Chapter 4

The Sun Goes Up; the Sun Goes Down

In This Chapter

- Where the Sun rises and sets changes over time
- Solstices and equinoxes
- The tilt of the Earth's axis sets the season
- The Sun follows the ecliptic: the equation of time
- The Sun moves among the stars on a yearly cycle

A story is told about a grizzled veteran reporter who was next to a novice reporter at a desert location, both waiting for the night to end. The novice said, "Will the Sun rise over there in the east?" And the more experienced reporter replied, "If it doesn't, you will have yourself one hell of a story."

In this chapter, we discuss the position of the Sun in the sky as observed in different ways and how it affects our Earth.

Sunrise, Sunset

Since the time of Copernicus, Kepler, and Galileo, people have known that the Sun doesn't actually rise. Actually, of course, the Sun holds steady at the center of our solar system; it is our Earth that is turning. Only from our point of view, standing or sitting on our rotating Earth, does the Sun appear to move in the sky.

Fun Sun Facts

A traditional story is told about what happened in 1616 after Galileo, having been shown the instruments of torture (like the rack) by authorities of the Inquisition, abjured his claim that the Earth moved around the Sun instead of vice versa. As Galileo left the room, he murmured, "And yet it moves," meaning the Earth.

From our position on Earth, we can imagine that there is a *celestial sphere*, a large sphere surrounding us with the stars pasted on it. It appears as though that celestial sphere is rotating overhead. Actually, the Earth rotates on its axis once every 24 hours—that is, once a day. At any moment, half the Earth—the side that is facing the Sun—gets sunlight, making daytime. The other half gets no sunlight, and so it is nighttime.

The frontispiece from Galileo's book on The Dialogue of the Two World Systems, *published in 1632. This book led to Galileo's house arrest. The figures are labeled, left to right, Aristotle, Ptolemy, and Copernicus, but the figure labeled Copernicus is drawn with Galileo's face.*

(Jay M. Pasachoff)

The Sun rises in the eastern part of the sky, goes high in the sky to our south, and sets in the west. Usually, though, it doesn't actually rise exactly east or set exactly west. And it never passes exactly overhead in the continental United States. That overhead point is called the zenith, and the Sun reaches it in the United States only for people in Hawaii.

To simplify the matter, let us imagine three cases. Two of them are especially simple. First, let us put ourselves at the equator. Next, let us put ourselves at the North Pole. Finally, let us go to our actual situation, approximately one third or one half of the way between the equator and the pole. That brings us from a latitude of about 26° for the Florida Keys to 35°, which passes through southern California and Georgia, to latitudes of about 45°, which pass through Oregon, Minnesota, and northern New England, up to 50° on the central and western border with Canada.

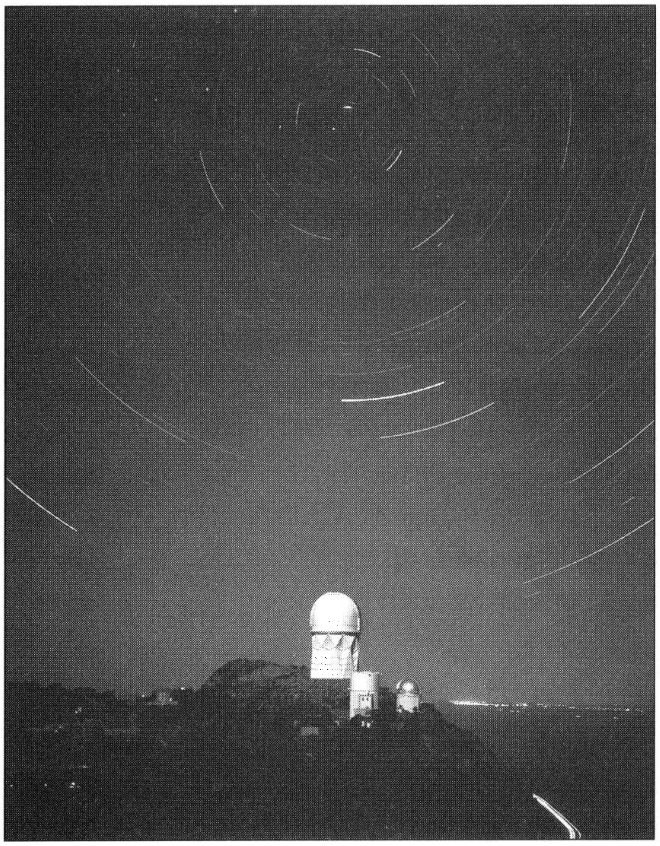
Sun Words

The **celestial sphere** is the imaginary sphere surrounding the Earth with the stars on it. The **zenith** is the point in the sky directly over your head.

