National Aeronautics and
Space Administration

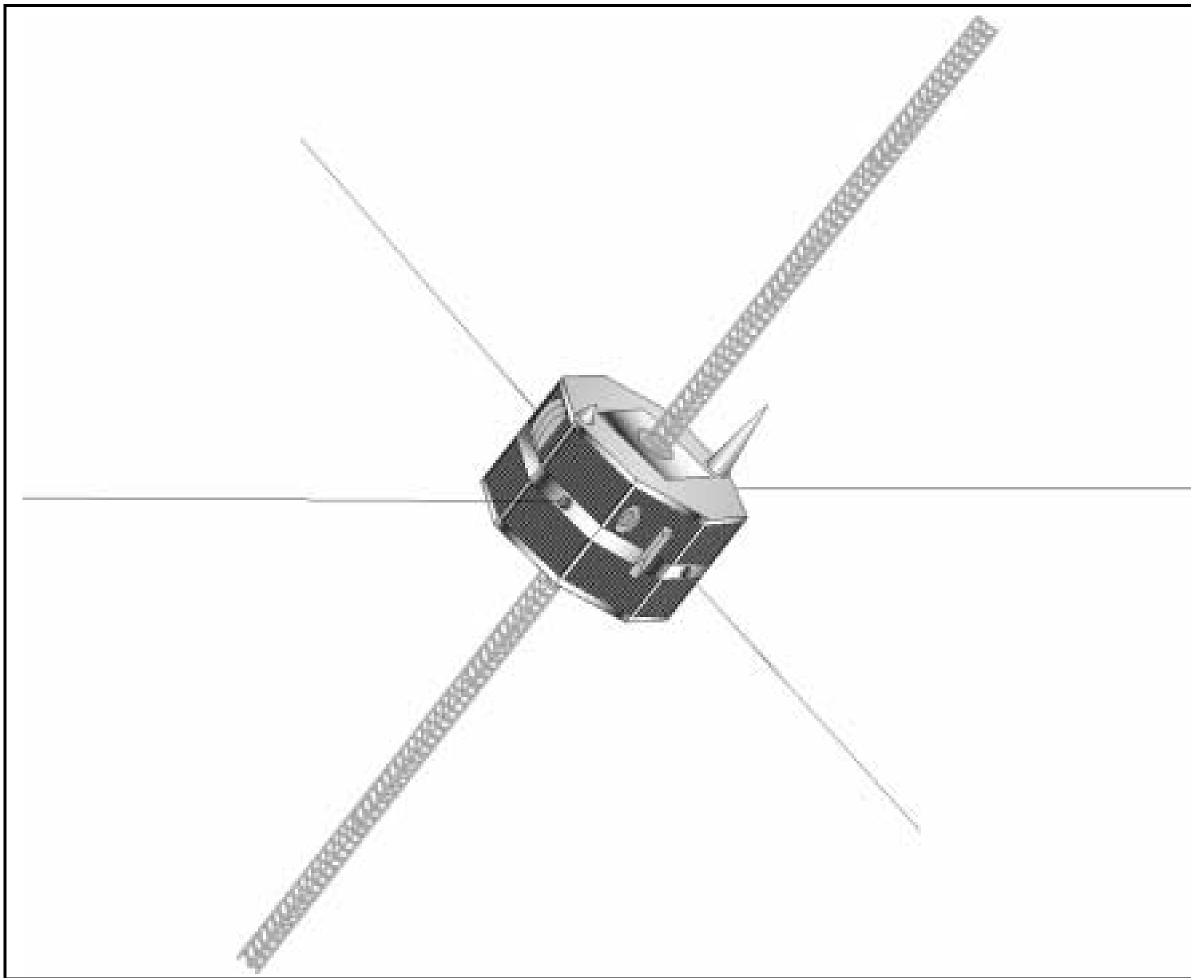
Educational Product	
Educators & Students	Grades 9-12

EG-2000-XX-XXX-GSFC

The Mission and Instruments of IMAGE

Part 1: An Analysis of a NASA Mission

An Educator Guide with Activities in Space Science



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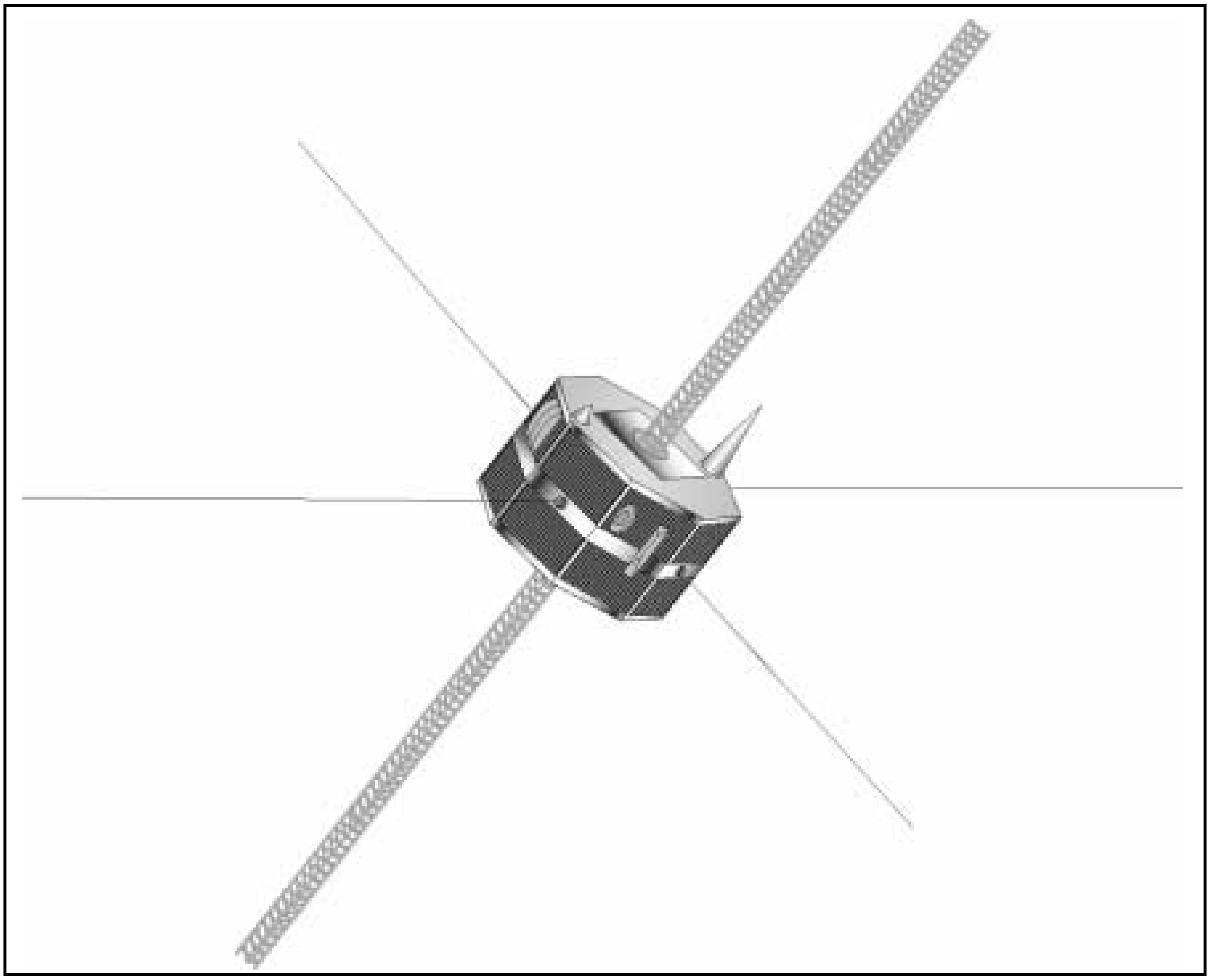

Acknowledgments

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This resource was developed by the NASA Imager for Magnetopause-to-Auroral Global Exploration (IMAGE)

Information about the IMAGE Mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

National Aeronautics and
Space Administration
Goddard Space Flight Center

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The Mission and Instruments of IMAGE – Part 1

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The Mission and Instruments of IMAGE – Part 1

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A. SCIENCE AS INQUIRY															
Science as Inquiry	*	*	*	*	*										*
B. PHYSICAL SCIENCE															
Motions and Forces							*	*				*	*	*	*
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Historical Perspectives	*	*	*	*	*						*	*	*		*

NCTM MATH STANDARDS	Chapter 1					Chapter 2						Chapter 3			
	1	2	3	4	5	1	2	3	4	5	6	1	2	3	4
Number and Operations Standard															
Large/small numbers												*	*	*	*
Compute fluently	*	*	*									*	*	*	*
Algebra Standard															
Analyze change: graphical data				*	*										
Geometry Standard															
Specify locations: polar coordinates									*	*	*				
Measurement Standard															
Units and scales				*					*	*	*			*	
Data and Probability Standard															
Display and discuss bivariate data				*							*				
Problem Solving Standard															
Apply a variety of problem solving strategies	*	*	*	*											
Reasoning and Proof Standard															
Various types of reasoning						*	*	*							
Connection Standard															
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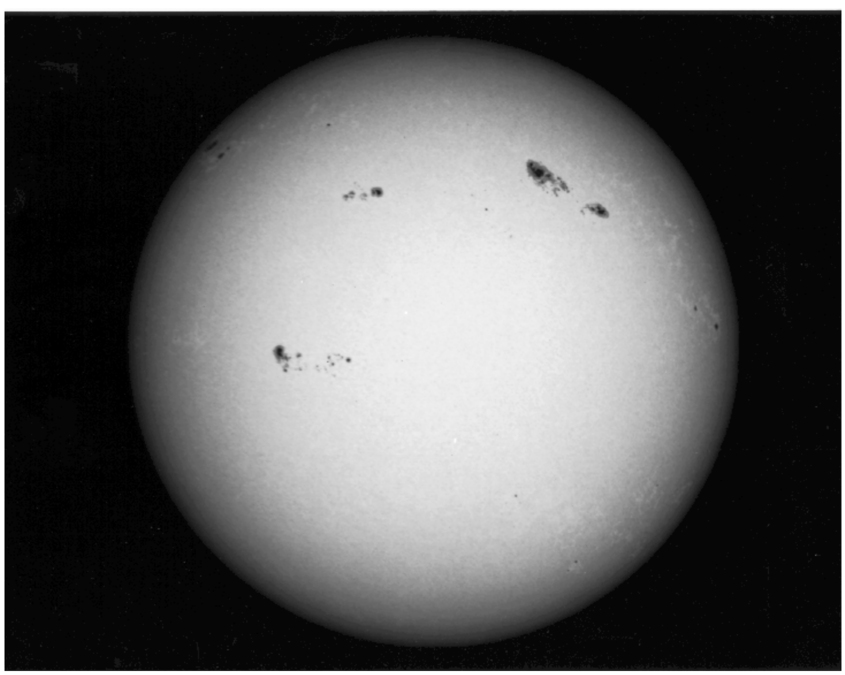
Chapter 1

Solar Physics and the IMAGE Mission

A Short History of Solar Physics

For centuries, the sun has been seen as a constant in the sky. Its risings and settings are dependable; its appearance seemingly unchanging; its reliability a given in the life of humans. More recently, however, scientists have determined that the sun is surprisingly variable and that this variability can have very real (and detrimental) effects on Earth.



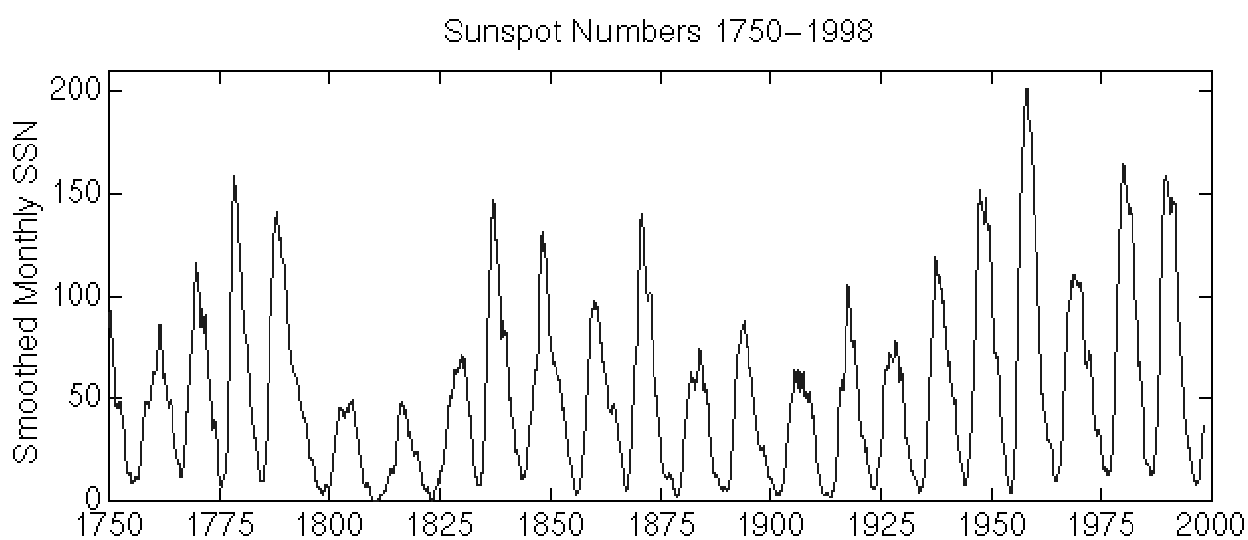
Sunspots were an early example of variability on the sun. Sunspots are regions of the sun that are cooler than the surrounding surface of the sun, and therefore appear darker than the surrounding area. More than 300 years ago, it was noticed that the number of sunspots appearing on the sun at any given time was not constant.

In 1843, Heinrich Schwabe, after 17 years of careful observation of sunspots, noticed a roughly 11-year cycle in the number of sunspots. The number of sunspots seemed to increase and then decrease over time so that the highest number of sunspots (solar maximum) occurred about 11 years apart with low numbers of sunspots (solar minimum) occurring in the intervening times.

When scientists checked earlier sunspot observations, they found that the 11-year cycle had in fact been going on for over 100 years (and, presumably, for much longer than that).

As careful observations have been continued since 1843, the 11-year cycle has been verified repeatedly. It should be noted that the sunspot cycle is not always exactly 11 years, but 11 years is an average value for the length of the cycle.

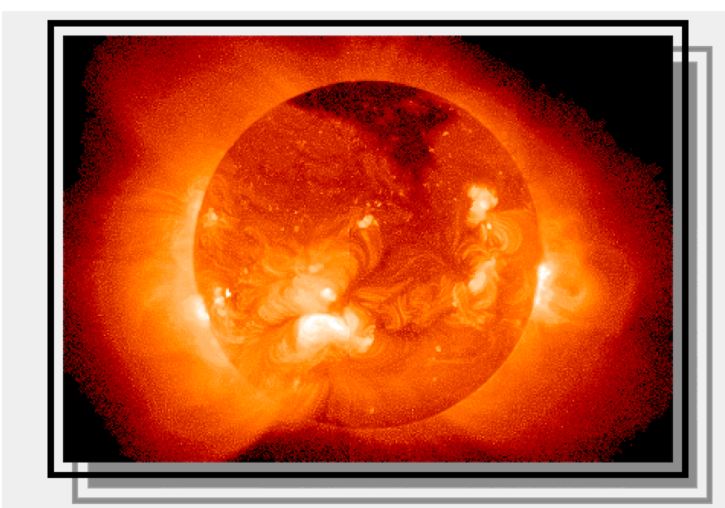
While the cyclic variability of sunspots was interesting to scientists, there was no obvious connection between the sunspot cycle and anything happening on Earth. In 1859, a connection would be observed for the first time.



