

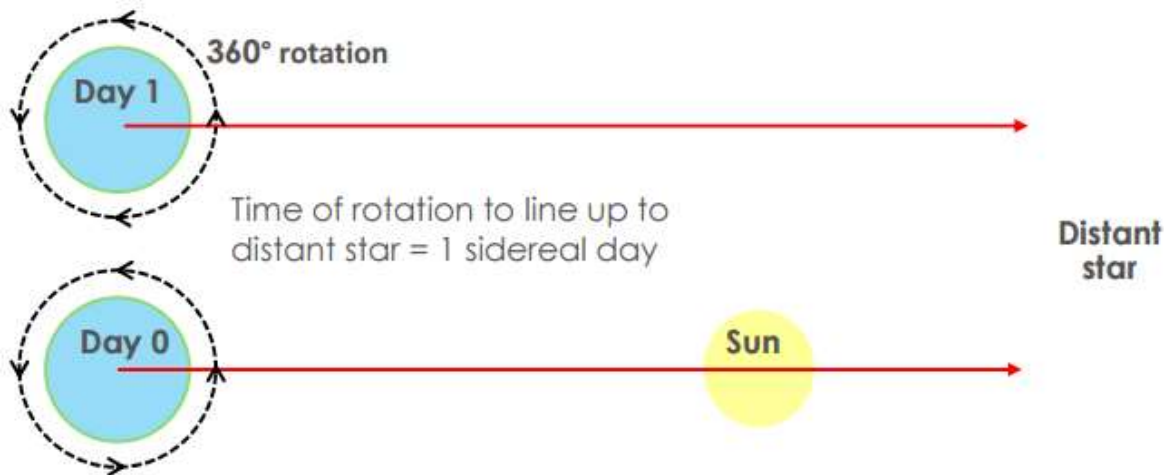
# Summary Notes - Topic 4: Time and the EMS System



## 4.1 Sidereal and Synodic (Solar) Days

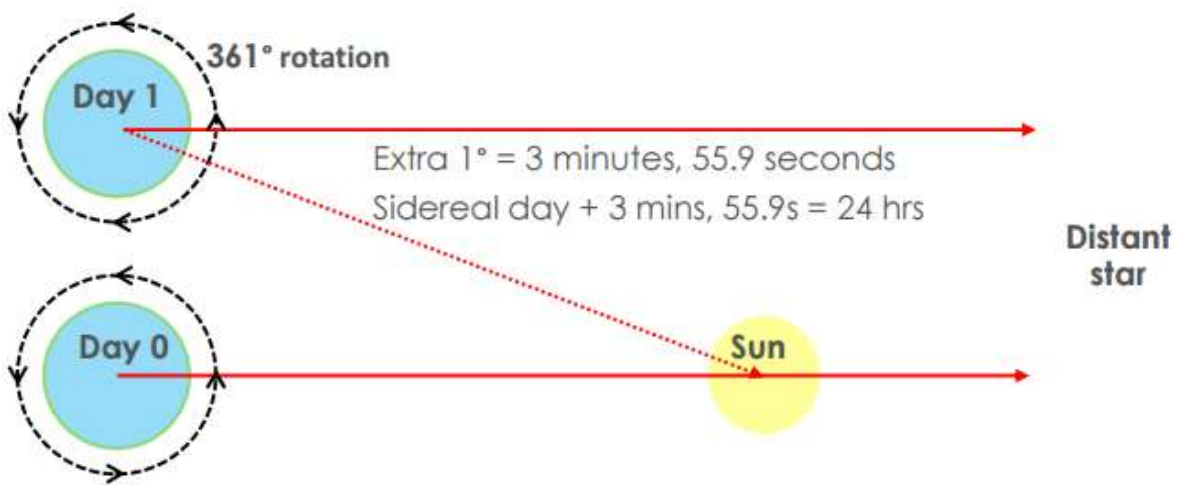
Sidereal relates to the Earth's position in relation to a distant star (not the Sun).

- **Sidereal Day:** The time taken for Earth to complete one full rotation ( $360^\circ$ ) relative to the background stars. This lasts **23 hours, 56 minutes, and 4 seconds**.



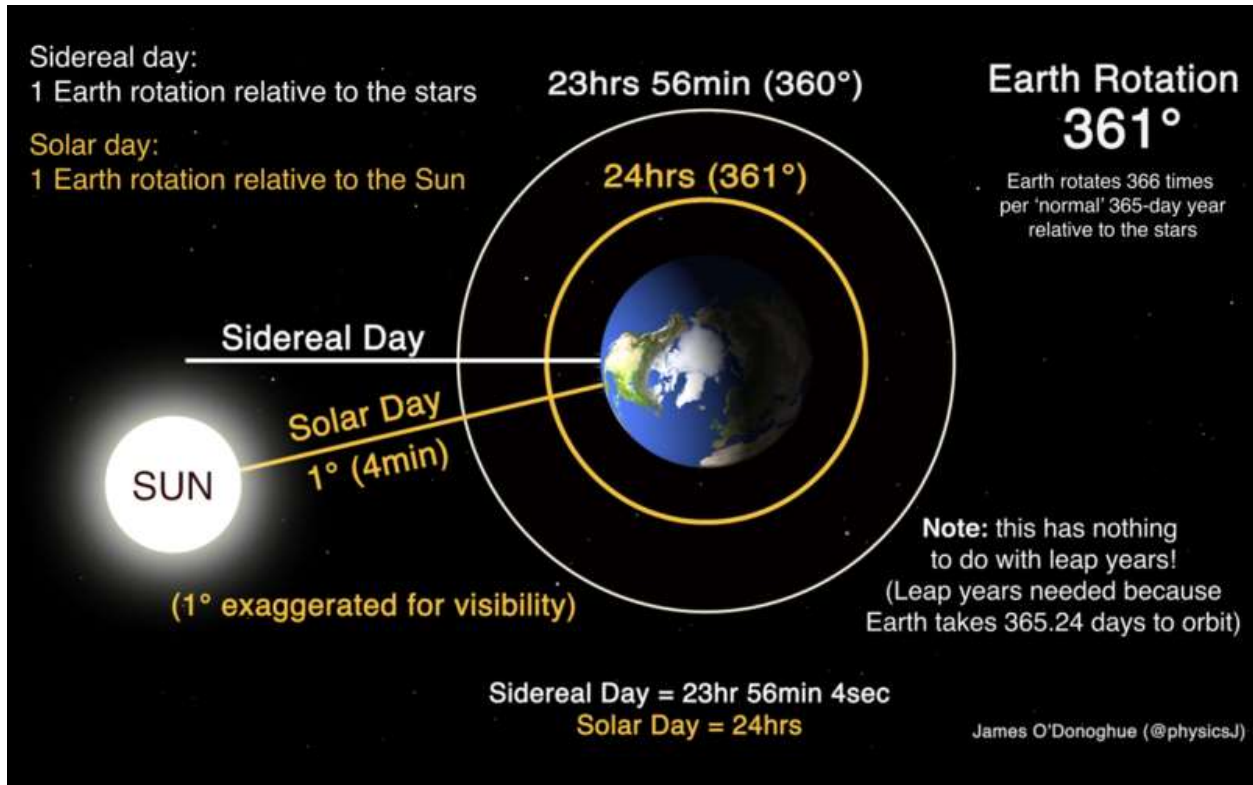
Synodic relates to Earth's position in relation to the Sun.

