Appendix 1: Tides

We have read a great many marine biology, marine ecology and rocky shore texts between us. They vary enormously in their content, accessibility and dare we say, interest value. An irritating constant though is the unsatisfactory treatment of tides; the material is either glossed over or intimidatingly mathematical. This appendix is an attempt to strike a happy medium and since tidal movements are the single most important environmental factor affecting life on the rocky shore, and they cause zonation, we hope the reader will feel the effort of reading this material is a worthwhile investment of their time.

The fact that the sea appears to go in and out is an obvious feature to anybody familiar with the coast of Great Britain. It is not an obvious feature to those that aren't. When Julius Caesar invaded Britain, at Deal in Kent, in 55 BC he made the rather embarrassing mistake of leaving his fleet on the beach at the base of the cliffs. Shortly afterwards the boats were smashed to bits on the cliffs by the incoming spring tide. Julius Caesar was used to the Mediterranean where there is very little rise and fall of the sea, or in other words, where there is a small tidal range.

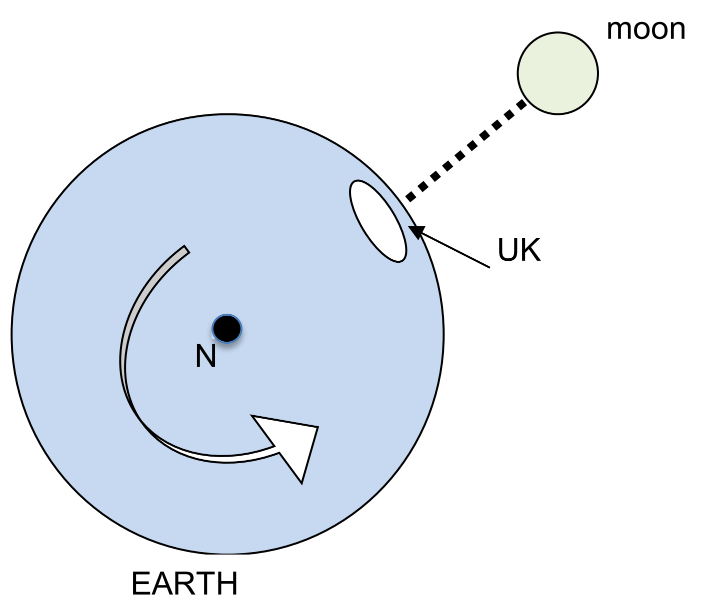
The rise and fall of the sea is referred to as 'tidal movement', and tides themselves are defined, in the Admiralty Tide Tables, for example as 'the vertical oscillation of the sea in response to the tide-raising forces of the moon and sun'.

The size and timing of the tides vary each day in accordance with daily, monthly and yearly tidal patterns, which in turn are produced by the changes in the relative positions of the moon and sun to the earth. In the sections below, we describe these tidal patterns, and explain why they occur.

THE DAILY PATTERN

Perhaps the first question to address is why the daily tidal pattern is longer than 24 hours (24 hours and 50 minutes is the average value, though it does vary). Imagine you are able to hover hundreds of miles above the North Pole and look back at the surface of the earth. You can see the United Kingdom (UK) and the moon is visible directly above it from your point of reference (See Figure A.1)

Figure A.1: The daily pattern



Imagine also that the moon is stationary relative to the earth.

As the earth spins on its axis the UK will move round, relative to the moon, as the arrow indicates. In this instance it would take 24 hours before the UK was back under the moon again. (See Figure A.2)

Figure A.2: The daily pattern

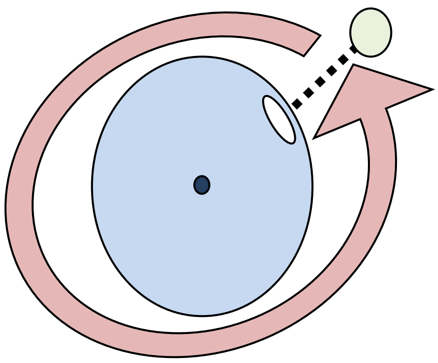
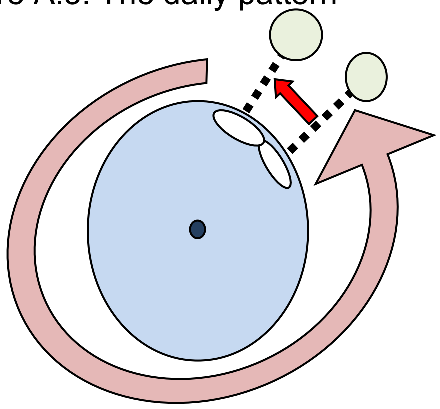


