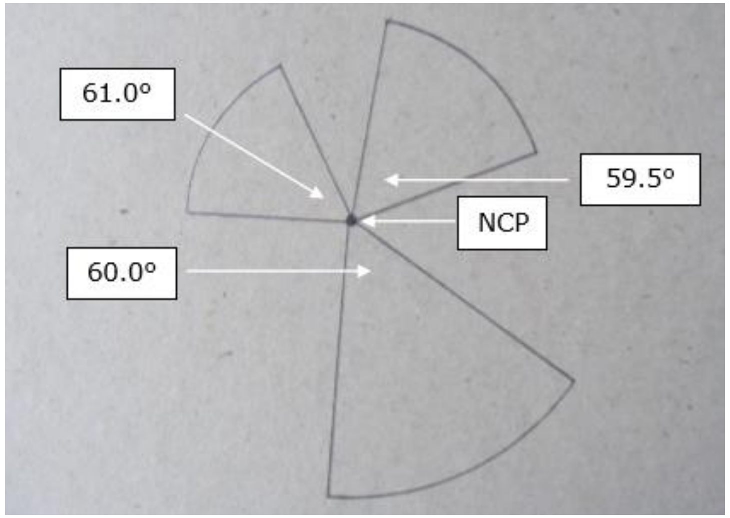
Astronomy **Summary Knowledge Organiser** – Chapter 11 (Topic 4) **Time and the Earth-Moon-Sun cycles (i)**

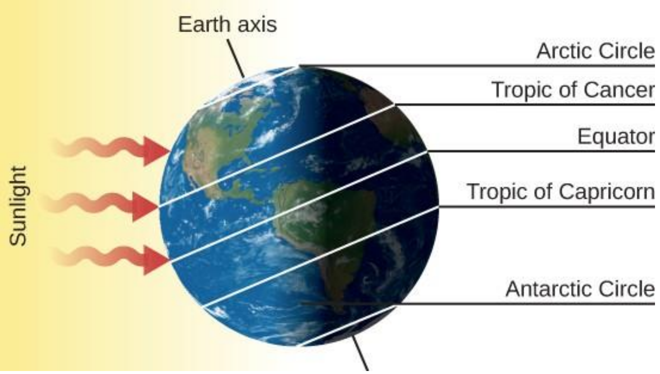
The **SIDEREAL DAY** is measured **with respect to the STARS**.

It lasts **23 hours 56 minutes and 4 seconds**. This is the time between a **star completing two successive** passages across the observers meridian (the **line connecting** the **due north and south** points on the observers horizon, that also passes through their **zenith**). To cause this to happen the **Earth must rotate** **360°**.

The length of Earth's sidereal day (its **sidereal period**) can be found by taking '**long exposure photographs**' of stars moving around the **North Celestial Pole**(see below) and measuring the mean angle that the stars appear to have moved (angle subtended) during that exposure time. The formula below the image then allows you to calculate the length of the sidereal day.

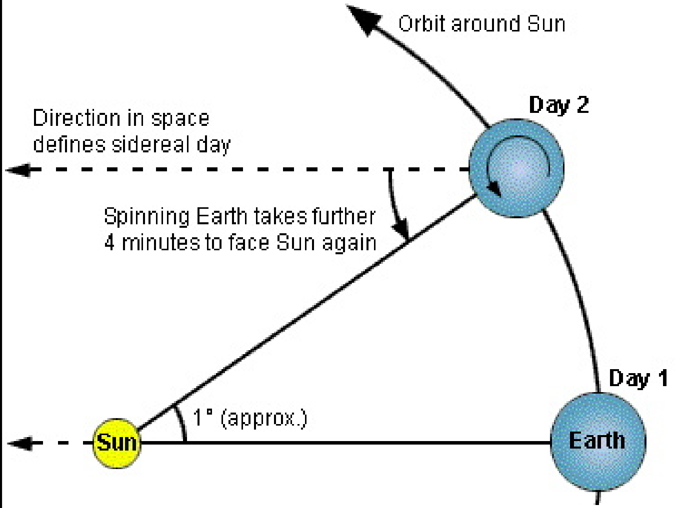


$$\text{length of sidereal day} = \frac{\text{exposure time} \times 360°}{\text{mean angle subtended by arcs}}$$



The **SOLAR DAY (or SYNODIC DAY)** is measured using the movement of the **MEAN SUN** across the sky. It lasts **24 hours**.

