

## The Earth's Orbit and the Reasons for Seasons

Many of our most interesting astronomical and meteorological phenomena derive from the particular nature of the Earth's orbit. Thus, understanding the size, shape and orientation of our orbit in space will help us understand these phenomena.

The earth **revolves** around the sun in an **elliptical orbit**. Remember that motion around a central object is revolution; spinning about an axis is rotation. Thus, the Earth revolves around the sun once per year, and rotates on its axis once per day.

As we learned last summer, planets revolve around the sun in elliptical orbits, with the sun at one focus. The diagram below reminds us of the geometry of an ellipse.

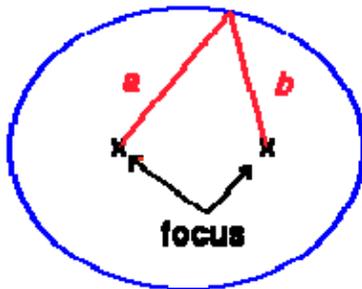
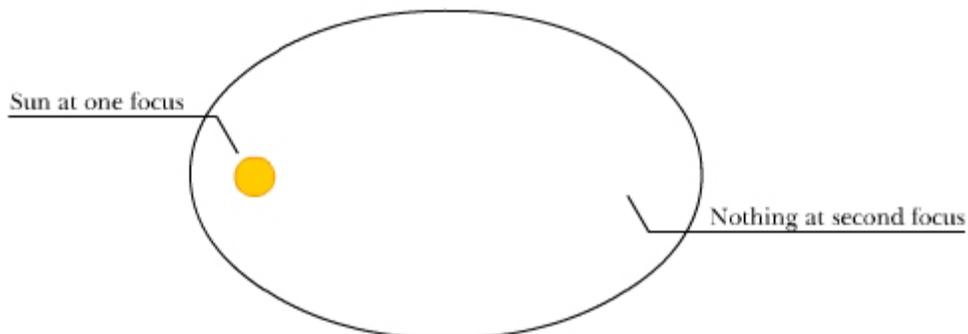


image courtesy University of Tennessee at Knoxville Astronomy Dept.

The sun is at one of these foci points, while the other focus is devoid of any astronomical significance. As is easily seen in the figure below, a planet in an elliptical orbit varies its distance from the sun throughout the course of a revolution.



The size of the Sun is greatly exaggerated in this diagram

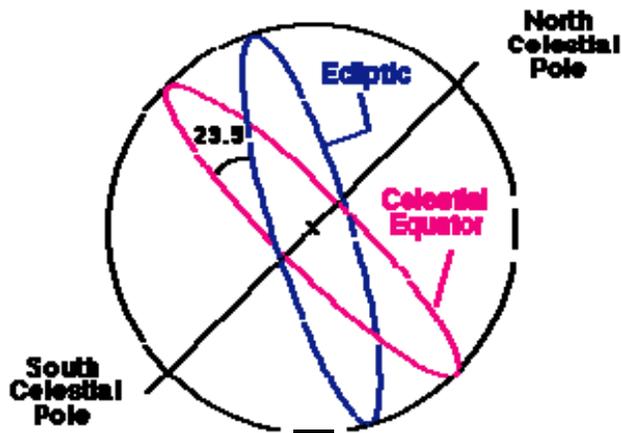
Image courtesy Iowa State University

We use the term **eccentricity** to refer to the degree of non-circularity of an ellipse. A perfect circle has an eccentricity of zero; a straight line represents the most eccentric possible orbit and has an eccentricity value of 1. Most planets have very small eccentricities (the Earth's is 0.03, so the diagram above is much exaggerated), although [Mercury](#) has an eccentricity of 0.20, and [Pluto](#) has a very elongated orbit of eccentricity

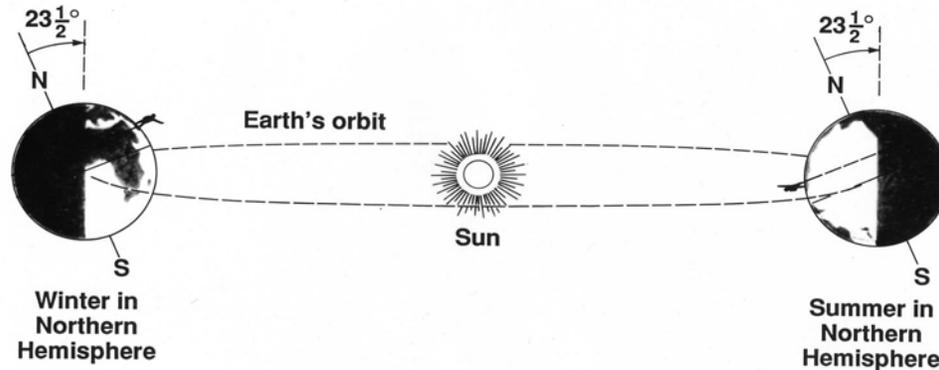
0.25. The great non-circularity of Pluto's orbit explains why it is sometimes closer to the sun than Neptune.