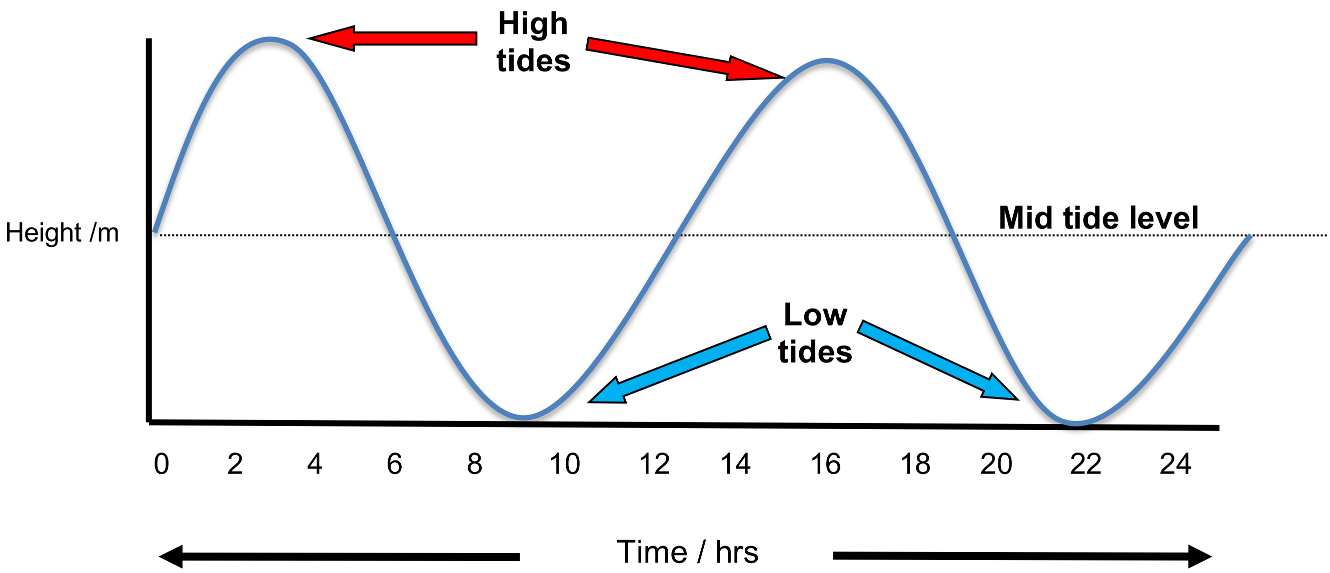
Figure A.3: The daily pattern



But the moon does move: it orbits the earth and note that the direction of orbit is the same as the direction of the earth's spin. By the time the UK had returned to its starting point it would no longer be under the moon. There would need to be some extra time 'allowed' for the UK to catch up with the moon (Fig A.3). This is important because our position relative to the moon dictates the state of the tide, so to achieve the same position relative to the moon (and therefore the same tidal state) the extra time of approximately 50 minutes is required.

If, instead of observing from space, one was able to watch what actually happens to the sea over the same period of time, say from the vantage point of the top of a cliff, the following might be seen. (See Fig A.4).

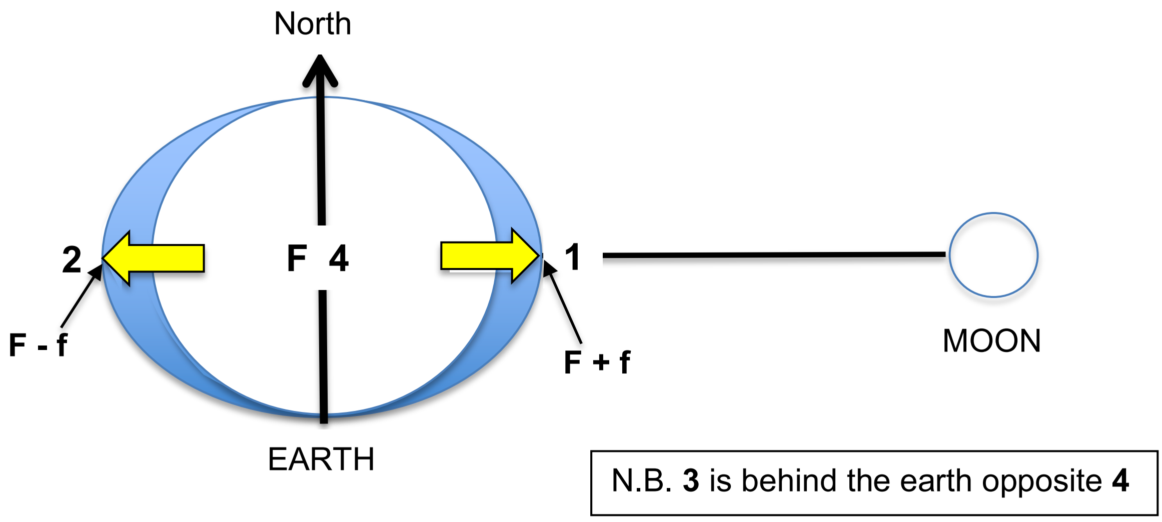
Figure A.4: The daily pattern (24 hrs and 50 minutes approx.)



Imagine that, at the start of your vigil, the sea is at mid tide level, which is taken as the average height about which the sea rises and falls. Over the course of the day you would see the water rise up to a maximum height then fall to a minimum height and then repeat this procedure. In other words in the UK, there are two high and two low tides per day.

AN EXPLANATION: Of all the heavenly bodies in our solar system the moon has the greatest gravitational effect on earth's water because it is closest; for the moment we will ignore the sun. Tide-raising forces occur, and therefore water moves, if there is a difference between the gravitational pull of the moon on the water and that on the earth, at any point of earth. Because the earth is rigid we can assume the moon's gravitational pull is the same wherever you are on earth. Let us call this force F. (See Figure A.5)

Figure A.5: Daily pattern explanation.



From the vantage point of space again, but this time at equatorial height, you might witness the situation diagrammatically represented in Fig.A.5. Assume, for the moment, that there is no land so the earth is covered with seawater.

At 1 in Fig A.5. The moon's pull on the rigid earth is F (as it is everywhere). The moon's pull on the water is greater than F, because the water is closer to the moon than the underlying rock and gravitational force is inversely proportional to distance i.e. the closer you are to the moon the greater its gravitational effect will be. Call the force on the water F + f. Therefore the force on the water is bigger than that on the rigid earth and this pulls water towards the moon. Hence the tidal bulge at 1, which is a High Tide.

At 2 in Fig A.5. The moon's pull on the earth = F. The moon's pull on the water is less than F (say F - f) because the water is further away (i.e. there is a greater force pulling the earth towards the moon than is pulling the water). So there is a bulge of water at 2, which is a High Tide, because the water is temporarily left behind in space!