- **Synodic (Solar) Day:** The time taken for the Sun to return to the same position in the sky as observed from Earth. This lasts **24 hours**.
- The difference between sidereal and synodic days (and months) is due to the Earth's orbit around the Sun. It takes slightly longer to rotate so that the same part of the Earth is lined up with the Sun.



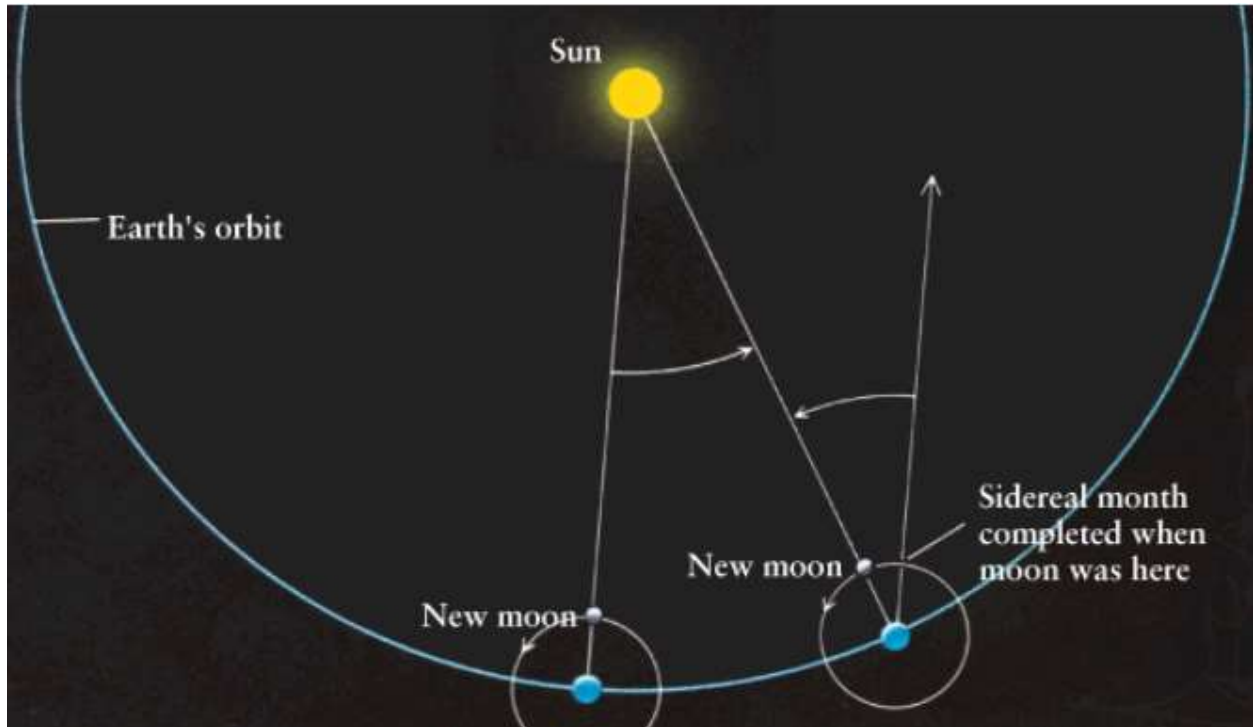
Sidereal days are the basis for **diurnal motion**, the motion of stars and celestial bodies across the sky, over the course of a day.

Synodic days are the basis for several modern practices such as calendars, day-to-day timekeeping, cultural and religious practices based on lunar phases.



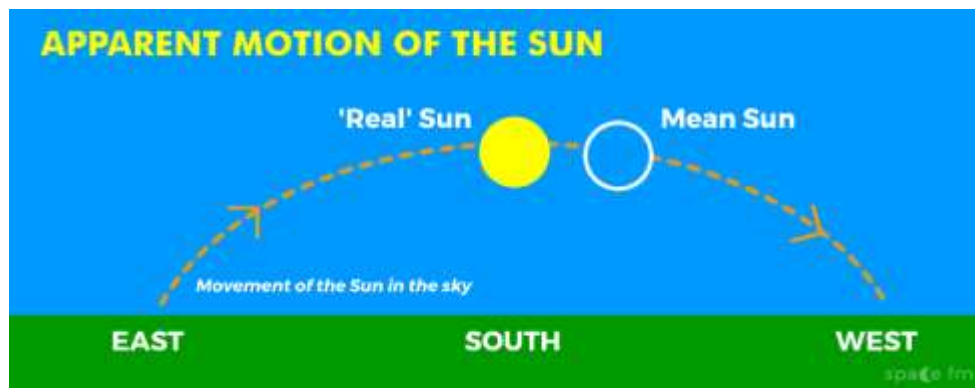
## 4.10 Sidereal vs. Synodic (Solar) Months

- **Sidereal Month:** 27.3 days (time taken for the Moon to orbit Earth relative to the stars).
- **Synodic Month** (often called **Lunar Month**): 29.5 days (time taken from one New Moon to the next).
- The difference is due to Earth's movement in its orbit.



