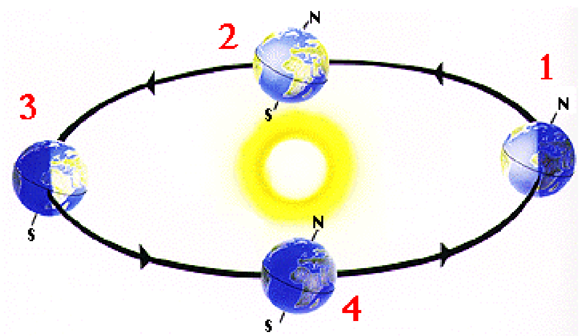
The Seasons on a Planet like Earth

As the Earth travels around the Sun, it moves in a giant circle 300 million kilometers across. (Well, it is actually a giant ellipse but the shape is so close to that of a perfect circle that you probably could not tell the difference by looking at it). That circle lies in a plane that astronomers call "the plane of the ecliptic" and the Moon and most of the other planets stick pretty close to that plane, too. There are many viewpoints from which we can imagine viewing this plane.

Viewpoint A: If we were to watch the Earth from some distant spaceship just a little above that plane, we might see something like this NASA illustration.



Notice that the orbit of the Earth does not look like a perfect circle here only because we are looking at the circle from the side. Also notice that the Earth's axis of rotation is not perpendicular to the plane of the ecliptic. It is 23.4° away from perpendicular and that angle does not change very much (although it has varied by a few degrees during the past 40,000 years). Notice that the North Pole is always pointing the same way as it moves around the Sun. By coincidence, it turns out that during this millennium it points toward the star Polaris, so we call Polaris the "North Star."

Viewpoint B: Now think of yourself as standing on some other distant space ship looking down on the Northern Hemisphere of the Earth but standing far enough away that you can see the entire orbit of the Earth. From our new vantage point, a connecting line from our spaceship to the Sun would be perpendicular to the plane. From this viewpoint the orbit of the Earth would appear to be a nearly perfect circle, but the North Pole of the Earth would still not be pointing toward us.

Using a java-compliant browser (Explorer and Mozilla work well) go to…
http://www.instruction.greenriver.edu/physics/seasons/
Click on the first animation: The north pole, observed from space

Getting oriented to this animation: The black dot on the Earth represents the North Pole seen from Viewpoint B above. To convert from Viewpoint A to Viewpoint B, we have to look down on the plane of the ecliptic from the top and turn our heads 90° to the side. The animation starts with the Earth in position #2 from the first drawing. This is orientation of the Earth during the Spring Equinox (trust us: you'll see why soon).

Click on the “Play” button. (Or the “1 month >>” button if you like.)

- **What do you notice about the daylight that reaches the North Pole as time goes on after the Spring Equinox?**

After about 91 days it will be the summer solstice (and the Earth should be near the SUMMER SOLSTICE label at the top of the screen). If you don’t want to wait 91 days (or if you have waited too long) you can click on the “Summer Solstice” button to restart the animation there.

- **What do you notice about daylight at the North Pole near the time of the Summer Solstice?**

If you have not done so already, click on the “1 season >>” button a couple of times.

- **Describe the motion of North Pole (or the axis of the Earth) as the Earth moves around the Sun.**

<u>Scroll to the bottom of the screen and move on to the next animation.</u>

This animation is much like the last except that now there is a “city” (shown by the red dot) to illustrate the rotation of the Earth about its axis. The city is in the northern hemisphere, about 45° north of the equator. Again, the animation begins at the Spring Equinox. Click the “Play” button.

- **As you watch the red dot move around the North Pole, what would you say about the lengths of days and nights (*in this city*!) near the spring equinox? (Hint: If it is going too fast, click Reset and then use the “3 hour>>” button.)**

- **Using whatever buttons you want, move ahead to the summer solstice. As you watch the red dot move around the North Pole, what would you say about the lengths of days and nights (*in this city*!) near the summer solstice?**

- **The above two observations were about the *length* of daylight at these two times of year. What would you guess about the *intensity* of daylight at these two times of year? (Go ahead and guess!)**

Repeat your observations above for the autumn equinox. You do not need to write anything here, but discuss your observations with your classmates.

Another viewpoint:

The two viewpoints we have examined so far are useful for keeping track of the Sun, the Moon, and the Earth, but at some point we will need to take a closer look at the Earth. We need a viewpoint from which to do that.

Scroll to the bottom of the screen and move on to the next animation.

The Moon has been removed from this animation and from all that follow. Since the moon is not directly related to our seasons, we do not need to consider it any further. This animation does show a blue dot in space. We imagine that this blue dot is a flying saucer and that we can ride around in this flying saucer and follow the Earth around the Sun.

