# Your Time-and-Tide-Clock – How it works, setting it up and keeping it accurate

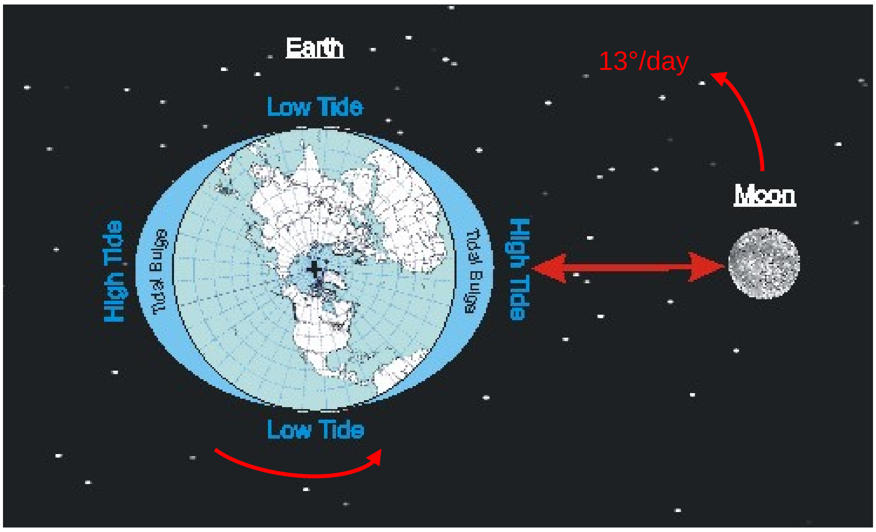
A time-and-tide clock models the *mean* daily motions of both the Sun and Moon. It can be used by astronomy buffs to indicate the approximate position of the Moon in the sky, or, since the Moon is the major cause of the daily tides, it can show you the tide times for your location. Included in the explanation below are instructions for setting up your clock and information about factors affecting its accuracy.

**The hour hand** on a clock rotates around the dial once every 12 hours (half a solar day) because it is designed to move in time with the mean motion of the Sun. A **solar day** is the mean interval between one upper transit of the Sun and the next. (Upper transit is when, exactly halfway between rising and setting, it crosses your local meridian of longitude.) On a standard clock set for your location, the hour hand shows the approximate position of the Sun in the sky. It shows 12 o'clock when the Sun is near upper transit ("high noon") and it also shows 12 o'clock at midnight, about the time that the Sun is transiting the opposite meridian exactly halfway around the globe from you. It shows 6 o'clock at mean sunrise and at mean sunset.

**The tide hand** on a time-and-tide clock moves approximately in time with the *mean* motion of the Moon. If correctly set for your location and kept in proper adjustment (this will be discussed later), it points straight up around the time that the Moon is transiting your meridian and again about half a tidal day later, around the time that the Moon is transiting the opposite meridian exactly halfway around the globe from you. The tide hand points straight down at mean moonrise and at mean moonset.

**A tidal day** (sometimes inaccurately called a lunar day) is the mean interval between one upper transit of the Moon and the next. This is about 24 hours, 50 minutes. (The reason it takes this long is explained in the sidebar.) Ideally, the tide hand should make a single rotation around the dial in exactly half that time, just as the hour hand takes half a *solar* day to do the same. However, the gearing ratios on most time-and-tide mechanisms can only approximate a tide-hand rotation period of this length, which, in any case, is itself an approximate value. Therefore, for greater long term accuracy, it is advisable to periodically adjust the position of the tide hand manually. How this should be done and how often will be discussed later. Some additional explanations are required first.

The Moon's gravity stretches the Earth's oceans toward it where the Moon is directly overhead and away from it on the opposite side of the globe. This produces two tidal bulges, one on the meridian that the Moon is transiting, the other on the opposite meridian, halfway around the globe from there. Therefore, most places have **two high tides per tidal day**. At open ocean beaches, they occur when the Moon is at upper transit and again half a tidal day (about 12 hrs, 25 minutes) later. **Low tide** occurs halfway between the two high tides, about 6 hrs, 12 min's after high tide.




