Ch.19 - Physical Processes in the Solar System

p.714 | §19.1 A Brief Survey |

Planets naturally form in the equatorial disks around young stars.
51 Pegasi (1st extrasolar planet found around main sequence star) found in 1995. As of 2/1/18, 3,728 planets have been found.

General Characteristics of the Planets
(Table 19.1) (Fig. 19.1)

Terrestrial planets: Mercury, Venus, Earth, Mars
Giant (Jovian) planets = gas giants (Jupiter, Saturn) + ice giants (Uranus, Neptune).

p.715 Moons of the Planets
Moon is largest moon relative to parent planet, but Io, Ganymede, + Callisto (of Jupiter) + Titan (of Saturn) are physically larger.

p.716 The Asteroid Belt
The Titius-Bode rule (or Bode's rule), discovered in late 1700's describes orbital radii of planets out to Uranus. (Table 19.2)
Although it works well, + also works for moons of Jupiter, Saturn, + Uranus, most experts think it's just a coincidence.
However, the prediction of a planet at 2.8 A.U. led to the discovery of asteroid Ceres at 2.77 A.U. - the largest asteroid, R~1000 km.
Since then, thousands more asteroids have been found in the asteroid belt between Mars + Jupiter.
Some moons are captured asteroids, while others formed with their parent planet.

p.717 The Comets + Kuiper Belt Objects
Comets are dirty snowballs ~10 km in diameter which emit tails of dust + gas when they get close to the Sun.
Short-period ($\lesssim 100$ yrs) comets come from Kuiper belt, a collection of icy objects near the ecliptic beyond Neptune.
Long-period ($\lesssim 1{,}000{,}000$ yrs) comets come from spherical Oort Cloud, 3000-100,000 A.U.

Meteorites
When asteroids collide they produce fragments called meteoroids.
A meteor is the streak of light produced by a meteoroid

19.1b 2/20/18

Characteristic	Terrestrial	Giant
Basic form	Rock	Gas/Ice/Rock
Mean orbital distance (A.U.)	0.39–1.52	5.2–30.0
Mean "surface" temperature (K)	215–733	70–165
Mass ($M_\oplus$)	0.055–1.0	3.88–11.2
Mean density (kg m^{-3})	3933–5515	687–1638
Sidereal rotation period (equator)	23.9 h–243 d	9.9 h–17.2 h
Number of known moons	0–2	13–63
Ring systems	no	yes

Table. 19.1 General characteristics of planets.

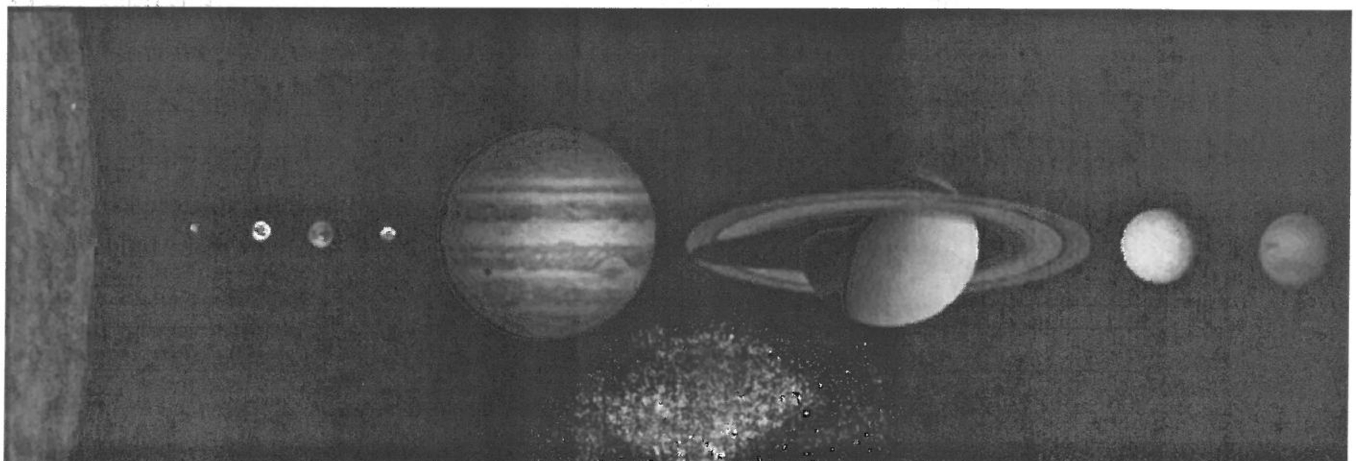

Fig. 19.1 Relative sizes of Sun & planets. Pluto has been removed.

