A LEVEL MATHS 9709 · PAPER 4 MECHANICS · 4.5 · ~5 MIN READ

Energy, work and power

Work done by a force, kinetic and gravitational potential energy, the work–energy principle with resistances and friction, conservation of energy on smooth surfaces, and power as force × velocity for vehicles on level roads and hills.

Work done | Kinetic energy | Potential energy | Work–energy principle | Work against friction | Conservation of energy | Power P = Fv | Maximum speed

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Paper tag = **where it is examined** FORMULA LIST (MF19) given in the exam M1 A1 B1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Work done = force × distance moved in the direction of the force:** Fd cos θ.
- **Work–energy principle:** change in KE + change in PE = work done by driving forces − work done against resistances.
- **Power = rate of doing work = Fv,** where F is the driving force. At maximum speed, the driving force equals the total resistance.
- **Energy methods** avoid finding the acceleration, and work on curved paths where suvat doesn't.

BY THE END YOU CAN

- Calculate work done by a constant force, including at an angle to the motion.
- Use kinetic energy ½mv² and gravitational potential energy mgh.
- Use the work–energy principle, including with friction and resistances.
- Use P = Fv, including vehicles accelerating or moving at maximum speed on level ground and on slopes.

1 Work and energy

Definitions

$$W = Fd\cos\theta \ ; \ KE = \tfrac{1}{2}mv^2 \ ; \ GPE = mgh$$

θ is the angle between the force and the direction of motion

- **Units:** joules (J). A force perpendicular to the motion (like R on a horizontal floor) does no work.
- **Only the vertical height** matters for GPE: a particle moving 10 m up a slope at angle α rises 10 sin α.

WORKED EXAMPLE

A box is dragged 5 m along the floor by a 40 N force at 30° above the horizontal. Find the work done by the force.

1. $W = 40\cos 30° \times 5$ M1
2. **$= 173$ J** A1

2 The work–energy principle

Energy in and energy out

$$\tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2 + mg(h_2 - h_1) = W_{\text{driving}} - W_{\text{resistance}}$$

on a smooth surface with no driving force: KE + PE is constant

WORKED EXAMPLE

A particle slides from rest down a smooth curved path, falling a vertical height of 3.2 m. Find its speed at the bottom.

1. $\tfrac{1}{2}mv^2 = mg \times 3.2$ M1
2. **$v^2 = 64 \Rightarrow v = 8$ m s^{-1}** A1

WORKED EXAMPLE

A particle of mass 2 kg is projected up a rough slope at 8 m s^{-1}. The slope has sin α = 0.6 and μ = 0.25. Use energy to find how far up the slope it travels.

1. R = 20 × 0.8 = 16 N, F = 0.25 × 16 = 4 N B1
2. ½ × 2 × 64 = 2 × 10 × (0.6d) + 4d M1 A1
3. **64 = 12d + 4d ⇒ d = 4 m** A1

COMMON MISTAKE

Counting friction twice, or adding the GPE gain as work against friction. Write a single equation: KE lost = PE gained + work against friction.

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3 Power

P = Fv

$$P = Fv$$

F is the driving force (not the resultant); P in watts, 1 kW = 1000 W

- **Maximum speed:** acceleration is zero, so driving force = resistance (+ mg sin α uphill).

WORKED EXAMPLE

A car of mass 900 kg has maximum power 18 kW and resistance 600 N. (a) Find its maximum speed on a level road. (b) Find its acceleration when travelling at 20 m s^{-1} at full power. (c) Find its maximum speed up a hill with sin α = 1/20.

1. (a) 18000/v = 600 ⇒ **v = 30 m s^{-1}** M1 A1
2. (b) F = 18000/20 = 900 N; 900 − 600 = 900a ⇒ **a = 0.333 m s^{-2}** M1 A1
3. **(c) 18000/v = 600 + 900 × 10 × 1/20 = 1050 ⇒ v = 17.1 m s^{-1}** M1 A1

COMMON MISTAKE

Using P = ma v or putting the resultant into P = Fv. F in P = Fv is the driving force. The 2024 Paper 4 report flagged this.

LINKING QUESTION

The forces come from Forces and equilibrium and Newton's laws; energy in Physics is in Work, energy and power.

Test yourself — cover the answers first

QUICK CHECK

1. Find the KE of a 4 kg mass moving at 5 m s^{-1}.
2. How much work does the normal reaction do on a horizontal floor?
3. A car's engine has power 30 kW at 15 m s^{-1}. Find the driving force.
4. At maximum speed on level ground, what is the acceleration?
5. A 2 kg mass rises 5 m. Find the PE gained.

EXAM-STYLE

6. A cyclist and bike (80 kg) freewheel down a hill, descending 12 m vertically over 200 m, and speed up from 4 to 12 m s^{-1}. Find the average resistance.
7. A pump lifts 50 kg of water through 6 m each second and gives it speed 4 m s^{-1}. Find the power.
8. A lorry of mass 12 000 kg climbs a hill with sin α = 0.05 at constant speed 15 m s^{-1} against resistance 3000 N. Find its power.

Show answers

1. 50 J
2. none
3. 2000 N
4. zero
5. 100 J
6. PE lost 9600; KE gained 5120; work against resistance 4480 J ⇒ R = 22.4 N
7. (3000 + 400) J per second = 3.4 kW
8. F = 3000 + 6000 = 9000 N; P = 135 kW

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