## 12.1 TIDES : MEANING AND CONCEPTS

Waves, currents (both surface and deep ocean currents), and tides are of vital significance among various types of ocean movements. Waves and ocean currents have already been discussed in the preceding chapters 8, 9, 10 and 11 of this book. Different aspects of tides, such as meaning, characteristic features, tide generating forces, tidal times, types of tides, theories of the origin of tides etc. are being discussed in this chapter.

Tides are, in fact, the most important of all the ocean movements because tidal currents affect the whole water mass from sea surface to the bottom.

The rise and fall of seawater due to gravitational forces (centrepetal) of the sun and the moon are called tides. P. R. Pinet (2000) has defined the tide in the following manner :

> *"Tides are waves with very long wavelengths—much longer than ordinary wind waves-that cause sea level to rise and fall with extraordinary regularity. In fact, tides are the most uniformly varying phenomenon in the ocean."*
>
> — P.R. Pinet, 2000

It appears from the above statements that tides are simply periodic rise and fall of sea level caused by external sources e.g. sun and moon. According to H.V. Thurman and A.P. Trujillo (1999) "Tides are the periodic rising and lowering of average sea level that occurs throughout the oceans of the world."

## 12.2 TIDES : CHARACTERISTIC FEATURES

As stated above tides are rhythmic rise and fall of ocean surface caused by the gravitational (attractional) forces of the sun and the moon. The ocean tides are characterized by the following typical features :

- Tides are single wave phenomenon which covers the entire ocean basin. On the other hand, wind-generated sea waves are succession of waves approaching the sea shore one after another. The front of the tidal wave causes upward movement of seawater (rise of sea level) in one part of the ocean basin, while downward movement or say fall of sea level on the other side of the same ocean basin.

- Tides are shallow water waves but with very long wavelength even in the deep ocean basin.
- Tides are differentiated from wind-driven sea waves with respect to wavelength, wave height, mode of origin etc. Tidal waves and simple wind-driven sea waves have one common aspect i.e. source of forces responsible for the origin of tides and sea waves. Both have external sources for their origin. Tides are originated due to interactions of the sun and moon with ocean surfaces while sea waves are generated by wind-drag. Besides, sea waves are also originated by other factors such as atmospheric pressure, temperature variations, salinity variations etc.
- Tides are low waves but with high energy, while sea waves are high waves with low energy. Very high sea waves such as rogue waves and storm breakers have very high crests but are localized phenomena but tides are widespread phenomena because they stretch across the entire ocean basin.
- Like wind-driven sea waves tidal waves are also characterized by crests (rise of water) and troughs (fall of water). The tidal wave height is called **tidal range.** The vertical difference between high tide water (crest of tidal wave), and low tide water (trough of tidal wave) is called the tidal wave height or tidal range which generally varies between less than 2 metes to more than 4 meters. On the basis of height tidal range is divided into the following three categories (fig. 12.1) :
  (1) **microtidal range,** height (wave height) less than 2 meters
  (2) **mesotidal range,** wave height between 2 to 4 meters
  (3) **macrotidal range,** wave height more than 4 meters
- The rise of seawater and its movement toward the coast is called **tide** and the resultant high water level is known as **high tide water** (H.T.W.), while the fall of seawater and its movement toward the sea is called **ebb** and the resultant low water level is known as **low tide water** (L.T.W.).
- There is much variation in the height of high and low tides at different places in different oceans because of varying characteristics of the depth of ocean water, configuration of sea coasts and coastlines and openness or closeness of the seas.
- Gravitational pull of ocean water is called **tidal bulge** which occurs at two places, one bulge is toward the moon and the other is away from the moon on the opposite side of the earth i.e opposite to the first bulge. The tidal bulges created on the earth's water surface by the gravitational force of the moon are called **lunar tidal bulges** (fig. 12.4, at T place, facing the moon, and at A place, oriented on the opposite side of the earth). These two bulges are high tides. Thus each place on the earth experiences bulges or high tides twice each day i.e. they occur at the interval of 12 hours 25 minutes each day. The total period of two bulges (tides) each day is called **lunar day.** It may be mentioned that **solar day** is of about 24 hours.
- Like moon, as referred to above, sun also produces bulges on opposite sides of the earth by its gravitational force (pull). The bulges created by the sun on the earth's water surface are called **solar bulges.** One bulge is oriented toward the side of the sun while the other bulge is oriented toward the opposite side of the earth. Since the distance of the sun from the earth is far greater than the distance between the moon and the earth, the size of solar bulge is 46 percent smaller than the lunar bulge because the gravitational pull of the moon far exceeds the gravitational pull of the sun.
- The coastward transgression of seawater under the influence of tidal waves or simply tidal bulge is called **flood tide** while seaward regression of water of tidal bulge is called **ebb tide.**
- Any place on the earth facing oceans (also seas) will experience two **flood tides** and two **ebb tides** each lunar day.