burning up in the Earth's atmosphere.
A remnant which strikes Earth's surface is a meteorite.
Some meteors come from disintegrated comets.

p. 718 Solar System Formation: A Brief Overview

As the pre-solar nebula contracted due to its own gravity, conservation of angular momentum caused it to spin faster + the formation of an accretion disk.
In the inner disk, it was to hot for anything but rock to solidify.
Beyond the asteroid belt, ices could also solidify.
The greater masses + lower temperatures of the outer planets allowed them to accrete gas.
The same thing happened on a smaller scale to form the systems of moons around the Jovian planets.

p. 719 §19.2 Tidal Forces

The gravitational force exerted on a mass elements of the Earth is stronger on the side of Earth facing the Moon.
This differential force is called the tidal force, because it is the cause of ocean tides.
There are 2 high tides every 24h 53 min, including a ~10cm tide in Earth's solid crust.
"Tides" in Moon's crust are much larger - ~20m.

p. 719 The Physics of Tides

(Fig. 19.2) Force between Moon + mass element m_1 in Earth:

$F_m = G\frac{Mm_1}{r^2}$ (M = Moon mass)

Differential force between 2 mass elements $dF_m = -2G\frac{Mm}{r^3}dr$
Tidal force $\propto 1/r^3$, which is why Moon is important than Sun for Earth tides.
Can also find difference between forces at center + surfaces
(Fig. 19.3, 19.4) Tidal force elongates Earth + raises 2 high tides per day.

p. 721 The Effects of Tides

Earth's rotation drags tidal bulges ahead of Earth-Moon line ⇒ friction slows Earth rotation by 0.0016 s century^{-1}. (Fig. 19.5)
By conservation of angular momentum, Moon moves outwards by 3-4 cm yr^{-1}. Eventually 1 side of Earth will face Moon.

19.2b 2/22/18

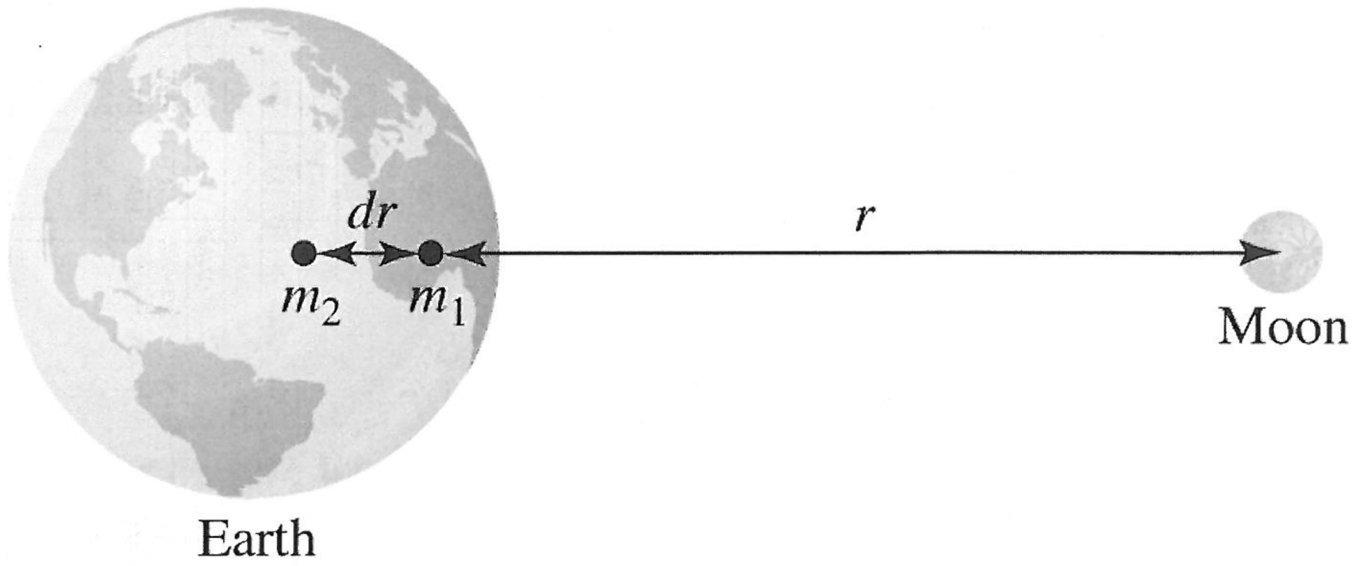

Fig. 19.2 The tidal force on Earth due to the Moon arises because of the varying values for the Moon's gravitational attraction at different locations inside the planet.