At 3 & 4 in Fig A.5. The moon's pull on the earth = F and the moon's pull on the water = F,
therefore the force on the earth is equal to the force on the water so there are no tide raising forces here but because of 1 and 2 the water is 'pulled to the sides'. This means that if the water is elsewhere Low Tides occur at 3 and 4.

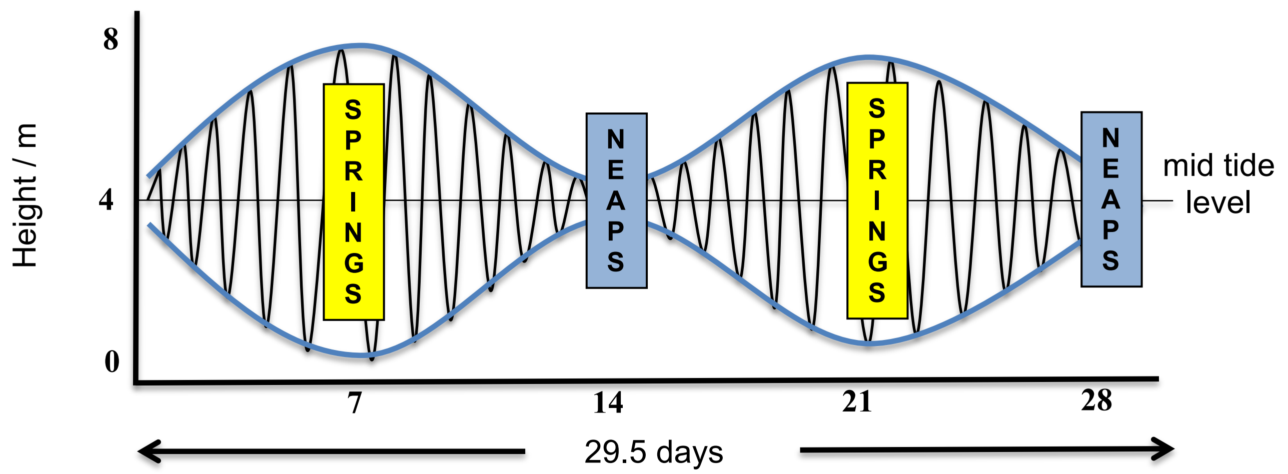
As the earth spins on its axis the UK for example would pass near to 1 where there would be a high tide, 3 where there would be a low tide, 2 a high tide and 4 a low tide. Therefore in 24 hours 50 minutes the UK would experience two high and two low tides.

It is reassuring to know that the sum total of all tide-raising forces, some towards the moon, some away from it, is zero so the danger of crashing into the moon is remote for the foreseeable future.

THE MONTHLY TIDAL PATTERN

If the rise and fall of the water were observed for a monthly tidal cycle a change in the amplitude of the oscillations would be observed. See Fig A.6.

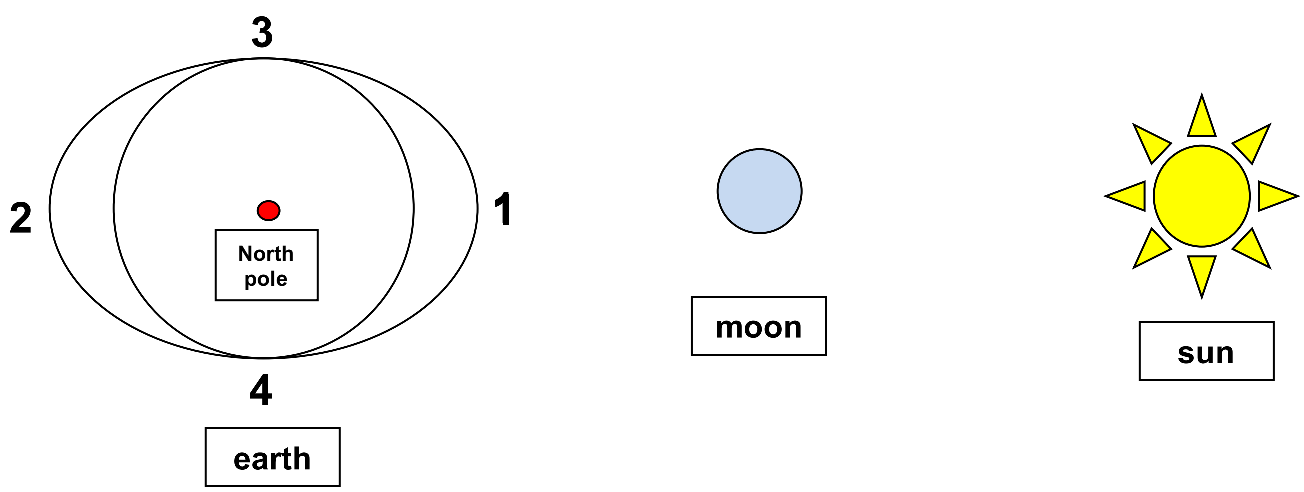
Figure A.6: The monthly pattern (Approx. 29.5 days)



Over the lunar cycle the height of the high tide varies, as does that of low tide. When the high tide is especially high then the low tide is especially low and vice versa. In other words there are times in the month when there is a large difference between high and low tide, i.e. the tidal range is large and times when the tidal range is small. The former are called spring tides and the latter, neap tides. They alternate with each other on approximately a weekly basis.