Solstices and Equinoxes

Let's go first to the equator, putting on our swimsuits. From this position, everything rises straight up. Polaris, often called the north star, lies on the northern horizon. (Polaris is near the north celestial pole, which lies above the Earth's North Pole. It is within 1° of the north celestial pole, though it isn't exactly there.) All the stars appear to move in half circles around Polaris. Near it, stars execute little circles, rising straight up and over only to set straight down. Farther south toward the east on the horizon, the half circles we see are larger. Due east, stars rise straight up, pass directly overhead (passing through our zenith), and set due west.

Just where the Sun is among the stars varies over the year. On two days during the year, known as the vernal equinox and the autumnal equinox, the Sun rises due east and sets due west. But over the year, the Sun changes the position of its sunrise, something known at least as far back as the time over 4,000 years ago when Stonehenge was built. The vernal equinox occurs around March 21. It is called an "equinox" because, geometrically, day and night are equal. (We really mean *daytime* and *nighttime;* the word *day* has different meanings: the duration of sunlight and the 24-hour period of Earth's rotation.) Actually, that calculation of an equinox is for a mathematical point at the center of the Sun. Of course, really the Sun is bigger than a point, and its top rises a little ahead of its center. That is one of the reasons daytime is a little longer than nighttime on the day of the equinox.



Star trails around the north star, Polaris. Polaris is a fairly faint star, but it happens to be located near the north celestial pole.

(National Optical Astronomy Observatories/AURA/NSF)

For three months following the vernal equinox, the Sun rises farther north on the horizon each day. It does so at a rapid rate for a while, but close to three months later, it rises less and less rapidly farther north, until it appears to pause on the horizon for a few days around June 21, which is the summer solstice. Then it starts moving south on the horizon for the next three months until about September 22, when we have the autumnal equinox.

At the equinoxes, the Sun crosses the celestial equator, the giant circle on the celestial sphere that lies above the Earth's equator. At the autumnal equinox, it is moving day by day from north to south, and it rises due east and sets due west. Only at the equinoxes does it do that. And only for observers at the equator does it go straight overhead on that day.

The units used to measure how far north or south the Sun is of the celestial equator are called declination. Declination is measured in degrees north or south of the celestial equator.

For our position at the equator, it is direct to see that the declination corresponds to the angle on the horizon north or south of the equator. Angle measured around the horizon is called azimuth. Due north has azimuth of 0°, east has azimuth of 90°, south has azimuth of 180°, and west has azimuth of 270°.

Now let us imagine ourselves at the North Pole, wearing heavy parkas. Mostly we can be standing on ice while there, though sometimes the ice opens and ships can sail up to it. While at the North Pole, the north celestial pole (marked by Polaris, the north star, nearby it) is directly overhead. The stars move in small circles high in the sky and in larger circles lower down. The circles are all horizontal. The stars neither rise nor set in the sky.

At the time of the vernal equinox, the Sun is at the equator. Since the equator lies on our horizon all around, we see the Sun all the time. As Earth turns, the Sun appears to move around the horizon but is always visible. We say that it is the "midnight Sun," since it is visible even at midnight.

For the next three months, the Sun gets higher in the sky, until it reaches an altitude (the height above the horizon in degrees) of 23½°. Then it gets lower and lower until, another three months later, at the autumnal equinox, it is again at the equator. We have had six months of sunlight. The day, if we define it as when the Sun is up, has been six months long.

Fun Sun Facts

At and near the South Pole, the Sun is set for many months each year. It is dark and, therefore, cold. But in the Antarctic springtime each year, when the sunlight hits the cold upper atmosphere for the first time in months, some of the ozone (a molecule containing three oxygen atoms) is torn apart in interactions with chlorine. That chlorine has been put into the atmosphere in Freon from air conditioners, spray cans, and other human-made sources. Use of older kinds of Freon has been banned from future air conditioners, and different propellants are now used in spray cans. Partly as a result the ozone hole may have stopped getting bigger each year. We hope that the ozone layer will recover completely, in some decades. Eventually, it should no longer ever appear. We will discuss the ozone hole further in Chapter 27.