Imagine that we look at the Earth through a window in the flying saucer. The flying saucer is oriented so that Sun is always directly to our left and the North Pole of the Earth is toward the top of our window (although not always straight up due to the tilt of the Earth). We cannot see the Sun through the window but we can see sunlight on the Earth.

- **What would we see through our window at the start of the animation (at the spring equinox)? Sketch what you think you would see and compare your ideas with your classmates.**

- **Click “Play” (or any other buttons) until the time is exactly 92 days (this is approximately the summer solstice rounded off to the nearest day, but do not use the “summer solstice” button yet). Notice that whole number of 24-hour days have gone by but daylight in the city is not the same as it was at the spring equinox. What would you see through the window now?**

Click “Play” or click “1 season >>” a few times. Try to imagine what you would see as you followed the Earth around in your little spaceship. You do not need to write anything here, but discuss your ideas with your classmates.

<u>Scroll to the bottom of the screen and move on to the next animation.</u> (Note: The next few animations are large and they may take a moment to load onto your computer.)

This is the view from the spaceship window. Click “Play” click “1 week>>” a few times to see if the view agrees with your predictions. Remember, you are not expected to understand the effects on weather and the seasons just yet. At this point you should only be checking to see whether the view through the window agrees with what you expected.

- **Does the view agree with your predictions? Discuss any differences (if any) that you may see.**

- **Click on “summer solstice” and repeat the process above. Does the view agree with your predictions?**

Repeat this process for the autumn equinox and the winter solstice. Discuss your observations with classmates. Consult an instructor if you do not understand what you are seeing. This is the viewpoint that will be used in all of the animations that follow so it is important to understand what is happening.

- **If we only look at the Earth through the window, we see a spinning ball and the axis seems to be moving. As seen through the window, at the spring equinox the North Pole seemed to lean toward us and at the summer solstice it seems to lean to the left. Is the axis really moving? Explain your reasoning.**

<u>Scroll to the bottom of the screen and move on to the next animation.</u> (Again, this may take a moment to load onto your computer.)

Now we are ready to closely examine a planet from our new point of view. This planet isn't exactly the same as the Earth since this is a planet where years are 40 days long, but we'll get to that in a moment.

The Sun is far to the left, far out of our field of vision. The left side of the Earth is in daylight and the right side is in darkness. The time of year is again set to be the spring equinox (for the northern hemisphere).

- **You may notice that your animator illustrated the Earth with the part on the far left a very bright green which fades to darker shades as we move toward the right. This continues until you get to the line that divides day from night. Consider the shading of the part that is in daylight. Some of the illuminated regions are *significantly* lighter than others. Why is this so? (Remember everything you have done so far and be careful about your choice of words!)**

Now play. In order to make the changes in the seasons visible, this animation was made such that an entire year is just 40 days long. Each season requires only ten days, so (unlike life on the real Earth) the orientation of this planet relative to the Sun changes noticeably in 24 hours. Notice that for this animation time is measured in *hours*, not days.

The tilt of this planet's axis is, however, exactly the same as that on Earth in the 21st century. At the spring equinox, our little spaceship is on the same side as the tilt of the North Pole. At the autumn equinox, our spaceship is on the same side as the South Pole.

The latitude of the city (the red dot) is exactly 45° N (which is to say that the city is located 45° north of the equator). That is pretty close to the exact latitude of Portland (Oregon), Montreal (Quebec), and Venice (Italy). The latitude of Seattle is about 47° N.

If you have not already done so, try clicking on the button for "Show/Hide city behind the planet." Although unrealistic, this allows us to follow the motion of our city when it is on the side of the planet away from us.

Play around and enjoy the view.

Click on “Spring Equinox.” The animation will run for a moment and then stop near local noon for our city. Think about the intensity of light (and other solar radiation) at this time. Do the same for “Summer Solstice” and “Winter Solstice.” Think about the intensity of light at local noon at each of those times of year.

- **On which day at noon is the intensity the greatest? On which day at noon is the intensity the least? *Why?* (Again, choose your words carefully!)**

The tilt (or *obliquity*) of the Earth’s axis is not completely constant. It wobbles by a few degrees every 40,000 years or so. Imagine that the tilt of the planet were *greater* than is currently the case on planet Earth (and thus greater than shown in these pictures). Look again at local noon at the two solstices and the spring equinox.