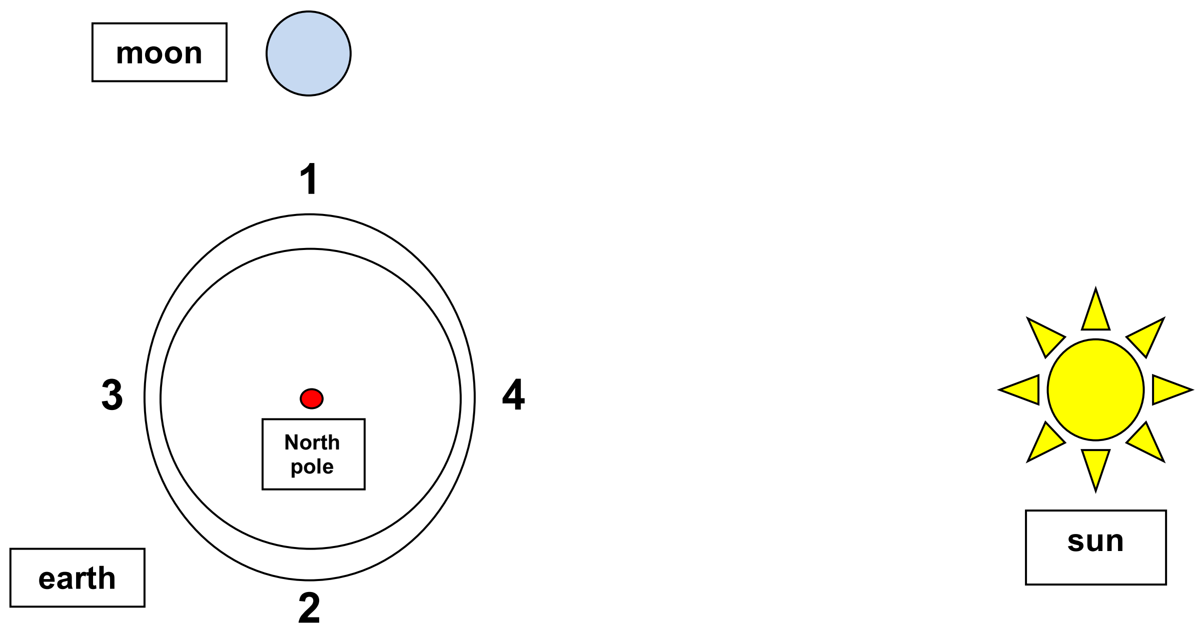
AN EXPLANATION - The monthly tidal pattern is due to two things: - 1. The moon orbiting the earth
2. The additional effect of the sun.

Figure A.7: SPRING TIDES - [Looking down on the North Pole]



As the moon orbits the earth there are times when its gravitational effects compliment those of the sun and SPRING TIDES occur. There are other times when the moon opposes the sun and this is when NEAP TIDES occur. See Figs A.7 & A.8 for an explanation.

Figure A.8: NEAP TIDES - [Viewed from above the North Pole]



For the reasons explained in the daily pattern, if the moon is producing a high tide at 1 then so is the sun. Likewise at 2 if the moon is pulling the earth towards it, leaving the water behind in space (temporarily), then so is the sun. Therefore both the moon and the sun's tide raising forces are combined to produce very high tides. If the water is 'pulled to the sides' then this means that the low waters at 3 & 4 will be very low.

Approximately one week after Figure A.7 the moon will have moved to a position where it makes a right angle with the earth and sun. Again using the theory from the daily pattern, the moon produces a high tide at 1 & 2 BUT this time the sun's tide raising forces oppose those of the moon because if they were on their own they would produce a high tide at 3 & 4. Because the moon is closer it 'wins' thus the high tides are at 1 & 2 and the lows are at 3 & 4 but they are lower high tides and higher low tides than in Figure A.7.

As the moon continues its orbit around the earth approximately a week later it will have reached the position illustrated in Fig A.9 below.

The easiest way to think of this situation is that since the earth, moon and sun are back in line, with no tide raising forces above or below this line, then the tide raising forces combine to produce spring tides again.

In figure A.10 the heavenly bodies are back at right angles so they act in opposition to produce neap tides.

Approximately one week after this the cycle begins again.

IN SUMMARY **- if the heavenly bodies (earth, moon and sun) are in line their tide raising forces combine to produce spring tides and if the moon and sun are approximately at right angles they act in opposition to produce neap tides.**

Figure A.9: SPRING TIDES [same view]

