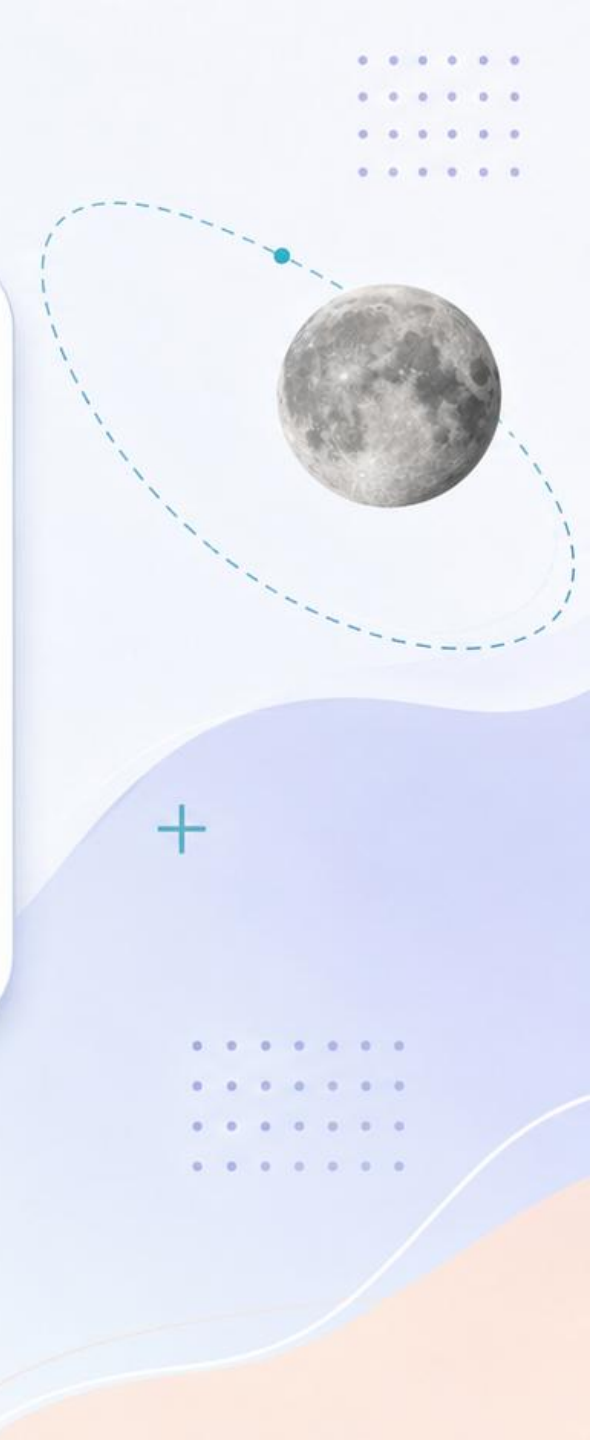


Chapter 7

Gravitation

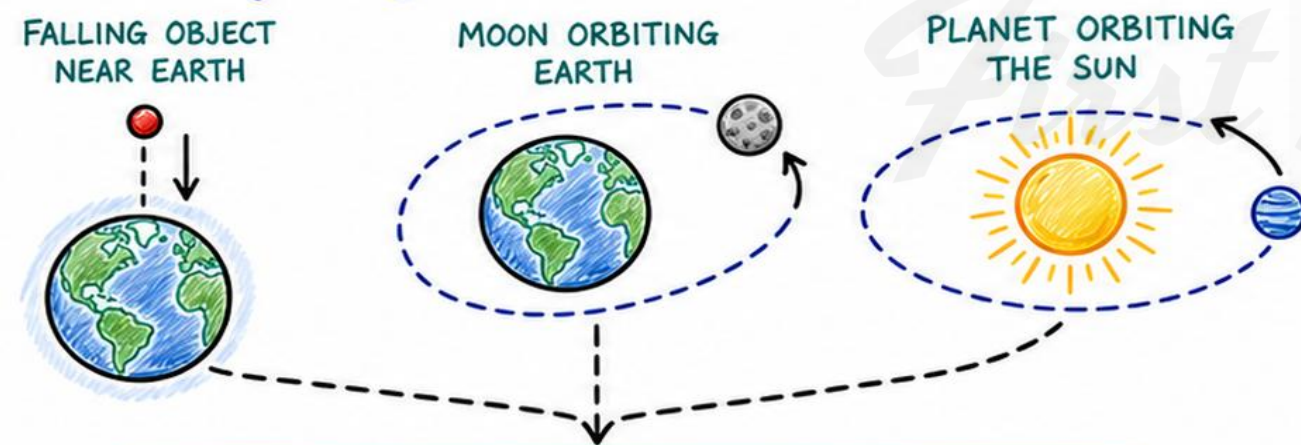
Gravity • Orbits • Satellites


$$F = G \frac{m_1 m_2}{r^2}$$



GRAVITATION: THE BIG IDEA

- Gravitation is the mutual force of attraction between any two masses.
- Near Earth, every freely falling body accelerates toward Earth with $g \approx 9.8 \text{ m s}^{-2}$ when air resistance is neglected.
- This acceleration is independent of the falling body's mass.



ONE INTERACTION explains falling bodies, the Moon's orbit and planetary motion.

