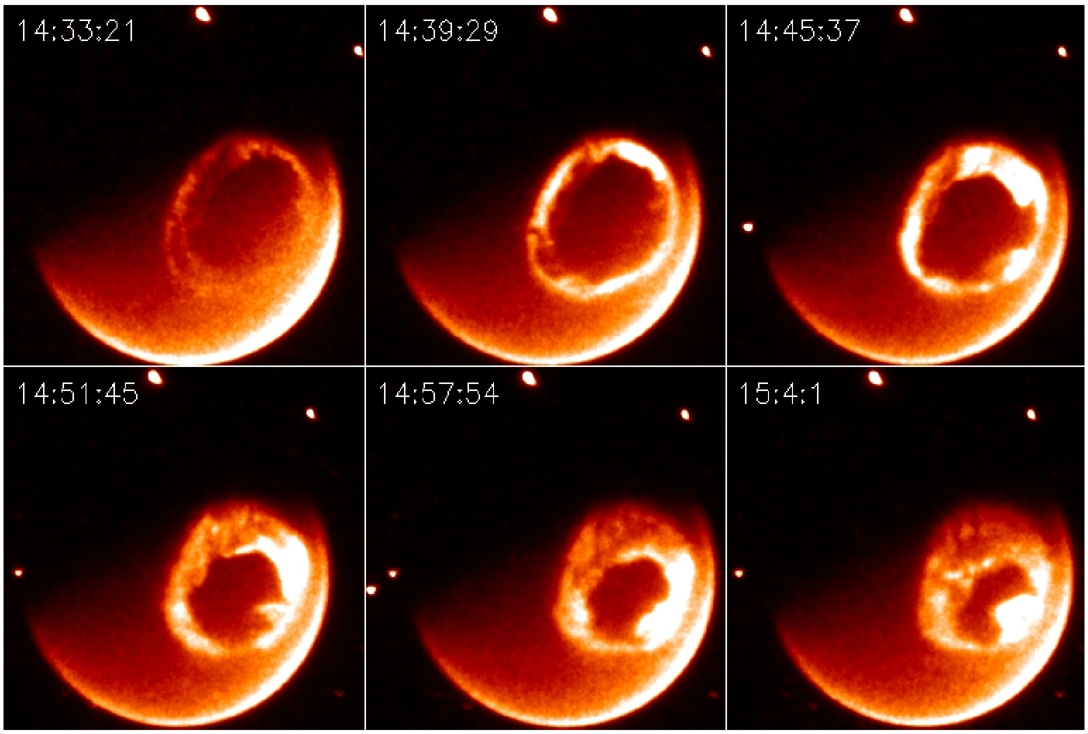
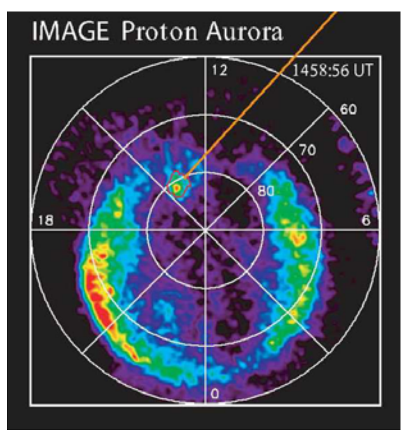
Adventures in Space Science Mathematics





A collection of mathematics and reading activities for Grades 7-9 that explore the Sun-Earth System.

This series of math activities will help students understand some of the real-life applications of mathematics in the study of the Sun and Earth as a system. Through math and reading activities, students will learn:

…How to search for trends and correlations in data
…How to extract the average, maximum and minimum from data
…How to use scientific notation to work with very large and small numbers
…How to use a scale drawing to estimate the sizes of an aurora
…How to use the Pythagorean Theorem to calculate magnetic field strength
…How to use simple equations to convert raw data into physical quantities

This booklet was created by the NASA, IMAGE satellite program's Education and Public Outreach Project.

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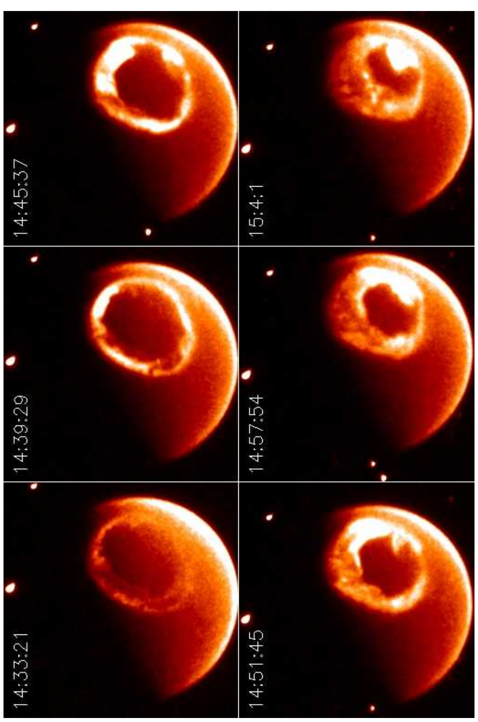
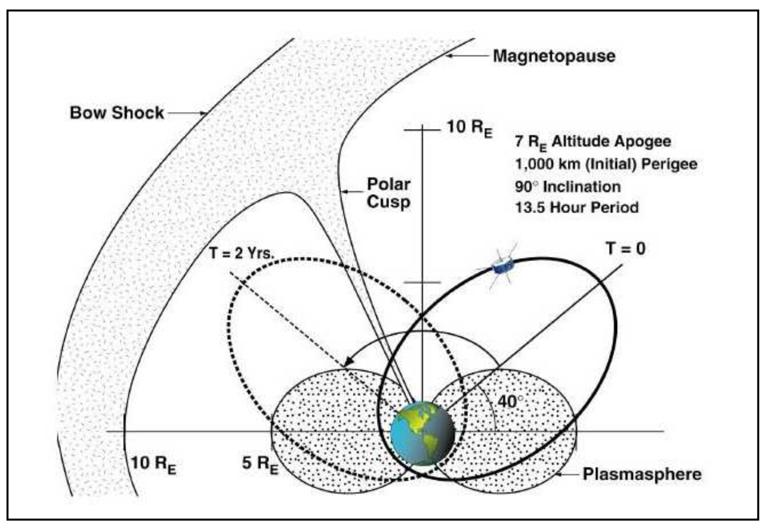




A series of images (left) of the Northern Lights from space taken by the IMAGE satellite. The satellite orbits Earth in an elliptical path (above), which takes it into many different regions of Earth's environment in space.

