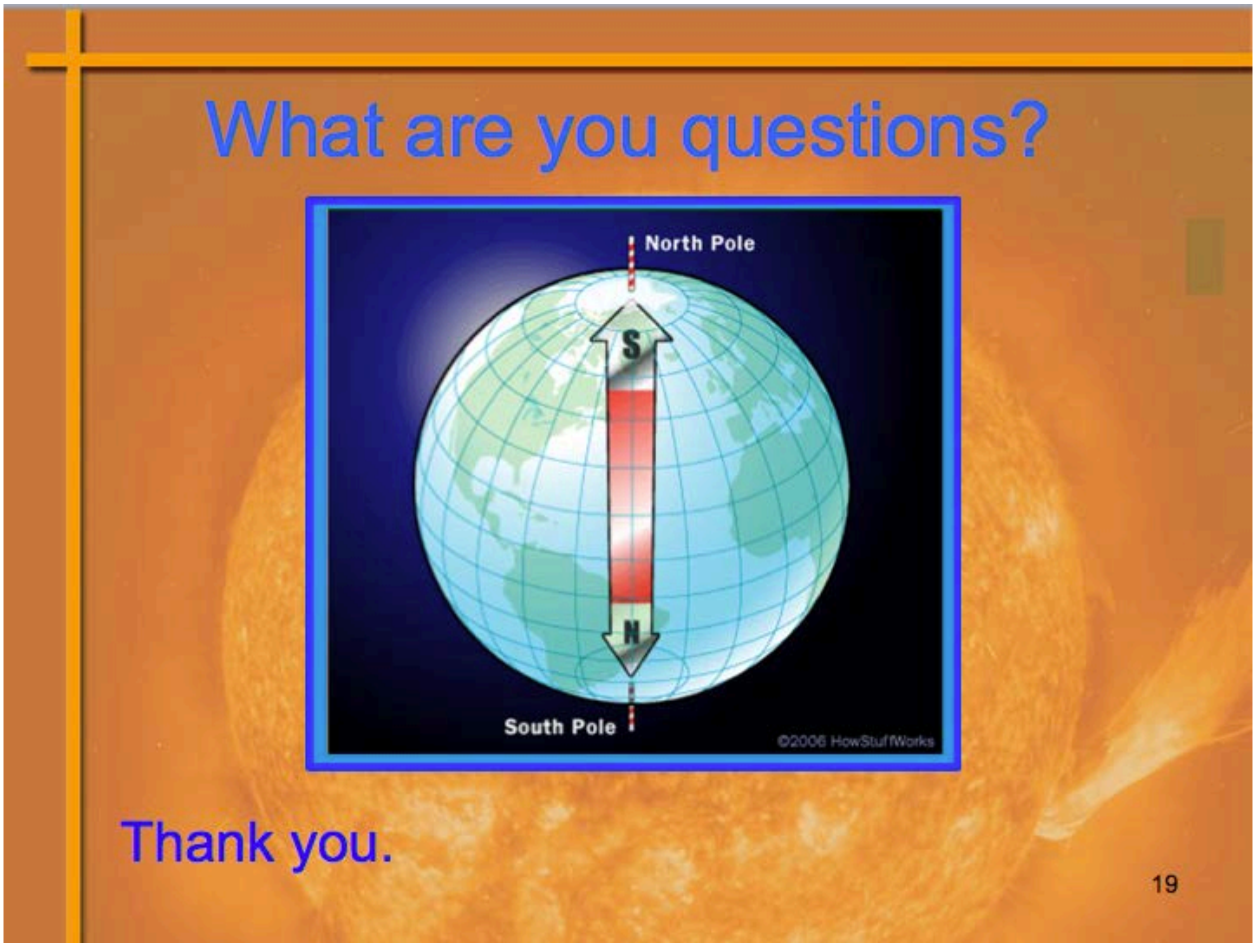
In this activity, students will create their own electromagnet, and study its magnetic fields with their Magnaprobes or compasses.

Image credits: Deborah Scherrer

[3] https://www.britannica.com/science/Curie-point

More resources:

- http://www.school-for-champions.com/science/magnetic_field_moving_charges.htm#.VczVW7d61VY
- http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/exploring_magnetism/s2.html#act2
- https://www.google.com/search?client=firefox-b-1-d&q=making+a+simple+magnet
- https://sciencing.com/make-super-strong-permanent-magnets-6520830.html
- https://www.youtube.com/watch?v=Wm9_DqQKmd0
- https://www.sciencebuddies.org/science-fair-projects/project-ideas/Elec_p035/electricity-electronics/strength-of-an-electromagnet?from=YouTube
- https://www.google.com/search?client=firefox-b-1-d&ei=EvC-XuGZMsbz-gTH37KgCQ&q=how+to+magnetize+a+nail&oq=how+to+magnetize+a+nail&gs_lcp=CgZwc3ktYWIQAzICCAAyAggAMgYIABAWEB4yBggAEBYQHjIGCAAQFhAeMgYIABAWEB4yBggAEBYQHjIGCAAQFhAeOgQIABBHOgQIABBDOgUIABCRAjoFCAAQgwFQ4hVYwkRgwEZoAHABeACAAdYFiAHAIZIBDDAuMjAuMS41LTEuMZgBAKABAaoBB2d3cy13aXo&sclient=psy-ab&ved=0ahUKEwjh6uzVz7bpAhXGuZ4KHcevDJQQ4dUDCAs&uact=5#kpvalbx=_4_C-Xt3tL475-wSgh5GYAw32
- https://sciencing.com/magnetize-things-6377.html



Slide 19

This is the end of Section 1.

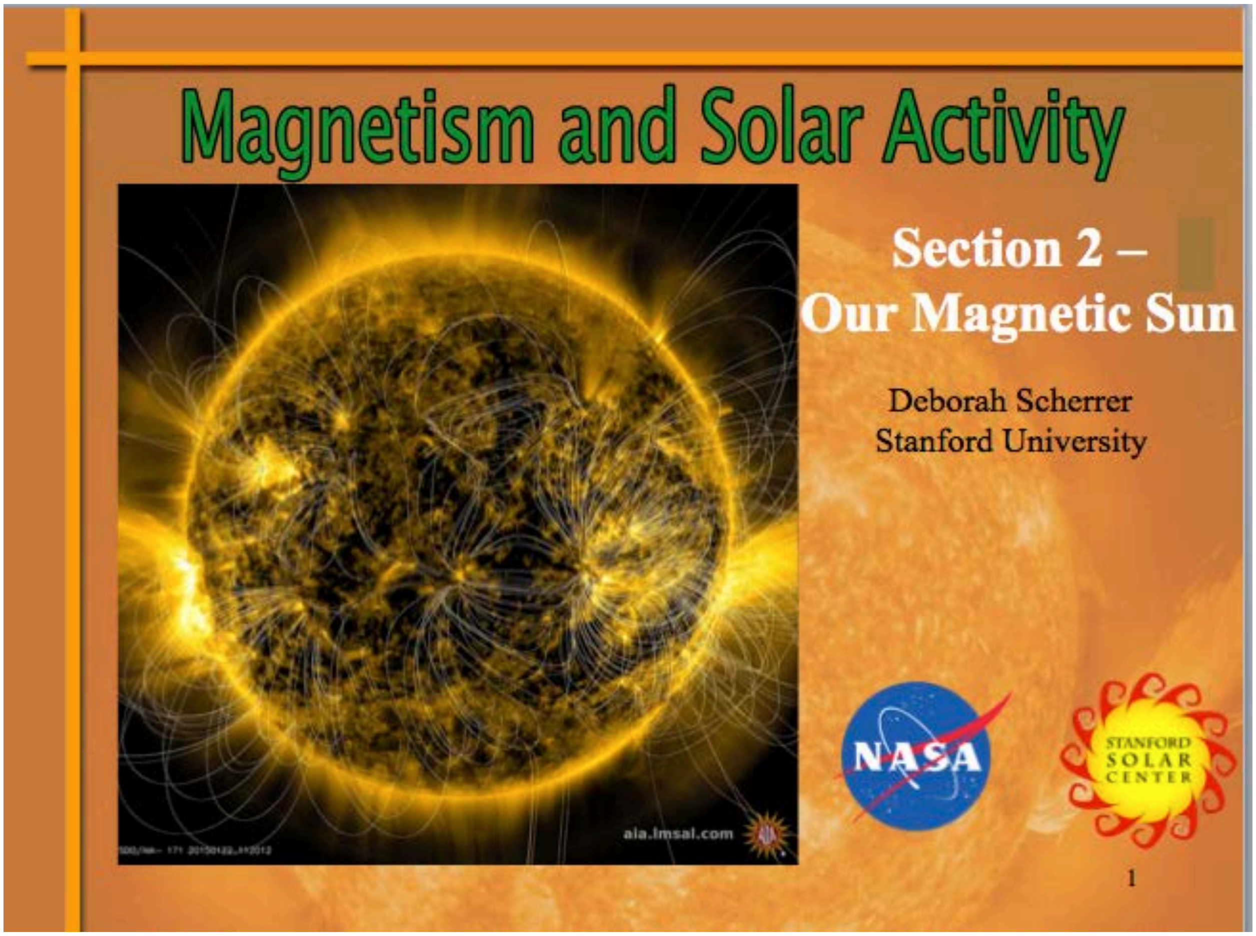
Section 2 will cover the magnetic fields on the Sun. This requires the next PowerPoint.

You can follow directly to Section 2, or start it on a different day.
Or, Section 2 could stand-alone for a discussion of magnetic activity on the Sun.

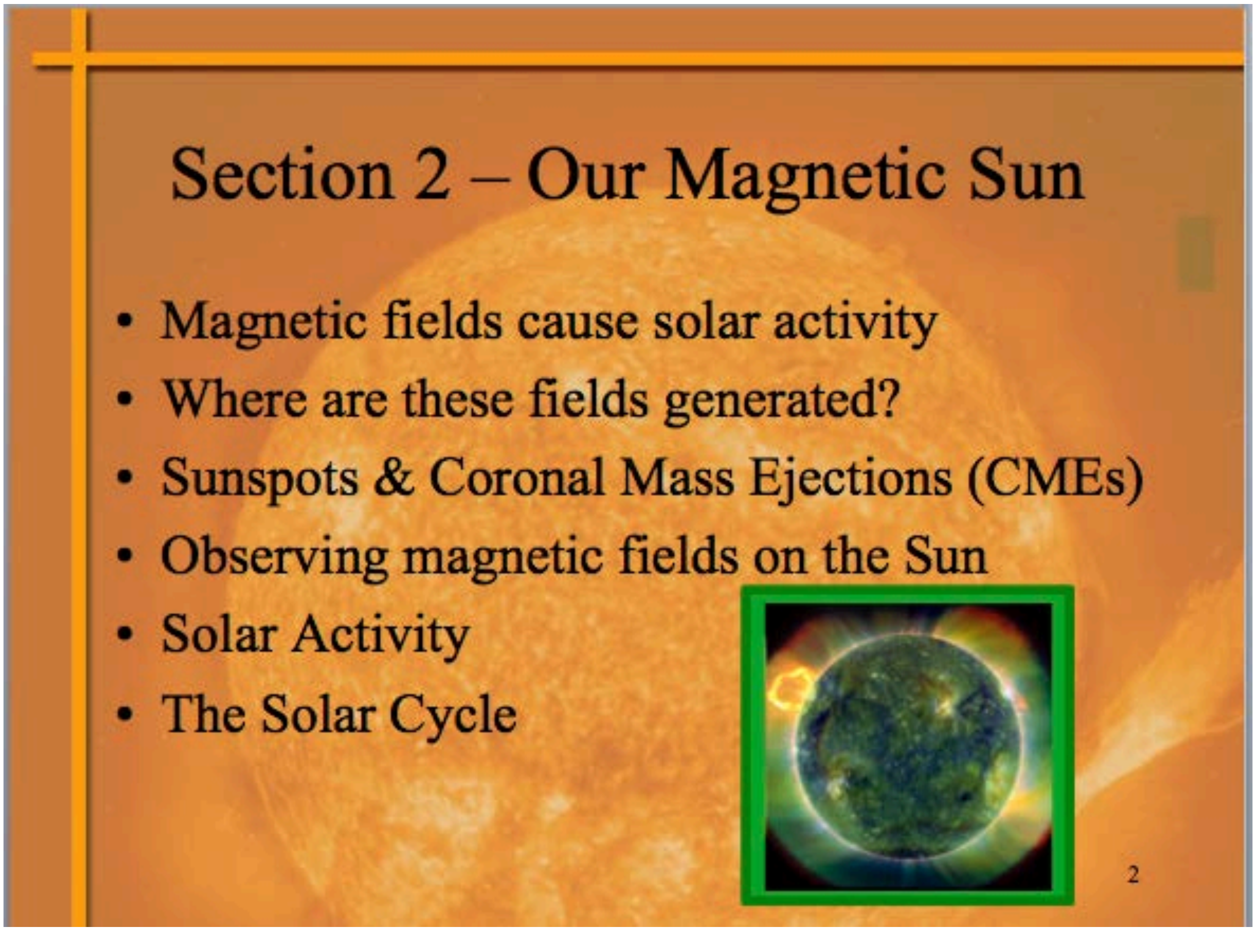
Section 2 – Our Magnetic Sun

Section 1 focused on hands-on activities to explore the nature of magnetism on Earth.

Section 2 is more focused on a selection of videos, simulations, and imagery, most from NASA solar missions, to interpret and explain what is going on at the Sun. Many of these are stunning and beautiful. But sometimes they are hard to get going in the presentation. So, don't give up.

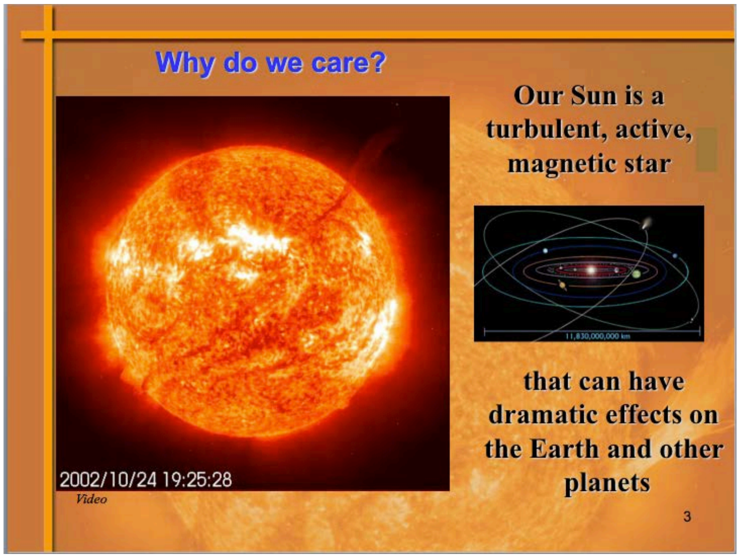


Slide 1



Slide 2

Students will use NASA visual imagery to explore the difference between magnetic fields on the Earth and magnetic fields on the Sun, how solar magnetic fields are structured and generated, how most forms of solar activity are based on magnetic fields and actions, and that there is a cycle to solar activity on the Sun.



Slide 3 - video

Our Sun is a turbulent, active, magnetic star

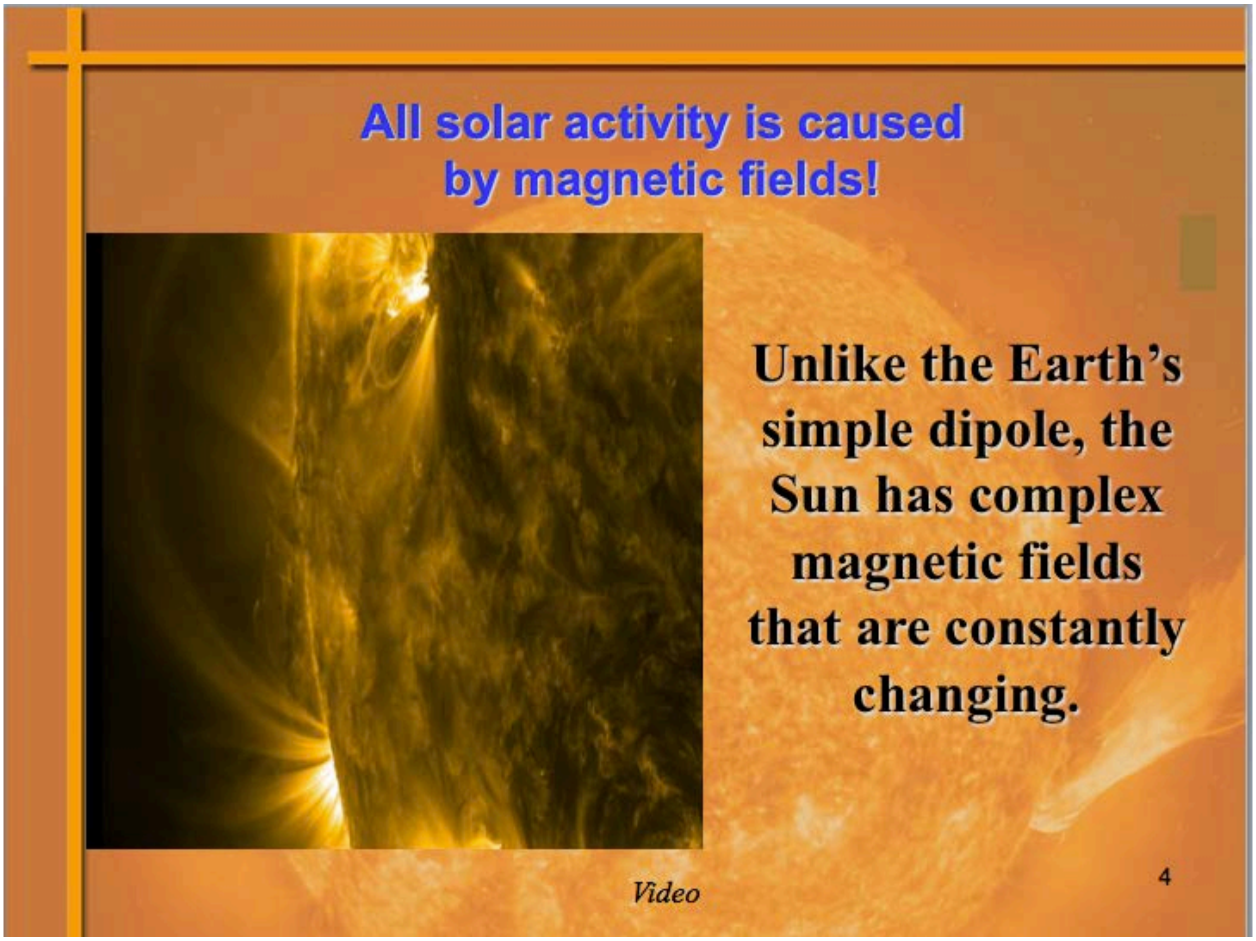
Video of solar activity over a period of days
The video on the left of the slide demonstrates solar activity over a period of consecutive days. It demonstrates a collection of complex forms of solar activity. Allow your students to examine these for a moment. It will run continuously until stopped.

Sun and magnetism
It's hard for students to image that magnetism has anything to do with the Sun. But, it's the key factor in solar activity. So, now that we/they have a basic understanding of magnetic fields on the Earth, how does this knowledge relate to the Sun? Turns out that all solar activity is caused by and related to magnetic fields! It also turns out that solar activity can have a dramatic, and sometimes devastating, affect on the Earth!

How long have we known this?
Solar activity and related events have been recorded since the 8th century BCE (~2800 years ago). Babylonians inscribed and possibly predicted solar eclipses, while the earliest extant report of sunspots dates back to the Chinese *Book of Changes,* c. 800 BCE. The first existing description of the solar corona was in 968, while the earliest sunspot drawing was in 1128. A solar prominence was described in 1185 in the Russian Chronicle of Novgorod. In Europe, the invention of the telescope led to major advances in understanding, including the first detailed observations, by Galileo, in the 1600s.

New research is suggesting that peoples of the New World also observed the Sun, and possibly discovered secrets relating to solar activity, long before the Chinese.

Video: Large erupting and twisting prominence movie, SOHO/EIT 304A. (Oct. 25, 2002) SOHO is a project of international cooperation between ESA and NASA. Solar system image from Cosmic Distance Scale, created by Maggie Masetti, courtesy of NASA. http://heasarc.gsfc.nasa.gov/docs/cosmic/solar_system.html



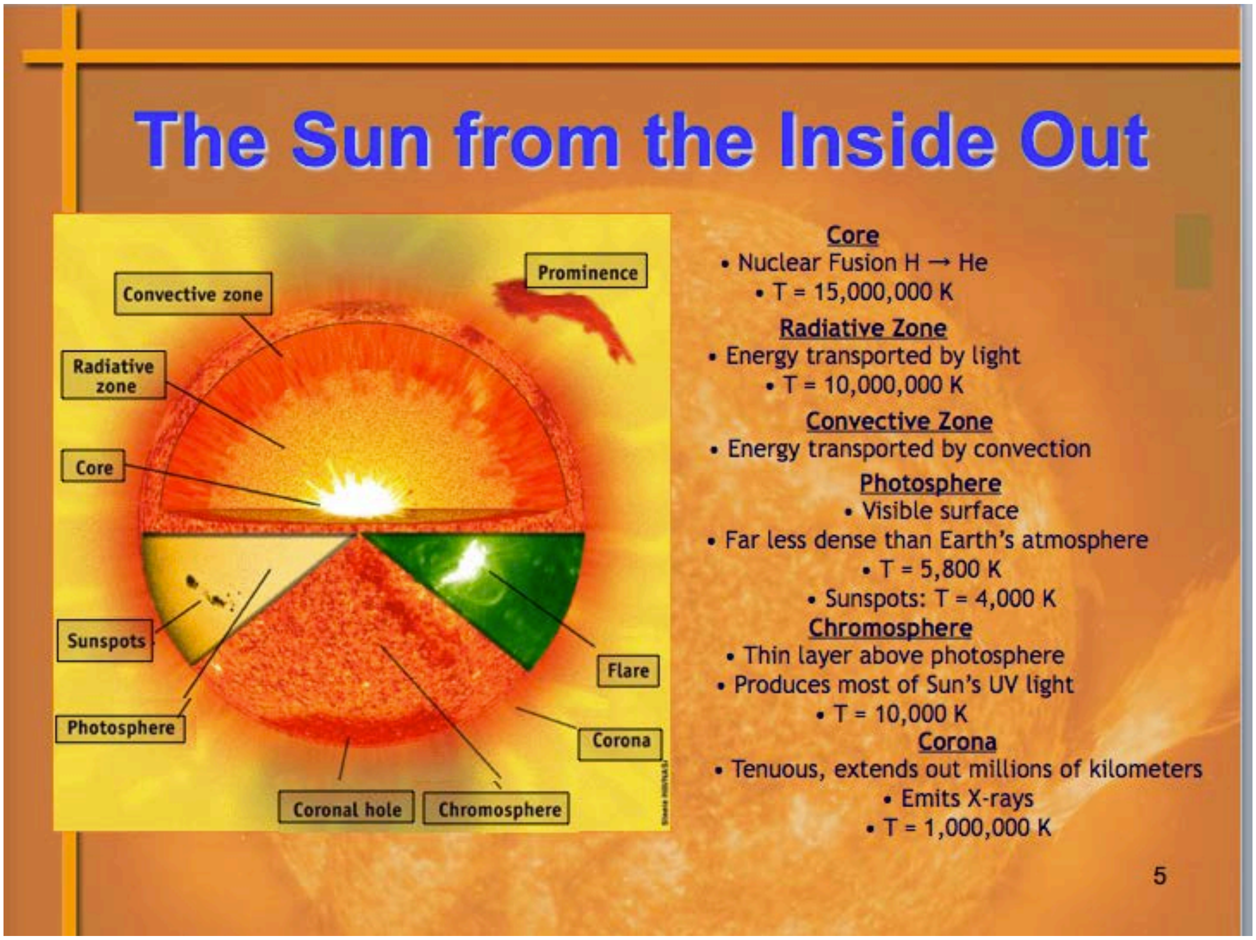
Slide 4

Video shows dynamic prominences and other solar activity on the Sun.

Solar activity includes phenomena occurring within the magnetically heated outer atmosphere in the Sun. These phenomena take many forms, including solar wind, energy bursts such as solar flares, coronal mass ejections (CMEs) or solar eruptions of plasma, coronal heating, and sunspots. More on this later.

The source of these phenomena is a dynamo caused by churning and shearing of layers within the Sun. Because the material in the Sun is electrically charged, this shearing generates strong magnetic fields. These fields rise to and through the solar surface, churning and interacting, often breaking and reconnecting. Details coming in the next slide.

Image credits: The AIA instrument on NASA's Solar Dynamics Observatory mission.



Slide 5

The Sun from the Inside Out

Like the Earth, or an onion, the Sun has layers. We'll work from the inside out.

This slide requires multiple clicks to show all the information.

(1st click) Core: The Sun's core is extremely hot and dense. With a heat about 15 million Kelvin (roughly equivalent to 15 million Celsius), reactions inside the core produce gamma rays by nuclear fusion.   The Sun fuses ~620 million metric tons of hydrogen and makes ~606 million metric tons of helium EVERY SECOND!   The core is where the Sun's heat/high energy is generated.

(2nd click) Radiative Zone:
Upward from the core towards the solar surface, densities and temperatures drop. So energy from the core can *slowly* make its way outward. Because the area around the core "radiates" the core's energy outward, we call this layer the Radiative Zone.

(3rd click) Convective Zone:
Beyond the Radiative Zone, the temperatures and densities lower again. In this area, large "pockets" of gas form near the bottom and rise as they (relatively) cool. Eventually, they will

lose enough energy that they crash back down, heating up again. This is similar to observing boiling oatmeal or fudge. The surface of boiling fudge has what we call "granulation", and surface of the Sun has a very similar appearance! Of course, on the Sun the granules are the size of the state of Texas. We'll see a bit of granulation in the next slide.

So, we call this layer the Convection Zone because it is similar to how a pan of water is heated – energy comes in at the bottom and is carried up by convection.