While observing sunspots on September 1, 1859, Richard Carrington noticed a pronounced brightening of a region near the sunspots, which then faded in brightness back to that of the normal solar surface. Less than a day later the aurora showed a large increase in brightness. What Carrington had seen was a solar flare, which is an eruption of material from the solar surface. The ensuing increase in the aurora is called a magnetic storm. The connection between activity on the sun, as evidenced by sunspots and solar flares, and events on Earth has been investigated by scientists ever since. What Carrington saw was actually a very rare event. Typically, solar flares seldome produce any dramatic optical effects on the sun, nor do they produce aurora. But in time, a more common phenomenon was discovered.

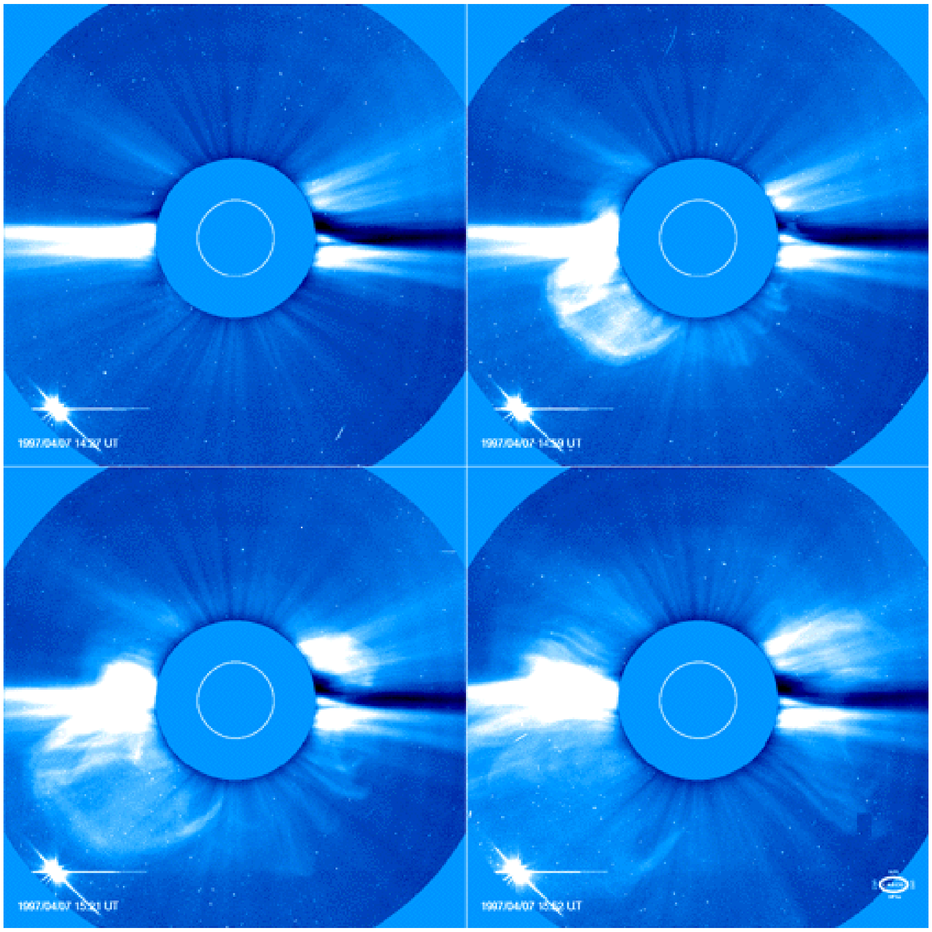
Towards the end of the 19th Century and during much of the 20th, astronomers recognized that aurora tended to be more common during sunspot maximum, and were especially linked to very large sunspot groups. Another connection between the sun and Earth that was postulated involved the “solar wind”. The solar wind is a stream of charged particles, called a plasma, flowing outward from the sun in all directions. This combination of positive ions and free electrons could not be detected directly until the early years of the space age. Particle detectors on some early spacecraft measured the composition and speed of the solar wind particles.

Since the solar wind consists of charged particles, the motion of these particles is affected by any magnetic fields they encounter. When these particles impact the Earth’s magnetic field, they cause disruptions in the field that accelerate already trapped plasmas to high energies. The arrival of these energetic particles in the upper atmosphere of the Earth is what results in the aurora. The auroras occur near the north- and south- magnetic poles because these energetic particles follow Earth’s magnetic field lines to those regions.



In 1973, a new phenomenon on the sun was observed from Skylab. This was a very large-scale eruption from the sun's upper atmosphere – the corona. Called coronal mass ejections, CMEs, these eruptions can release billions of tons of plasma at millions of kilometers per hour. It is thought that CMEs have the most effect on the Earth environment of any other forms of solar activity.

The IMAGE spacecraft is continuing the investigation of the connection between solar activity levels and the Earth. Scientists still do not know exactly how the magnetosphere responds, and how particles within its influence are accelerated to high energies. In order to understand what the IMAGE mission will study, we must first know something about the Earth and its magnetic field.



A Coronal Mass Ejection (CME) imaged by the NASA, SOHO satellite. The sun is represented by the dashed circle in the upper right of each frame. The images represent a time span of about two hours.

The Sunspot Cycle - A Series of Activities

(Teacher: The following activities can be done in sequence or separate activities can be selected.)

Materials needed:

Students:	Piece of notebook paper for tables plus:
Activities 1,2,3	Sunspot Number 1700 - 1996 (Table 1 and Table 2)
Activity 4	Graph paper
Activity 5	Sunspot Number 1611 - 1700 (Table 4)
Teacher:	
Activities 1,2,3	Transparency of Table 1
Activity 3	Transparency of Table 3 (Maxima and Minima ...)
Activity 4	Transparency of graph paper with scales indicated
Activity 5	Transparency of Table 4; Transparency of "Graph of Sunspot Numbers"

Activity 1

Distribute a copy of the Sunspot Number Data to each student or pair of students.

Instructions for students:

1. Start at the top of any column in Table 1 or the first column (1851) in Table 2 of the Data Table.
(Teacher: Make sure some students (or groups) start at the top of each column.)

2. Scan down the column until you find the first maximum number of sunspots. You can recognize a maximum because after the maximum, the number of sunspots becomes smaller. Circle the first maximum.

(Teacher: use the transparency of Table 1 to demonstrate this step. Use the column headed 1791 as your example. In this column, two potential difficulties are illustrated. First, the number at the top is a high number and the following numbers become smaller. The first number in this column is NOT a maximum as can be seen by looking at the bottom of the preceding column. In searching farther down for the first maximum, the second problem with the data appears. The sunspot number for 1802 (45) is followed by a smaller number the next year (43) which is then followed by a larger number in 1804 (48). 1804 is the first maximum in this column. It should be pointed out that while the sunspot number changes from high to lower to high in two years, this does not represent more than one sunspot cycle! The sunspot numbers for 1802-03-04 should be viewed as staying fairly constant with the 1804 value representing the maximum. This is NOT the only place in the data where the steady increase followed by steady decrease is not the rule, and if you do not point out this problem with the data, the results of the activity will not be satisfactory. A third problem that will arise is when the sunspot number is the same for 2 (or more) years and it is a maximum value: Which year is the maximum? Here you can point out that since we are finding the average value, it does not matter much which year you choose since the average value of the adjacent cycles will not be affected. Or you can just use a rule such as "Choose the first value if there is a repeated value.")

3. Continue down the column circling each maximum as you come to it. Continue until you have circled ten more maxima. (Total of 11 maxima circled.)

4. Count the number of years from one maximum to the next and record in a column headed

Cycle Length
Max to Max
(Years)

5. Find the average number of years between maxima. This is the length of the sunspot cycle.
(Teacher: Notice that students are finding the average value of 10 numbers, so calculators should be unnecessary. There will be some variation in this average, but all results should round off to 11.)

Questions to consider:

1. Is the cycle length the same each time?
2. What is the longest cycle length found?
3. What is the shortest cycle length found?
3. Do the average cycle lengths have anything in common?
4. The last sunspot maximum occurred in 1989. When would we expect the next solar maximum? Are we sure it will happen exactly then?

Activity 2

Instructions to students:

1. Using the same Data Table, starting in the same column as Activity 1, and beginning at your first circled maximum, scan down the column and draw a box around each minimum number of sunspots.
(Teacher: If colored pencils are available, different colors could be used to identify maxima and minima.)

2. Continue this until you have boxed the minimum after the last maximum circled in Activity 1. A total of 11 minima will be boxed.

3. Count the number of years between sunspot minima and record in a table column headed:

Cycle Length
Min to Min
(Years)

4. Find the average number of years between minima. This is another way to determine the length of the sunspot cycle.

Questions to consider:

1. Is the cycle length the same each time?
2. What is the longest cycle length found?
3. What is the shortest cycle length found?
3. Do the average cycle lengths have anything in common?

Activity 3

1. Using the same Data Table and starting in the same column, count the number of years between the first maximum and the following minimum. Record this in a table headed

Fall to Minimum
(Years)

2. Move to the next maximum and continue this process until the column has 10 entries.

3. Find the average number of years for the sunspot number to fall to the minimum.

4. Count the number of years between each minimum and the next maximum. Record this data in a column headed:

Rise to Maximum
(Years)

5. Move to the next minimum and continue this process until the column has 10 entries.

6. Find the average number of years for the sunspot number to rise to maximum.

Questions to consider:

1. What is the range of values in the "Fall to Minimum" column?
2. What is the average value for the "Fall to Minimum"?
3. What is the range of values in the "Rise to Maximum" column?
4. What is the average value for the "Rise to Maximum"?
5. Are the rise times and fall times the same?

(Teacher: Rise times average 4.8 years, Fall times average 6.2 years. It is important that students see these times as different. Display a transparency of the Table 3"MINIMA AND MAXIMA ..." .)

Activity 4

1. Use the graph paper provided (Page 13). Notice that the highest sunspot number available on the graph paper is 120. If a higher sunspot number is encountered in the data, the point can be positioned above the grid with the value written next to the point.

2. Plot the yearly sunspot number for each year in the range you have been assigned. Be sure to label the years on the horizontal axis.
(Teacher: Each student can be assigned a range of years starting from a given year. Ranges for each student can be 30 years, 50 years, or 100 years.)

3. Connect the points on your graph.

4. Get together with other students who have used different years and tape the graphs together on the front board.

Questions to consider:

1. Is the Solar Cycle easy to see when looking at the graph?
2. Is the spacing between the maxima exactly constant on the graph?
   Did you expect it to be?
3. Is it true to say that the Solar Cycle is exactly 11 years long?

Activity 5

(Teacher: Distribute a copy of Table 4 Sunspot Number 1611 - 1700 to each group.)

Questions to consider:

1. What is the most common sunspot number that appears on this table?
2. During how many years (of the 90 years shown) is the sunspot number zero?
3. The sunspot number is missing for how many years?
4. Why do you suppose the numbers are missing for these years?

(Teacher: Display a transparency of the sunspot graph.)

5. What is the period from about 1640 to 1700 called? Why is it called this?

Table 1. Sunspot Number from 1700 - 1850

Year N	Year N	Year N	Year N	Year N
1700... 5				
1701...11	1731...35	1761...86	1791...67	1821...7
1702...16	1732...11	1762...61	1792...60	1822...4
1703...23	1733...5	1763...45	1793...47	1823...2
1704...36	1734...16	1764...36	1794...41	1824...9
1705...58	1735...34	1765...21	1795...21	1825...17
1706...29	1736...70	1766...11	1796...16	1826...36
1707...20	1737...81	1767...37	1797...6	1827...50
1708...10	1738...111	1768...70	1798...4	1828...64
1709... 8	1739...101	1769...106	1799...7	1829...67
1710... 3	1740...73	1770...101	1800...14	1830...71
1711... 0	1741...40	1771...82	1801...34	1831...48
1712... 0	1742...20	1772...67	1802...45	1832...28
1713... 2	1743...16	1773...35	1803...43	1833...9
1714...11	1744... 5	1774... 31	1804...48	1834...13
1715...27	1745...11	1775... 7	1805...42	1835...57
1716...47	1746...22	1776...20	1806...28	1836...121
1717...63	1747...40	1777...93	1807...10	1837...138
1718...60	1748...60	1778...154	1808...8	1838...103
1719...39	1749...81	1779...126	1809...3	1839...86
1720...28	1750...83	1780...85	1810...0	1840...65
1721...26	1751...48	1781...68	1811...1	1841...37
1722...22	1752...48	1782...38	1812...5	1842...24
1723...11	1753...31	1783...23	1813...12	1843...11
1724...21	1754...12	1784...10	1814...14	1844...15
1725...40	1755...10	1785...24	1815...35	1845...40
1726...78	1756...10	1786...83	1816...46	1846...61
1727...122	1757...32	1787...132	1817...41	1847...98
1728...103	1758...48	1788...131	1818...30	1848...125
1729...73	1759...54	1789...118	1819...24	1849...96
1730...47	1760...63	1790...90	1820...16	1850...67

Table 2. Sunspot Number from 1851 - 1996

Year N	Year N	Year N	Year N	Year N
1851...64	1881...54	1911...6	1941...47	1971...67
1852...54	1882...60	1912...4	1942...31	1972...69
1853...39	1883...64	1913...1	1943...16	1973...38
1854...20	1884...64	1914...10	1944...10	1974...34
1855...7	1885...52	1915...47	1945...33	1975...16
1856...4	1886...25	1916...57	1946...93	1976...13
1857...22	1887...13	1917...104	1947...152	1977...27
1858...59	1888...7	1918...81	1948...136	1978...92
1859...94	1889...6	1919...64	1949...135	1979...155
1860...96	1890...7	1920...38	1950...84	1980...154
1861...77	1891...36	1921...26	1951...69	1981...140
1862...59	1892...73	1922...14	1952...31	1982...116
1863...44	1893...85	1923...6	1953...14	1983...67
1864...47	1894...78	1924...17	1954...4	1984...46
1865...31	1895...64	1925...44	1955...38	1985...18
1866...16	1896...42	1926...64	1956...142	1986...14
1867...7	1897...26	1927...69	1957...190	1987...32
1868...38	1898...27	1928...78	1958...185	1988...98
1869...74	1899...12	1929...65	1959...159	1989...154
1870...139	1900...9	1930...36	1960...112	1990...146
1871...111	1901...3	1931...21	1961...54	1991...144
1872...102	1902...5	1932...11	1962...38	1992...94
1873...66	1903...24	1933...6	1963...28	1993...56
1874...45	1904...42	1934...9	1964...10	1994...30
1875...17	1905...63	1935...36	1965...15	1995...17
1876...11	1906...54	1936...80	1966...47	1996...9
1877...12	1907...62	1937...114	1967...94	
1878... 3	1908...48	1938...110	1968...106	
1879... 6	1909...44	1939...89	1969...106	
1880...32	1910...19	1940...68	1970...104	