## Solar, Sidereal and Tidal days

Halfway between rising and setting, every heavenly body reaches **upper transit** when it crosses the observer's longitude.

**A mean solar day** is the mean time between successive upper transits of the Sun. Upper transit of the Sun is sometimes called "high noon", so called in order to distinguish it from noon on a clock, which is the *mean* time of high noon at the centre meridian of your time zone.

If you live right at the centre of your time zone (e.g. in Greenwich, London for Time Zone 0 (GMT), in eastern Alexandria for Time Zone +2, or, for Time Zone +10 (AEST), in the Blue Mountains west of Sydney), and you observe the exact time at which the Sun reaches upper transit each day of the year, the average of those times, i.e. the mean time of high noon at your location, will be 12 o'clock.

The circuit, repeated daily, of the heavenly bodies across the sky from east to west is called their **diurnal motion**. This motion is not real, it is *apparent* motion caused by the Earth's rotation from west to east on its own axis. We are like passengers on a train travelling east for whom the trees in the window appear to be moving westward.

**A sidereal day is the time** between successive upper transits of a fixed star. This is how long **it takes (about 23h, 56m) for the Earth to make one rotation**. During that time it also moves a short distance eastward (about 1°) along the path of its annual orbit of the Sun. Therefore, the Earth must rotate 361° (not 360°) to again point the same meridian back at the Sun from its new position relative to the Sun. It takes another 4 minutes to rotate through that extra 1°. This is why **a mean solar day is 24 hours.**

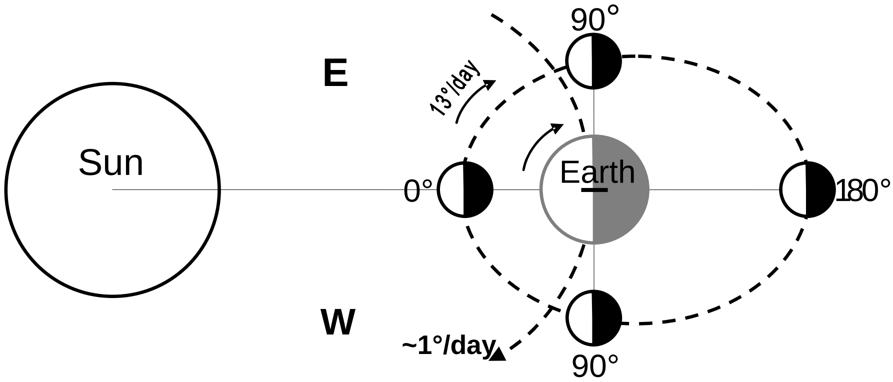
**A tidal day** is the mean time between successive upper transits of the Moon rather than of the Sun. **The Moon orbits the Earth from west to east** (the same direction as the Earth's rotation). Each day, the Moon travels, on average, an angular distance of about 13° along the path of this orbit. Therefore, the Earth must rotate (360 + 13)° to again point the same meridian at the Moon's new position in the sky. This takes approximately **24h, 50m**, which is why a tidal day is this long. See an animation demonstrating this at: http://www.oceanservice.noaa.gov/education/kits/tides/media/supp_tide05.html.

Unlike the Moon's diurnal motion, which is only apparent, the Moon's orbital motion is real, is **in the opposite direction to its diurnal motion**, and is much slower than its diurnal motion. As viewed from Earth, the net effect of these two opposite motions is that the Moon's diurnal motion westward is slightly slowed by its real motion eastward.

This is like our train passengers watching a car moving alongside the track eastward (like the train), but slower than the train. Like the trees, it appears to be moving

Because a tidal day is longer than a solar day, each day of the monthly cycle of lunar phases, **upper transit of the Moon occurs** about 50 minutes later than the day before. At New Moon, First Quarter, Full Moon & Last Quarter, it occurs, respectively, at about noon, 6 pm, midnight and 6 am.