## 4.2 Apparent Solar Time (AST) and the Role of the Sun

- **Apparent Solar Time** is a method of timekeeping that uses the Sun's position in the sky across the meridian (East to West) as a reference point.
- **Local (Apparent) Noon** occurs when the Sun reaches its highest point (meridian) in the sky, so shadows on a tall stick would point exactly north or south.
- AST is based on the apparent motion of the actual Sun. It is based on the apparent solar day, the interval between two successive returns of the Sun to the local meridian. **AST** can be crudely measured by a **sundial**.
- The length of a solar day varies throughout the year (due to Earth's elliptical orbit and axial tilt) and the accumulated effect produces seasonal deviations of up to 16 minutes from the mean.



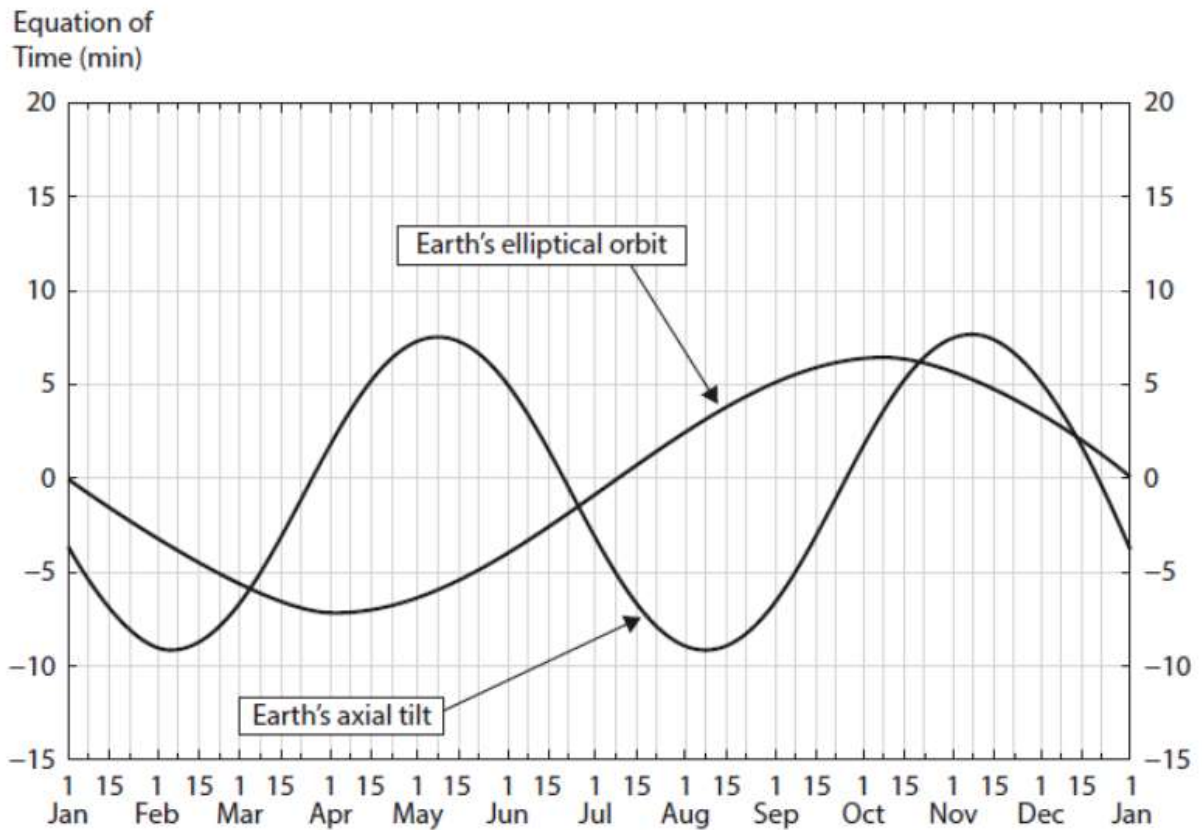
## 4.3 Mean Solar Time (MST) and Local Mean Time (LMT)

- **Mean Solar Time (MST)**: uses the average of the **AST** across the year, making it so that every day has the same length.
- Measured using a fictional '**Mean Sun**' that we assume moves at a constant speed across the meridian.
- As it is averaged, each day has the same length (24 hours) and is therefore more useful in people's day-to-day lives.
- It does, however, mean that the Sun's meridian is not always exactly at noon.
- **Local Mean Time (LMT)**: The MST for a specific longitude. To measure LMT we use the prime meridian as a starting point.
- Each degree of longitude is worth around 4 minutes (+ or – from the 0 degrees time).
- The **Mean Sun** is a hypothetical sun moving at a constant rate to define MST.

## 4.4 The Equation of Time

- Equation of Time = Apparent Solar Time (AST) - Mean Solar Time (MST).
- This equation accounts for the small daily variations in the Sun's position.
- The result of this calculation tells us how far ahead or behind the actual Sun is compared to the fictional 'Mean Sun'.

