Chapter 8
Tides
Tides and Wave Forms

- Tides have a wave form.

- They differ from other waves, because they are caused by the interactions between the ocean, Sun, and Moon.

- The crest of the wave form is high tide, its trough low tide.

- The vertical difference between high tide and low tide is the tidal range.

- Tidal period is the time between consecutive high or low tides varies between 12 hours 25 minutes and 24 hours 50 minutes.
The Measurement of Tides

Figure 08.01: The water level in the well responds only to tidal fluctuations.

Tidal Range

Figure 08.02a: Low tide at a bay of Campobello Island, Canada.

Figure 08.02b: High tide at the same bay.

(a and b) © Andrew J. Martinez/Science Source
Tides and Tidal Ranges

• There are three basic types of daily tides defined by their period and regularity:
  – **Diurnal tides** (1 high, 1 low)
  – **Semidiurnal tides** (2 high, 2 low, similar tidal range)
  – **Mixed tides** (2 high, 2 low, different tidal range, most common)

• Over a month the daily range of the tide varies systematically with the cycle of the Moon, causing
  – **Spring tides** (highest high tide, lowest low tide)
  – **Neap tides** (lowest high tide, highest low tide)

• Tidal range is also altered by
  – Ocean basin/bay/harbor/inlet shape
  – Seafloor configuration
Figure 08.03a: Tidal variation (in centimeters) measured at Pensacola, Florida, is of a diurnal tide: one high tide and one low tide occur during a 24-hour period.

Figure 08.03b: Tidal variation (in meters) measured at San Francisco, California, is of a mixed tide: two high tides and two low tides of unequal tidal range occur during a 24-hour period.
Tides Result from Gravitational Attraction and Centrifugal Effect

- Gravity varies directly with mass and inversely with distance.
  - Although much smaller, the Moon exerts twice the gravitational attraction and tide-generating force as the Sun, because the Moon is closer to Earth than the Sun.

- Gravitational attraction pulls the ocean toward both the Moon and Sun, creating two gravitational tidal bulges in the ocean (high tides).

- Centrifugal effect is the push outward from the rotation of Earth–Moon or Earth–Sun systems about their respective “common centers of mass.”
Tidal Patterns

**Diurnal**
- One high tide/one low tide per day

**Semidiurnal**
- Two high tides/two low tides per day
- Tidal range about same

**Mixed**
- Two high tides/two low tides per day
- Tidal range different
- Most common
Gravitational Forces

- Gravitational force derived from Newton’s Law of Universal Gravitation
  - Every object that has mass in the universe is attracted to every other object.
Gravitational Forces

• Gravitational force proportional to product of masses
  – Increase mass, increase force
• Inversely proportional to the square of separation distance

\[ F_g = \frac{Gm_1m_2}{r^2} \]
Gravitational Forces

- Greatest force at **zenith** – closest to moon
- Least force at **nadir**
  – furthest from moon and opposite zenith

\[ \frac{G m_1 m_2}{r^2} \]
Centripetal Force

- Center-seeking force
- Keeps planets in orbit via gravitational attraction
- Tethers Earth and Moon to each other
Resultant Forces

- Mathematical difference between gravitational and centripetal forces
- Relatively small
- **Resultant force** has significant horizontal component

- **Lunar bulges**
  - Result when force pushes water into two simultaneous bulges
    - One toward Moon
    - One away from Moon
Idealized Tidal Bulges

- Water bulges away from Moon
- Water bulges toward Moon
- Equator
- Earth's rotation
- Average sea level
Tidal Bulges

Gravitational attraction and centrifugal force produce two tidal bulges of water of about the same size, positioned on opposite sides of the Earth.

Figure 08.05a: Gravitational attraction varies with the distance separating the masses.

Figure 08.05b: Water is also displaced to the side of the Earth that faces away from the Moon.

Figure 08.05c: Gravitational attraction and centrifugal force produce two tidal bulges of water of about the same size, positioned on opposite sides of the Earth.
Tidal Bulges (Continued)

- For equilibrium tides, the latitude of the tidal bulges is determined by the \textbf{declination}.
  - Declination is the angle between Earth’s axis and the lunar or solar orbital plane.

Sun to earth $23.5^\circ$, lunar and solar bulges shift from equator, unequal tides
Tide Occurences

• **Spring tides** occur when:
  – Earth, Moon, and Sun are **aligned in a straight line**.
  – The tidal bulges display **constructive interference**, producing high high tides and low low tides.
    • Spring tides coincide with the **new and full Moon**.

• **Neap tides** occur when:
  – Earth, Moon, and Sun are **aligned forming a right angle**.
  – Tidal bulges display **destructive interference**, producing low high tides and high low tides.
    • Neap tides coincide with the **first and last quarter Moon**.