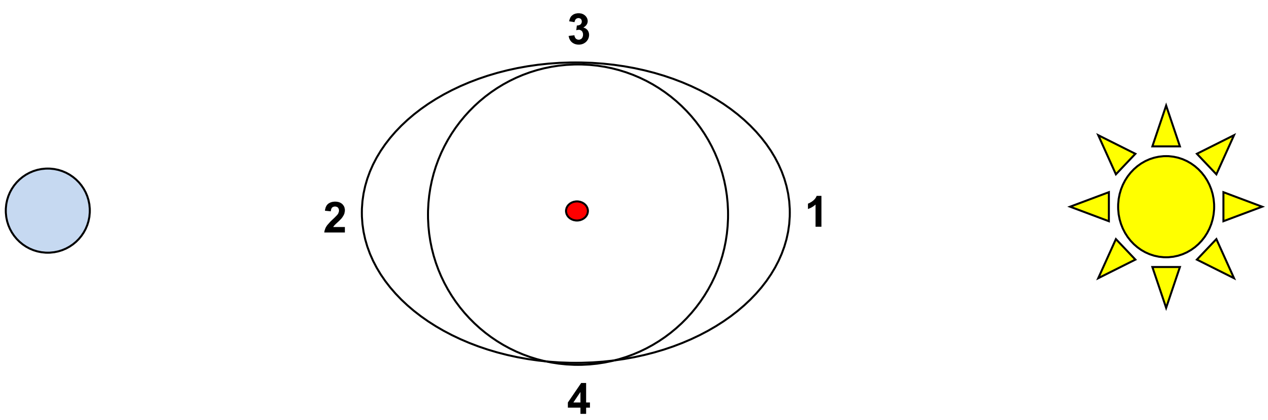
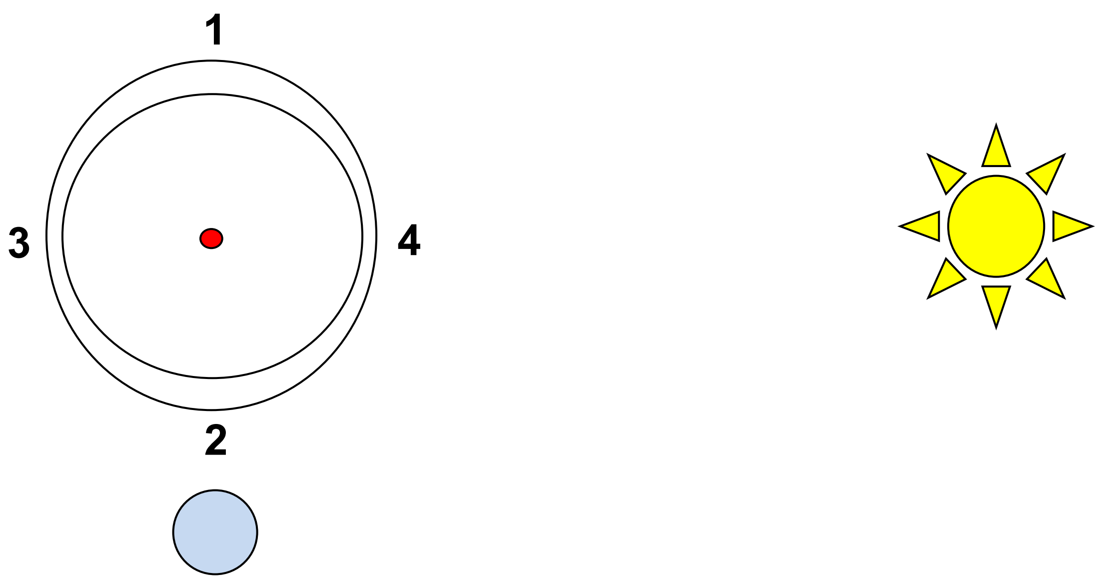


Figure A.10: NEAP TIDES [same view]

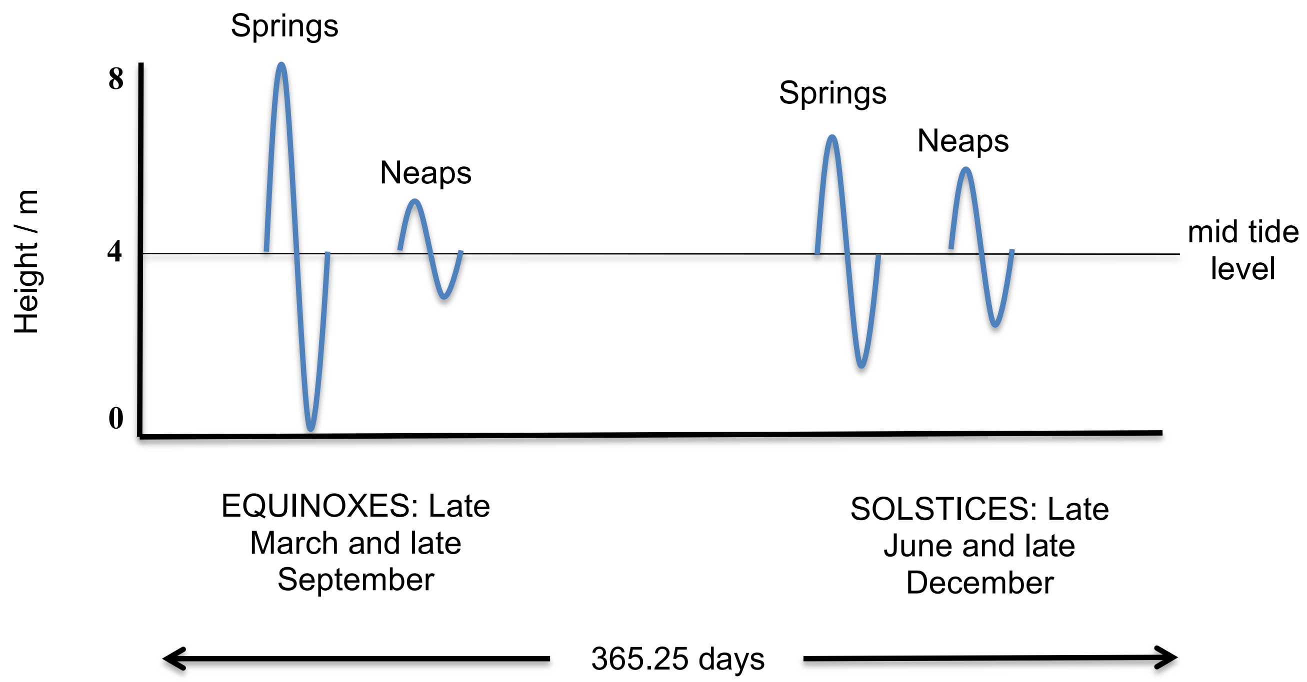


If you look once again at Figure A.7, hopefully you can see that this situation would produce an eclipse with the moon directly between the earth and sun. This does not occur monthly because the heavenly bodies are rarely that precisely in line, the moon could be slightly raised from the surface of the page and this would still produce a spring tide. If the moon were in such a position all you would see of it from earth would be either a ‘sliver’ or ‘crescent’, so Fig A.7 represents the position of the heavenly bodies when there is a NEW MOON. By the same argument Figure A.9 shows the configuration for a FULL MOON. Figures A.8 & A.10 are the moon’s first and last quarters respectively.