Twice in each monthly cycle of lunar phases, **at New Moon and at Full Moon, the Sun, Moon and Earth are in line with one another.** The notional beginning of this cycle is at New Moon when the Moon is between the Sun and the Earth. At that time, the far side of the Moon is fully facing the Sun and its near side (the side facing Earth) is completely dark, so we cannot see the Moon unless it eclipses the Sun. Halfway through the cycle, the Sun and Moon are on directly opposite sides of the Earth. The Moon's near side is then fully facing the Sun and is completely illuminated, so we see a full moon. (If the Moon enters the Earth's shadow, there will be a lunar eclipse at that time.)




The Moon's position and its angular distance from the Sun as seen from Earth (i.e. its elongation) at the phases: New, First Quarter, Full, and Last Quarter

This diagram (not to scale) is drawn from a southern hemisphere point of view. We are looking at the Earth from above the South Pole. For a nice animation (northern hemisphere view), see: http://www.sumanasinc.com/webcontent/animations/content/moonphase.html.

The Moon's position in the cycle of phases affects the strength of the tides. **Spring tides occur at New and Full Moon**, when the three bodies are in line with one another and the tidal pull of both Sun and Moon work in the same or in directly opposite directions, resulting in the most extreme tides (the highest floods and the lowest ebbs). **Neap tides occur when the Moon is at First Quarter and Last Quarter**. The angle Sun-Earth-Moon is then 90° and the tidal force exerted by the Sun is in a different direction from that of the Moon, so they work against one another, resulting in the weakest tides (moderate floods and ebbs). There are two spring-neap-spring-tide cycles per lunar month.

A time-and-tide clock will model these alignments of the Sun, Earth and Moon. **The tide hand and the hour hand will be aligned** with one another at *mean* New Moon and at *mean* Full Moon. (See sidebar: "The Accuracy of a Clock".) During the rest of the lunar month, the tide hand will lag behind the hour hand. Half of the angle between them (measured clockwise from the tide hand while the Moon is waxing and counter-clockwise when it is waning) is the mean moon's angular distance from the Sun (called **elongation** in astronomy), thus indicating the current phase of the Moon. For example, at First Quarter and at Last Quarter (when we see half of the Moon's waxing or waning disc), the angle Sun-Earth-Moon is 90° and the angle between the tide hand and the hour hand will be 180°.

## Setting up and adjusting your time-and-tide clock

Set out below are the procedures for properly setting up your time-and-tide clock for your location. For best results, this should be done at the next New Moon or Full Moon, whichever comes first. One will occur some time within the next 15 days. If you absolutely cannot wait and must set it up immediately, an alternative procedure may be used based on the most recent occurrence, but it involves more work and is highly prone to human error. Either way, you must determine the date and time at your time zone of the next or most recent occurrence of either New Moon or Full Moon.

westward in the window, but slower than the trees due to its real motion in the opposite direction. Similarly, each day, the Moon reaches upper transit about 50 mins later than the day before.

### The Accuracy of a Clock

Nature does not operate like clockwork. Planetary orbits are eccentric ellipses, not circles, and therefore the motions of the planets and moons are not uniform. A clock hand moving at a constant speed can only model the *mean* motion of the Moon, which means that it will reflect the Moon's true position only on average. The real Moon will be sometimes ahead of the tide hand and sometimes behind it. This is another reason why the tide hand may need to be periodically adjusted.

### New Moon, Full Moon, Lunation

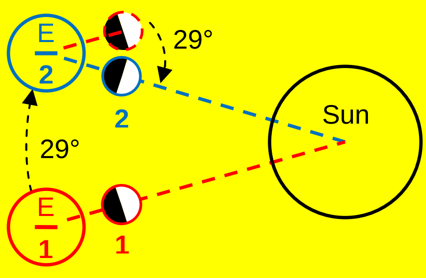
**At New Moon**, when the angle Sun-Earth-Moon is 0°, the Moon is said to be in conjunction with the Sun. At this time (called **lunar conjunction** in astronomy), **the Moon is at the same celestial longitude as the Sun**. At Full Moon, when the angle Sun-Earth-Moon is 180°, the Moon is said to be in opposition to the Sun. At this time (called **lunar opposition** in astronomy), the Moon is at the opposite celestial longitude from that occupied by the Sun.