During each **solar day**, the motion of the Earth as it continues its **orbit around the Sun** means the Earth actually rotates **361°** with respect to the background stars, before the Sun **returns to the same position in the sky**.



The **four seasons** and the **annually changing rising and setting times of the Sun** are caused by a combination of the **Earth's orbit of the Sun** and its **axis of rotation being tilted by 23.5°**.

At the **SPRING & AUTUMNAL EQUINOX** the Earth's axis is **tilted at 90° relative to the Sun** and so **days & nights are roughly equal in length**. On this date the **Sun will be directly overhead at midday** if you are stood on the **Equator**.

Spring equinox = March 21st	Summer Solstice = June 21st
Autumnal equinox = September 23rd	Winter Solstice = Dec 21st

On the **SUMMER SOLSTICE** the Earth's axis (Northern Hemisphere) is **tilted directly towards the Sun** and so this is the **longest day** of the year and so has the **shortest night**. On this date the **Sun will be directly overhead at midday** if you are stood at a latitude of **23.5° North** (on the **Tropic of Cancer**).

For the **WINTER SOLSTICE** the **opposite** is true and the Sun can be seen directly overhead on the **Tropic of Capricorn** (**23.5° South**).

The Moon completes **one orbit of Earth** in **27.3 days**, this is called a **SIDEREAL MONTH**. However, due to the **continuing motion of the Earth around the Sun** during that time, it takes **29.5 days** to get from New Moon to New Moon, this is called the **SOLAR SYNODIC MONTH** or **lunar phase cycle**. Because the **Earth completes 27° of its orbit of the Sun** whilst the Moon completes one orbit of the Earth, the Moon has to continue its motion for an extra 2.2 days before it is again **directly aligned with the Sun and Earth**.

1 New moon 2 Waxing crescent 3 First quarter half moon
4 Waxing gibbous 5 Full moon 6 Waning gibbous
7 Third quarter half moon 8 Waning crescent

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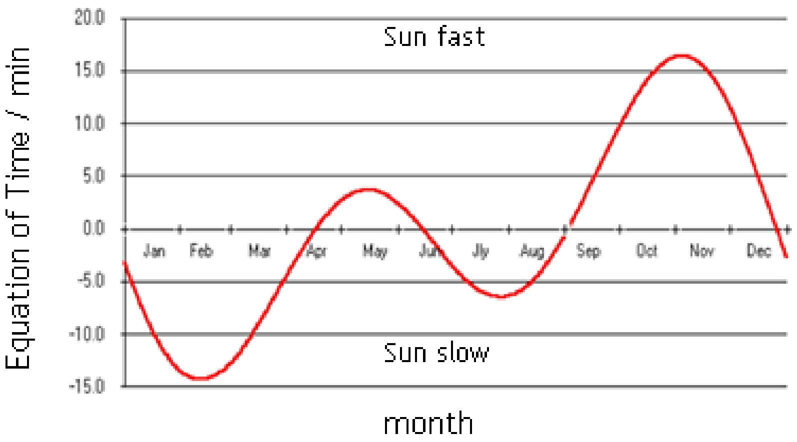
The traditional **SUNDIAL** (shown to the right) has a triangular metallic GNOMON that **points to the North Celestial Pole**. The gnomon casts a shadow onto a **graduated scale** on the flat surface below from which the time can be read. Sundials tell us the **APPARENT SOLAR TIME (AST).** Clocks tick by the same amount every second of every day of the year but sadly the motion of the Sun across the sky is not regular, sometimes it appears to move fast and some times more slowly. Due to this the **AST read of a sundial** usually **needs a CORRECTION** to change it to a **MEAN SOLAR TIME (MST)**, based on a **MEAN SUN** that **moves regularly across the sky**!