THE YEARLY TIDAL PATTERN

If tidal movements were observed for a whole year, from a suitable vantage point, it would become apparent that the size of spring and neap tides vary from month to month. (See fig. A.11)

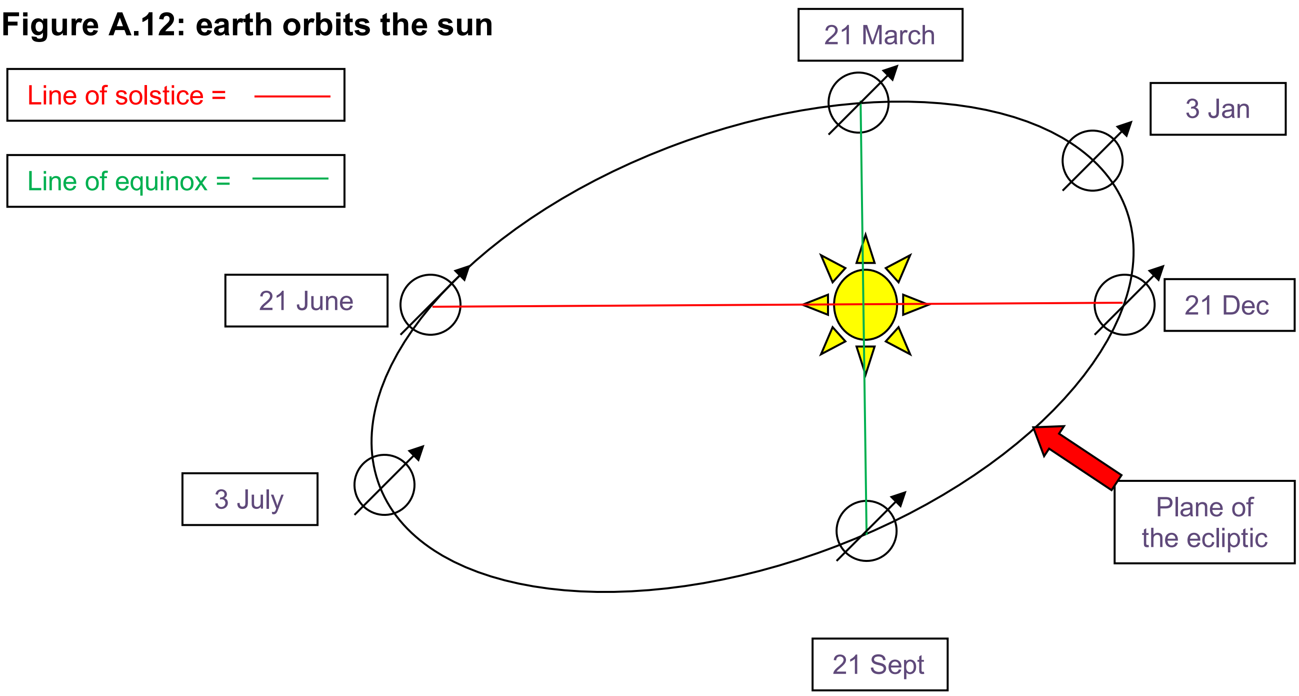
Figure A11: The yearly pattern (Approx. 365.25 days)



AN EXPLANATION -

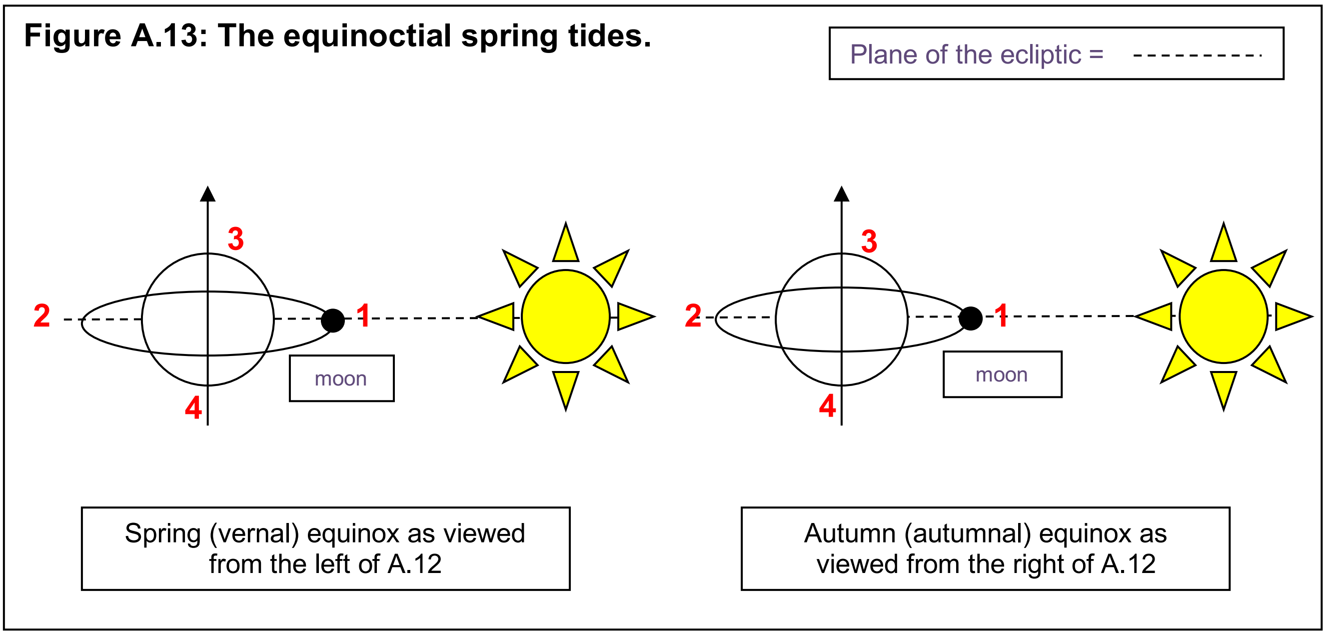
The yearly tidal pattern of 365.25 days is due to the earth orbiting the sun. See Figure A.12

Figure A.12: earth orbits the sun



During the spring (vernal) and the autumn (autumnal) equinoxes the sun appears to be exactly over the equator and day and night lengths are equal. (Hence the name equi = equal, nox = nights.) This is also the time of year when the moon's orbit around the earth coincides with the plane of the ecliptic, (the plane of earth's orbit round the sun, see Fig A.12.) when the moon is in either spring tide position. See Figure A.13. The earth is closest to the sun on approximately Jan 3rd (periapsis) and furthest away (perhaps surprisingly) on July 3rd (apoapsis).

