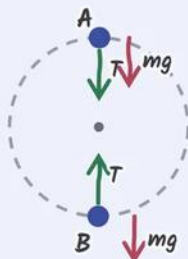


one law running planets and falling stones alike, and the difference between mass and weight

Kepler's three laws *

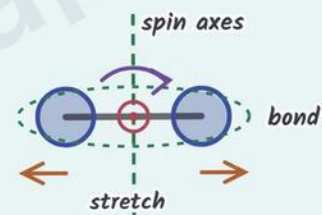
- **first law**: every planet moves in an **ellipse** with the Sun at **one focus**, not at the centre
- **second law**: the line joining a planet to the Sun sweeps **equal areas in equal times**
- so a planet moves **faster when nearer** the Sun and slower when further away, which is what the second law really says
- **third law**: the square of the period is proportional to the cube of the mean distance, $T^2 \propto r^3$
- these were found from **observation alone**, before any explanation existed
- Newton's law of gravitation later **explained** all three, which is why the two topics sit in one chapter



a planet on its orbit with the Sun off to one side rather than at the middle: the shaded slice swept near the Sun is short and wide while the one swept far away is long and thin, and the two have the same area, which forces the planet to move faster when it is close

Newton's universal law of gravitation

- every two bodies attract each other with a force proportional to the product of their masses
- and inversely proportional to the square of the distance between their centres
- so $F = G \frac{m_1 m_2}{r^2}$, the force acting along the line joining them
- G is the universal gravitational constant, the same everywhere in the universe, with value $6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
- the force is **always attractive** and never repulsive, which sets gravity apart from the electric force
- the two forces on the two bodies are **equal and opposite**, so the Earth is pulled towards a falling stone exactly as hard as the stone is pulled towards the Earth



two masses with the line joining their centres marked: the pull acts along that line, each body drawn towards the other with the same size of force, and the separation used in the formula is the whole centre to centre distance