**A lunar month** is generally regarded as being the time it takes for the Moon to go through a whole cycle of lunar phases, beginning at New Moon. This is called the Moon's **synodic period** or a **synodic lunation**, from the Greek word synodos (meeting). It is so named because at each lunar conjunction (the notional beginning of this cycle), the Sun and Moon "meet" at the same celestial longitude, as seen from Earth.

### Length of a cycle of lunar phases

The Moon orbits the Earth in about 27.32 days (a sidereal lunation), but it takes a little longer – about **29.53 days** – for the Moon to go through a full cycle of phases.

Since the Earth orbits the Sun, the Moon is orbiting a moving, not a stationary Earth. Therefore, the Moon has to go **more than 360°** around the Earth to again come back into line between the Sun and the Earth's new position. It takes the Moon another 2.21 days to do this. In that time, it must go another **29°** around the Earth to reach conjunction, because in the same 29.53 days (a synodic lunation), the Earth also travels **29°** along its annual path around the Sun. At http://www.sumanasinc.com/webcontent/animations/content/sidereal.html you can see a nice animation demonstrating this.



**One source for moon-phase information** is http://aa.usno.navy.mil/data/docs/MoonPhase.php – the U.S. Naval Observatory's Astronomical Applications Department. Note that the dates and times given there (and in most other sources) are in UT (Universal Time), which, for our purposes, may be regarded as the same as Greenwich Mean Time (GMT). (Some sources may specify that the times are given in UTC (Coordinated Universal Time), which is also the same as GMT.) The times are given in 24-hour clock time (00:00 to 23:59).

You will need to **convert the date and time** given there to the date and time at your time zone by adding or subtracting the difference between your time zone and Time Zone Zero (GMT). Add for places west of Greenwich and subtract for places east of Greenwich, and remember to change the date if this gives you a time in the next or previous day. (Remember also to adjust for Daylight Saving Time where and when applicable.) E.g. Australian Eastern Standard Time (AEST) is Time Zone +10, so Sunday, 16:15, GMT = Monday, 02:15, AEST. Once you have the necessary information, follow one of the three procedures (A, B or C) given below.

## Three methods for setting up your clock

For these procedures, when adjusting the position of just the tide hand, do so by using the dedicated **tide-hand adjustment knob**. This moves the tide hand independently of the other hands.

Methods A and B will set up your clock so that the tide hand shows the position in the sky of the mean moon. It will also show the times of the tides at ocean beaches and bodies of water connected to the sea where the tides are not subject to the delays and aberrations described on page 4. If they are, then method C may be more suitable.

**A. Simple Method:** This method is the easiest and most reliable. It must be done at the next New Moon or Full Moon. It assumes that the clock is running and is showing the correct time of day for your time zone.

At the exact time of the New Moon or Full Moon, move the tide hand so that it lines up exactly with the hour hand, both pointing at the same position on the dial. (Use the tide-hand adjustment knob.)

**B. Any-Time Method:** This is based on the most recent past occurrence of a New Moon or Full Moon, whichever has occurred last. It has the advantage that it may be used immediately, but it is tedious and prone to human error. It may require extensive turning of the time hands and it is easy to miscalculate the number of rotations you must turn the hour hand through or to miscount them while turning the hands. This method is not very practical if the last New Moon or Full Moon occurred more than a few days ago.