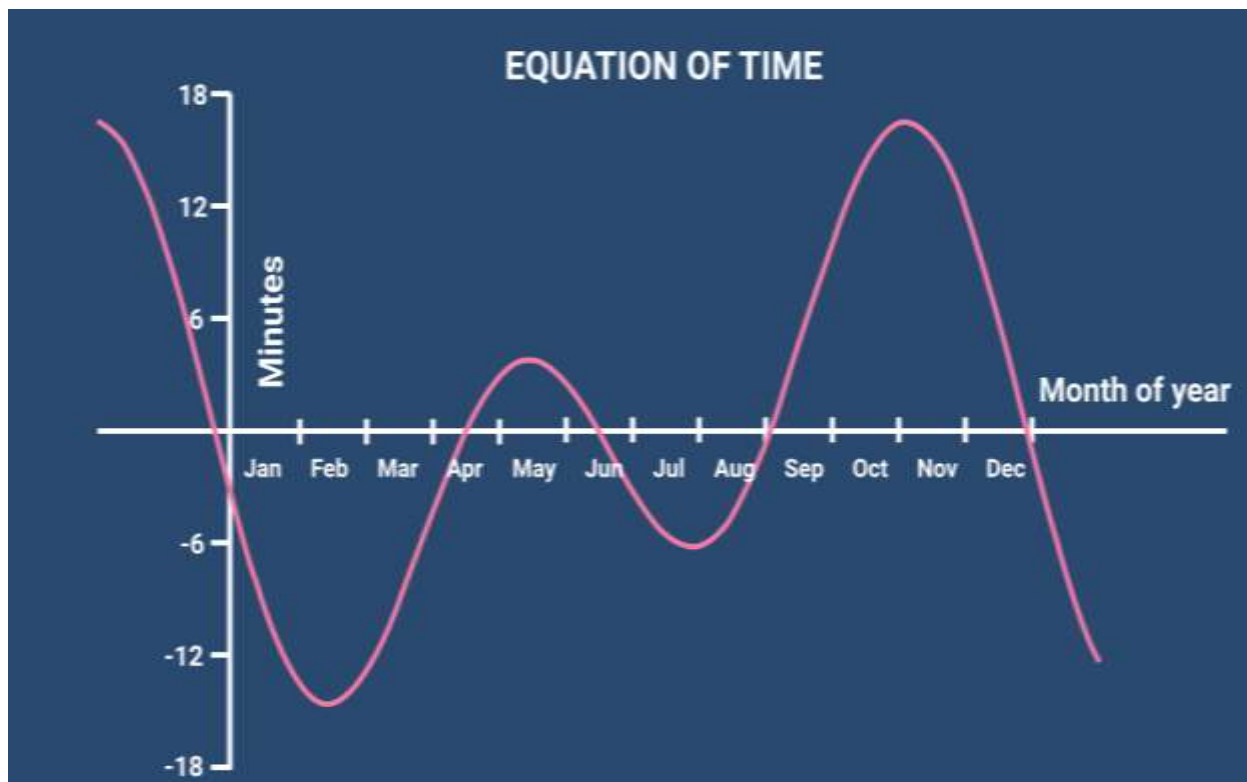
The graph below shows how the Earth's tilt and its elliptical orbit both contribute to the outcome.



## 4.5 & 4.6 Annual Variation of the Equation of Time

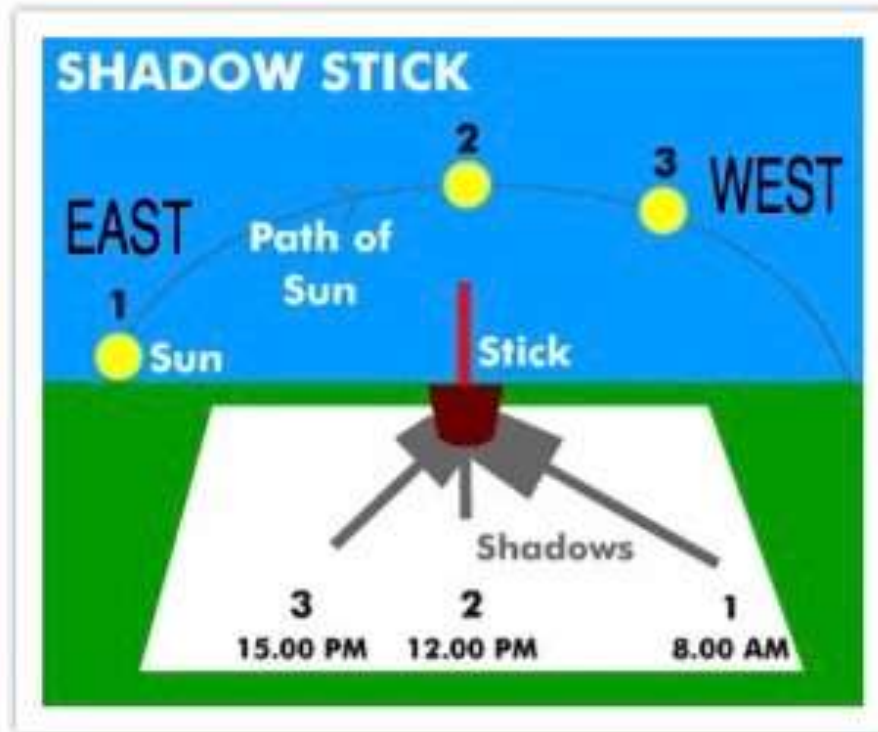
- The Equation of Time varies due to:
  1. **Earth's elliptical orbit:** The speed of Earth's orbit changes due to Kepler's Laws.
  2. **Earth's axial tilt:** The Sun's apparent motion is not uniform.

The variation follows a predictable pattern, with peaks in February, May, July, and November. The graph below shows the combined result of the two effects. Anything above 0 means that AST is ahead of MST (sundial reads a later time than the actual local time, and the Sun reaches its meridian early). Anything below 0 means that AST is behind MST (sundial reads an earlier time than the actual local time and the Sun reaches its meridian late).



## 4.7 Determining Local Noon Using Shadows

- **Shadow Stick Method:**
  1. Place a vertical stick in the ground.
  2. Mark the shortest shadow of the day—this occurs at local noon.
- This method was historically used to measure time before clocks.