(3rd click) Photosphere (i.e. surface):
The top of the Convection Zone is the photosphere, the "surface" or part of the Sun that we can see. This is where the light comes from. Solar telescopes can show a great detail of what is happening in the photosphere. In fact, it looks much like the surface of the boiling fudge or oatmeal that we mentioned previously. This "splotchy" appearance is technically termed "granulation", and it is caused by the top of the convection cells (pockets of gas) reaching the surface, then cooling by radiating their energy away as light, then crashing back down again. By this time, the solar surface has dropped to about 5,800 Kelvin (about 10,000 F).

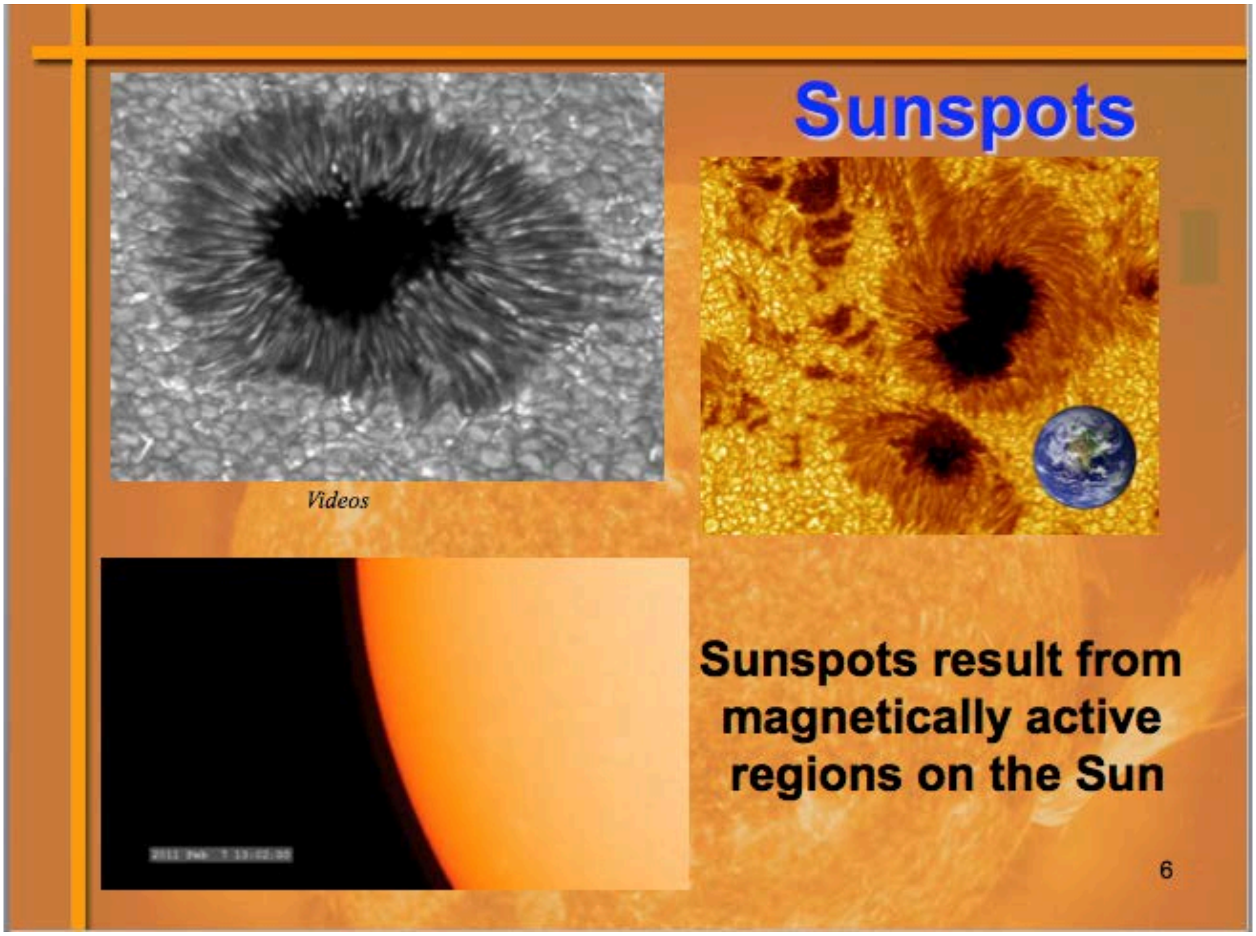
(4th click) Chromosphere:
Chromosphere implies color, and the thin chromosphere emits a reddish glow as super-heated hydrogen burns off. This "red fringe" is sometimes seen during a total solar eclipse.

(5th click) Corona:
Above the Sun's surface (photosphere & chromosphere) the temperature continues to drop, then suddenly heats up again. This outermost layer of the Sun is called the corona, and why the corona is hotter than the surface is one of the not-yet-understood mysteries of the Sun. (See http://solar-center.stanford.edu/FAQ/Qcorona.html.) The corona can be seen during a total solar eclipse. It is very thin, and extends out millions of kilometers into space.

Going Further:
Since even telescopes cannot see below the Sun's surface, scientists infer what's going on inside the Sun by studying acoustic (sound) waves that it produces. This is similar to an Earth seismologist inferring internal structure by studying waves traveling through the interior during an earthquake. For students interested in learning more about helioseismology, see
http://solar-center.stanford.edu/about/helioseismology.html

Now that we have an idea of how the Sun is structured, let's start examining its magnetic fields.

Image Credits: Solar & Heliospheric Observatory (SOHO). SOHO is a project of international cooperation between ESA and NASA. The flare, sunspots and photosphere, chromosphere, and the prominence are all clipped from actual SOHO images of the Sun.



Slide 6 - videos

Sunspots and magnetic fields

2 videos show the movement and changes of sunspots over a period of days

(Note – in the lower video it takes several seconds before the sunspots appear)

A sunspot is a very magnetically active place on the Sun, usually in a region of many smaller fields. These active regions are dominated by strong magnetic areas where a concentrated portion of the solar magnetic field pokes through the solar surface layers. These Active Regions are also responsible for solar flares, prominences, coronal mass ejections, and other solar disturbances.

Sunspots are cooler than the rest of the solar surface because the strong magnetic fields inhibit convective motions, and thus the escape of heat from below the sunspots. But they are in no ways "cool"!

The video on the upper left shows a single sunspot, probably about 3 times the diameter of the Earth. Around the sunspot you can see the Sun's granulation, similar to the surface of boiling fudge.

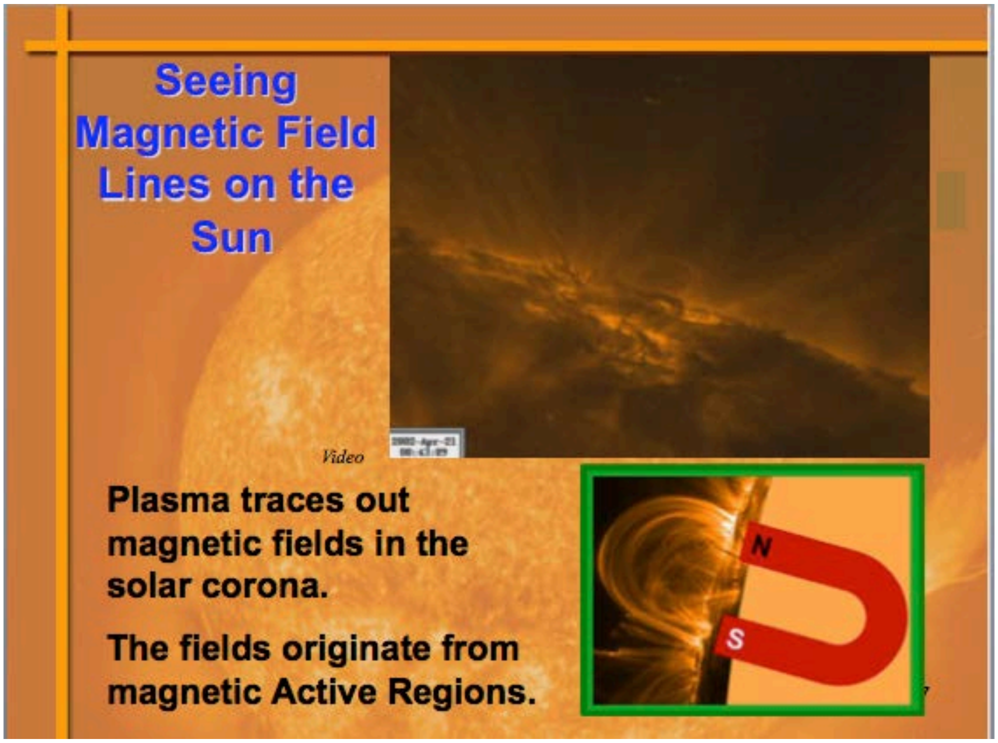
Sunspots can exist separately or in sunspot groups. Long-lived sunspots can last up to several months, but most survive only a matter of days. Sunspots are constantly changing due to the fluctuating magnetic fields. The movie on the lower left shows an active region with a large collection constantly moving and changing sunspots. The movie follows the region across the face of the Sun.

The next slide will detail the relationship between sunspots and magnetic fields.

Going Further:
Although Galileo and the German Jesuit Christoph Scheiner each observed sunspots in 1611, and vied bitterly in their lifetimes over who deserved the credit for "discovering" them, **T**homas Harriot was very likely the first historical person to see sunspots through a telescope, in December 1610.

However, large sunspots are occasionally visible by naked eye, especially in cloudy conditions or near sunrise or sunset. So, it's very likely that sunspots had been observed by humans centuries before the 1600s.

Movie Credits: SOHO/MDI. SOHO is a project of international cooperation between ESA and NASA.
Movie Files: DOT_SU~1.MPG



Slide 7

Seeing magnetic field lines on the Sun

Video: Time-lapse video shows magnetic fields in action

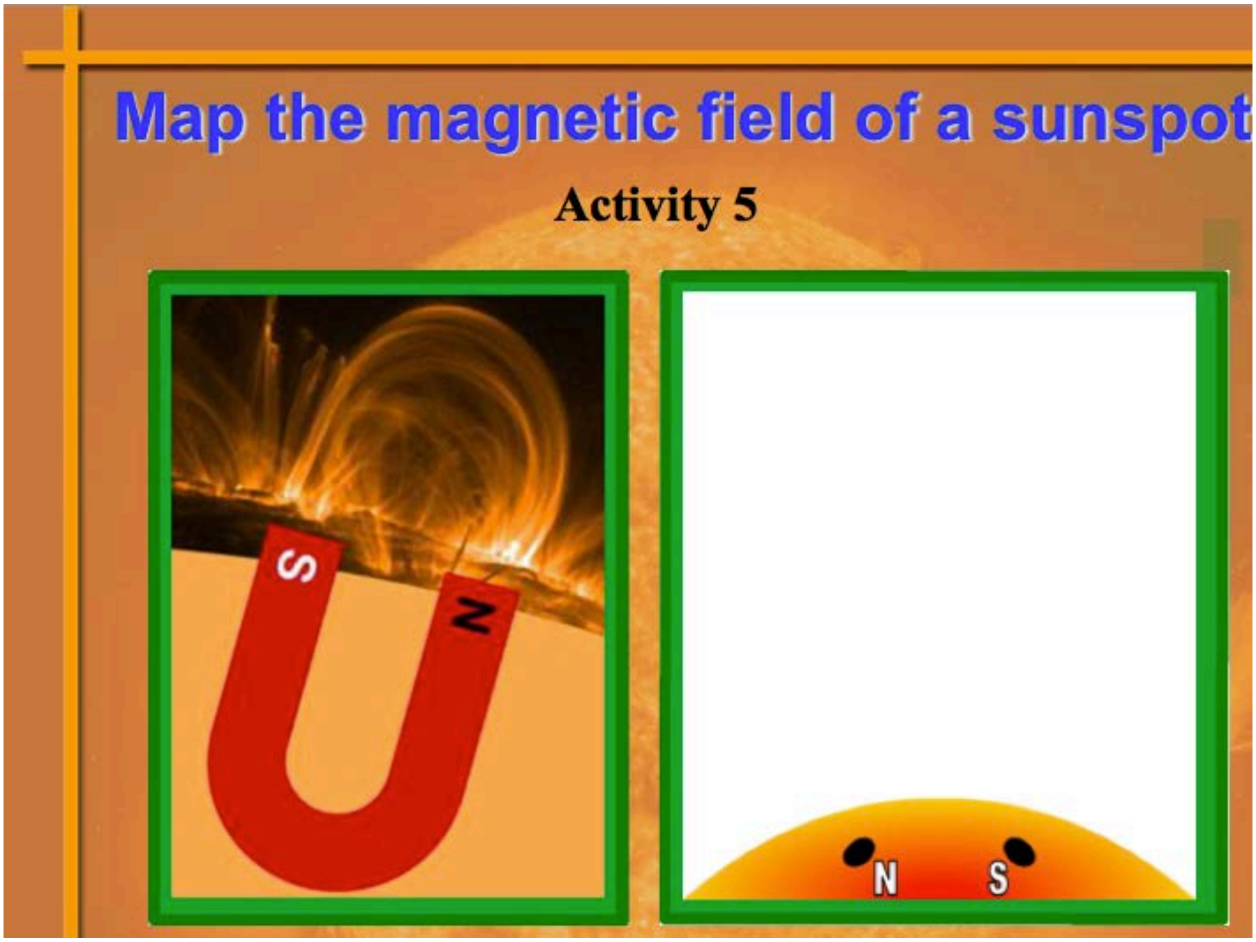
You can't see magnetic fields. But just as iron filings can be used to demonstrate the shape of magnetic fields, the plasma (hot ionized gas) of the Sun is forced by the fields to move along the magnetic field lines. Thus these visible plasmas give us a good tracer for the shape of the fields. We call these beautiful moving arches "coronal loops".

Putting all the information together creates a picture where sunspots are the "footprints" of the coronal loops. The coronal loops are made of plasma trapped in a very strong magnetic field. That same magnetic field penetrates down into the convection zone and inhibits the convection of gas in that region. This causes the gas there to cool faster than the surrounding region.

The strength of the magnetic fields in sunspots can get up to 2000-4000 Gauss (Gauss is a unit of magnetic field strength). The average magnetic field strength on the surface of Earth is about ½ Gauss, and the average magnetic field strength on the surface of the Sun is about 1 Gauss. So the magnetic fields in sunspots are **extremely** strong.

With the next slide, students will trace or model the magnetic fields of a sunspot.

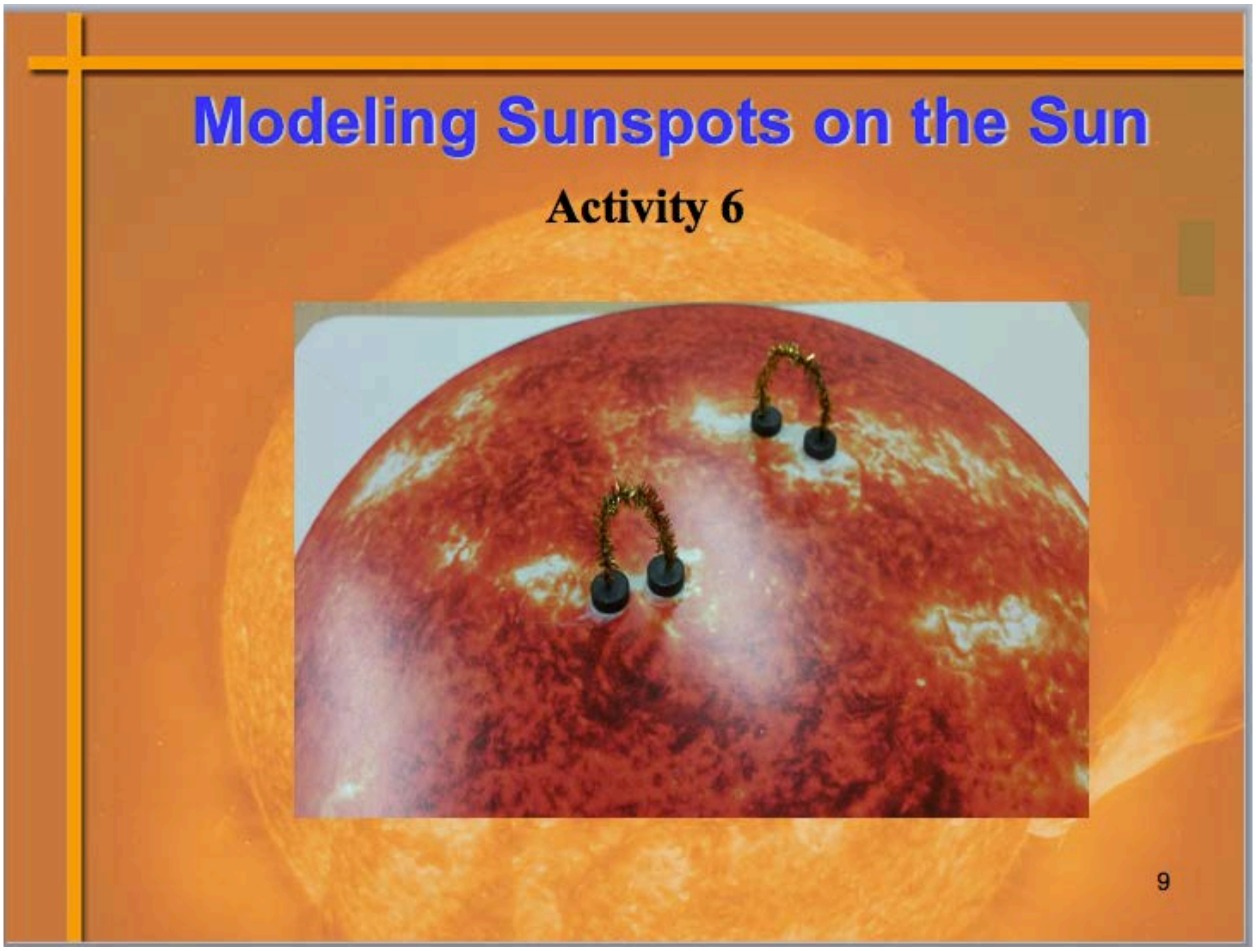
Image Credits: From the Transition Region and Coronal Explorer (TRACE) satellite, a NASA Small Explorer (SMEX) mission to image the solar corona and transition region at high angular and temporal resolution. TRACE operated from 1998 to 2010.
http://trace.lmsal.com/
Movie File: T195_020421_XflareAR9906.mov



Slide 8

Activity 5: Tracing the magnetic field of a sunspot – See Appendix G

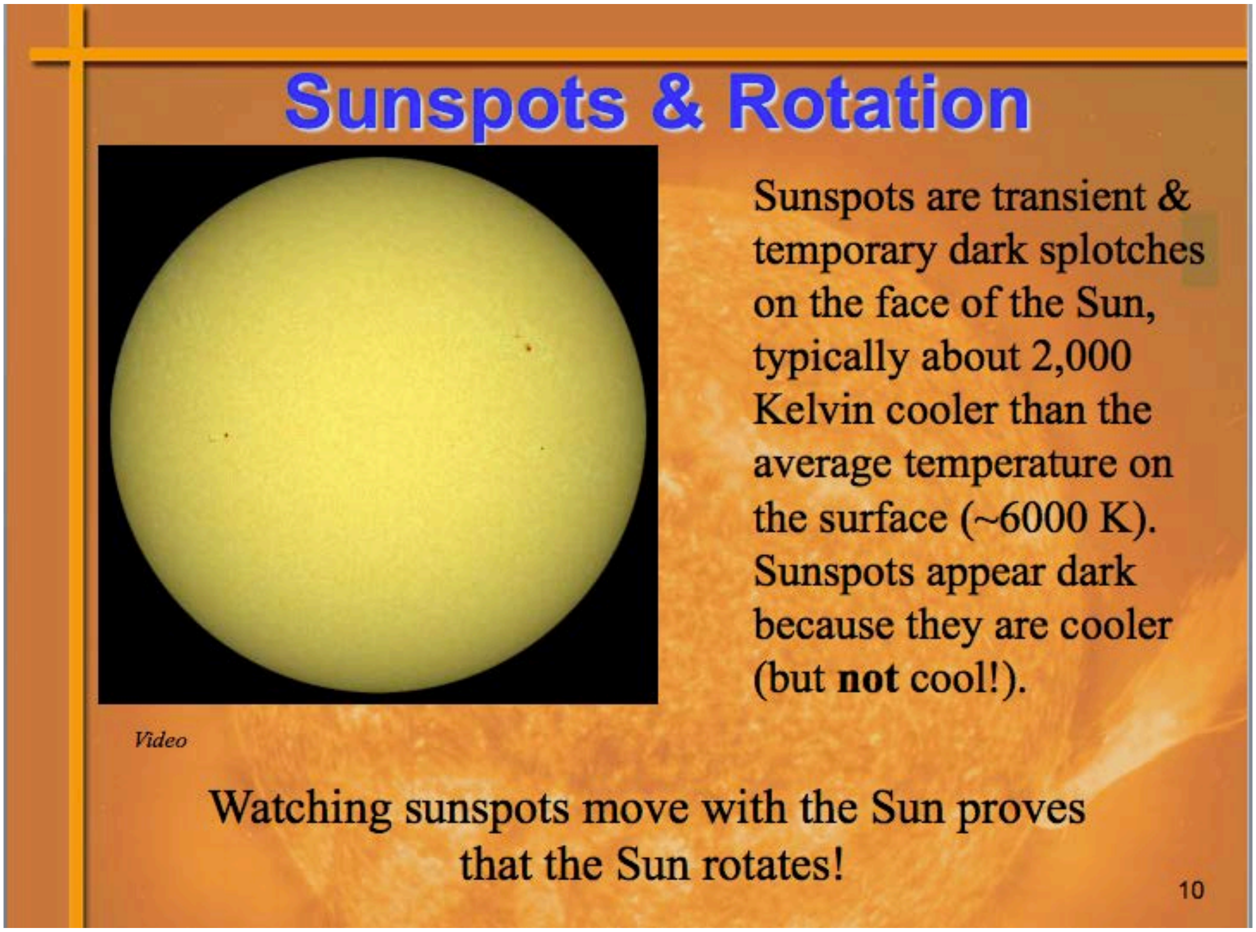
This activity was excerpted from
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/



Slide 9

Activity 6: Modeling Sunspots on the Sun – See Appendix H

This activity was developed by Deborah Scherrer.



Slide 10

Sunspots show rotation

Video shows sunspots on the Sun while the Sun is rotating

Now that we have examined sunspots in detail, let's look at the larger picture.

Sunspots are essentially magnetic storms on the Sun. They not permanent features - they come and go and constantly change in appearance. Sunspots are caused by the twisting and turning of magnetic fields that have erupted through the Sun's surface. Sometimes there are a lot of spots on the Sun, and sometimes there are none.

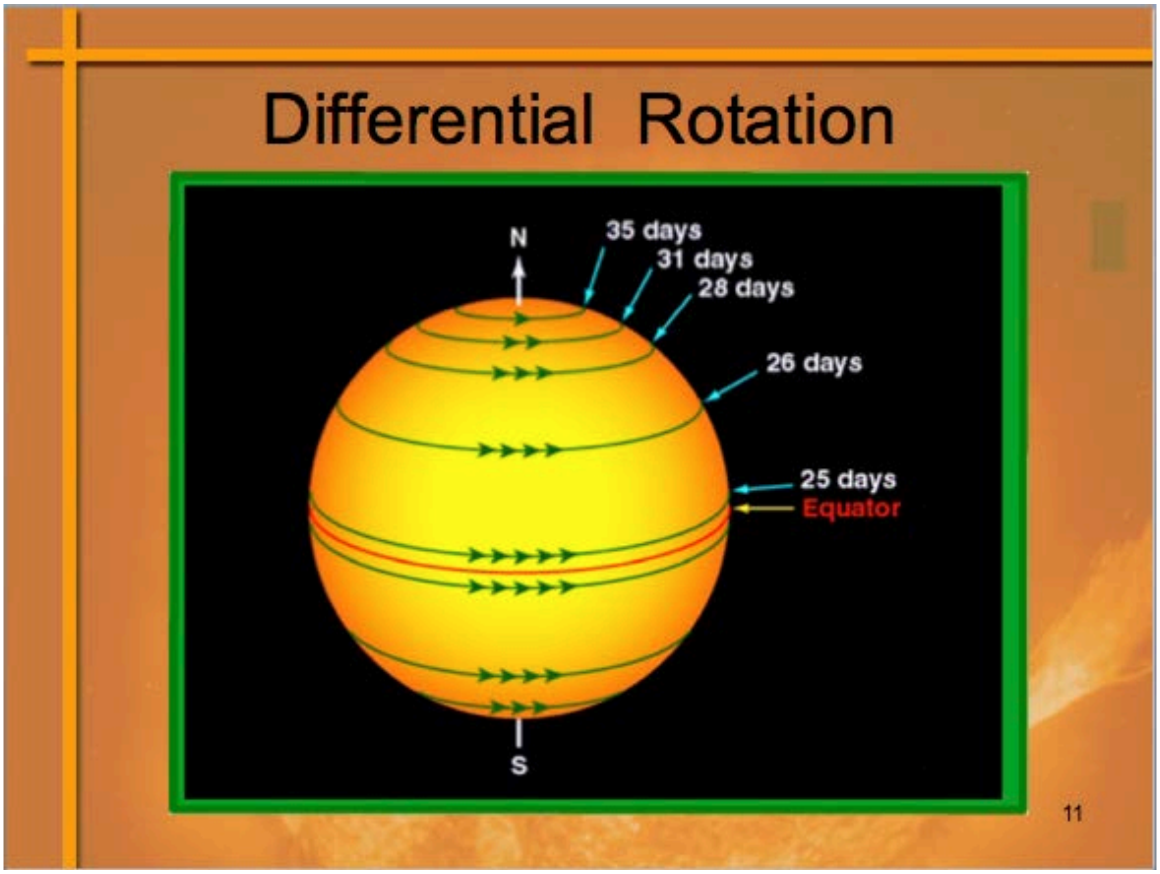
These sunspot storms are about 2000K cooler than the solar surface, and more than 5 times dimmer. Hence they appear comparatively "dark" to us. But they are still very hot!

