Forces

Model answers and marking points

GCSE science 6-mark questions

This topic online

1 Priya sets off on her bike along a long, flat, straight road. She pushes on the pedals so that the forward driving force on the bike stays the same the whole time.

Her speed increases quickly at first, then increases more slowly, and after a while it stops changing.

Explain why her speed changes in this way. Refer to the forces acting on Priya and her bike. (6 marks)

Model answer

When Priya first sets off she is moving slowly, so the air resistance on her is small. The forward driving force is much bigger than the backward resistive forces, so there is a large resultant force forwards. A resultant force makes an object accelerate, and since a = F / m, a large resultant force gives a large acceleration, so her speed increases quickly.

As her speed increases, the air resistance gets bigger. The driving force stays the same, so the resultant force forwards gets smaller. This means her acceleration decreases and her speed goes up more slowly.

Eventually the air resistance and friction together are equal to the driving force. The forces are now balanced, so the resultant force is zero. With no resultant force there is no acceleration, so Priya keeps moving at a constant top speed. Up and down, her weight is balanced by the normal contact force from the road the whole time, so she does not accelerate vertically.

Marking points (credit any 6 relevant points, linked in a sensible order)

- At the start she is moving slowly so air resistance is small
- The driving force is much bigger than the resistive forces, so there is a large resultant force forwards
- A resultant force forwards makes her accelerate (a = F / m), so her speed increases quickly
- As her speed increases, air resistance (drag) increases
- The driving force stays the same, so the resultant force gets smaller
- A smaller resultant force gives a smaller acceleration, so her speed rises more slowly
- Eventually air resistance plus friction equals the driving force
- The forces are balanced, so the resultant force is zero
- With zero resultant force there is no acceleration, so she moves at a constant (top) speed
- Weight and the normal contact force from the road are balanced throughout as the road is flat

How it is marked

- 5-6 marks: links each stage of the motion to the size of the resultant force, explains that drag grows with speed and reaches the point where forces balance and acceleration is zero.
- 3-4 marks: explains that air resistance increases with speed and that speed becomes constant when forces balance, but one stage is missing or the link to acceleration is weak.
- 1-2 marks: names some forces or says air resistance increases, with little or no link to how the speed changes.

What loses marks

- Saying the driving force decreases, when the question says it stays the same
- Saying the forces are balanced so she stops, instead of moving at constant speed
- Describing the speed changes without linking them to resultant force and acceleration

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2 A delivery company tested one of its vans on a test track. The table shows the thinking distance and braking distance at different speeds, on a dry road with an alert driver.

Speed in m/s	Thinking distance in m	Braking distance in m
10	7	8
20	14	32
30	21	72

Use the data to describe how thinking distance and braking distance change with speed. Then explain how stopping distance would change if the van was driven on a wet road by a tired driver. (6 marks)

Model answer

Stopping distance is the thinking distance plus the braking distance. Thinking distance is directly proportional to speed. When the speed doubles from 10 m/s to 20 m/s, the thinking distance doubles from 7 m to 14 m, and at 30 m/s it is three times as big, 21 m. This is because during the reaction time the van is still travelling at a constant speed, and distance = speed x time.

Braking distance rises much faster. Doubling the speed from 10 m/s to 20 m/s makes the braking distance four times bigger, from 8 m to 32 m. This is because the kinetic energy depends on the speed squared, so the brakes have to do much more work to stop the van. At 30 m/s the total stopping distance is 93 m, compared with only 15 m at 10 m/s.

A tired driver has a longer reaction time, so the thinking distance would increase. A wet road reduces the friction between the tyres and the road, so the braking distance would increase. Together, these would make the stopping distance much longer at every speed.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Stopping distance = thinking distance + braking distance
- Thinking distance is directly proportional to speed: doubling speed from 10 to 20 m/s doubles it from 7 m to 14 m
- This is because the van travels at a constant speed during the reaction time, and distance = speed x time
- Braking distance increases much faster than speed: doubling speed from 10 to 20 m/s makes it four times bigger (8 m to 32 m)
- This is because kinetic energy depends on speed squared, so much more work must be done by the brakes
- At 30 m/s the stopping distance is 93 m, compared with 15 m at 10 m/s
- A tired driver has a longer reaction time, so the thinking distance increases
- A wet road reduces the friction between the tyres and the road, so the braking distance increases
- Both effects together make the overall stopping distance much longer at every speed

How it is marked

- 5-6 marks: uses figures from the table to show the different patterns for thinking and braking distance, gives a reason for each, and explains the separate effects of tiredness and a wet road.
- 3-4 marks: describes both trends with some use of data and links tiredness and wet roads to longer distances, but with little explanation or without matching each factor to the right part.
- 1-2 marks: makes simple statements such as faster means longer stopping distance, with little use of the data.