TIDES

- The heights of high and low tides are never identical rather these greatly vary. In other words, no two high tides or two low tides are ever of same height.
- The monthly and annual cycles of tidal ranges also change because they are dependent on the changing distances of the sun and the moon from the earth because of elliptical shape of the earth's orbit.
- There are two high tides (spring tides) and two neep tides in every month.
- There are exceptions to the occurrences of two high tides and two low tides each lunar day in some localities due to complex factors. Thus, the tidal patterns of a lunar day are divided into the following 3 patterns :

(1) **Diurnal tidal pattern** referes to the occurrence of only one high tide and one low tide each lunar day in shallow seawater.

(2) **Semidiurnal tidal pattern,** two high tides, and two low tides each lunar day having almost identical tidal heights of successive high and low tides. Such tidal pattern occurs along the western parts of the Atlantic Ocean facing east coasts of the USA.

(3) **Mixed tidal pattern** is characterized by the occurrences of diurnal as well as

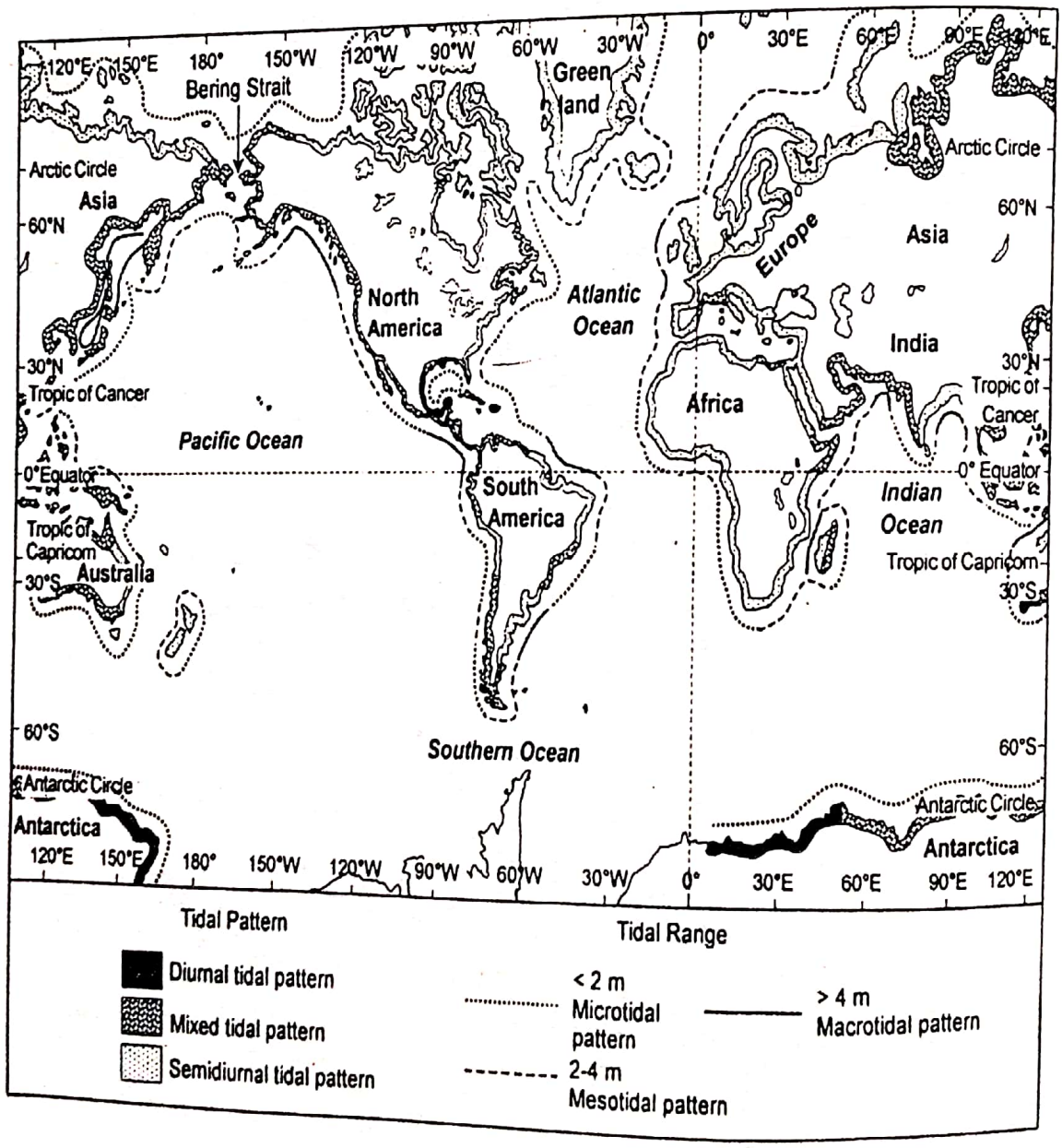


*Fig. 12.1 : Tidal patterns and tidal range along the coastlines of the world. After A. Couper, 1983, in P.R. Pinet, 2000.*

semidiurnal tidal patterns but the heights of successive high or low tides are never identical rather they frequently change. This tidal pattern is the most common pattern of the occurrences of tides almost in all the oceans. The variations in the heights of successive high and low tides of mixed tidal pattern are called **diurnal inequalities.**

- The steep wall of water created in the narrow estuaries of rivers that debouch in the oceans or in the bays having narrow and constricted mouths due to incoming tide is called **tidal bore.** Tidal bore is formed due to friction of seaward flowing rivers and incoming tidal waves. The frictional obstruction caused by incoming tide to the free flow of the river forces the water to rise upto abnormal height, and thus tidal bore is formed.

