


Chapter 10: Tides

Remember that tides are waves that are caused by the gravitational attraction of moon and sun. Tidal waves are the longest of all waves, L can be up to half the Earth's circumference.

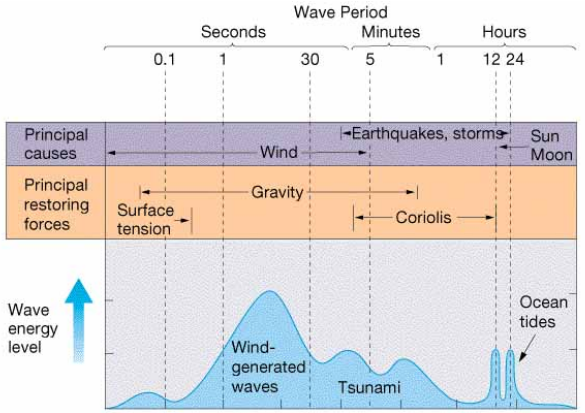


Fig. 9-2

Waves are created by a 'disturbance'.

* **wind** (wind waves, L= 60-150 m), where most of ocean's wave energy is located.
* **earthquakes** (seismic waves, L = 200 km)
* **sun/moon** (tidal waves, planetary scale).

Restoring force is

***gravity** (gravity waves).

*surface tension (capillary waves)

Tides:

1. Understanding the Earth-Moon system

The **Earth-Moon system** revolves as a system once a month around its center of mass. The center of mass of both systems is located inside the earth (about one quarter of earth's radius below the surface of the earth). It is called the **barycenter**.

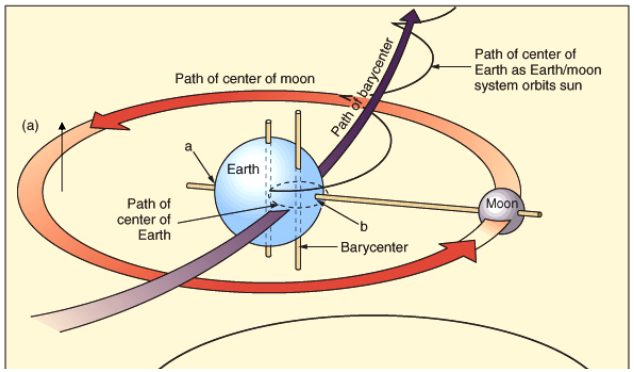


Fig. 10-1a

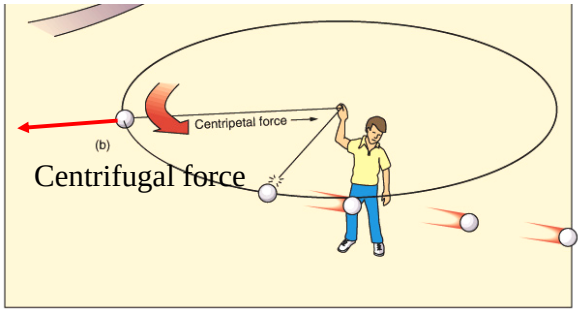


Fig. 10-1b

Tides
2. Understanding centripedal and centrifugal force

Centripedal force is the force that keeps the moon (ball) in a stable orbit around the earth (person) and counterweighs the **centrifugal** force, just has the opposite direction. For a stable orbit both need to be in balance.

Tides:
3. Understanding gravity

$$F_{gravity} = \frac{Gm_1m_2}{r^2}$$

where;

F = Force in Newtons (N)

G = Gravitational constant = $6.67 \times 10^{-11} Nm^2 / kg^2$

m_1, m_2 = mass of each body in kilograms (kg)

r = distance between the 2 bodies in metres (m)

Newton's universal law of gravitation:

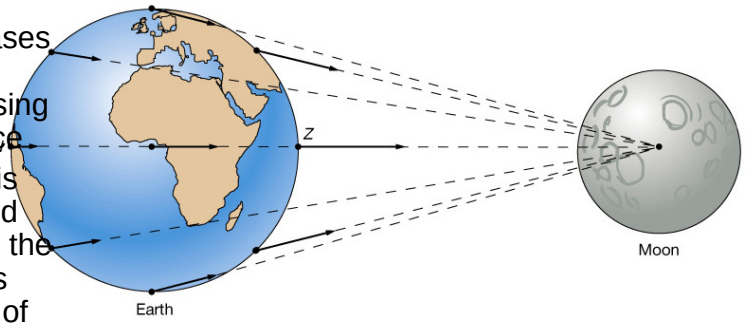
Every particle of mass in the universe attracts every other particle of mass. Gravitational force is proportional to the mass of both bodies and inversely to square of the distance between the 2 bodies.

What causes tides?

- Tides are created by the imbalance between two forces:
  1. Gravitational force of the Moon and Sun on Earth
     - If mass increases (↑), then gravitational force increases (↑)
     - If distance increases (↑), then gravitational force greatly decreases (↓↓)
  2. Centripetal (center-seeking) force required to keep bodies in nearly circular orbits

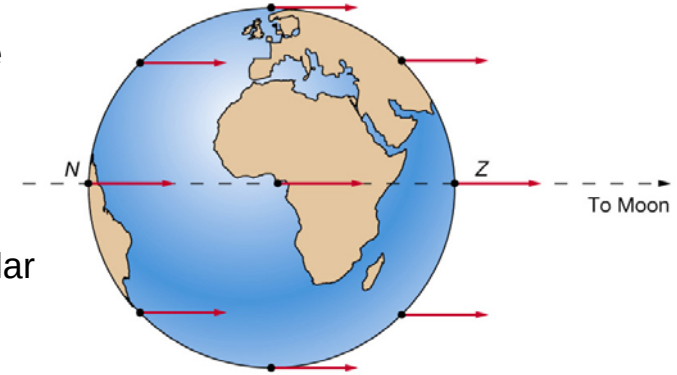
Gravitational forces on Earth due to the Moon

- Force decreases with increasing distance
- Force is directed toward the Moon's center of mass

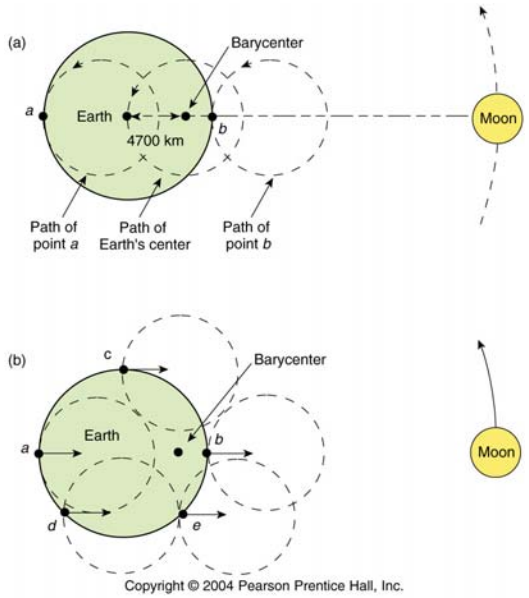


Centripetal forces on Earth due to the Moon

- Force is the same everywhere on Earth
- Force is directed perpendicular to Earth's center everywhere on Earth



The same direction and magnitude of the centripedal force is required to hold objects in their orbital paths.