For more classroom activities about aurora and space weather, visit the SpaceMath@NASA website at:

http://spacemath.gsfc.nasa.gov

Introduction

We live next to a very stormy star, the Sun, but you would hardly notice anything unusual most of the time. Its constant sunshine hides spectacular changes. But unless you lived in the Arctic and Antarctic regions of Earth, you would have no clue. Only the dazzling glow of the Northern Lights suggests that invisible forces are clashing in space. These forces may cause all kinds of problems for us, and our expensive technology (Activity 1). It doesn't take long for a 'solar storm' to get here, either. Once they arrive, that change Earth's magnetic field (Activity 2), and these lead to the displays of the aurora which humans have marveled at for thousands of years. Aurora light up the sky with billions of watts of power (Activity 3) and cover millions of square kilometers (Activity 4). Why does all this happen? (*Photo- Auroral curtain by Jan Curtis)*

Space Weather

It has to do with Earth's magnetic field and how it is disturbed by solar storms and the solar wind. The wind carries its own magnetic field with it (Activity 5), and travels at speeds of millions of kilometers per hour (Activity 6). Scientists keep track of this interplanetary storminess using numbers that follow its ups and downs (Activity 7) just like meteorologists follow a storm's speed, pressure and humidity. Periods of increased and decreased solar activity (Activity 8) come and go every 11 years. Solar flares also have their own story to tell (Activity 9) just like flashes of lightning in a bad storm. (*Photo - Coronal Mass Ejection seen by SOHO satellite)*

Models and Forecasting

Scientists have to keep track of many different kinds of phenomena in the universe, both big and small. That's why they have invented a way to write very big and very small numbers using 'scientific notation (Activity 10, 11, 12). They also have to master how to think in three-dimensions (Activity 13) and how to use mathematical models (Activity 14). Once they find the right models, they can use them to make better predictions (Activity 15) of when the next solar storm will arrive here at Earth, and what it will do when it gets here! *(Sketch of Earth's magnetic field)*

The following table connects the activities in this booklet to topics commonly covered in Grade 6, 7 and 8 pre-algebra and algebra textbooks.

Topic Area	Activity Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Scientific Notation, Operations										X	X	X			
Sequences mean, median, mode							X	X							
Scale drawings				X											
Speed Distance, time						X									
Equations and substitution									X				X	X	
Positive & negative numbers					X										
Decimal math.			X												
Time calculations		X													
Reading & math	X														
Venn diagrams															X

Hey! Who Turned Out the Lights?

Astronomers were busily tracking "Active Region 5395" on the Sun when suddenly it blasted-out a huge cloud of super-hot gas on March 10, 1989. Three days later, and seemingly unrelated to the solar blow-out, people around the world saw a spectacular, and entertaining, Northern Lights display. The distant solar storm 93 million miles away had silently set in motion a chain of events reaching from the Sun's fiery surface to the skies overhead. Most newspapers that reported this event thought that the spectacular aurora was the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the most people in the Northern Hemisphere had never seen the Northern Lights dancing in their evening skies. But this particular explosion of matter and energy did much more than just dazzle and confuse the casual sky watcher as it painted the heavens with shifting colors and shapes.

At 2:45 AM on March 13, electrical currents created by the impact of this storm found their way into the electrical circuitry of the Hydro-Quebec Power Authority. Giant capacitors tried to regulate these currents but failed within a few seconds as automatic protective systems took them off-line one by one. Suddenly, the entire 9,500 megawatt output from Hydro-Quebec's La Grande Hydroelectric Complex began to waver. Power swings tripped the supply lines from the 2,000 megawatt Churchill Falls generation complex, and 18 seconds later, the entire Quebec power grid collapsed. The cascading of events lasted barely 97 seconds. It was much too fast for human operators to react, but it was more than enough time for 21,500 megawatts of badly needed electrical power to suddenly disappear from service.

For nine hours, large portions of Quebec were plunged into darkness. A thousand miles away, even Maryland, Virginia and Pennsylvania were affected as half of the capacitors in the Allegheny Power System went off-line. In many ways, it was a sanitized calamity. It was wrapped in a diversion of beautiful colors, and affected a distant population mostly while they slept. There were no houses torn apart, or streets flooded from powerful hurricanes. There was no dramatic TV News footage of waves crashing against the beach. There were no tornadoes cutting a swath of destruction through Kansas trailer parks.

The calamity passed without mention in the major metropolitan newspapers, yet six million people were affected as they awoke to find no electricity to see them through a cold Quebec wintry night. Some engineers from the major North American power companies were not so calm. They worried how this Quebec blackout could easily have escalated into a $6 billion catastrophe affecting most US East Coast cities. All that prevented 50 million people in the US from joining their Canadian friends in the dark were a few dozen heroic capacitors on the Allegheny Power Network. ***(Excerpted from the book "The 23rd Cycle". Author: Dr. Sten Odenwald)***

1. **If the solar storm took 3 days to travel 150 million kilometers to Earth, how fast was it traveling in kilometers per hour?**

2. **How much time elapsed between the arrival of the storm at Earth, and the time when the Quebec power system failed?**

3. **How long did the blackout continue?**

4. **What kinds of severe problems could occur in a typical city during a blackout in the daytime? In the nighttime?**

Space Weather: http://image.gsfc.nasa.gov/poetry/weather01.html

A Solar Storm Timeline

Scientists using the NASA's IMAGE satellite have been studying how the Earth's environment changes during a solar storm. This environment is filled with invisible clouds of gas. It is a bit of a mystery how these clouds are created by solar storms which pass by Earth.

This activity uses satellite data to study a solar storm and its impact on Earth's environment in space.

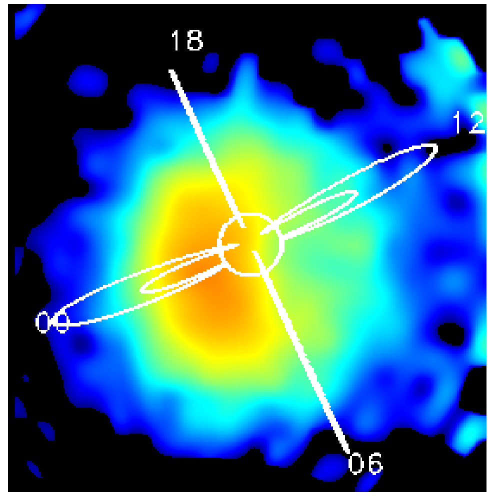


IMAGE spots a plasma storm near Earth.

Scientists construct a timeline to investigate how natural phenomena change in time. This is often the first step in identifying their causes.

Drawing conclusions from simple time calculations

Now you try!

Here's how to do it!

15:21 A solar flare erupts on the Sun
15:30 A disturbance is detected on Earth
How many minutes later was the Earth disturbance witnessed after the flare erupted?

15hours 30minutes
- 15hours 21minutes
----
9 minutes later.

Solar Storm Timeline

Day	***Time***	***What Happened***
Tuesday	**4:50 PM**	**Gas eruption on Sun**
Thursday	**3:36 AM**	**Plasma storm reaches Earth.**
Thursday	**5:20 AM**	**Storm at maximum intensity.**
Thursday	**5:35 AM**	**Auroral power at maximum.**
Thursday	**11:29 AM**	**Aurora power at minimum.**
Thursday	**2:45 PM**	**Space conditions normal**

1) How much time passed between the solar gas eruption and its detection near Earth?