The correction applied to the AST to change it to the MST that we use in our 24 hour clocks is called the **EQUATION of TIME (EOT).**

The value of the EOT can be <u>negative</u> or <u>positive</u> and changes throughout the year, it is shown on the graph below.

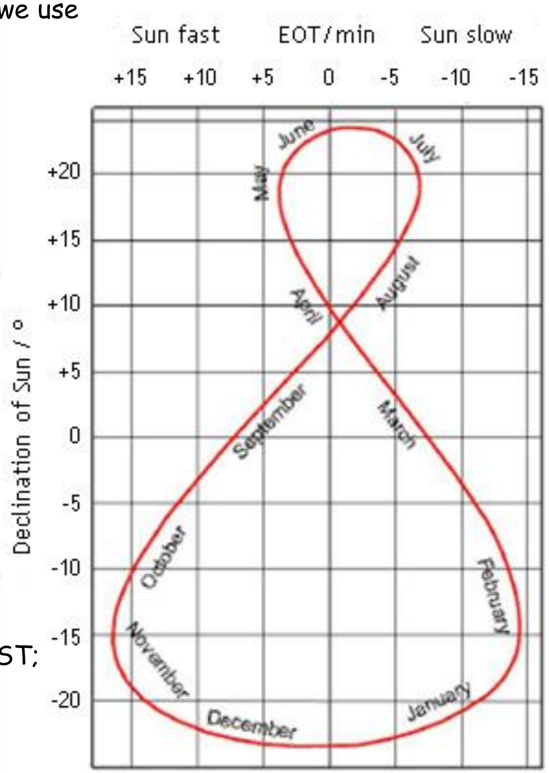


The following **formula** allows you to calculate the EOT, AST or MST;

$$EOT = AST - MST$$

Rearranging,

$$MST = AST - EOT$$



The image above is an **ANALEMMA** that shows the **variation of the EOT** along with both the Sun's declination & month.

If the **EOT is a positive value** it is because the **real Sun is fast** (and so AST will be ahead of MST). A **negative EOT** means a **slow real Sun**.

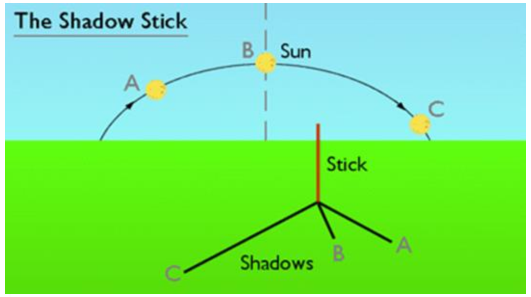
If a sundial reads 11.20 on a day the **EOT is -13 mins**, then the MST is 11.33.

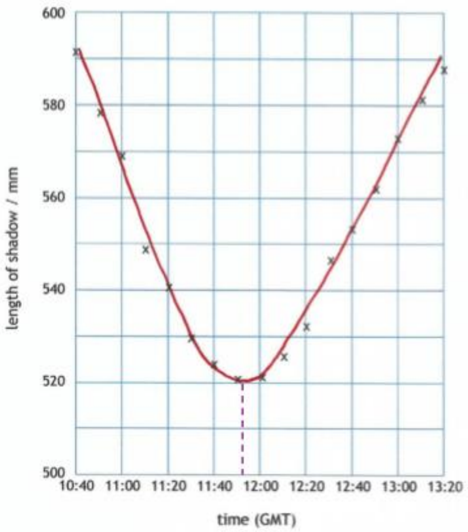
If you look in the **ANALEMMA** below (the '*wobbly snowman*') it must be the month of February and the Sun will be low in the sky!