- Resultant forces are:
  - The difference between gravitational (G) and centripetal (C) forces
  - Directed away from Moon on the side of Earth opposite Moon
  - Directed toward Moon on the side of Earth

Resultant forces

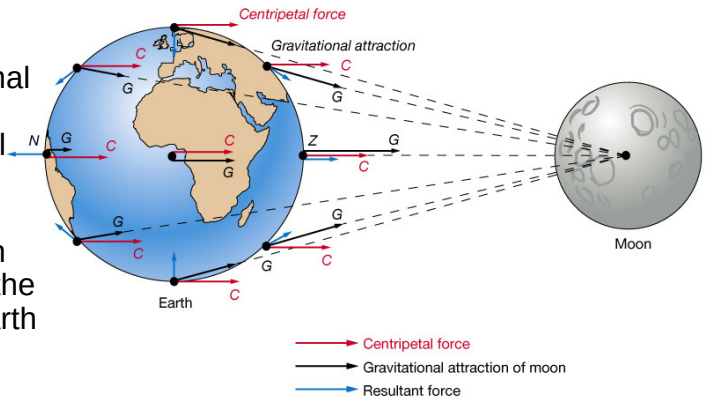


Figure 10-6

Tide-generating forces

- Tide-generating forces are the **horizontal component** of the resultant force
- Maximized along a "latitude" of 45º relative to the "equator" between the zenith and nadir

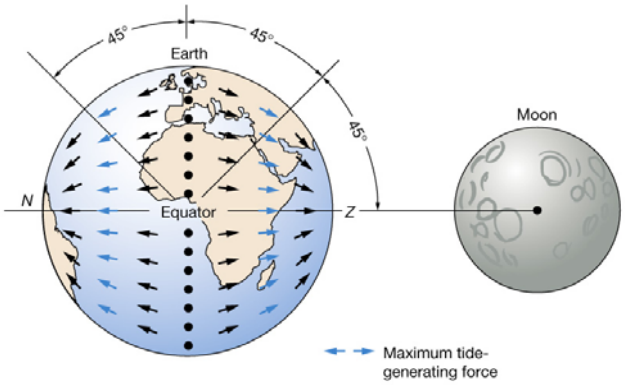


Figure 10-7

- Tide-generating forces produce 2 bulges:
  1. Away from Moon on side of Earth opposite Moon
  2. Toward Moon on side of Earth facing Moon
- Earth rotates into and out of tidal bulges, creating high and low tides

Tidal bulges

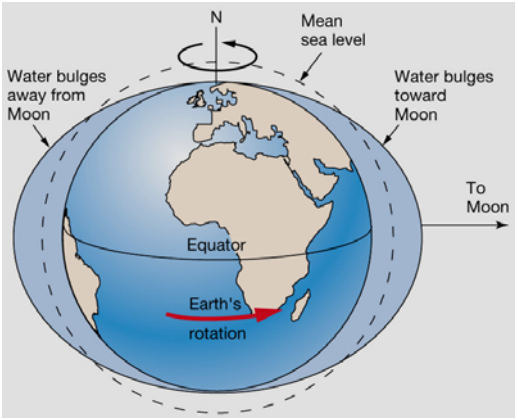


Figure 10-8

'Idealized tidal theory'

The lunar day

- Tidal bulges follow Moon as it rotates around Earth
- Lunar day is 50 minutes longer than a solar day because the Moon is moving in its orbit around Earth (lunar cycle is 29.5 days long)

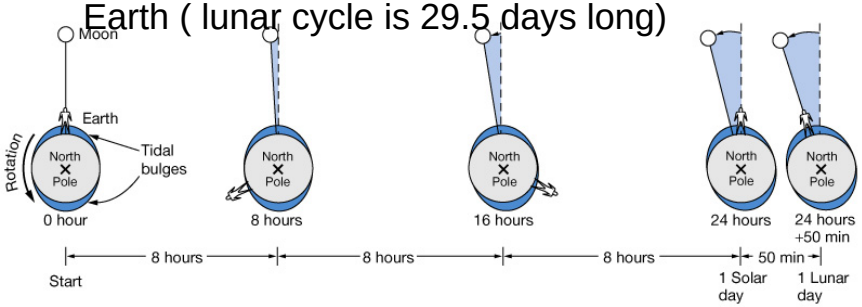


Figure 10-9

The influence of the Sun

- The Sun is much more massive than the Moon but **much** further away
- Solar bulges are 46% the size of lunar bulges

