Tides

• Newton's gravitational force law says that the force of gravitation attraction depends strongly on the separation between two objects.

• The same applies to different portions of an extended object like the Earth or the Moon.
Tides

- The Earth (and the more flexible oceans) are stretched between these differing forces raising tidal bulges both toward and away from the Moon.

\[ F_{gravity} = \frac{Gm_1 m_2}{R^2} \]
Tides

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Too much pull – Earth is stretched toward the Moon.

Too little pull – Earth bulges away from the Moon.
Tides

- The more-flexible water gets stretched more than the solid Earth.
  - These ocean tides remain aligned with the Moon while the solid Earth rotates through them.
  - Locations typically experience two high tides a day.
    - Tides are more complicated because of the sloshing due to land-masses getting in the way.
Bay of Fundy, Canada
An Alternative View of Tides

• Objects orbit their common center of gravity (technically the “barycenter” of their orbit).

![Diagram showing the balance between gravitational and centrifugal forces]

• Tides are all about the balance between gravity and centrifugal force – like a ball on a string.
  • These forces balance at the center of the Earth.
    - Closer to the Moon the Moon's gravity wins – extra tugging
    - Farther from the Moon the Moon's gravity is insufficient to counter the centrifugal force – extra “flinging”
      • The Earth gets stretched between these two forces.
The Sun's Role in Tides

• The Sun also has significant gravitational influence on the Earth.
  • It is much further away than the Moon, but also much more massive.
  • Solar tides are about 1/3 the strength of Lunar tides.
• When the Sun and Moon align (New and Full Moon) tides are higher than when they raise tides in different directions (First and Last Quarter Moon).
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Note that planetary tides, often invoked by nutcase theories of global doom from planetary alignment, are vanishingly insignificant compared to the Sun and Moon.

Jupiter's tidal force on Earth is 1/100,000th that of the Sun's.
Tides and the Slowing of Earth's Rotation

- Since the Earth spins faster than the Moon orbits
  - the Earth tries to drag its tidal bulges out of line with the Moon
  - the Moon, in turn, tries to pull them back into alignment.
    - The consequence is that Earth rotation is slowing and the Moon is getting farther from the Earth.
Yellow arrows = bulk gravitational attraction between Earth and Moon
• Focus on the “near” tidal bulge – it feels a slightly greater force than the “far” one.

• The green arrows represent the gravitation pull between the Moon and the material in this tidal bulge.

• The direction of this pull works **against** the direction of Earth's rotation, slowing down the rotation of the Earth.
• The pull of the tidal bulge on the Moon can be decomposed into a component directed toward the center of the Earth and a component directed along the Moon's orbit.

• The component directed along the Moon's orbit gives the Moon a boost as if it had a rocket engine attached – moving it further from the Earth over time.
The Changing Day

• Due to tidal effects the day gets about 1 second longer every 50,000 years.
  • About 300 million years ago the day was only 22 hours long.
  • The day will be 25 hours long in another 150 million years.

• The second was defined using measurements from more than 200 years ago.
  • Using this “stale” second, The Earth runs slow enough that we have to add a leap second into timekeeping every couple of years.
Consequences for the Moon

• Tidal coupling moves the Moon a few centimeters further from the Earth each year.

• Although small, this effect is measured to great accuracy with pulses of laser light bounced off of retro-reflectors on the Moon.
Consequences for the Moon

• Tidal coupling moves the Moon a few centimeters further from the Earth each year.
  • The Moon was once much closer – maybe 1/20^{th} it's current distance.
  • We live in the last era where total solar eclipses are possible.
    – Total eclipses are becoming increasingly less frequent.
    – soon (in about 100 million years) all central eclipses will be annular.
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Consequences for the Moon

- The Moon's rotation has “stopped” relative to the Earth
  - The Earth was even more effective at slowing the Moon's rotation.
    - Although it may have originally spun rapidly, the Moon is now in a state where it turns at the same rate that it orbits the Earth.
Consequences for the Moon

- The Moon's rotation has “stopped” relative to the Earth
  - This “tidal locking” is the natural end state of a planet/moon system.
  - Even now, the Moon is slowing the Earth's rotation toward the goal of the Earth always keeping the same face toward the Moon.
  - Once an object is in “synchronous rotation” it's tidal bulges remain aligned and there is no more tidal friction.
Consequences for the Moon

- From Earth we can only see one side of the Moon.
The Dark Far Side of the Moon

- From Earth we can only see one side of the Moon.
  - The other side of the Moon (which has 2-week long days just like the near side) was not observed until the Space Age.
Lockheed Martin Proposes Manned Mission to the Dark Side of the Moon

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