## 12.3 TIDE GENERATING FORCE

The origin of tides in the oceans is primarily concerned with the gravitational forces of the sun and the moon. It may be pointed out that the earth rotates from west to east and revolves around the sun following an elliptical orbit. Similarly, the moon rotates from west to east and revolves around the earth (fig. 12.2) along an elliptical orbit so that the distance between the moon and the earth changes (fig. 12.2) during different times in every month. The period of the farthest distance between the moon and the earth (407,000 km) is called **apogee** while the period of the nearest distance (356,000 km) is called **perigee** (fig. 12.3).

The surface of the earth with its diameter of 12,800 km (8,000 miles) is 6,400 km nearer to the moon than its centre. The centre of the moon is 3,84,800 km (2,40,000 miles) away from the centre of the earth. The earth's outer surface is 3,77,000 km (2,36,000 miles) away from the outer surface of the moon. It is evident that the earth's outer surface, which is opposite to that surface of the earth which faces the moon (fig. 12.4 T) is 3,90,400 km away from the moon's surface. The gravitational force of the moon will be maximum at the earth's surface facing the moon (at T in fig. 12.4) while it will be minimum at the opposite side of the earth (at A in fig. 12.4). Consequently, the water of the earth's surface facing the moon is attracted and pulled and high tide occurs (fig. 12.4). High tide is also formed at the opposite side of the earth (A in fig. 12.4) simultaneously because of the reactionary force (centrifugal) of the gravitational (centripetal) force of the moon causing outward bulge of water.

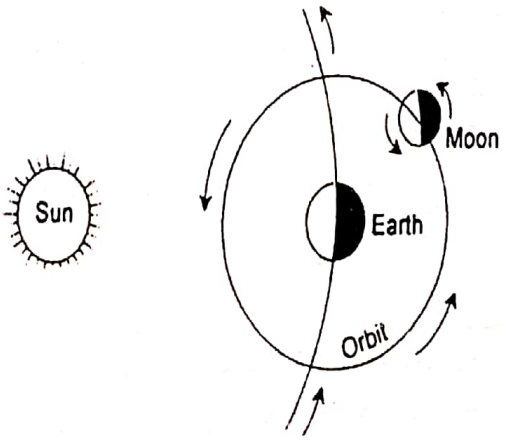


*Fig. 12.2 : Similar direction of rotation and revolution of the earth and the moon.*