The <u>**annual variation**</u> in the EOT is **CAUSED BY**;

The **EARTH'S ELLIPTICAL ORBIT** – **Earth travels around the Sun at different speeds** in its orbit, fastest at perihelion and slowest at aphelion!

The **TILT of the EARTH'S AXIS** – in the months **close to the summer & winter solstice** the **real Sun moves across the sky (East to West) faster** than in the months closest to the Spring & Autumnal Equinox. At times close to the equinoxes a large component of the real Sun's apparent motion is northwards or southwards and therefore the Sun's east to west motion lags behind the mean Sun.





A **SHADOW STICK** is a **thin vertical stick** that casts a shadow that can be measured in length, at different times during the day, to find **LOCAL NOON** & **LONGITUDE**. As the Sun **rises** in the east & sets in the west, it will be **low in the sky** and so the **shadows will be long**.
When the **Sun culminates** at local noon, it will be **high in the sky** and so the shadow cast will be at its **shortest**! *This is shown in the graph above.*

The <u>difference</u> between the **time of local noon** shown on the graph (lowest point of the line of best fit plotted)(AST) and the **time read on a watch**, phone or clock (MST) is <u>due to</u> the **EOT** and/or the observers **longitude**.

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If data from a shadow stick experiment shows that it is local noon (**AST = 12.00**) on a day when the **EOT is -8 mins** we can use the EOT formula to calculate the Local Mean Time (shown below);

EOT = AST - MST rearranged;

MST = AST - EOT

MST = 12.00 - (-8)

MST = 12.00 + 8

MST = 12.08

This calculation suggests the **Local Mean Time to be 12.08** but the **MST** (as shown on civil watches) might in fact be **12.04** (**4 minutes difference**). This final difference between the calculated Local Mean Time and the MST shown on watches must be due to the longitude of the observer. If the Local Mean Time calculated by the shadow stick is **4 minutes ahead** of the MST read on a watch or phone, the observer must be **1° East** of the **Greenwich Meridian**. So, **long. = 1° East.**

1° = 4min 5° = 20min 15° = 1hour

Any observations that produce a **Local Mean Time** that is **EARLIER than the MST(Greenwich Mean Time) shown on a watch or phone** prove that the observers longitude is **WEST of the Greenwich Meridian.** e

Every 4 mins of time is equivalent to one degree of longitude.

On the image to the right, at any location East of the Prime/ Greenwich Meridian, the LMT calculated will be later than GMT.

The LONGITUDE at SEA PROBLEM

In the 17th Century there was a rapid expansion in the number of ships going off to sea to explore new territories, to wage war or to trade gold, silk or spices. Captains could easily determine their ships **LATITUDE** by using the **altitude** of either **Polaris at night** or the **Sun at local noon**. However, calculating a ships **LONGITUDE** whilst out on the ocean was a **huge problem** that caused many shipwrecks and fatalities!

In theory, finding longitude at sea was a simple process – use the position of the Sun to find the Local Mean Time on the ship and then compare it to the Local Mean Time in the port from where the ship sailed – the difference in time (after taking the EOT into account) could then be converted into degrees of longitude, east or west of the port. However, knowing the LMT back at the port after a long journey required a clock that kept accurate time, even on rough seas, this was beyond the clockmakers of the time.

Eventually, after many attempts failed, in 1761, the **horologist JOHN HARRISON** solved the longitude problem when he invented and manufactured a **MARINE CHRONOMETER** (pictured right) that was capable of keeping accurate 'home-port' time, even aboard ships that were sailing in conditions of raging seas, extreme temperatures, high humidity and salinity!

Before rail travel became common in Britain in the mid 1800's people relied on Local Mean Time in all parts of life. But since **LMT differed from city to city** due to their **different longitudes** this caused huge problems in such things as creating train timetables. Finally, in 1880 the Government **standardised time** for the whole country with the local mean solar time at Greenwich in London, it was called **GREENWICH MEAN TIME (GMT).** Years later, other countries followed the British example and so the Earth was eventually split into one hour time zones (15° of longitude wide).