Like the Earth and other planets, the Sun rotates, or spins, about its axis. Galileo was the first to notice this when observing dark "blotches" he saw on the Sun. Tracking the blotches for several days as they appeared to move across the Sun's surface, he determined that the Sun was actually rotating.

Going further:
Galileo's critics refused to believe that the Sun was not "perfect", since it had been made by a "perfect God". They claimed the dark spots were actually undiscovered planets transiting the Sun's disc. For years after Galileo, some solar observers would not "count" as sunspots those features that were not round and hence qualify as unknown planets! Your students can prove Galileo right in this website about the issue:

http://solar-center.stanford.edu/galileo/

Video Credit: Dr. Philip Scherrer, Stanford University. Based on SDO data.
Movie File: IC.2001.mpg
http://soi.stanford.edu/press/ssu11-01/



Slide 11

Differential Rotation

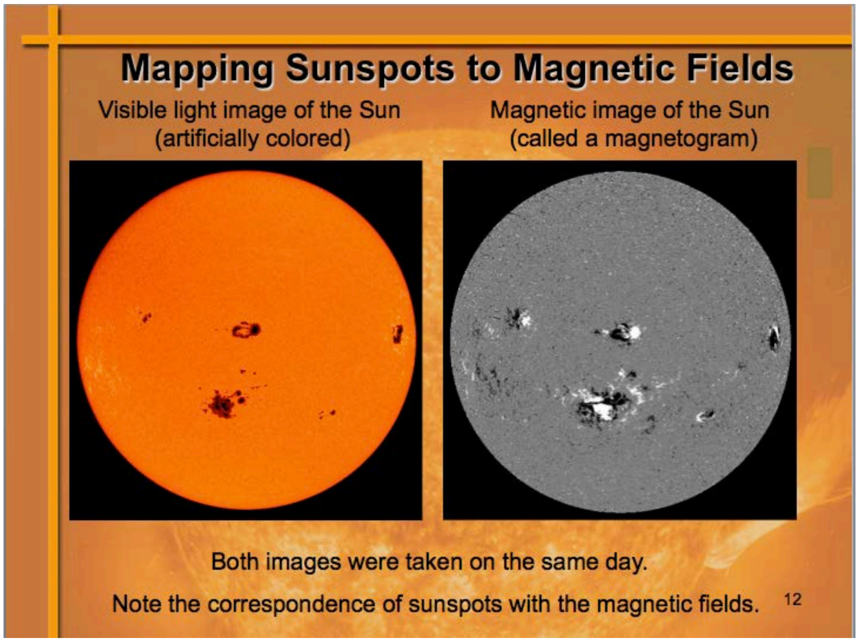
The Sun is a ball of gas and not a solid object like Earth. So it is not constrained to all rotate at the same rate. The rotation rate of the Sun varies at different latitudes on the solar disk – it is faster at the equator and slower near the poles. The core and interior portions rotate at their own rates as well. The fact that the Sun's surface experiences differential rotation is key to understanding the generation of magnetic fields in the Sun.

Teachers - you can learn more about differential rotation by watching this brief lecture available on YouTube video:
https://www.youtube.com/watch?v=dkyqi5AWn58

Students are occasionally confused about differential rotation. On the Earth, different places at different latitudes rotate at different speeds. But each place returns to where it started in 24 hours. This is different from differential rotation.

Going Further: The Earth also has forms of differential rotation – the trade winds. In addition, scientists at Columbia University's Lamont-Doherty Earth Observatory have found that the Earth's inner core is rotating faster than the planet itself!

Image credit: NASA



Slide 12

Mapping Sunspots to Magnetic Fields

Both these images were produced on the same day. Note the correspondence of sunspots to magnetic fields.

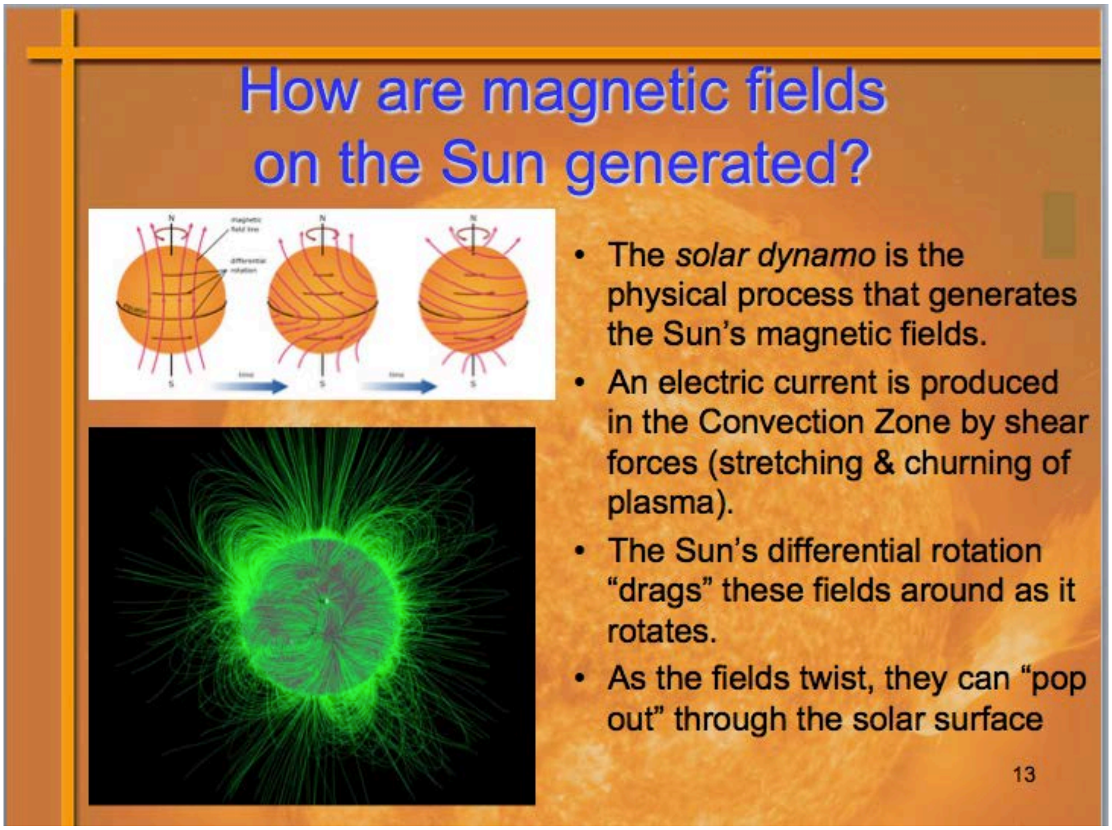
On the left is a “white” or visible light image of the solar surface showing sunspots. (Although the Sun is white, the image has been artificially colored orange so that details are easier to see.)

The image on the right is called a magnetogram. It shows the strength and location of magnetic fields on the Sun. This magnetogram shows "line-of-sight" magnetic fields -- that is, those either pointing directly towards us or away from us. The black are regions of negative magnetic polarity (inward directed, or pointing toward the center of the Sun) and the white regions positive (outward directed, pointing toward us) polarity. Grey areas indicate that there is little magnetic field at all. (Any colors could have been chosen; the grey-black-white is just a common convention.)

“Storms” on the Sun are caused by disturbances to its complex magnetic fields. Notice that where a sunspot appears on the left image, there is a corresponding area on the right image showing active magnetic fields. However there can be many regions that show strong magnetic fields with no corresponding sunspots. From this we can determine that sunspots are not the only sign of solar magnetic activity.

The visible light image shows some of the largest sunspot groups ever recorded. They were readily visible without a telescope. Naked-eye sunspots had been observed and recorded by the ancient Chinese as early as 28 BC. But never look directly at the Sun to look for them!

Image Credits: Both from SOHO/MDI. SOHO is a project of international cooperation between ESA and NASA



Slide 13

The Solar Dynamo - how magnetic fields on the Sun are generated

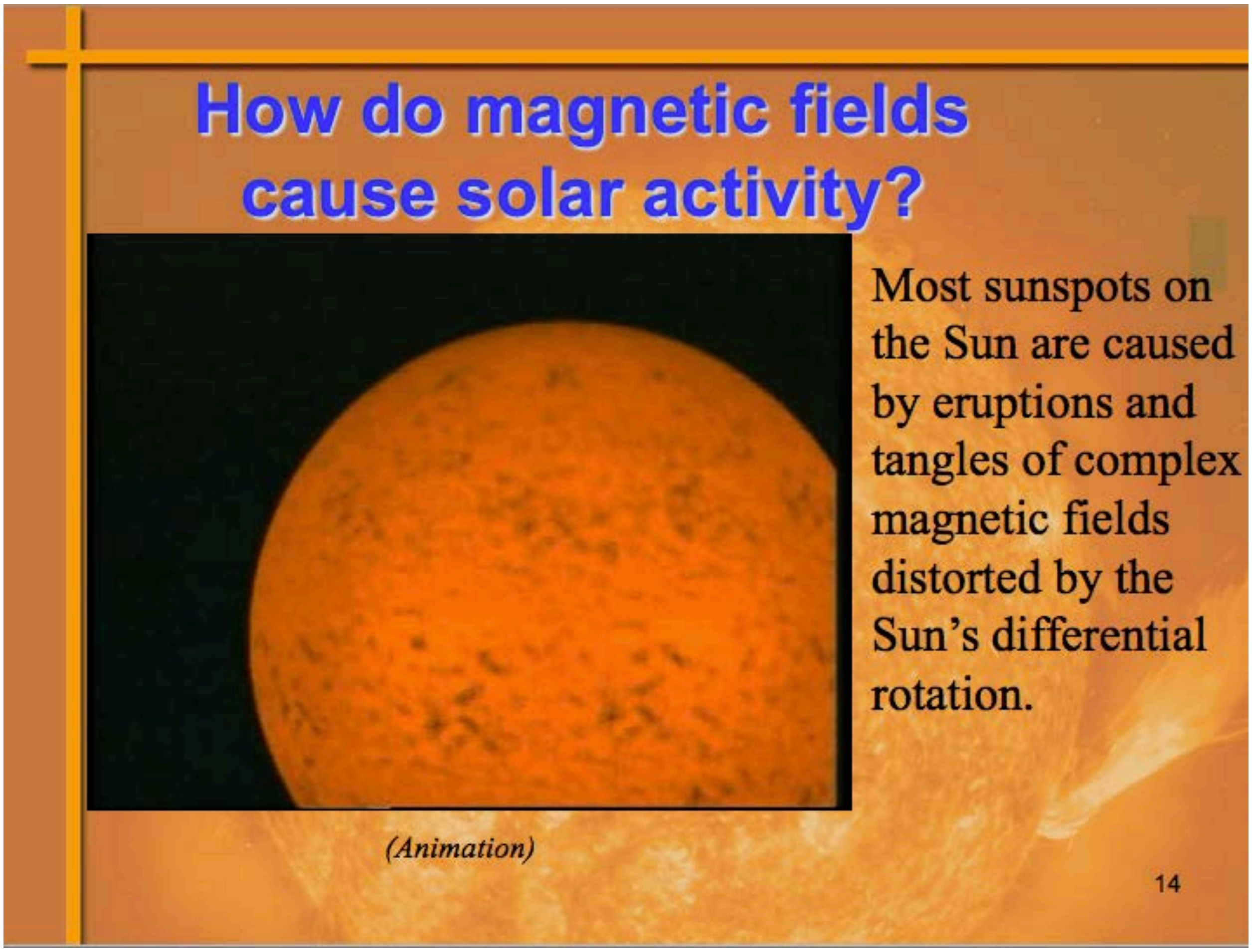
The Sun has an overall magnetic field much as Earth does, although it is not caused by a churning core. It is thought that the magnetic fields on the Sun are generated by currents of electric charges produced in the Convection Zone, the layer below the solar surface..

The Sun is made of plasma – gas so hot that the electrons have been stripped off the atoms. That leaves negatively-charged electrons and positively-charged protons running around separately! The charged particles cannot easily cross over from one magnetic field line to another. So, in this way the magnetic field becomes "frozen" into the plasma.

However, if the particles are moved with some large motion due to a different force (e.g. convection), they will drag the magnetic field with them. This can distort and change the magnetic field if different parts of the gas move at different rates or in different directions. Making matters more complicated, the differential rotation of the Sun causes the magnetic fields to become more and more twisted. This results in little loops of the magnetic field pushing up through the solar surface, forming sunspots and what we call "coronal loops" – like the green lines above the solar surface in the image on the slide.

Eventually, all these magnetic fields become so twisted and entangled that they eventually burst apart. On the next slide, we'll see what happens when these magnetic fields burst!

Image credits: NASA



Slide 14

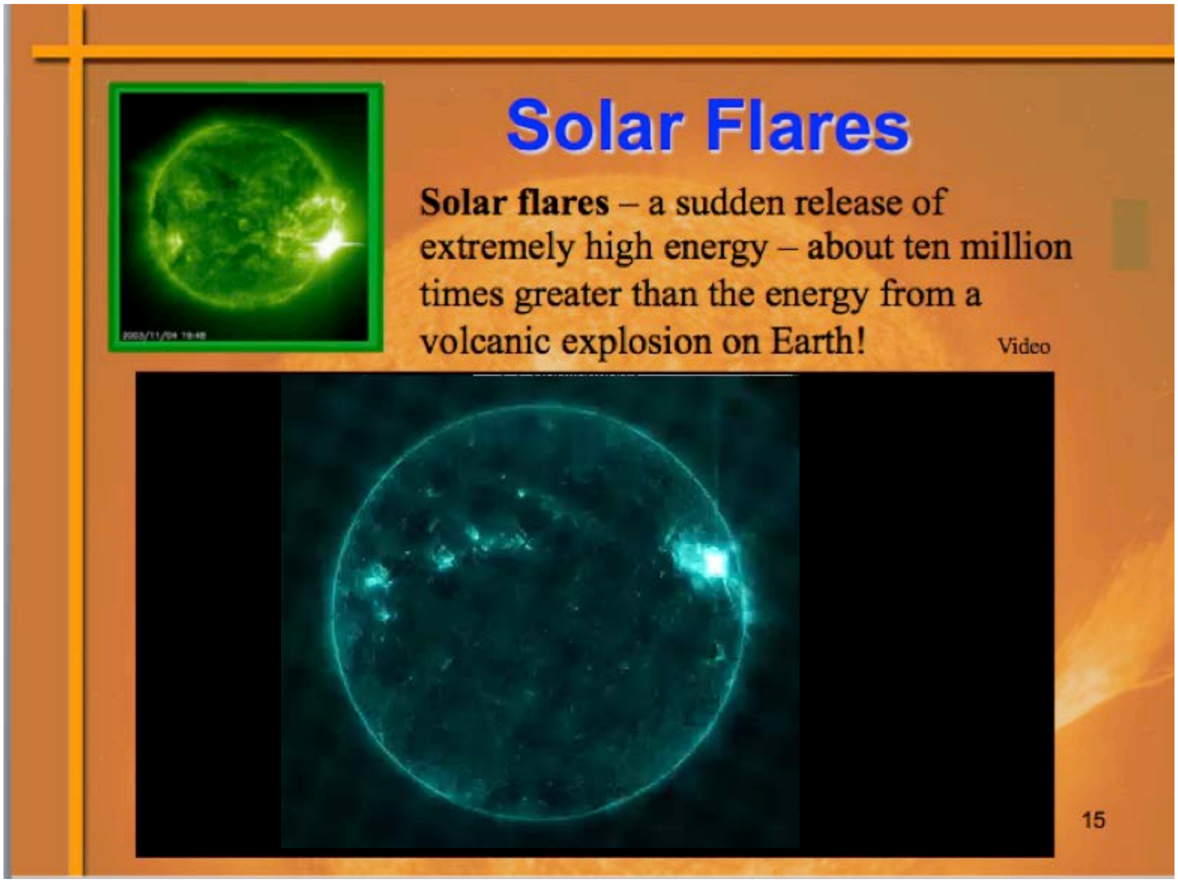
Video - Sunspots, differential rotation, and magnetic fields

Magnetic fields being distorted by the Sun's differential rotation, ultimately "pop" and explode through the surface, usually indicated by sunspots. The animation will continue to play until moving to the next slide.

Plasma, as on the Sun, is ionized gas (gas where the electrons have been stripped from their atoms) and can carry an electrical current. Electrical currents, in turn, generate magnetic fields. Magnetic fields change with, and can generate, electric fields that push charges around, making more magnetic fields.

The complex interaction of these effects creates the tangled mess of coronal loops seen in this video and the previous images. The SOHO animation shows how the Sun's magnetic field winds up and loops out. Areas where the magnetic loops puncture the surface of the Sun appear to us as sunspots crowned by coronal loops. When the loops become disturbed, broken, or snap and reconnect, we see activity such as flares, prominences, and ejections of mass.

Animation Credit: SOHO. SOHO is a project of international cooperation between ESA and NASA.
Animation File: dynamo.mpg



Slide 15

Solar Flares

Video – solar flares in action

The video shows various images of a particularly large solar flare captured by NASA's Solar Dynamics Observatory. The various solar colors represent different wavelengths of light, mostly extreme ultraviolet.

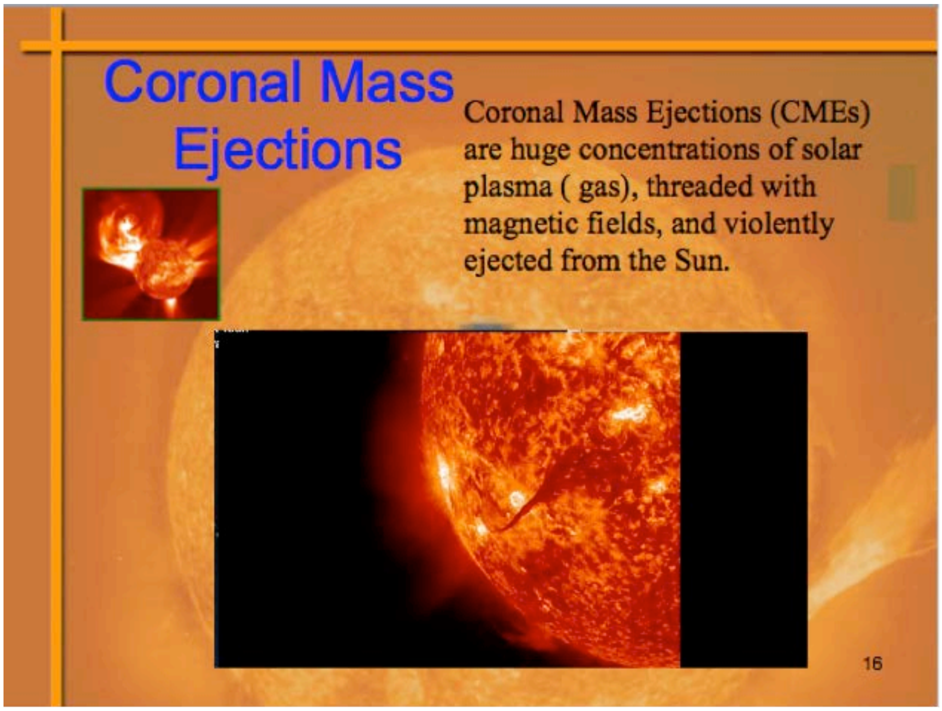
Solar flares are the most powerful explosions in all the solar system. They appear to us as sudden, rapid, and intense increases in brightness from relatively small regions in the Sun's corona (atmosphere). The amount of energy released in a single solar flare is ten million times greater than the energy released from a volcanic explosion here on Earth. They can have dramatic impacts on our lives here on Earth and on astronauts living and working in space. (more on this is Section 3).

Going farther:
Actually, though the solar flare's energy is 10 million times greater than that from a volcanic explosion, the explosive energy per unit is not so great because it's spread over a much larger area.
Extracted from Exploring Magnetism in Solar Flares:
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/in_Solar_Flares/s4.html

“Solar flares occur when magnetic fields in the Sun’s atmosphere rapidly change shape and generate currents of electrically charged plasmas. The energy released by flares takes the form of light, heat, and the movement of large amounts of plasma. Light from across the entire electromagnetic spectrum, from radio waves to gamma rays, can be generated in the biggest flares. Some flares are associated with gigantic eruptions of matter that are ejected out into interplanetary space. Such eruptions are called Coronal Mass Ejections (or CMEs for short). The name is very descriptive as these events are literally ejections of mass from the Sun’s corona. Flares also heat up the plasma in the corona and chromosphere of the Sun. The temperature of the corona is very high. This is unusual since most hot objects get cooler as distance from the heat source increases (the source of the Sun’s heat is in its core). New observations from the NASA spacecraft RHESSI (Ramaty High Energy Solar Spectroscopic Imager) suggest that the curiously high temperature of the corona may be caused by large numbers of very small solar flares that occur frequently.”

“Magnetic fields play a major role in solar flares, but scientists do not yet have a complete understanding of how. The simplest model involves sunspots and coronal loops. Sunspots are places where strong loops, “coronal loops”, of the Sun’s magnetic fields poke through the solar surface. So, sunspots can be thought of as the visible “footprints” of coronal loops. Above the sunspots, the magnetic field loops trap hot plasma. These magnetic loops dynamically twist and churn and become entangled with other loops coming up through the surface. At some point, a loop breaks and then immediately snaps back to a reconnection. This sends a huge surge of energy down into the footprint/sunspot of the loop, much like when you stretch a rubber band between 2 fingers and the rubber band breaks, snapping your fingers with the released energy. That sudden surge of energy downward generates a solar flare. This will be demonstrated in the next video/slide.

Still image from SDO/AIA instrument
Video from NASA



Slide 16

Coronal Mass Ejections (CMEs)

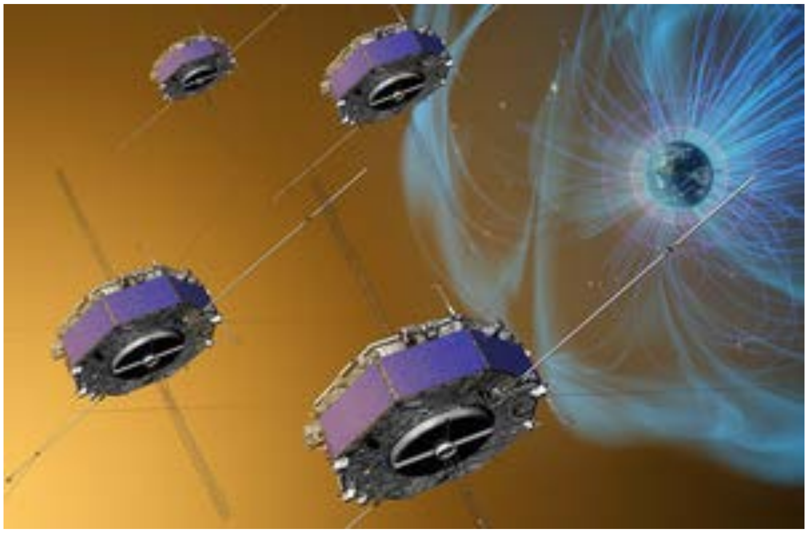
Video – CMEs

Coronal Mass Ejections are just what they sound like – huge concentrations of solar plasma (gas), threaded with magnetic field lines, and violently ejected from the Sun. Like solar flares, they can have dramatic effects on Earth. More about this in Section 3.

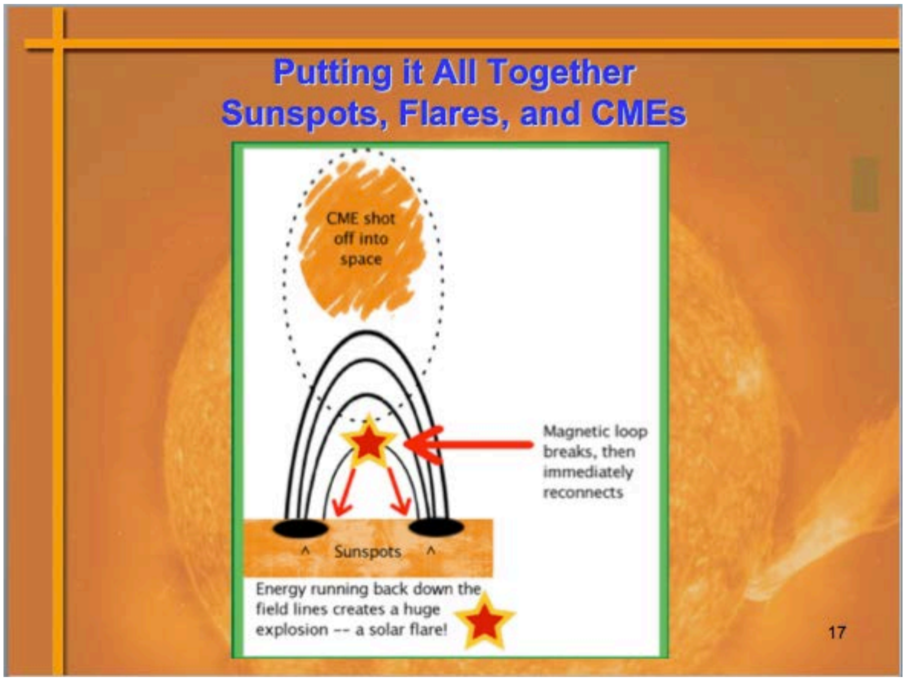
Going farther:
From http://solarscience.msfc.nasa.gov/CMEs.shtml
"Coronal mass ejections (or CMEs) are huge bubbles of gas threaded with magnetic field lines that are ejected from the Sun over the course of several hours. Although the Sun's corona (atmosphere) has been observed during total eclipses of the Sun for thousands of years, the existence of coronal mass ejections was unrealized until the space age. The earliest evidence of these dynamical events came from observations made with a coronagraph on the 7th Orbiting Solar Observatory (OSO 7) from 1971 to 1973. A coronagraph produces an artificial eclipse of the Sun by placing an "occulting disk" over the image of the Sun. During a natural eclipse of the Sun the corona is only visible for a few minutes at most, too short a period of time to notice any changes in coronal features. With ground based coronagraphs only the innermost corona is visible above the brightness of the sky. From space the corona is visible out to large distances from the Sun and can be viewed continuously."