Now let us go to our real position, at moderate latitudes. Now the whole sky seems to tilt for us. At the vernal equinox, the Sun still rises due east, but now it slants toward the south as it goes through the day. It again sets due west. On succeeding days, it rises farther and farther north, until June 21, when it rises 23½° north of due east. Then it rises farther south each day until September 22, when it is again rising due east. For the rest of the year, it rises south of due east.

Fun Sun Facts

Though the longest day of the year in terms of daylight is June 21, the latest sunset doesn't occur until June 27. The earliest sunrise takes place on June 15.

Fun Sun Facts

Why isn't the duration of sunlight equal to the amount of nighttime on the days of the equinoxes? First, as we have seen, the top of the Sun rises a couple of minutes ahead of the center of the Sun, for which the calculations are made. Second, the Earth's atmosphere bends sunlight, so when we are looking straight out, we are really seeing light that has been bent downward a bit toward us. That adds another couple of minutes. Third, the Earth's orbit around the Sun is elliptical, and the Earth's speed on its orbit around the Sun varies smoothly over the year. That adds a little more time. Daytime actually is greater than nighttime by about 10 minutes at the day of the equinoxes. It takes a few extra days around the times of the solstices for actual day and actual night to be equal. Thus, equal day and equal night occur a few days before the vernal equinox and a few days after the autumnal equinox.

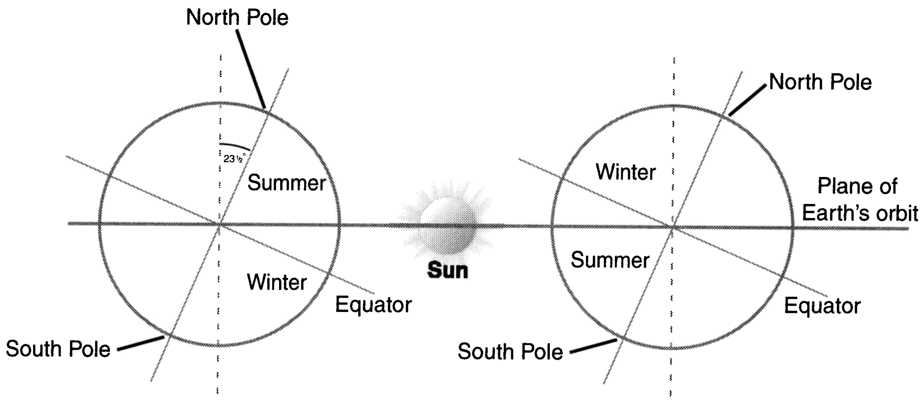
Princess Summerfallwinterspring

In the early years of television, from 1947 through 1960, a favorite kids' show was based on the puppet Howdy Doody. Howdy now lives in the Smithsonian in Washington. Along with the main characters—Howdy and live people playing Buffalo Bob and Clarabelle, the clown—were some secondary characters. One of the nicest was Princess Summerfallwinterspring. Her name embodied the seasons.

But why do we have seasons? Many people think incorrectly that the seasons occur because the Earth is at different distances from the Sun at different times of year. But that idea is just wrong. Though the Earth's orbit is an ellipse, the ellipse is so close to being a circle that the difference in distance doesn't matter. Furthermore, the Sun is actually closest to the Earth on January 4 each year. That is winter for us in the northern hemisphere, not the summer that would be the result if the distance mattered.

No, the seasons are caused by the tilt of the Earth's axis. The axis stays pointing in the same direction as the Earth moves around the Sun. In the summertime, the north half of the axis is pointed toward the Sun. For us at middle northern latitudes, the Sun is more nearly overhead. It is up longer and is higher in the sky. Those factors make it hotter for us. Because the Sun is overhead, each bit of sunlight brings its full energy to the area of Earth it hits.

What is it like in the southern hemisphere when we have summertime in the northern hemisphere? The Sun is then low in the sky there and is up for a relatively short time each day. That makes it cooler for the southern hemisphere. Each bit of sunlight is spread out, since it hits the Earth at a big angle. Thus, the energy in that sunlight has to heat more area of the Earth, and the Earth is just cooler. That makes it winter for them.



