TIDES

“I derive from the celestial phenomena the forces of gravity with which bodies tend to the sun and several planets. Then from these forces, by other propositions which are also mathematical, I deduce the motions of the planets, the comets, the moon, and the sea.”

—Sir Isaac Newton, 1686

Tides

- Written observations by Herodotus (~450 BCE, remember him?}
- Took Isaac Newton (“Mr. Gravity”) to explain
- History of efforts to harness tidal energy date back to at least Middle Ages (Europe)
  - Lift water to greater height (“potential energy”) → It runs downhill (“kinetic energy”)
  - Can be used to turn wheel, generate electricity, etc.
  - Tides do this naturally, regularly (though storage, ecological effects, etc.)

Tides at Seattle vs Tacoma vs Port Townsend

At Seattle, tide dropped 4 feet (from +2 ft to -2 ft) during one 2-hour class period!

Puget Sound → Lake Washington

Seattle tide station → Bellevue

http://www.mobilegeographics.com:81/locations/5706.html

http://www.dairiki.org/tides/daily.php
Tides

- **Tide** = Periodic rise and fall of sea surface (avg sea level) at a given location - Occurs throughout world

- Measured most often along coast, where shoreline provides fixed frame of reference

- Periodic measurement = Measured at fixed time intervals (e.g., hourly). Usually a measuring stick embedded in bottom.

- Continuous measurement = With float and electronic recording device

How Long Is a “Day”? 

- Earth spins on its own axis once per solar day
  - One complete spin per solar day = 24 hr
- Moon revolves around Earth once per lunar day
  - One complete revolution per lunar day = 24 hr 50 min
- (Earth revolves around Sun once per year)
  - (One complete revolution per year = 365.25 days)

**Solar day** = 24 hr, **Tidal day** = **Lunar day** = 24 hr 50 min

- Moon revolves around Earth in same direction as Earth spins on its axis, though not quite perfectly matched timing (Moon takes a little longer)
How Long Is a “Day”?  
- Solar day = 24 hr  
- Tidal day = Lunar day = 24 hr 50 min  

Solar Day  
Lunar Day  
So each day, tides arrive ~50 minutes later  
(And moon rises later & later)

How Are Tides Classified?  
- By number of high/low tides per day and relative tidal heights  
- Tidal curve = Plot of water surface height vs. time (daily, monthly)  
- Tidal period = Time between 2 successive high tides (or 2 successive low tides)  
- Datum = Mean sea level (“0”) = A reference point for height  
- Tidal range = Difference in height between a high tide and the next low tide (or vice versa)  
- Tidal inequality = Difference in height between a high tide and the next high tide (or between successive low tides)  
  
- Makes 3 types of tides: Diurnal, Semi-diurnal, and Mixed

Types of Tidal Cycles  
Diurnal tides = 1 high tide + 1 low tide each lunar day. Tidal period = 24 hr 50 min.  
Semi-diurnal tides = 2 high tides + 2 low tides each lunar day, and each tide is the same height as the previous one. Tidal period = 12 hr 25 min. Tidal ranges equal.  
Mixed tides = 2 high tides + 2 low tides each lunar day, but each tide is a different height than the previous one. Tidal period = 12 hr 25 min. Tidal ranges unequal. (= Mixed semi-diurnal)
Tides & The Forces That Cause Them

- Tides are regular and predictable changes in the level of the ocean.
- Tides are caused by the gravitational forces of the Moon and Sun, and the motion of Earth.
- The reason tides are so regular and predictable is that the forces that cause them (gravity, and the spin of the Earth) are very regular and predictable.
- The wavelength of tides can be half the circumference of Earth! Tides are therefore the longest of all waves. Act as “shallow-water waves”.
- Tides are an example of forced waves, because they are never free of the forces that cause them.

What Makes the Tides?

- Moon has more effect (Sun’s effect is ~46% of Moon’s effect), so let’s consider Earth-Moon system first
- Earth & Moon orbit around a point called their common center of mass
- 2 competing forces:
  - Gravity: Pulls Earth and Moon together
  - Inertia (“centripetal force”): Acts to keep Earth and Moon apart. “Outward flinging”.
- Whichever force is stronger will pull the ocean more in its direction
  - Gravity makes a tidal bulge on side of Earth facing Moon
  - Inertia makes tidal bulge on opposite side of Earth (= slightly smaller bulge)
The Equilibrium Theory of Tides

Earth & Moon orbit around a point called their **common center of mass** (barycenter).

Equilibrium theory = **ideal** model; no continents etc.

See Fig. 10.3, p. 230

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Tidal Bulges

- 2 nearly-equal & opposite tidal bulges
- **Earth rotates beneath the tidal bulges!**
- Any point on Earth passes under a bulge 2x a day
- So, 2 high tide + 2 low tides per day predicted from this model (mixed tides, as slightly different sizes of the bulges)

See Fig. 10.5, p. 230 & Fig. 10.6, p. 231
The Sun & Moon Together

So far we have only considered the role of the Moon in causing tides. But the Sun also causes 2 tidal bulges, for the same reasons that the Moon does.