1. Note the date and time at your time zone (day d, at time T) of the last New Moon or Full Moon.
2. Remove the battery, and set the clock to time T.
3. Align the tide hand with the hour hand as described in method A.
4. Advance the time hands to the start of the next hour after time T. We will call this time T1. (This is to make steps 5 & 6 easier.) Skip this step if time T = hh:00 (i.e. if the minutes value is zero). In that case, T1 = T.
5. Calculate the total number of hours (**hhh**) in the interval between time T1 and time T2, which is the beginning of the current hour on today's date. Calculate this interval as (24 × w) + h, where w is the number of whole days (of 24 hours) within that interval, and h is the number of remaining hours in excess of w whole days.
6. Advance the time hands by exactly **hhh** whole hours. Pay close attention to this process, being very careful to count the number of hours correctly.
7. Finally, advance the time hands further until the minute hand points to the correct position on the dial to show the current time, then immediately insert the battery to start the clock.

**C. Tidal Offset Method:** This method of setting up your clock may be more suitable for showing tide times at bodies of water like bays or inlets where, as described on page 4, the tides are delayed from those at open ocean beaches at the same longitude. When set in this way, the tide hand will: (a) not show (at least not directly) the position in the sky of the mean moon, and (b) will only correlate with the tides if they are not subject to any of the other, more complex aberrations mentioned on page 4. If the delay factor is constant and stable rather than variable, this method should work. This method assumes that the clock is running and showing the correct time for your time zone.

1. Determine, well in advance, the date and time at your time zone of the next occurrence of New Moon or Full Moon. (We have discussed above how to obtain this information.) We will call this time M.
2. From time M, count forward or backward to the closest occurrence of 12 o'clock in the standard time of your time zone. (If your clock is set to Daylight Saving Time, count to 1 o'clock.) We will call this time T.
3. Determine, from information published by your local marine authority, when the next high tide after time T will occur at your body of water. We will call this time H.
4. At time H, move the tide hand (using the tide-hand adjustment knob) so that it points straight up. (If your clock is set one hour forward for Daylight Saving Time, point the tide hand at the one o'clock position.)

## Periodic adjustments of the tide hand

In a couple of places above, we mentioned factors that make it advisable to periodically adjust the tide hand to maintain long term accuracy. One factor mentioned is that a clock movement will usually only approximate the required rotation period (half a tidal day) of the tide hand due to the limitations of the gearing ratios. The tide hand will therefore gain or (more commonly) lose time by a small amount each tidal day. If allowed to keep accumulating, this gain or loss will soon mount up to a significant amount. Another factor is that a clock can inherently only model the Moon's *mean* motion, not its real motion, which is not uniform. Therefore, it is advisable to make regular adjustments to the tide hand to keep it on time and to keep it more or less in sync with the Moon. The simplest way to make the necessary adjustment is to follow the same procedure described above for the initial setup of your clock. (Use either method A or method C.) I recommend you do this once every lunar month at Full Moon.

**Terminology – Mean Moon**

The term "mean motion" is used extensively here to refer to the average properties (period, angular speed, etc) of a motion like that of the Moon, which is not uniform. This term is fairly understandable, but the term "**mean moon**", used in several places, may seem a little odd and deserves some explanation.

The **mean moon is an imaginary body** used in calculations, to which we ascribe a uniform motion, which is the calculated mean of the Moon's real motion. For those calculations, we likewise assume a **mean sun** and a **mean earth**.

When speaking of matters to do with motion (periods, speeds, and suchlike), we can speak of the (real) Moon's mean motion, but when speaking of an assumed spatial position of the Moon at a particular instant of time based on the Moon's mean motion, what we really mean is the position of the *mean moon*. When we speak of a mean New Moon, mean Full Moon, mean elongation angle, etc (all spatial positions), **these are the positions of the *mean moon* relative to the *mean sun***.