What loses marks

- Saying both distances are proportional to speed
- Saying a wet road increases thinking distance or that tiredness increases braking distance
- Describing trends without quoting any numbers from the table

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3 Tomasz hangs weights on a steel spring and on a strip of modelling clay. For each one he adds a load, measures the extension, then removes the load.

Load in N	Spring extension in cm	Clay extension in cm
1	2.0	0.6
2	4.0	1.9
3	6.0	4.1

When each load is removed, the spring goes back to its original length but the clay stays stretched.

Compare how the spring and the clay behave when they are stretched. (6 marks)

Model answer

Both the spring and the clay extend when a load is added, and both extend more as the load increases. However, the pattern is different.

The spring's extension is directly proportional to the load. Every extra 1 N adds exactly 2.0 cm, so it obeys Hooke's law, F = k x e. Its spring constant is 1 N / 2.0 cm = 0.5 N/cm, which is 50 N/m. It has not gone past its limit of proportionality. The clay's extension is not proportional to the load. Each extra newton stretches it more than the one before: the increases are 0.6 cm, 1.3 cm and 2.2 cm.

When the loads are removed, the spring returns to its original length, so it has been elastically deformed. The work done stretching it was stored as elastic potential energy, which is released as it springs back. The clay stays stretched, so it has been inelastically deformed and its change of shape is permanent.

If much larger loads were used, the spring could also pass its limit of proportionality and stop returning to its original length.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Both stretch (extend) when a load is added, and the extension increases as the load increases
- The spring's extension is directly proportional to the load: each extra 1 N adds 2.0 cm
- So the spring obeys Hooke's law, F = k x e, with a spring constant of 0.5 N/cm (50 N/m)
- The clay's extension is not proportional: each extra newton adds more extension than the last (0.6, 1.3, 2.2 cm)
- The spring is elastically deformed: it returns to its original shape when the load is removed
- The clay is inelastically (plastically) deformed: it does not return to its original shape
- The work done stretching the spring is stored as elastic potential energy, which is released when it springs back
- Over this range the spring has not gone past its limit of proportionality
- If the spring were loaded much more, it could pass its limit of proportionality and also stop returning to its original length

How it is marked

- 5-6 marks: makes several point-by-point comparisons using the data, covering proportionality, elastic versus inelastic deformation and a link to Hooke's law or energy.
- 3-4 marks: makes some valid comparisons, such as one returns to shape and one does not, with some use of data, but treats the two materials mostly separately.
- 1-2 marks: describes one material only, or makes a single simple comparison.

What loses marks

- Describing the spring and the clay in two separate paragraphs with no comparison words
- Calling the clay elastic because it stretches
- Saying the clay obeys Hooke's law because its extension increases with load

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4 **Higher tier**

Two ice skaters, Kemi (mass 50 kg) and Oliver (mass 75 kg), stand still facing each other on smooth ice. They put their hands together and push each other apart.

Explain what happens to the motion of the two skaters after the push. Use ideas about forces and momentum in your answer, and include a calculation comparing their speeds. (6 marks)

Model answer

Before the push both skaters are still, so the total momentum of the system is zero. When Kemi pushes on Oliver, Oliver exerts an equal and opposite force on Kemi, by Newton's third law. These forces act for the same length of time, so both skaters gain momentum of the same size but in opposite directions.

The ice is smooth, so friction is very small and there are no outside forces. This means it is a closed system and momentum is conserved. The total momentum after the push must still be zero, so Kemi's momentum and Oliver's momentum are equal in size and opposite in direction. They glide apart in opposite directions.