- **How would these pictures change if the tilt of this planet were increased? How would the intensity of light at the city change during summer? …during winter?**

- **Imagine that the tilt of the planet were *less* than on planet Earth (and thus less than shown in these pictures). Look again at local noon at the two solstices and the spring equinox. How would these pictures change if the tilt of this planet were reduced? How would the intensity of light at the city change?**

- **Click on “spring equinox” and look at the row of dots just below the city. These dots have a latitude of only 30° N. Look at the summer solstice and the winter solstice. How does the intensity of light at these dots compare to that at the city?**

- **Click on “spring equinox” and repeat the exercise above for the row of dots just above the city. These dots have a latitude of 60° N. How does intensity of light in summer and winter at these dots compare to that at the city?**

Now think about life in the city again. Click on “24 hours>>”. Think about the passing of a day and how the intensity of light varies during 24 hours. Click on “24 hours >>” a few more times and think about how the intensity of light varies over several days. (Remember, a season on this planet is only ten days long.)

- **Describe the changing intensity of light over a period of 24 hours near the spring equinox.**

- **Describe how your answer would change if you looked at the next 24-hour period or a 24-hour period a couple of days later.**

Discuss your ideas with a classmate and with a teacher.

When you are ready to do so, **scroll down and go on to the next animation.**

This animation is the same as the last with the exception that it comes with a graph of solar intensity as a function of time. The horizontal axis of the graph is the time measured in "fractions of a year" which looks strange until quite a few days go by, but don't worry about that.

Click "Play" and let a couple of days (50 – 60 hours) go by. (Then click "Pause")

- **Does the intensity of light change with time as you predicted it would? Discuss**

- **Click "Play" and let about 300 hours go by. If you didn't see the animation, could you look at the graph and identify the time of the summer solstice? How?**

A note about language: The word "sol-stice" refers to a time when the Sun (sol) is static or unchanging. The graph gives us an idea why ancient astronomers chose this name.

Scroll down and click on "Speed up the animation."

It would take a long time to run the previous animations for two "40-day years", so in order to make the animation go faster, some details were removed from the animation. Click "Play" and the animation really moves. To make the graph more readable you may want to click on "Track maximum intensities" and then sit back as the years fly by.

As two years go by, the animation will pass through two summer solstices and two winter solstices.

- **Can you identify the solstices on the intensity graph? How?**

- **Imagine this animation and graph were produced for a planet with greater obliquity (tilt). In what ways would the graph differ? (Hint: you can think back to your answer to a similar question on page 7.)**

- **Imagine this animation and graph were done for a city with a latitude of only 30° N. In what ways would the graph differ?**

- **What about for a city with a latitude of 60° N?**

<u>Scroll down and go on to the next animation</u>. This animation should look familiar. You've seen one just like this before, but we can use it to do a quick experiment (that would take months to do on Earth). The animation should stop at time "12 hours" which is just about local noon at the spring equinox. You can move the time ahead and back in increments as small as 12 minutes.

- **Move the time ahead and back and watch the dot to determine the length of daylight at the city during the spring equinox. Record your result here.**

- **Click on "Summer Solstice." Move the time ahead and back to determine the length of daylight at the city during the summer solstice. Record your result.**

- **Click on "Autumn Equinox." Adjust the time to determine the length of daylight at the city during the autumn equinox. Record your result.**

- **Click on "Winter Solstice." Adjust the time to determine the length of daylight at the city during the winter solstice. Record your result.**

- **After watching the animation at each of these times, explain why the length of daylight changes throughout the course of the year.**

Scroll down and go on to the next animation. (Which may take a while to load.)

This animation does the work of measuring the lengths of the days for you. When the city is in daylight, the graph starts counting. It stops when the city reaches nightfall. You can read numbers off of the graph by *left-clicking* on it. You can get a bigger graph by *right-clicking* on it and enlarging the picture that you get (which you can then left-click on as well).

- **Does the graph agree with the measurements that you made?**

- **By looking only at the graph, can you identify the solstices? How?**

- **How would the graph differ on a planet that had a greater obliquity (tilt)?**

The data on this graph is a little "choppy" since some accuracy was sacrificed to get the animation and the graphing program to run at the same time. We can produce more accurate graphs if we shut down the animation.

To produce a more accurate graph, click on "Show more detail in the hours on the graph." The web page that comes up shows two graphs, but the one on the right is just a close-up of the middle portion of the one on the left. (Try "Rapid Plot" if you are in a hurry.)

Whenever you are ready, click on "I'm done. Go on."

Congratulations! You are done with these animations on the seasons on Earth. Before we quit, think about it one more time:

What causes the seasons on Earth? What's important in determining our seasons? (You may have two answers to that one.) What isn't important (although most people seem to think it is)?