NASA's Magetospheric Multiscale Mission (MMS): MMS is a robotic space mission to study the Earth's magnetosphere using four identical spacecraft flying in a tetrahedral formation. The spacecraft were launched on 13 March 2015, and as of March 2020, the MMS spacecraft have enough fuel to remain operational until 2040.

MMS is important for allowing, for the first time, measurements of the critical electron diffusion region, the site where magnetic reconnection occurs. Magnetic reconnection in Earth's magnetosphere is one of the mechanisms responsible for the aurora,(and it is additionally important to the science of controlled nuclear fusion because it is one of the mechanisms preventing magnetic confinement of the fusion fuel).



CME still image from ESA/NASA SOHO
Video from NASA
Artist depiction of the Magnetospheric Multiscale Mission spacecraft from NASA/GSFC - https://svs.gsfc.nasa.gov/12239



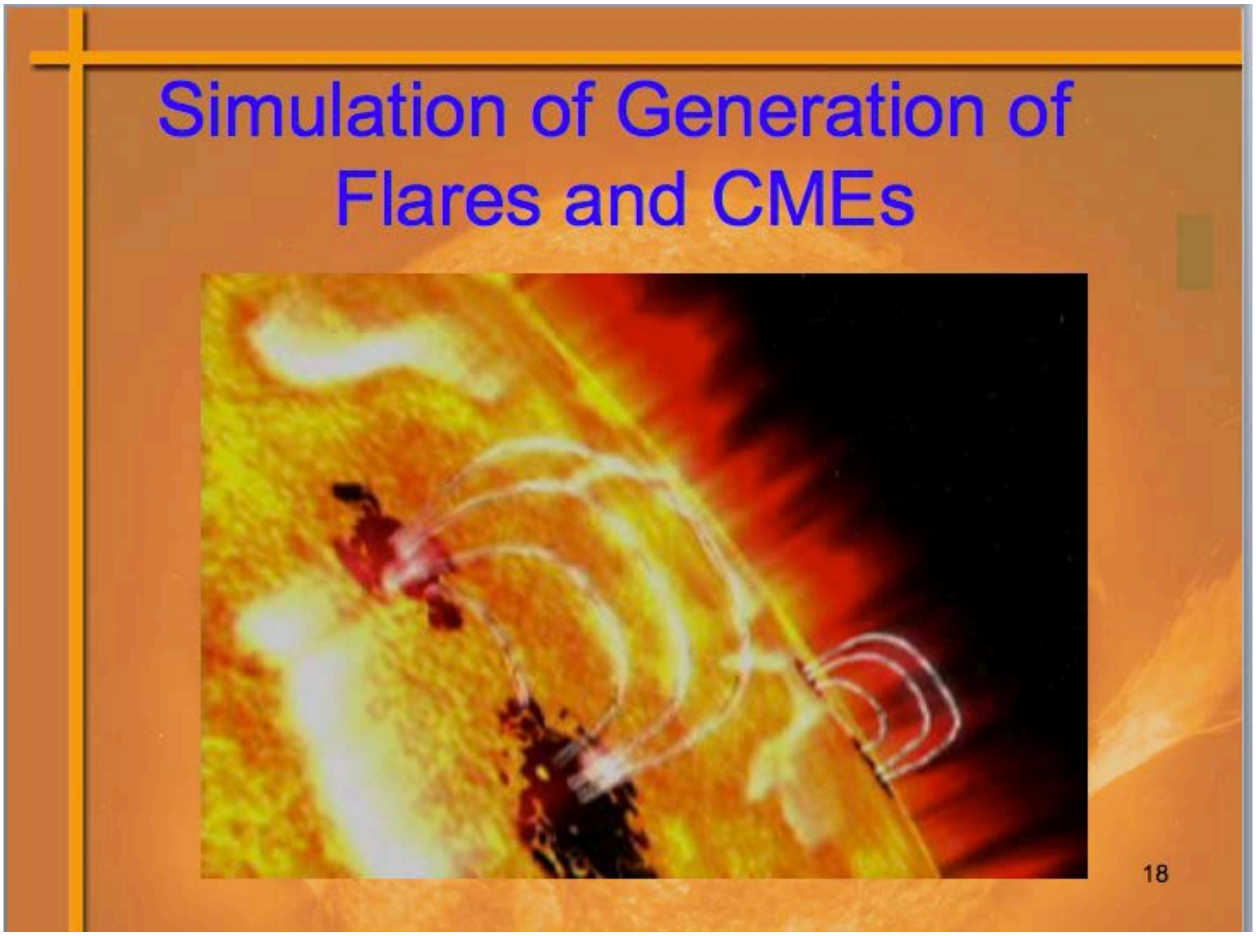
Slide 17

Putting together sunspots, solar flares, and CMEs

Before presenting the slide presentation, the teacher should study Appendix I, which gives a pictorial representation of the information here. It is provided for the teacher's benefit, but could also be distributed to the students.

A quick summary of Appendix I:
New studies show that the Sun's solar activity may all be part of the same mechanism. Here's a quick summary, but the educator should make use of Appendix I for details.

1. Regions of intense magnetic fields (shown in the animation as white loops or giant arches) are formed from many small magnetic structures in the Convection Zone. We can see these loops because electrified gas (i.e. plasma) is trapped within them.
2. These magnetic fields/loops rise upwards from within the solar interior.
3. They eventually "break through" the solar surface.
4. The areas where the magnetic fields break through appear as sunspots, usually with a positive and a negative pole because of the magnetic fields of the loops.
5. Once the loops rise above the surface, they are continually interfered with by more magnetic fields, which cause the fields to twist and contort.
6. Occasionally a magnetic field line/loop will be stressed enough that it eventually breaks.
7. This results in
    - Energy below the break running back "down" the field line
    - The field almost immediately reconnects, either to its original "self" or to another field line. This is termed *magnetic reconnection*
8. When the energy that is forced down "hits" the surface, a huge explosion is generated – a solar flare!
9. When the magnetic field lines reconnect, a "blob" of plasma may be released/pushed away from the solar surface – a CME!

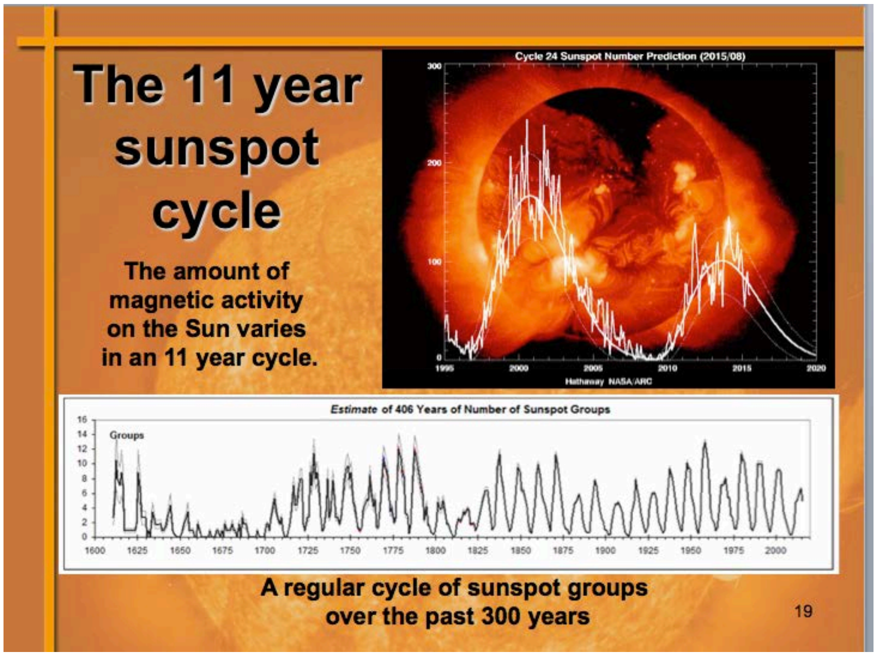


Slide 18

Animation of generation of flares and CMEs

This is an excellent animation demonstrating the procedures described in the previous slide. You may have to show it to your students several times, pointing out critical points such as where the field breaks through the solar surface to cause sunspots, where the fields interact & disconnect (causing a solar flare and a CME) and reconnect.

Animation Credit: NASA/Goddard Space Flight Center Conceptual Image Lab. Walt Feimer, lead animator.



Slide 19

The sunspot cycle

The amount of magnetic activity on the Sun varies in an approximate 11-year cycle. That is, the Sun will be covered with sunspots and activity at Solar Maximum, The number of spots will decline to very few at Solar Minimum, and then climb back up again. This process takes about 11 years to complete. It is not a perfectly regular cycle, some peaks are higher, some lower.

Aside:
Actually, the cycle is more accurately described as a 22-year cycle. Once the Sun completes a normal 11-year cycle, its poles are flipped. Another cycle begins, though with the poles of the Sun, and the fields of the sunspots, now in opposites places.

In 1848 Rudolph Wolf devised a daily method of estimating solar activity by counting the number of individual sunspots and groups of spots on the face of the Sun. Wolf chose to compute his sunspot number by adding 10 times the number of groups to the total count of individual spots, because neither quantity alone completely captured the level of activity. Today, Wolf sunspot counts continue since no other index of the Sun's activity reaches into the past as far and as continuously. The chart at the bottom of the slide lists the Sunspot Numbers from the 1600s to the present. This is a recently revised chart based on new research (see Leif Svalgaard, Ken Schatten, *Reconstruction of the Sunspot Group Number: the Backbone Method;* Solar Physics Journal, 28 July 2015).

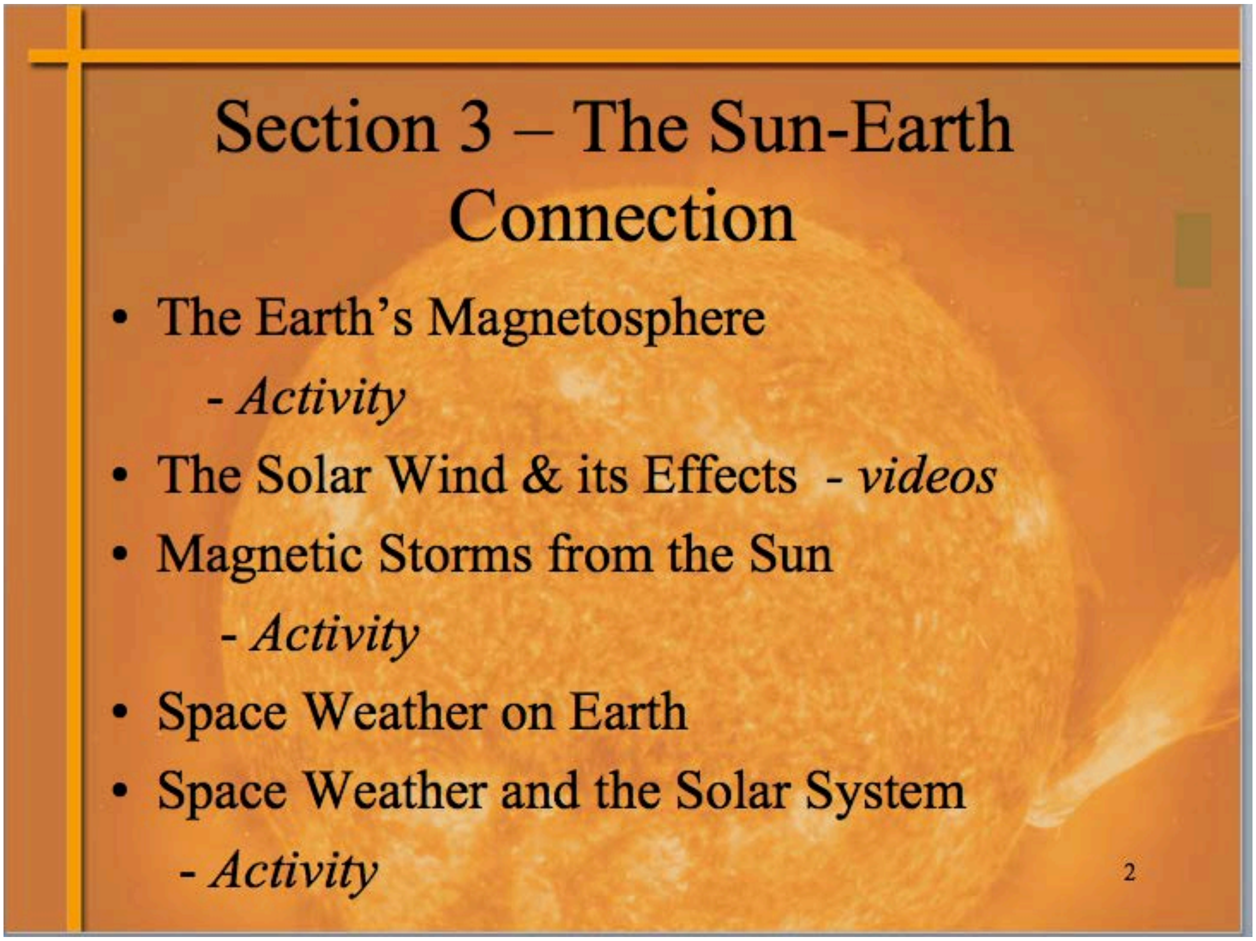
Note that the current solar cycle (~2020) is very low, about as weak as the one a century ago.

Nobody understands for sure why there is a solar cycle nor why it behaves the way it does. It is one of the more interesting questions scientists are studying about the Sun.
Image Credit: http://solarscience.msfc.nasa.gov/images/ssn_predict_l.gif

Slide 20

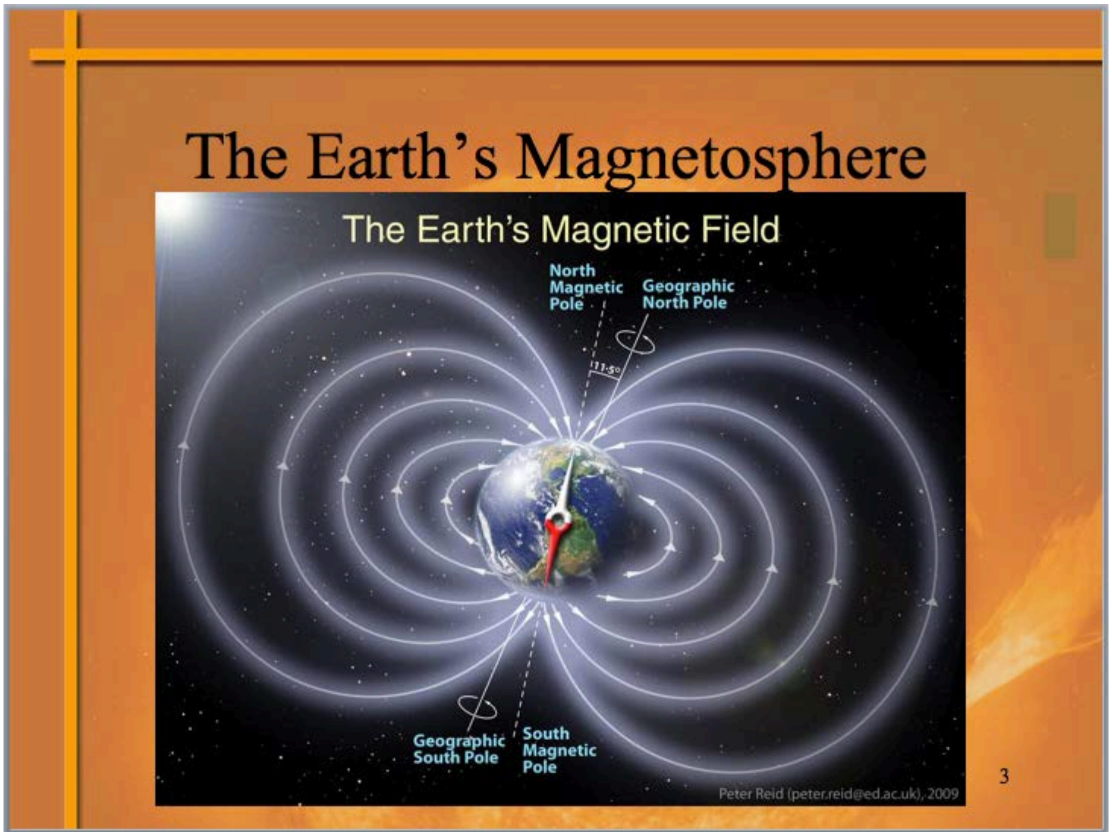
Section 3 will concern the interaction of the Earth's and the Sun's magnetic fields.
Image credit: NASA/SDO AIA instrument

Section 3 - The Sun – Earth Connection



Slide 1

Students will explore the Earth's magnetic field (magnetosphere) in the context of the solar wind. They will understand the extensive impact solar activity can have on the Earth its technology, and its life forms. Then they will extend what they have learned to understand how the Sun's activity can also have a dramatic effect on space travel and much of the rest of the solar system.



Slide 3

The Earth's Magnetosphere

"Magnetic fields around planets behave in much the same way as a bar magnet. But at high temperatures, metals lose their magnetic properties. So it's clear that Earth's hot iron core isn't what creates the magnetic field around our planet."[4]

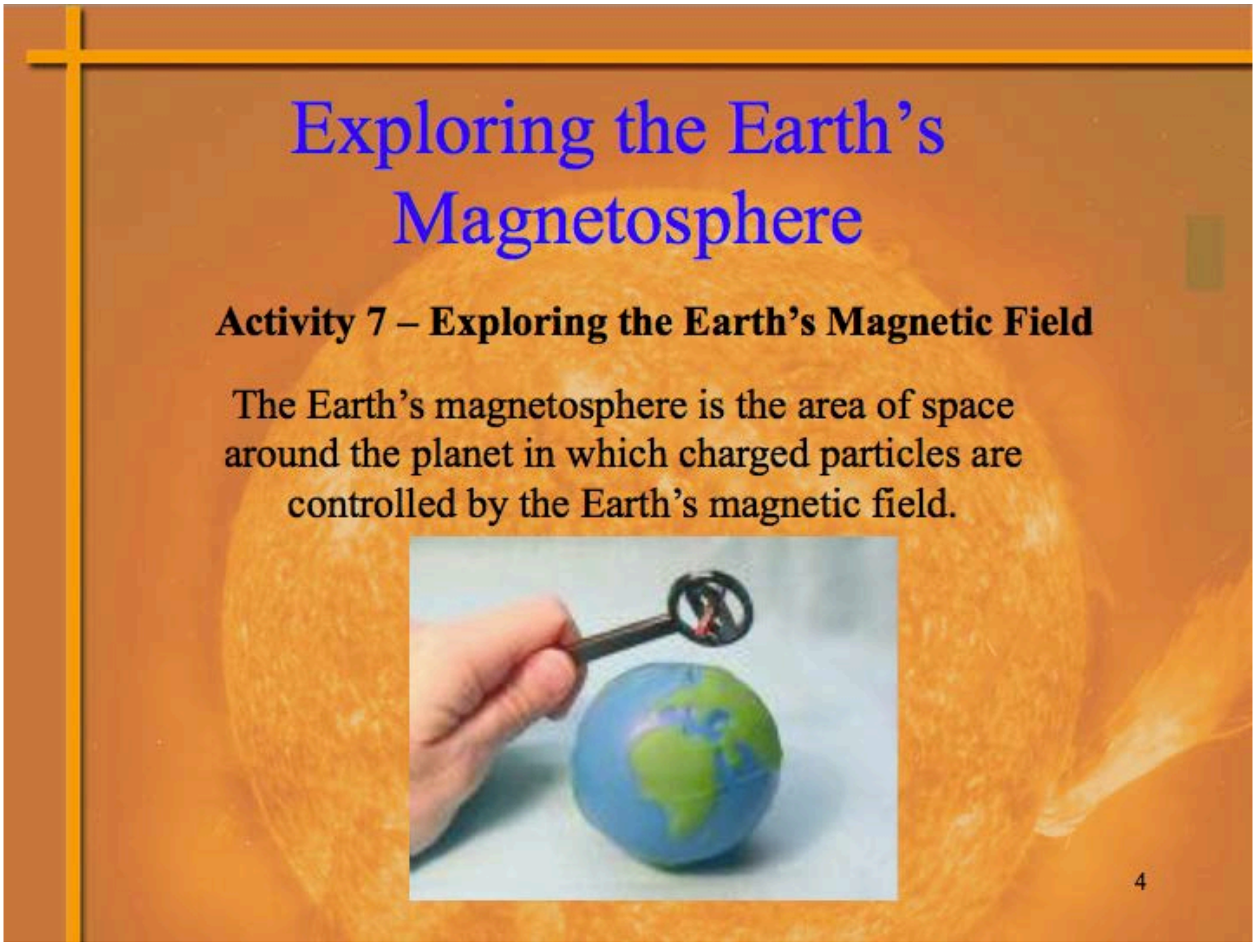
The Earth has a core of molten iron. The flowing of liquid metal in the outer core generates electric currents. The spinning of the Earth on it's axis causes these currents to form a magnetic field which works its way up through the Earth and extends around the planet.

The Earth's magnetic field is extremely important to sustaining life on Earth. Without it, large amounts of high energy radiation from the Sun would bathe our planet and solar activity would threaten our technology.

See also: http://www.geomag.bgs.ac.uk/education/earthmag.html

Image credits: Schematic illustration of Earth's magnetic field.
Credits: Peter Reid, The University of Edinburg

[4] https://cosmosmagazine.com/geoscience/what-creates-earth-s-magnetic-field



Slide 4

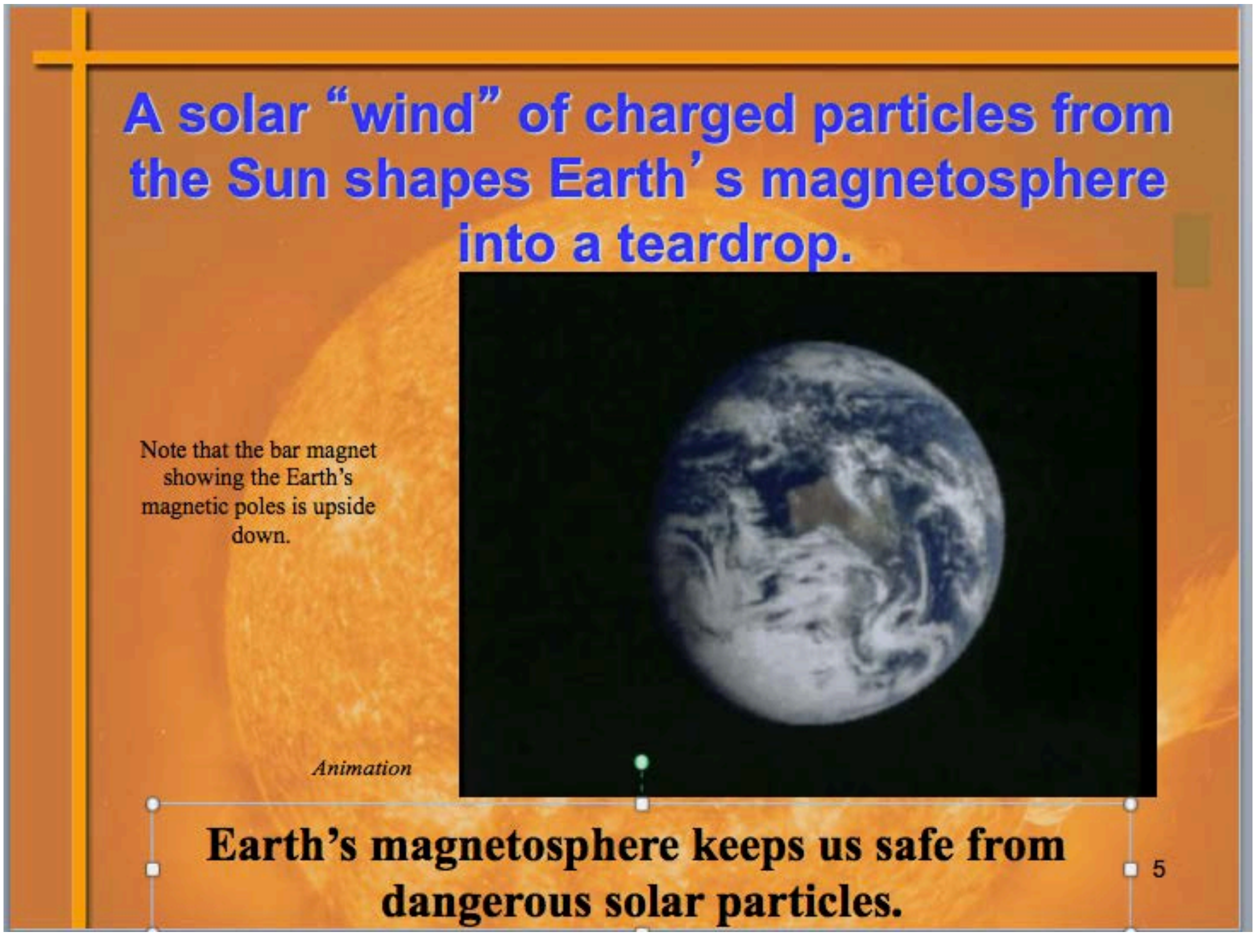
Activity 7 – Exploring the Earth's Magnetic Field – See Appendix J

Materials:

- Small Earth ball with magnet inside (instructions for making these are in Appendix J)
- Magnaprobe (instructions for these are in Appendix B)

Procedure:
Have the participants explore their Earth model with the Magnaprobe. Assure they notice that the magnetic field lines at the pole are perpendicular to the pole's surface and that magnetic field lines at the equator are horizontal to the surface.

Ask students to discuss their findings.



Slide 5 - video

The Solar Wind

Video: showing the solar wind's impact on Earth's magnetosphere

We have seen how the Earth has a large magnetic field, the magnetosphere, that emanates from near the Earth's rotational poles and surrounds the planet. And we have seen that the Sun has millions of magnetic fields, emanating from its Convection Zone, and extending through its surface up into the solar corona.

