The rotating Earth

In the last article, we mentioned that the Sun seems to rise in the East and to set in the West, because the Earth rotates from the West to the East. A careful reader may have also noticed that not only the Sun, but also the stars must seem to be moving because the Earth is rotating. To understand what I mean, see Fig. 1, and Fig. 2. In Fig. 1, we have drawn the rotating Earth and the celestial sphere. Let me explain what the celestial sphere is. Stars are much farther away than the size of the Earth. More than billion times the size of the Earth. Therefore, it would be impossible to draw the Earth and the stars on the same page. Therefore, it is convenient to draw the stars as if they were located on the celestial sphere, by dragging them to it. After all, when observing the stars, what is important is not how far they are but on which directions they are located. Drawing the stars on the celestial sphere doesn't change the direction. In Fig. 2, we see the perspective on the Earth. If you are on the Earth, you don't see the Earth is rotating, because you are rotating with the Earth. Instead, you see that the other things, the stars on the celestial sphere are rotating in the opposite direction. This rotating direction is denoted by the two big arrows.

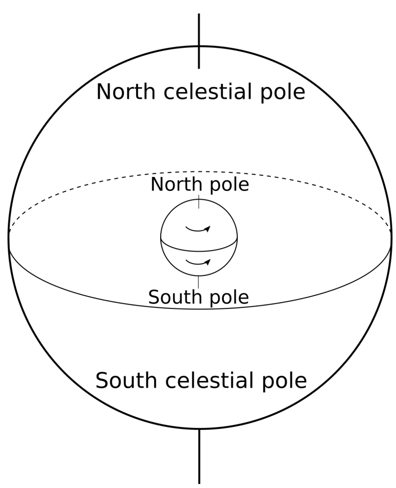

Figure 1: The Earth rotating with the celestial sphere fixed in the sky.

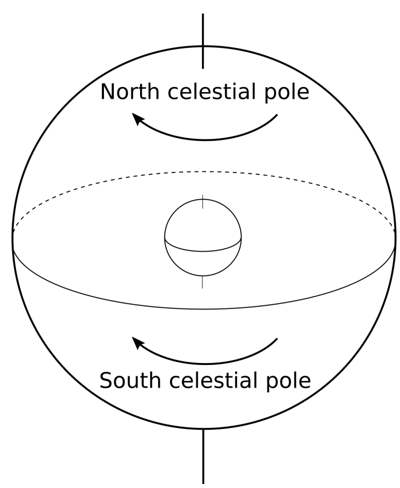

Figure 2: The Earth now is fixed and the celestial sphere has an apparent rotation.

Now, imagine you are at the North Pole. Then, the North Celestial Pole is right above your head. You will also see that the stars are rotating around the North Celestial Pole as their center. See Fig. 3 for what you see as an observer at the North Pole. You see a half sphere, and the base of the half-sphere is a circle, which denotes the horizon. The observer is at the center of the circle, and the arrows denote the rotating direction of the stars. The altitude of the North Celestial Pole is 90° as denoted in the figure. 90° is also the latitude of the North Pole. Now, imagine that you look at the sky as the observer on Fig. 3. Then, you will see that the rotating direction will be the counter-clockwise direction as in Fig. 4.

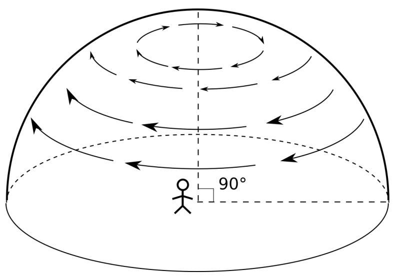

Figure 3: The rotating celestial sphere seen at the North Pole.

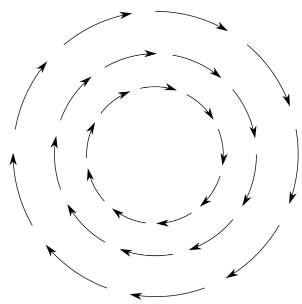

Figure 4: The observer view of Fig. 3.

Now, imagine you are at the equator. Then, the North Celestial Pole is at the Northern horizon. See Fig. 5. As the North Celestial Pole is at the horizon, its altitude is 0°. 0° is also the latitude of the equator. Now, imagine you are at the latitude 30° N. See Fig. 6. Then, the North Celestial Pole is located at the Northern sky with the altitude 30°.

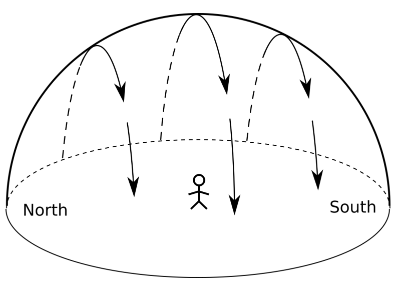

Figure 5: The rotating celestial sphere seen from the equator.