Table 3. MINIMA AND MAXIMA OF SUNSPOT NUMBER CYCLES

Sunspot Cycle Number	Year of Min*	Smallest Smoothed Monthly Mean**	Year of Max*	Largest Smoothed Monthly Mean**	Rise to Max (Yrs)	Fall to Min (Yrs)	Cycle Length (Yrs)
-	1610.8	--	1615.5	--	4.7	3.5	8.2
-	1619.0	--	1626.0	--	7.0	8.0	15.0
-	1634.0	--	1639.5	--	5.5	5.5	11.0
-	1645.0	--	1649.0	--	4.0	6.0	10.0
-	1655.0	--	1660.0	--	5.0	6.0	11.0
-	1666.0	--	1675.0	--	9.0	4.5	13.5
-	1679.5	--	1685.0	--	5.5	4.5	10.0
-	1689.5	--	1693.0	--	3.5	5.0	8.5
-	1698.0	--	1705.5	--	7.5	6.5	14.0
-	1712.0	--	1718.2	--	6.2	5.3	11.5
-	1723.5	--	1727.5	--	4.0	6.5	10.5
-	1734.0	--	1738.7	--	4.7	6.3	11.0
-	1745.0	--	1750.3	92.6	5.3	4.9	10.2
1	1755.2	8.4	1761.5	86.5	6.3	5.0	11.3
2	1766.5	11.2	1769.7	115.8	3.2	5.8	9.0
3	1775.5	7.2	1778.4	158.5	2.9	6.3	9.2
4	1784.7	9.5	1788.1	141.2	3.4	10.2	13.6
5	1798.3	3.2	1805.2	49.2	6.9	5.4	12.3
6	1810.6	0.0	1816.4	48.7	5.8	6.9	12.7
7	1823.3	0.1	1829.9	71.7	6.6	4.0	10.6
8	1833.9	7.3	1837.2	146.9	3.3	6.3	9.6
9	1843.5	10.5	1848.1	131.6	4.6	7.9	12.5
10	1856.0	3.2	1860.1	97.9	4.1	7.1	11.2
11	1867.2	5.2	1870.6	140.5	3.4	8.3	11.7
12	1878.9	2.2	1883.9	74.6	5.0	5.7	10.7
13	1889.6	5.0	1894.1	87.9	4.5	7.6	12.1
14	1901.7	2.6	1907.0	64.2	5.3	6.6	11.9
15	1913.6	1.5	1917.6	105.4	4.0	6.0	10.0
16	1923.6	5.6	1928.4	78.1	4.8	5.4	10.2
17	1933.8	3.4	1937.4	119.2	3.6	6.8	10.4
18	1944.2	7.7	1947.5	151.8	3.3	6.8	10.1
19	1954.3	3.4	1957.9	201.3	3.6	7.0	10.6
20	1964.9	9.6	1968.9	110.6	4.0	7.6	11.6
21	1976.5	12.2	1979.9	164.5	3.4	6.9	10.3
22	1986.8	12.3	1989.6	158.5	2.8		
Mean Cycle Values:		6.0		112.9	4.8	6.2	11.1

Notes to Table 3:

*When observations permit, a date selected as either a cycle minimum or maximum is based in part on an average of the times extremes are reached in the monthly mean sunspot number, in the smoothed monthly mean sunspot number, and in the monthly mean number of spot groups alone. Two more measures are used at time of sunspot minimum: the number of spotless days and the frequency of occurrence of "old" and "new" cycle spot groups.

**The smoothed monthly mean sunspot number is defined here as the arithmetic average of two sequential 12-month running means of monthly mean numbers.

For additional information, visit the National Geophysical Data Center at:

ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/maxmin

Table 4: Sunspot Number from 1611 - 1700

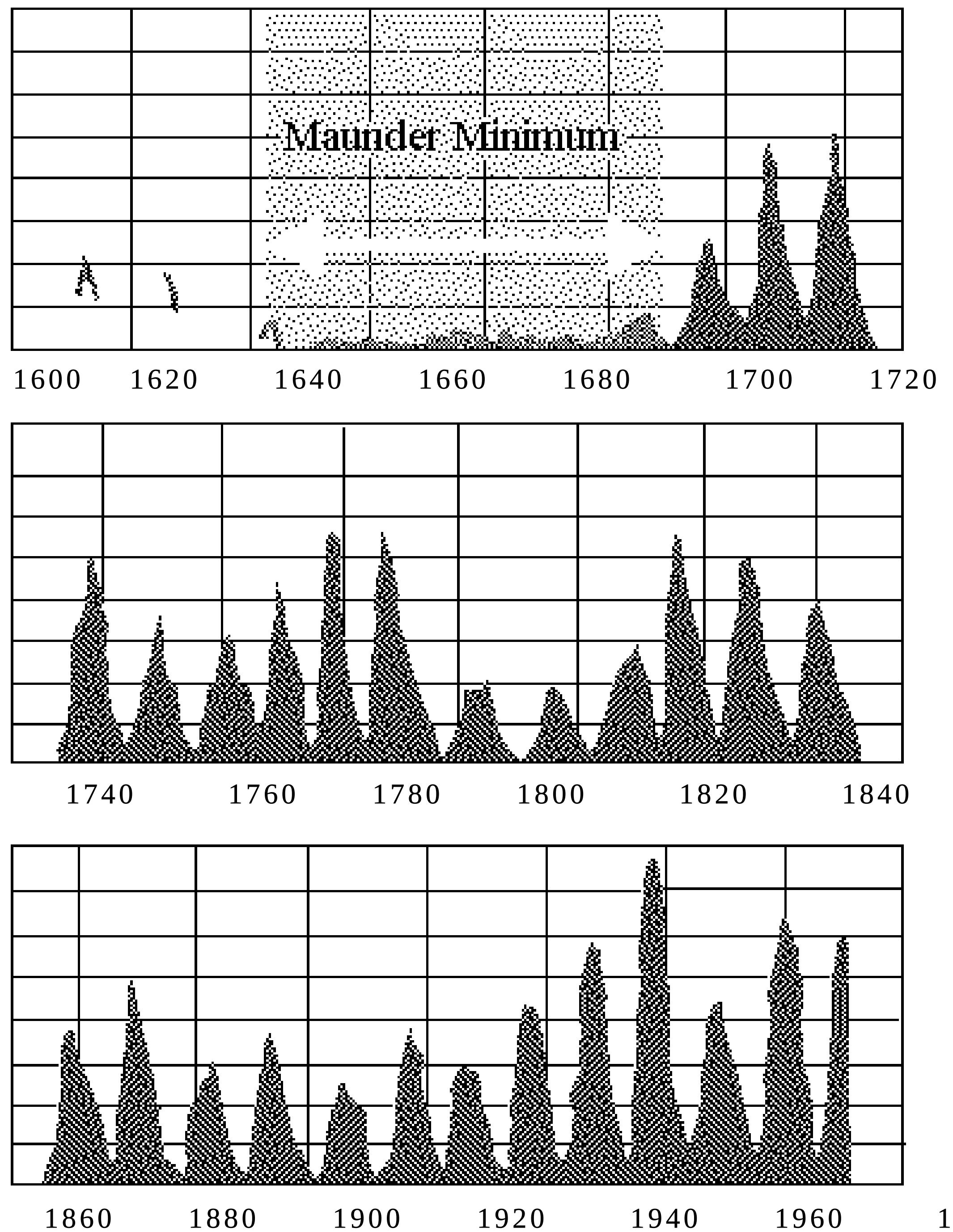
Year	N	Year	N	Year	N
1611	30	1641		1671	6
1612	53	1642	6	1672	4
1613	28	1643	16	1673	0
1614		1644	15	1674	2
1615		1645	0	1675	0
1616		1646		1676	10
1617		1647		1677	2
1618		1648		1678	6
1619		1649		1679	0
1620		1650	0	1680	4
1621		1651	0	1681	2
1622		1652	3	1682	0
1623		1653	0	1683	0
1624		1654	2	1684	11
1625	41	1655	1	1685	0
1626	40	1656	2	1686	4
1627	22	1657	0	1687	0
1628		1658	0	1688	5
1629		1659	0	1689	4
1630		1660	4	1690	0
1631		1661	4	1691	0
1632		1663	0	1692	0
1633		1663	0	1693	0
1634		1664	0	1694	0
1635		1665	0	1695	0
1636		1666	0	1696	0
1637		1667	0	1697	0
1638		1668	0	1698	0
1639		1669	0	1699	0
1640		1670	0	1700	2

NOTE: Sunspot numbers were not determined in the same way for this table as for the previous table. The actual sunspot number, when it is greater than zero, during this time would probably have been higher if the same rule for determining sunspot number had been used. When the sunspot number is zero, it would probably be that regardless of the rule used for calculating it.

Additional information can also be found online at:

ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/

Graph of Sunspot Numbers



Chapter 2

Earth's Magnetosphere and the IMAGE Mission

For hundreds of years, sailors have relied on magnetic compasses to navigate the oceans. These sailors knew that the Earth's magnetic north pole was not in the same place as the geographic North Pole, and they were able to make the necessary corrections to be able to determine where they were (and, more important, how to get home!). In modern times, we have found that the magnetic North Pole does not even stay in the same place, but moves around a significant amount. Small corrections are needed in order to use the magnetic pole for navigation purposes.

The Earth has a magnetic field that has a shape similar to that of a large bar magnet (Figure 1). To the north is the magnetic north pole, which is really the south pole of the Earth's bar magnet. (It has to be this way since this pole attracts the north pole of the compass magnet!) The sun also has a magnetic field that is more complicated than, but similar to, that of the Earth. The sun, through its solar wind, has a large impact on the shape of Earth's magnetic field.

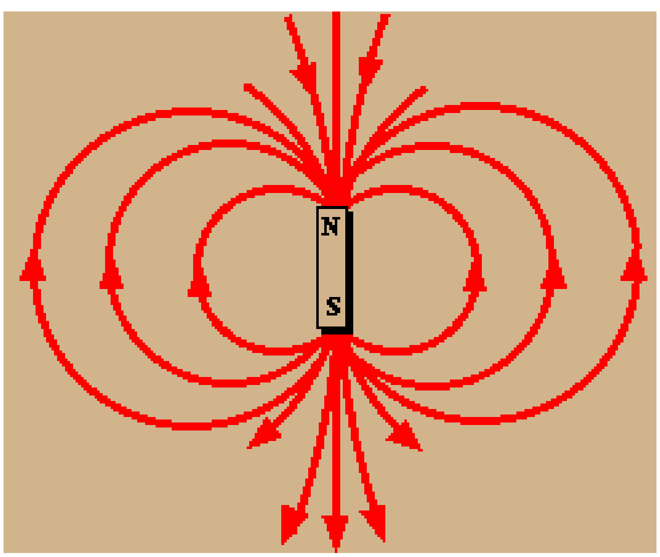


Figure 1. The Magnetic field of a bar magnet. Notice the symmetry and direction of the field lines. Remember, the magnetic North Pole is not located in the same place as the geographic North Pole.

As the solar wind flows outward from the sun and encounters Earth's magnetic field, it pushes the Earth's field in on the side toward the sun and stretches it out on the side away from the sun. The result is a magnetic field shape that is not symmetric in the same way as the field of a bar magnet.

The region around Earth where Earth's magnetic field is the predominate field is called the **magnetosphere** (Figure 2). Outside this region, in the region called **the Interplanetary Magnetic Field (IMF)**, the solar magnetic field is strongest. The boundary line between the magnetosphere and the IMF is called the **magnetopause**. The part of the magnetosphere that extends from Earth away from the sun is called the **magnetotail**.

On the sun side, the magnetosphere extends to a distance of about 10 Earth radii (10 **Re**) under normal solar conditions. On the side away from the sun, the magnetosphere is stretched by the solar wind so it extends a great distance. (For comparison, the moon orbits at a distance of about 60 Re .)

Conditions on the sun, and the related solar wind, are not constant over time. When the sun is at the active stage of the 11-year solar cycle, solar flares and CMEs are more common. This increased activity can result in large-scale disturbances of the magnetosphere called magnetic storms. The most common effect of a magnetic storm is an increase in the **aurora borealis**, or Northern Lights. In the Southern Hemisphere, they are called the Aurora Australis or the 'Southern Lights'.

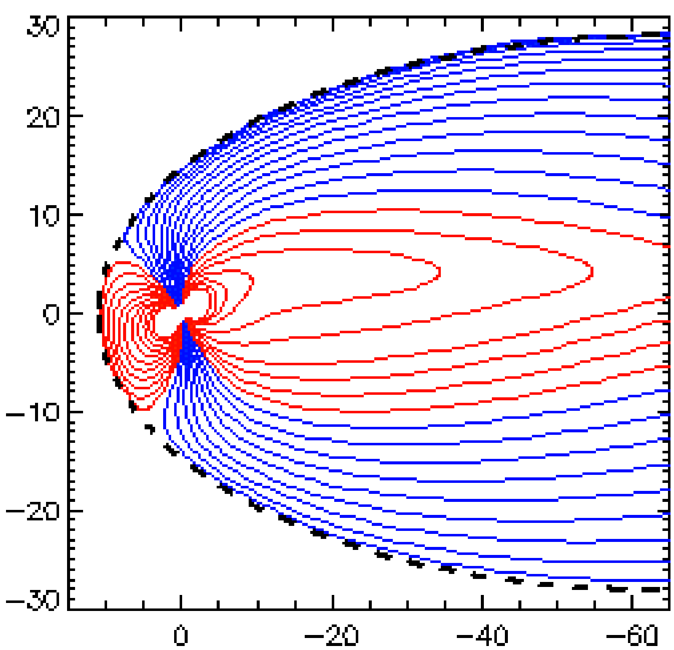


Figure 2. Earth's magnetosphere. The sun is located far to the left at a distance of 22,900 **Re.** Earth is located at (0,0). The dashed line is the magnetopause. The unit of distance in the diagram is the Earth radius (Re).

Other effects are also observed and some of them are dangerous and can cause serious damage. These effects include:

1. Induced currents in power company transformers that can cause overload conditions and damage equipment. It is thought that a magnetic storm that resulted from a CME caused the blackout in the northeastern United States and eastern Canada in 1989.
2. Induced currents in pipelines can cause in increase in corrosion and leads to leaks and breaks. The Alaskan oil pipeline was designed to minimize this effect.
3. Astronauts in space can be exposed to dangerous levels of charged particles. For this reason, extra-vehicular activities on the space shuttle would be curtailed if a solar storm were predicted or observed.
4. Heating of the atmosphere by solar particles causes the atmosphere to expand slowing low orbit satellites and causing them to descend. This is the process that, over time, is thought to have caused the decay of the orbit of Skylab in the 1970's.
5. Satellites in high orbits are subjected to energetic charged particles that can cause damage to electronic components. Failure of some communication satellites, which are in geosynchronous orbits, has been attributed to the impact of severe solar storms..
6. Radio communications can be disrupted because of changes in the ionosphere caused by solar flares.