2) How long after the plasma storm reached Earth did the aurora reach their maximum power?

3) How long did the storm last near Earth from the time the plasma was detected, to the time when space conditions returned to normal?

<u>Extra for Experts!</u>
If the Earth is 150 million kilometers from the sun, how fast did the storm travel from the Sun in kilometers per hour?

Aurora Power!

Scientists use decimal numbers a lot when measuring objects or processes! This activity uses data from the National Oceanic and Atmospheric Administration (NOAA) POES satellite to compare the Northern Lights displays in terms of how many watts of energy they produce.

Note: A kilowatt is one thousand watts, but a gigawatt is one billion watts! A kilowatt of electricity can run a small house, but a gigawatt can run a small city.

Auroras are very common to see in northern regions of Canada and Alaska. They light up the skies in swirling color.

Scientists make measurements that are usually expressed in decimal form.

Applied decimal arithmetic: addition, subtraction and division

Here's how to do it!

How much more powerful was an aurora with 987.45 gigawatts, than an aurora with 324.98 gigawatts?

987.45 gigawatts
- 324.98 gigawatts

662.47 gigawatts

Now you try!

Aurora Power

Date	Power
4-11-01	528.1
4-18-01	828.3
11-24-01	497.7
2-18-00	17.6
8-27-01	96.5
11-6-01	484.7
5-23-02	387.3
2-5-02	244.8
9-4-02	580.2

This table lists some major storms detected by the NOAA POES satellite, and the total power that they produced in gigawatts (Gw). Use this table to answer the questions below.

1) What was the difference in power between the strongest and weakest aurora detected?

2) If 48 storms like the one on February 18, 2000 were combined, how much different would they be than the power from the strongest storm in the table?

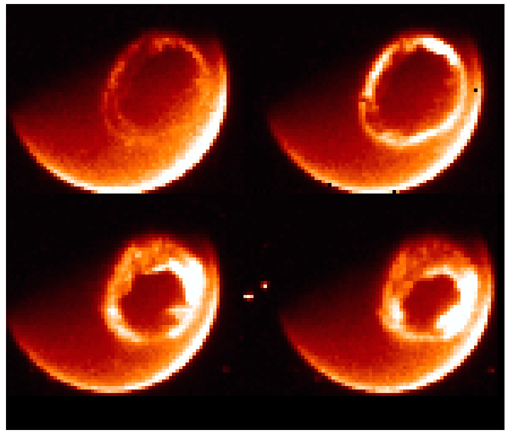
3) What is the sum of the power for all nine storms?

4) How many times more powerful was the April 18, 2001 storm than the storm detected on August 27, 2001?

How big is an aurora?

The IMAGE satellite orbits Earth, and has a camera that can view the Northern and Southern Lights from space. As the solar activity level increases and decreases, the size of the aurora increases and decreases.

This activity will let you use data from this satellite to measure the diameter of the Auroral Oval and its changes during a solar storm event.



The ring of Northern Lights from space.

Scientists use satellites to study phenomena that are too vast to be studied from the ground.

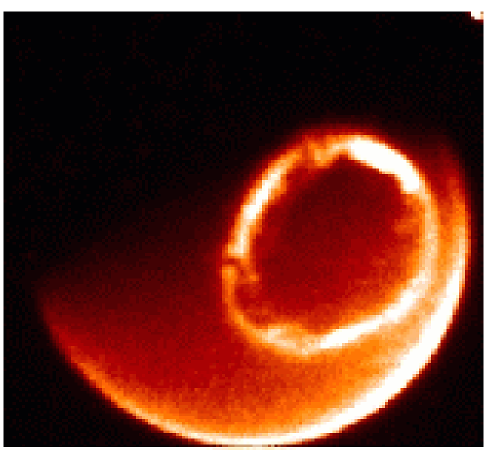
Photographs can be used to measure the size of an object.

Now you try!

Here's how to do it!

1. **With a ruler, measure the diameter of the Earth's disk in millimeters in the illustration. (Answer: About 30 mm)**
2. **The diameter of the Earth in this image is 13,000 kilometers, so the scale of the image is (13000 km)/(30 mm) = 433 kilometers/mm.**
3. **The diameter of the Oval is about 15 mm, so using the image scale, the diameter of the Oval is:**

15 x 433 = 6,500 kilometers



This photograph is from the IMAGE 'Far-Ultraviolet Imager' instrument obtained on July 14, 2000. It shows the size of the auroral oval during a severe solar storm.

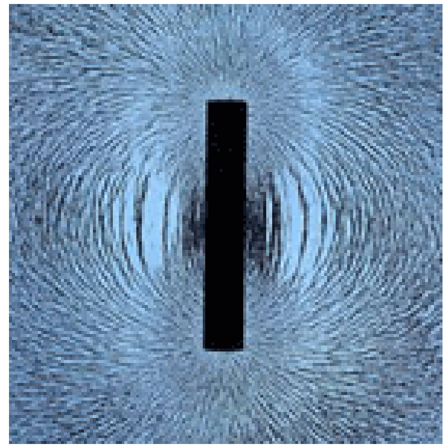
1) Estimate the inside and outside diameters of the auroral oval.

2) Calculate the oval's area in millions of square kilometers.

Solar magnetism!

When a solar storm travels through space, it carries part of the Sun's magnetic field with it. The Advanced Composition Explorer (ACE) satellite measures the strength of this field and its polarity (North or South). This polarity information is recorded as a negative (south) or a positive (north) number.

In this exercise, you will learn how to work with negative and positive numbers.



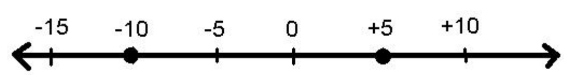
The magnetic field of a toy magnet.

The sign of a number (+ or -) is used by scientists to record information about magnetic polarity (North or South)or the direction of motion (forward or backward).

Negative and positive numbers can be understood by using a number line.

Here's how to do it!

The ACE satellite measures the solar wind magnetic field on two days and records the value -10.0 on Monday, and +5.0 on Tuesday. By how much did the magnetic field change between the two days?



Answer: (+5) - (-10.0) = +15.0

Now you try!

Draw a number line, and plot the following points. Then answer the questions.

Solar Wind Magnetism Data Series

-15, +5, -2, -15, -20, -8, +4,
+8, +5, +2, +5, -15, +6

a) What is the range of the measurements?

b) What is the smallest value recorded?

c) What is the largest value recorded?

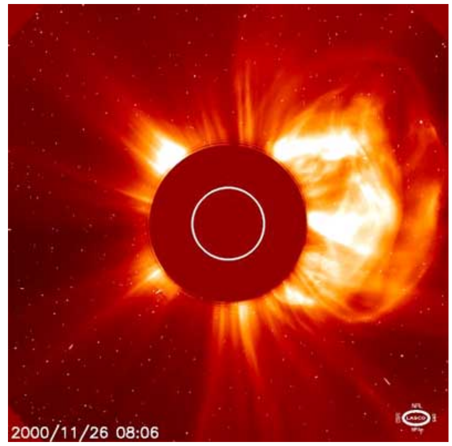
d) What is the median value recorded?

e) What is the average value recorded?