The seasons are caused by the tilt of the Earth's axis, not from changes in the Earth's distance from the Sun.

If the Earth's orbit weren't tilted, we wouldn't have seasons. Mars's orbit is (now) tilted at about the same angle as Earth's. So Mars has similar seasons. Each Martian spring, giant dust storms arise as a result of the change in seasons. The planet Uranus is lying on its side, so its seasons are very strange. Its set of seasons takes 84 years to cycle, since that is Uranus's orbital period around the Sun. The North Pole of Uranus, for example, has a midnight Sun that lasts 42 years followed by 42 years of darkness.

Figure 8s in the Sky

Ice skaters do figure 8s all the time, but did you know that the Sun does a figure 8s in the sky with respect to the stars? It does so in part because the Sun doesn't keep good time—at least, not good time compared to your watch.

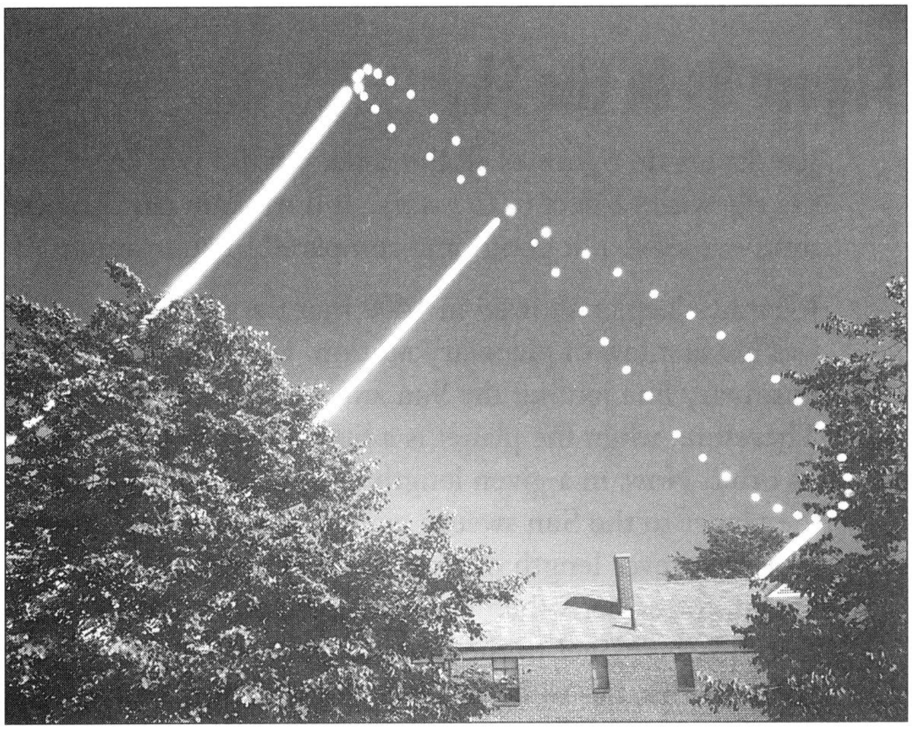
Johannes Kepler showed in 1609 that the planets go around the Sun in ellipses, which was his first law of planetary motion. His second law of planetary motion was that the imaginary line joining the Sun and a planet sweeps out equal areas in equal times. Therefore, when the planet is a little closer to the Sun, it has to move a little faster on its orbit. Now, in a given length of time, as a planet moves on its orbit, the line joining the planet to the Sun sweeps out a triangle, with the sharp point of the triangle at the Sun. Whatever length of time we consider (say, a day), the area of that triangle has to remain the same. When the planet is closer to the Sun, the two legs of the triangle that link the planet to the Sun are relatively short. So the third leg, the one along the planet's orbit, has to be relatively long. A long arm, corresponds to a high speed for the planet in its orbit.

As a result, the Sun appears to move a little faster in the sky in the wintertime, since the Sun is closest to the Earth on January 4 each year. If you define "noon" as when the Sun is due south of you, then you don't have to worry about the Sun's rate. But if you carry a watch, you can discover (perhaps by putting up a stick to cast a shadow) that the Sun isn't actually due south at noon on your watch.