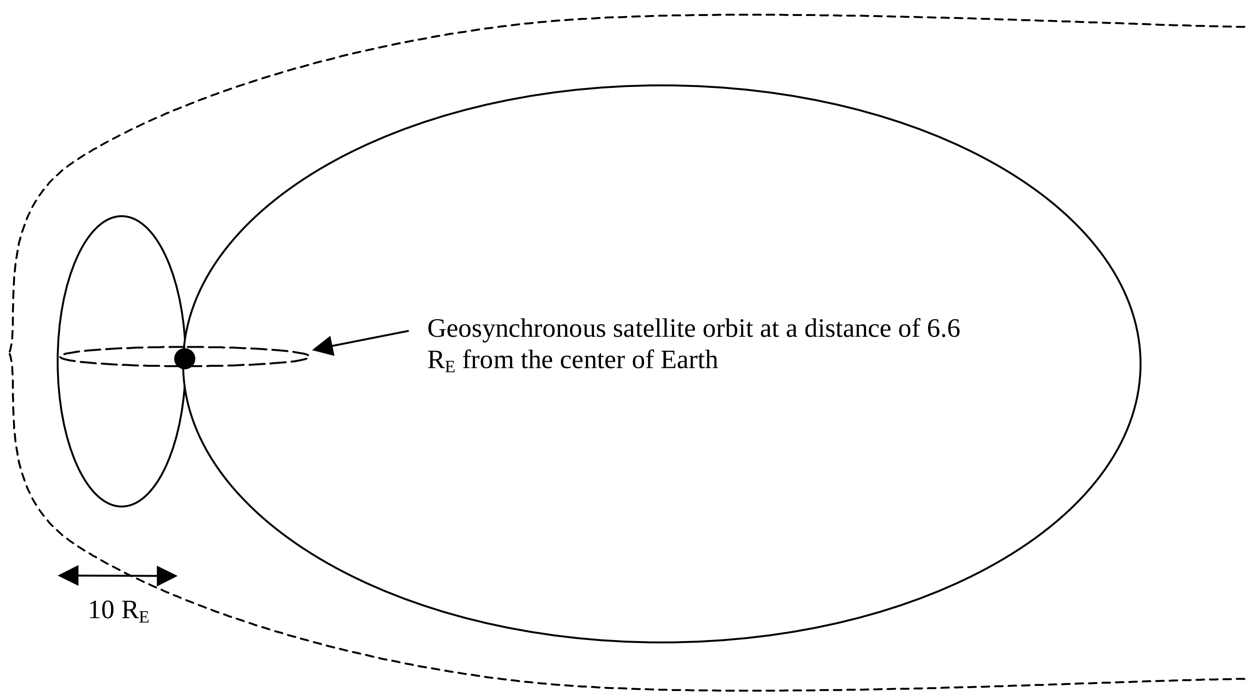


Figure 3. The magnetosphere under quiet solar conditions.
The dashed line is the magnetopause.

The two main effects on the magnetosphere of magnetic storms are:

1. The magnetopause in the sunward direction is pushed in from its normal distance of 10 Re .
2. The magnetotail is pinched inward.

The added pressure on the sunward side increases the number of particles that are forced into the magnetosphere. During severe solar storms, this boundary can pass inside the orbits of geosynchronous satellites and subject them to the direct effects of the solar storm. In the magnetotail, charged particles are following the magnetic field lines down the tail away from Earth. When the magnetotail gets pinched in, a phenomenon called **magnetic reconnection** can occur. This happens when magnetic field lines within the magnetotail are forced together in such a way that they try to cross (which is not allowed for magnetic field lines) and, instead, reconnect forming a shorter, closed magnetic field line in place of the extremely long field lines extending down the magnetotail. Figures 4, 5 and 6 show the reconnection process.

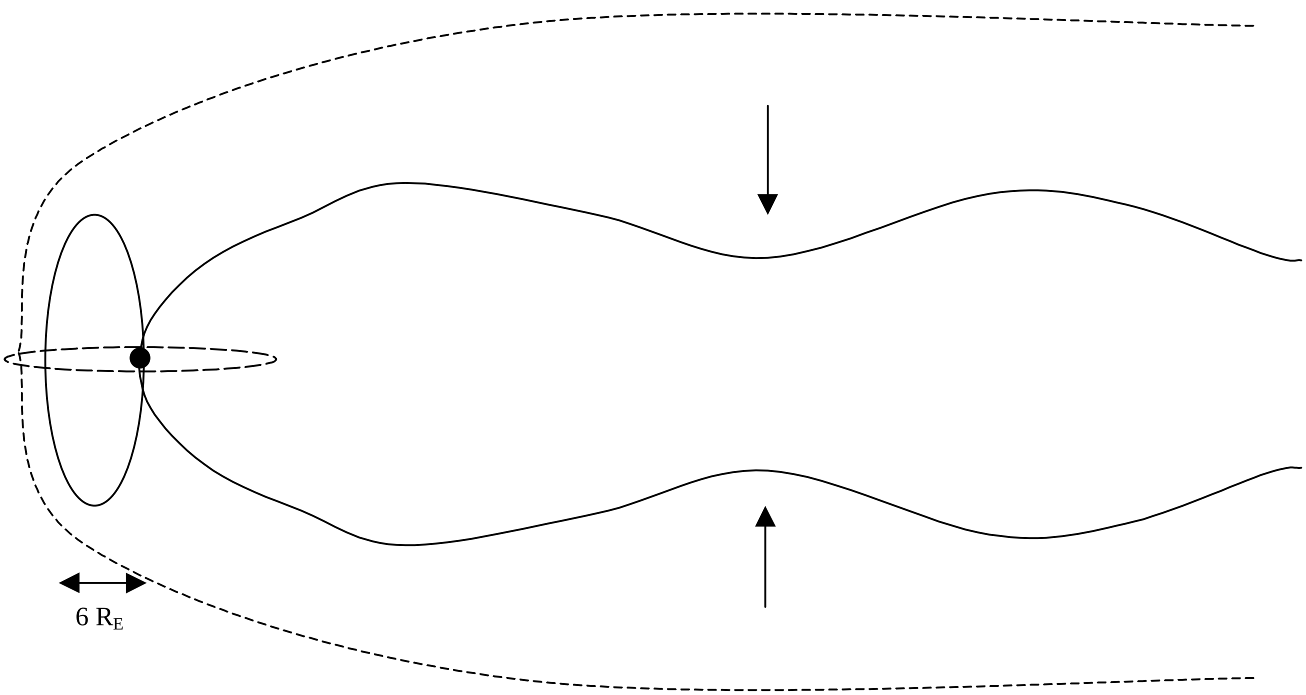


Figure 4. The magnetosphere under active solar conditions after a CME. The sunward magnetopause has been pushed in to 6 Re and the magnetotail has been pinched in (arrows). Note that the geosynchronous orbit now extends outside of the magnetopause.

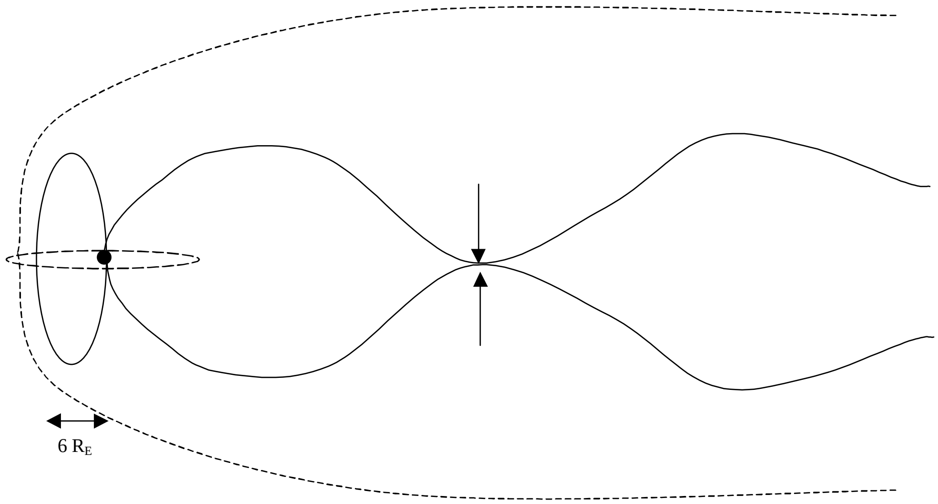


Figure 5. The arrows indicate the point of magnetic reconnection.

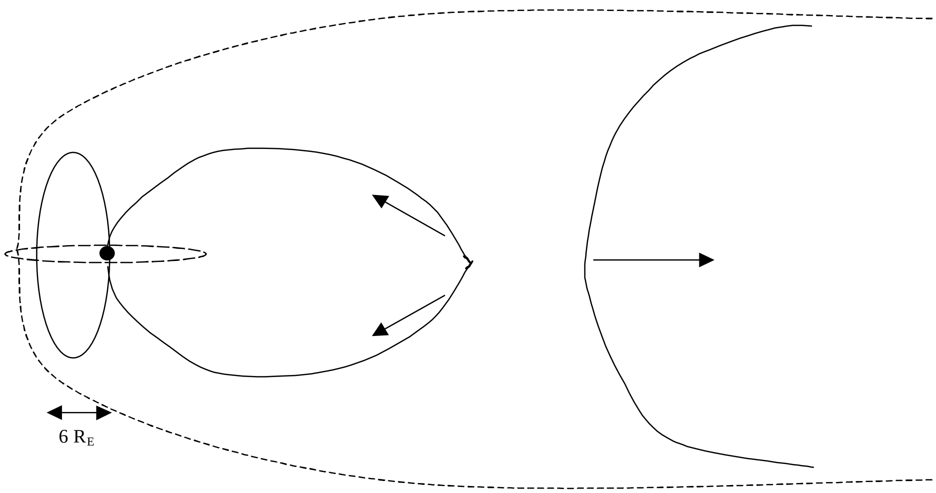


Figure 6. The magnetic field lines just after reconnection. The arrows indicate the direction of movement of the magnetic field lines which carry with them all of the charged particles moving along them at the time of reconnection.

The process of reconnection results in large numbers of particles moving with high energy both toward and away from Earth. It is thought that the process that carries particles away from Earth is similar to, but on a smaller scale than, the process on the sun that results in a CME. Of interest here, though, are the particles that are brought back toward Earth as the reconnected field line rebounds into position nearer Earth. Some of these charged particles find an easy path north and south into the auroral zones and some of them are captured near the Earth and held there by magnetic field lines forming the radiation belts. As these particles move along magnetic field lines north and south, they rebound back along the field line from the polar regions. As they bounce back and forth, the charges migrate slowly around the Earth in the region from about 2 Re to about 7 Re. This movement of charge is known as the **ring current**.

IMAGE will measure the location of the magnetopause, the brightness and location of the aurora and the composition, energy and location of the ring current.

The Magnetosphere

Objective:

Students will sketch the shape of the Earth's magnetosphere using a set of templates as a guide.

Using the templates:

1. Make copies of the two templates on heavy paper or card stock (1 set per student).
2. On each template, the center (gray) circle represents the Earth. Concentric circles are each 1 Earth Radius (1 Re) larger in radius than the preceding circle.
3. To use the template, place it under the paper so that the circles can be seen through the paper. The circles at radius equals 5 Re and 10 Re from the center of the Earth are solid lines to make them easier to see.

Activity 1. The size and shape of "normal" magnetosphere

1. Use Template #1 and orient the paper with the long dimension vertical.
2. At the far left of the page label the "SUN" and indicate with arrows the direction of the light from the sun and the solar wind – from left to right.
3. Move the template so that the Earth is centered between the top and bottom of the page and about 10 centimeters from the left edge of the page.
4. Trace the Earth from the center of the template and shade it in.
5. Directly to the left of the Earth (toward the sun) place a mark at 10 Re.
6. Directly above and below the Earth, place marks at 15 Re. Notice that the template only goes to 11 Re, so you will have to estimate this location.
7. Draw a smooth parabolic shape connecting the first mark (vertex) with the top mark and extend the shape off the page to the right. Do the same with the first mark and the bottom mark.
8. Label this shape: "Magnetopause"

Under normal conditions of solar wind, the magnetopause is located at about 10 Re from the Earth towards the sun. The magnetotail extends a large distance (many 10s of Re) in the direction away from the sun.

Activity 2. The "disturbed" magnetosphere

1. Use Template #2 and orient the paper with the long dimension vertical.
2. At the far left of the page label the "SUN" and indicate with arrows the direction of the light from the sun and the solar wind – from left to right.
3. For this activity, two diagrams will be drawn on the page. The first will be on the top half of

the page; the second will be on the bottom half.

4. On the top half, place the template with the Earth about 6 centimeters from the left edge of the page. Draw the "normal" magnetosphere as in Activity 1. Label this diagram "Normal Magnetosphere".
5. On the bottom half, place the template so that the Earth lines up directly under the first diagram. From the Earth, count out 7 Re to the left and place a mark.
6. Directly above and below, place marks at 10 Re.
7. Draw a smooth shape to represent the magnetopause. Label this diagram "Disturbed Magnetosphere"

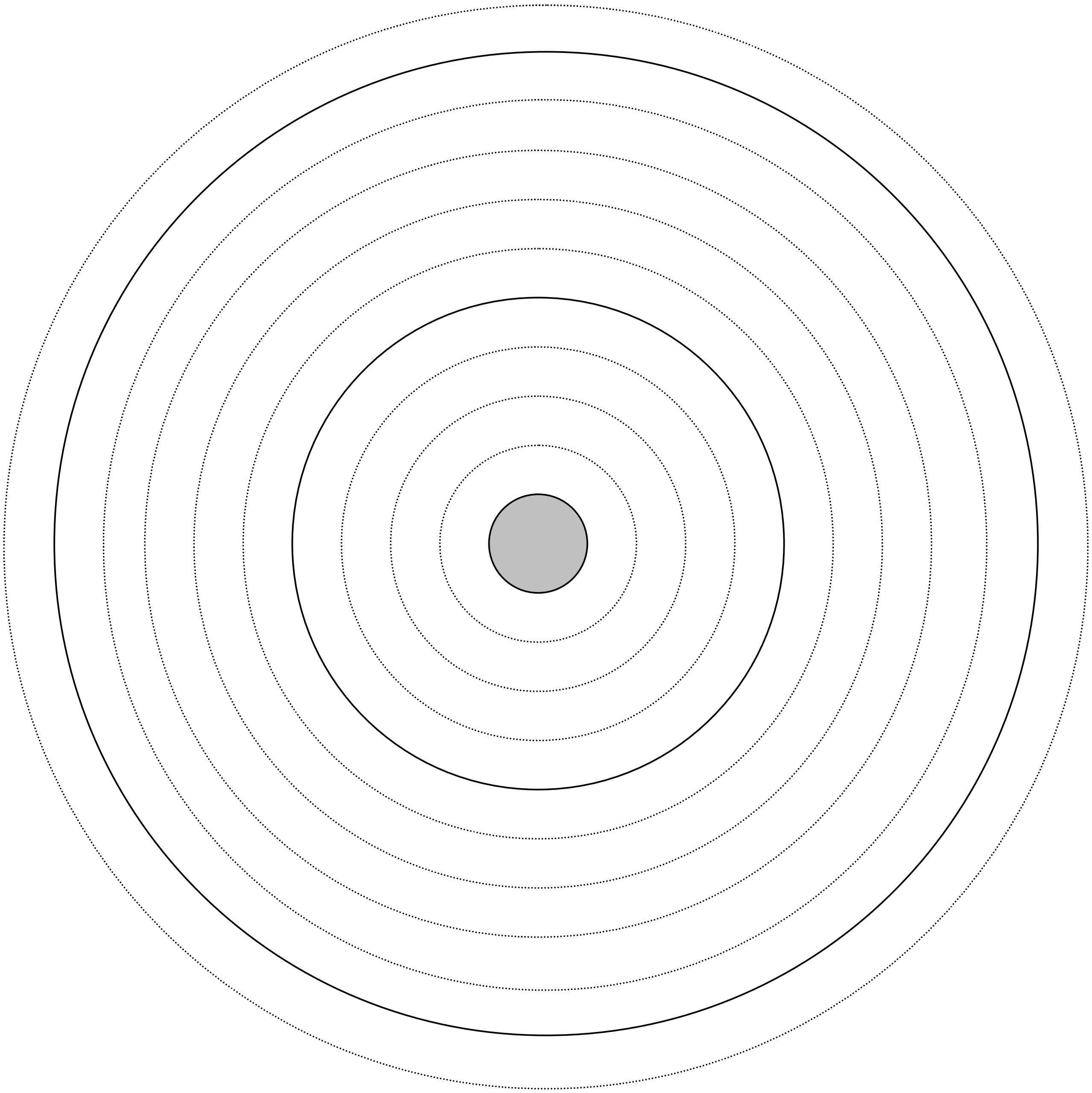
"Disturbed" conditions occur with the arrival of the increased solar wind levels as the result of a coronal mass ejection (CME). The effect of this magnetic storm is to push the magnetopause in toward the Earth from the sunward direction (from 10 Re to 7 Re or even less). The magnetosphere is also compressed inward toward Earth above and below and the magnetotail is also constricted.