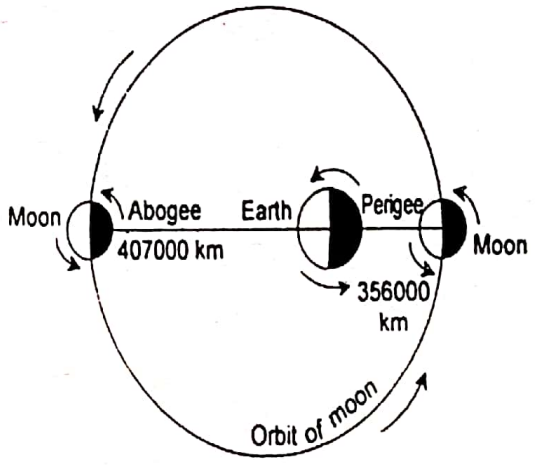


*Fig. 12.3 : Varying distances between the earth and the moon. Situations of apogee and perigee.*

It may be mentioned that tides are caused in the earth's ocean due to the following two main factors :

- gravitational force (attraction) of the moon, and

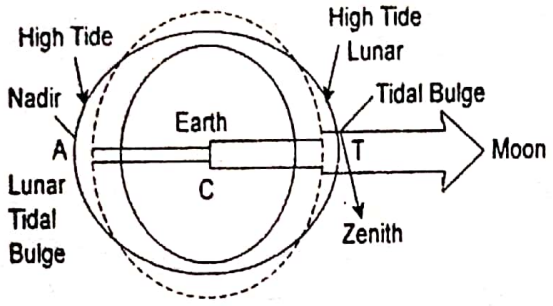


*Fig. 12.4 : Effects of gravitational force of moon on earth's water surface and occurrence of high tides. Simultaneously there are two lunar bulges on the earth's surface at place T, facing the moon (zenith) and at place A, on opposite side of the earth (nadir).*

➢ centrifugal force associated with the rotation of the earth and the moon.

The following principles govern the strength of gravitational attraction between two celestial bodies :

1. Gravitation attraction is proportional to the mass of the body i.e. the greater the mass of a body, the greater the gravitational attraction and vice versa. 'In fact, the strength of gravitational attraction varies directly with the masses of interacting bodies' (P.R. Pinet, 2000).

2. Gravitational attraction also depends on the distances between two interacting bodies. In fact, the gravitational force is inversely proportional to the square of the distance between two interacting bodies of varying masses. In a very simple term, the greeter the distance between two interacting bodies, the lesser the gravitational force and vice versa. It may be mentioned that there is some difference between gravitational force and tide generating force. Thus, tide-generating forces tend to 'vary inversely as the cube of the distance from each point on the earth to the center of the tide-generating object (moon or sun), instead of varying inversely to the square of the distance as does gravitational attraction' (H.V. Thurman and A.P. Trujillo, 1999).

This is to remember that though the mass of the sun is 10 million times greater than the mass of the moon but the strength of gravitational attraction of the moon is 2 times more than the sun because the moon is 390 times closer to the earth than the sun. This is why the moon has twice the tide-generating force on the earth's surface to that of the sun's tide-generating force on the earth, and thus, moon is more potent source of tide generation on the earth's surface than the sun.

Thus, the tide-generating force of the moon causes two **lunar tidal bulges** on the earth's surface at the same time. One bulge of ocean water, located at T in fig. 12.4, is on that side of the earth which faces the moon. This side of the bulge is called **zenith.** The other lunar tidal bulge, located at A in fig. 12.4, is on opposite side of the earth, opposite to that side of the earth (T in fig. 12.4) which faces the moon. This side of lunar bulge is called **nadir. The zenith lunar bulge** (at T in fig. 12.4) is caused by the gravitational attraction of the moon, while the **nadir lunar bulge** (at A in fig. 12.4) is generated by the 'centrifugal effect associated with the rotation of the earth and the moon.'

Thus, two tides and ebbs are experienced twice at every place on the earth's water surface within 24 hours. When the sun, the earth and the moon are in the same line (at the time of full moon and new moon) their gravitational forces work together and high tides are formed (fig. 12.5). On the other hand, when the sun and the moon are at the position of right angle with reference to the earth (fig. 12. 6), the gravitational forces of the sun and the moon work against each other and hence low tides are formed. This situation occurs during the 8th day of each fortnight of a month.