Because it is convenient to wear watches, the world has defined an average time, called mean solar time, for watches and clocks to keep. But on a day-to-day basis, the Sun doesn't keep that average. Sometimes it is ahead, and sometimes it is behind.

Remember also that sometimes the Sun is at northern declinations—that is, north of the celestial equator. And sometimes the Sun is at southern declinations—that is, south of the celestial equator.

The two effects together can show up in interesting ways. The following figure shows a very remarkable image made by setting up a camera in a window for a year. The photographer, Dennis di Cicco, had his camera set to take a photo at the same time of the morning, 8:30 A.M., every two weeks. You can see that the Sun is sometimes ahead of its average and sometimes behind, and how much it is ahead or behind varies at the same time the Sun's height above or below the celestial equator varies. This image shows the Sun's positions tracing out a figure eight. At certain times of the year, di Cicco, an editor of *Sky & Telescope* magazine, left the camera open from sunrise onward for a while, to show the angle at which the Sun rose.



The analemma, shown as a series of actual photographs taken at the same time of day every 10 days for a year. The Sun was photographed through a dense, special solar filter, and on one day, the background was photographed without a filter. On certain days, the camera was also left open to expose the Sun rising.

(Dennis di Cicco)

In the preceding figure, the summer solstice shows the Sun at the highest point, at upper left, and the winter solstice shows the Sun at the lowest point, at lower right. This figure-8 shape is known as the *analemma*, and you sometimes find an analemma drawn onto a globe, for convenience. It is often put in the middle of the Pacific Ocean, just because there is a lot of blank space there.

The Solar Scoop

You can see analemmas on the Internet at the Astronomy Picture of the Day, antwrp.gsfc.nasa.gov/apod for July 9, 2002, and for March 20, 2003, using the following: antwrp.gsfc.nasa.gov/apod/ap020709.html, for 2002 July 09 and antwrp.gsfc.nasa.gov/apod/ap030320.html for 2003 March 20.

At the widest point of the analemma, the Sun is about 16 minutes ahead or behind mean solar time (see the preceding figure). Some of the difference comes from the varying speed of the Earth in its orbit around the Sun, and the rest comes from the tilt of the Earth's axis.

If you look at a sundial, you will find that the time on the sundial differs by as much as 16 minutes from the time on your watch. But if you make the shadow stick (known as the gnomon) on a sundial in the shape of an analemma, you have a sundial that keeps time and that matches time on your watch, and you can read it to a minute or so of accuracy.

The comparison of the apparent time kept by the actual Sun with the mean solar time kept on your watch is called the equation of time.

Fun Sun Facts

Most people are familiar with four basic time zones for the United States: Eastern, Central, Mountain, and Pacific. But the Virgin Islands are in the Atlantic Time Zone and Alaska, Hawaii, and Samoa have their own time zones. A group of South Pacific islands, including Guam and the Northern Marianas, are in a time zone fairly recently (in 2001) named Chamorro. So there are eight United States time zones.

Russia is so big that it spans nine time zones. How many time zones does China have? The answer is one. Everyone in China is on Beijing time, even though China is so broad.

Not all time zones are spaced at hourly intervals. The central part of Australia is only a half hour off from time in eastern Australia. That makes a gap of 1½ hours to the time zone of western Australia. Nepal's time zone is only 15 minutes off from India's. King Edward VII of England kept time a half hour different from Greenwich mean time at one of his estates.

In the Zone

If you kept time by the actual Sun, then somebody a few miles to the west of you would have noon slightly later than you do. These small effects didn't matter until the growth of the network of trains in the nineteenth century meant that it would be good to have a standard set of time zones. The time zones were set up at an international conference in 1884. Within each time zone, the time would be the same. Since the Sun goes 360° around Earth in 24 hours, it goes 15° in 1 hour. Therefore, each time zone was made one hour wide. The time zones are spaced with their centers at 15° intervals.

Saving Daylight

If you live in Hawaii, the Sun sets at about 6 P.M. all year, a little later, but not very much later, in the summer. But if you live at temperate latitudes, the length of the day varies a lot more.

Let's say that as you go into April, you notice that the days are getting longer. It is lighter longer after you get home from work or school. To give yourself more sunlight hours, then, why not just take 7 P.M., when it gets dark, and call it 8 P.M.? So, if you get home at 6 P.M. from work or school, you now have two hours of sunlight (6 P.M. to 8 P.M.) instead of only one. Businesses can then sell a lot of extra items, like barbecue briquettes. But if you are a farmer who works until sundown, then your after-work interval until bedtime is likely to be shorter.