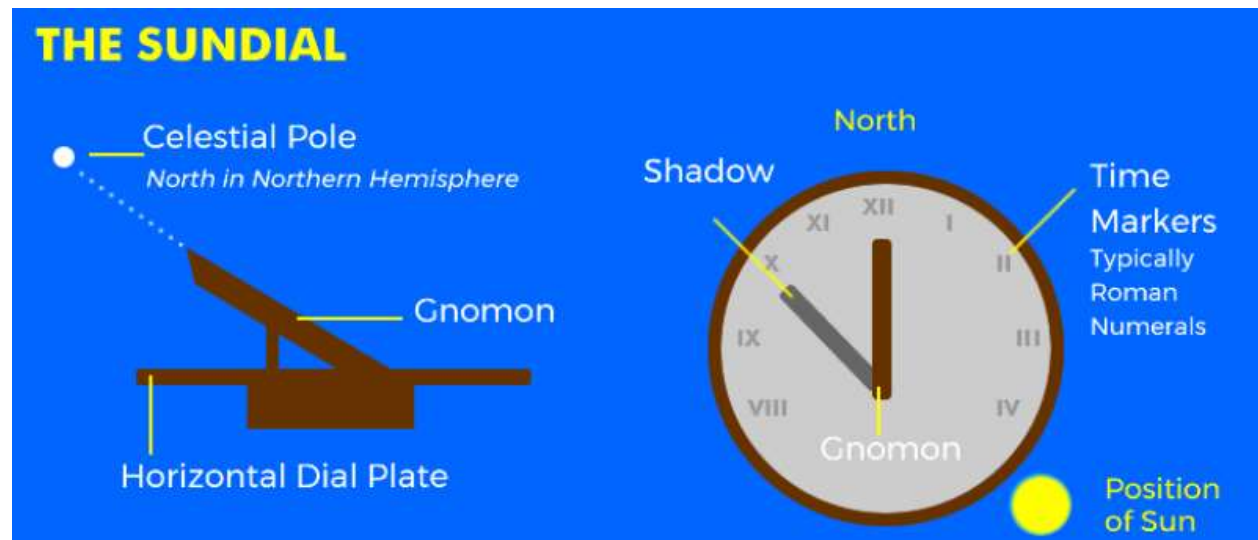


## 4.8 Sundials: Structure and Use

- **Sundials** use shadows to tell time based on the Sun's position.
- The **gnomon** (shadow-casting part) must be at an angle set to the **latitude** of its position and aligned due North. This means that it would point towards the Celestial Pole.
- Time is read where the shadow falls on the hour markers (giving AST, which can be corrected to give local MST using the Equation of Time).

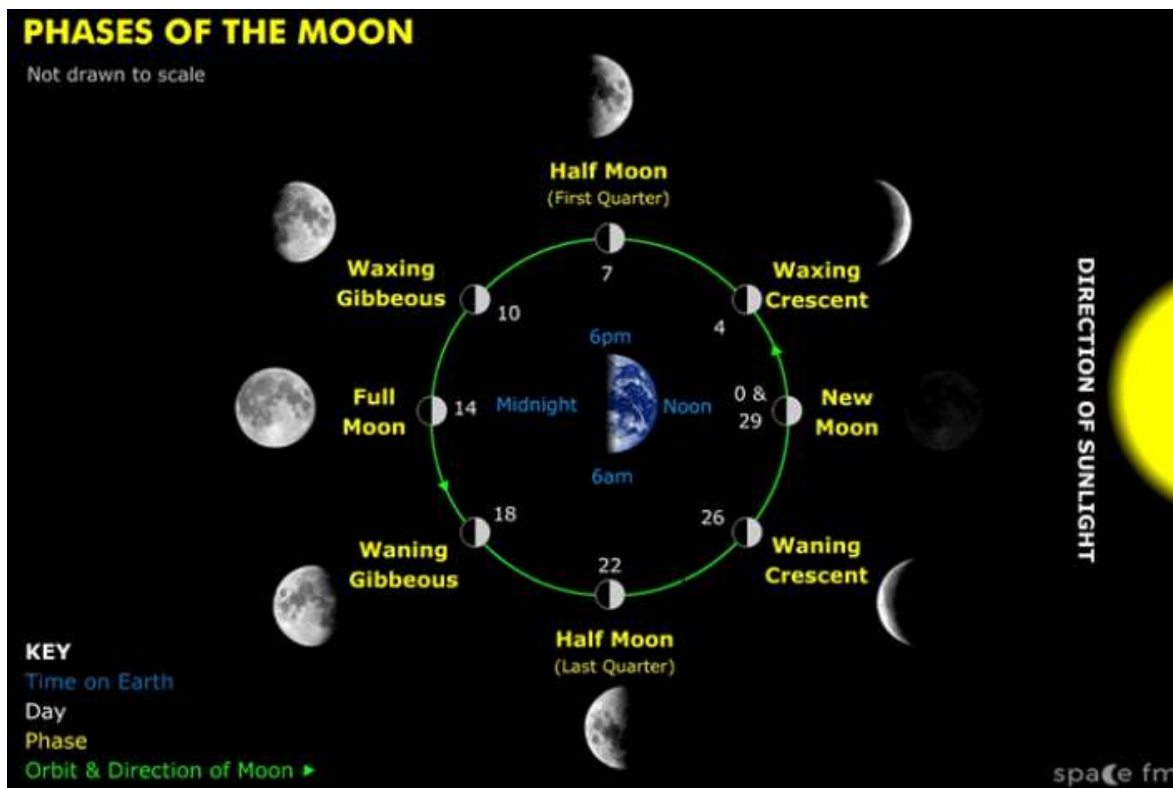


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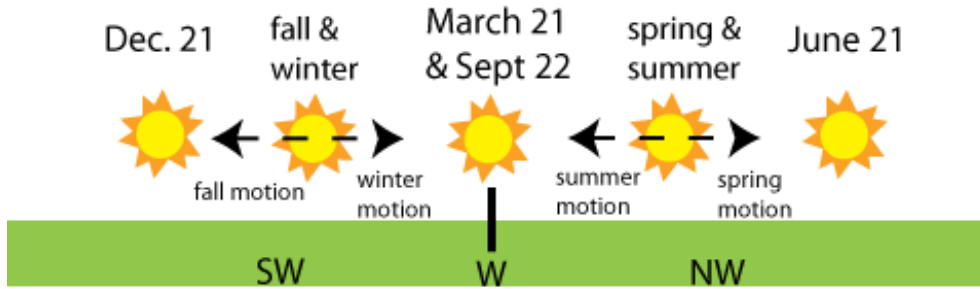


## 4.9 Lunar Phase Cycle

- The **synodic (lunar) month** is approximately **29.5 days**.
- The Moon is a natural satellite of the Earth. It cannot generate its own light as it is non-luminous. It reflects light from the Sun. The apparent shape of the Moon depends on how much of the side of the moon reflecting light is visible from Earth. The different apparent shapes of the moon are called the phases of the moon.
- Phases:
  - New Moon
  - Waxing Crescent
  - First Quarter
  - Waxing Gibbous
  - Full Moon
  - Waning Gibbous
  - Last Quarter
  - Waning Crescent
- **'Waxing'** before a phase name means the proportion of the illuminated side visible is increasing, and **'Waning'** means the proportion of the illuminated side visible is decreasing.