Solar storm speeds

The sun often ejects clouds of gases into space. Some of these fast-moving clouds can be directed at Earth. Astronomers call them Coronal Mass Ejections (or CMEs). When these CMEs arrive, they can cause spectacular aurora, damage satellites, or cause electrical blackouts.

In this exercise, you will learn how scientists use the speeds of these clouds to predict when they will arrive at Earth.



The Sun ejects clouds of gas into space carrying billions of tons of matter.

Scientists need to know how fast things move in order to study where they come from and what causes them.

The speed of an object is defined as the distance it travels divided by the time it takes.

Here's how to do it!

The ACE satellite measures the speed of the solar wind and clouds of gas from the Sun. Its sensor detects a cloud moving at 980 kilometers per second. How long will it take for it to travel from the spacecraft to Earth, if the distance is 1.5 million kilometers?

Answer: Time = (1,500,000 km) / (980 km/sec)
= 1,530 seconds

Now you try!

Cloud Speeds

Date	Speed
5-10-02	423.0
5-18-02	497.0
5-23-02	897.0
7-12-02	548.0
7-20-02	931.0
7-23-02	516.0
9-19-02	756.0
1-11-02	647.0
1-19-02	455.0
3-05-02	705.0
3-18-02	480.0
3-29-02	379.0
4-01-02	795.0
8-10-02	469.0

The table shows cloud speeds measured in kilometers per second. Assume that the clouds detected by the ACE satellite were the CMEs produced on the Sun.

1) What was the fastest speed measured?

2) What was the slowest speed measured?

3) What was the average speed measured?

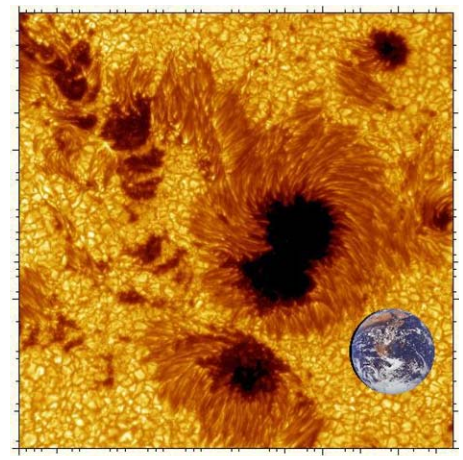
4) What is the fastest speed in miles per hour?

5) If the Sun is 150 million kilometers from Earth, how many hours would it take the fastest and the slowest CMEs to reach Earth?

Space weather indicators

Sunspots are a sign that the Sun is in a stormy state. Sometimes these storms can affect Earth and cause all kinds of problems such as satellite damage and electrical power outages. They can even harm astronauts working in space.

Scientists use many different kinds of measurements to track this stormy activity. In this exercise, you will learn how to use some of them!



This sunspot is as big as Earth!

Looking at sequences of numbers can help you identify unusual events that depart from the average trend.

Every sequence can be defined by its largest, smallest and average values.

Now you try!

Here's how to do it!

An astronomer counts sunspots for 5 days and gets the following sequence:

149, 136, 198, 152, 145

Maximum = 198
Minimum = 136
Mean = (149+136+198+152+145)/5 = 156
Median = 149

Find the maximum, minimum, mean and median of each sequence.

1) Number of Sunspots

241	240	243	229	268	335	342	401	325	290	276	232	214

2) Number of Solar Flares

5	7	13	8	9	14	9	13	16	6	14	15

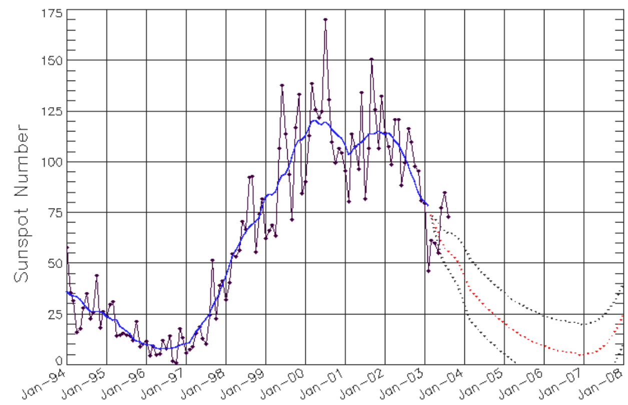
3) Aurora Power (measured in billions of watts!)

171.2	122.2	219.4	107.9	86.2	112.4	76.2	39.8	153.9

Sunspot cycles

The Sun is an active star that goes through cycles of high and low activity. Scientists mark these changes by counting sunspots. The numbers of spots increase and decrease about every 11 years in what scientists call the Sunspot Cycle.

This activity will let you investigate how many years typically elapse between the sunspot cycles. Is the cycle really, exactly 11-years long?



The sunspot cycle between 1994 and 2008

Scientists study many phenomena that run in cycles. The Sun provides a number of such 'natural rhythms' in the solar system.

Sequences of numbers often have maximum and minimum values that re-occur periodically.

Here's how to do it!

Consider the following measurements taken every 5 minutes:

100, 200, 300, 200, 100, 200, 300, 200

1. **There are two maxima (value '300').**
2. **The maxima are separated by 4 intervals.**
3. **The cycle has a period of 4 x 5 = 20 minutes.**
4. **The pairs of minima (value = 100) are also separated by this same period of time.**

Now you try!

Sunspot Numbers

Solar Maximum | Solar Minimum

Year	Number	Year	Number
2000	125	1996	9
1990	146	1986	14
1980	154	1976	13
1969	106	1964	10
1957	190	1954	4
1947	152	1944	10
1937	114	1933	6
1928	78	1923	6
1917	104	1913	1
1905	63	1901	3
1893	85	1889	6
1883	64	1879	3
1870	170	1867	7

This table gives the sunspot numbers for pairs of maximums and minimums in the sunspot cycle.

1) From the solar maximum data, calculate the number of years between each pair of maxima.

2) From the solar minimum data, calculate the number of years between each pair of minima.

3) What is the average time between solar maxima?

4) What is the average time between solar minima?

5) Combining the answers to #3 and #4, what is the average sunspot cycle length?

Solar flares

Solar flares are powerful explosions of energy and matter from the Sun's surface. One explosion, lasting only a few minutes, could power the entire United States for a full year. Astronauts have to be protected from solar flares because the most powerful ones can kill an astronaut if they were working outside their spacecraft.

In this exercise, you will learn how scientists classify flares, and how to decode them.

