STUDY FORMULA BOOKLET

# Cambridge 9709 Maths Paper 4: mechanics

Of what Paper 4 needed, MF19 prints only the four constant acceleration equations, the quadratic formula, tan x = sin x / cos x and the x^n rules. Learn first F = ma, F = μR, resolving, momentum, energy, work done and P = Fv.

GIVEN printed in the formula list (MF19) LEARN IT not in MF19: learn it

Built by CuratedPrep from 41 past question papers for Paper 4 in our question bank, March 2020 to November 2025. Given means it is in the List of formulae and statistical tables (MF19) given in every paper. Learn it means a past question needed it and the exam did not print it.

## Forces and equilibrium

MF19 prints none of these, so every row in this section is Learn it.

### Components of a force

θ is the angle between the force and the line you resolve along: the component along that line is F cos θ and the component at right angles to it is F sin θ. Resolve every force that does not lie along your two perpendicular axes, then add the components with signs. A force that already lies along an axis is not resolved. Used in: Nov 2025 paper 45 Q1, forces in equilibrium, find P and Q; Jun 2025 paper 41 Q2, resolving in the direction of P; Mar 2022 paper 42 Q5(b).

$$F\cos\theta \text{ (along)}, \qquad F\sin\theta \text{ (across)}$$

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### Resultant of a set of forces

X and Y are the totals of the components in two perpendicular directions, and θ is measured from the X direction. Say which line the angle is from, or draw it, because an angle on its own is not enough. Used in: Nov 2025 paper 41 Q3, magnitude and direction of the resultant of four forces; Nov 2025 paper 42 Q7(a); Jun 2025 paper 45 Q4(a).

$$R = \sqrt{X^2 + Y^2}, \qquad \tan\theta = \frac{Y}{X}$$

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### Friction

R is the normal contact force, found by resolving perpendicular to the surface; it is not always mg. A smooth contact has F = 0. 'On the point of slipping' means limiting equilibrium. Used in: Nov 2025 paper 41 Q5, on the point of slipping down a plane; Nov 2025 paper 41 Q8(b), coefficient of friction for a block pulled at 20 degrees; Nov 2025 paper 45 Q5(b).

$$F \leqslant \mu R, \qquad F = \mu R \text{ (limiting equilibrium, or sliding)}$$

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### Weight components on a slope

θ is the angle of the plane to the horizontal. With no other force pushing into or away from the plane, R = mg cos θ. Used in: Jun 2025 paper 41 Q1, block pulled up a rough plane; Jun 2025 paper 42 Q5(b), particle on a rough 30 degree plane; Nov 2025 paper 45 Q5(b).

$$\text{down the slope: } mg\sin\theta, \qquad \text{into the slope: } mg\cos\theta$$

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## Kinematics of motion in a straight line

MF19 prints the four constant acceleration equations and the x^n rules. The graph areas, average speed and the calculus relations are Learn it.

### Area of a triangle

On a velocity-time graph the area between the graph and the time axis is the distance travelled, so split the graph into triangles, rectangles and trapezia. Used in: Nov 2025 paper 43 Q1(b), total distance from triangles on an athlete's graph; Jun 2023 paper 41 Q4(c); Nov 2021 paper 42 Q1(b).

$$A = \tfrac{1}{2} \times \text{base} \times \text{height}$$

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### Area of a trapezium

On a velocity-time graph a and b are the parallel sides along the time axis, and h is the greatest speed. Used when a body speeds up, holds a steady speed, then slows. Used in: Nov 2025 paper 45 Q2(b), trapezium for a total distance of 1350 m; Jun 2025 paper 42 Q4(b), distance from A to B; Nov 2021 paper 42 Q1(b).

$$A = \tfrac{1}{2}(a + b)h$$

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### Average speed

Use total distance, not displacement, and the whole time including any stops. Used in: Nov 2023 paper 41 Q3(c), average speed of a bus; Jun 2023 paper 41 Q4(c); Jun 2022 paper 43 Q3(c), from a displacement-time graph.

