# AM-05.04 — Kepler’s laws: three rules for understanding orbital motion

### Essential answer

Kepler’s laws: three rules for understanding orbital motion. Kepler's three laws answer three practical questions: what shape is the orbit, how does speed change along it, and how does orbital size control the period? The rest of the course turns that idea into an auditable line of reasoning: explicit units, stated assumptions, reproducible calculations, order-of-magnitude checks and interpretation limits. A result is useful only when the reader can explain what it measures, where every input came from and which engineering decision it can support.

### Reasoning map

1. 1 — Build a mental picture before using a formula
2. 2 — Essential vocabulary before going further
3. 3 — Understand the mechanism step by step
4. 4 — The formula, only now
5. 5 — What the units tell you

Kepler's three laws answer three practical questions: what shape is the orbit, how does speed change along it, and how does orbital size control the period?

focus — a defining point of an ellipse; the central body occupies one focus.

### Before calculating

| | |
|---|---|
| **Quantity:** | AM-05.04 — Kepler’s laws: three rules for understanding orbital motion |
| **Check:** | units + order of magnitude + assumptions |
| **Decision:** | state what the result actually supports |

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## 2 — Essential vocabulary before going further

focus — a defining point of an ellipse; the central body occupies one focus.

area — measure of a surface.

radius vector — line from the central body to the spacecraft.

period T — time for one revolution.

semi-major axis a — measure of orbital size.

## 3 — Understand the mechanism step by step

Ideal orbital motion follows an ellipse with the central body at one focus.

The line from body to spacecraft sweeps equal areas in equal times, requiring faster motion near periapsis and slower motion near apoapsis.

For objects orbiting the same body, $T^2$ is proportional to $a^3$.

## 4 — The formula, only now

How to read it: T is period, π is pi, μ is gravitational parameter, and a is semi-major axis. Superscript 2 means squared; superscript 3 means cubed.

If $a_2/a_1 = 2$ around the same body, then $T_2/T_1 = \sqrt{(2^3)} = \sqrt{8} \approx 2.83$.

## 5 — What the units tell you

### Active reading

| | |
|---|---|
| **Sections:** | 2 — Essential vocabulary before going further ; 3 — Understand the mechanism step by step |
| **Verification:** | A value is usable only with its unit and calculation boundary. |
| **Exercise:** | change one assumption and predict the direction of change before recalculating |

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## 6 — Three concrete demonstrations

Near periapsis the shorter radius must sweep through a larger angular change in the same time, so the spacecraft moves faster.

If a doubles, T is multiplied by $2^{(3/2)} \approx 2.83$, not merely 2.

Using AU for a and years for T around the Sun yields the convenient normalized relation $T^2 = a^3$.

## 7 — Why this matters for a Mars mission

Kepler's laws connect orbital drawings to timing and are essential for interplanetary transfer reasoning.

## 8 — Common traps and misleading intuitions

placing the central body at the geometric centre of every ellipse.

reading equal area as equal distance.

assuming T scales linearly with a.

comparing orbits around different bodies without adjusting μ.

## 9 — What I should be able to explain at the end

explain the idea in ordinary words

read and pronounce the important symbols

repeat at least one calculation without hidden steps

### Active reading

| | |
|---|---|
| **Sections:** | 6 — Three concrete demonstrations ; 7 — Why this matters for a Mars mission |
| **Verification:** | A value is usable only with its unit and calculation boundary. |
| **Exercise:** | change one assumption and predict the direction of change before recalculating |

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identify what the simplified model assumes and does not prove

## Kepler as a prediction model rather than a recital

Kepler's three laws answer different questions: orbit geometry, how motion changes along that geometry, and how size relates to period. Correct use means selecting the law that matches the quantity being investigated, not merely reciting all three in order.

The equal-areas law reflects conservation of angular momentum for a central force. Near periapsis the spacecraft must cover a longer arc in the same time to sweep the same area, which provides the physical reason for higher speed there.

The third law, $T^2 \propto a^3$ for the same central body, is a powerful order-of-magnitude check. Doubling semi-major axis does not double period; it multiplies it by 2^(3/2). That simple test can catch a bad intuition before mission software is ever opened.

## 10 — Guided exercises and answers

## 11 — NASA / JPL sources for further study

NASA Science — Basics of Space Flight, Gravity & Mechanics

NASA Science — Basics of Space Flight, Trajectories

### Active reading

| | |
|---|---|
| **Sections:** | Kepler as a prediction model rather than a recital ; 10 — Guided exercises and answers |
| **Verification:** | NASA Science — Basics of Space Flight, Gravity & Mechanics \| NASA Science — Basics of Space Flight, Trajectories |
| **Exercise:** | change one assumption and predict the direction of change before recalculating |