

# The Global Positioning System

[http://cfa-www.harvard.edu/space\\_geodesy/ATLAS/gps.html](http://cfa-www.harvard.edu/space_geodesy/ATLAS/gps.html)

**Classroom time: 40 minutes**

## Material Covered:

- Earth in Space
- Satellites around the Earth
- The Global Positioning System
- Positioning with GPS
- Student Worksheet: ["Seeing" Satellites](#)

## Earth in Space

Our galaxy, the [Milky Way](#), is a mere speck in the vast expanses of the Universe. Our closest star, the Sun, is simply one more among the millions and millions of stars that form the Milky Way. Our planet, the Earth, is one of the nine "satellites" that revolve around the Sun following an [elliptical orbit](#). The other planets, from closest to the Sun to farthest away, are Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The Earth's orbit lies between those of Venus and Mars. Because all nine planets orbit the Sun they are referred to as solar planets. The rules that govern the motions of the solar planets (in fact of all heavenly bodies) are known as celestial mechanics, which scientists like [Johannes Kepler](#) and [Isaac Newton](#) discovered hundreds of years ago.

The orbits described by the nine solar planets are very accurately known nowadays and constitute a very organized and fascinating clockwork machine. The [force](#) that holds them together and describes their relative motions is called [gravity](#). The nearer a planet is to the Sun, the more strongly gravity tugs on it and the faster has to travel along its orbit not to fall onto the Sun. The Earth, at about 150,000,000 [km](#) (93,000,000 miles) from the Sun, travels at a [mean orbital velocity](#) of about 30 kilometers per second (68,000 miles per hour) and completes a full revolution around it in exactly one year. The other solar planets have orbital velocities that differ from that of Earth. They complete a full revolution around the Sun in either less or more than a year, depending on whether they are closer or farther away from the Sun than the Earth is.

Many planets, in turn, have one or more [satellites](#) orbiting them. For example, the Earth has one [natural satellite](#), the [Moon](#). The Moon is about 385,000 kilometers (240,000 miles) away from the Earth and completes a full revolution around it in about [29 days](#). The different positions of the Moon relative to the Earth (and the Sun) determine its known [phases](#): Waxing, Full, Waning and New.

So, how would you define a satellite? It is simply a body that orbits another. [Gravity](#) provides the glue for the orbital motion.

## Satellites around the Earth

The accurate knowledge of [celestial mechanics](#) and the careful study of the motions of natural satellites, like the Moon, have enabled scientists to build [artificial satellites](#) and send them into space. Most artificial satellites are orbiting the Earth. A few satellites have been launched to explore other planets of our Solar System. An example of one such satellite is Viking, which explored Mars.

Powerful [rockets](#) are used to send artificial satellites into space. If the launching speed of the rocket is too low the satellite will fall back onto Earth because the gravitational attraction exerted by the Earth on the satellite would be too high for the satellite to overcome. The same happens to a rock thrown by a person from the Earth's surface, if falls back onto the Earth. On the other hand, if the launching speed is too high, the satellite will not be confined by the Earth's gravity and it will escape to outer space. You can imagine that placing a satellite in a particular orbit requires some accurate calculations and careful work.

Artificial satellites serve multiple purposes nowadays. Some examples of varied use of satellites are:

- [Telecommunications](#)
- [Weather forecasting](#)
- [Military applications](#)
- [Scientific research](#)
- [Geophysics](#)

The orbits of some satellites are synchronized with the rotation of the Earth. If their speed matches exactly the speed of rotation of the Earth, they look as if they are stationary on the sky and they are therefore called [geostationary](#) satellites. If the relative speeds are not the same, the satellites look to us like the Moon, rising and setting, sometimes even several times a day.

We need some form of communication with the satellites to send them commands and to retrieve the information that they acquired while orbiting the Earth. Although they have different means to communicate this information, the basic alphabet used consists of [radio waves](#), which are exactly the same type of waves used to broadcast television and radio programs. A good reason for using radio waves for communication is that they are not affected much by weather conditions. One can send and receive them on a perfectly clear day or in the middle of a snow storm, during the day or at night.