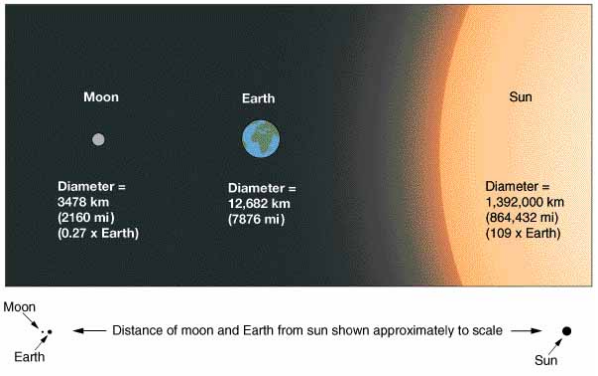
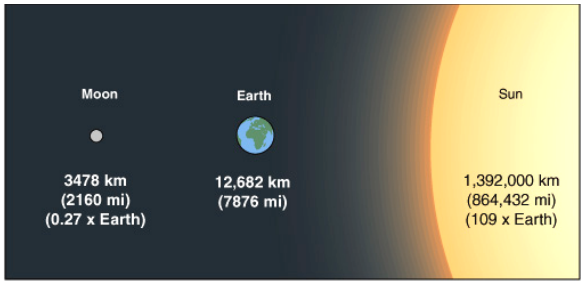
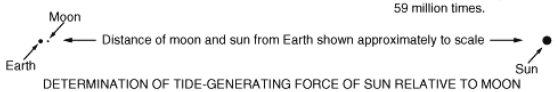


Figure 10-10

Why 46%?



Tide-Generating Body	Distance from Earth (avg)	Mass (Metric tons)	Relative Tide-Generating Effects
Moon	384,835 km (234,483 mi)	7.3×10^{19}	Based on relative masses, the sun is 27 million times more massive than the moon and has 27 million times the tide-generating effect. However, since the sun is 390 times farther than the moon from Earth, its tide-generating effect is reduced by 390^3, or 59 million times.
Sun	149,758,000 km (93,016,845 mi)	2×10^{27}	



DETERMINATION OF TIDE-GENERATING FORCE OF SUN RELATIVE TO MOON

$$\text{Tide-generating force} \propto \frac{\text{Mass}}{(\text{Distance})^3} \propto \frac{\text{Sun–27 million times more mass}}{(\text{Sun–390 times farther away})^3}$$

$(390)^3 = 59{,}000{,}000$ Thus, $\frac{27 \text{ million}}{59 \text{ million}} = 0.46$ or 46%

The sun has 46% the tide-generating force of the moon.

The monthly tidal cycle caused by the combined effects of lunar and solar bulges (29½ days)

- About every 7 days, Earth alternates between
  - Spring tide
    - Alignment of Earth-Moon-Sun system (syzygy)
    - Lunar and solar bulges constructively interfere
    - Large tidal range
  - Neap tide
    - Earth-Moon-Sun system at right angles (quadrature)
    - Lunar and solar bulges destructively interfere
    - Small tidal range
- Time between two successive spring (neap) tides is one half of the lunar cycle (about two