What happens when these 2 magnetic systems interact?

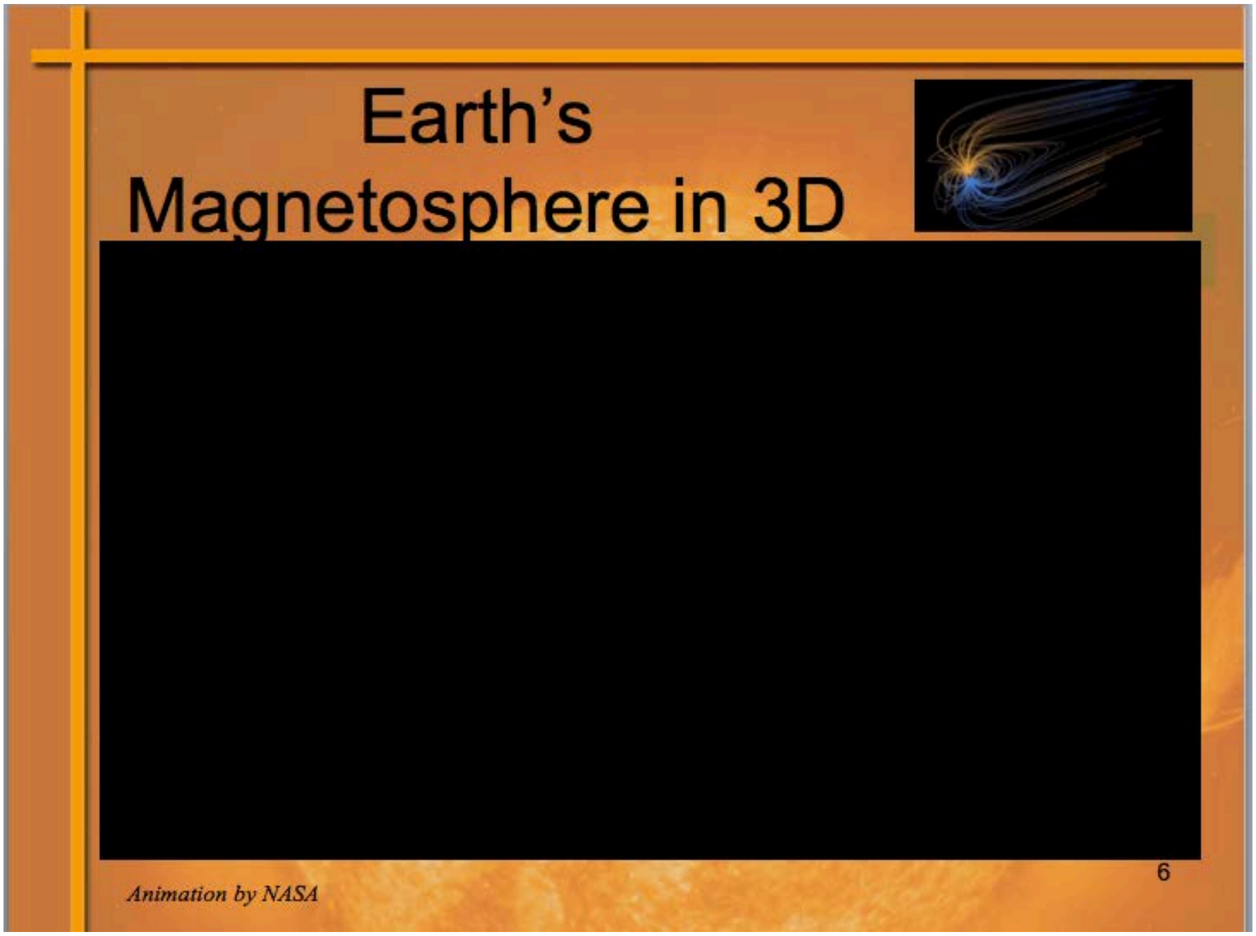
The solar wind
Video shows how the solar wind shapes Earth's magnetosphere.

Expanding coronal gas, or solar wind, fills interplanetary space. Solar magnetic fields embedded in the plasma are carried into space by the solar wind to form the interplanetary magnetic field. The solar wind streams from the Sun in all directions at about a million miles per hour (~1.5 million km/hr). The source of the solar wind is the Sun's hot corona, where temperatures are so high that the Sun's gravity cannot hold on to the plasma.

The solar wind is not uniform. Although it is always directed away from the Sun, it changes speed according to activity. High and low speed streams can interact with each other and alternately pass by the Earth and planets as the Sun rotates.

As we learned, the Earth’s magnetosphere would normally have a very uniform shape - like the field around a bar magnet (shown in the movie). However, due to the million km/hr electrically charged solar wind constantly buffeting the Earth, the shape of Earth’s magnetosphere is compressed on the side facing the Sun and stretched out on the side facing away. Variations in the solar wind speed can affect the Earth's magnetic field and produce storms in the Earth's magnetosphere.

Movie File: 6magnet4.avi



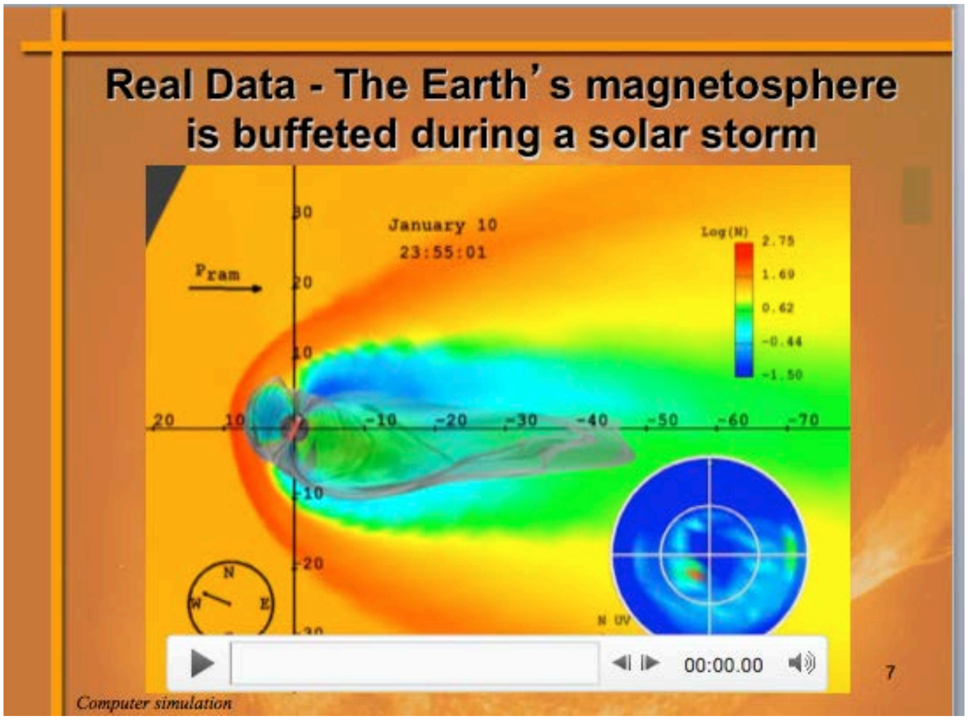
Slide 6 - video

Video – 3D animation of the Earth’s magnetosphere

A glorious animation, with audio, of the Earth’s magnetosphere in 3D.

This video is provided for for its artistic content and to help students understand the nature of the Earth’s magnetic field in 3D.

Credit: NASA https://www.youtube.com/watch?v=k67OGI-ur3I



Slide 7 - video

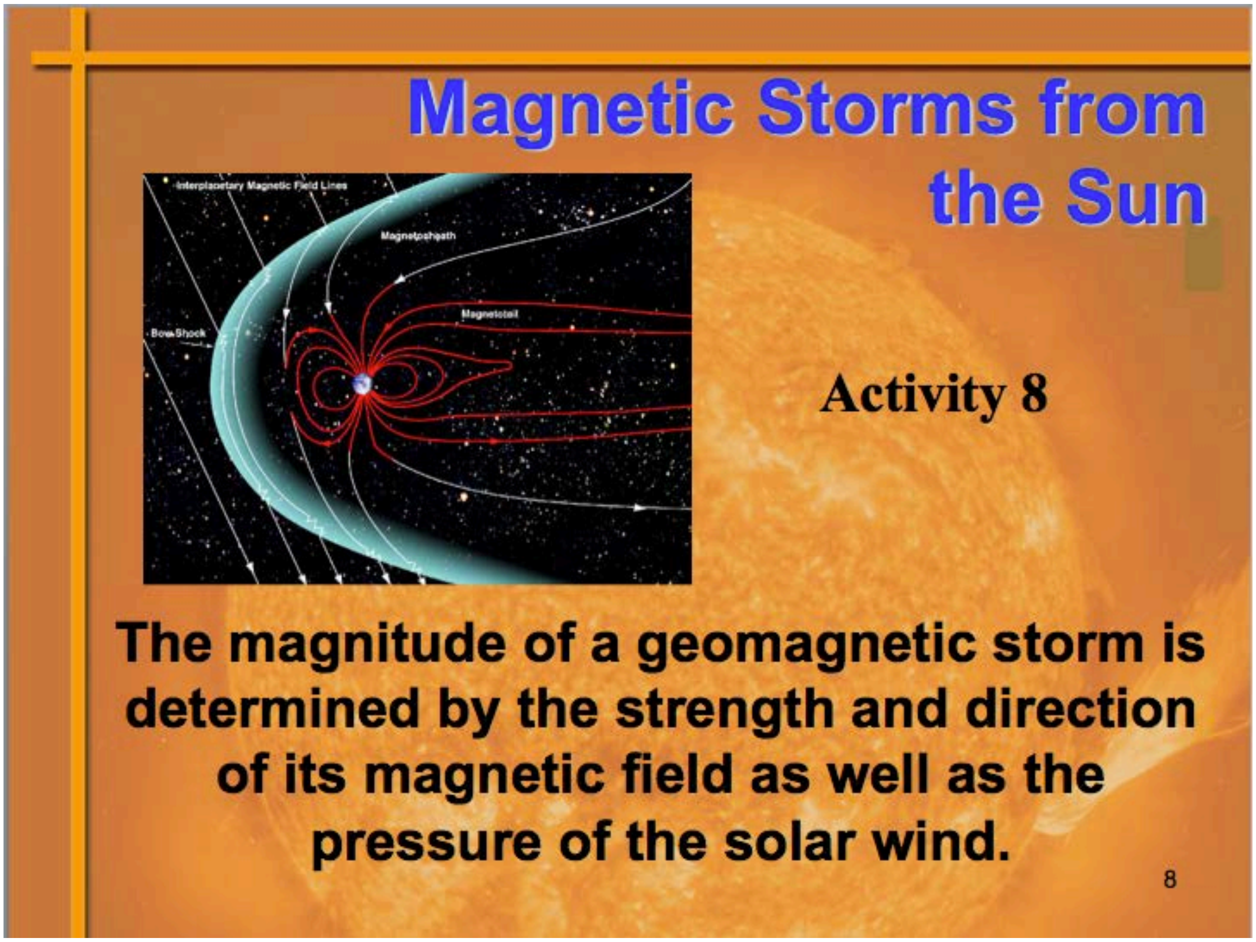
Video simulation of the Earth's magnetosphere being buffeted by the solar wind and a CME

The video is a computer simulation, based on actual data, of the Earth's magnetosphere being buffeted by the solar wind and then changing shape as a coronal mass ejection impacts the Earth's magnetic field. The simulation spans approximately 4 hours worth of data.

Here's a description of the items you see:

- The Earth is the small "ball" at the center point of the axes. You can see a red bar through the Earth, indicating the orientation of the Earth's magnetic field.
- The grey contours show the changing shape of the magnetosphere. The colors tell how much plasma is present – red indicating a high density and blue low.
- As the simulation starts, the field is relatively normal. As the Earth becomes bombarded by the coronal mass ejection, the field turns almost completely red.
- On the upper left is an arrow labeled "Pram". This is the Solar Wind Dynamic (or Ram) Pressure, the pressure and direction the solar wind exerts on the Earth's magnetosphere. One could think of it as the intensity of the ejection.
- On the lower left a small compass indicates the direction and strength of the magnetic field in the ejection.
- The circular inset on the lower right simulates where and what auroras would be seen if looking directly down at the Earth's North Pole.

Image credit: Charles C. Goodrich, University of Maryland, Space and Plasma Physics Group GGS/University of Maryland Space Plasma Physics project. See http://www.spp.astro.umd.edu/htmls/JanCloud/jan10-11.html
Movie File: ion-ms-jan_6.mpg



Slide 8

Activity 8 - Magnetic Field of a CME impacting the Earth - Appendix K

Activity developed by Deborah Scherrer, Stanford Solar Center.

Materials:

- Worksheet from Appendix K
- Pen or pencil

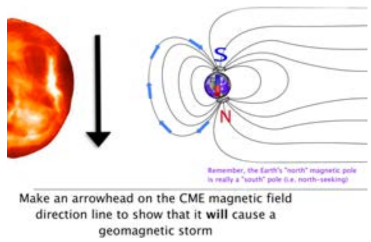
Procedure:

1. Provide the information below
2. Pass out the worksheet
3. Ask students to label the directions of the magnetic field in each of the drawings.

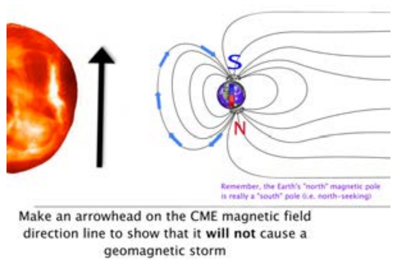
A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar event (e.g. Coronal Mass Ejection or a sudden high speed increase in the solar wind) that interacts with Earth's magnetic field. The magnetic field from the Sun is present in the eruption. The increase in solar wind pressure compresses the magnetosphere and generates electric currents in the Earth's magnetosphere and ionosphere.

The direction of the magnetism in the eruption will determine how much effect the storm has on Earth. If the solar wind field is pointing northward, it will generally slip by the Earth's magnetosphere and little harm will be done. However, if the ejection has a southward direction, it will be conducive to magnetic reconnection (i.e. a rapid conversion of magnetic field to energy) - meaning it will interact with, and integrate into, Earth's magnetic field, rapidly injecting magnetic & particle energy into the Earth's magnetosphere[5]. It will also add to (and hence extend) the magnetotail and have direct access to the Earth's poles. This can cause serious disruptions. Until scientists figure out how to determine a CME's direction of magnetism before it reaches us, we will not be able to predict the severity of such dangerous solar storms.

Here is the correct labeling:



This CME has a south-facing field, which is opposite the Earth's magnetic field. Hence the fields will be conducive to magnetic reconnection and the CME will disrupt the Earth's magnetosphere, causing a geomagnetic storm.



The CME above has a North-facing field, which is the same as the Earth's. Therefore the Earth's magnetosphere will "repel" the CME and it will cause little damage.

Image from: http://wormholeriders.org/science/?p=24505

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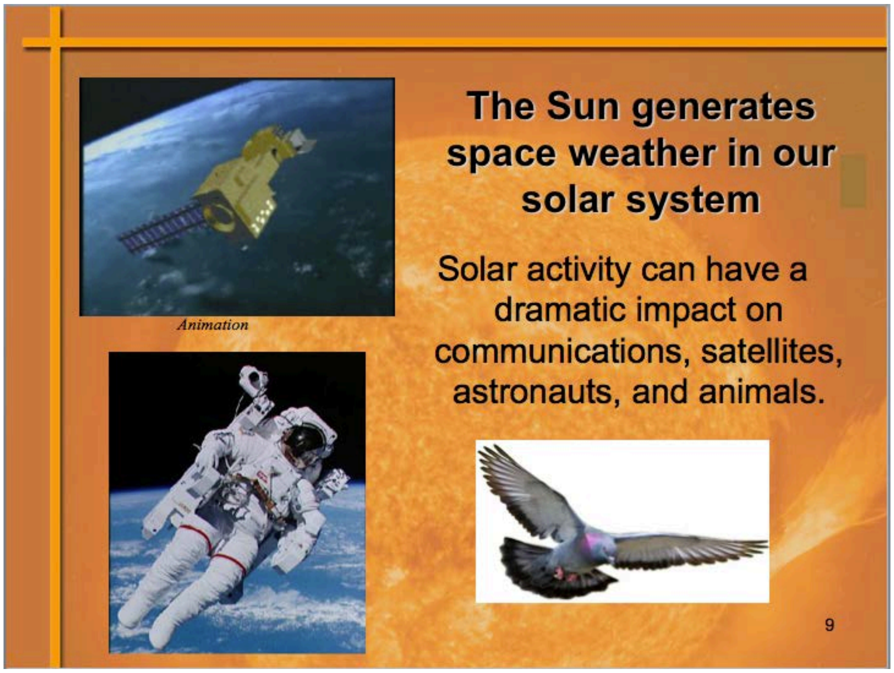
5 NASA's MMS mission is designed to study these particular events. See http://mms.gsfc.nasa.gov/



Slide 9

Space Weather

The Sun can generate conditions in space that have the potential to seriously affect Earth and other planets. We call these conditions "space weather". The causes can include radiation storms and ejections from the Sun as well as disturbances in the Earth's magnetic field caused by gusts of plasma from the Sun.

These geomagnetic storms can
- Trigger beautiful aurora displays
- Damage/destroy satellites
- Disrupt power grids and electrical systems
- Interfere with cell phones, GPS, and other communications
- Cause ionospheric disturbances which interfere with radio communications
- Cause expensive rerouting of aircraft away from the poles because of the threat to communications
- Threaten astronauts and high-flying airplanes with their radiation!
- Induce currents in pipelines, hence dramatically increasing corrosion rate
- Disrupt animal movements and migrations (pigeons, bats, sea turtles, dolphins & whales, etc.) because these animals rely on the Earth's magnetic field to find their way

Scientists are working to predict the occurrence of solar storms much like meteorologists predict weather on Earth.

Upper left movie: An animation of a satellite getting "fried" by a solar event. The arcing seen in this animation could damage electronics and permanently disable the satellite.
Image credits: Astronaut courtesy of NASA *Movie File: sizzler.avi*

Slide 10 – videos

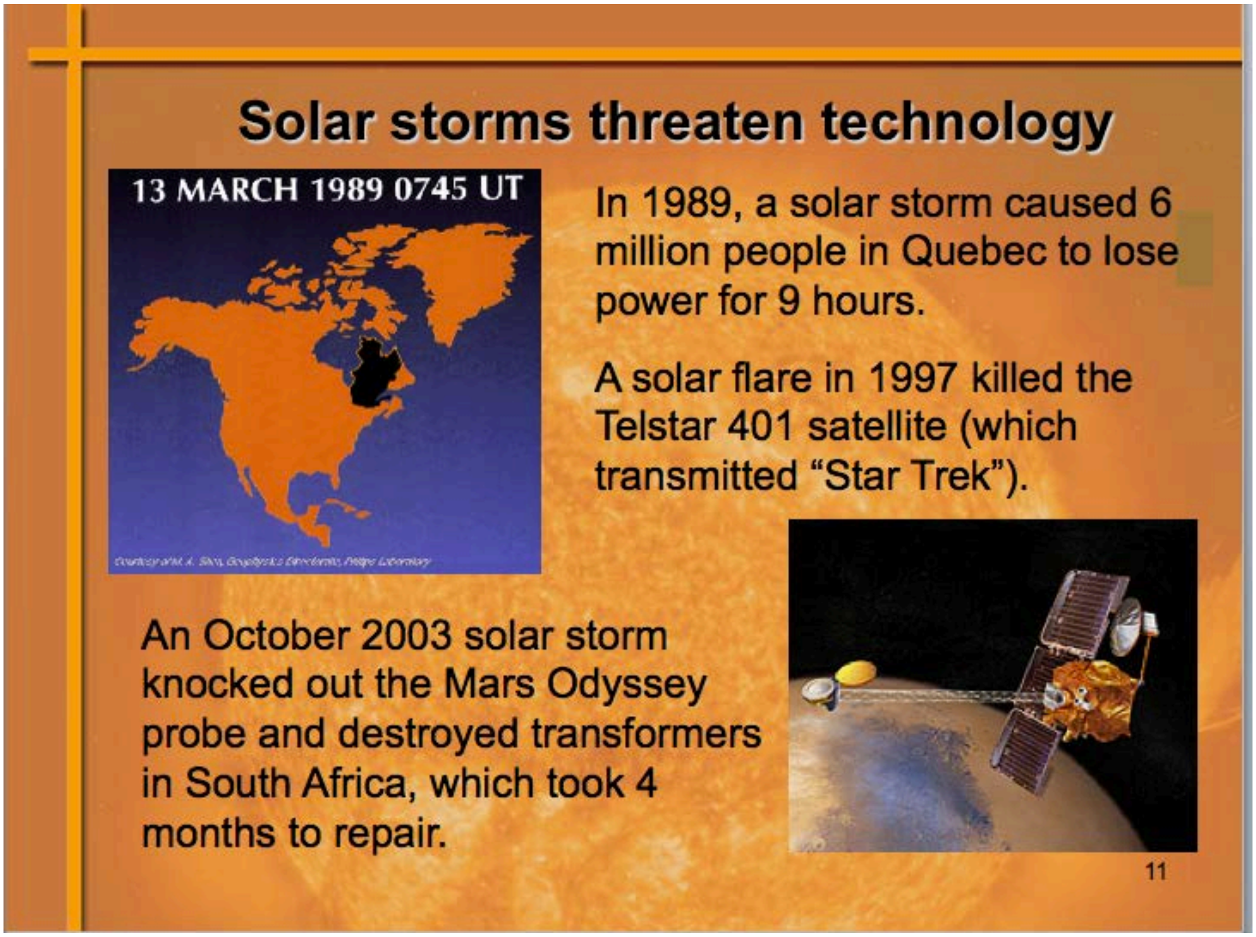
Video – solar activity produces aurorae

In the animation, a solar event sends a stream of charged particles towards Earth. The particles interact with the Earth's magnetosphere. The particles follow the magnetic field lines into the magnetotail, where they break, then immediately meet in a *reconnection*. The particles then flow back to the Earth's poles and interact with the gases in our atmosphere.

Aurorae, sometimes called Northern or Southern Lights, are beautiful displays of color in the high-latitude sky. The energy that drives the auroral currents comes from the action of the solar wind on the magnetosphere. High-energy particles become trapped in the Earth's magnetic field. As these particles spiral back and forth along the magnetic field lines, they come down into the atmosphere near the north and south magnetic poles where the magnetic field lines disappear into the body of the Earth.

The delicate colors are caused by energetic electrons colliding with oxygen and nitrogen molecules in the atmosphere. This excites the molecules, and when they decay from the excited states they emit the light that we see in the aurora. The aurora green color is due to atomic oxygen, whereas any blue color visible is from the interaction with nitrogen molecules.

Image Credits:
Upper left photograph of an aurora near Monikie, north of Dundee, Scotland, 30th October 2003. John Gilmour. From http://aurorawatch.lancs.ac.uk/ *Lower left aurora photo by Craig M. Groshek from Wikipedia, released to the Public Domain.*
Movie File: recon.mpg



Slide 11

Solar storms threaten technology

In 1989 a large solar storm caused damage to a power station in Quebec and left 6 million people in Canada and the US without power for 9 hours.

A solar storm in October 2003 knocked out an instrument on NASA's Mars Odyssey probe orbiting Mars. Ironically, the instrument was designed to assess the hazards humans would face if they were to visit the Red Planet.

The same October 2003 storm caused a blackout in Sweden, damaged two Japanese satellites and interfered with navigation and radio systems, and also crippled South Africa's power supply by damaging 15 large transformers. It was 4 months before full power was restored.

Image Credits: Mars Odyssey spacecraft, NASA

Slide 12

Space weather affects the solar system

Since the Moon and Mars have neither atmosphere nor much of a magnetosphere, astronauts are at risk from solar radiation and X-rays. If astronauts were traveling to or walking about on the Moon or Mars during a significant solar storm, they might be debilitated or even killed!   In fact, finding a way to protect astronauts is one of the key challenges of sending humans to Mars. More about this on the next slide.

Image Credits: Moon, Saturn, Jupiter, Neptune courtesy NASA
Mars Science Laboratory rover using ChemCam to analyze a rock. Artist's conception, courtesy French Space Agency (CNES) and Los Alamos National Laboratory.

Slide 13

Space weather on the Moon and Mars

Solar radiation is a **key factor** for astronaut safety as they venture to the Moon and eventually Mars. NASA is exploring a variety of techniques and technology to mitigate different types of radiation during space travel. Below are some excerpts from this excellent article: https://www.nasa.gov/feature/goddard/2019/how-nasa-protects-astronauts-from-space-radiation-at-moon-mars-solar-cosmic-rays

"Radiation is energy packaged in electromagnetic waves or carried by particles. The energy is handed off when the wave or particle runs into something else, like an astronaut or a spacecraft. These electromagnetic waves are dangerous because they pass right through skin, shedding energy and fragmenting cells or DNA on their way. This damage can increase risk for cancer later in life, or in extreme cases, cause acute radiation sickness in the short-term."

"On Earth, humans are safe from this harm. Earth's protective magnetic bubble, the magnetosphere, deflects most solar particles. The atmosphere also quells any particles that do make it through. The International Space Station cruises through low-Earth orbit, within Earth's protection, and the station's hull helps shield crew members from radiation too."