## The Global Positioning System

The [Global Positioning System](#) (GPS) is a constellation of about 24 [artificial satellites](#). The GPS satellites are uniformly distributed in a total of six orbits such that there are four satellites per orbit. This number of satellites and spatial distribution of orbits insures that at least eight satellites can be simultaneously [seen](#) at any time from almost anywhere on Earth. The GPS satellites circle the Earth at an altitude of about 20,000 km (13,000 miles) and complete two full [orbits](#) every day. The GPS satellites are not in a [geostationary](#) orbit, but rise and set two times per day. Each satellite broadcasts [radio waves](#) towards Earth that contain information regarding its position and time. We can receive this information by using special receivers, called [GPS receivers](#), which can detect and decode this information. By combining signals transmitted by several satellites and received simultaneously, a GPS receiver can calculate its [position on the Earth](#) (i.e., its [latitude and longitude](#)) with an accuracy of approximately 10 m. There are more sophisticated receivers that can be used to determine position with an accuracy of a few millimeters.

## Positioning with GPS

What does it mean to determine our "position" on the Earth? The usual method is to refer to a terrestrial position (i.e., position on the Earth) by its latitude and longitude. Therefore, most GPS receivers will display their current latitude and longitude. The usual format for displaying this information is in degrees and minutes. There are 360 degrees in a complete circle, and 60 minutes in one degree. The familiar symbol for "degree" is  $^{\circ}$ . The symbol for minute is  $'$ . The minutes are usually displayed as a decimal number, like 36.2536'. Both latitude and longitude are angles, and they therefore have to be measured in reference to a well defined  $0^{\circ}$  line.

### ***Latitude: North vs. South Hemispheres***

The latitude is measured relative to the equator. The equator is latitude  $0^{\circ}$ , and is neither in the Northern or Southern Hemisphere. If a location is in the Northern Hemisphere, the latitude will be followed or preceded by the letter N. If a location is in the Southern Hemisphere, the latitude will be followed or preceded by the letter S. Sometimes no letter is given, and the latitudes in the Southern Hemisphere will be expressed as a negative number.

### ***Longitude: Measured East vs. Measured West***

By historical convention, longitude is measured relative to the "Greenwich" or "Prime" Meridian. ("Meridian" means "line of longitude.") Unlike latitude, we do not express the hemisphere (east or west) of the longitude, but rather the direction towards which the angle of longitude is measured from the Prime Meridian. If we measure an angle east of the Prime Meridian, we write the letter E preceding or following the longitude. If we measure an angle west of the Prime Meridian, we write the letter W preceding or following the longitude. Given the

longitude measured one way, we can calculate the longitude measured the other way using the formulas:  $W = 360 - E$  and  $E = 360 - W$ .

Sometimes, negative values are used to express longitudes measured west. Thus, the following longitude values are all equivalent:  $W\ 90^\circ$ ;  $E\ 270^\circ$ ; and  $-90^\circ$ .

## Student Worksheet: "Seeing" Satellites

In the Global Mapping Experiment, we will talk about the "visibility" of a satellite, or when we can "see" a satellite. By this terminology, we do not mean that we can, with the unaided eye, see the satellite (although it is sometimes possible to do so, especially when the Sun glints off it). We use the term "visibility" and "seeing" to mean "to have an unobstructed view of." Since the GPS satellites orbit the Earth in a non-geostationary orbit, they will rise and set. After they have set, for example, they are below the horizon and therefore "not visible." We cannot "see" satellites below the horizon. After they rise, satellites are above the horizon and thus potentially "visible."

Sometimes, even after satellites rise, their view is obstructed. Sometimes a building or tree will get in the way. That is usually not a good situation. When you perform the [Global Mapping Experiment](#), try to stay away from such obstructions like buildings or trees. You want to maintain good sky visibility so that you can see as many satellites as possible.

Students can complete the worksheet ["Seeing" Satellites](#) in class or as homework, at your discretion. The worksheet is intended to start the students thinking about the concepts of sky visibility and seeing satellites. These are important concepts for the [Global Mapping Experiment](#).

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