It seems obvious to most people that the distance variation between the Earth and Sun throughout the course of the year must be highly significant. In fact, the Earth is approximately 91.5 million miles from the sun at our closest point (known as **perihelion**, and approximately 94.5 million miles at our most distant (called **aphelion**). However, the Earth-sun distance variation does not explain why the Earth experiences seasons.

To understand why the Earth has seasons, we must go back to our discussion of the celestial sphere. We know that the Earth revolves around the sun in an elliptical orbit, and that this orbit lies in a specific plane called the **ecliptic**. As the figure below shows, the Earth's equator does not lie in the plane of the ecliptic, rather, the equator is inclined from the ecliptic by  $23\frac{1}{2}$  degrees.



This orientation also means that the rotational axis of the Earth is not perpendicular to the ecliptic, but "tilted" as shown in the diagram below:



### Cause of seasons

Hartmann/The Cosmic Journey, 4th ed., Fig. 2-8; The Cosmic Voyage, Fig. 2-5

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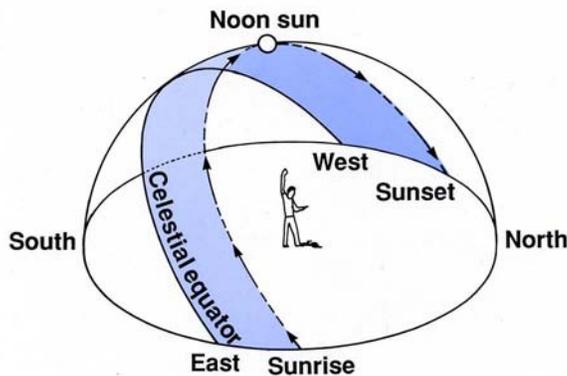
image courtesy Lunar and Planetary Lab/Univ. of Arizona

This "tilt" (the term used by astronomers is **obliquity**; we say the obliquity of the Earth is 23.5 degrees, since that is the angle between the equator and ecliptic) of the rotational axis means that the Northern Hemisphere is tilted toward the sun in June, and away from the sun in December. (The situation for the Southern Hemisphere is reversed, with the Southern Hemisphere tilted toward the sun in December and away from the Sun in June.)

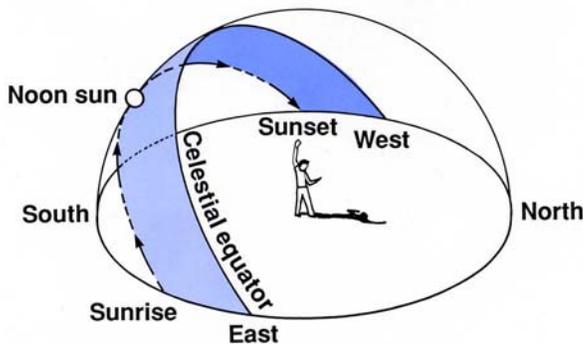
Many texts stop at this point and do nothing more to explain why there are seasons. However, we should examine more deeply **why** the obliquity of the Earth causes seasons. There are several factors we need to consider to explain this completely.

These factors all relate to the fact that when the Earth is tilted toward the sun, the sun appears higher in the sky (something we know from experience and something we simulated on the celestial sphere).

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a Summer Solstice



b Winter Solstice

**Paths of the Sun at summer and winter solstice**

Seeds, Horizons, 3rd ed., Fig. 3-5; Foundations of Astronomy, 1990 ed., Fig. 2-15

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image courtesy LPL/UofA

There are two reasons why the angle of the sun in the sky (we call this angle the **altitude** of the sun) effects the intensity of sunlight received on the Earth. The first of these factors

can be seen from the following diagram:

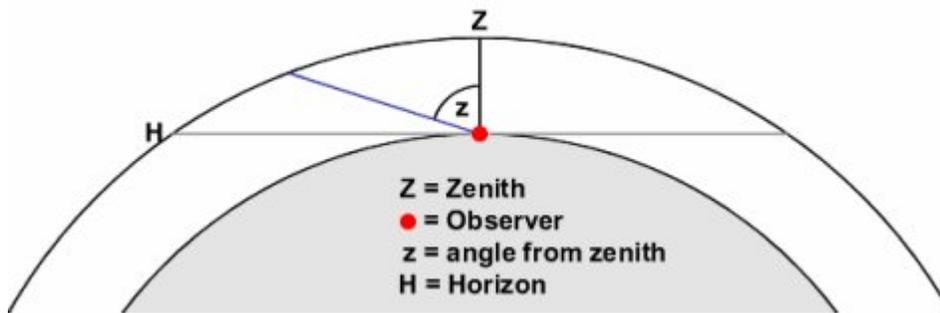
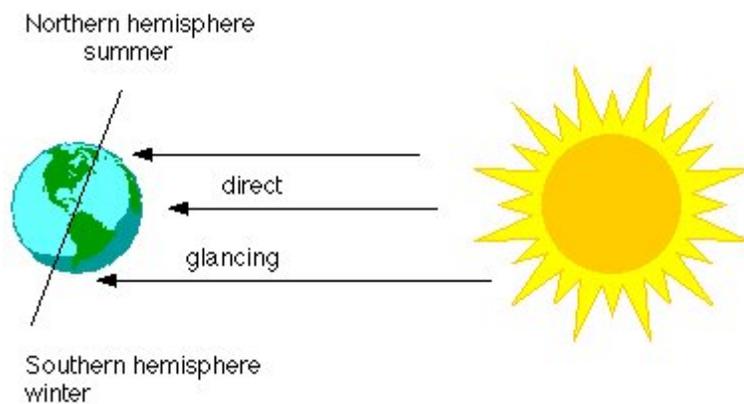


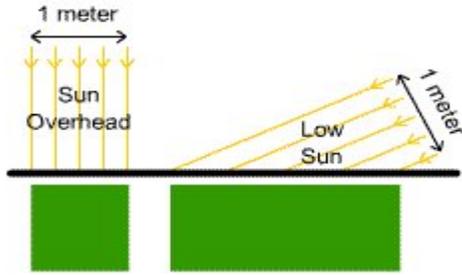
image courtesy Univ. British Columbia

This image shows the Earth surrounded by its atmosphere (denoted by the upper curve). Imagine the observer views the sun directly overhead; then, the rays of sunlight have to travel through a relatively thin layer of atmosphere as it travels along the line from z to the observer. However, if the sun is low on the horizon, see how much more atmosphere sunlight has to travel as it moves along the path from H to the observer. Since the particles and gases that make up our atmosphere can scatter and absorb sunlight before it reaches the surface of the Earth, less sunlight will reach the Earth if that light has to travel through a greater thickness of atmosphere.

The second important reason why the altitude of the sun determines surface heating is illustrated below:



Look carefully at some details in the diagram directly above. Notice that three solar rays drawn are parallel to each other. However, because the Earth is spherical, these rays will strike the Earth at different angles. The top and bottom rays, for instance, hit the Earth at grazing angles, while the middle ray will strike the Earth perpendicular to its surface. The angle at which sunlight strikes the Earth determines the intensity of the energy reaching the ground, and thus determines the amount of warming that will occur due to solar heating.



The diagram directly above shows this nicely. In both cases, we consider a beam of sunlight one meter across, so we ensure that we are considering the same amount of incoming sunlight. When the sun is overhead, this amount of light is concentrated in an area one meter across on the surface of the Earth. However, if the sun is at low angle (as shown on the right), the same amount of incoming solar energy is spread over a much larger portion of the Earth's surface.

These diagrams should make it clear that when the sun is high in the sky, the sun causes greater surface warming and thus higher temperatures; a low sun angle means there is less surface warming and consequently lower temperatures.

***Classroom Activity:***

Darken the lights in your room, and shine a powerful flashlight on the board or screen or other suitable surface. First, orient the flashlight so its light strikes the screen perpendicularly. In other words, orient the flashlight so its light simulates the drawing on the left. Note how bright the illuminated area is, and the size of the brightly illuminated area. Next, turn the flashlight so the light strikes the surface as shown in the drawing on the right. Notice how much larger and dimmer the illuminated area is. This is because the same amount of light is emitted from the flashlight of course, but now that amount of light is spread over a larger area, and cannot illuminate (or warm) that area as much as before. We can apply the concept of density here, and talk about the **energy density** of the light. In which of these two cases do you think the energy density is greater? What is your explanation for that?