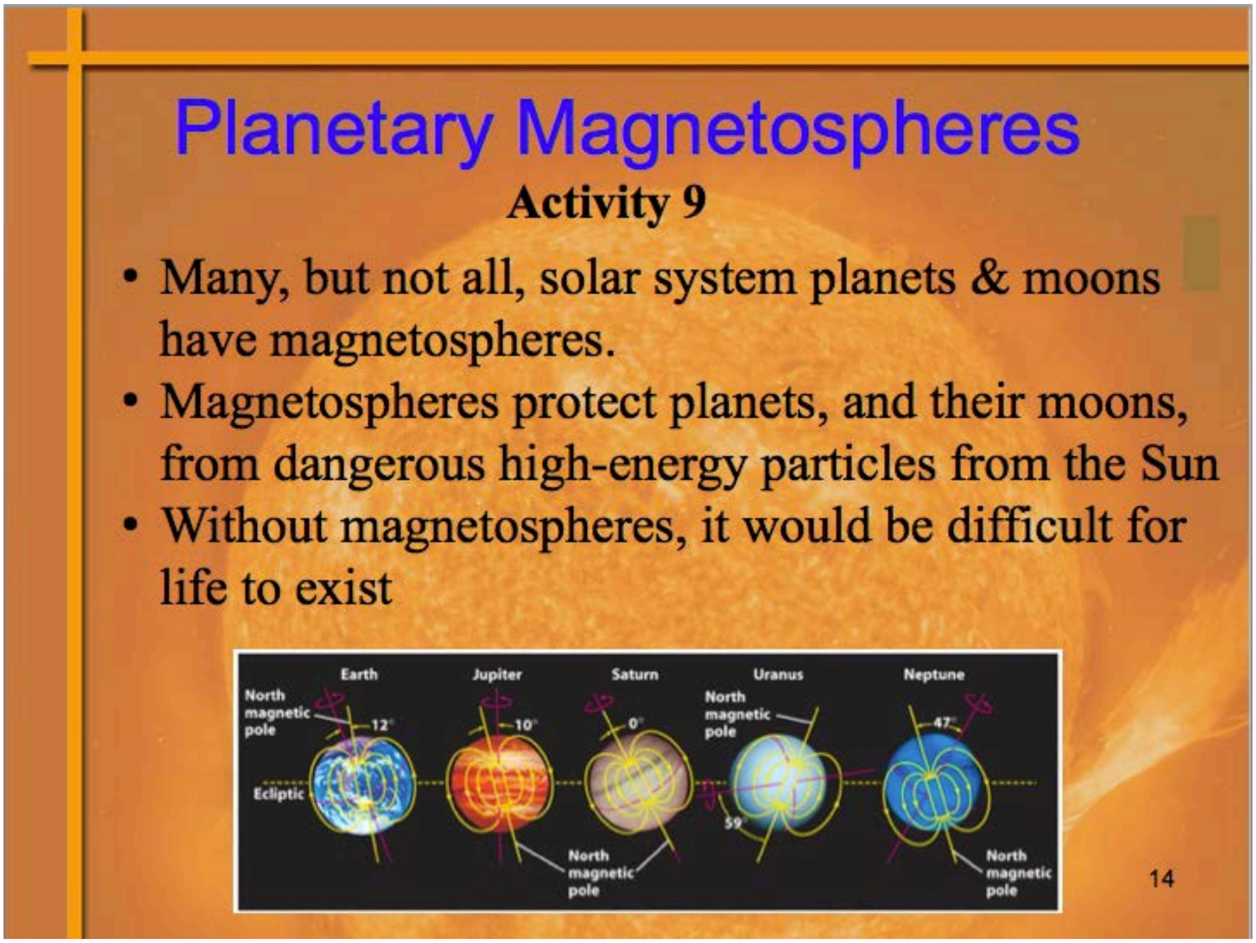
But beyond Earth's safe magnetosphere, human explorers will face the harsh radiation of space. Not only solar radiation, but galactic cosmic rays, particles from long-gone, exploded stars elsewhere in the Milky Way — constantly bombard the solar system at near-light speeds.

"Going to the Moon will help NASA collect crucial data and develop the necessary tools and strategies to one day safely send human explorers to Mars. The journey to Mars will take much longer than a trip to the Moon, and crew members will face much more radiation exposure. And, unlike Earth, Mars has no magnetic field to divert radiation."

Perhaps some of your students will become these planetary explorers!

See also:
https://www.space.com/34519-mars-space-weather-forecasting-critical-for-astronauts.html
https://www.astrobio.net/mars/space-weather-on-mars/

Image credit: A futuristic colony on the Moo
A model of the Hermes spacecraft, developed for the film "The Martian".



Slide 14

Planetary Magnetospheres

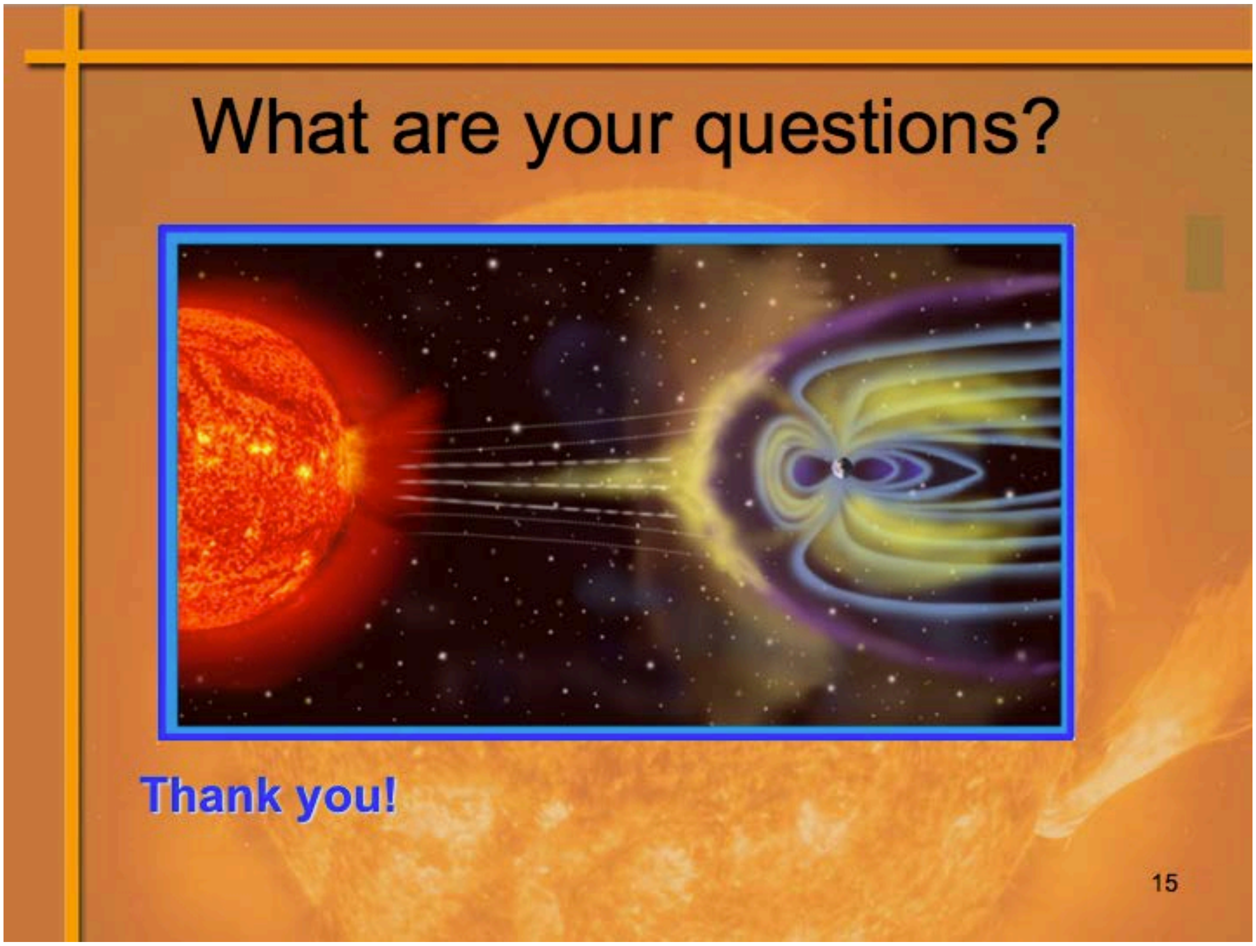
Activity 9: Planetary Magnetospheres – See Appendix L

Magnetospheres protect planets and moons from dangerous solar radiation. Earth's Moon, Venus, Mercury, and Mars have only weak magnetospheres, making it difficult for humans to safely visit there. (Mercury does have a global dipole magnetic field that interacts with the solar wind to form a magnetosphere. It is probably maintained by a dynamo of free charges in its huge iron core. The field strength is only 1% of Earth's however. So it is the weakest planetary dipole field in the Solar System.)

Some theorize that life could not develop on a planet or moon without a magnetosphere.

Students will examine models of the various planets to locate their magnetic poles and hence identify the planet. A mysterious exoplanet is also included. See Appendix L for complete instructions.

Activity developed by Deborah Scherrer, Stanford Solar Center.



Slide 15

Appendices

Appendix A – Activity 1 – Exploring Magnetic Poles

Activity developed by Deborah Scherrer, Stanford Solar Center

Activity Summary: Students will learn about the poles of magnetic fields by experimenting with various types of magnets.

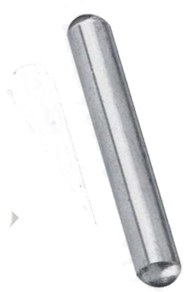
Student Objectives:

- Students will discover that magnets have either zero, 2, or more poles (but never one).
- Students will discover that the direction of magnetic fields determines the location of poles of a magnet.
- Students will understand what happens when a magnet is cut in half.
- Students will understand how the manufacturing process determines the location of the poles in a magnet.
- Students will learn that a complex magnetic system can have more than 2 poles.

Materials Needed (per team of students):

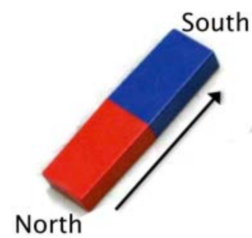
1. Magnaprobe (pole finder), as described in Appendix B.
2. Bar magnet and/or regular cow magnet
3. Flat or disk magnet
4. Magnetic marble
5. Horseshoe magnet (2)
6. Lodestone
7. Other interesting magnets, if available
8. Worksheet – Exploring Magnet Poles (see below)

Appendix C lists sources for materials.



Procedure:
Step 1: Divide participants into teams of 2-3 and pass out materials.

Step 2: Explain to them that they are to use their magnaprobes to explore and locate the poles in the various sample magnets.

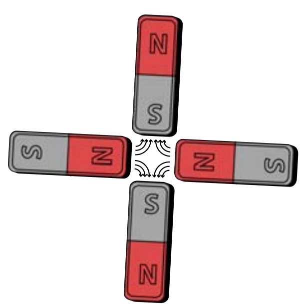


Step 3: Pass out the worksheets and ask them to answer the following questions:

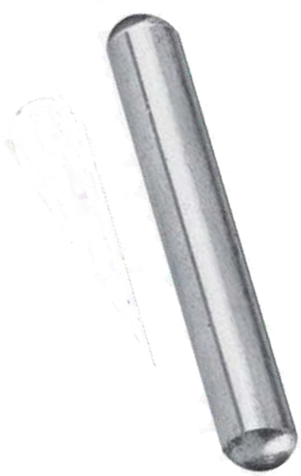
- Ask them to hypothesize where the poles are in the various magnets and mark these on their worksheets.
- Ask students to explore with their magnaprobes to find where the poles are in the various magnets and mark them on their worksheets. Once they have found the poles, have them draw the direction of the magnetic field inside the magnets. For example, see the image at right.
- How many, and where are the poles in the lodestone?
- What happens if you break a magnet in half?
- What defines where the poles are in a magnet?
- Can a magnet have more than 2 poles?

Step 4: Have teams report back on their findings. Answers:

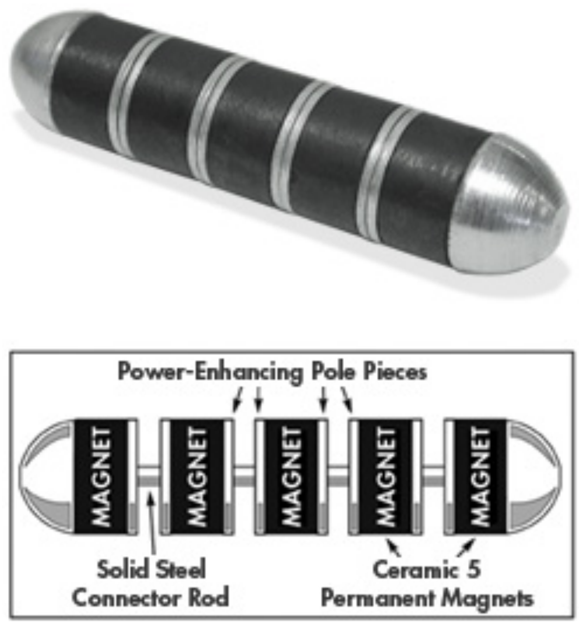
1. Poles in a bar magnet: *At each end with the magnetic field pointing from North to South*
2. Poles on a flat or disk magnet: *On each flat side, with the field pointing from North to South*
3. Poles on a sphere: *A sphere will have a North and a South pole, just as the Earth does.*
4. Poles on a rounded horseshoe magnet – *none. The magnetic field will be going around the circle. There are no poles because there is no place for the magnetic field to "get out" of the magnet.*
5. Poles on a lodestone: *A lodestone will also have a North and a South pole, usually found opposite each other at odd positions in the rock.*
6. *When you break a magnet in half, the 2 halves will each have a North and a South pole.*
7. *The direction of the magnet field determines where the poles are in a magnet. The manufacturing process determines the direction of the field and the poles can be produced anywhere in the shape of the magnet.*
8. Yes, *complex magnetic systems can have multiple poles*. For example,



Going Further:
In fact, manufactures of cow magnets have designed a better cow magnet than the regular cylindrical one, and it has multiple magnetic poles. “Cow magnets are popular with dairy farmers and veterinarians to help prevent Hardware Disease in cattle. While grazing, cows eat everything from grass and dirt to nails, staples and bits of bailing wire (referred to as tramp iron). Tramp iron tends to lodge in the honeycombed walls of the reticulum, threatening the surrounding vital organs and causing irritation and inflammation, known as Hardware Disease. The cow loses her appetite and decreases milk output (dairy cows), or her ability to gain weight (feeder stock). Cow magnets help prevent this disease by attracting stray metal from the folds and crevices of the rumen and reticulum. One magnet works for the life of the cow!” (*text from website below*)



Traditional cow magnet with 2 poles



Multi-poled cow magnet

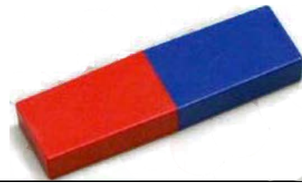
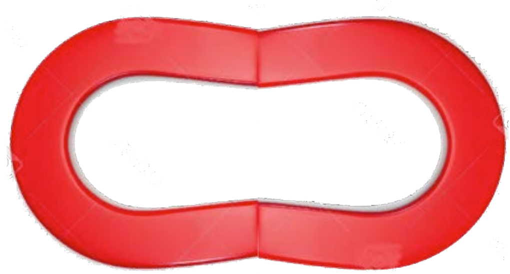
http://www.magnetsource.com/Solutions_Pages/cowmags.html

Worksheet #1 – Exploring Magnet Poles

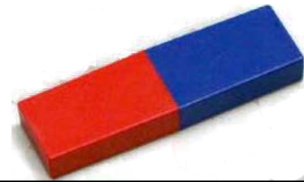
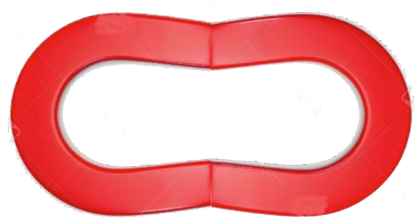
Name: ___________________________

Date: ____________________________

1. **Hypothesize** and mark where you think the magnetic poles will be in the following magnets:

Bar magnet or cow magnet	 
Horseshoe magnet	
Flat or disk magnet (e.g. refrigerator magnet)	 
Magnetic marble or spherical magnet	
Lodestone	
Horseshoe magnet bent into round shape & welded together (simulate by using 2 horse magnets)	

2. **Now, examine your magnets and mark where the magnetic poles actually are:**

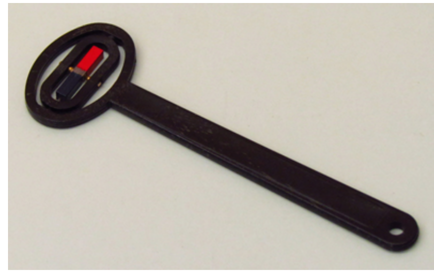
Bar magnet or cow magnet	 
Horseshoe magnet	
Flat or disk magnet (e.g. refrigerator magnet)	 
Magnetic marble or spherical magnet	
Lodestone *How many poles does the lodestone have? Mark them.*	
Horseshoe magnet bent into round shape & welded together (simulate by using 2 horse magnets) *How many poles does the round magnet have? Mark them.*	

3. What happens when you break a magnet in two?

4. What defines where the poles are in a magnet?

5. Can a magnet have more than 2 poles? ________________
   If you think so, draw how to arrange your magnets to show this?

Appendix B – Obtaining or Making Magnaprobes (Magnetic Pole Finders)



You can purchase Magnaprobes™ (or magnetic pole finders) or build them from simple materials.

Purchase (some examples):
- Google for "magnaprobe" or "magnetic pole finder"
- Science Lab Supplies: ~$4.60

  https://www.sciencelabsupplies.com/Magnaprobe.html
- Apex Magnets: ~$9
  https://www.apexmagnets.com/catalogsearch/result/?q=accessories%2Bpole-identifiers
- Indigo Instruments: ~$10
  https://www.indigoinstruments.com/magnets/accessories/magnetic-force-3d-compass-magnaprobe-44702.html
- Educational Innovations: ~$10
  http://www.teachersource.com/product/magnaprobe/electricity-magnetism
- Pasco: ~$15
  https://www.pasco.com/products/lab-apparatus/electricity-and-magnetism/magnetic-fields/se-7390

Build your own - Inexpensive:
*Materials needed***:**
- Strong sewing thread
- Plastic straw, 10cm (4") long piece
- Small, inexpensive bar magnet
- Tape or glue

Directions:
- Wrap one end of the sewing thread around the center of your small magnet and secure with tape or glue. Allow enough tail for the thread to be threaded through your straw and your magnet to hang freely.
- Push the thread through the straw. Hold the straw vertically with the magnet dangling just below the bottom of the straw. The magnet should be able to spin freely on the thread.
- Fold the top of the thread over onto the outside of the top of the straw, then tape it into place. If you wish, leave a small tab of tape sticking out for students to write their names on.
- Label the poles of your magnet, if they are not already labeled.

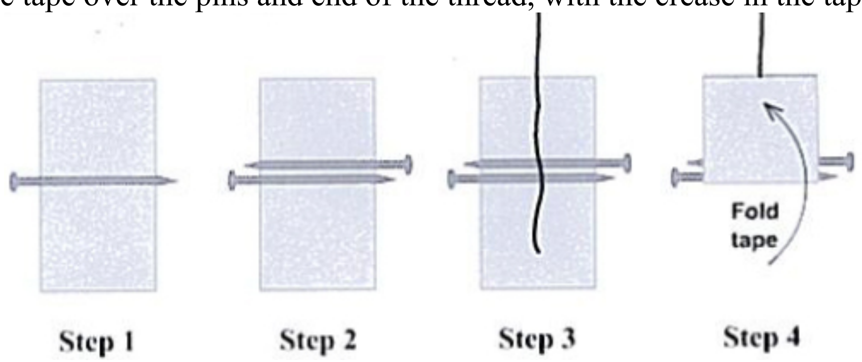
Build your own – Really Cheap:

*Materials needed***:**

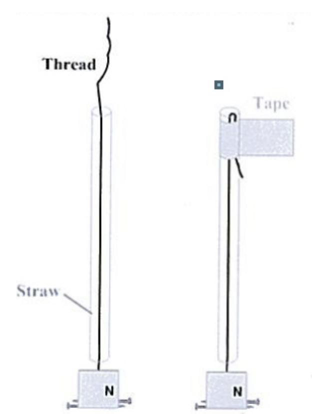
- Strong sewing thread
- Plastic straw, 10cm (4") long piece
- 2 steel straight pins
- Masking tape
- Magnet

Directions:

1. Place a small piece (about 4cm or 1.5" long) of masking tape on your desk with the sticky side up. Lay one pin across the tape
2. Lay the second pin right next to the first, but with the point in the opposite direction. Have the heads of the pins protrude a bit on each side.
3. Lay one end of the thread across the pins and tape, running perpendicular to the pins.
4. Fold the tape over the pins and end of the thread, with the crease in the tape at the pins.



5. Push the thread through the straw. Hold the straw upright (its length should be vertical) with the taped pins dangling just below the bottom of the straw. The top of the tape holding the pins should be just below (about 2-3mm or ¼ ") the bottom of the straw without touching it. The taped pins should be able to spin freely on the thread.
6. Fold the top of the thread over onto the outside of the top of the straw, then tape it into place. Leave a small tab of tape sticking out for students to write their names on.
7. Stroke the pins lengthwise from left to right several times with one pole of a permanent magnet. This will magnetize the pins.
8. Hold the straw upright with the pins dangling beneath. Move the north pole of the magnet near the pins. One end of the pins will point towards the north end of the magnet. This is the south pole (north-seeking end) of your magnetometer. Label this by writing a small "S" on the end of the tape holding the pins.



Adapted from *A Resource for Teacher*s from *Windows to the Universe*: http://www.windows2universe.org. Originally developed by LASP for the Terra Bagga activity: http://lasp.colorado.edu/education/outerplanets/lessons/grades6-8/Terra Bagga.pdf

Appendix C– Sources for Magnets and Related Materials

Magnets:
Arbor Scientific http://www.arborsci.com
Edmund Scientifics http://www.scientificsonline.com
Educational Innovations http://www.teachersource.com
Ward's Natural Scientific http://wardsci.com
Science Kit & Boreal Labs http://www.sciencekit.com
Home Training Tools http://www.hometrainingtools.com
Apex Magnets https://www.apexmagnets.com/
Bar magnets can be made by lining up several of the inexpensive ceramic magnets.
Lodestones can be purchased at low cost on amazon.com
http://www.amazon.com (search on "lodestone")
Cow magnets are cheapest from pet/farm supply stores:
http://www.valleyvet.com
http://www.magnetsource.com/Solutions_Pages/cowmags.html
Slaughter houses sometimes give away recovered magnets

< High quality neodymium

Inexpensive ceramic magnets >

Magnaprobes:
See Appendix B

Student compasses:
- Clear ones work best: http://www.arborsci.com/small-clear-compasses-20-pack
- For other suppliers, google "plastic compass"

Appendix D – Activity 2: Making a Magnet by understanding Domains

Teachers: view these videos first. It is not necessary that your students also view them, but it's ok if they do:

- https://www.youtube.com/watch?v=1vQDlB-0mC8
- https://www.youtube.com/watch?v=BJ7CwPuyvSg

Objective:
Students will learn that aligning the domains in a normally non-magnetized object will turn it into a temporary magnet.

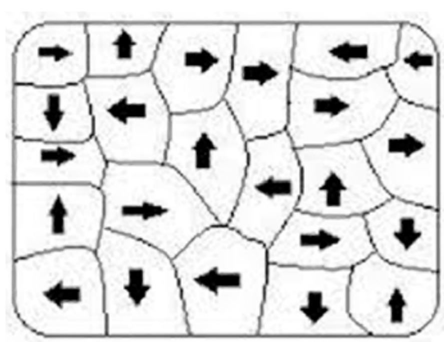
Materials:

- An iron or steel nail for each student
- A bar magnet for each student
- A pile of paper clips for each student
-

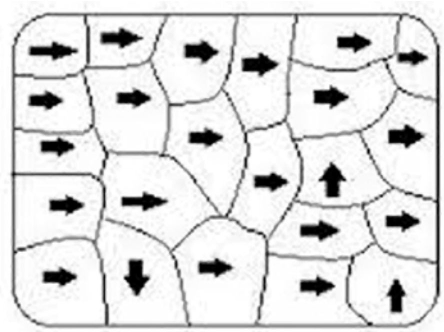
Procedure:

1. Pass out the materials to each student, or pairs of students.
2. Have the students attempt to pick up the paper clips with the nail. It doesn't work. They should already know that picking up the paper clips with the magnet will work.
3. Have the students grip the magnet with one hand and rub the nail from top to bottom. They must always use the same pole of the magnet and stroke the nail in the same direction. The nail's magnetism increases with each stroke.
4. Have the students check their magnetic nail with the paper clips.
5. They can experiment with various numbers of strokes, comparing with other students' experiences. They can also continually monitor the magnetic strength of the nail until it returns to its normal, non-magnetic state. How long does this take? Would it be faster with heat?

Background:
Steel or iron nails do not normally stick to each other because their magnetic domains are scattered:



But when you stroke the nail in a single direction with a permanent magnet, the domains become lined up and the nail becomes magnetized:



Permanent magnets have their atoms aligned all the time. Temporary magnets have their atoms aligned only while under the influence of a strong external magnetic field. Stroking a nail with a strong magnetic will cause it to become magnetized, though only for a short period of time since the nail's material is not strong enough to hold the domains in place. In addition, overheating a permanent magnet, or striking it with a heavy object, will rearrange its atomic structure and turn it into a temporary magnet.

Appendix E – Activity 3: Mapping Magnetic Fields

Materials

- Magnetic compasses
- Bar or cow magnets (if they don't already have them)
- Plain piece of paper
- Pencils
- Adhesive tape
- Mapping Magnetic Fields Worksheet

Procedure

1. Pass out materials
2. Warn participants to put their other magnets out of the way
3. Ask the participants to learn how to use the compass by placing it in front of them on a flat surface. Make sure the compasses are kept away from the magnets. Rotate the entire compass so that the red or pointed end is pointing toward the "N" (north). This is the direction of magnetic north.
4. Have the participants place the bar magnet in the center of a sheet of paper and tape it down. Tell them they will now trace the magnetic force field shape around the magnet. Ask them to hypothesize what they think the field will look like and share their thoughts with a neighbor.
5. Have participants move the compass around the magnet to get a feel for how the arrow moves. Have them draw a dot at some point near the magnet and place the center of the compass over the dot
6. Draw an arrow head at the location of the arrow head of the compass.
7. Move the compass center to this new arrow and again draw an arrow at the location of the compass needle head. Repeat.
8. Continue steps 4-6 until the line meets the magnet (or edge of paper). Remove the compass from the paper and draw lines connecting the dots with arrows indicating the direction that the compass points.
9. Pick another spot near the magnet and repeat the process.
10. Ask students to report on what they have discovered to a neighbor.