- ★ Gravity near Earth is one example of universal gravitation.

HISTORICAL PATH

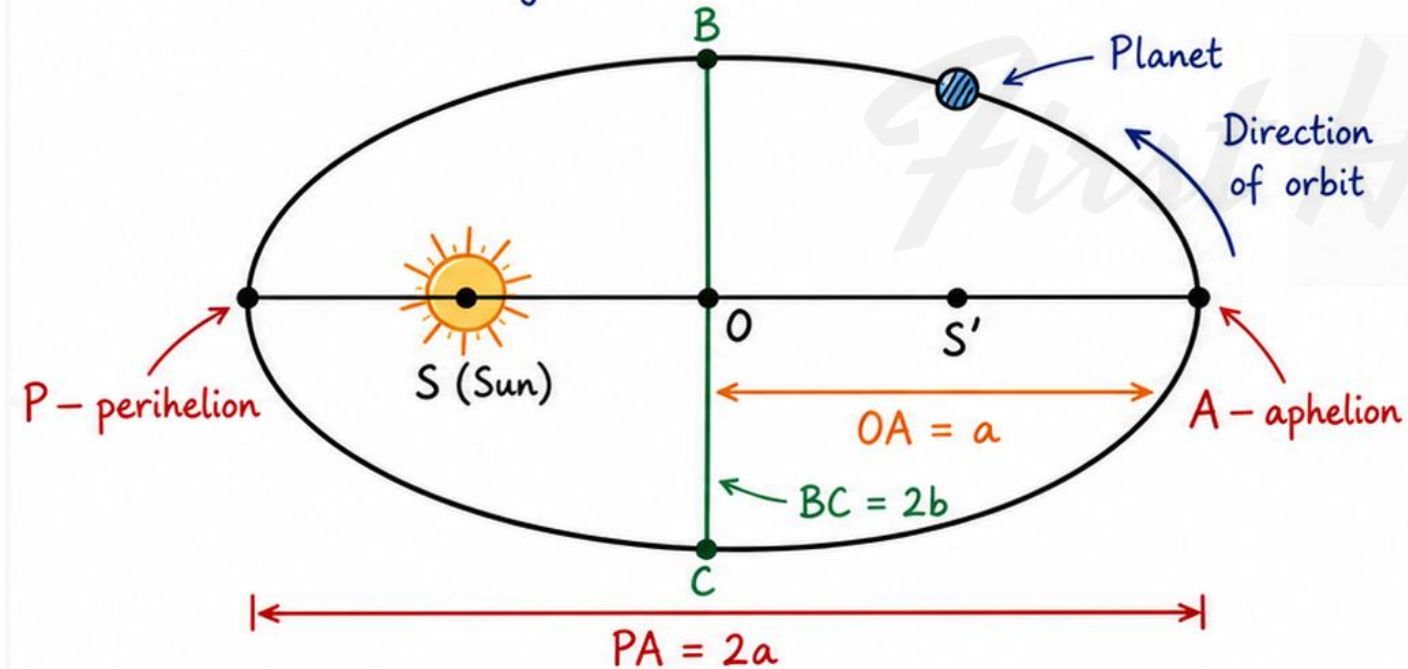
- Ptolemy — geocentric model
- Aryabhatta (5th century CE) — heliocentric model mentioned
- Copernicus — planets move around a fixed Sun
- Galileo — falling-body experiments
- Tycho Brahe — precise planetary observations
- Johannes Kepler — three laws from Tycho's data
- Isaac Newton — universal law of gravitation

★ Earthly falling and celestial orbits follow the same physical law.