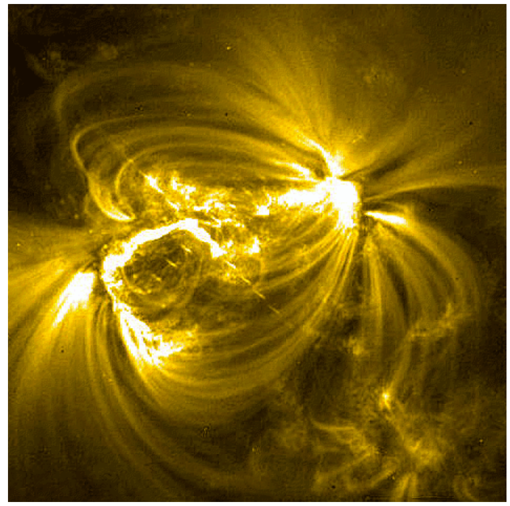


Image of Sun showing flare-like eruption.

Scientists create alphabetic and numerical scales to classify phenomena, and to assign names to specific events.

Simple equations can serve as codes.

Now you try!

Here's how to do it!

A solar flare scale uses three multipliers defined by the letter codes C = 1.0, M=10.0, X=1000.0.

…A solar flare might be classified as M5.8 which means a brightness of (10.0) x (5.8) = 58.0.
…A second solar flare might be classified as X15.6 which means (1000.0) x (15.6) = 15,600.0

The X15.6 flare is (15,600/58) = 269 times brighter than the M5.8 flare.

The GEOS satellite has an X-ray monitor that records daily solar flare activity. The table below shows the flares detected between January 11 and March 3, 2000.

Flare Codes for Major Events

Date	Code	Date	Code
1-11	M1.5	2-12	M1.7
1-12	M2.8	2-17	M2.5
1-18	M3.9	2-18	C2.7
1-22	M1.0	2-20	M2.4
1-24	C5.3	2-21	M1.8
1-25	C6.8	2-22	M1.2
2-3	C8.4	2-23	C6.8
2-4	M3.0	2-24	M1.1
2-5	X1.2	2-26	M1.0
2-6	C2.4	3-1	C6.9
2-8	M1.3	3-2	X1.1

1) What was the brightest flare detected during this time?

2) What was the faintest flare detected during this time?

3) How much brighter was the brightest flare than the faintest flare?

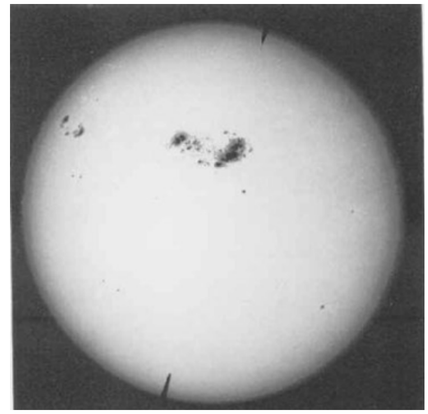
4) What percentage of the flares were brighter than M1.0?

Scientific notation I

Physicists and astronomers almost always use very small or very large numbers in the calculations or measurements.

Scientific notation is the best, and most compact, way to work with very large and small numbers.

This activity will review how to write numbers in this form, and translate them back into ordinary numbers.



Solar diameter 1.392 x 10^9 meters

Scientific notation is a compact way to write very large or small numbers that scientists frequently encounter in studying the universe.

Scientific notation is used to write very large or small numbers.

Here's how to do it!

Count the number of places to move the decimal point to the right or left and write the number like this:

The number 1,350,000,000 can be written as

1.35 x 10^{+9}

The number 0.000000000000017 can be written as

1.7 x 10^{-14}

Now you try!

1) Re-write the following numbers in Scientific Notation:

- **a) 5,990,000,000,000,000 kilometers**
- **b) 0.000135 centimeters**
- **c) 299,794.5 kilometers/second**
- **d) 147,000,000 kilometers**
- **e) 0.00000000000000000000000000000000165 centimeters**
- **f) 31,000,000 seconds**
- **g) 1.458 trillion cubic kilometers**

2) Write these in normal numerical form:

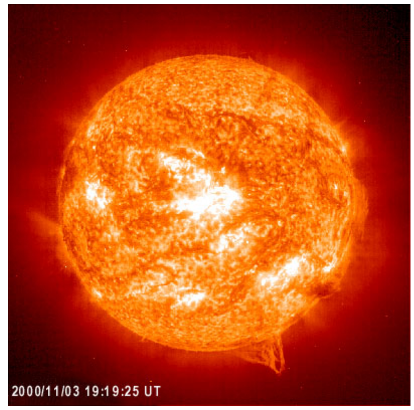
- **a) 1.45 x 10^{-3} centimeters**
- **b) 3.1 x 10^{+12} cubic centimeters**
- **c) 8.7 x 10^{+4} seconds**
- **d) 2.99 x 10^{+10} centimeters/second**
- **e) 1.9 x 10^{-33} seconds**
- **f) 5.4 x 10^{+27} kilograms**
- **g) 8.9 x 10^{+10} watts**

Scientific notation II

Physicists and astronomers almost always use very small or very large numbers in the calculations or measurements.

Scientific notation is the best, and most compact, way to work with very large and small numbers.

This activity will review how to divide numbers in this form.



Density of Sun = $\dfrac{1.9 \times 10^{33} \text{ grams}}{1.38 \times 10^{33} \text{ cubic cm}}$

Scientific Notation simplifies calculations with large or small numbers.

Scientific Notation provides an easy means to divide large and small numbers together.

Here's how to do it!

State the problem: 7.5×10^{-11} / $4.5 \times 10^{+20}$

Group the factors: $(7.5 / 4.5) \times (10^{-11} / 10^{+20})$

Subtract the exponents: $1.67 \times 10^{(-11 - (+20))}$

Answer: 1.67×10^{-31}

Now you try!

Perform these divisions using scientific notation.

1) Density of a star in grams/cc:

2.1×10^{33} / 3.1×10^{32}

2) Speed of solar wind in km/sec:

1.47×10^{8} / 2.7×10^{5}

3) Density of a proton in grams/cc:

1.64×10^{-24} / 3.7×10^{-38}

4) Speed of Sun around Milky Way in centimeters/second :

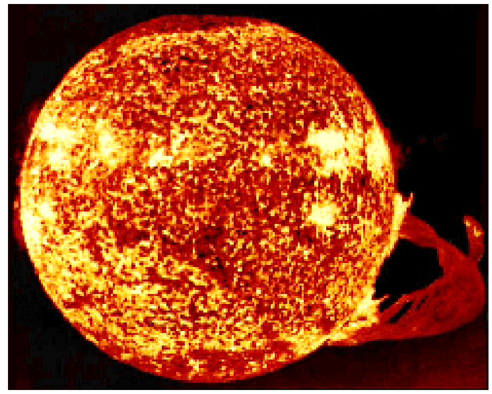
2.7×10^{23} / 6.3×10^{15}

Scientific notation III

Physicists and astronomers almost always use very small or very large numbers in the calculations or measurements.

Scientific notation is the best, and most compact, way to work with very large and small numbers.

This activity will review how to multiply numbers in this form.



Surface area of the Sun = 4 x (3.141) x (6.97 x 10^5)^2 square kilometers

Scientific notation simplifies calculations with large or small numbers.

Scientific Notation provides an easy means to multiply large and small numbers together.