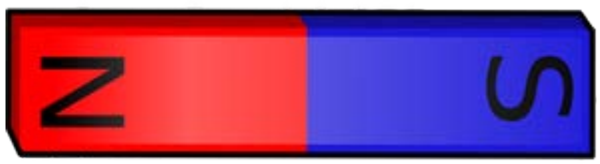
This activity was excerpted from UC Berkeley's *Exploring Magnetism* guide. The more extensive activity is available at:
http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/exploring_magnetism/index.html

Worksheet – Mapping Magnetic Fields

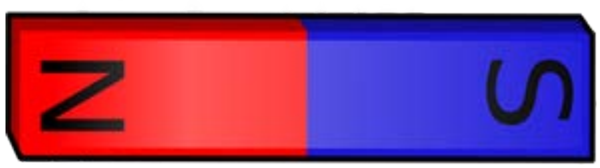
Name: ___________________________

Date: ____________________________

1. Draw what you hypothesize the magnetic field will look like around a bar magnet:



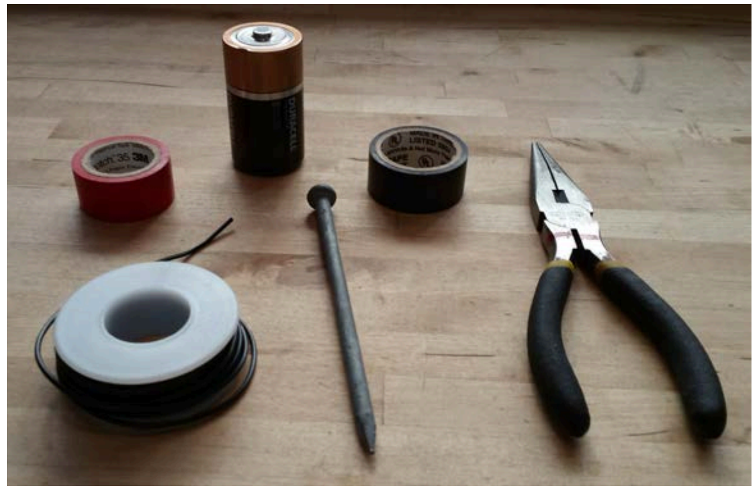
2. Draw how it looks with your measurements from the compass (or turn in your compass sheet):



3. What direction does the field flow or point? ______________

Appendix F – Activity 4: Create an Electromagnet

Create an electromagnet with some copper wire and a nail.



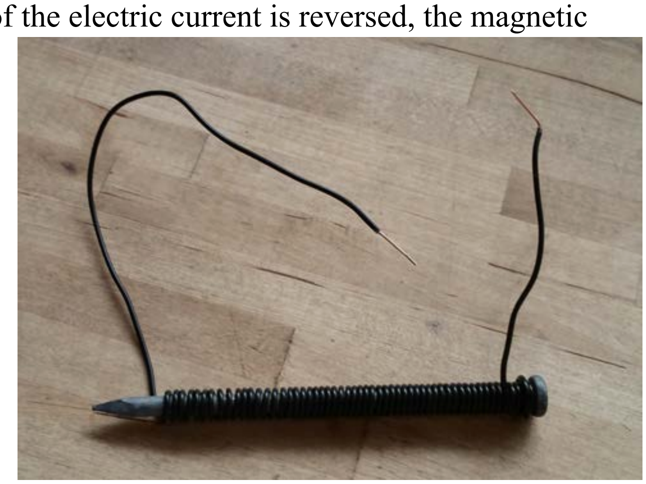
Materials
- One iron nail fifteen centimeters (6 in) or longer
- About three meters (10 ft) of insulated copper wire
- One D-cell battery
- A pair of wire strippers
- Adhesive or masking tape
- Paper clips or something magnetic
- A Magnaprobe or small compass

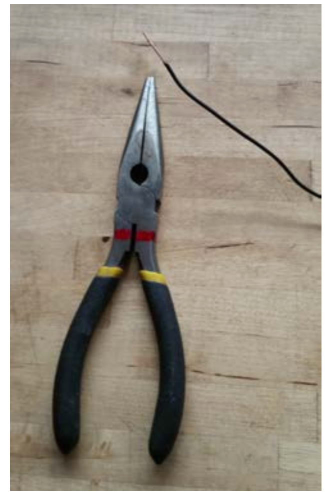
Warnings:
- Magnetic fields can damage TVs and computers.
- Take care when working with electronics.

Procedure

Step 1: Wrap the wire around the nail. Neatly wrap the wire around the nail. The more wire you wrap around the nail, the stronger your electromagnet will be. Make certain that you leave enough of the wire unwound so that you can attach the battery.

When you wrap the wire around the nail, make certain that you wrap the wire all in one direction (i.e. either clockwise or counter-clockwise). You need to do this because the direction of a magnet field depends on the direction of the electric current creating it. The movement of electric charges creates a magnetic field. If you could see the magnetic field around a wire that has electricity flowing through it, it would look like a series of circles around the wire. If an electric current is flowing directly towards you, the magnetic field created by it circles around the wire in a counter-clockwise direction. If the direction of the electric current is reversed, the magnetic field reverses also and circles the wire in a clockwise direction. If you wrap some of the wire around the nail in one direction and some of the wire in the other direction, the magnetic fields from the different sections fight each other and cancel out, reducing the strength of your magnet.





Step 2: Remove some insulation: Some of the copper wire needs to be exposed so that the battery can make a good electrical connection. Use a pair of wire strippers to remove a few centimeters of insulation from each end of the wire.

Step 3 - Connect the wire to the battery. Attach one end of the wire to the positive terminal of the battery and the other end of the wire to the negative terminal of the battery. Use tape if necessary. If all has gone well, your electromagnet is now working! Try picking up some paper clips.

Now use your compass or Magnaprobe to explore the magnetic field around the nail.

What happens if you switch the wires to the opposite ends of the battery?

What happens if you wrap the wire the opposite to what you did first? (e.g. from clockwise to counterclockwise)

What happens if you put a double wrapping of wire on the nail?

Appendix G – Activity 5 – Mapping the magnetic field of a sunspot

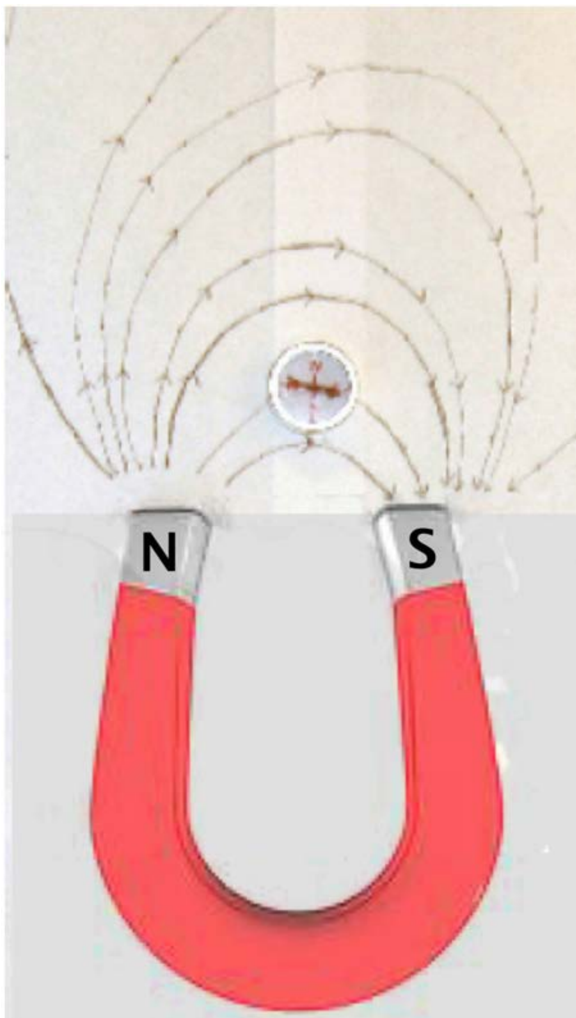
Activity 5: Mapping the magnetic field of a sunspot

Extracted from http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/

Pass around

1. Student worksheet – Sunspot Field Activity (following)
2. 1 horseshoe (or 2 bar magnets)
3. Compass

Ask participants to predict what the magnetic field of a sunspot might look like. Then, have them use the horseshoe magnet to model the magnetic fields of a sunspot with the compass. Procedures are described in Activity 3.



Worksheet – Sunspot Field Activity

Name: ___________________________

Date: _____________________________

Appendix H – Activity 6 – Modeling the Magnetic Fields of Sunspots

The teacher may prepare one example for the students, or the students may prepare their own.

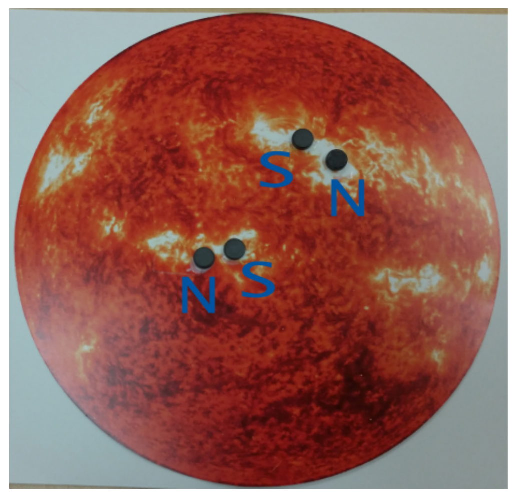
Activity 6: Modeling Sunspots and Prominences on the Sun

Activity developed by Deborah Scherrer, Stanford Solar Center.

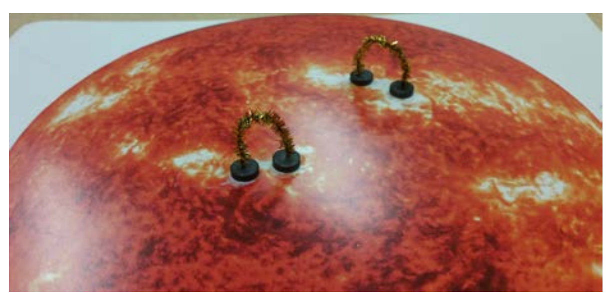
Materials, per team:

- Picture of the Sun (flat image) or round Styrofoam™ ball (10cm/4” to 20cm/8” diameter)
- 4 small disk-shaped magnets
- Pipe cleaner
- Glue
- Paint, if desired for Styrofoam™ ball
- Magnaprobe

1. **Simple, easy version:**
    a. Glue pairs of magnets onto your flat image of the Sun. These represent sunspots. Sunspots usually come in pairs, one with a North polarity and one with a South. So, make sure each pair has an N and S magnet. The pairs in the northern hemisphere will be opposite polarity to the pairs in the southern hemisphere, as in the photograph. Make sure you glue at least 2 sets of spots in each hemisphere. Don’t point out the differences in polarity to the students yet.



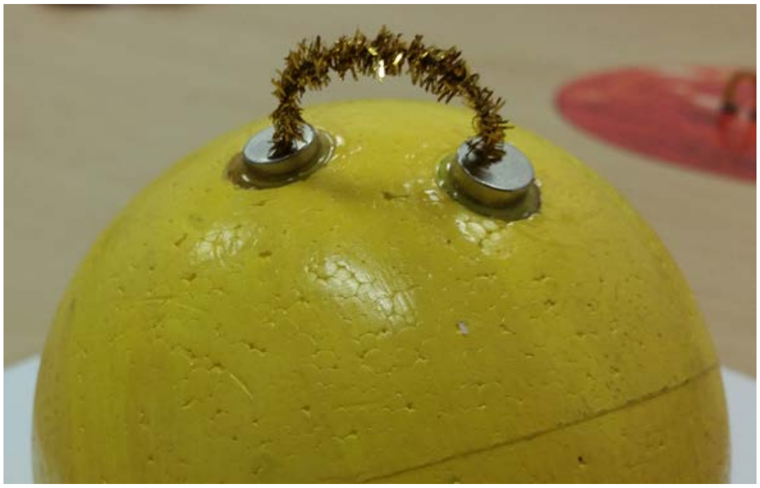
    b. Cut small pieces of pipe cleaner, bend them into arches, and stand them up on the magnet pairs. These represent prominences or coronal loops.



    c. Ask students to use their Magnaprobes to explore the polarity of the sunspots. Ask leading questions, if necessary, to help them discover that the different hemispheres have different polarity.

2. **More elaborate model:**
   a. Paint your Sun Styrofoam™ ball if you with. But note that the Sun is actually white, not yellow. (See http://solar-center.stanford.edu/activities/SunColor/.) Glue pairs of magnets onto your Sun ball. These represent sunspots, as above. Sunspots usually come in pairs, one with a North polarity and one with a South. So, make sure each pair has a N and S magnet. The pairs in the northern hemisphere will be opposite polarity to the pairs in the southern hemisphere, as in the flat Sun above. Make sure you have at least 2 pairs in each hemisphere.

   b. Cut small pieces of pipe cleaner, bend them into arches, and stand them up on the magnet pairs. These represent prominences or coronal loops.

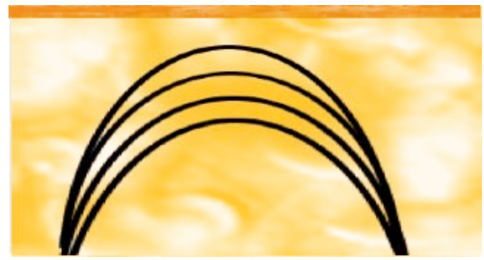


   c. Ask students to use their Magnaprobes to explore the polarity of the sunspots. Ask leading questions, if necessary, to help them discover that the different hemispheres have different polarity.

Appendix I – Explaining the solar activity animation to the teacher

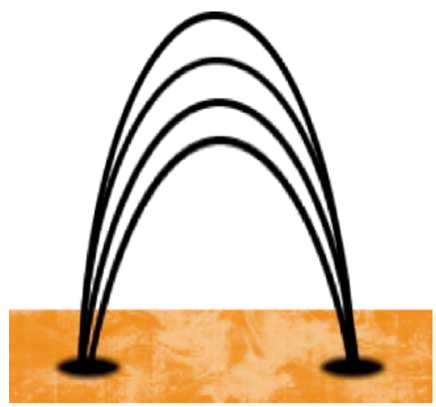
New studies show that some of the Sun's solar activity may all be part of the same mechanism. However, these mechanisms are complex and not completely understood. The animation on Slide 18 of Part 2 shows one *possible* scenario for the generation of a flare and coronal mass ejection.

Regions of intense magnetic fields (shown here as loops or giant arches) are formed from many small magnetic structures in the Convection Zone. We can see these loops because electrified gas (i.e. plasma) is trapped within them.



These magnetic fields/loops rise upwards from within the solar interior and eventually "break through" the solar surface.

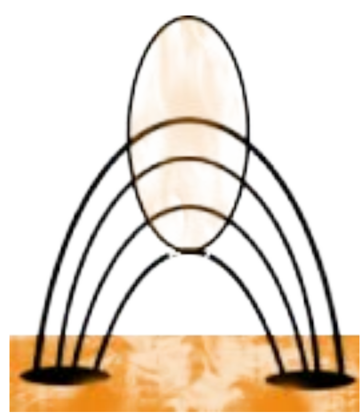
The areas where the magnetic fields break through appear as sunspots, usually with a positive and a negative pole because of the magnetic fields of the loops.



^ Sunspots ^

Once the loops rise above the surface, they are continually interfered with by more magnetic fields rising, which cause the fields to twist and contort.

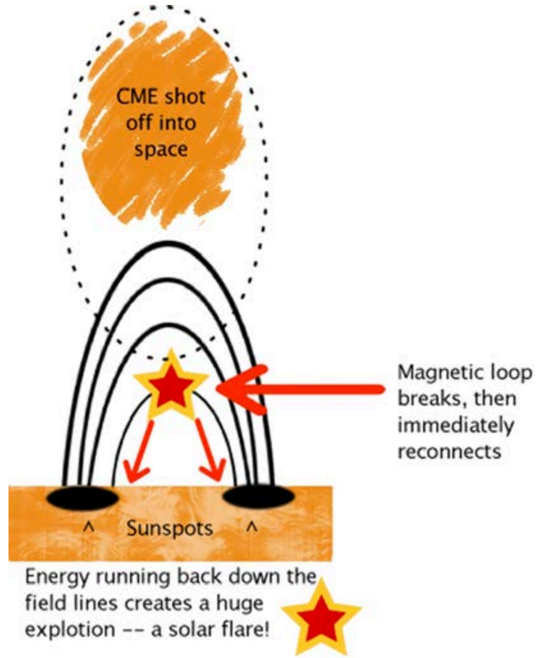
Occasionally a magnetic field line will be stressed enough that it could eventually twist and break, possibly with a loop above the break.



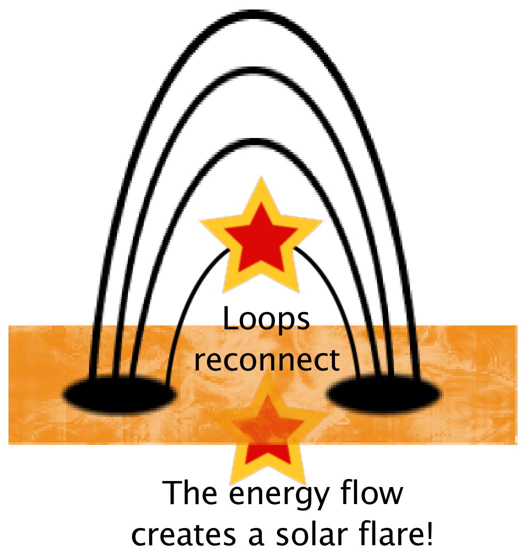
This results in energy below the break running back “down” the field line.

The field almost immediately reconnects, either to its original “self” or to another field line.

If there were a blob of plasma above the break, it would be energetically pushed away from the solar surface – a CME!

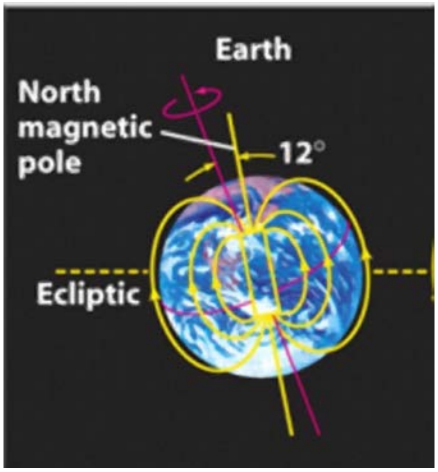


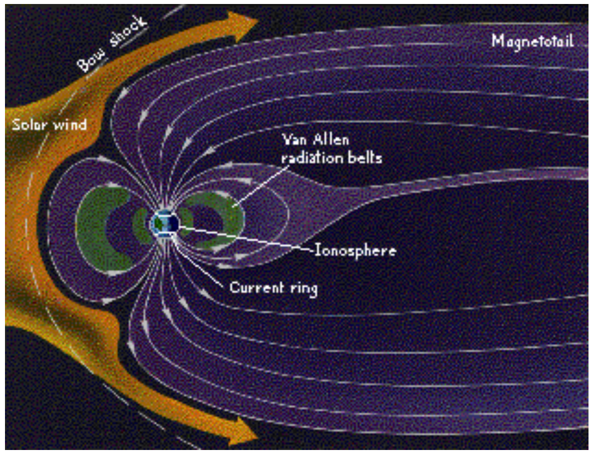
When the energy that is forced down “hits” the surface, a huge explosion is generated – a solar flare!



Appendix J – Activity 7 - Exploring the Earth's Magnetosphere

The Earth's magnetosphere is the area of space around the planet in which charged particles are controlled by the Earth's magnetic field. Near the surface the magnetic field resembles that of a dipole. Farther away from the surface, the field lines are significantly distorted by the solar wind. For ease, you are going to ask your students to explore the close-up magnetic field of the Earth.





Materials:

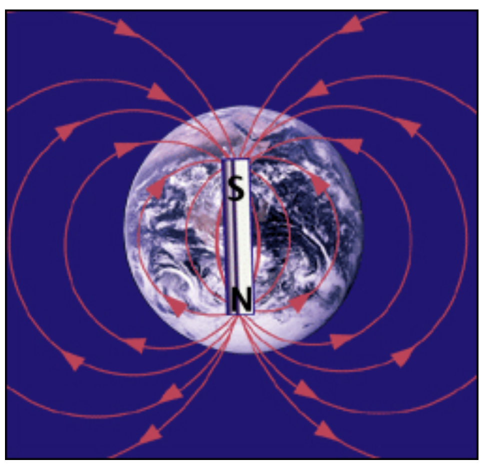
- One squishy Earth ball (2"-3" diameter) per team. These can be readily purchased or you could make your own out of clay or Model Magic:
  https://www.squishymart.com/world-earth-globe-stress-ball
  http://www.officeplayground.com/Mini-Earth-Squeeze-Balls-12-Pack-P132.aspx
- One bar magnet per Earth ball
- Sharp knife
- Glue
- Magnaprobes

Prepare the Earth ball:

1. Make a couple slices into the Earth ball near one of the poles.
2. Determine which is the South end of the magnet.
3. Push the magnet into the Earth ball, to the center, making sure that the South end of the magnet faces the Earth's North pole.
4. Try to tilt it about 12 degrees from the Earth's axis of rotation.
5. Or, you can slice the Earth balls in half, insert the magnet, then glue them back together,

Procedure:

1. Divide your students into teams.
2. Have them explore the Earth ball with their magnaprobes.
3. Have them discuss their findings then draw the Earth's magnetic field that they found. Have the teams report back. Make sure they noticed that the magnetic field is perpendicular to the planet at the Earth's poles, and parallel to it at the equator, and that the magnetic fields completely envelope the globe (i.e. are 3D).



Their drawings should look something like this.

Appendix K – Activity 8 - Magnetic Field of a CME impacting the Earth

Activity developed by Deborah Scherrer, Stanford Solar Center.

In the slide image, the CME has a south-facing field, which is opposite the Earth's magnetic field. Hence the fields will be conducive to magnetic reconnection and the CME will disrupt the Earth's magnetosphere, causing a geomagnetic storm.

Materials:

- Worksheet (below)
- Pen or pencil

Procedure:

- Hand out the student worksheet and ask students to label the poles of the CME's magnetic field to show which will impact the Earth and which will not.
- Have students discuss their answers

Background Information:
A geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar event (e.g. Coronal Mass Ejection or a sudden high speed increase in the solar wind) that interacts with Earth's magnetic field. The magnetic field from the Sun is present in the eruption. The increase in solar wind pressure compresses the magnetosphere and generates electric currents in the Earth's magnetosphere and ionosphere.

The direction of the magnetism in the eruption will determine how much affect the storm has on Earth. If the solar wind field is pointing northward, it will generally slip by the Earth's magnetosphere and little harm will be done. However, if the ejection has a southward direction, it will be conducive to magnetic reconnection (i.e. a repaid conversion of magnetic field to energy). -- meaning it will interact with, and integrate into, Earth's magnetic field, rapidly injecting magnetic & particle energy into the Earth's magnetosphere[6]. It will also add to (and hence extend) the magnetotail and have direct access to the Earth's poles. This can cause serious disruptions. Until scientists figure out how to determine a CME's direction of magnetism before it reaches us, we will not be able to predict the severity of such dangerous solar storms.

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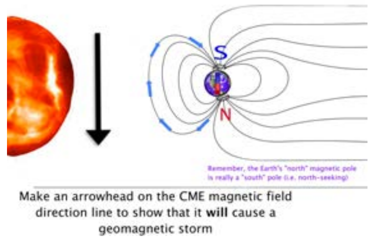
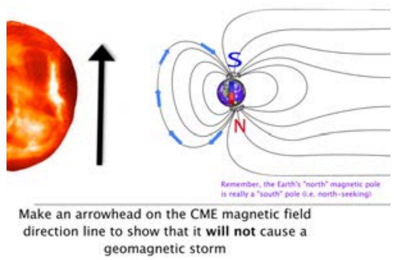
[6] NASA's MMS mission is designed to study these particular events. See http://mms.gsfc.nasa.gov/

Here is the correct labeling:



This CME has a south-facing field, which is opposite the Earth's magnetic field. Hence the fields will be conducive to magnetic reconnection and the CME will disrupt the Earth's magnetosphere, causing a geomagnetic storm.

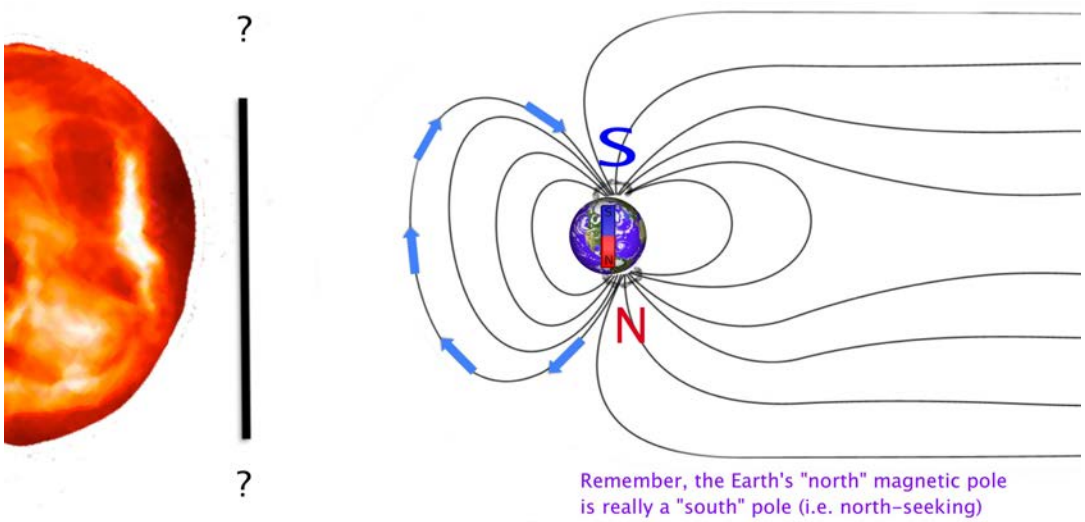


The CME above has a North-facing field, which is the same as the Earth's. Therefore the CME will not significantly interfere with the Earth's magnetosphere and will cause little damage.