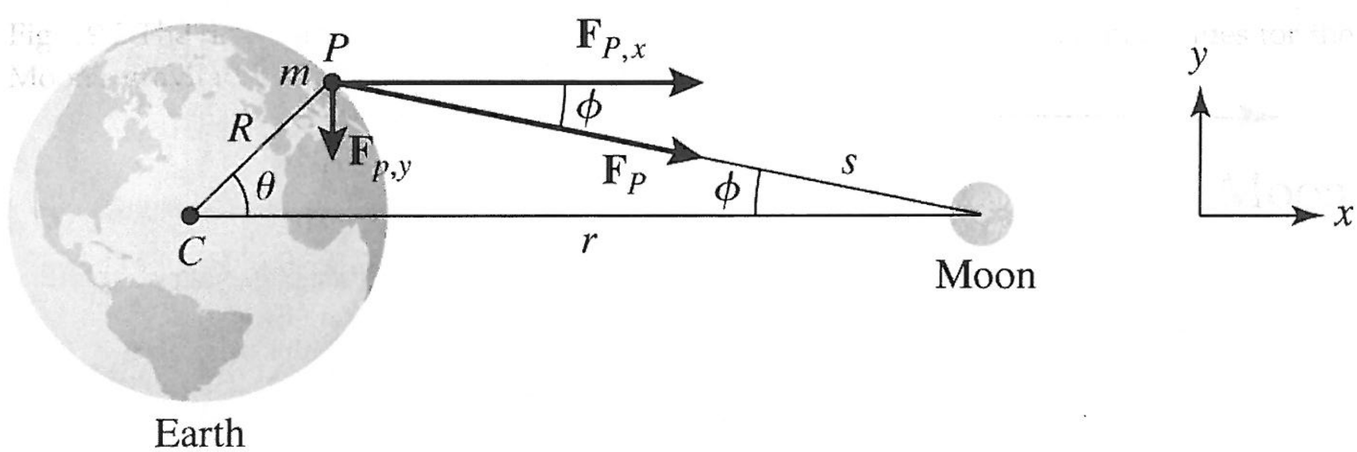

Fig. 19.3 The geometry of the tidal force acting on Earth due tot he Moon.

19.2C 2/22/18

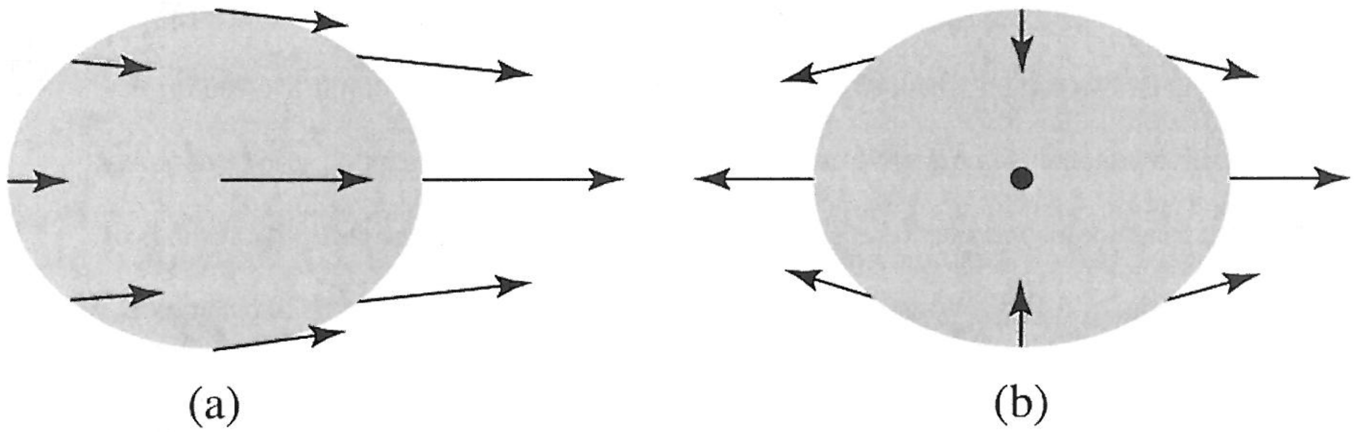

Fig. 19.4 (a) The gravitational force of the Moon on the Earth. (b) The differential gravitational force on Earth, relative to its center.