Earth-Moon-Sun positions and the monthly tidal cycle

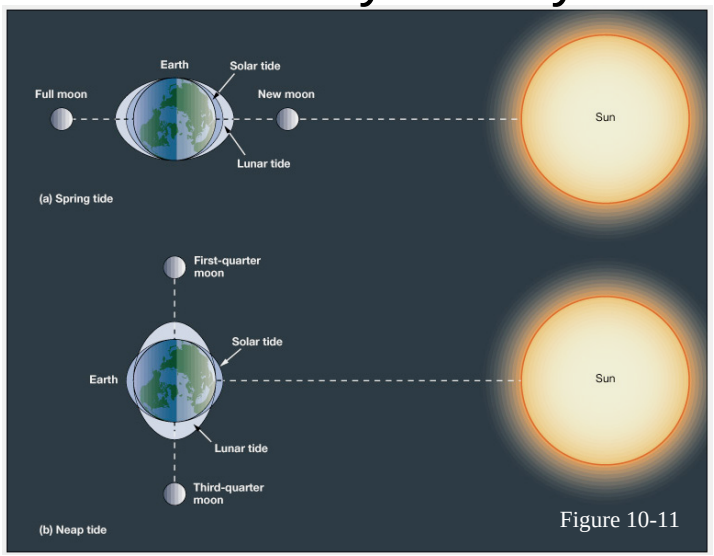


Figure 10-11

Effect of declination

- The plane of the Moon's orbit is tilted 5º with respect to the ecliptic
- Together with Earth's tilt of 23.5 º, the center of the tidal bulges may be up to a maximum of 28.5º from the Equator
- Moon goes through one complete cycle in

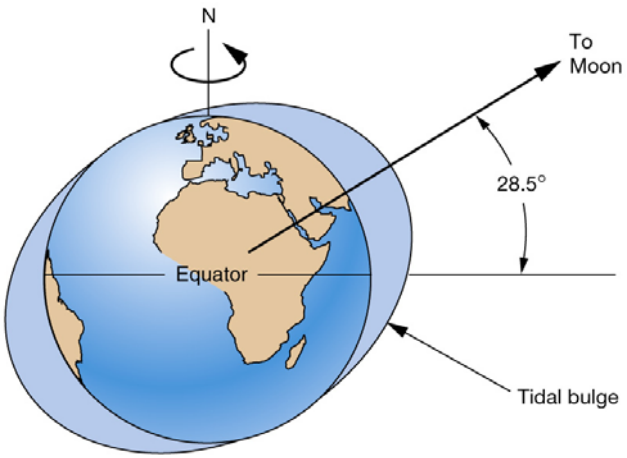


Figure 10-15: Maximum declination of tidal bulges from Equator. See also Fig. 10-14