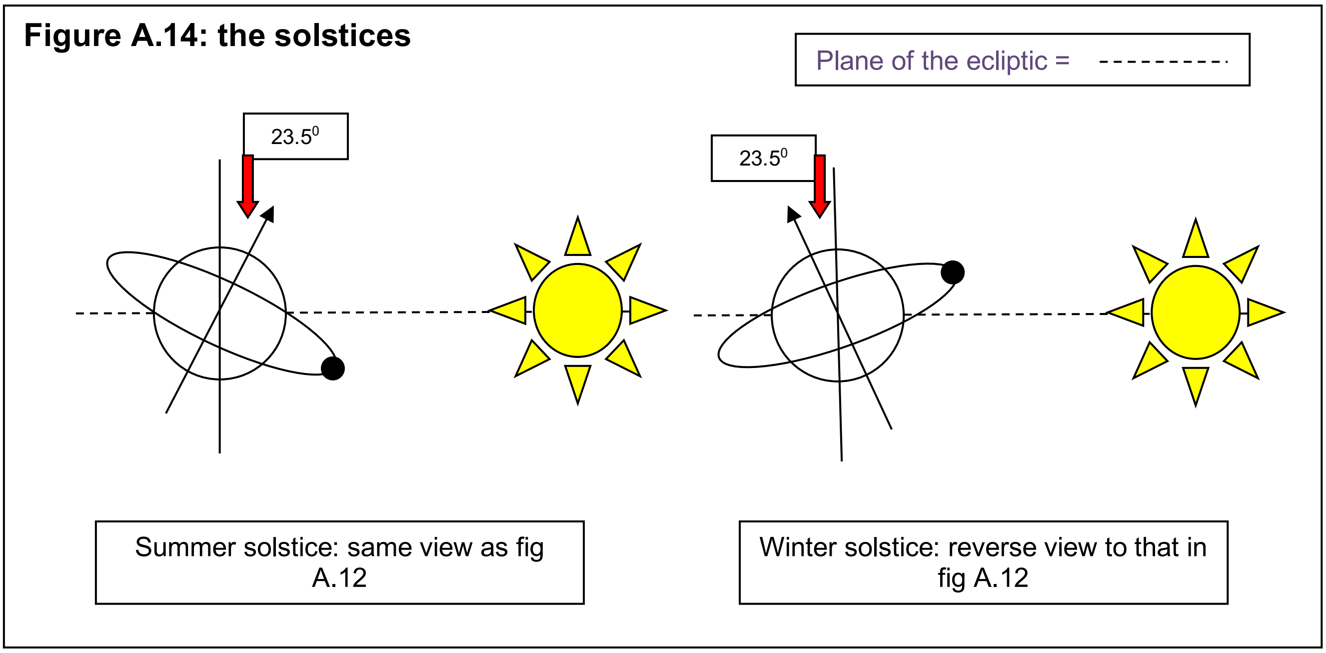
Figure A.13: The equinoctial spring tides.



Over the course of the year spring tides (1 and 2 in fig A.13) are greatest when the planets are most nearly in line. The smallest neap tides (3 and 4 in fig A.13) occur one week after the equinoxes because the suns opposition to the moon is greatest.

During the SOLSTICES in late June and December the moon's orbit no longer coincides with the plane of the ecliptic for the spring tide positions (see Fig A.12.). Thus the spring tide ranges are smaller as the heavenly bodies are not in line. See figure A.14.

Figure A.14: the solstices



Neap tides are larger at this time of year because the sun's opposition to the moon is less than at the equinoxes.

SUMMARY OF IMPORTANT TIDAL INFORMATION

In the UK there are two high and two low tides per day. The time from high to low water or vice versa is approximately 6 hours and 12 minutes.

Over the course of a lunar cycle there are two periods of spring tides and two of neap tides alternating with each other on approximately a weekly basis.

Over the course of a year spring and neap ranges vary. The largest spring tides occur at the equinoxes in late March and late September followed by the smallest equinoxes one week later. The smallest spring tides occur at the solstices in late June and December. The largest neaps occur one week after this.

SOME INTERESTING TIDAL FACTS.

Tidal movements are affected by the weather. If there is a low-pressure system (cyclone) over the British Isles then the air does not 'push down' on the sea as much as normal. The sea will flex slightly and come higher up the rocks than predicted. If tidal forces pulling water up the Thames, for example, are accompanied by strong winds in the same direction and low air pressure, this combination of factors could flood large areas of London. The Thames Barrier was built to prevent this happening. On the east coast of England, during a great storm on the night of 31 January 1953, the tide rose up to 3m above predicted levels, overwhelming sea defences and causing loss of life, widespread devastation and flooding.

So much water pours out of the Amazon that tidal forces are unable to reverse this flow until the last quarter of an hour of the tidal cycle. When spring tide forces finally overcome the flow of water out of the Amazon they create a Tidal Bore described as a 'several miles long waterfall travelling UPSTREAM at a speed of 12 knots for 300 miles'. Ships are advised to avoid this phenomenon although some people do attempt to surf the wave. The river Avon sports a similar, if rather more modest, spectacle.