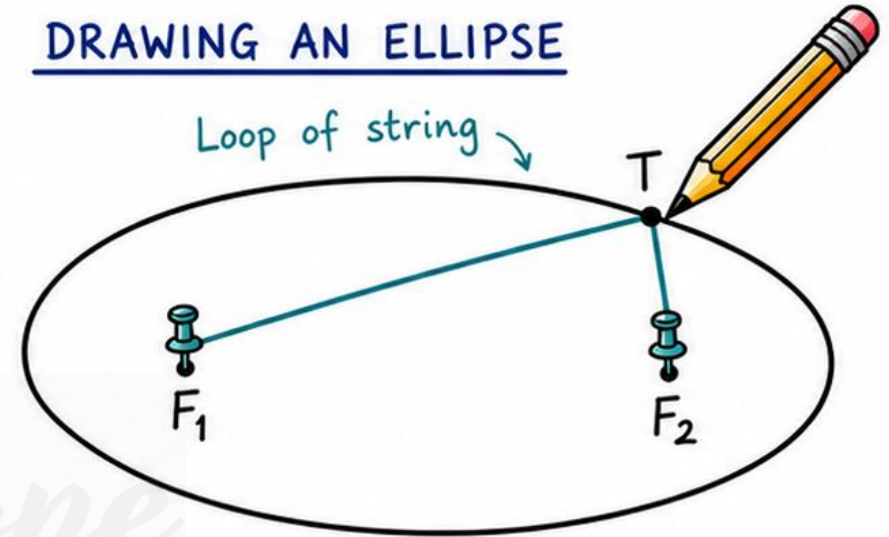
ELLIPSE ANATOMY & KEPLER'S FIRST LAW

KEPLER'S FIRST LAW — LAW OF ORBITS

- Every planet moves in an elliptical orbit with the Sun at one focus.
- A circle is a special ellipse: its two foci merge and the semi-major axis becomes the radius.



DRAWING AN ELLIPSE



- F₁ and F₂ are the foci.
- For every point T on the ellipse:

$$TF_1 + TF_2 = \text{constant}$$

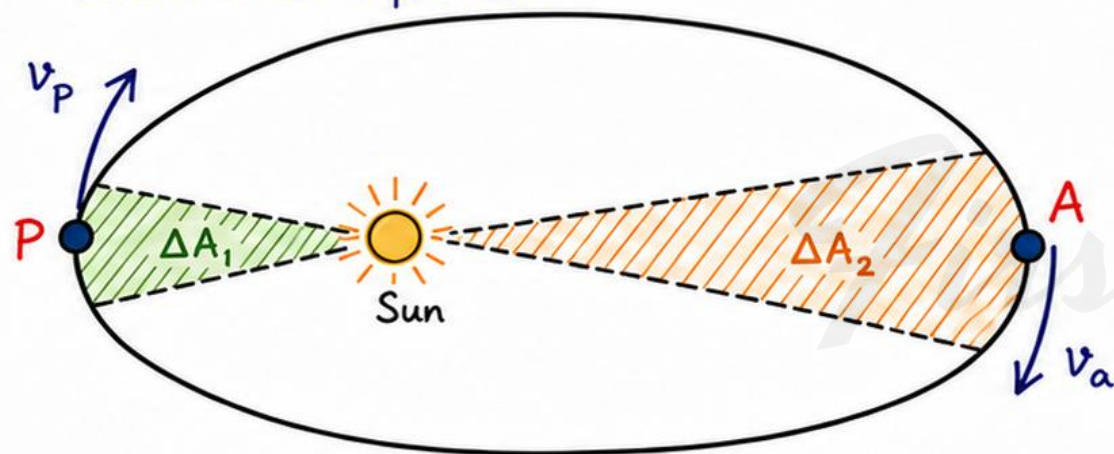
- O is the midpoint of the major axis.
- Semi-major axis = half of the longest diameter.

★ Kepler replaced circular planetary paths with ellipses based on Tycho Brahe's observations.

KEPLER'S SECOND & THIRD LAWS

2. LAW OF AREAS

- The line joining a planet to the Sun sweeps equal areas in equal intervals of time.
- The planet moves faster near perihelion and slower near aphelion.



$$\begin{aligned}\Delta A_1 &= \Delta A_2 \\ \Delta t_1 &= \Delta t_2\end{aligned}$$

$$v_p > v_a$$

$$\frac{\Delta A}{\Delta t} = \text{constant}$$

3. LAW OF PERIODS

- The square of a planet's time period is proportional to the cube of the semi-major axis of its orbit.

$$T^2 \propto a^3$$

$$\frac{T^2}{a^3} = \text{constant}$$

T = time period of revolution

a = semi-major axis

- For planets orbiting the same Sun, the constant is the same.
- For a circular orbit of radius r around mass M :

$$T^2 = \left(\frac{4\pi^2}{GM} \right) r^3$$

For an ellipse, replace r by the semi-major axis a .

Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune give nearly the same T^2/a^3 .

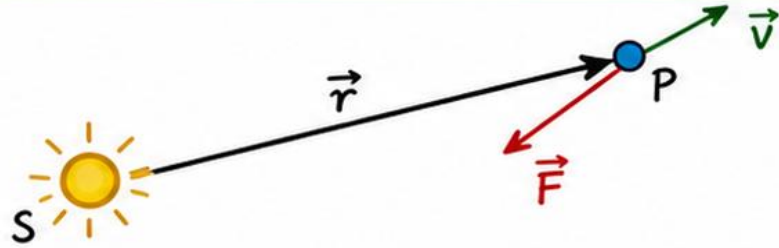
Chapter data range $\approx (2.95 \text{ to } 3.01) \times 10^{-34} \text{ y}^2 \text{ m}^{-3}$.



Equal areas explain changing orbital speed; $T^2 \propto a^3$ connects orbital size and time.

WHY EQUAL AREAS? ANGULAR MOMENTUM

CENTRAL FORCE $\Rightarrow$ CONSTANT AREAL VELOCITY



1. In a small time Δt , displacement $= v \Delta t$
2. Swept area:

$$\Delta A = \frac{1}{2} |\vec{r} \times \vec{v} \Delta t|$$

3. With $\vec{p} = m\vec{v}$ and $\vec{L} = \vec{r} \times \vec{p}$:

$$\frac{\Delta A}{\Delta t} = \frac{|\vec{r} \times \vec{p}|}{2m} = \frac{L}{2m}$$

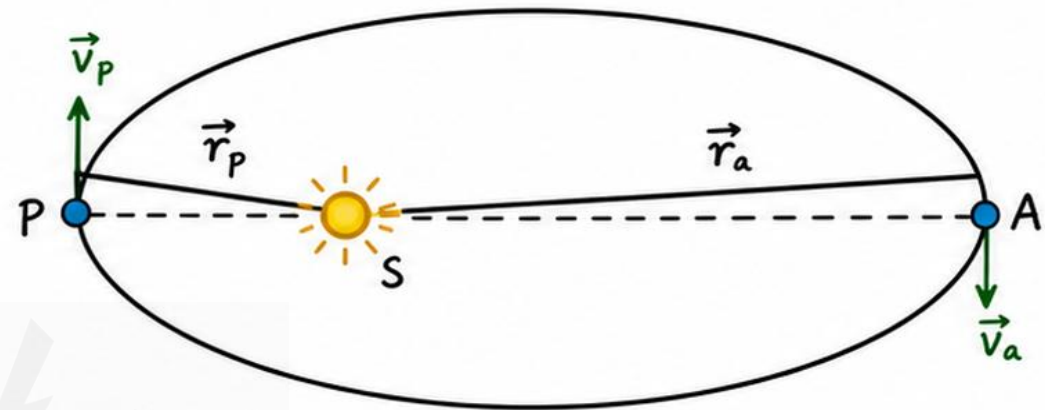
4. Gravity is a central force:

$$\vec{\tau} = \vec{r} \times \vec{F} = 0 \Rightarrow \vec{L} = \text{constant}$$

Therefore:
$$\frac{\Delta A}{\Delta t} = \text{constant}$$

Kepler's second law follows from conservation of angular momentum. It holds for any central force, not only the inverse-square law.

PERIHELION - APHELION CALCULATION



At P: $L_p = m r_p v_p$

At A: $L_a = m r_a v_a$

Conservation: $L_p = L_a$

$$m r_p v_p = m r_a v_a$$

$$\frac{v_p}{v_a} = \frac{r_a}{r_p}$$

Since $r_a > r_p$, $v_p > v_a$

Equal areas take equal times.
A larger swept sector takes longer to traverse.

$$\text{CENTRAL FORCE} \Rightarrow \text{ZERO TORQUE} \Rightarrow \text{CONSTANT } L \Rightarrow \text{EQUAL AREAS IN EQUAL TIMES}$$

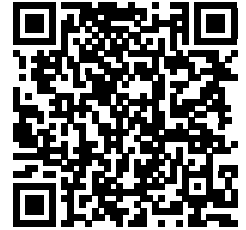


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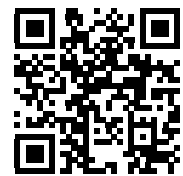


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