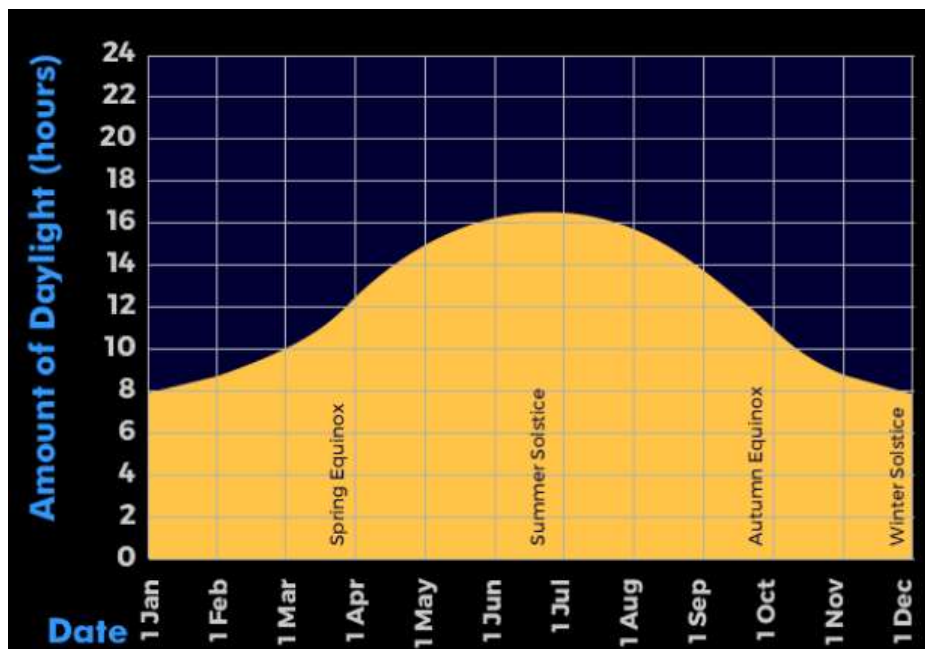


## 4.11 Annual Variation in Sunrise and Sunset Times



Sunset position changes throughout the year. Note: change “W” (west) to “E” (east) for the sunrise position.

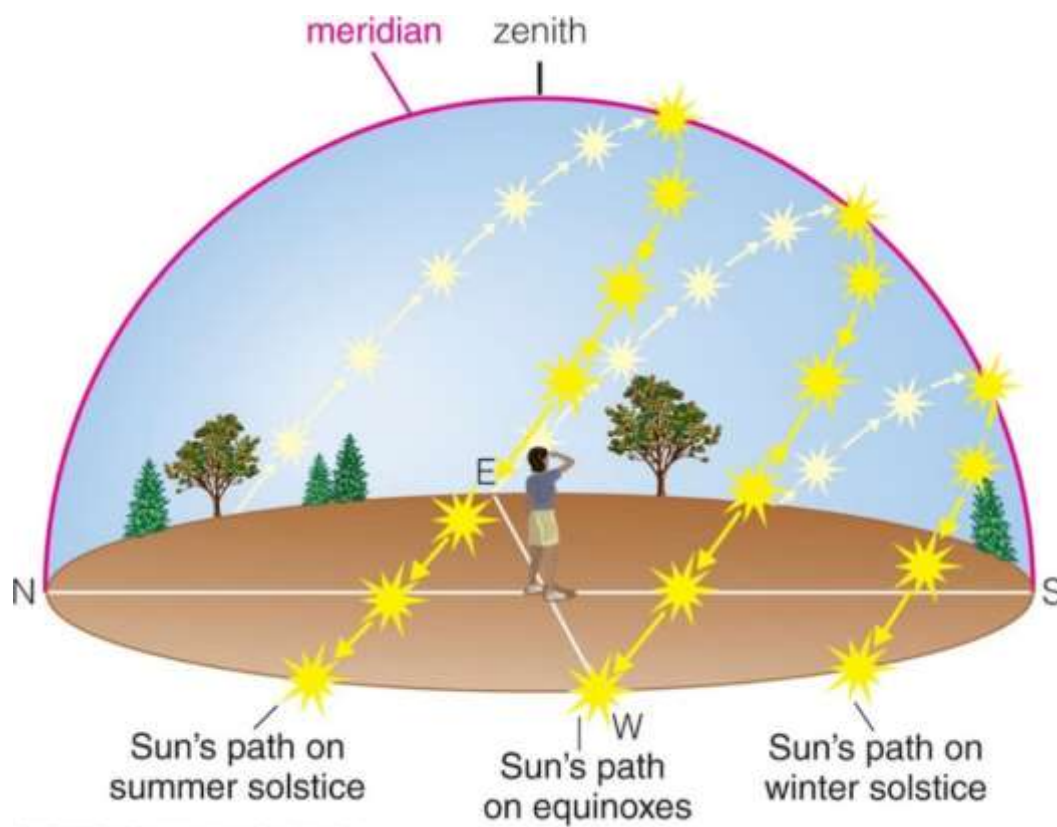
- The exact time and position of sunrises and sunsets vary from place to place and at different times of the year. There are two reasons for this:
  1. Earth’s elliptical orbit around the Sun:  
The orbital speed of the Earth is not constant, which affects how the Sun appears to move against background stars.
  2. The Earth’s axial tilt  
This can cause the Sun to appear higher in the sky at noon (when tilted towards the Sun in the summer months) or lower in the sky at noon (when tilted away from the Sun in the winter months).