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

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### Velocity and acceleration from displacement

Differentiate s to get v, then v to get a. Use it when s, v or a is given as a function of t, because the constant acceleration equations then do not apply. Used in: Nov 2025 paper 43 Q4(a), velocity from displacement; Nov 2025 paper 43 Q4(b), acceleration when the direction of motion changes; Jun 2025 paper 43 Q7(a).

$$v = \frac{\mathrm{d}s}{\mathrm{d}t}, \qquad a = \frac{\mathrm{d}v}{\mathrm{d}t} = \frac{\mathrm{d}^2 s}{\mathrm{d}t^2}$$

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### Derivative of x to the power n

Differentiate each term of s or v in turn: bring the power down and reduce it by 1. When v is given as a product of two brackets, expand it first (the Nov 2025 paper 41 Q7(a) scheme also allows the product rule). Used in: Nov 2025 paper 41 Q7(a), acceleration at a given time; Nov 2025 paper 43 Q4(a); Jun 2025 paper 41 Q7(a), differentiating s to find when X is at rest.

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

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### Velocity and displacement from acceleration

Add a constant each time and find it from the starting conditions, such as v = 0 at t = 0 when the particle starts from rest. When a or v changes with time, v = at and s = vt score no marks in the schemes. Used in: Nov 2025 paper 45 Q4(a), integrating a = kt - 3 to get v; Nov 2025 paper 41 Q7(b), total distance from v; Nov 2020 paper 41 Q4.

$$v = \int a \,\mathrm{d}t, \qquad s = \int v \,\mathrm{d}t$$

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### Power of x

Integrate each term of a or v: raise the power by 1 and divide by the new power. Use limits between two times for a distance or a displacement. Used in: Nov 2025 paper 41 Q7(b), integrating a quadratic v; Nov 2025 paper 45 Q4(b), distance between two times; Nov 2020 paper 41 Q4, distance before instantaneous rest.

$$\int x^n \, dx = \frac{x^{n+1}}{n+1} \quad (n \neq -1)$$

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### First equation

u is the initial velocity, v the final velocity, a the acceleration and t the time. Take one direction as positive and use a negative a for slowing down. It also gives a = (v - u)/t. Used in: Nov 2025 paper 41 Q6, speed of a particle after 2 s on a smooth slope; Jun 2025 paper 42 Q4(b), speed of a car after 30 s; Mar 2023 paper 42 Q1(b), time for a crate to stop.

$$v = u + at$$

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### Second equation

Use it when u, v and s are known and you want the time, because it does not need a. Used in: Nov 2025 paper 42 Q3(a), time for a car to go 175 m while speeding up from 15 to 20 m $s^{-1}$; Mar 2024 paper 42 Q7(a), time to reach B; Nov 2021 paper 43 Q3(b), ball falling 5 m.

$$s = \frac{1}{2}(u + v)t$$

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### Third equation

Use it when u, a, t and s are involved but not v, for example for a particle released from rest. Used in: Nov 2025 paper 45 Q5(c), length of a plane from the time to slide down it; Nov 2025 paper 43 Q5(b), time B is in motion; Mar 2020 paper 42 Q2(a), time to move 1.44 m.

$$s = ut + \frac{1}{2}at^2$$

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### Fourth equation

Use it when u, v, a and s are involved but not t, for example the distance to stop or the speed after a distance. Used in: Nov 2025 paper 41 Q6, distance up the plane after a collision; Jun 2025 paper 42 Q5(c), distance up the plane after a string breaks; Jun 2025 paper 42 Q4(c), distance while braking.

$$v^2 = u^2 + 2as$$

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### Acceleration due to gravity

Not on the sheet: printed on the front of the paper. Take g = 10, as the front of the paper says. A body falling or thrown upwards has acceleration g downwards: with upwards positive, use a = -g. Used in: Nov 2025 paper 42 Q4(a), two particles projected vertically upwards; Nov 2025 paper 45 Q3(b), weight component of a car on a slope; Nov 2021 paper 43 Q3(b), a ball released from rest.

$$g = 10 \text{ m s}^{-2}$$

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## Momentum

MF19 prints no momentum formulas, so every row here is Learn it.