• **Earth on its axis and the Moon in its orbit** both **revolve eastward**.
  – This causes the tides to occur **50 minutes later each day**.
Tidal Phenomena

- **Tidal period** – time between high tides
- **Solar day**
  - Time between two successive overhead suns
  - 24 hours
- **Lunar day**
  - Time between two successive overhead moons
  - 24 hours, 50 minutes
- High tides are 12 hours and 25 minutes apart
Notes

The Moon rotates around the Earth in the same direction as the Earth spins, and the surface deformation must rotate with it. It takes slightly longer than a day for the Moon to be directly over the same point on the Earth’s surface, this is called a lunar day. Likewise, the period between two high tides is half lunar day
Tidal Bulges – Sun’s Effect

- Similar to lunar bulges but much smaller
- Moon **closer** to Earth, and smaller diameter, exerts greater gravitational force
- Sun’s tidal forces ~46% that of Moon
Spring and Neap Tides

A **spring tide**—popularly known as a "King Tide"—refers to the 'springing forth' of the *tide* during new and full moon. Sun and Moon in line with each other

A **neap tide**—seven days after a spring tide—refers to a *period of moderate tides* when the sun and moon are at right angles to each other.
Tidal Movements

• In the **dynamic model of tides**, movement of tides across ocean basins is:
  – Deflected by the **Coriolis effect**
  – Blocked by continental landmasses

• The result is a **rotary** wave.
  – Each day it completes:
    • Two cycles around the basin, if the tide is **semidiurnal**
    • One cycle around the basin, if the tide is **diurnal**
The Dynamic Model of Tides

1. As Earth rotates east to west, the tidal bulge is forced against the western edge of the basin.
2. It piles up and causes a pressure gradient.
   Water flows downslope and is deflected to the right by the Coriolis effect.
3. Deflection causes water to build up against the southern edge of the basin.
4. The resulting pressure gradient causes currents to reverse and flow northward.
5. Water is deflected toward the eastern side of the basin.

The effect is a rotary system, in which high and low tides occur on opposite sides of the basin.

The system rotates **counterclockwise** (in the Northern Hemisphere).
The Dynamic Model of Tides (Continued)

Figure 08.08a: Tidal bulges are not stationary relative to the Moon.

Figure 08.08b: As the Earth rotates from west to east, the tidal bulge of water is forced against the western side of the basin, where it piles up and creates a pressure gradient.
Wave Movement

• A rotary wave is part of an amphidromic system (rotary standing wave).

• The wave progresses about a node (no vertical displacement) with the antinode (maximum vertical displacement) rotating about the basin’s edges.
Amphidromic Systems

Figure 08.09a: In the Northern Hemisphere, the tidal bulge created by the tide-raising forces circulates counterclockwise around the basin.

Figure 08.09b: An idealized amphidromic system is pictured for one component of a semidiurnal tide in the Northern Hemisphere, showing cotidal and corange lines.
• **Cotidal lines** connect points on the rotary wave that experience high tide at the same time.
  – Cotidal lines are not evenly spaced.
    • This is because tides are shallow water waves and their **celerity** depends upon water depth.

• **Corange circles** are lines connecting points that experience the same tidal range.
  – The lines form **irregular circles** that are concentric about the node.
  – Tidal range **increases outward from the node**.
Rotary Motion

- Amphidromic systems rotate clockwise in the Southern Hemisphere and counterclockwise in the Northern Hemisphere because of Coriolis deflection.

- Irregular coastlines distort the rotary motion.

- Actual tide expressed at any location is a composite of up to 65 different tidal components.
Global Amphidromic Systems for the Main Lunar Component

Figure 08.11: The amphidromic systems in the world’s oceans.
Global Amphidromic Systems for the Main Lunar Component

Figure 08.11: The amphidromic systems in the world’s oceans.
In Long and Narrow Basins, Tides Cannot Rotate

- Currents in these basins simply reverse direction between high and low tide.
- Cotidal and corange lines are nearly parallel to each other.
- Tidal ranges increase if a bay tapers landward because water is funneled toward the basin’s narrow end.
- Tidal resonance occurs if the period of the basin is similar to the tidal period.
  - Resonance can greatly enhance the tidal range (Bay of Fundy).
- A tidal bore is a wall of water that surges upriver with the advancing high tide.
Tides in Restricted Basins

Figure 08.13a: An idealized amphidromic system is calculated here for a semidiurnal tide in a broad basin.

Figure 08.13b: This map depicts the actual amphidromic system for the Gulf of St. Lawrence.

Figure 08.13c: In narrow basins, flow is restricted, so true amphidromic systems do not develop.

Figure 08.13d: Cotidal and corange lines are generalized for the Bay of Fundy (see part b), a narrow basin.

Tides in Coastal Waters

- **Bay of Fundy** in Nova Scotia
  - World’s largest tidal range

17m, 56 feet!
Tides in Coastal Waters

- **Tidal Bores**
  - Tide-generated wall of water
  - Moves up certain rivers
- **Conditions needed for tidal bores**
  - Large spring tidal range of at least 6 m (20 ft)
  - Abrupt flood tide and short ebb tide phases
  - Low-lying river with seaward current
  - Shallowing of landward sea floor
  - Narrowing of basin in upper reaches
Tidal bores
Qian Tang Jiang River, China

World’s Largest Tidal Bore in China’s Qiantang River
Qian Tang Jiang River, China
Brazilian surfer Alex “Picuruta” Salazar tidal bore surfing on the Amazon River
The movement of water toward and away from land with the tides generates \textit{tidal currents}.

A \textbf{flood current} is the flow of water \textit{toward the land} with the \textit{approaching high tide}.

An \textbf{ebb current} is the flow of water \textit{away from the land} with the \textit{approaching low tide}.

Offshore, the tidal currents inscribe a \textit{circular path} over a complete tidal cycle.

Nearshore, the tidal currents produce simple \textit{landward and seaward currents}. 

**Currents**
Currents and Power

- If we have a large bay connected to the ocean by a narrow opening, electricity can be generated from tidal currents if the tidal range is greater than 5 m.

- A dam is constructed across the opening.

- Water is allowed to flow into and out of the bay, driving turbines and generating power.
Power from the Tides

Figure 08.17: The generation of power during an entire tidal cycle is shown.