Predicted idealized tides

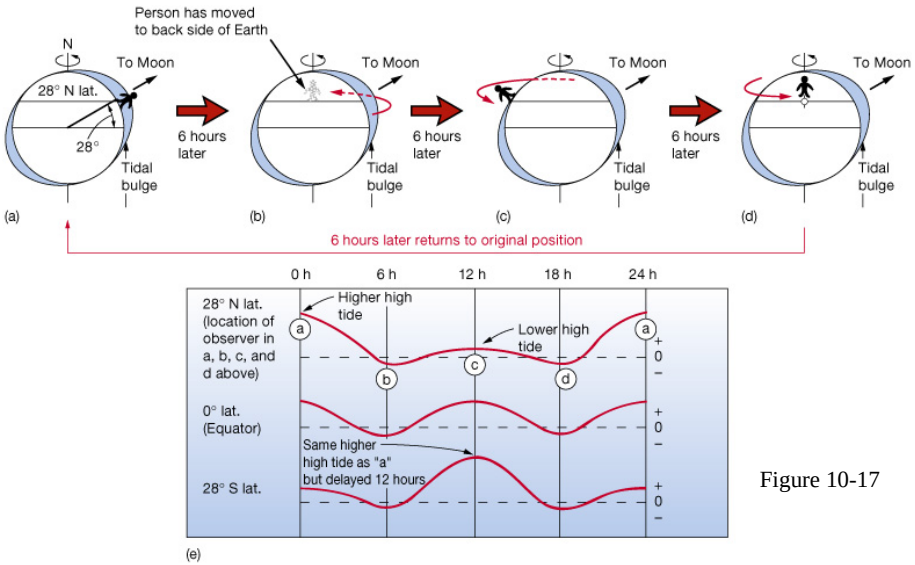


Figure 10-17

Effect of elliptical orbits

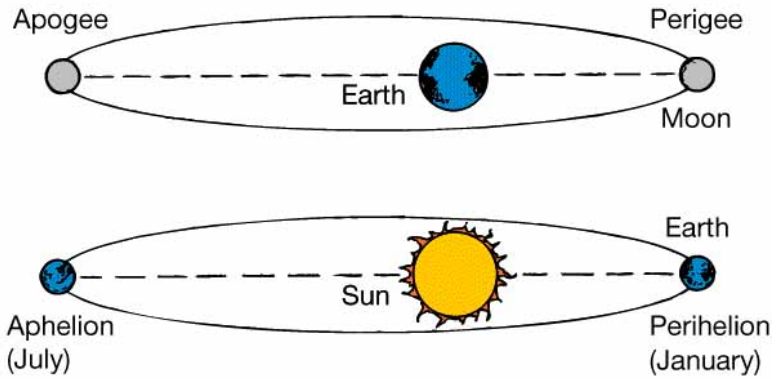


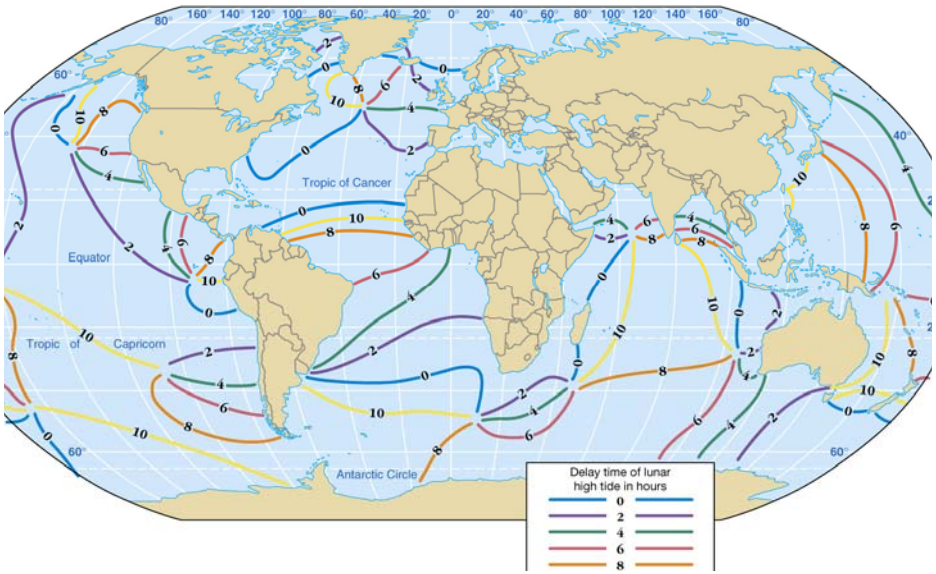
Fig. 10-16. Orbits are not exactly circular, but elliptical. Moon has a stronger tide-generating force when it is in the Perigee (point closest to earth). Equally, the sun has its strongest tide-generating force in the perihelion (January).

Summary of tides on an idealized Earth

- Most locations have two high tides and two low tides per lunar day
- Neither the two high tides nor the two low tides are of the same height because of the declination of the Moon and the Sun (except when they are above the equator which is rare!!)
- Yearly and monthly cycles of tidal range are related to the changing distances of the Moon and Sun from Earth
- Each week, spring and neap tides alternate, thus in a lunar month there are two spring and neap tides.