## 12.4 TIME OF TIDES

On an average, every place experiences tides twice a day. Since the earth completes its rotation in roughly 24 hours, every place should experience tide after 12 hours but this never happens. Each day tide is delayed by 26 minutes because the moon also rotates on its axis (west to east) while revolving around the earth. Since the earth rotates from west to east and hence the tide

centre shifts westward. When the tide centre completes one round, the moon's position is ahead of the tide centre by that time because the moon also revolves around the earth, with the result the tide centre takes another 52 minutes to come under the moon. Thus, a particular tide centre takes 24 hours 52 minutes to come under the moon but by that time there is another tide at the opposite side of the referred tide centre and this happens after 12 hours 26 minutes.

Let us understand this process with the help of a diagram (fig. 12.7). Suppose if P experiences first tide at 4 P.M., the second tide will occur at 4.26 A.M. and the next tide will be experienced at 4.52 P.M. The moon is at 'K' location (fig. 12.7) and the place 'P' on the earth's water surface under the moon (K) will experience tide at 4 p.m. The place 'P' after completing its full rotation in 24 hours comes to its original place but by that time the moon moves to 'L' position which is above 'F' place on the earth's surface. Now the place 'P' has to cover extra distance of P-F so that it may come under L position of the moon and 'P' may experience next tide. The earth has to spend 52 minutes to cover P-F distance. The moon completes its one revolution around the earth in 27 days, 7 hours, 43 minutes and 17.5 seconds (average 27.5 days). Thus, the P-F distance is 2/55th part of the moon's orbit. The place 'P' will take 24×60×2/55=52 minutes to cover the distance of 2/55 (P-F) part of the moon's orbit, therefore, the place 'P' will experience next tide at 4.26 A.M. when it is at O place and subsequent tide occurs at 4.52 P.M. It is evident that at each place every day tide occurs after 12 hours and 26 minutes and after the tide, ebb occurs after 6 hours 13 minutes. It may be pointed out that each place experiences tide twice a day *i.e.* when the place is under the moon and when the place is at the opposite side of the moon and thus each tide at particular place is delayed by 26 minutes daily.