### Linear momentum

Momentum is mass times velocity, in kg m $s^{-1}$ or N s, and it has a direction. Use the mass in kg, never the weight. Used in: Jun 2025 paper 41 Q5(a), momentum 4 N s and kinetic energy 16 J give m and u; Nov 2025 paper 41 Q2(a), a 3 kg particle hits a 5 kg particle.

$$p = mv$$

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### Conservation of momentum

Take one direction as positive and give each velocity its sign; a particle moving the other way has a negative velocity. Use masses, not weights: the schemes give M1 A0 if g is included. Used in: Nov 2025 paper 41 Q2(a), the two possible speeds of Q; Nov 2025 paper 45 Q6, collision with a loss of kinetic energy; Jun 2025 paper 41 Q5(b).

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

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### Particles that coalesce

After a coalescence the two particles move together with one common velocity v. Used in: Jun 2025 paper 45 Q2(a), hammerhead and nail; Jun 2025 paper 42 Q2, kinetic energy lost when two particles coalesce; Nov 2021 paper 42 Q7(c).

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

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### Kinetic energy lost in a collision

Find the speeds after the collision from momentum first, then work out each kinetic energy with 1/2 $mv^2$. A given percentage lost, such as 35%, means KE after = 0.65 x KE before. Used in: Nov 2025 paper 41 Q2(b), find the energy lost in a collision; Nov 2025 paper 45 Q6, 35% of the kinetic energy is lost; Jun 2025 paper 42 Q2.

$$\text{KE lost} = \text{KE before} - \text{KE after}$$

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## Newton's laws of motion

MF19 prints none of these, so every row here is Learn it.

### Newton's second law

F is the resultant force in the direction of motion, so subtract the resisting forces from the driving force. Write one equation for each particle, with the signs matching the direction of the acceleration. Used in: Nov 2025 paper 41 Q1(a), driving force of a car; Nov 2021 paper 42 Q2(a), tension in a rope; Mar 2020 paper 42 Q2(b).

$$F = ma$$

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### Weight

The weight of a mass m kg is mg newtons, acting vertically downwards, with g = 10. In momentum equations use mass only. Used in: Nov 2025 paper 41 Q5, force 8mg and weight mg on a plane; Jun 2025 paper 42 Q3, find m from equilibrium; Nov 2025 paper 45 Q3(b).

$$W = mg$$

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### Acceleration down a slope

From mg sin θ = ma on a smooth plane. On a rough plane use mg sin θ - μ mg cos θ = ma. Used in: Nov 2025 paper 41 Q6, acceleration of A down a smooth plane; Nov 2020 paper 41 Q7(a), a = 5 on a smooth 30 degree plane.

$$a = g\sin\theta \quad \text{(smooth)}$$

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### Vehicle on a road or hill

D is the driving force, R the resistance and θ the angle of the hill; take D = P/v when the power is given. Drop mg sin θ on a horizontal road, and add it instead of subtracting it when going down the hill. Used in: Nov 2025 paper 45 Q3(b), acceleration of a car up an incline; Nov 2025 paper 42 Q2, locomotive and coach down a hill; Jun 2025 paper 43 Q5(b).

$$D - R - mg\sin\theta = ma$$

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### Connected particles or a vehicle with a trailer

The particles share one acceleration, and the tension in a light string or tow-bar cancels when you take the whole system. Use it to find a first, then use one particle's equation to find T. Used in: Nov 2021 paper 42 Q2(a), van towing a trailer; Nov 2025 paper 45 Q5(b), particle P or the whole system; Mar 2020 paper 42 Q6(a), tow-bar force.

$$\Sigma F = (m_1 + m_2)a$$

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## Energy, work and power

MF19 prints none of these, so every row here is Learn it.

### Work done by a constant force

d is the distance moved and θ the angle between the force and the direction of motion; use W = Fd when the force is along the motion. Used in: Jun 2025 paper 42 Q1(b), 25 N force at 20 degrees; Nov 2025 paper 43 Q3(b), pulling force at 36 degrees.

$$W = Fd\cos\theta$$

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### Work done against friction

Find R by resolving perpendicular to the surface first. If the pull has an upward component, R is not mg. Used in: Nov 2025 paper 43 Q3(a), work done against friction for a block pulled at 36 degrees; Jun 2025 paper 42 Q7, particle moving up and down a rough plane.

$$W = Fd = \mu Rd$$

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### Kinetic energy

Use the speed in m $s^{-1}$; energy is in joules. Used in: Jun 2025 paper 41 Q5(a); Nov 2025 paper 42 Q3(b), change in kinetic energy of a car; Nov 2020 paper 41 Q1(b).