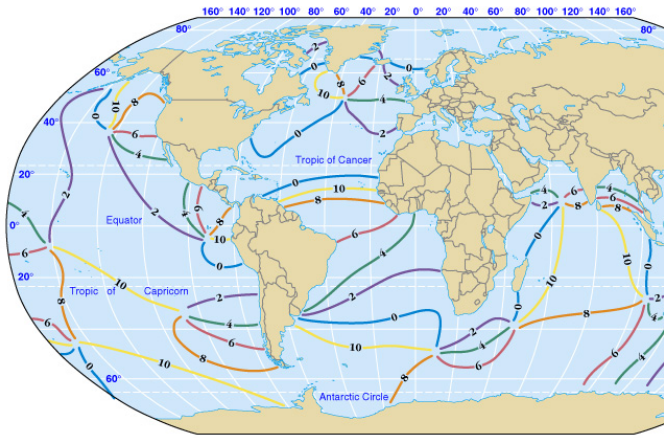
But..reality hits in for the tides: Dynamic theory of Tides

- Tidal bulges are wave crests of waves with a wavelength of 20,000km (half of circumference of Earth)
- They are shallow water waves (of course) so their speed is determined by water depth and is around 700km/h, not fast enough to keep up with Earth's rotation
- Waves break up into cells with centers called **amphidromic points**. Wave crests and troughs move around these points counterclockwise in NH and clockwise in SH
- So, **Coriolis effect** and the **shape of the ocean basins** influence the location and distribution of the amphidromic points



Tides in the ocean

- Cotidal map shows tides rotate around amphidromic points
- Each line shown the time of the main lunar high tide in lunar hours
- Tidal ranges increase with increasing distance from amphidromic points
- Make one rotation in one



Tidal patterns

- Diurnal
  - One high and one low tide each (lunar) day
- Semidiurnal
  - Two high and two low tides of about the same height daily
- Mixed
  - Characteristics of both diurnal and semidiurnal with successive high and/or low tides having significantly different heights

Tidal patterns in the U.S.

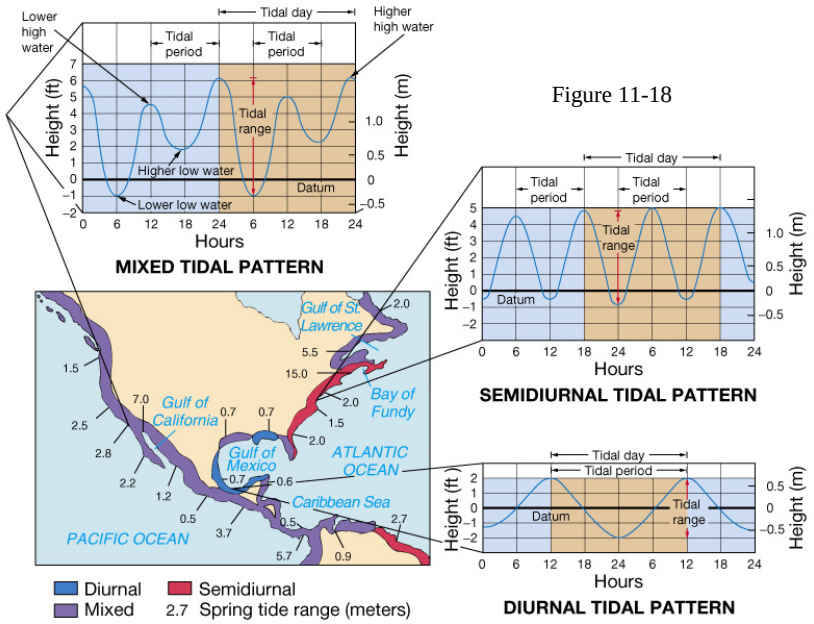
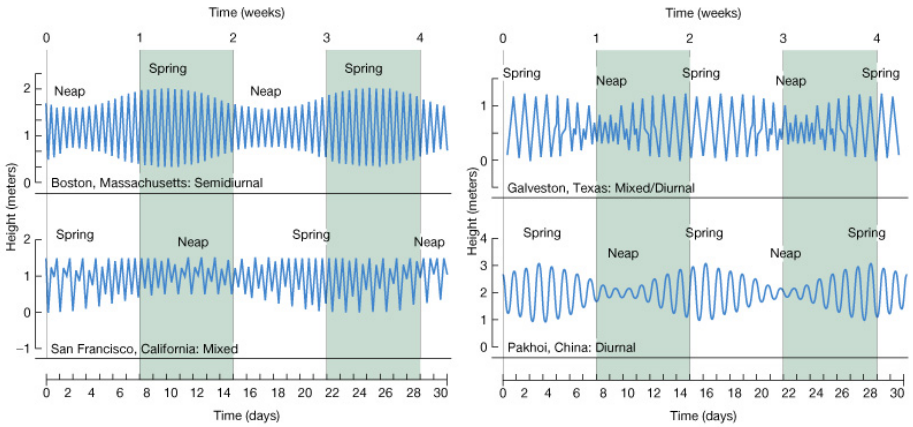