Momentum = mass x velocity. Since 50 x v(Kemi) = 75 x v(Oliver), Kemi's speed is 75 / 50 = 1.5 times Oliver's speed. For example, if Oliver moves backwards at 2.0 m/s, Kemi moves the other way at 3.0 m/s. The lighter skater moves faster because the same momentum is shared over a smaller mass.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Before the push both are still, so the total momentum is zero
- When Kemi pushes on Oliver, Oliver pushes back on Kemi with an equal and opposite force (Newton's third law)
- The forces act for the same time, so each skater gains momentum of the same size
- The ice is smooth so there is very little friction: the system is closed and momentum is conserved
- Total momentum after the push must still be zero
- So their momenta are equal in size and opposite in direction: they move apart in opposite directions
- Momentum = mass x velocity, so the lighter skater must move faster
- 50 x v(Kemi) = 75 x v(Oliver), so Kemi's speed is 1.5 times Oliver's speed
- For example, if Oliver moves at 2.0 m/s, Kemi moves at 3.0 m/s

How it is marked

- 5-6 marks: uses zero total momentum before and after, equal and opposite forces, and a correct calculation showing Kemi moves 1.5 times as fast in the opposite direction.
- 3-4 marks: explains that they move in opposite directions and the lighter one moves faster, with some reference to momentum, but the calculation or the conservation idea is incomplete.
- 1-2 marks: states that they move apart or that one moves faster, without a correct momentum explanation.

What loses marks

- Saying the heavier skater exerts a bigger force
- Forgetting that momentum is a vector, so the total of zero needs opposite directions
- Getting the speed ratio the wrong way round

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5 A small building firm needs a crane arm to lift loads of up to 2000 N. The load hangs 3.0 m from the pivot. A counterweight is fixed on the other side of the pivot to stop the crane tipping. Two designs are suggested.

Design	Counterweight in N	Distance of counterweight from pivot in m
A	4000	1.0
B	3000	2.0

Evaluate the two designs. Use calculations of moments to support your answer and give a conclusion.

Separate science only

(6 marks)

Model answer

A moment is the force multiplied by its perpendicular distance from the pivot. The biggest load gives a moment of 2000 N x 3.0 m = 6000 Nm. By the principle of moments, the crane balances when the moment of the counterweight equals the moment of the load.

Design A gives a moment of 4000 N x 1.0 m = 4000 Nm. This is less than 6000 Nm, so at full load the crane would tip over towards the load. It could only safely lift about 4000 / 3.0 = 1300 N, which is not enough.

Design B gives 3000 N x 2.0 m = 6000 Nm, which exactly balances the biggest load. It also uses a lighter counterweight, so it needs less material and puts less weight on the ground. A drawback is that the counterweight sits further from the pivot, so the crane needs more space behind it. When nothing is being lifted, the counterweight causes a large unbalanced moment, so the base must be strong enough to resist it.

Overall, design B is the better choice because it is the only design that can balance the full 2000 N load.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Moment = force x perpendicular distance from the pivot
- Maximum moment of the load = 2000 N x 3.0 m = 6000 Nm (anticlockwise, say)
- For balance, the clockwise moment of the counterweight should equal the moment of the load (principle of moments)
- Design A: 4000 N x 1.0 m = 4000 Nm, less than 6000 Nm, so the crane would tip towards the load at full load
- Design A could only safely lift loads up to 4000 / 3.0 = about 1300 N
- Design B: 3000 N x 2.0 m = 6000 Nm, which exactly balances the maximum load
- Design B uses a lighter counterweight, so less material and less weight on the ground
- Design B needs a longer arm behind the pivot, so it needs more space to swing
- With no load, design B's counterweight has a large unbalanced moment, so the base must resist it
- Conclusion: design B is better because only B can balance the full 2000 N load

How it is marked

- 5-6 marks: calculates the load moment and both counterweight moments correctly, uses the principle of moments to judge each design, notes a further advantage or drawback, and gives a justified conclusion.
- 3-4 marks: calculates some moments correctly and compares the designs, with a conclusion that is only partly supported.
- 1-2 marks: makes simple comments about the designs, such as the heavier counterweight is safer, with no correct moment calculations.

What loses marks

- Choosing design A because its counterweight is heavier without calculating moments
- Multiplying by the wrong distance or adding force and distance

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- Giving a conclusion with no reason linked to the calculations

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