Activity 3. The magnetotail

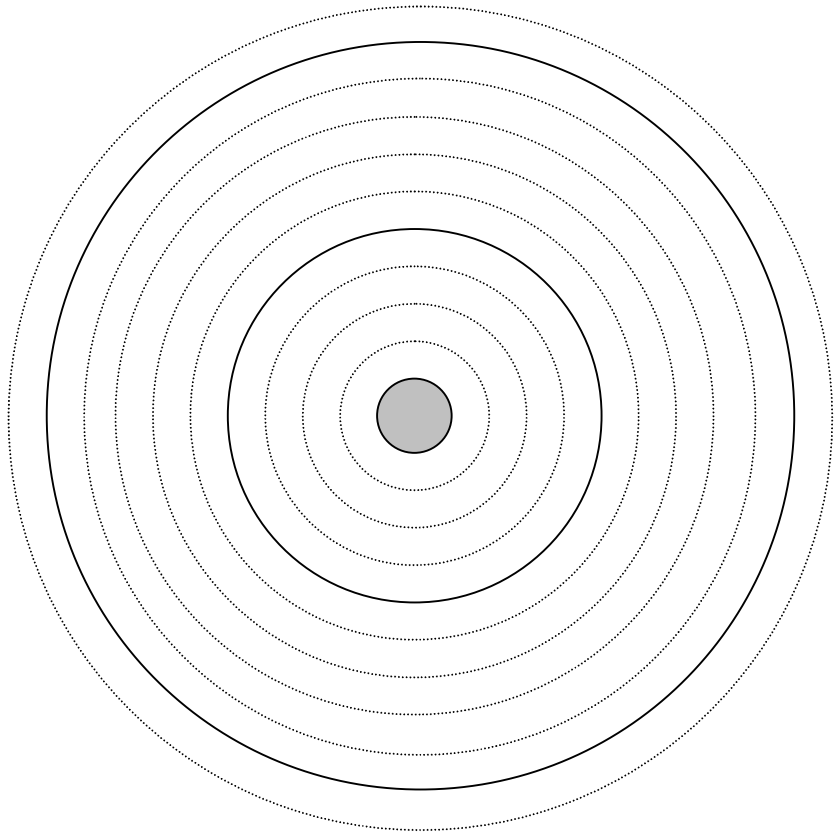
1. Use Template #2 and orient the paper with the long dimension horizontal.
2. At the far left of the page label the "SUN" and indicate with arrows the direction of the light from the sun and the solar wind – from left to right.
3. For this activity, two diagrams will be drawn on the page. The first will be on the top half of the page; the second will be on the bottom half.
4. On the top half, place the template with the Earth about 6 centimeters from the left edge of the page. Locate the sunward magnetopause (10 Re) and the positions above and below Earth (15 Re) as in Activity 1. When you draw in the magnetopause and extend the shape to the right, allow the lines to extend all the way across the page without getting very close together. This is the magnetotail. The magnetotail extends in the direction away from the sun for a very large distance (tens of Re).
5. On the bottom half, place the template so that the Earth lines up directly under the first diagram. From the Earth, count out 7 RE to the left and place a mark. Above and below the Earth, place marks at 10 RE. Draw in the magnetopause, but when you extend the magnetopause to the right draw the shape so that there is a pronounced narrowing of the magnetotail as the magnetopause boundaries extend off the page.

It is in this area of constriction of the magnetotail that reconnection occurs under solar storm conditions. When reconnection occurs, particles that are following magnetic field lines in the tailward direction can be rerouted back toward Earth. These particles, which under normal conditions would be lost into the magnetotail, return toward Earth where they contribute to the aurora and provide charged particles for the ring current and other structures in the plasmasphere. The IMAGE satellite will attempt to determine the exact paths and timing of the movement of these charges in magnetic storm conditions.

Template #1: 10 Re = 15 cm.



Template #2: 10 Re = 10



The Wandering Magnetic Pole

Purpose:

To investigate the nature of the magnetic North Pole, a position that is often thought of as constant but, in fact, moves significantly over the years.

Objective:

To develop perceptual abilities using polar coordinates, a frame of reference new to many students.

Procedure:

- Make transparencies of any desired materials from the student activity pages.
- Copy and distribute the student activity pages.
- Introduce the material in a manner suited to the class level:
  1 Ninth grade students may need some introduction to some (or each) separate activity.
  2 Twelfth grade students should be able to work all activities with no intervention by the teacher.
- Go over some (or all) of the responses using a transparency key done by the teacher. Discuss the precision available in the data and maps in light of the variations in responses from students that may be considered equivalent. (For example, estimates of precision are given for each activity here:

  Activity 4: Latitude: $\pm .2^{o}$ Longitude: $\pm 5^{o}$

  Activity 5: Distance: ± 10 kilometers

  Activity 6: Location of pole is a function of the precision of each of the three quantities listed above. If the pole position is in the correct grid space, that is probably good enough.

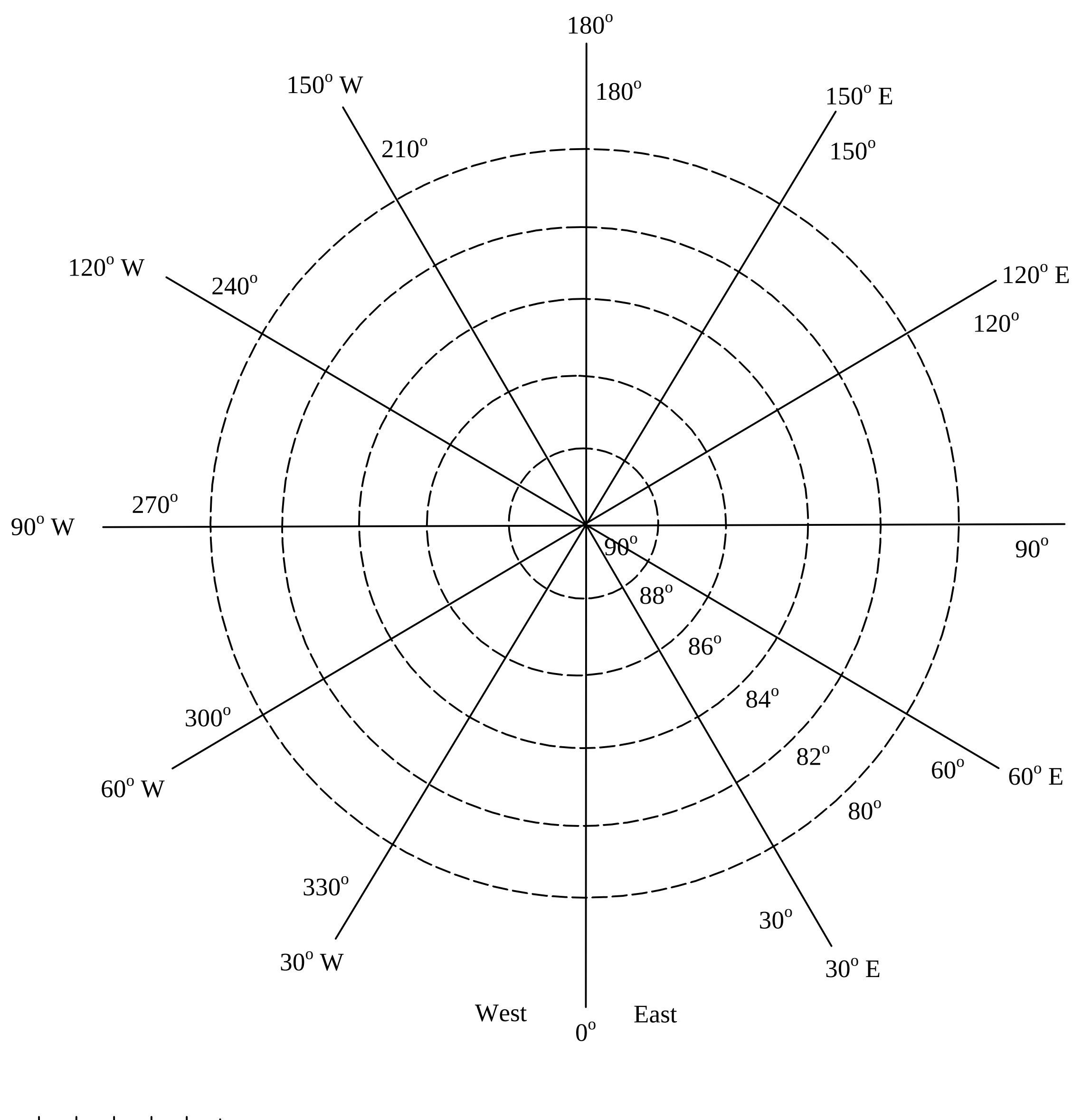
Extension and homework assignments:

Blank map grids are provided for the teacher to create custom assignments similar to activities 4 and 5.

Activity 6 can be used as a homework assignment by selecting a different pair of dates (for example 1500 – 1600) and having the students answer questions 1 to 4 from Activity 6.

Shown below is a view of the Earth with the geographic North Pole at the center. Latitude is shown as concentric circles with the North Pole having a latitude of 90^o. Notice that this map shows only the region very near the North Pole. Longitude is measured in degrees measured from the Prime Meridian (0^o which passes through Greenwich, England. Longitude can be given in degrees east or west of the Prime Meridian or in degrees measured counterclockwise (east) from the Prime Meridian. In these activities we will use degrees measured counterclockwise from the Prime Meridian, so longitude can have a value of from 0^o to 360^o.

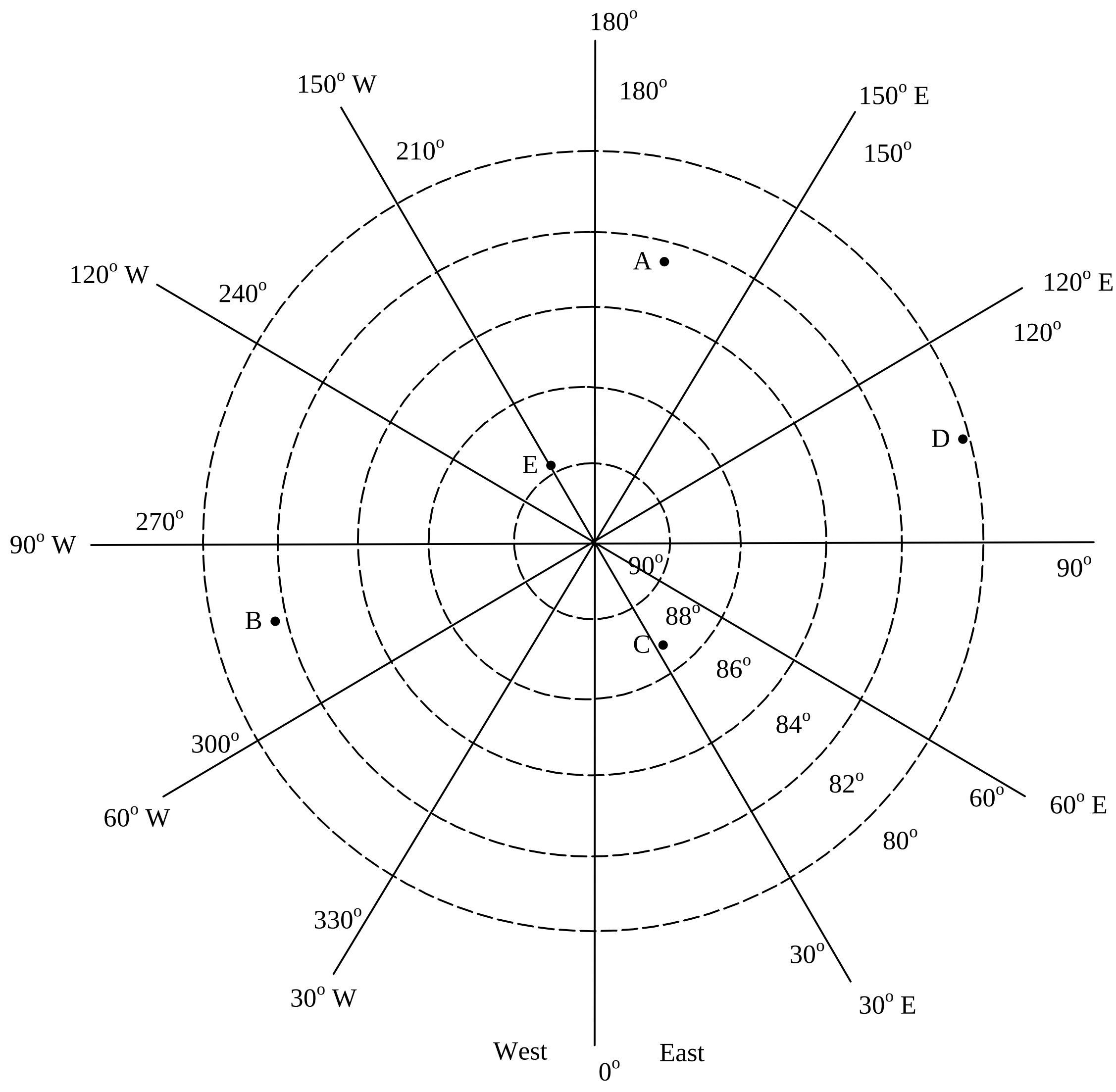
(Blank map grid.)



