Weight and motion under gravity

M8.3 · Mechanics · revision notes

Weight is the force of gravity on a mass, $W = mg$, where g is taken as 9.8 m s^{-2} unless you are told otherwise. This subtopic covers vertical motion under gravity using suvat (objects thrown up or dropped) and vertical motion with other forces, such as a crate lifted by a cable.

Key facts

- $W = mg$, in newtons
- $g = 9.8$ m s^{-2} unless told otherwise
- Moving freely under gravity: acceleration g downwards
- Greatest height: $v = 0$
- Up positive: $a = -9.8$
- Lifting with tension T: $T - mg = ma$
- Falling with resistance R: $mg - R = ma$
- g depends on location: it is not a universal constant

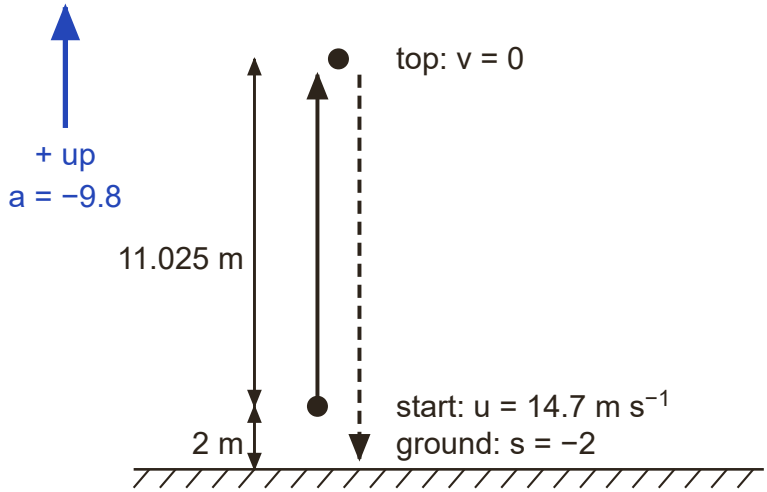
Notes

Weight and g

- Weight is the gravitational force on an object: $W = mg$ newtons, acting vertically downwards.
- g is the acceleration due to gravity. Use $g = 9.8$ m s^{-2} unless the question gives a different value, such as 9.81 or 10.
- g is not a universal constant: it varies slightly with location on the Earth (for example with height and latitude) and is much smaller on the Moon. Near the Earth's surface the model takes it as constant.
- Mass stays the same wherever the object is; weight depends on g

Moving freely under gravity

- 'Moving freely under gravity' means the only force is the weight, so the acceleration is g downwards, whatever the mass.
- Choose a positive direction. With up as positive, $a = -9.8$ and a point below the start has a negative displacement.

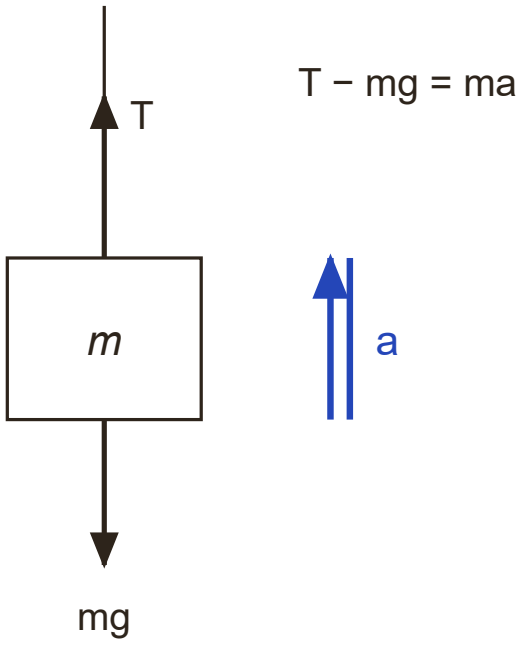


With up as positive, a = −9.8 and the ground is at s = −2

- At the greatest height $v = 0$
- Without air resistance the motion is symmetrical: the time up equals the time down to the same level, and the speed at any height is the same going up as coming down.

Vertical motion with other forces

- If other forces act, use $F = ma$ vertically. For a crate lifted by a cable with tension T: $T - mg = ma$ (up positive).



Up positive: T − mg = ma

- A falling object with air resistance R: $mg - R = ma$, so its acceleration is less than g
- Accelerating upwards needs $T > mg$; moving at constant speed needs $T = mg$; slowing down while moving up needs $T < mg$

How to answer each type of question

M = method mark, A = answer mark, B = a mark on its own, dM = depends on the earlier method mark.