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## 4.12-4.14 Equinoxes, Solstices, and the Sun's Apparent Motion

- An **equinox** is when the Sun's position is directly above the equator. During an equinox day and night are approximately the same length, as shown in the graph above (at approx. 20<sup>th</sup> March and 20<sup>th</sup> September)
- A **solstice** is when the Sun reaches its highest or lowest point in the sky during the year.
  1. **Summer solstice** (around 21<sup>st</sup> June) is when the Sun reaches its highest noon position during the year, and daylight hours are greatest. At this time areas north of the Arctic circle experience 24-hour daylight.
  2. **Winter solstice** (around 21<sup>st</sup> December) is when the Sun reaches its lowest noon position during the year, and daylight hours are the least. At this time areas south of the Antarctic circle experience 24-hour daylight.



## 4.15-4.17 Local Time, Time Zones, and GMT

- **Longitude affects time:** Every **15° longitude = 1-hour time difference**, so every **1° longitude = 4-minute time difference**.
- When measuring **Local Mean Time (LMT)**, we use the **prime meridian** as the starting point. If it is 13:00 at the prime meridian, the LMT would be 12:56 at 1° W and 13:04 at 1° E. If you are on the prime meridian (for example in Greenwich, London) then LMT is the same as the MST we find using the Equation of Time.
- To simplify things the Earth is split into 24 **time zones**, each **15° of longitude** wide. They all use the prime meridian as the reference point.
- **Coordinated Universal Time (UTC):** This is the World's Time Standard. Governments and regulatory bodies have agreed to use it as the sole global reference point for time zones. When a country determines its time zone, the law text will show the difference, or offset, of the local time from UTC.
- **Greenwich Mean Time (GMT):** Standard time for the Prime Meridian (0° longitude). Like all other time zones, its current time is derived from UTC—it just so happens that the UTC offset is zero. So, GMT equals UTC, and a GMT clock ticks in perfect unison with a UTC clock.
- **Daylight Savings Time (DST) and British Summer Time (BST):** From Time and Date website: "Daylight Saving Time (DST) is the practice of setting the clocks forward 1 hour from standard time during the summer months, and back again in the autumn, in order to make better use of natural daylight.". We put our clocks forward at the end of March (we call this '**British Summer Time**') so we have more light in the summer evenings and put our clocks an hour back to GMT in October, so our mornings are less dark.



## 4.19-4.20 Longitude and Astronomical Methods

- **Longitude Determination Methods:**

- 1) **Shadow-stick method** (uses the Sun's position and Equation of Time).
  - a) To work out your longitude have an accurate clock set to GMT. Record the time at which the Sun was highest in the sky and the shadow was shortest. This is your Local Noon, 12:00pm, according to AST (Apparent Solar Time)
  - b) Use the Equation of Time to convert your AST the MST for your longitude (or your Local Mean Time, LMT).
  - c) Note the difference in time between your LMT of 12:00 pm and the GMT noted from your clock. If your LMT is earlier than/behind GMT then you are West of the Prime Meridian. If your LMT is later than/ahead of GMT then you are East of the Prime Meridian.
  - d) For every four minutes difference the longitude is  $1^\circ$  away from the Prime Meridian.

Worked example:

Shortest shadow recorded at 11:50am, Equation of time for that date = -14 minutes

*Equation of Time = Apparent Solar Time – Mean Solar Time*, so, we can rearrange to find MST for our longitude (or LMT):

$$\text{Mean Solar Time} = 12:00 - (-14) = 12:14\text{pm}$$

Compare with GMT:  $\text{GMT} - \text{LMT} = 11:50 - 12:14 = -24$

As our LMT is 24 minutes **later than/ahead of** our GMT measurement we must be **East** of the prime meridian (watch reading of 11:50am).

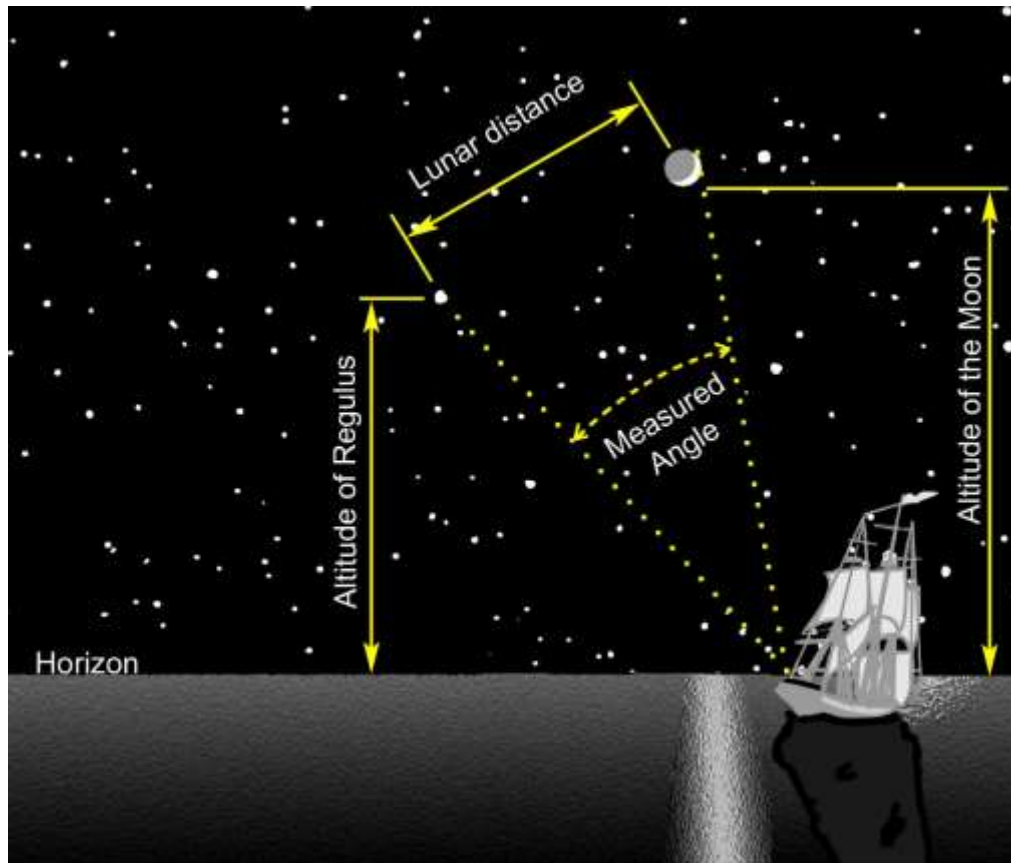
**$24/4 = 6$** , so we must be  **$6^\circ$  E**.

