Orbital motion and satellites

4.8.1.3 · Space physics · revision notes

How gravity keeps planets, moons and artificial satellites in their orbits, and how these objects are similar and different. Higher tier students must also explain why an orbiting object's velocity changes while its speed stays the same, and why the radius of a stable orbit must change if the speed changes. GCSE Physics only, not in Combined Science.

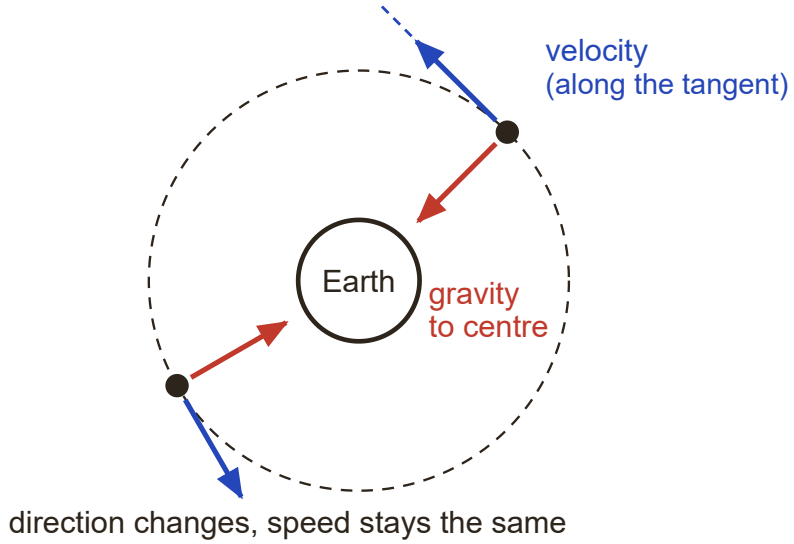
Key facts

- Gravity provides the force that keeps planets and satellites in their orbits
- Artificial satellite: made by people and launched into orbit
- Speed = distance ÷ time (time in seconds for m/s)
- Grade 7+ only Gravity acts towards the centre of the orbit, at right angles to the motion
- Planet: orbits a star. Moon: a natural satellite that orbits a planet
- One circular orbit: distance = 2 × π × radius
- Grade 7+ only Circular orbit at constant speed: the velocity changes because the direction changes
- Grade 8+ only Stable orbit: smaller radius → higher speed; if the speed changes, the radius must change

Notes

Gravity and orbits

- Gravity is the force that keeps planets, moons and artificial satellites moving in their orbits.
- You can treat these orbits as circles.
- Without gravity, an orbiting object would carry on moving in a straight line and fly off into space.



Gravity (red) always points to the centre, at right angles to the velocity (blue). Dashed: the path with no gravity.

Planets, moons and artificial satellites

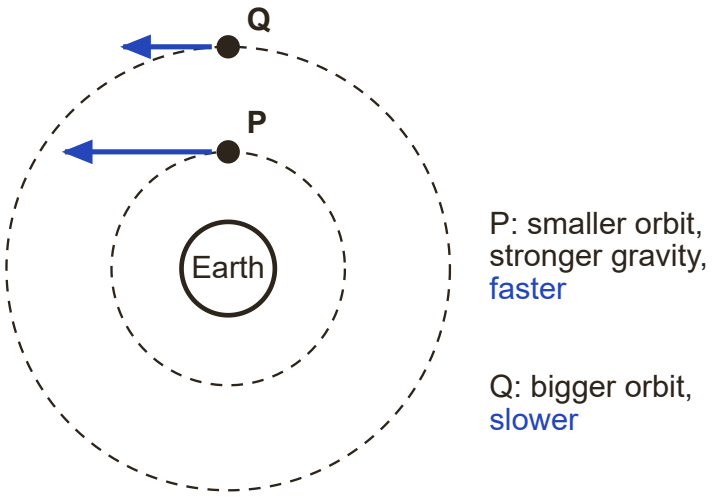
- A **planet** orbits a star (in our solar system, the Sun).
- A **moon** is a natural satellite: it orbits a planet.
- An **artificial satellite** is made and launched by people. Most orbit the Earth, for jobs such as communications, weather monitoring and navigation.
- Similarities: all are kept in orbit by gravity, all orbit a more massive object, and all move in (nearly) circular orbits. Planets and moons do not give out their own visible light: they reflect the Sun's light.
- Differences: what they orbit, whether they are natural or made by people, their size, the radius of the orbit, and the time they take to complete one orbit (the period).

Changing velocity at constant speed Grade 7+ only

- In a circular orbit, gravity always acts towards the centre of the orbit, at right angles to the direction the object is moving.
- So gravity changes the direction of motion, but not the speed.
- Velocity is a vector: it has a size (the speed) and a direction. The direction keeps changing, so the velocity keeps changing even though the speed is constant.
- A changing velocity means the object is accelerating, towards the centre of the orbit.

Speed and radius of a stable orbit Grade 8+ only

- For each orbit radius there is only one speed at which an object can stay in a stable orbit.
- The closer an object is to the planet (or star) it orbits, the stronger the gravitational pull on it, so a smaller orbit needs a higher speed to be stable.



The smaller the orbit, the faster the object must move to stay in it.

- So if the speed of an object in a stable orbit changes, the radius of its orbit must change too.
- An object in a smaller orbit also takes less time to go round once: it moves faster and has a shorter distance to travel.