Figure 11-18

Monthly tidal curves



See Figure 10-21

world's largest tidal range

(a)

Tidal energy is focused by shape and shallowness of bay

Maximum spring tidal range in Minas Basin = 17 meters (56 feet)

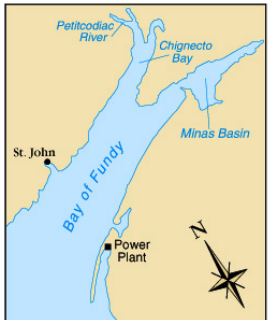


Figure 10-25

Coastal tidal currents

- Tidal currents occur in some bays and rivers due to a change in tides
  - Ebb currents produced by outgoing tides
  - Flood currents produced by incoming tides

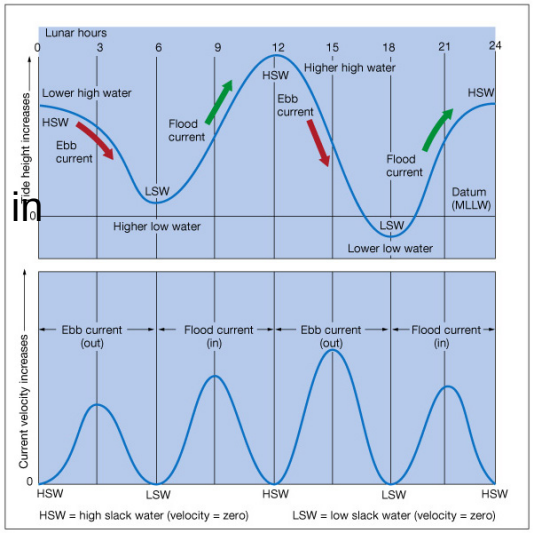
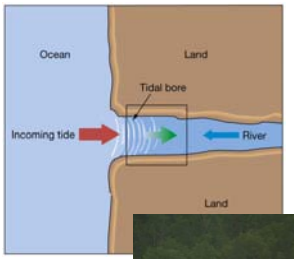


Figure 10-25

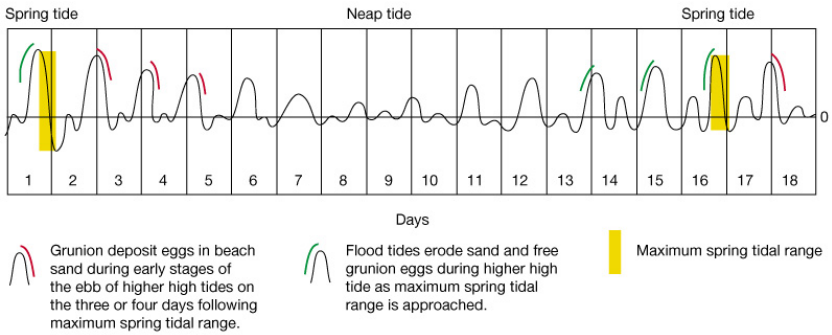
Tidal bore = a true tidal wave

- Wall of water that moves upriver
- Caused by an incoming high tide
- Occurs in some low-lying rivers
- Can be large enough to surf or raft



See Fig. 11-26

Grunion and the tides



- Grunion are the only fish that come completely out of water to spawn

•Spawning cycles are timed precisely with the tides

Figure 11A