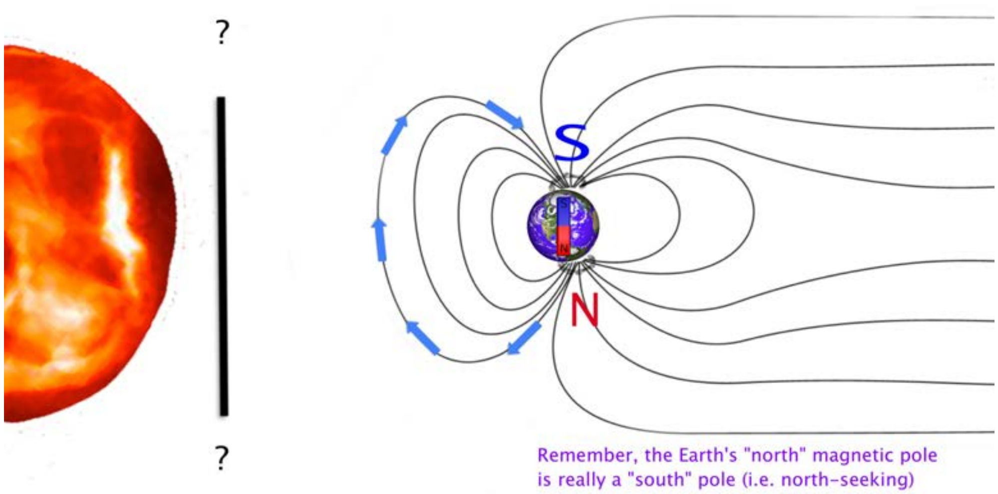
Worksheet – Geomagnetic Storms

Name: ___________________________

Date: ____________________________

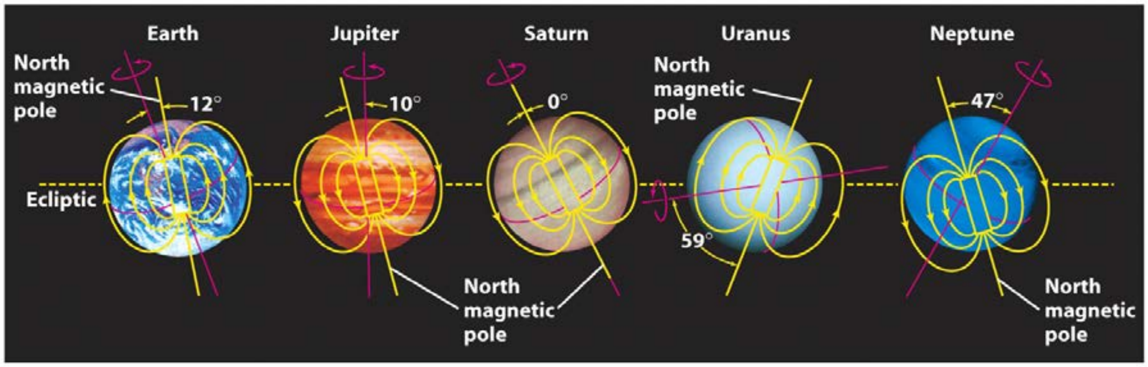


Make an arrowhead on the CME magnetic field direction line to show that it **will** cause a geomagnetic storm



Make an arrowhead on the CME magnetic field direction line to show that it will **not** cause a geomagnetic storm

Appendix L – Activity 9 - Planetary Magnetospheres



Activity developed by Deborah Scherrer, Stanford Solar Center.

Activity Summary: Students will explore the magnetic poles of various planets and identify them. They will also explore the complex magnetic field of a hypothetical exoplanet.

Student Objectives:

- Students will learn about the magnetic poles of the planets in our solar system
- Students will learn that magnetic poles need not correspond with rotational poles
- Students will discover that planets (or moons) can have multiple poles

Materials:
- Some sort of objects you can make a globe out of:
    - Clear plastic 2-part spheres (5cm-10cm; 2”-4”) like those available in craft stores and used for making Christmas decorations
    - *Or* Model Magic or clay material
    - *Or* Paper Mache (http://www.dltk-kids.com/type/how_to_paper_mache.htm)

- Magnaprobes (see Appendix B)
- Magnets, like
    - Small disk magnets (.6cm or 1/4”) (if using plastic spheres)
    - *or* small, high quality bar magnets (if using clay-like material)
- Glue
- Paint
- Black marker
- Student Worksheet

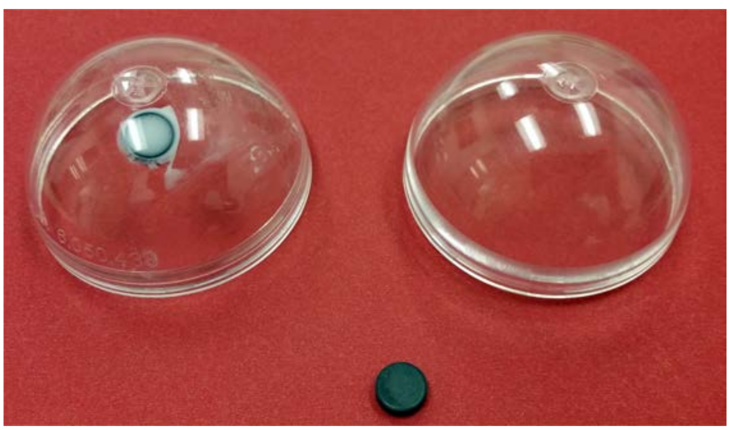
Preparation:
- The teacher should construct 5 model planets (information below)

Procedure*:*

1. Arrange students into 5 groups
2. Give each group a model planet
3. Ask students to use their magnaprobes to locate the magnetic poles of their planet
4. Using their worksheet, ask students to agree on which planet they have
5. Pass the mystery planet to the group on their left
6. Repeat steps #3 through #5 until they have explored all the planets
7. Have groups report on their findings

Teacher Instructions for Constructing Model Planets

1. Create 5 globes either out of Model Magic, clay, paper mache, or plastic globes, but do not let them harden yet. If using plastic globes, do not glue the halves together yet.
2. Refer to the planet imagery below. Using 2 disk magnets for each planet, find the North pole of one and push it into the material where the North pole of the planet should be. Likewise for the South pole. If you are using bar magnets, push them into the material in the proper orientation. Cover up the magnets with a small amount of clay, Model Magic, or paper mache. You want them to be invisible but still findable with a magnaprobe. If you are using plastic globes, glue the disk magnets onto the inside of the globes. Do this for Jupiter, Saturn, Uranus, and Neptune. For the exoplanet, use 4 disk magnets (or 2 bar magnets) and arrange their poles according to the imagery.



Glue disk magnets onto inside of plastic spheres

Insert bar magnet into clay-like material

3. Let the clay/Model Magic/paper mache harden (usually overnight). If using globes, you might want to fill them with something (clay?) that would make them heavier. Then glue them together.
4. Paint each planet a different color, but not necessarily the color of the planet being represented. Remember which planet is which color.
5. When the paint is dry, use the marker to mark a big dot at the axes of rotation (2 per globe). You'll need to use your magnaprobe to find the poles you have installed in the planets.
6. Mark each planet with an A, B, C, D, or E.

Teacher Reference Sheet - Planetary Magnetospheres

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Jupiter

Magnetic poles offset 10 degrees from rotational axis

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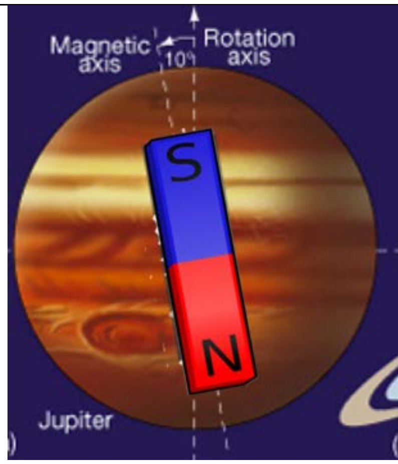

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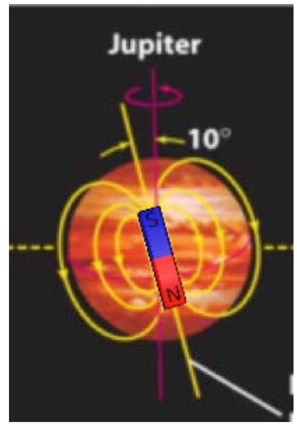

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Saturn

Magnetic poles same as rotational axis

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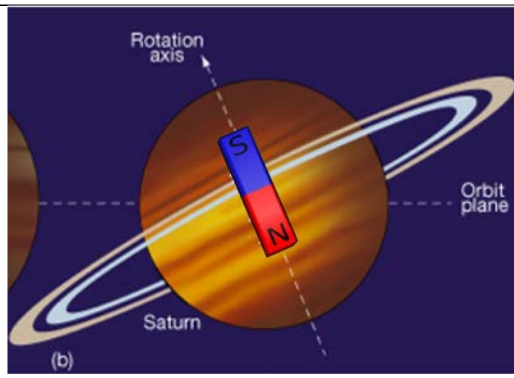

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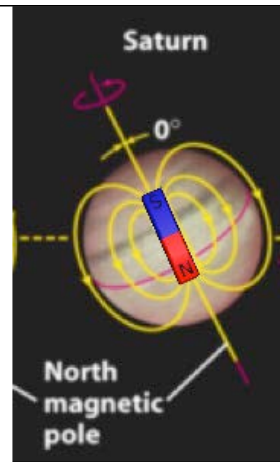

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Uranus

Uranus rotates on its side. Its magnetic pols are offset ~60 degrees from its rotational axis and not centered in the planet

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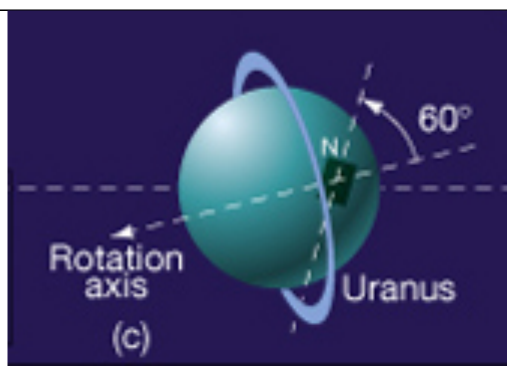

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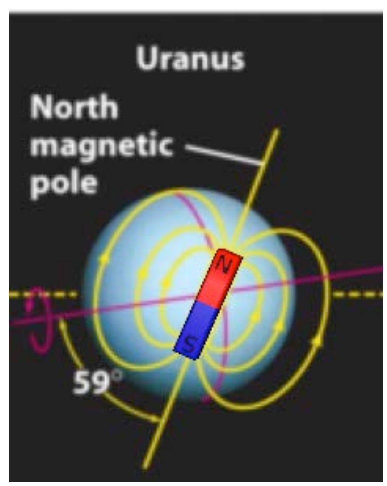

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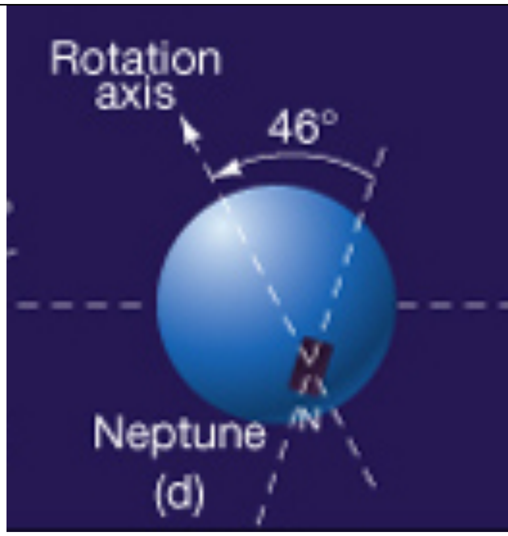
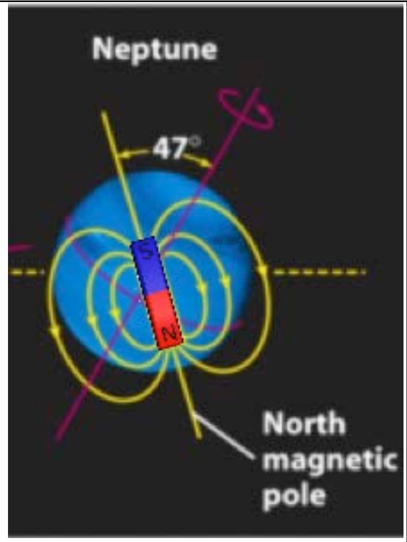
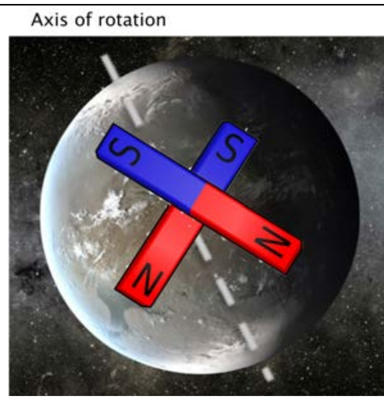
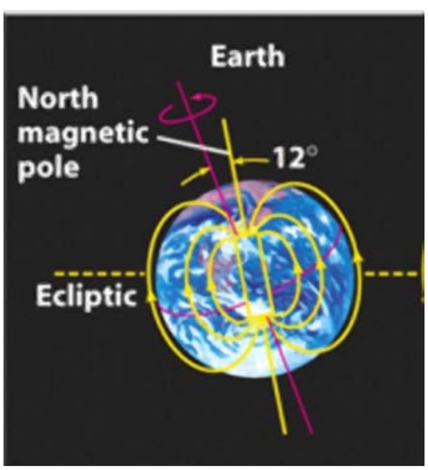
Neptune Magnetic poles offset ~46 degrees from rotational axis and not centered in the planet		
Exoplanet Planets or moons could have multiple magnetic poles, perhaps generated by slurious internal seas		



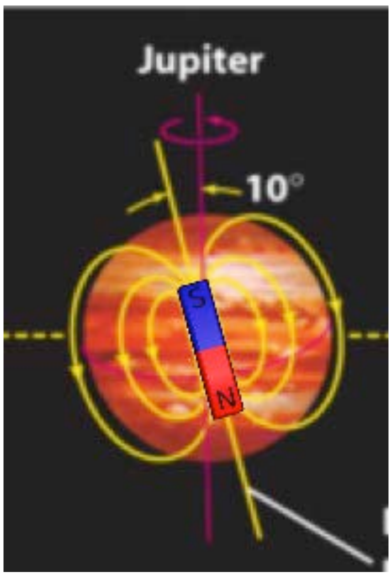
Earth's magnetosphere, for reference

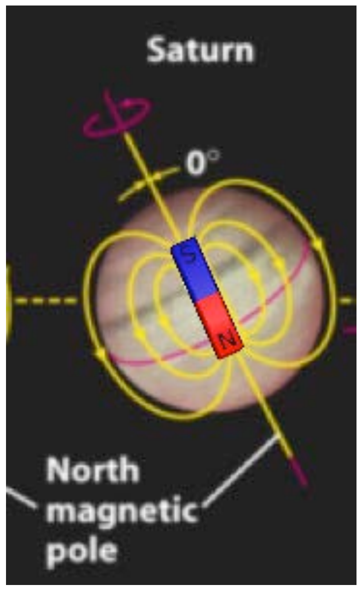
Student Worksheet –
Exploring Planetary Magnetospheres

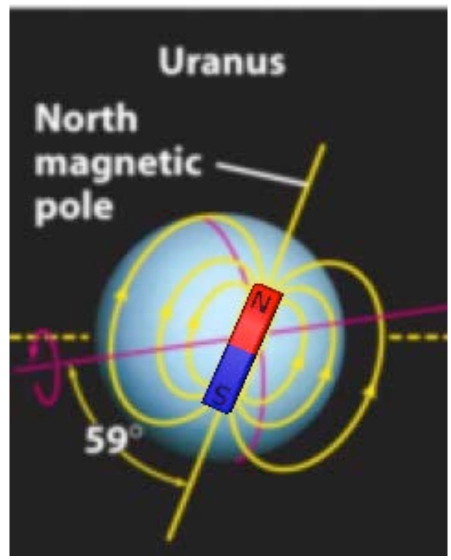
Team Name: ____________________

Date: ____________________

Your teacher will pass out 5 mystery planets (A-E). Identify the planets by their magnetic poles.







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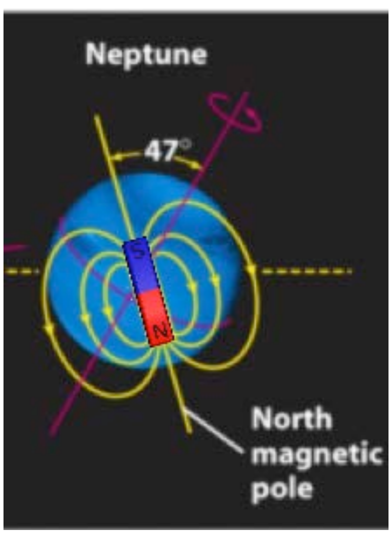

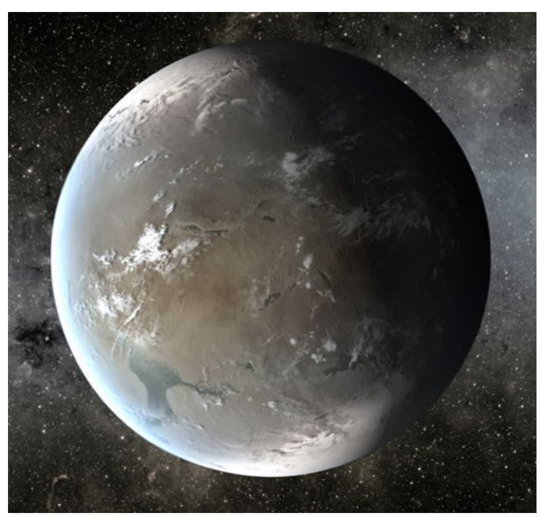

Draw the poles you found in this exoplanet

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Appendix M – Additional Resources

Magnetism:

- http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/
  http://cse.ssl.berkeley.edu/SegwayEd/lessons/exploring_magnetism/pdf_Files.html
  An outstanding collection of 7 lessons on magnetism. Many of the activities for this slide set were excerpted from these resources. For extensive lessons on magnetism, this is a top choice. Targeted to grades 6-9, 8-12, and 9-14.
- https://www.livescience.com/38059-magnetism.html
  Another excellent resource that answers questions such as "What is Magnetism? " and explores concepts such as magnetic fields & magnetic force. Includes descriptive text and videos.
- https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Solar_System_Magnetism.html#.Vcejebd63Sc
  A NASA resource exploring Solar System Magnetism. Subjects include energy heat, & magnetism; general science; planet Earth; solar system and stars.
- http://nasawavelength.org
  NASA Wavelength is a collection of peer-reviewed educational materials related to NASA missions, research, and topics. Search here for "magnetism".
- Many slides also offer additional resources on the particular topics covered. These are included with the slide descriptions in this Teacher Guide.

Solar & Related Missions:

- NASA Solar Dynamics Observatory: http://sdo.gsfc.nasa.gov/
  SDO's goal is to understand the influence of the Sun on the Earth and near-Earth space by investigating the Sun's magnetic fields, how this magnetic energy is generated, and how this energy affects solar activity and the Earth.
- NASA Magnetospheric MultiScale Mission (MMS): http://mms.gsfc.nasa.gov/
  Launched in 2015, MMS is a NASA robotic space mission to study the Earth's magnetosphere, using four identical spacecraft flying in a tetrahedral formation.
- NASA Parker Solar Probe: https://www.nasa.gov/content/goddard/parker-solar-probe
  The Parker Solar Probe is a NASA robotic spacecraft launched in 2018, with the mission of repeatedly probing and making observations of the outer corona of the Sun.
- NASA Interface Region Imaging Spectrograph (IRIS): http://iris.gsfc.nasa.gov/
  A NASA solar observation satellite. to investigate the physical conditions of the solar limb, particularly the chromosphere of the Sun
- ESA/NASA Solar and Heliospheric Observatory (SOHO):
  http://sohowww.nascom.nasa.gov/
  SOHO is a spacecraft orbiting the Sun and built by a collaboration of the European Space Agency (ESA) and NASA. SOHO was designed to study the internal structure of the Sun, its extensive outer atmosphere, and the origin of the solar wind.. SOHO has also discovered almost 4,000 comets!
- NASA STEREO: http://stereo.gsfc.nasa.gov/

In 2006, two nearly identical spacecraft were launched into orbits around the Sun that cause them to respectively pull farther ahead of and fall gradually behind the Earth. This enables stereoscopic imaging of the Sun and solar phenomena such as coronal mass ejections

- NASA HINODE: https://www.nasa.gov/mission_pages/hinode/mission.html
  Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions.

Appendix N – Glossary

- *Active region, solar* – Active Regions on the Sun are places where the Sun's magnetic field is disturbed. Sunspots are indicators of active regions. These regions often spawn various types of solar activity including solar flares and coronal mass ejections (CMEs).
- *Charged particles* - In physics, a charged particle is a particle with an electric charge, meaning that the molecule or atom has lost or gained electrons to make it unbalanced. It may be an ion, such as a molecule or atom with a surplus or deficit of electrons relative to protons. Another charged particle may be an atomic nucleus devoid of electrons, such as an alpha particle (i.e. a helium nucleus*)*
- *Coronal loops* - Bright, curving structures that appear as arcs above the Sun's surface. These consist of plasma trapped within magnetic fields.
- *Coronal Mass Ejection (CME)* - a significant release of plasma and accompanying magnetic field from the solar corona. They are often associated with Active Regions and solar flares.
- *Curie point*, also called Curie Temperature – the temperature at which certain magnetic materials undergo a sharp change in their magnetic properties. Permanent magnets are often made by heating a metal item to the Curie point then allowing it to cool while exposed to a strong magnetic field.
- *Ferrimagnetic/ferromagnetic* – material having a high susceptibility to magnetization. Ferromagnetic materials can be made into permanent magnets. https://sciencing.com/differences-between-ferrimagnetism-ferromagnetism-8488277.html
- *Flare, solar* - a brief eruption of intense high-energy radiation from the Sun's surface, associated with sunspots and Active Regions, and causing electromagnetic disturbances on the Earth, as with radio frequency communications and power line transmissions.
- *Geomagnetic* - Earth's magnetic field, also known as the geomagnetic field, is the magnetic field that extends from the Earth's interior out into space, where it interacts with the solar wind, a stream of charged particles emanating from the Sun.
- *Lodestone* - a naturally magnetized piece of the mineral magnetite. Lodestones are naturally occurring magnets, which can attract iron. Only some lodestones are magnetic. It is believed these were struck by lightning to cause their magnetization.
- *Magnet* - a material or object that contains a magnetic field.
- *Magnetic* - objects that are magnetic are attracted to objects with a magnetic field
- *Magnetic direction* – the direction of the magnetic field lines in a magnetized object. This is defined to be the direction in which the north end of a compass needle points.
- *Magnetic domain* - is a tiny region within a magnetic material in which the magnetic fields of atoms are grouped together and pointing in the same direction. The alignment is caused by electrons having the same spin and direction. But you can visualize magnetic domains as miniature bar magnets within a material.
- *Magnetic field* - a region around a magnetic material or a moving electric charge within which the force of magnetism acts
- *Magnetic reconnection* - refers to the breaking and reconnecting of oppositely directed magnetic field lines in a plasma. In the process, magnetic field energy is converted to plasma kinetic and thermal energy. Reconnection is at the heart of many spectacular events in our solar system, including aurorae and solar flares.

- *Magnetism* - a class of physical phenomena that are mediated by magnetic fields. Electric currents and the magnetic moments of elementary particles give rise to a magnetic field, which acts on other currents and magnetic moments. Magnetism is one aspect of the combined phenomenon of electromagnetism.
- *Magnetite* - a rock mineral and one of the main iron ores, with the chemical formula Fe_3O_4. It is one of the oxides of iron, and is ferromagnetic, meaning that it is attracted to a magnet and can be magnetized to become a permanent magnet itself. It is the most magnetic of all the naturally occurring minerals on Earth.
- *Magnetogram* – an image of the magnetic fields on the Sun. See http://solar-center.stanford.edu/solar-images/magnetograms.html.
- *Magnetopause* - the boundary between a planet's or moon's magnetic field and the solar wind.
- *Magnetosphere* - a region of space surrounding an astronomical object (e.g. the Earth) in which charged particles are affected by that object's magnetic field. It is created by a star, planet, or moon with an active interior dynamo. In the space environment close to a planetary body, the magnetic field resembles a magnetic dipole.
- *North-seeking pole* – Most all magnets have a north-seeking pole (abbreviated to just north pole or N). It is the end that points north. This is often colored red on a magnet or compass. Magnetic poles are often referred to as being positive or negative. Generally, the south pole is termed positive, and the north negative.
- *Planetary magnetospheres* - formed by the interaction of the supersonic magnetized solar wind plasma with the ionospheres and intrinsic magnetospheres of the planets.
- *Plasma* - a state of matter in which an ionized gaseous substance becomes highly electrically conductive to the point that long-range electric and magnetic fields dominate the behavior of the matter. The *plasma* state can be contrasted with the other states: solid, liquid, and gas.
- *Reconnection* - see magnetic reconnection
- S*olar Wind Dynamic* (or Ram) Pressure - For planetary science, the magnetopause is the boundary between the planet's magnetic field and the solar wind. The location of the magnetopause is determined by the balance between the pressure of the dynamic planetary magnetic field and the dynamic pressure of the solar wind.
- *South-seeking pole* – see North-seeking pole