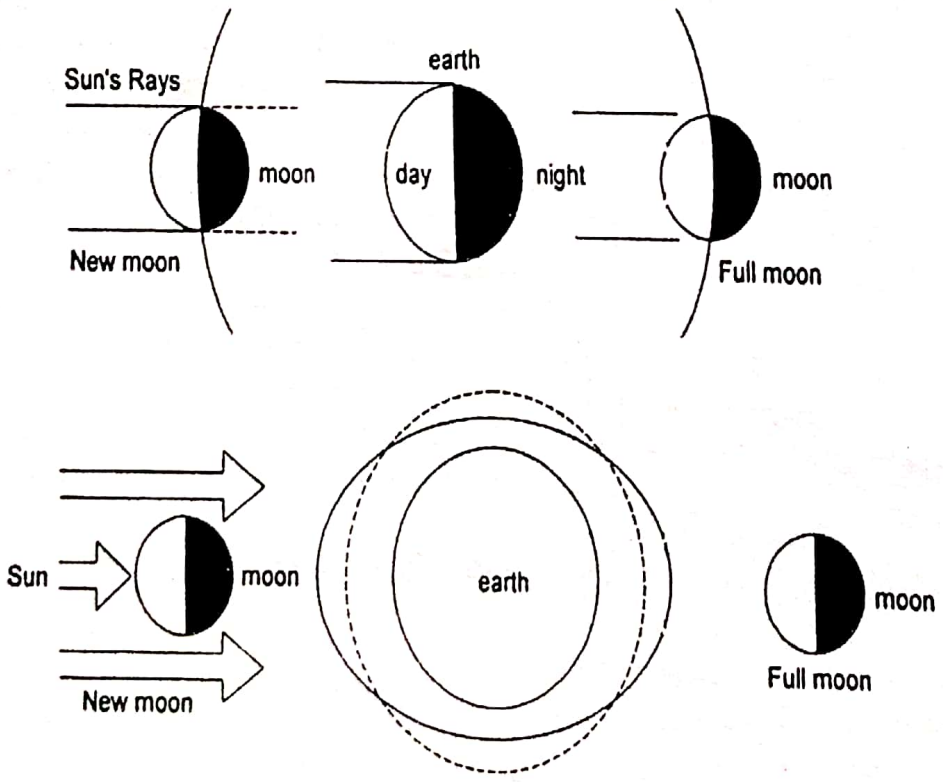


*Fig. 12.5 : situations of full and new moon and high tide.*

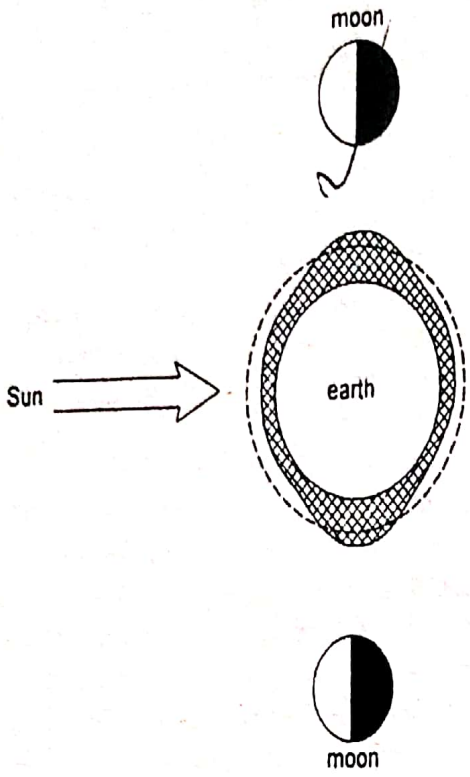


*Fig. 12.6 : situation of quarature and low tide.*

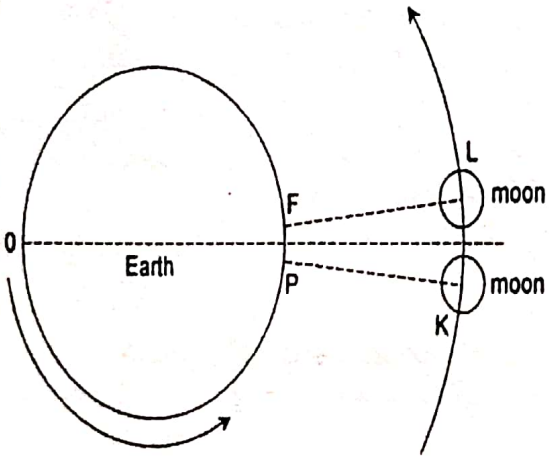


*Fig. 12.7 : Time of the occurrence of tide.*

## 12.5 TYPES OF TIDES

The oceanic tides are caused due to tide producing forces of the sun and the moon. There is a lot of temporal and spatial variation in the tide producing forces because of different positions of the sun and the moon with the earth. Because of variations in the intensity of tide producing forces several types of tides are caused. A few important types of tides are given below :

- spring tides
- neep tides
- tropical and equatorial tides
- apogean and perigean tides
- diurnal and semi-diurnal tides
- equinoctical spring tides
- direct and indirect tides (zenith and nadir tides)

### Spring Tides

Very high tide is caused when the sun, the moon and the earth are almost in the same line. Such high tides are called spring tides. The position of the sun, the moon and the earth in a straight line is called **syzygy.** When the sun, the moon and the earth are in sequential order in a straight line, in other words when the sun and the moon are in one side of the earth, the position is called **conjunction** (the situation of solar eclipse). When the position of the earth is inbetween the sun and moon, this is called **opposition** (fig. 12.8). On the other hand, when the sun, the earth and the moon are in a position of a right angle (fig. 12.6), this position is called **quadrature.** The positions of **conjunction** and **opposition** take place during **new moon** and **full moon** respectively. In these situations the gravitational forces of the sun and the moon work together with combined force and thus high tide is caused. The height of such spring tides is 20 per cent more than the normal tides. Such tides occur twice every month (during full moon and new moon) and their timing is fixed.

### Neep Tides

The sun, the earth and the moon come in the position of quadrature (*i.e* form right angle) on seventh or eighth day of every fortnight of a month and thus the tide producing forces of the sun and the moon work in opposite direction, with the result low tide is caused. Such tide, which is lower in height than the normal tide, is called neap tide. The height of neap tides is generally 20 per cent lower than the normal tides.