$$\mathrm{KE} = \tfrac{1}{2}mv^2$$

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### Gravitational potential energy

h is the vertical height gained or lost. Used in: Nov 2025 paper 41 Q4, PE lost by A and gained by B; Jun 2025 paper 45 Q1; Mar 2020 paper 42 Q3(a), height h from an energy equation.

$$\mathrm{PE} = mgh$$

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### Vertical height on a slope

d is the distance moved along a plane at angle θ to the horizontal, so the PE change is mg d sin θ. Used in: Nov 2025 paper 41 Q4, B moves 0.75 m up a plane with sin θ = 0.6; Jun 2025 paper 45 Q1, box pulled 12 m up an 8 degree plane; Nov 2023 paper 41 Q1.

$$h = d\sin\theta$$

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### Work-energy principle

Use it when the question says use an energy method; constant acceleration equations then score no marks (the Nov 2021 paper 42 Q3(a) scheme says so). Put each term on the correct side. Used in: Nov 2025 paper 42 Q3(b), average power by an energy method; Jun 2025 paper 45 Q1, work done by the pulling force; Nov 2025 paper 43 Q3(b).

$$\text{WD by driving force} = \Delta\mathrm{KE} + \Delta\mathrm{PE} + \text{WD against resistance}$$

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### Conservation of energy (no resistance)

Use it on a smooth surface or curved track, where only the heights and speeds matter. Used in: Nov 2023 paper 41 Q1, distance up a smooth plane; Nov 2021 paper 42 Q3(a), speed at the bottom of a track; Mar 2020 paper 42 Q3(a).

$$\tfrac{1}{2}mu^2 + mgh_1 = \tfrac{1}{2}mv^2 + mgh_2$$

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### Power

F is the driving force and v the speed; P in watts, so 1 kW = 1000 W. It gives F = P/v, which goes into Newton's second law. Used in: Nov 2025 paper 41 Q1(b), power of a car engine; Nov 2025 paper 45 Q3(a), same power on a flat and an incline; Jun 2025 paper 41 Q4(a).

$$P = Fv$$

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### Average power

Work in joules and time in seconds give power in watts. Used in: Nov 2025 paper 42 Q3(b), average power of an engine; Mar 2022 paper 42 Q1(b), time from an average power of 12.5 kW; Mar 2020 paper 42 Q1(a).

$$\text{average power} = \frac{\text{work done}}{\text{time taken}}$$

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## Algebra and trigonometry from Paper 1

Mechanics papers assume Paper 1 algebra. MF19 prints the quadratic formula and tan x = sin x / cos x.

### Quadratic equation

Use it when a time or speed is the root of a three-term quadratic. The schemes ask for the correct formula, or correct factors, and for the unrealistic root to be rejected. Used in: Nov 2025 paper 43 Q2(b), steady speed as a root of a quadratic; Jun 2025 paper 45 Q5(b); Jun 2025 paper 42 Q4(b), value of T.

$$ax^2 + bx + c = 0 \;\Rightarrow\; x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

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### Discriminant

MF19 prints the quadratic formula, which contains $b^2$ - 4ac, but not what its sign means: $b^2$ - 4ac < 0 means no real roots, so the equation never has a solution. Used in: Nov 2025 paper 45 Q4(a), velocity never zero, show k < 4.5; Nov 2025 paper 41 Q7(c), does P return to O.

$$b^2 - 4ac$$

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### Right-angled triangle trigonometry

Questions give an angle as sin θ = 0.6 or tan θ = 3/4. Sketch the right-angled triangle (3, 4, 5 for tan θ = 3/4) to read off the other ratios without a calculator. Used in: Mar 2025 paper 42 Q6(a), plane with tan alpha = 0.5; Nov 2023 paper 41 Q1, tan θ = 3/4; Nov 2022 paper 43 Q7(a).