This kind of transition is called daylight saving time and, in European countries, "summer time." Most places in the continental United States follow daylight saving time, adding an hour in the spring and taking an hour away in the fall.

By moving the clock forward in the springtime, it means that 6 A.M. is now 7 A.M. In the fall, when you move the clock back, 7 A.M. becomes 6 A.M., and kids waiting for schoolbuses might have to stand in the dark. So some people are opposed to daylight saving time.

Hawaii doesn't follow daylight saving time because the length of the day doesn't vary much at its latitude. Alaska doesn't follow daylight saving time because so much of it has midnight Sun. Much of Indiana, the part on Eastern time, doesn't follow daylight saving time. The opening show of the TV series *The West Wing* in 2002–2003 revolved around some of the characters getting stranded because they didn't realize that they were switching time zones as they traveled in Indiana.

Some places are on double daylight saving time. Two extra hours of daylight can save a lot of oil.

Keeping the Calendar

Once around the Sun for the Earth makes a year. But while we sit on the Earth as it travels, Earth spins on its axis. And each time it spins, it is one day more. For the moment, let's take the grand point of view, looking down from high above the solar system, out among the stars. From that point of view, when the Earth spins 365 times, it isn't quite back to its one-year position in its orbit. Earth has to spin about another quarter of the way before it gets back to the position that marks the passage of one year.

Thus, our year is 365 days long. But thousands of years ago, people didn't know so much, and tended to keep track of time more with the moon. (That is why we have the name month, which comes from "moonth." The Moon goes around the Earth around every 28 days, pretty close to the 30 or 31 days of our usual month.)

About 4,000 years ago, the Babylonian year had 360 days, and they occasionally added an extra month, to make the number of days average 365. Today's Jewish calendar similarly adds 7 leap months every 19 years.

Back in Roman times, the number of days in a year wasn't standardized. The emperor Julius Caesar called for a 445-day year in 46 B.C.E. to bring the dates of the year in line with the seasons. The Julian calendar, which was also part of his reform, introduced our basic system of leap years. The Julian calendar's year was 365 days long most of the time, but every fourth year, an extra day was added. That made the average year 365¼ days long.

Actually, however, the year is about 11 minutes short of 365¼ days. So after centuries, the calendar drifted out of synch with the seasons again. The sixteenth-century Pope Gregory XIII convened a group of astronomers and others to carry out calendar reform. He particularly wanted Easter to be realigned with the spring. The Pope, acting on the recommendations, declared that the day after October 4, 1582, would be October 15, 1582. The Gregorian calendar continued the system of leap years. But it omits the leap year every hundredth year, to make the year a little shorter. And that corrects by too much, so it restores the leap year every four hundredth year. That is why the year 2000 was a leap year, even though 1900 was not. This reform will keep the calendar in step with the seasons for thousands of years.

Fun Sun Facts

It was very confusing for people during the 10 days that were skipped on the calendar. "Give us back our fortnight," was the cry. Of course, people didn't really grow older by 10 days; it merely appeared that way on the calendar.

Though many countries adopted the Gregorian calendar in 1582, Britain and its American colonies didn't adopt it until 1752. At that time, we skipped 10 days—the day after September 2 was September 13. The calendar, which we adopted then, also moved the first day of the year back from March 25, about the equinox, to January 1. Until then, dates in January, February, and most of March would have been in one year in the Julian calendar and another year in the Gregorian. If you look at George Washington's family bible, which is preserved at Mt. Vernon by the Ladies' Association of the Union, you see his birth recorded as "11th day of February 1731/2." Skipping the 10 days made his birthday February 22 for us, and we use 1732 as the year.

The Least You Need to Know

- The Sun rises as much as 23½° north or south of east, depending on the time of year.
- On about March 21 and September 22, the Sun goes from one side of the equator to the other, making the equinoxes.
- Day and night aren't quite equal on the days of the equinoxes.
- The seasons are caused by the tilt of the Earth's axis, not by the Earth's changing distance from the Sun.
- Time zones were set up to standardize time within bands hundreds of miles wide, since the Sun is usually ahead or behind time on your watch.