Here's how to do it!

State Problem: $1.5 \times 10^{-11} \times 4.5 \times 10^{+20}$

Group the factors: $(1.5 \times 4.5) \times (10^{-11} \times 10^{+20})$

Add the exponents: $6.75 \times 10^{(-11 + 20)}$

Answer: 6.75×10^{9}

Now you try!

Multiply these numbers using scientific notation.

1) Energy in ergs of Sun in 1 year:

$4.1 \times 10^{33} \times 3.1 \times 10^{7}$

2) Number of seconds in 1 year:

$8.6 \times 10^{4} \times 3.65 \times 10^{2}$

3) Centimeters in 1 light year:

$6.32 \times 10^{4} \times 1.47 \times 10^{11}$

4) Mass of a large star in grams:

$1.64 \times 10^{-24} \times 3.5 \times 10^{57}$

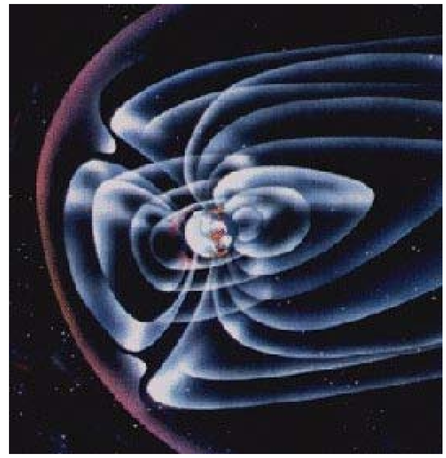
5) Number of stars in the visible universe:

$2.5 \times 10^{11} \times 7.5 \times 10^{10}$

Thinking in three dimensions

In the Cartesian 'X-Y' coordinate system, a pair of 2 numbers (x, y) define the address of a point on the plane. Because we live in a 3-dimensional world, a third number needs to be added to define a point (x, y, z). Many physical quantities are represented in this way.

This activity will let you use data from NASA's ACE satellite to calculate the strength of the solar wind's magnetic field using the Pythagorean Theorem.



A perspective drawing of Earth's 3-dimensional magnetic field.

Scientists represent many physical quantities by triplets of numbers which form the sides of a 3-dimensional triangle in space.

A simple extension of the Pythagorean Theorem lets you calculate 3-dimensional quantities. Here's what it looks like:

$$W^2 = X^2 + Y^2 + Z^2$$

Here's how to do it!

A scientists measures the three components to the velocity of a satellite (x, y, z) in kilometers per second, and finds:

(145.0, 103.0, 523.7)

The total speed, V, of the satellite is given by

$$V^2 = (145.0)^2 + (103.0)^2 + (523.7)^2$$
$$V^2 = 21{,}025.0 + 10{,}609.0 + 274{,}261.7$$
$$V^2 = 305{,}895.7$$
$$V = 533.1 \text{ kilometers per second}$$

Now you try!

Solar Wind Velocity

Date	X	Y	Z	B^2	B
1-7	10.9	-5.7	-1.0		
1-10	-10.2	+11.4	-4.0		
4-17	+9.6	-18.6	+14.5		
5-23	-4.8	+22.2	+16.6		
5-28	-0.88	+0.94	+0.18		
7-11	-2.8	-3.6	+1.2		

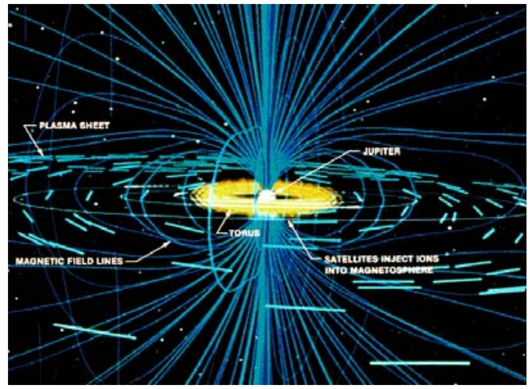
In 2002, the ACE satellite measured the three components to the solar wind magnetic field at a location 1.5 million kilometers from Earth. The table above gives the data for a series of these observations. Use the 3-dimensional Pythagorean Theorem, together with the three magnetic field measurements (X, Y, Z), to calculate the total strength of the solar wind field.

Enter the answer in the last column.

Mathematical models and forecasting

Scientists use, and create, many different kinds of equations to help them quantify their data, and make predictions.

A scientific theory describes how quantities ought to be logically related to each other, and provides a mathematical procedure for working with nature in a symbolic way.



A model of Jupiter's magnetic field.

Equations are used to extract information from data, and to model how qualities (speed, distance, temperature etc) are interrelated.

Equations help scientists extract information from basic data, and allow them to make predictions.

Here's how to do it!

If a pebble falls from the top of a building and takes 10.0 seconds to reach the ground, how high is the building? This equation predicts the distance of the fall (H) based on the time (T)

$$H = 9.8\ T^2$$

with T=10.0 seconds :

$$H = 9.8\ (10)^2 \text{ meters} = 980 \text{ meters}$$

Now you try!

Evaluate the following equations for the indicated values of the variables:

1) $S = d + V\,T + 1/2\ a\,T^2$ for $a = 32$, $V = 25.7$, $d = 5.5$ and $T = 15.7$

2) $E = m\,c^2$ for $m = 15$ and $c = 299{,}792.5$

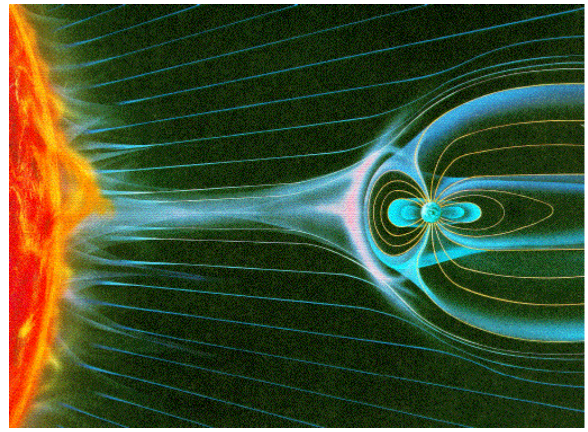
3) $L = 4\pi\ R^2\ S\ T^4$ for $R = 6.9 \times 10^{10}$, $S = 0.000058$ and $T = 5770.0$

4) $M = 9.54 \times 10^{15}\ T\,m^3$ for $T = 3987.6$ and $m = 30.5$

What causes a solar storm?

A solar flare as a violent explosion of magnetic energy on the sun. A Coronal Mass Ejection is a billion-ton cloud of gas exploding from the solar surface. Scientists can detect these 'solar storms' and measure how Earth's environment changes.

What scientists would like to learn is, how do you predict what will happen near Earth by looking at events taking place on the Sun, or in space?



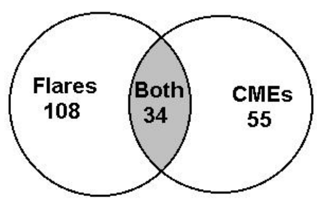
Storms from the Sun sometimes make their way to Earth. Space physicists try to predict what will happen when these storms arrive, and forecast their arrival.