Activity 4. Plotting Positions in Polar Coordinates

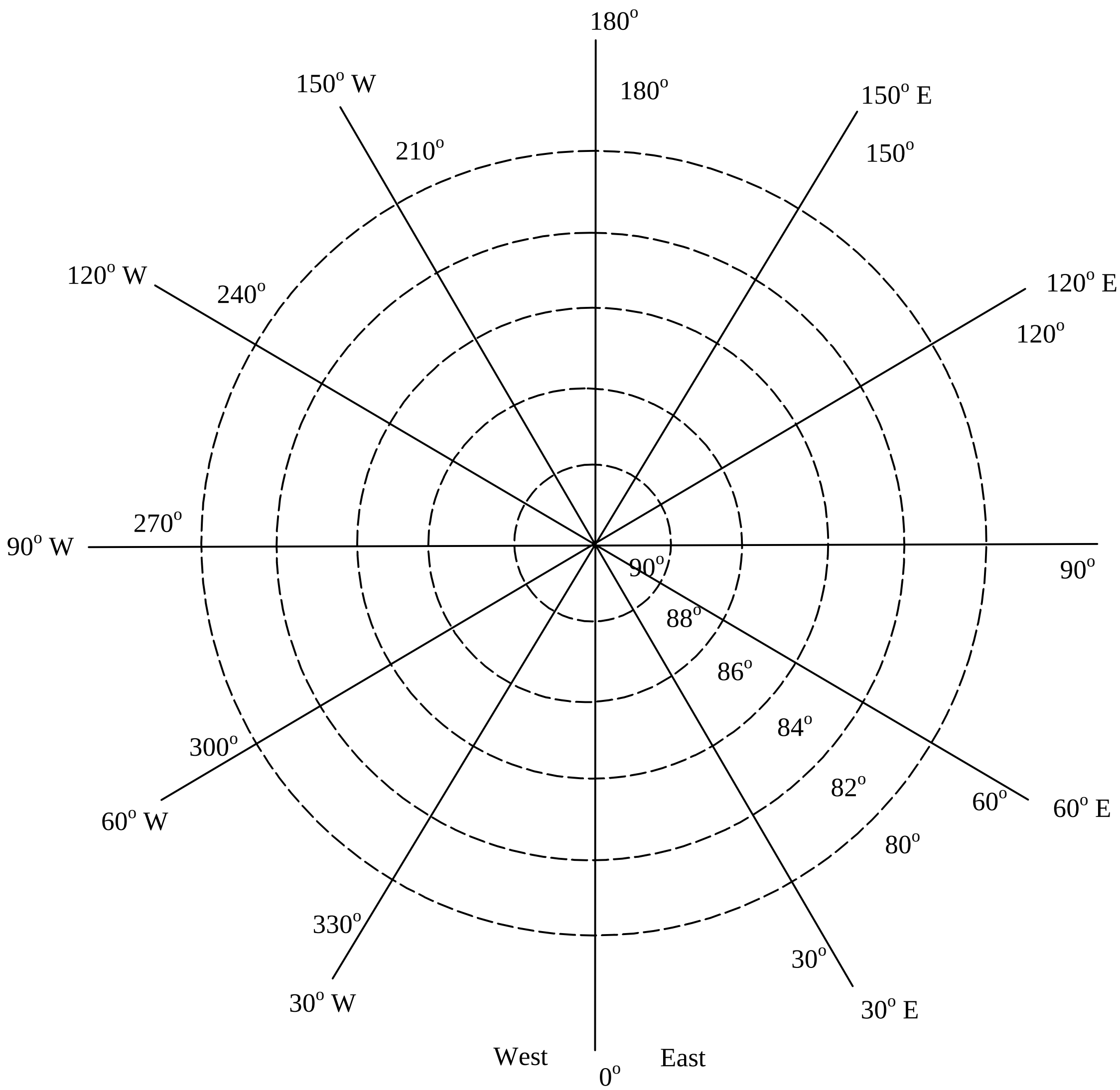
Using the map shown, give the positions of the lettered locations. The first answer is given. Notice that you have estimate latitude values since the concentric circles represent 2 degree increments. Longitude values must also be estimated since the longitude lines shown are 30 degrees apart. (Because of the estimating required, you should only expect your answer to be within a degree of the given answer for latitude and within about 5 degrees for longitude.)

Point	Latitude	Longitude
A	82.7°	167°
B		
C		
D		
E		



On the map shown below, plot the points given. Remember to estimate between the latitude circles and the longitude lines. Watch the labels carefully as you find the correct positions.

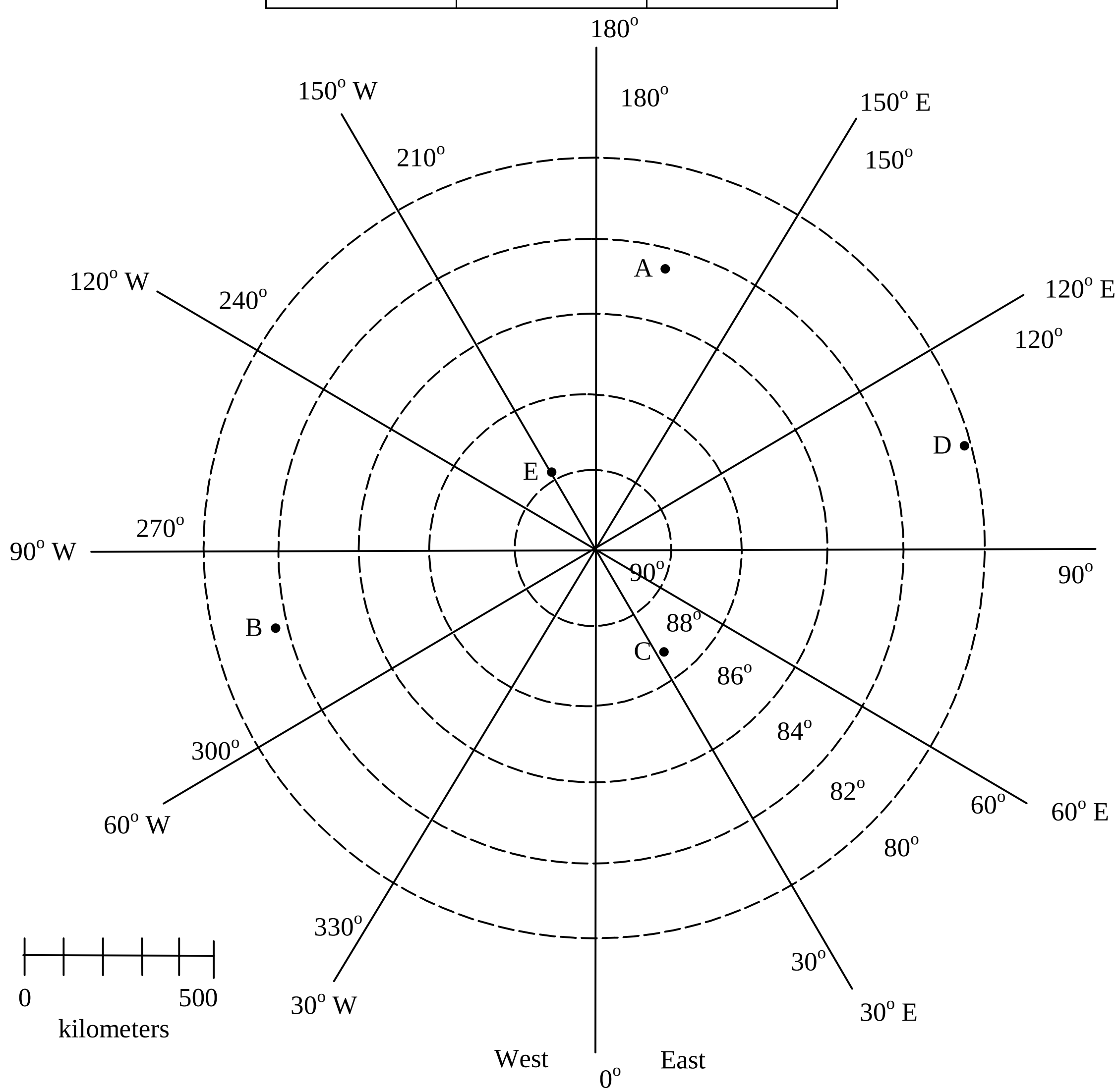
Point	Latitude	Longitude
A	88^o	310^o
B	82^o	60^o
C	85^o	195^o
D	81.7^o	260^o
E	83.9^o	121^o



Activity 5. Measuring Distance on the Polar Map

Using the distance scale given, make a scale on a separate paper that will allow you to measure distances up to 2000 kilometers. Using the map below, measure the distances indicated in the table. The first example is worked for you.

From Point	To Point	distance
A	B	1400 km
B	C	
C	D	
D	E	
E	A	
B	D	
C	A	
E	B	

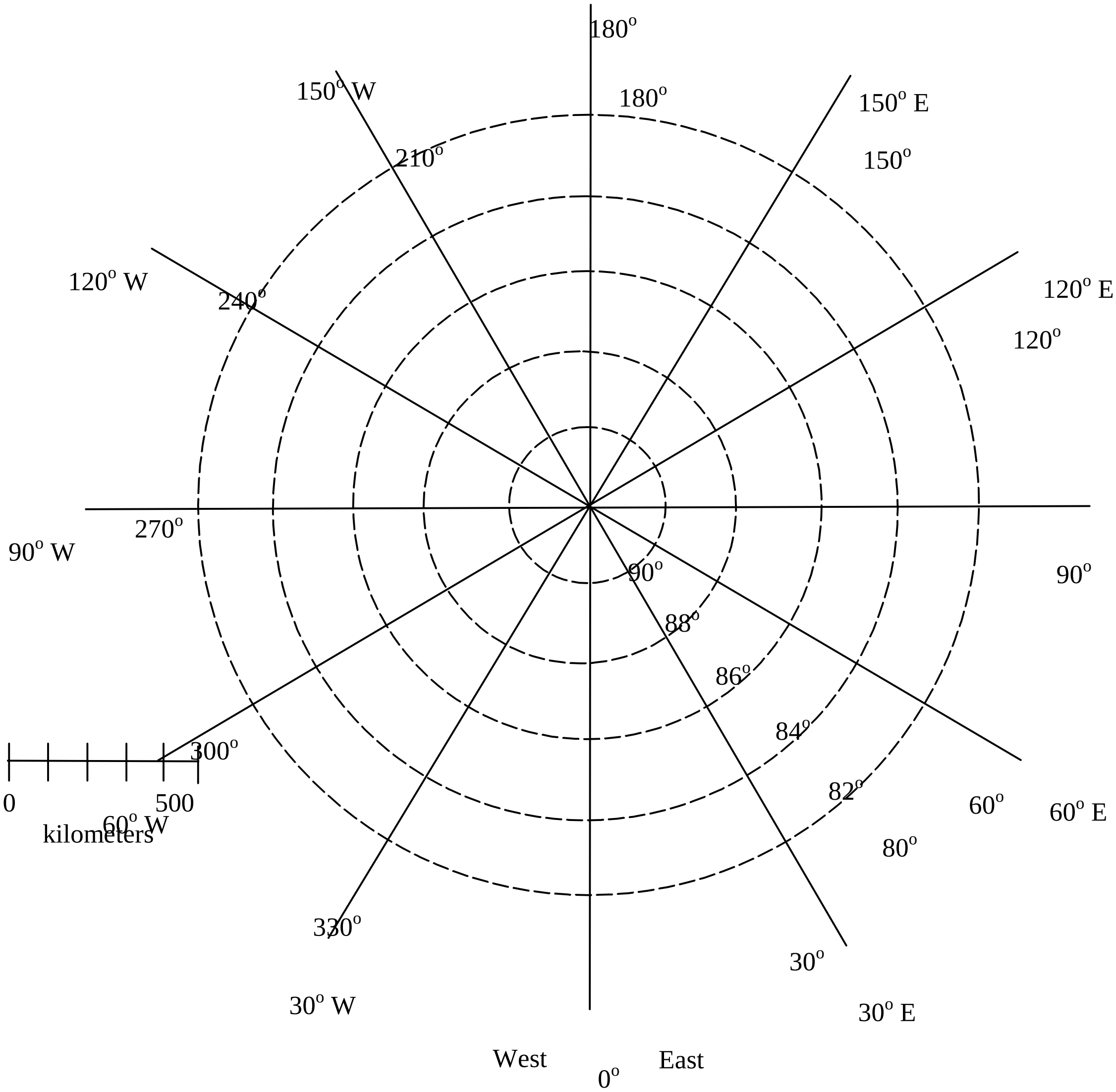


Activity 6. Earth's Wandering Poles

Before igneous rocks cool and harden, the liquid magma is acted on by the magnetic field of Earth. This causes some of the iron atoms in the rock to align with the magnetic field and "point" toward the magnetic north pole of Earth. When the rock hardens, these iron atoms are locked in position "pointing" toward the magnetic north pole. When scientists analyzed rocks formed at different times in the past, they found that the magnetic pointers did not point to the same location on the Earth. They interpreted this to mean that the position of the magnetic North Pole had moved over time. The magnetic North Pole is still moving today and, using modern instruments, we can measure this movement from year to year.

The following table shows the estimated position of the North Geomagnetic Pole over the past 2000 years. (This table is taken from The Earth's Magnetic Field by Ronald Merrill and Michael McElhinny, published in 1983 by Academic Press, page 100.) Plot the following positions on the map provided.

Year (AD)	Latitude	Longitude
0	86.4	121.4
100	87.7	143.9
200	87.7	160.3
300	88.9	131.9
400	86.0	316.3
500	86.1	343.5
600	85.6	6.6
700	84.1	33.4
800	81.8	28.0
900	80.2	38.0
1000	81.3	76.0
1100	85.3	110.0
1200	84.3	135.2
1300	83.2	189.1
1400	84.8	228.3
1500	86.3	301.5
1600	85.6	316.7
1700	81.1	307.1
1800	81.1	297.1
1900	82.3	288.2
1980	82.1	284.1



Look at the locations of the pole at 1000 AD and 1100 AD.

1. How far did the pole move? _________

2. How far did the pole move (in km) in one year? _________

3. How far did the pole move in meters in one year? _________

4. Approximately how far did the pole move per day? _________

5. Estimate when the Geomagnetic North Pole was at the same location as the Geographic North Pole (Latitude = 90 ^{o}). _________

6. What assumptions must be made to answer Question 5?

Chapter 3

The Orbit of IMAGE

<u>Kepler's First Law of Planetary Motion</u>

The definition of an orbit is the path followed by an object as it moves around another under the influence of gravity. About 400 years ago, Johannes Kepler discovered that the orbits of the planets around the sun were in the shape of ellipses. An ellipse is the set of points such that the sum of the distances to two fixed points is constant. Each fixed point is called a focus of the ellipse and the two points are called foci.

While Kepler's First Law describes the orbit of planets around the sun, it turns out that this law applies to any object in orbit around any other. The simplest orbital path is a circle. This is a special case of Kepler's law that occurs when the two foci are placed at the same point – the center of the circle. The Space Shuttle is often placed in a circular orbit around Earth. A typical altitude for the Space Shuttle is 400 kilometers measured from Earth's surface. The radius of orbit for the space shuttle is equal to the radius of Earth (Re) plus the altitude:

R = Re + 400 km. (Re = 6,400 kilometers.

R = 6,400 + 400

R = 6,800 kilometers.

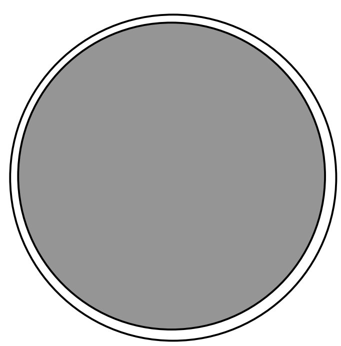


Figure 1. The space shuttle orbit at an altitude of 400 kilometers.