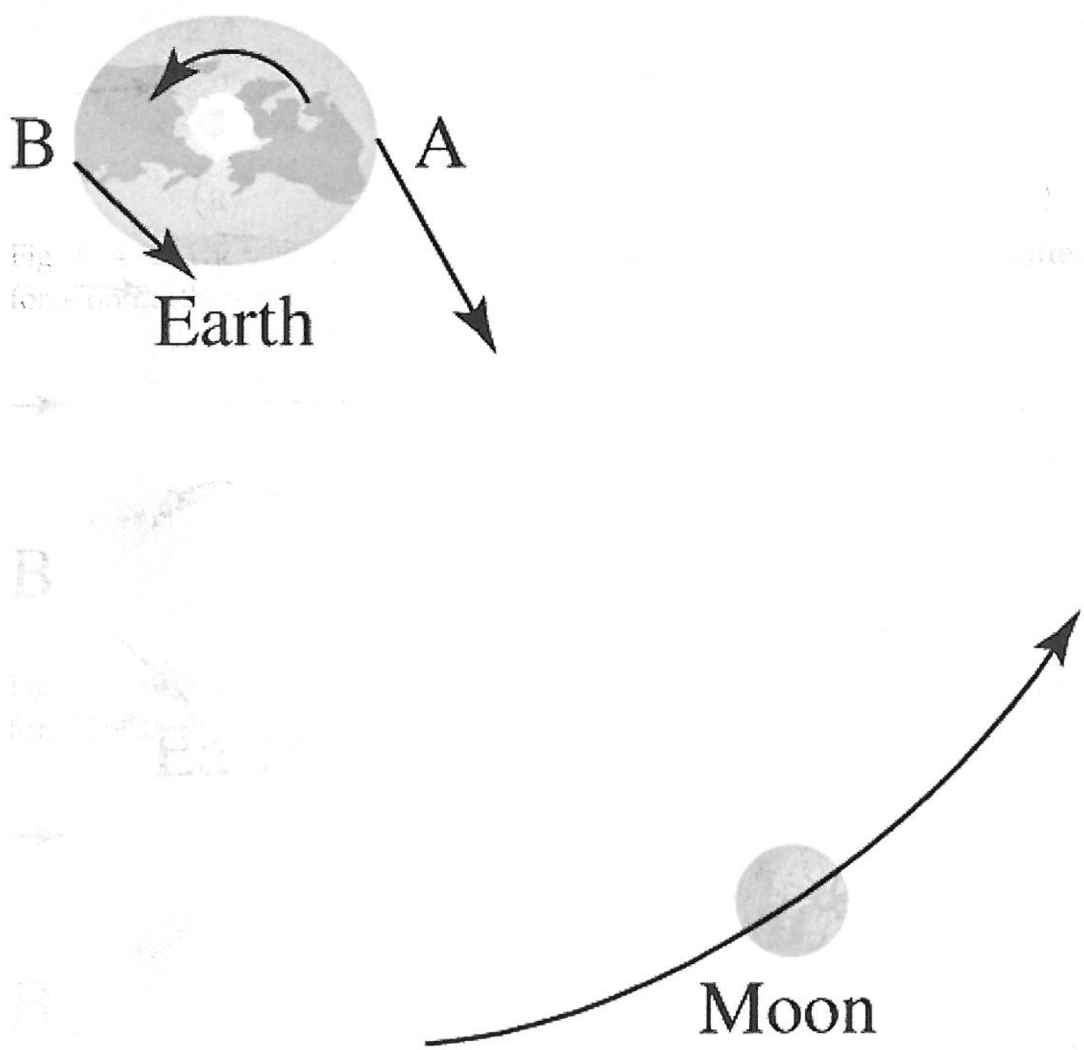

Fig. 19.5 Earth's bulge A is closer to the Moon than is bulge B, resulting in a net torque on the planet (not to scale).

p.722 Synchronous Rotation

Moon is already in 1-1 synchronous rotation.
Synchronous rotation is common in the solar system.

p.723 Additional Tidal Effects from the Sun

Due to $1/r^3$ dependence, tidal forces due to Sun are smaller, but cause more extreme spring tides at New + Full Moon, + less extreme neap tides at 1st + 3rd quarter phase.

p.723 The Roche Limit

When a moon comes within a certain distance (the Roche limit) of a planet it will be tidally disrupted.
Roughly this occurs when the gravitational attraction of a mass element at the moon's surface to the moon is less than the tidal force: $\frac{GM_m}{R_m^2} < \frac{2GM_p R_m}{r^3}$

In terms of average densities this is

$$r < f_R \left(\frac{\bar{\rho}_p}{\bar{\rho}_m}\right)^{1/3} R_p$$

Edouard Roche found in his more accurate 1850 analysis $f_R = 2.456$.

Ex. 19.2.1 Saturn: $\bar{\rho}_p = 687\ kg\ m^{-3}$, $R_p = 6.03 \times 10^7 m$
For a moon w/ $\bar{\rho}_m = 1200\ kg\ m^{-3}$, Roche limit is $1.23 \times 10^8 m$.
The rings are mainly within this limit, + large moons outside ⇒ rings may have come from tidal disruption of moons.

p724 | §19.3 The Physics of Atmospheres |