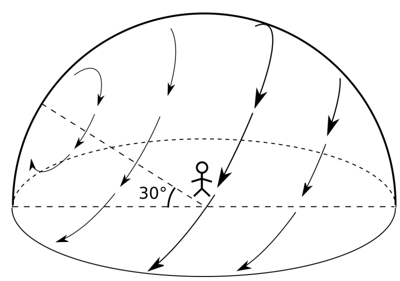

Figure 6: The rotating celestial sphere at a latitude of 30° N.

Suppose you are a navigator of a ship in ancient times. It is important to find your location at sea to arrive at your destination safely. However, it is not an easy job if you are on the middle of the ocean without any islands or lands nearby. Nowadays, you can easily find your location by GPS, but there were no GPSs in ancient times. So, how did the navigators find their location? If you find your longitude and latitude your job is done. Finding the latitude is easy. You can just measure the altitude of the North Celestial Pole, if you are on the Northern hemisphere, or the altitude of the South Celestial Pole, if you are on the Southern hemisphere. At the moment (21st century) a star called "Polaris" is very near the North Celestial Pole. Therefore, it is often called “the North Star.” Once you locate the North Star on the night sky your latitude can be easily measured.

How about your longitude? It’s much harder, because it requires a good clock. To understand this, let me first explain the relation between the longitude and the time difference. The Earth rotates once a day, i.e., 24 hours from the West to the East. (Actually, the Earth rotates once not every 24 hours, but 23 hours 56 minutes and 4 seconds. I will explain later why there is such a difference in “History of Astronomy from the late 17th century to the early 20th century.” For the time being, we can ignore this issue.) As a whole rotation is $360°$, the Earth rotates $15°$ per an hour. From a perspective of someone on the Earth, the Sun moves westwards $15°$ in longitude per an hour. Let me give you an example. The longitude of Philadelphia, United States is $75°$ W, and the longitude of London, United Kingdom is $0°$. Therefore, it takes 5 hours ($= 75°/15°$) for the Sun in London comes over to Philadelphia. Thus, the local time in Philadelphia is 5 hours late than the local time in London. Actually, the Sun is located at due south around noon. Therefore, the noon comes in Philadelphia 5 hours later than the noon in London. When Philadelphia is noon the London is 5 pm.

Now, suppose you are in London, United Kingdom. You set your watch in London time, and go to Philadelphia either by sea or by airplane. Upon arriving, you look at the Sun, and find out that the Sun is located at due south. Then, you will know that it is noon in Philadelphia. If you look at your watch, it will say it is 5 pm in London. Thus, you can figure out the longitude of Philadelphia. It is $75°$ W($= 15° \times 5$).

How can we figure out the longitude at night when there is no Sun? Don’t worry. We can see stars, and the stars can play exactly the same role as the Sun did play in our example. Just as we could figure out the longitude from the location of the Sun and a good clock, we can figure out the longitude from the location of the stars and a good clock. On the Northern hemisphere, the stars seem to rotate $15°$ per an hour in counter-clockwise direction. Just like the Sun passes due south at noon, if you know at what time certain stars pass due south or due north in certain dates of year from previous astronomical observations, you can figure out your local time, and then you can figure out your longitude from a good clock you set at a distant reference location.

So, you see that there are two elements needed to determine the longitude. Astronomical observation, and a good clock. The astronomical observation is the easy part.

Humanities have been doing it for quite a long time. The good clock is the hardest part. As determining longitude was not easy, some ships turned toward the latitude of their destination and moved westwards or eastwards along the line of a constant latitude. This way, they could not surely miss their destination. However, this would mean that the ships were not following the paths that would take the shortest time. This was a big trouble, because the seamen could not eat fresh vegetables or fresh fruits for a longer period of time, which caused diseases as scurvy.

In the 17th century, the famous scientist Galileo Galilei suggested a method to determine the longitude, but it was never used at sea, but on land. From 1767 to the middle of the

19th century, "the lunar distance method" was widely used to determine the latitude. In the middle of the 19th century, accurate clocks that can work on ship became affordable, largely replacing the lunar distance method. (Pendulum clocks which are accurate, but cheap and easy to make cannot work on ships, because ships are rolling at sea.) We will talk more about Galileo Galilei's method and the lunar distance method in our later article on history of astronomy.

Summary

- Due to the rotation of the Earth, the stars at night seem to rotate around the North Celestial Pole and the South Celestial Pole.
- The altitude of the North Celestial Pole is given by the latitude of the observation point.
- Therefore, the latitude is easy to measure.
- On the other hand, the longitude used to be hard to measure at sea, until the invention of affordable accurate clocks that work on rolling ships.