Statistical data can be used to draw conclusions about cause-and-effect relationships, even though the details of the process are unknown.

Venn diagrams help astronomers sort out statistical information.

Here's how to do it!

In 2000, 142 solar flares, and 89 Coronal Mass Ejections were spotted on the Sun. 34 flares happened at nearly the same time as CMEs. What percent of CMEs are not accompanied by solar flares?



$$\frac{89-34}{89} = 0.62$$

or 62 %

Now you try!

1) In the sample problem above, what percentage of solar flares do not happen during CMEs? A news reporter says that solar flares produce CMEs. Is this an accurate statement? Explain.

2) A NASA satellite called ACE measures changes in the magnetism of the gas flowing away from the sun. During 2000 it detects 56 severe magnetic changes. Another satellite called SOHO detects 55 CMEs of which 29 happen at the same time as the ACE disturbances. The IMAGE satellite detects aurora in the polar regions of Earth. A total of 63 bright Aurora are detected during the 56 ACE magnetic 'storms'. There are 31 cases where aurora are seen at the same time as the magnetic disturbances. a) What percentage of CMEs cause magnetic disturbances? b) What fraction of magnetic disturbances lead to major aurora on Earth?

3) Can CME's be reliably used to predict when the next Aurora will occur? Explain.

Teacher Answer Page

Activity 1

Question 1)

150 million kilometers / (3 days x 24 hours) = 2.1 million kilometers per hour.

Question 2)

The electrical event began at 2:45 AM and lasted 97 seconds.

Question 3)

The Quebec blackout lasted nine hours.

Question 4)

Students are being asked to consider what kinds of electrical systems can be affected by a blackout. The recent 2003 blackout which struck the East Coast of the US is a good resource for examples of situations that can arise during a blackout. Severe problems would involve hospital surgery wards losing power, people trapped in elevators in high-rise buildings among other situations.

Activity 2

Problem 1)

Eruption on Tuesday at 4:50 PM
Detection near Earth on Thursday at 3:36 AM

First day passes to Wednesday at 4:50 PM +24h
Now to get from Wednesday afternoon at 4:50 PM to Thursday morning at 3:36 AM Need to add an additional 7:10 + 3:36 = 10:46. Now add this to 24h to get the answer. **Answer: 34 hours and 46 minutes.**

Problem 2) 5:35 AM - 3:36 AM = **1 hour and 59 minutes**

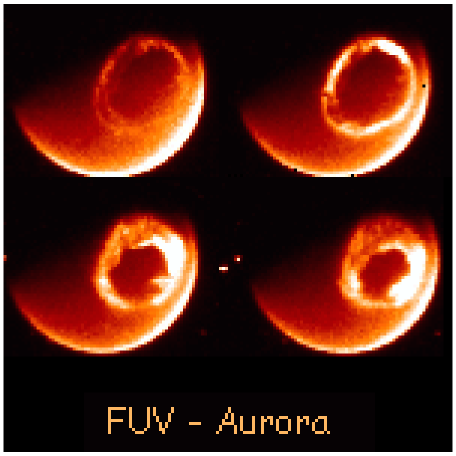
Problem 3) 2:45 PM - 3:36 AM = 14:45 - 3:36 = **11 hours and 9 minutes**

Extra Credit) 150,000,000 / (34 h 46 minutes) = **4.31 million km/hour**

Activity 3

Problem 1) 828.3 - 17.6 = **810.7 gigawatts**
Problem 2) 48 x 17.6 = **844.8 gigawatts** compared to one storm with 828.3 gigawatts
Problem 3) **3,665.2 gigawatts** or 1.6652 trillion watts
Problem 4) 828.3/96.5 = **46.6 times greater**

Activity 4



The diameter of the partial Earth disk is about 60 millimeters. The scale of the photograph is therefore 13,000/60 = 217 kilometers per millimeter.

Problem 1) The diameter of the inside of the oval is about 20 millimeters or 20 x 217 = 4340 kilometers. The outside diameter of the oval is about 27 millimeters or 27 x 217 = 5860 kilometers.

Problem 2) The area of the oval is found by taking the difference of the larger and smaller circles. The area of the two circles with diameters of 5860 and 4340 kilometers is found by using the formula for the area of a circle, $A = \pi R^2$, with $\pi = 3.14$, and R = 5860/2 = 2930 kilometers for the larger circle and R = 4340/2 = 2170 kilometers for the smaller circle. The larger circle area is $A = 3.14 (2930)^2 = 2.69 \times 10^7$ square kilometers.
The smaller circle area is $A = 3.14 (2170)^2 = 1.48 \times 10^7$ square kilometers. Subtracting the larger from the smaller gives the oval area of 1.21×10^7 square kilometers, or 12.1 million square kilometers in the units requested.

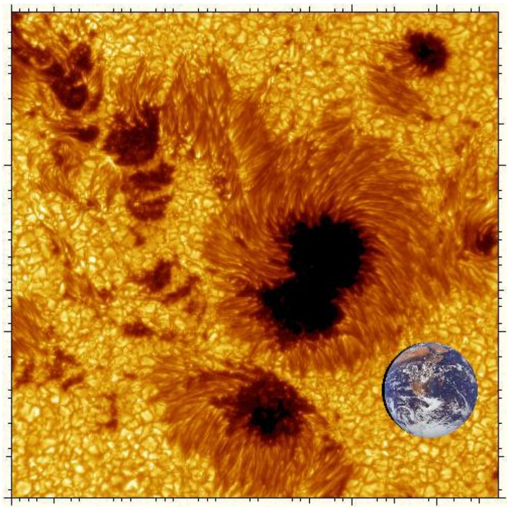
Activity 5

A) [-20, +8]
B) -20
C) +8
D) Sorted -20 -15 -15 -15 -8 -2 +2 +4 +5 +5 +8
Median = -2 (In a list of 11 elements, the value in the 6th place 1/2 way between extremes)
Mode = -15 (most often measured)
E) (-20 -15 -15 -15 -8 -2 +2 +4 +5 +5 +8)/11 = -47/11 = -4.3

Activity 6

Problem 1) 931.0 kilometers per second
Problem 2) 379.0 kilometers per second
Problem 3) 8498/14 = 607 kilometers/second
Problem 4) (931) x (3600) x 0.62 = 2.08 million miles/hour
Problem 5) Fastest: 150,000,000/931.0 = 161,000 seconds or 44.75 hours
Slowest = 150,000,000/379.0 = 396,000 seconds or 110 hours

Activity 7



Problem 1) Maximum = 401, minimum = 214
Ordered = 214, 229, 232, 240, 241, 243, 268, 276, 290, 325, 335, 342 ,401. Median = 268. Mean = (214 + 229 + 232 + 240 + 241 + 243 + 268 + 276 + 290 + 325 + 335 + 342 + 401)/13 = 3436/13 = 264.3