Figure 1 shows the orbit of the Space Shuttle drawn to scale with the Earth. Notice how close to Earth the Space Shuttle seems to be, even though at this altitude it is moving well above most of the Earth's atmosphere

In the case of an elliptical orbit, the distances from the object to the foci must have a constant sum. Figure 2 shows several points on an ellipse and the distances

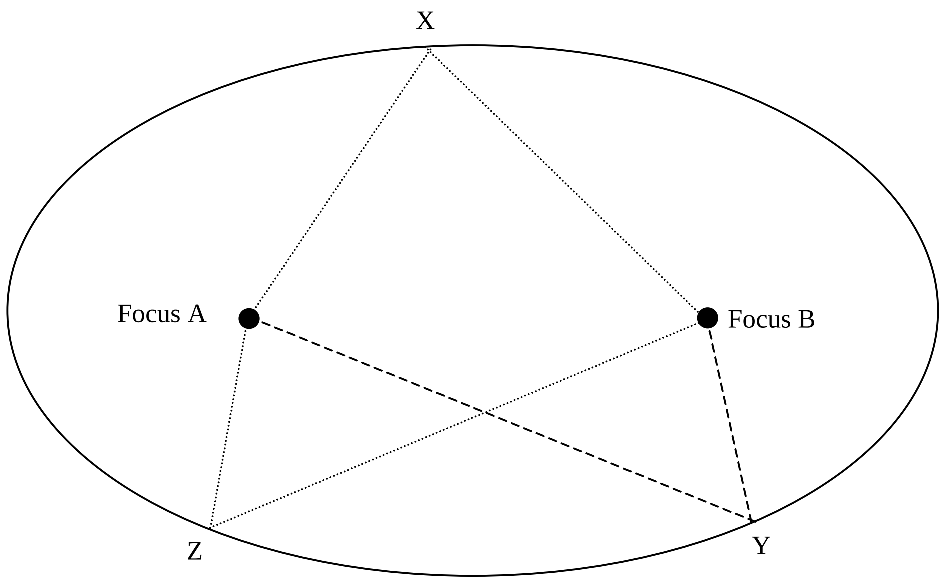


Figure 2. Distance: AX + XB = AY + YB = AZ + ZB

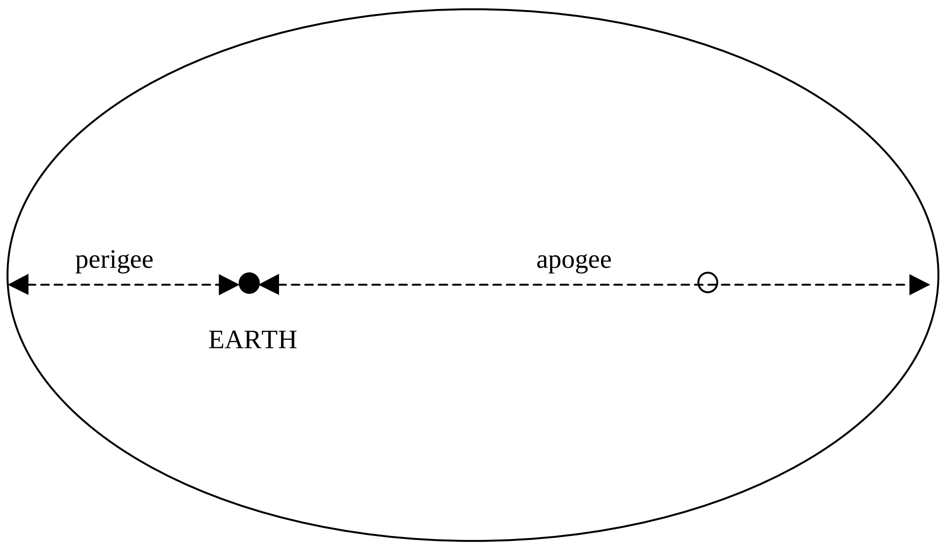


Figure 3. Parts of an elliptical orbit.

Figure 3 shows an elliptical orbit around Earth. The perigee is the point in the orbit (measured from the center of Earth) where the object is closest to Earth; apogee is the point where the object is farthest from Earth. As an object moves from apogee, it is accelerated by gravity to a higher speed so that the speed of the object is highest at perigee. As inertia carries the object away from perigee, the force of gravity acts to slow the object so that it is moving at its slowest speed when it reaches apogee. This lead to Kepler's Second Law of Planetary Motion.

Kepler's Second Law of Planetary Motion

> Kepler's Second Law of Planetary Motion:
>
> The line connecting the planet to the sun sweeps out equal areas in equal times.

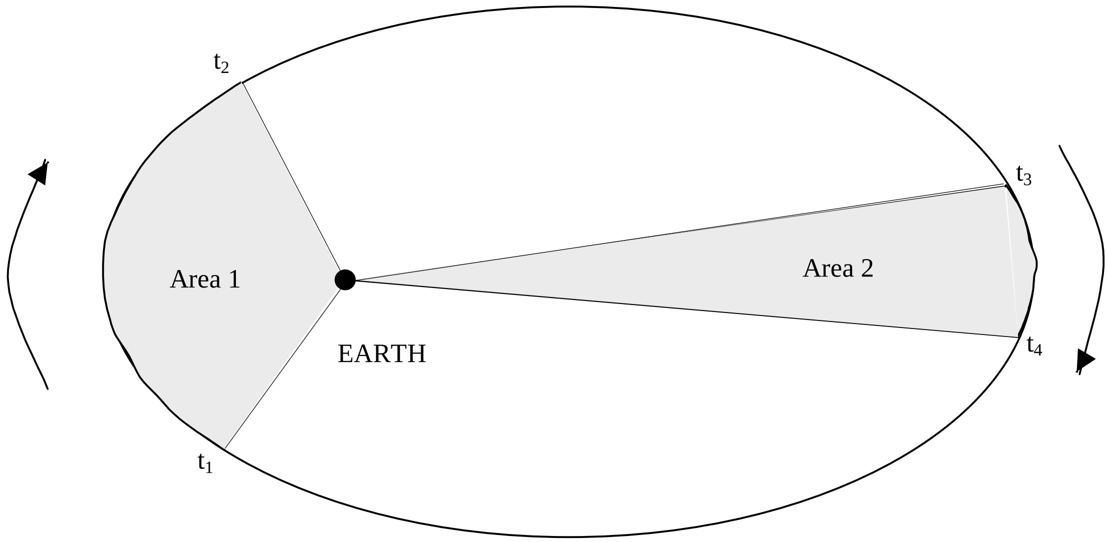


Figure 4. Illustration of Kepler's Second Law. If the time between t1 and t2 is the same as that between t3 and t4 then Area 1 = Area 2. When the distances between these pairs of points are compared, the difference in speeds is apparent.

Eccentricity of Orbits

Not all ellipses look alike. Some are nearly circular and some are very stretched out and thin. Ellipses of different shapes have different eccentricities.

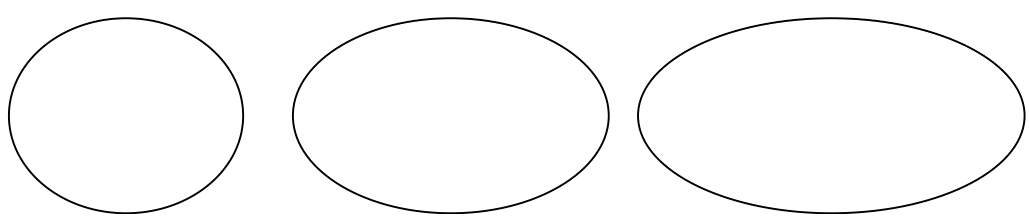


Figure 5. Ellipses of different eccentricities.

The eccentricity of an ellipse is defined using the following diagram:

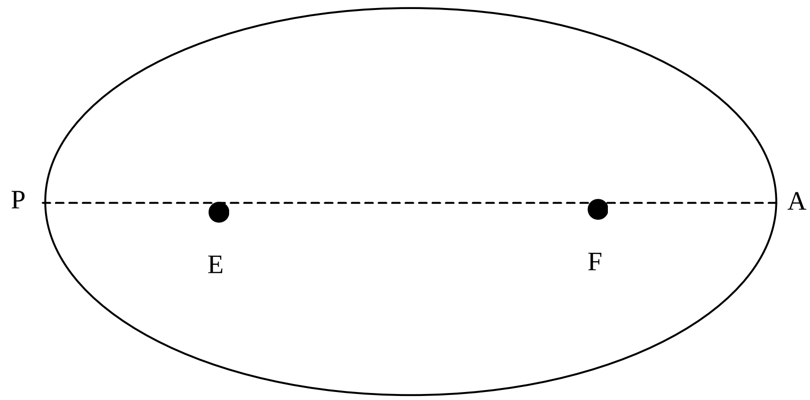


Figure 6. An ellipse with important points labeled.
E : the object being orbited (Earth) F : the other focus of the ellipse
P : the perigee point of the orbit A : the apogee point of the orbit

Using the points identified in Figure 6, the eccentricity (e) of an ellipse is defined by:

$$e = \frac{EF}{PA}$$

The Orbit of IMAGE

The orbit of the IMAGE spacecraft is described as follows:

perigee : 1,000 kilometers altitude
apogee : 7 Earth radii (Re) altitude

Notice that these values are not measured from the center of Earth. Kepler's First Law requires the distances to be expressed from the center of the objects. To find the distance from the center of the Earth, you must add the radius of the Earth (approximately 6400 kilometers) to each value from above:

perigee : 6,400 km + 1,000 km = 7,400 km
apogee : 6,400 km + 7(6,400) km = 51,200 km (8 Re)

The eccentricity of the IMAGE orbit can be calculated from these numbers:

EF = apogee – perigee = 51,200 – 6,400 = 44,800 km
PA = apogee + perigee = 51,200 + 6,400 = 57,600 km

$$e = \frac{EF}{PA} = \frac{44,800}{57,600} = .78$$

This is a very eccentric orbit.

The following diagram is an approximate view of the orbit of IMAGE. A more careful drawing may be done as an activity (Activity 3).

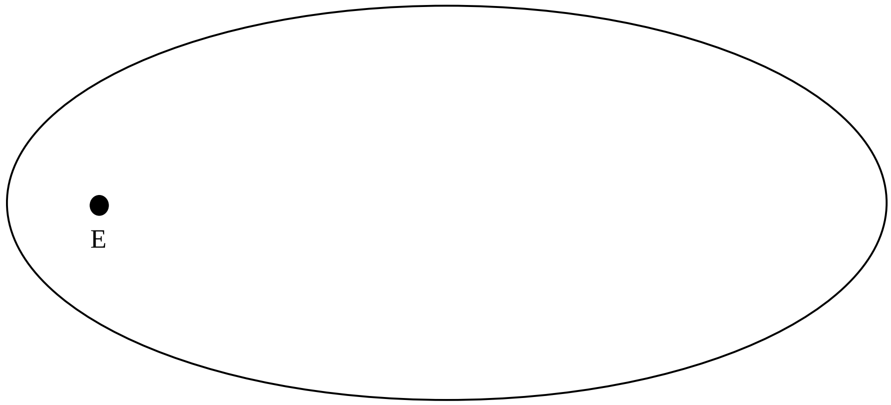


Figure 7. The orbit of IMAGE.   ‘E’ is the position of Earth at one focus

When Earth is added to scale, we get the best view of the orbit of IMAGE. The perigee and apogee were selected to be over the North and South Poles. These orbits are, therefore, called Polar Orbits. They are commonly used by military spy satellites and civilian research satellites because they eventually pass over all points on the Earth.

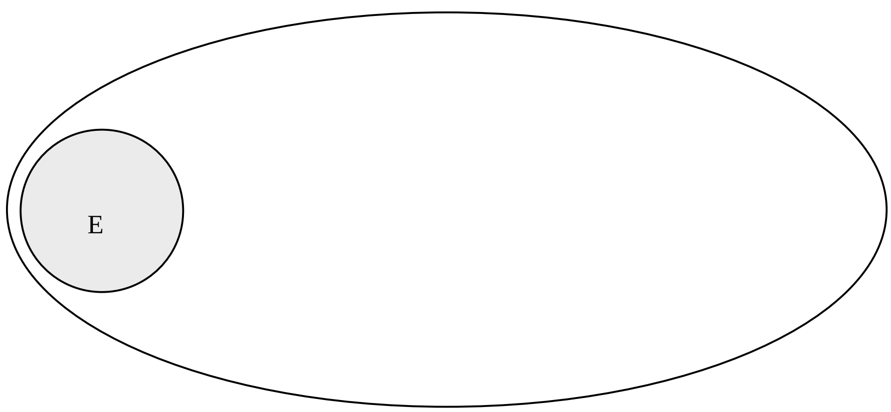


Figure 8. The orbit of IMAGE

The Center of Mass of Orbiting Systems

While we often think of one object orbiting another, in fact each object exerts a gravitational force on the other. The result is that both objects move around a common point located somewhere between the centers of the objects called the center of mass. Since the center of mass is essentially the "balance point" of the two-object system, its location can be determined using the lever equation:

$$m1d1 = m2d2$$

where: m = mass of the object
d = distance from the center of the object to the center of mass of the system
1 : object 1
2 : object 2

Sometimes it is acceptable to think of one object orbiting another, but sometimes it is very important to include the effects of each on the other and talk about their motions about the center of mass of the system.

When two objects have nearly the same mass, their center of mass is located about halfway beteen them. In that case, the two objects would be seen as orbiting each other. Some binary stars have nearly the same mass and this would be their type of apparent motion.

When one object is significantly larger than the other, the two objects would orbit a point that is closer to the more massive object. In this case, the smaller object would be seen to orbit the larger, but careful observation of the larger would reveal that its position in space is changing as it moves about the center of mass. In the case of the Moon orbiting the Earth, the center of mass is located 4,900 kilometers from the center of Earth, or 1,500 kilometers beneath the surface of Earth. Earth would be seen to "wobble" in space as the Moon orbits. Black hole candidates such as Cygnus X-1 located 6,000 light years from the sun, were discovered by observing a wobble in the position of a star that did not seem to have a companion star. Subsequent observation of X-rays from the star was a confirming indication of the black hole. Extrasolar planets (planets orbiting other stars) are now detected by observing the variation in the velocity of a star as it wobbles due to the presence of unseen companions.

In the case of the IMAGE satellite, the "wobble" in the position of Earth due to IMAGE would be impossible to detect. The mass of Earth is about 6×10^{24} kilograms while the mass of IMAGE is only 536 kilograms. The location of the center of mass is so close to the center of Earth that the "wobble" would be less than the diameter of the nucleus of an atom!