How to answer each type of question

Give a similarity or a difference between orbiting objects 1 to 2 marks Grade 4

1. Say what each object orbits: a star, a planet, or (for most artificial satellites) the Earth.
2. Say whether each object is natural or made by people.
3. For a similarity use gravity or the circular orbit. For a difference, write about both objects.

Example. The Moon and a weather satellite both orbit the Earth.
Give **one** similarity and **one** difference between the Moon and the weather satellite.

Model answer.

Similarity: both are kept in orbit by the Earth's gravity (1).
Difference: the Moon is a natural satellite, whereas the weather satellite was made and launched by people (1).
Also accept for the difference: the Moon is much bigger, or the Moon takes longer to complete one orbit.

Calculate the speed of a satellite in a circular orbit

3 marks | Grade 6

1. Find the distance for one orbit: 2 × π × radius (the question usually gives you this equation).
2. Convert the time for one orbit into seconds.
3. Use speed = distance ÷ time and give the unit, m/s.

Example. A satellite moves in a circular orbit of radius 7.1×10^6 m around the centre of the Earth. It takes 100 minutes to complete one orbit.
distance travelled in one orbit = 2 × π × radius
Calculate the speed of the satellite.

Model answer.

distance = $2 \times \pi \times 7.1 \times 10^6 = 4.46 \times 10^7$ m (1)
time = $100 \times 60 = 6000$ s (1)
speed = $4.46 \times 10^7 \div 6000 = 7400$ m/s (1)
(7430 or 7440 m/s is also correct)

Explain why the velocity changes but the speed does not

2 to 3 marks | Grade 7

1. Say that gravity acts towards the centre of the orbit.
2. Say that this is at right angles to the direction of motion, so it changes the direction but not the speed.
3. Say that velocity is a vector, so a change of direction is a change of velocity.

Example. A satellite moves in a circular orbit around the Earth at a constant speed.
Explain how the force of gravity changes the velocity of the satellite but not its speed.

Model answer. The force of gravity on the satellite acts towards the centre of the Earth (1). This force is at right angles to the direction the satellite is moving, so it changes the satellite's direction but not its speed (1). Velocity is a vector (it includes direction), so the velocity changes even though the speed stays the same (1).

Explain how orbital speed and orbit radius are linked

2 marks | Grade 8

1. State which orbit needs the higher speed: the one with the smaller radius.
2. Give the reason: gravity is stronger closer in, so a faster speed is needed to stay in a stable orbit.
3. If asked, link back: a change of speed needs a change of radius.

Example. Satellites P and Q are both in stable circular orbits around the Earth. The radius of the orbit of P is smaller than the radius of the orbit of Q.
Explain which satellite is moving faster.

Model answer. Satellite P (1), because closer to the Earth the gravitational force is stronger, so P must move faster to stay in a stable orbit at its radius (1).

Don’t lose marks

- Saying there is no gravity in space, or no force on a satellite. Gravity is what keeps it in orbit.
- Saying that the speed changes in a circular orbit. The speed is constant; the direction, and so the velocity, changes.
- Saying the resultant force acts outwards or in the direction of motion. It is gravity, acting towards the centre.
- Leaving the time in minutes or hours in a speed calculation. Convert to seconds to get m/s.
- Using a height above the Earth's surface as the orbit radius. The radius is measured from the centre of the Earth, so add the Earth's radius if you are given a height.
- Mixing up the objects: a moon orbits a planet, not the Sun; an artificial satellite is not a moon.

More tips

Memory tricks

- 'Closer means quicker': the smaller the orbit, the higher the speed and the shorter the time for one orbit.
- Imagine whirling a ball on a string: the string pulls the ball inwards, like gravity. If the string breaks, the ball flies off in a straight line.
- Speed is only a size; velocity is a size and a direction. Going round a circle changes the direction, so the velocity changes.
- Sense check: satellites orbiting the Earth usually travel at a few thousand metres per second. A much smaller answer usually means the time was left in minutes or hours.

Exam technique

- Higher tier: in orbit questions, use these key phrases: 'towards the centre', 'at right angles to the motion', 'velocity is a vector', 'direction changes'.
- For similarity and difference questions, write a full comparison, e.g. 'A moon orbits a planet, whereas a planet orbits a star.'
- In orbit calculations, show each step (distance, time in seconds, speed) and give the unit.
- If you are given a table of orbit radii and speeds or times, describe the pattern using both quantities, e.g. 'as the radius increases, the speed decreases'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **State the force that keeps objects in orbit**
Gravity provides the force that keeps planets, moons and artificial satellites in their orbits.

Grade 4 — **Tell apart planets, moons and artificial satellites**
Planets orbit a star, moons orbit planets, and artificial satellites are made and launched by people.

Grade 5 — **Give similarities between orbiting objects**
All are held in orbit by the gravity of a more massive object and move in (nearly) circular orbits.

Grade 6 — **Calculate orbital speed from radius and time**
Use speed = distance ÷ time, where the distance for one orbit is $2 \times \pi \times$ radius.

Grade 7 — **Explain changing velocity at constant speed**
Gravity acts at right angles to the motion, so it changes the direction, and so the velocity, but not the speed.

Grade 8

Link orbital speed and orbit radius

A stable orbit with a smaller radius needs a higher speed, so if the speed changes the radius must change.

Free notes, Full packs, practice papers and mock exams at chhetriacademy.com. Written for this site; not taken from past papers. Stuck? 1-to-1 tutoring with a free 30-minute trial lesson.