- 2) We can also use a **Sundial** in a similar manner:
  - a) Record the time from the Sundial, which shows AST
  - b) Convert your AST to MST for your longitude using the Equation of Time
  - c) Note the difference in time between your MST and your clock's GMT
  - d) Every 4 minutes difference is  $1^\circ$  of longitude (with the difference between E and W explained above)

### 3) Lunar Distance Method (compares Moon's position to stars).

Using a sextant, the navigator precisely measures the angle between the moon and another body. That could be the Sun or one of a selected group of bright stars lying close to the Moon's path, near the ecliptic. At that moment, anyone on the surface of the earth who can see the same two bodies will, after correcting for parallax, observe the same angle. The navigator then consults a prepared table (Nautical Almanac) of lunar distances and the times at which they will occur. By comparing the corrected lunar distance with the tabulated values, the navigator finds the Greenwich time for that observation. Knowing Greenwich time and local time (LMT), the navigator can work out longitude.

This method has some flaws. Noticeably it depends on a clear sky and accurate measurements being taken at sea. Early tables had a larger margin of error than later versions, so a fraction of a degree could result in the navigator being several nautical miles away from their destination. The Earth is not uniformly spherical which adds to the error.



## Shadow-stick and Sundial Calculation Questions

Use: 4 minutes of time =  $1^\circ$  longitude.

Equation of Time (EoT): +ve = sundial slow ( $\text{EoT} = \text{AST} - \text{MST} \Rightarrow \text{MST} = \text{AST} - \text{EoT}$ ).

### Q1

A student finds local apparent noon using a shadow stick (shortest shadow). At that instant the clock at Greenwich reads 12:20 GMT. The Equation of Time is +4 min (sundial 4 min slow). Find the student's longitude and state E or W of Greenwich.

### Q2

At local apparent noon, a student's clock at Greenwich shows 11:32 GMT. The Equation of Time is -6 min (sundial 6 min fast). Find the student's longitude and state E or W.

### Q3

At a location, a sundial reads 12:05 AST at the same instant that GMT is 10:35. The Equation of Time is -10 min (sundial 10 min fast). Find the longitude and state E or W.

### Q4

At a location, a sundial reads 11:44 AST when GMT is 14:00. The Equation of Time is +16 min (sundial 16 min slow). Find the longitude and state E or W.

### Q5

A town is at longitude  $45^\circ$  E. A sundial there reads 13:30 AST. The Equation of Time is +8 min (sundial 8 min slow). Calculate the GMT at that instant.

## 4.21 Longitude and Horological Methods

**Marine Chronometer** (Harrison's method for precise timekeeping at sea).

Horology is the study of time and to say someone is a horologist means they make clocks, watches and other timekeeping devices. John Harrison was a noted clockmaker in the 18th century who recognised the problem with using pendulum clocks on ships (ships movement effects the pendulum). He improved the technology and made innovations, some of which are still used in timekeeping devices today. His 'H4' – the 'Sea Watch' was the most accurate clock used for maritime use in its day.

At the time there was a 'Board of Longitude' set up by the government to arrive at an accurate time or method to solve the issue. The story is an interesting one which is worth researching. Subsequent and more affordable timekeepers that built on Harrison's work ensured the horological method was more successful.

Navigators could now tell the local time at Greenwich and easily calculate the difference between their local time. They no longer needed to take complex observations or rely on good weather to do so.



## Shadow-stick and Sundial Calculation Solutions

*Key relations:*

- $EoT = AST - MST \Rightarrow MST = AST - EoT$ .
- 4 minutes =  $1^\circ$  longitude.

### Q1 Solution

Local apparent noon  $\Rightarrow$  AST = 12:00. EoT = +4 min  $\Rightarrow$  MST = 12:00 + 0:04 = **12:04**.

Compare with GMT (12:20): Local time is 16 minutes **earlier than/behind GMT**, so we are **West**

Longitude =  $16 \div 4 = 4^\circ \Rightarrow$  **4° W**.

### Q2 Solution

Local apparent noon  $\Rightarrow$  AST = 12:00. EoT = -6 min  $\Rightarrow$  MST = 12:00 - 0:06 = **11:54**.

Compare with GMT (11:32): Local Time is 22 minutes **later than/ahead of GMT**, so we are **East**

Longitude =  $+22 \div 4 = +5.5^\circ \Rightarrow$  **5.5° E**.

### Q3 Solution

AST = 12:05, EoT = -10  $\Rightarrow$  MST = 12:05 - 0:10 = **11:55**.

Compare with GMT (10:35): Local time is 80 minutes **later than/ahead of GMT**, so we are **East**  
Longitude =  $+80 \div 4 = +20^\circ \Rightarrow$  **20° E**.

### Q4 Solution

AST = 11:44, EoT = +16  $\Rightarrow$  MST = 11:44 + 0:16 = **12:00**.

Compare with GMT (14:00): Local time is 120 minutes **earlier than/behind GMT**, so we are **West**

Longitude =  $-120 \div 4 = -30^\circ \Rightarrow$  **30° W**.

### Q5 Solution

AST = 13:30, EoT = +8  $\Rightarrow$  MST = 13:30 + 0:08 = **13:38**.

$\lambda = +45^\circ \Rightarrow 45 \times 4 =$  **180 minute difference** between GMT and LMT

We are **East** therefore we are **later than/ahead of GMT**.

Therefore GMT = MST - 180 min = 13:38 - 3:00 = **10:38**.