Because tidal movements are vertical oscillations about a point they 'ignore' horizontal distances completely. Thus if the tide is due to rise 50 cm in an hour it might appear to rise quite slowly up a vertical harbour wall. But if the same tide is moving over a gently sloping surface it will rush in to achieve the same gain in vertical height, There are some very flat sandy beaches in the south of France where the tide comes in so quickly that even if you were galloping on horseback the sea would overtake you and you would probably drown.

The shape of the land affects tidal movement a great deal. As water is pulled up the Bristol Channel it is forced into a narrower and narrower space. Seawater piles on top of itself and this contributes to the Bristol Channel having the second highest tidal range in the world. The Bay of Fundy in Canada has the largest, although only by about 50cm.

Tidal range varies greatly in Britain between about 0.5m at Machrihanish, in Scotland, and 15m under the Severn Bridge. The mean is probably between 3 and 4 metres.

Because of resistance to movement (inertia) of the earth's water bodies tidal effects are delayed by approximately 36 hours. For example a large spring tide associated with the full moon will occur a day and a half after the actual lunar event.

The earth is not covered in seawater. Landmasses divide the oceans/seas up into almost separate units each of which has its own characteristics (natural period of oscillation). These can, and do, differ widely. For example, on the Caribbean side of the Panama Canal the tidal range is 0.3m, on the Pacific side the range is 4.2m increasing to 6.5 m during spring tides. The Mediterranean, cause of Julius Caesar's embarrassment at Deal, has very little tidal movement. The characteristics of the ocean basin are such that the main tidal movement (or note) is almost opposite, and equal to, a tidal harmonic (frequencies about the main note), hence they cancel each other out. Similarly the double high water experienced at Southampton is not due to the difference in the time of arrival of the tidal wave around the Isle of Wight. It is due to the interactions of harmonics of the main tidal period. Double high tides can only occur where the amplitudes of the harmonics are appreciable compared with that of the main tidal period.

In the North Atlantic, there are two high and two low tides per day, both of similar height. The time from high to low water and vice versa is approximately 6 hours and 12 minutes. These two equal maxima and minima are referred to as semi-diurnal tides. If the moon were permanently over the equator then all latitudes would experience semi-diurnal tides. The moon's orbit is such that it appears to oscillate above and below the equator (declination no longer zero) and this can cause all sorts of complications including unequal tide heights within a daily cycle (e.g. Singapore) and a diurnal component as well as a semi-diurnal one. In some parts of the world the diurnal component is more important. The possible permutations are infinite; as a result there are no two places in the world, however close together, where the tides are exactly the same.

The time of high (and low) tide is later on succeeding days. The average is about 50 minutes, ranging from less than 30 minutes at springs to nearly 80 minutes at neaps. However, at any one place, spring and neap high tides always occur at approximately the same time of day. This can have profound impacts on the zonation of rocky shore organisms. If spring low tides always occur during the middle of the day (as they do in Pembrokeshire) then even the lower part of the shore may experience full sunlight. If spring low tides fall early in the morning, as they do in parts of Scotland, strong sunlight is not an issue.

The tide rises (and falls) most rapidly at half tide level, and in proportion to the tidal range on that day.

As a consequence of the earth's rotation and the individual characteristics of the ocean basins tidal waves appear to radiate outwards from a number of points, like the ripples produced by throwing a stone into a pond. These points are called 'amphidromic points' and represent areas where there is no tidal movement, as the tides move away from the amphidromic point the amplitude of the tide increases. There are five such points around the UK, three in the North Sea, one near Bournemouth and one northwest of Wexford, in the Irish Sea. The Bournemouth and Wexford amphidromic points, to be strictly accurate, are on land as a result of distortion to the system being caused by shallow water effects.

Perhaps the idea of amphidromic points maybe made more accessible with the analogy of a nice hot bath. Inevitably as you relax back you discover the soap is out of reach, between the taps. You bend your legs, retrieve the soap and then straighten them again. In doing so you will cause an oscillation of the water in the bath from the tap end to the end behind you. Movement of the water at each end of the bath is quite large, movement in the middle, say parallel to your hips, is minimal. If you imagine the same set up but now the bath is spinning, say anti-clockwise (in keeping with bodies of water in the northern hemisphere due to the earth's spin and associated coriolis force) then instead of having a line across the middle of the bath, where there is minimal water movement, there is now a point. Oscillations of the water increase with distance from this point. This point in the bath is a fairly reasonable approximation to an amphidromic point in an ocean basin. The major difference is that ocean basins (by virtue of their depth profiles, bottom characteristics and shape) are way more complex and the resulting tidal results similarly so. Note the North Sea has three amphidromic points not just one. Note also that the "tidal movements" set up in the bath are oscillations of the water body, the water doesn't actually go anywhere, the same is true of tidal movements in ocean basins. Mass movements of water are currents and are caused by a variety of other factors including temperature differentials, for example.

There can be no doubt that tidal movements are fiendishly complicated. Hopefully the reader has derived some entertainment and even illumination from the preceding summary. For those with a strong constitution a much more detailed explanation can be found in the "The Admiralty Tide Tables, Volume 1 European Waters". Two other volumes cover the rest of the world. Detailed predictions of every high and low water (for the year) are given for the Standard Ports together with corrections for the Secondary Ports nearby. A new edition is issued every year. Mean tide levels, averaged over a ten-year period, are tabled for every listed port.

There are also tidal prediction websites, many are free for data concerning the present week but future (and indeed past) data sets are only available as a subscription-based service. For a good example see:
http://easytide.ukho.gov.uk/