The Sun’s bulges are only about half the size of the Moon’s, because the Sun, although more massive than the Moon, is so much farther away from the Earth.

Like the Moon’s bulges, the Sun’s bulges also remain in the same position relative to the Sun. There is a bulge on the side of the Earth that faces the Sun, and a bulge on the opposite side.

The Sun gives monthly variations to tidal curves.

Monthly Tidal Cycles

• **Spring tides**
  – New Moon, Full Moon
  – Earth, Moon, Sun syzygy (lined up in a row; conjunction)
  – Larger tides

• **Neap tides**
  – First Quarter, Last Quarter
  – Earth, Moon, Sun quadrature (90° angle)
  – Smaller tides

The Sun & Moon Together

The Sun gives *monthly* variations to tidal curves.

*Spring tides* = Time of greatest tidal range. NOTHING TO DO WITH THE SEASON; THIS HAPPENS EVERY MONTH! Bulges are most extreme at times of full moon and new moon, because all 3 bodies (Sun, Moon, Earth) are all aligned = **Constructive interference**.

*Neap tides* = Time of least tidal range. Bulges are least extreme at times of first-quarter moon and third-quarter moon, because the 3 bodies (Sun, Moon, Earth) are at 90° angle = **Destructive interference**.
See Fig. 10.11, p. 233

Fig. 10.12, p. 234
### Complications to Simplest Equilibrium Theory

- Oceans do not cover entire Earth
- Oceans do not have uniform depth
- Ocean shapes vary
- Friction between ocean and seafloor
- Coriolis effect

### More Complications

- Moon doesn’t always revolve around Earth over equator
  - Lunar bulge ranges up to 28.5° N & S (monthly cycle)
- Tilt of Earth’s axis to Sun (gives seasons)
  - Makes solar bulge shift up to 23.5° N & S (yearly cycle)
More Complications

- Periods of lunar & solar variation different
  - Lunar = monthly (~28.25 days)
  - Solar = yearly (~365.25 days)

- Lunar day longer than solar day
  - Lunar = 24 hr 50 min
  - Solar = 24 hr

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<th>Symbol</th>
<th>Period in solar hours</th>
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(a) The seven most important partial tides

(b) Partial tides, computed tide, and observed tide at Pula, Yugoslavia (January 6, 1909). Note close fit of computed and observed tides.
The Dynamic Theory of Tides

- Explains the characteristics of ocean tides based on celestial mechanics (gravity of Sun & Moon acting on Earth) and the characteristics of fluid motion.
  - Rotary flow in open ocean basins
    - Amphidromic points (= nodes at the center of ocean basins; these are no-tide points)
    - Cotidal lines
    - Crest (high tide) rotates (CCW in NH, CW in SH)

Tides in Confined Basins

The tidal range is determined by basin configuration

- Broad, shallow basin

Fig. 10.16, p. 238
**Tides in Confined Basins**

The tidal range is determined by basin configuration.

**Narrow basin**

- Open ocean
- 2 m
- 3 m

**Bay of Fundy**

- Largest tidal range (spring tide max 17 m)
- Oscillation period close to tidal period
- Funnel shape of basin
- Shoals & narrows to N
- Basin oriented to R (Coriolis moves water toward R)
- Tidal bore also

**Tidal Bores**

- Waves created by tide rushes upstream
- Low-lying coastal river
- Large tidal range
- Up to 8 m high

**Tides and Marine Organisms**

Tides have a profound effect on coastal marine life.

Coastal life is sorted into zones and sub-zones, depending on the amount of emergence and submergence the organisms can tolerate.

Some organisms, e.g., grunions, time their reproductive cycles to the tides.
La Rance (France, 1966-) = The first major tidal power station
Generating 544 million kilowatt hours (240 megawatts) of electricity annually
Equivalent to ~a million 60-watt lightbulbs burning 10,000 hrs (416 days)
Powers ~240,000 homes = More than 10x the power of the next-largest tidal station (17 MW, Canadian Annapolis)

* Timing of tides - Not 24-hr cycle day
* Ecological disturbance
* Not applicable at most locations (need tidal range >16 ft)

“5-Minute Write”
Summarize the main points of today’s lecture.
List 3 to 5 questions you have, based on today’s lecture.
What did you find most interesting about today’s lecture?
How was the lecture relevant to you?
Summary of characteristics of equilibrium tides on the idealized Earth.

· Any location (except the poles) will 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 for the rare occasions when the Moon and Sun are simultaneously above the Equator).
· Monthly and yearly cycles of tidal range are related to the changing distances of the Moon and Sun from Earth.
· Each week, there would be alternating spring and neap tides. Thus, in a lunar month, there are two spring tides and two neap tides.

Fig. 10-14, p. 236