Activity 1: Drawing Elliptical Orbits

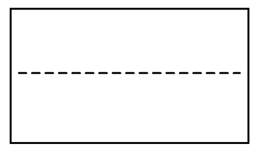
Materials:

8.5 x 11-inch paper
30 cm ruler
string
2 thumb tacks
pencil

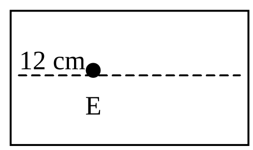
Ellipse #	Perigee	Apogee
1	7 cm	15 cm
2	2 cm	15 cm
3	13 cm	15 cm
4	1 cm	15 cm
5	10 cm	15 cm
6	15 cm	15 cm

Procedure:

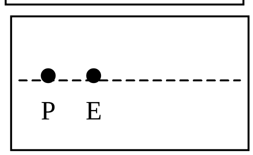
1. Draw a line lengthwise down the middle of a piece of paper.



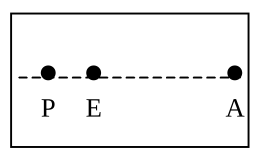
2. Measure and mark a point 12 centimeters from the left edge of the paper. Label this point E (for Earth).



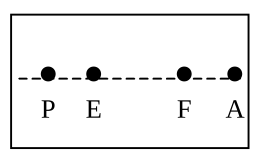
3. Measure and mark the perigee distance on the line to the left of E. Label this point P.



4. Measure and mark the apogee distance on the line to the right of E. Label this point A.



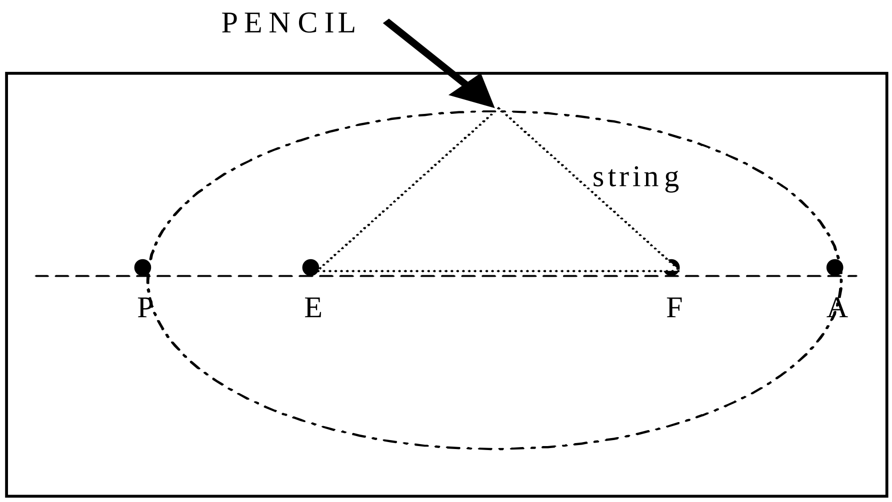
5. Measure and mark the perigee distance from point A to the <u>left</u>. Label this point F (for focus).



6. Place the paper on the cardboard and insert a thumbtack at points E and F, the foci of the ellipse.

7. Holding your pencil at point A, tie a loop of string around your pencil at A and the thumbtack at E. This loop represents the apogee distance which is the same for all ellipses in this activity, so the same string loop can b used for all 6 ellipses.

8. Making sure that the string is looped around both thumbtacks and keeping the string tight in a triangle shape with your pencil, move your pencil completely around the elliptical shape.



9. Repeat this process for the other ellipses.

Questions:

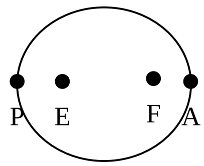
1. How are these shapes different? How are they alike?

2. Explain how this method of drawing an ellipse satisfies the definition of an ellipse.

3. A circle can be considered a special type of ellipse. What condition must be met for a circle to be considered an ellipse?

4. True or false?
   A. All circles are ellipses.
   B. All ellipses are circles.

Activity 2. Eccentricity of Orbits.



Given the elliptical orbit labeled as shown above, the eccentricity (e) of an ellipse is defined by:

$$e = \frac{EF}{PA}$$

where : EF is the distance between foci and
PA is the distance between perigee and apogee points.

Directions:

Calculate the eccentricity of each of the orbits found in Activity 1.

Ellipse #	EF	PA	e (eccentricity)
1			
2			
3			
4			
5			
6			

Questions:

1. What is the largest possible value for the eccentricity of an ellipse? Why?
2. What is the smallest possible value for the eccentricity of an ellipse? Why?
3. How would you describe an ellipse that has a large eccentricity?
4. How would you describe an ellipse that has a small eccentricity?
5. What is the eccentricity of a circle?

Activity 3. A Scale Drawing of the Orbit of IMAGE

The orbit of the IMAGE spacecraft is described as follows:

perigee : 1,000 kilometers altitude
apogee : 7 Earth radii (Re) altitude

Notice that these values are not measured from the center of Earth. Kepler's First Law requires the distances to be expressed from the center of the objects. To find the distance from the center of the Earth, you must add the radius of the Earth (approximately 6,400 kilometers) to each value from above:

perigee : 6,400 km + 1,000 km = 7,400 km
apogee : 6,400 km + 7(6,400) km = 51,200 km (8 Re)

To fit the scale drawing on a piece of paper, an appropriate scale must be chosen. This scale should be easy to us and also provide a large drawing. Since the paper is about 27 centimeters long, and we need to fit the sum of the apogee and perigee distances (51,200 km + 7,400 km = 58,600 km) on the paper, the following calculation can be done:

27 cm / 58,600 km = .00046 cm/km.

If we round this figure down to .0004 cm/km, we will have an easy scale factor to use and the following activities will fit on a piece of paper. To convert an actual distance, such as 15,000 km, to the scale distance, the following calculation is done:

15,000 km (.0004 cm/km) = 6 cm.

So a 6 centimeter distance on the paper would represent 15,000 kilometers in space.

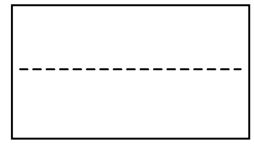
Directions: Fill in the following table.

Scale distance table:	Actual Distance	(Calculate to the nearest .1 cm for the scale distance.)	Scale Distance
Radius of Earth	6400 km	6400 km (.0004 cm/km)	2.6 cm
Perigee	7400 km	________ (.0004 cm/km)	
Apogee	51,200 km	_______ __ (______ ______)	

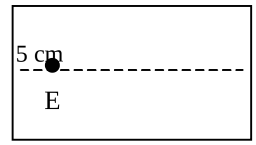
Materials:

8.5 x 11-inch paper
8.5 x 11-inch cardboard
30 cm ruler
string
2 thumb tacks
pencil
compass

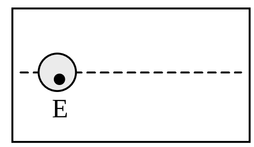
Directions for making the scale drawing:



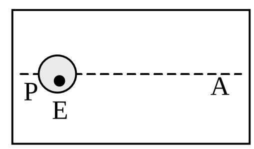
1. Draw a line lengthwise down the middle of a piece of paper.



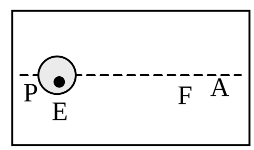
2. Measure and mark a point 5 cm from the left edge. Label this point E (for the center of the Earth).



3. Draw a circle with a 2.6 cm radius. Shade in this circle which represents the Earth.

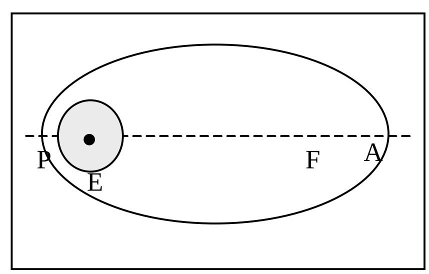


4. Measure the perigee scale distance to the left of E. Mark this P. Measure the apogee scale distance to the right of E. Mark this A.



5. Measure the perigee distance to the <u>left</u> of A. Mark this F (for focus).

6. Place the paper on the cardboard and insert a thumbtack at the point E and F, the foci of the ellipse.



7. Holding your pencil at A, tie a loop of string around your pencil at A and the thumbtack at E.

8. Making sure that the string is looped around both thumbtacks and keeping the loop tight in a triangle shape with your pencil, draw the complete scaled orbit for IMAGE.

Questions:

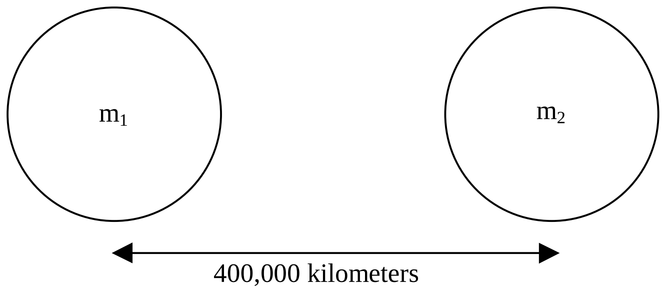
1. In calculating the distance from the center of Earth, we did not mention the radius of the IMAGE spacecraft. That radius is approximately 1 meter. Should this radius have been included in the calculation of perigee and apogee? Why or why not?

2. Calculate the eccentricity of the orbit of IMAGE.

Activity 4. The Center of Mass

Note: The following Problems 1-5 are hypothetical and all assume that an object is in orbit around Earth at an average distance equal to that of the moon in its orbit (400,000 kilometers).

Problem 1. Earth-sized object orbits Earth at a distance of 400,000 kilometers.



m1 d1 = m2 d2

m1 = mass of Earth = 5.98×10^{24} kilograms

m2 = m1 = 5.98×10^{24} kilograms

d1 = distance from the center of object #1 to the center of mass = ?

d2 = distance from the center of object #2 to the center of mass = ?

Notice that there are two unknowns (d1 and d2) in the problem; we need a second equation to find both unknowns. We know that the sum of these distances is the distance between the objects.

d1 + d2 = 400,000 kilometers = 4×10^{5} kilometers

or d2 = 400,000 - d1

Solving by substitution:

m1 d1 = m2 d2

m1 d1 = m2 (400,000 – d1)

m1 d1 = 400,000 m2 – m2 d1

m1 d1 + m2 d1 = 400,000 m2

d1 (m1 + m2) = 400,000 m2

d1 = (400,000 m2) / (m1 + m2)

Since in this special case m1 = m2 , the above simplifies to:

$$d1 = (400{,}000\ m2) / (m2 + m2) = (400{,}000\ m2) / (2m2) = 400{,}000 / 2$$

$$d1 = 200{,}000 \text{ kilometers} = 2 \times 10^5 \text{ kilometers}$$

The center of mass is 200,000 kilometers from m1 (Earth) or exactly midway between the two objects in the system (an unsurprising result!). If you could observe this system from a viewpoint fixed with respect to the stars, you would see both objects in motion at opposite ends of an invisible rotating diameter of a circle of radius 200,000 kilometers and center located at the center of mass of the system.

There are no examples in the solar system of objects of equal mass orbiting one another, but there are examples of binary stars of nearly equal mass orbiting a point about midway between them.

Problem 2. Mars orbits Earth at a distance of 400,000 kilometers.

m2 = mass of Mars = 6.46×10^{23} kilograms

Since Mars has a mass that is much smaller than Earth, its effect on Earth will cause Earth to appear to “wobble” as Earth moves around in its orbit round the sun. It is this kind of “wobble” in the position of some stars that allows us to infer the presence of another object orbiting the star. This has lead to the discovery of invisible neutron stars and black holes in orbit around visible companion stars and planets in orbit around stars.

Problem 3. Venus orbits Earth at a distance of 400,000 kilometers.

m2 = mass of Venus = 4.87×10^{23} kilograms

Problem 4. Jupiter orbits Earth at a distance of 400,000 kilometers.

m2 = mass of Jupiter = 6.70×10^{25} kilograms

Problem 5. The moon orbits Earth at a distance of 400,000 kilometers.

m2 = mass of the moon = 7.35×10^{22} kilograms

ANSWERS:

Problem 2. d1 = 3.9×10^4 kilometers (1/10 the distance from the center of Earth to Mars)

Problem 3. d1 = 1.8×10^5 kilometers (Just under halfway from Earth to Venus)

Problem 4. d1 = 3.7×10^5 kilometers (Over 9/10 the distance from Earth to Jupiter)

Problem 5. d1 = 4.9×10^3 kilometers (A little less than 8/10 of the way from the center of Earth to the surface of Earth)

Problem 6. Find the location of the center of mass of the Earth-satellite system of the IMAGE satellite in its orbit.

m1 = mass of Earth = 5.98×10^{24} kilograms

m2 = mass of IMAGE = 536 kilograms

d1 + d2 = average IMAGE distance from the center of Earth

= [perigee + apogee] / 2

= [(1 RE + 1,000 km) + 8 RE] / 2 RE = 6,400 km

= [7400 + 8(6,400)] / 2 = [5.86×10^4] / 2

d1 + d2 = 2.93×10^4 kilometers

ANSWER:

d1 = 5.3×10^{-18} km = 5.3×10^{-15} m

(About the diameter of a nucleus!)

Glossary

apogee	Farthest distance of an Earth-orbiting satellite in its orbit
aurora	“Northern Lights” or “Southern Lights”; glow in sky caused by solar wind particles entering Earth’s atmosphere.
center of mass	Balance point of a system of objects
CME	Coronal Mass Ejection; a huge explosion in the corona sending a large amount of solar wind outward from the sun
corona	Extremely hot outer layer of the solar atmosphere
eccentricity	Number (e) describing how nearly circular an ellipse is; e = 0 for a circle, e, approaches 1 for a long, thin ellipse.
ellipse	Set of points such that the sum of the distances to two fixed points is constant; an oval shape; the shape of orbits
focus	One of the points in the definition of an ellipse; plural is foci
geographic North Pole	Point where the spin axis of Earth intersects the surface
Geosynchronous	Describes the orbit of a communication satellite; orbit holds the satellite over the same spot on the Earth; orbit at a distance of 6.6 Re from the center of the Earth.
IMF	Interplanetary Magnetic Field; region of space where the solar magnetic field is the predominant field; most of the solar system is filled with the IMF.
Kepler’s First Law	Planet orbits are ellipses with the sun at one focus
Kepler’s Second Law	The line connecting a planet to the sun sweeps out equal areas in equal times; the Equal Area Law.
magnetic field	Region around a magnet (or a planet) where the magnetic effect is felt
magnetic north pole	Location on Earth of the north pole of Earth’s internal magnet; at this point, the magnetic field lines point straight down.

magnetic storm	Increase in the aurora due to the arrival of solar wind particles
magnetopause	Boundary between the magnetosphere and the solar wind.
magnetosphere	Region around Earth where Earth's magnetic field is the predominant field
magnetotail	The part of the magnetosphere that extends from Earth away from the sun
orbit	Path followed by an object as it travels around another body
perigee	Closest distance of an Earth-orbiting satellite in its orbit
plasma	Matter that includes charged particles formed by ionizing atoms
Prime Meridian	Longitude line where the longitude is 0^o; passes through Greenwich, England
Re	Radius of Earth; a common unit of distance when describing the magnetosphere
ring current	Charged particles held near Earth by Earth's magnetic field; range in distance from about 2 Re to 7 Re
solar flare	Explosion from the surface of the sun throwing charged particles into space.
solar maximum	Period of high solar activity; associated with a high sunspot number
solar minimum	Period of low solar activity; associated with a low sunspot number
solar wind	Flow of plasma from the sun
sunspot	Cooler region on the surface of the sun; appears dark
sunspot cycle	11-year cycle of the number of sunspots; variation in solar activity