Vertical projection: greatest height and time to land

5 to 7 marks **Grade D**

1. State your positive direction (usually up), so $a = -9.8$
2. Greatest height: $v = 0$ in $v^2 = u^2 + 2as$; add the launch height to get the height above the ground.
3. Time to land: the displacement is minus the launch height; solve the quadratic and take the positive root.

Example. A ball is thrown vertically upwards with speed 14.7 m s^{-1} from a point 2 m above horizontal ground. The ball is modelled as a particle moving freely under gravity.
(a) Find the greatest height of the ball above the ground.
(b) Find the time taken for the ball to reach the ground.

Model answer.

(a) Up positive: $0 = 14.7^2 - 2(9.8)s$ (M1), $s = 11.025$ (A1); height above the ground = 13 m (2 s.f.) or 13.0 m (3 s.f.) (A1)

(b) $-2 = 14.7t - 4.9t^2$ (M1 A1), so $4.9t^2 - 14.7t - 2 = 0$ and

$$t = \frac{14.7 + \sqrt{14.7^2 + 4(4.9)(2)}}{9.8}$$ (dM1) = 3.1 s (2 s.f.) or 3.13 s (3 s.f.) (A1)

Vertical motion with a tension or resistance

3 to 5 marks **Grade C**

1. Draw the forces: weight mg down, tension up, resistance opposing the motion.
2. Write Newton's second law in the direction of the acceleration.
3. Use suvat for speeds or times if asked.

Example. A crate of mass 50 kg is raised vertically by a light inextensible cable. The tension in the cable is 560 N.
(a) Find the acceleration of the crate.
(b) The crate starts from rest. Find its speed after 5 s.

Model answer.

(a) $560 - 50g = 50a$ (M1 A1), $a = 1.4$ m s^{-2} (A1)

(b) $v = 1.4 \times 5 = 7$ m s^{-1} (B1)

Two objects under gravity: when do they meet? 5 to 7 marks **Grade B**

1. Measure both heights from the same point (e.g. the ground) at the same time t
2. Write each height in terms of t, taking care with signs.
3. Set the heights equal and solve; check that both objects are still in the air.

Example. Ball A is released from rest at the top of a tower, 40 m above horizontal ground. At the same instant, ball B is projected vertically upwards from the ground directly below A, with speed 20 m s^{-1}. The balls move freely under gravity. Find the time at which the balls collide and their height above the ground at that moment.

Model answer.

Height of A: $40 - 4.9t^2$ (M1 A1)

Height of B: $20t - 4.9t^2$ (M1 A1)

$40 - 4.9t^2 = 20t - 4.9t^2$, so $t = 2$ s (M1 A1)

Height $= 40 - 4.9 \times 2^2$

$= 20.4$ m (A1)

Don't lose marks

- Using $a = +9.8$ when up has been taken as positive.
- Forgetting to add the launch height when asked for the height above the ground.
- Taking the negative root of a quadratic in t
- Giving weight in kg, or using m instead of mg for the weight in $F = ma$
- Giving too many significant figures: answers using $g = 9.8$ should be to 2 or 3 s.f.

More tips

Memory tricks

- Thrown up with speed u: time to the top $\frac{u}{g}$, greatest height $\frac{u^2}{2g}$ above the launch point.
- With up positive, $s = ut - 4.9t^2$, since $\frac{1}{2} \times 9.8 = 4.9$
- Look for multiples of 9.8: 14.7 = 1.5g, 19.6 = 2g, 24.5 = 2.5g. They often make answers come out neatly.
- In a meeting problem the $4.9t^2$ terms often cancel, because both objects have the same acceleration.

Exam technique

- Write 'taking up as positive' (or down) at the start of your working.
- Keep multiples of g exact, such as $50g$, until the last line.
- Know that g is not a universal constant: it depends on where you are, and the model treats it as constant near the Earth's surface.
- Common assumptions to state: the ball is a particle; air resistance is negligible.

What each grade needs

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

Grade E — **Calculate weight using $W = mg$**

Mass in kg, $g = 9.8$ m s^{-2}, weight in newtons.

Grade E — **Use suvat for vertical motion under gravity**

Take the acceleration as g downwards and choose up or down as positive.

Grade D — **Find the greatest height and time of flight**

At the top $v = 0$; when it lands the displacement is 0 or a known negative value.

Grade C — **Apply $F = ma$ to vertical motion**

For an object lifted by a cable, $T - mg = ma$

Grade B — **Solve problems with two objects under gravity**

Write both heights in terms of t, measured from the same point, and equate them.

Grade A — **Handle motion starting above the ground**

Use a negative displacement for a point below the start, solve the quadratic and reject the negative root.

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