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}, \quad \cos\theta = \frac{\text{adj}}{\text{hyp}}, \quad \tan\theta = \frac{\text{opp}}{\text{adj}}$$

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### Tangent as sine over cosine

Dividing an equation in sin and cos by cos turns it into an equation in tan, which gives the angle of a plane or a force. Used in: Nov 2025 paper 43 Q7(a), show that tan of the angle is given by a fraction; Nov 2025 paper 41 Q5, rearranged to tan θ = k.

$$\tan\theta \equiv \frac{\sin\theta}{\cos\theta}$$

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## Also learn these

**Equilibrium**

A particle in equilibrium has no resultant force, so the components in any two perpendicular directions each add to zero; on a slope resolve along and perpendicular to it. Used in: Nov 2025 paper 45 Q1; Nov 2025 paper 41 Q5; Jun 2025 paper 43 Q4.

**Resultant in a given direction**

If the resultant acts perpendicular to one force, the components of all the forces along that force add to zero. Used in: Jun 2025 paper 41 Q2; Mar 2022 paper 42 Q5(b).

**Smooth and rough contacts**

A smooth contact has no friction, so the surface pushes only at right angles; a rough contact has $F = \mu R$. Used in: Nov 2025 paper 41 Q8(a); Jun 2025 paper 42 Q5(a); Nov 2025 paper 45 Q6.

**Connected particles and strings**

A light inextensible string has the same tension throughout and, over a smooth pulley, the two particles have accelerations of the same size; write Newton's second law for each particle or for the whole system. Used in: Jun 2025 paper 42 Q5(a); Nov 2025 paper 45 Q5(a); Nov 2025 paper 43 Q5(a).

**When a string breaks**

After the break only gravity and friction act, so find the new acceleration and use the speed at that instant as u. Used in: Jun 2025 paper 42 Q5(c); Nov 2021 paper 41 Q7.

**Constant speed**

At a steady speed the acceleration is zero, so the driving force equals the resistance plus any weight component down the slope. Used in: Nov 2025 paper 45 Q3(a); Jun 2025 paper 41 Q4(a); Nov 2025 paper 43 Q2(b).

**Resistance that depends on speed**

When a question gives the resistance as kv or cv, find the constant from a steady speed or a known acceleration, then use $P = Fv$ and Newton's second law at the new speed. Used in: Jun 2025 paper 43 Q5(a); Nov 2025 paper 43 Q2(a); Jun 2025 paper 45 Q5(b).

**Velocity-time graph**

The gradient is the acceleration and the area between the graph and the time axis is the distance travelled; area below the axis is distance in the opposite direction. Used in: Jun 2025 paper 41 Q3(ab); Nov 2024 paper 42 Q1(a); Nov 2025 paper 43 Q1(b).

**Displacement-time graph**

The gradient is the velocity, so a straight line segment means constant velocity. Used in: Nov 2025 paper 42 Q1; Jun 2022 paper 43 Q3(c).

**Total distance and turning points**

Distance is not displacement: find when $v = 0$, integrate over each stage and add the sizes of the results. Used in: Nov 2025 paper 41 Q7(b); Nov 2025 paper 45 Q4(b); Jun 2025 paper 41 Q7(a).

**Greatest or least velocity**

Set the acceleration $dv/dt = 0$ to find the maximum or minimum velocity, or complete the square on a quadratic v; instantaneous rest is $v = 0$. Used in: Jun 2025 paper 42 Q6(a); Nov 2025 paper 43 Q4(a); Nov 2021 paper 42 Q4(b).

## Using the booklet in the exam

- Learn $F = ma$, $F = \mu R$, $W = mg$, $p = mv$, KE, PE, $W = Fd\cos\theta$ and $P = Fv$ before the exam: MF19 prints only the four constant acceleration equations for this unit.
- When a question says use an energy method, do not use $v^2 = u^2 + 2as$: the Nov 2021 paper 42 Q3(a) scheme gives M0 A0 for it. Write the work-energy equation instead.
- In force equations the schemes want the correct number of terms: resolve each force that needs it and leave out components of forces that already lie along an axis (Nov 2025 paper 41 Q5 scheme).
- Use mass, not weight, in a momentum equation. The Nov 2025 paper 41 Q2(a) scheme gives M1 only if you use weights instead of masses.
- When s or v depends on t, differentiate or integrate: $v = at$ and $s = vt$ score M0 (Nov 2025 paper 41 Q7(b) and Nov 2025 paper 45 Q4(a) schemes). Add the constant of integration from the starting conditions.
- When a quadratic gives two values, show the method and give a reason for rejecting the unrealistic one, as Nov 2025 paper 45 Q2(c) asks.

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