A BRIEF ESSAY ABOUT TIME

by

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Time is the interval between two measurable events, such as the ticks of a clock or the beat of a heart. Before the invention of clocks, people often used the apparent motion of the Sun across the sky to tell time. Time using the visible or real Sun is called ***local apparent solar time*** (LAST). This is the time indicated on a sundial, that is, it is time by the position of the Sun in the sky relative to one's ***local celestial meridian***. The latter is an imaginary circle in the sky running from the north point of one's horizon, through the point overhead (the ***zenith***), to the south point of one's horizon. When the Sun crossed one's meridian it was decided this would be midday or 12:00. Hence the terms ante meridian (AM) and post meridian (PM). In ancient times, it was also decided that the interval between two successive transits of the Sun past one's meridian should be called a day and that it consisted of exactly 24 hours.

However, LAST is not the time we use today on our clocks. There are two reasons for this. First, the Sun appears to move at a varying rate along an imaginary circle in the sky called the ***ecliptic,*** as a result of the Earth's variable speed in its elliptical orbit around the Sun. This means that the interval between transits of the Sun past one's meridian changes throughout the year. Secondly, the Earth's axis of rotation is tilted with respect to the plane of its orbit (which is the same as the plane of the ecliptic). This also causes the length of the apparent solar day to be different at different times of the year. Hence, keeping time by the real Sun is not practical in modern times.

The time we use on our clocks is called zone time, **ZT**. Everyone living within a specified zone of longitudes agrees to use the same time on their clocks, regardless of the exact location of the Sun in the sky, but close to it. Everyone within a specific time zone is actually using the mean or average solar time of the central meridian of that time zone. This is necessary in a world where people travel relatively large distances very quickly. However, modern zone time passes at a precise and constant rate, which is determined by modern atomic clocks. However, the length of the *mean solar day* has been tied into the rotation of the Earth on its axis in the following way: The length of the ***mean solar day*** is now defined to be 86,400.002 seconds, as kept by atomic clocks. That extra 0.002 seconds every day accumulates over a year to about 0.73 seconds. So after a year or two, we may need to add a second to our other clocks to have them agree with the atomic clock. Leap years complicated this a bit. That is, the length of the year of the seasons is not 365 days, but 365.2422 days. That is why we need to add an extra day to the calendar every year four years, except century end years not evenly divisible by 400, such as 1900. This is in accord with the Gregorian calendar rule developed by the astronomer Clavius for Pope Gregory XIII in 1582.

Leap yeas originated with the development and incorporation of the Julian calendar in the Roman Empire in 45 B.C. The old Roman calendar had 10 months and the new year began in spring. Later, January and February were added to make a 12 month year, but they were added to the end of the year rather than the beginning. Julius Caesar employed the Greek astronomer Sosigenes to develop a new calendar which became effective by imperial decree on January 1, 45 B.C. The Julian calendar introduced leap years, thereby making the average Julian calendar year to equal 365.25 days in length. But this is 11 minutes and 14 seconds longer than the true length of the year of the seasons (365.2422 days), which is called the **tropical year**. The tropical year is defined to be the length of time between two successive arrivals of the Sun at the **vernal equinox**, which is the point on the celestial equator where the Sun crosses the celestial equator moving from south of the equator to north. This event marks the first day of spring and the beginning of the year in the Roman Empire.

In 45 B.C., March 25 was the first day of spring and the first day of the year, but the initiation of the Julian calendar was on January 1 of that year. That is, it followed December 31, 45 B.C. Since the Julian calendar is slightly longer than the tropical year, the day the Sun arrived at the vernal equinox slowly began to come earlier and earlier every year. By the sixteenth century, the date of the vernal equinox had migrated to March 11. In 1582, Pope Gregory III enlisted the German Jesuit astronomer and mathematician Christopher Clavius to revise the calendar so that the first day of spring always occurred on the same day. This was accomplished by declaring that only century end years that are evenly divisible by 400 would be leap years. For example, 1600 would be a leap year but 1700 would not. In effect, this reduced the average length of the year to be 365.2425 days. So by papal decree, this calendar was put into effect in October of 1582. In addition, October 4, 1582 was followed by October 15, 1582, thereby dropping 11 days from that year. This had the effect of moving the date of the vernal equinox to March 21. This was intentional, since this was when the vernal equinox event was occurring at the time of the Council of Nicaea in the 4th century A.D.

Protestant counties such as England and its American colonies did not immediately institute this change. Eventually, Parliament adopted the Gregorian reform in 1752. This was accomplished by having September 2, 1752 be followed by September 14, 1752, thereby bringing the first day of spring to coincide with the calendar of other countries already using the Gregorian calendar. At this time, it was also decided to move January and February to the beginning of the year rather than have these months at the end of the year. This was accomplished by having January 1, 1752 become instead January 1, 1753. Therefore, 1752 had no January or February and was only 10 months long.

However, there is yet another complication here involving the keeping of time. This is the fact that, in addition to the complications just described, the Earth's rate of rotation is not constant. Actually the Earth is slowing down at an irregular and very slow rate. This is a consequence of gravitational tidal forces exerted by the Moon and the Sun on the Earth. Not only are there the noticeable tidal motions of the oceans but there is also a tide or distortion in the solid part of the Earth that runs like a ripple around the Earth as it rotates and the Moon moves in its orbit. These tides are robbing the Earth of some of its rotational energy, which is converted into heat. In other words, the tides are acting like brakes on the Earth's rotation. So ever so slowly, the Earth is slowing down at the rate of a very small fraction of a second every year. But this rate of slowing is irregular because there are many more complications. Nevertheless, the constant atomic time we attempt to keep on our clocks, gets out of step with the varying amount of time it takes for the Sun to appear to make successive transits of one's celestial meridian. What we want is to have our clocks agree more closely with what time it is by the Sun. Therefore, from time to time, it is necessary to adjust the definition of the length of the *mean solar day*, in order to have our clocks agree with the ever so slightly increasing length of the day. This means that the number of seconds that the atomic clock should have pass, or tick, in a day is becoming too small by about 0.0014 seconds every hundred years. That is, in a hundred years, the length of the mean solar day should be more than 86,400.002 seconds by about 0.0014 seconds.

The net result of all of the above is why we need to add an extra second to the length of 2008, but this is not done every year.

The Earth also exerts tides on the solid part of the Moon and over a period of several billion years the Moon's rotation has slowed down to the point where it rotates in the same time that it takes to move in orbit about the common center of gravity of the Earth-Moon System. This is why we never see the other side of the Moon. Ultimately, this is the fate of the Earth. The tidal breaking on the Earth will one day synchronize the Earth's rotation with the 27.3 day period of revolution that it shares with the Moon. This means the Earth will then keep the same side facing towards the Moon. This means you would only be able to see the Moon from that half of the Earth. But this will not happen for billions of years, and that is a long time. In fact, by that time the Sun, in the course of its evolutionary expansion, will have evaporated the Earth.

There is an additional complication that results from the tidal forces between the Earth and the Moon. Because the Moon's orbital motion is slower than the Earth's rotation, the tidal bulges that the Moon exerts on the Earth are not exactly along a line from the center of the Earth to the center of the Moon. Instead, the Earth's rotation, through friction, causes the bulge to precede the Moon by about 12 degrees. This bulge is then able to give the Moon a slight gravitational tug that accelerates the Moon's orbital speed. The result is that the Moon's orbital radius is very slowly increasing. This means the Moon is slowly spiraling outwards away from the Earth. That is, the Moon is very slowing getting farther and farther from the Earth at a rate of about 4 centimeters per year.