## Factors affecting the accuracy of your clock

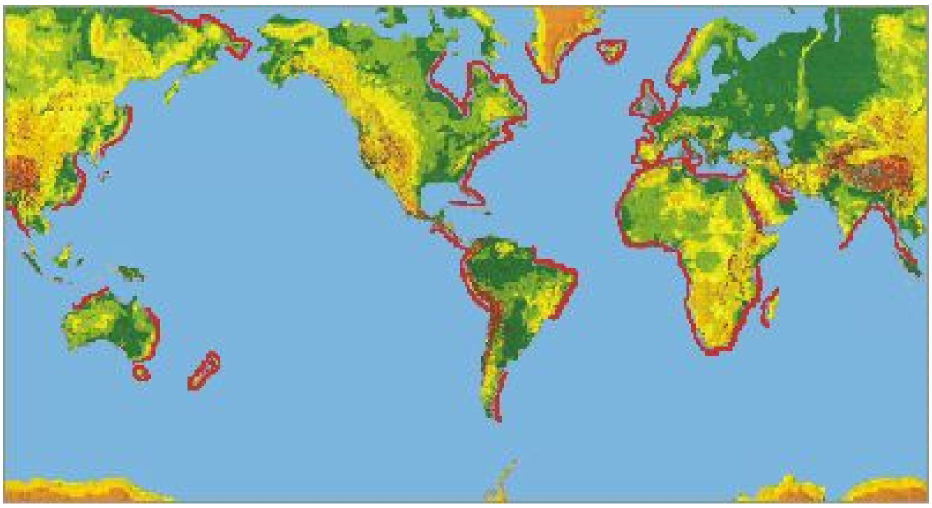
**Location:** When set up using method A or B above, the clock will model the mean moon's position in the sky for an observer at the **centre meridian** of your time zone. The further east or west you are from that meridian, the more the tide hand will be, respectively, behind or ahead of the mean moon by a constant amount. The difference will be 4 minutes per degree of longitude. If this difference is significant for your purpose, then, when setting up the clock (and when making a periodic adjustment of the tide hand), you can position the tide hand slightly ahead of or behind the hour hand to compensate for this difference. Be aware though that if you do this, the angle between the tide hand and hour hand will no longer accurately reflect the current lunar elongation as described on page 2.

For political reasons, Australian Central Standard Time is GMT + 9.5 instead of GMT + 9, which it should be on purely geographical grounds. Therefore, aside from the factor mentioned just above, the tide hand will be ahead of where it should be by half an hour (14.5° on the clock dial). You can compensate for this as suggested above.

**Daylight Saving:** Whenever your clock is set forward by one hour to show daylight saving time (DST) instead of standard time, the hour hand will point to the one o'clock position (rather than straight up) at upper transit of the Sun and it will point to the seven o'clock position (rather than straight down) at mean sunrise and sunset. The same will be true of the tide hand in relation to upper transit of the Moon and mean moonrise and moonset. Wherever the words "straight up" or "straight down" appear in the explanations or instructions contained here, if your clock is set to DST, substitute "the one o'clock position" for "straight up" and "the seven o'clock position" for "straight down".

## Tidal delays and other aberrations

We said above that high tides coincide with the Moon transiting the local meridian and the opposite meridian only at open ocean beaches. **In inlets, river estuaries and bays,** the local tides within those waters can be delayed somewhat from the times of the nearby ocean tides. This effect is especially pronounced in very large bays with narrow openings to the sea. They can take several hours to fill up and to empty out. A prime example of this is Melbourne's Port Phillip Bay, where, at the bay opening, the ebb flow of the receding tide exiting the bay through the heads often meets the incoming flow of the next high tide entering the bay. (For details of local tide movements in Port Phillip Bay, see: http://www.ppsp.com.au/PassagePlanning/TidesCurrents.html.)



**Other conditions** can also cause delays in the tidal times. Large continental land masses interfere with the westward travel of the tidal bulges and this causes many complex tidal cycles, especially on the west coast of North America. Ocean floor topography, bays and narrow inlets can cause resonance effects. Even weather conditions such as abnormal atmospheric pressure or high winds can temporarily alter the timing and the heights of the tidal cycle.

Tide clocks cannot take account of such factors. They are accurate in the areas of the map where the coastlines are outlined in red. They *may* not be in other areas.