Problem 2) Maximum = 16, Minimum = 5
Ordered = 5, 6, 7, 8, 9, 9, 13, 13, 14, 14, 15. Median = 9
Mean = (5 + 6 + 7 + 8 + 9 + 9 + 13 + 13 + 14 + 14 + 15)/11 = 113/11 = 10.3

Problem 3) Maximum = 219.4 Minimum = 39.8
Ordered = 39.8, 76.2, 86.2, 107.9, 112.4, 122.2, 153.9, 171.2, 219.4. Median = 112.4. Mean = (39.8 + 76.2 + 86.2 + 107.9 + 112.4 + 122.2 + 153.9 +171.2 + 219.4)/9 = 1089.2/9 = 121.0

Activity 8

Problem 1)
Maxima Table:

Year	Difference
2000	
1990	10
1980	10
1969	11
1957	12
1947	10
1937	10
1928	9
1917	11
1905	12
1893	12
1883	10
1870	13

Problem 2)
Minima Table:

Year	Difference
1996	
1986	10
1976	10
1964	12
1954	10
1944	10
1933	11
1923	10
1913	10
1901	12
1889	12
1879	10
1867	12

Problem 3)

Average time = (10 + 10 + 11 + 12 + 10 + 10 + 9 + 11 + 12 + 12 + 10 + 13)/12 = 130/12 = 10.8 years between sunspot maxima.

Problem 4)

Average time = (10 + 10 + 12 + 10 + 10 +11 + 10 + 10 + 12 + 12 + 10 + 12)/12 = 129/12 = 10.8 years between sunspot maxima.

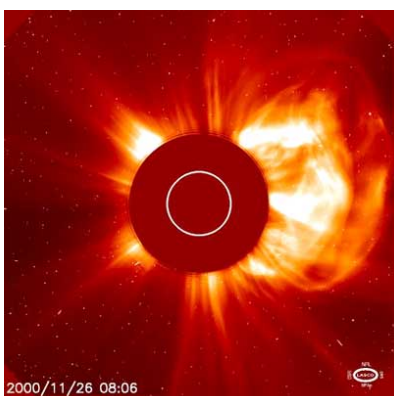
Problem 5)

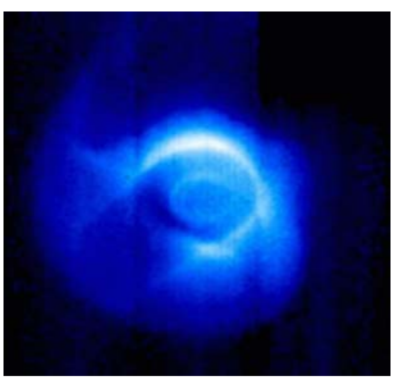
Average length = (10.8 + 10.8) / 2 = 10.8 years.

Activity 9

Problem 1) X1.2 on February 5 with a brightness of (1000) x 1.2 = 1,200.
Problem 2) C2.4 on February 6 with a brightness of (1.0) x 2.4 = 2.4
Problem 3) 1200/2.4 = 500 times brighter
Problem 4) There are a total of 22 flares in the table. There are 13 flares brighter than M1.0 but not equal to M1.0. The percentage is then (13/22) x 100% = 59%

Activity 10





Problem 1)

a) 5.99×10^{15} kilometers
b) 1.35×10^{-4} centimeters
c) 2.997945×10^{5} kilometers/second
d) 1.47×10^{8} kilometers
e) 1.65×10^{-33} centimeters
f) 3.1×10^{7} seconds
g) 1.458×10^{12} cubic kilometers

Problem 2)

a) 0.00145 centimeters
b) 3,100,000,000,000 cubic centimeters
c) 87,000 seconds
d) 29,900,000,000 centimeters/second
e) 0.0000000000000000000000000000000019 sec
f) 5,400,000,000,000,000,000,000,000,000 kg
g) 89,000,000,000 watts

Activity 11

Problem 1) Answer = 6.8 grams per cubic centimeter

Problem 2) Answer = 5.44×10^{2} kilometers per second

Problem 3) Answer = 4.43×10^{13} grams per cubic centimeter

Problem 4) Answer = 4.28×10^{7} centimeters per second

Activity 12

Problem 1) Answer = 1.27×10^{41} ergs

Problem 2) Answer = 3.14×10^{7} seconds

Problem 3) Answer = 9.29×10^{15} centimeters

Problem 4) Answer = 5.74×10^{33} grams

Problem 5) Answer = 1.88×10^{22} stars

Activity 13

Date	X	Y	Z	B^2	B
1-7	10.9	-5.7	-1.0	**152.3**	**12.3**
1-10	-10.2	+11.4	-4.0	**249.9**	**15.8**
4-17	+9.6	-18.6	+14.5	**648.3**	**25.5**
5-23	-4.8	+22.2	+16.6	**791.4**	**28.1**
5-28	-0.88	+0.94	+0.18	**1.68**	**1.29**
7-11	-2.8	-3.6	+1.2	**22.2**	**4.7**

Activity 14

Encourage students to use scientific notation where appropriate, and to be careful of the number of significant figures after the decimal point when using a calculator.

Problem 1) $D = 5.5 + 25.7\ (15.7) + 1/2\ (32)\ (15.7)^2 = 5.5 + 403.5 + 3943.8 =$ **4352.8**

Problem 2) $E = 15\ (299792.5)^2 =$ **1.35×10^{12}**

Problem 3) $L = 4\ (3.141)\ (6.9 \times 10^{10})^2\ (0.000058)(5770)^4 =$ **3.85×10^{33}**

Problem 4) $M = (9.54 \times 10^{15})\ (3987.6)\ (30.5)^3 =$ **1.08×10^{24}**

Activity 15

Problem 1)
There are a total of 108 solar flares spotted. If 34 solar flares happen at the same time as CMEs directed towards Earth, then there are (108-34) = 74 solar flares that happen when CMEs are not detected. The percentage = 74 x 100%/108 = 68%. So, 68% of all the major solar flares do not produce CMEs. In the very few words that a reporter often uses to describe the scientific concepts, the reporter says that solar flares produce CMEs. This statement is only true about 32% of the time. This means that, actually, most flares do NOT produce CMEs.

Problem 2)
a) Of the 55 CMEs directed towards Earth, 29 happen at the same time as the severe magnetic disturbances seen by the ACE satellite, so the percentage is 29/55 = 53%.
b) Of the 56 magnetic storms detected by the ACE satellite, 31 produced bright aurora seen by the IMAGE satellite so, 31/56 = 55% of the magnetic disturbances produce strong aurora.

Problem 3)
Of the 55 CME's that are detected heading towards Earth, 29 of these cause magnetic disturbances. But only 55% of the severe magnetic disturbances seen by the ACE satellite actually lead to strong aurora. This means that out of the CME's detected, only (29/55) x (55/100) = 0.29 or 29% caused strong aurora. This means that most CMEs do not produce disturbances near the Earth, and so the detection of CMEs headed towards Earth is not enough to help us reliably predict whether a strong aurora will be produced.