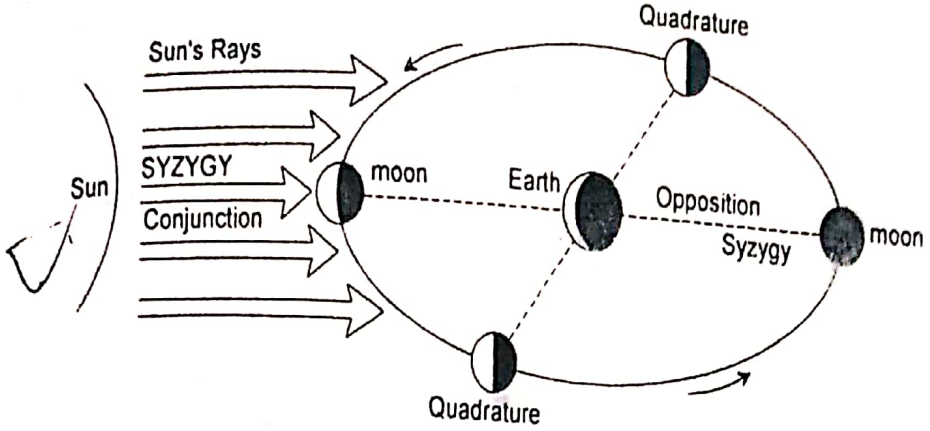


*Fig. 12.8 : Position of the sun, earth and moon and the situation of conjunction, opposition and quadrature.*

### Tropical and Equatorial Tides

Like the sun there is also northward and southward position of the moon in relation to the equator of the earth. If the sun completes its northward and southward position in one year *i.e.* in roughly 365 days, the moon completes it in 27.5 days or say in one **synodic month.** When there is maximum declination of the moon to the north of equator, the moon's rays fall vertically on the tide centres (near the **Tropic of Cancer**) and hence spring tides are caused. Such tropical tides move westward along the Tropic of Cancer. Spring tides are also caused along the Tropic of Capricorn which is opposite to the Tropic of Cancer. Thus, successive high and low water occurring along the tropics of Cancer and Capricorn are of unequal heights. Such tides and ebbs are of higher and lower heights than the normal tides and ebbs respectively. Such tides recur twice every month when the moon's rays fall vertically on the tropics of Cancer (during northward position of the moon) and Capricorn (during southward position of the moon). Thus, the tides occurring along the tropics of Cancer and Capricorn are called **tropical tides.** There is no diurnal inequality of tides in terms of heights of two neap tides and two spring tides because the moon is vertical on the equator every month. Such tides are called **equatorial tides.**

### Apogean and Perigean Tides

The nearest position of the moon with the earth is called **perigee** when the distance between them is 3,56,000 km. The tidal force of the moon is most powerful during this position and hence high tides are caused. Such tides, called as **perigean tides,** are 15 to 20 per cent higher than the normal tides. On the other hand, the tidal force of the moon is minimum during the position of **apogee** when the moon is at the farthest distance (4,07,000 km) from the earth and hence low tides are caused. Such low tides, called as **apogean tides,** are 20 per cent lower than the normal tides. When the spring tide and perigean high tide occur at the same time, the resultant tide becomes abnormal. Similarly, when neap tide and apogean tide occur at the same time, the water level becomes significantly low.

### Daily and Semi-diurnal Tides

The tides recurring at the interval of 24 hours 52 minutes daily are called diurnal or daily tides while the tides recurring at the interval of 12 hours 26 minutes are called semi-diurnal tides.

### Equinoctorial Spring Tides

The tides recurring at an interval of 6 months due to the revolution of the earth around the sun and sun's varying declinations are called equinoctical tides.

### Zenith and Nadir Tides

As stated earlier the strength of gravitational attraction of the moon is greatest at the

earth's water surface that faces the moon (T in fig. 12.4) at zenith, with the result high tidal bulge (high tide) is created at the zenith. This is called **zenith tide** or **direct tide.** Simultaneously high tide is also created at the opposite side (A in fig. 12.4, nadir) of the earth at nadir. Please remember this opposite side of the earth does not face moon but is opposite to that side of the earth (zenith) which faces the moon. This **nadir lunar tidal bulge** (high tide) is called **nadir tide** or **indirect tide** because it is not generated by the gravitational attraction of the moon, but is generated by the centrifugal force resulting from the rotation of the earth and the moon.