Gravity, Mechanics, Circular motion

[76 marks]

A planet has radius R. At a distance h above the surface of the planet the gravitational field strength is g and the gravitational potential is V.

1a. State what is meant by gravitational field strength. *[1 mark]*

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1b. Show that $V = -g(R + h)$. *[2 marks]*

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1c. Draw a graph, on the axes, to show the variation of the gravitational potential V of the planet with height h above the surface of the planet. *[2 marks]*

1d. A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1}. Calculate the gravitational potential at point P, include an appropriate unit for your answer. *[1 mark]*

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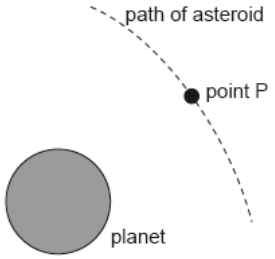
1e. The diagram shows the path of an asteroid as it moves past the planet. *[3 marks]*



When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

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1f. The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the **planet** when the asteroid is at point P. *[2 marks]*

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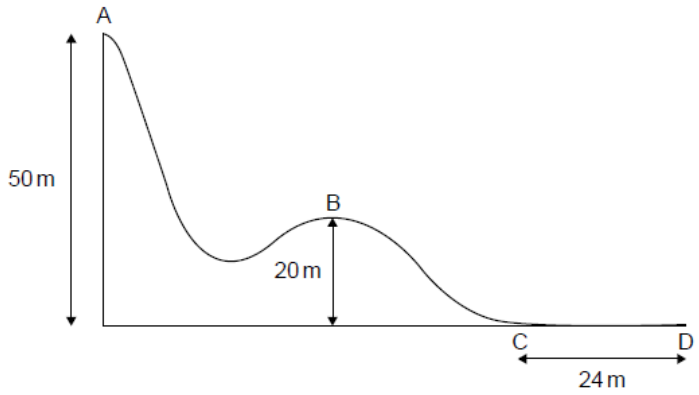
The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

2a. From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. *[2 marks]*
Show that the velocity at B is 12 m s^{-1}.

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2b. Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. *[2 marks]*

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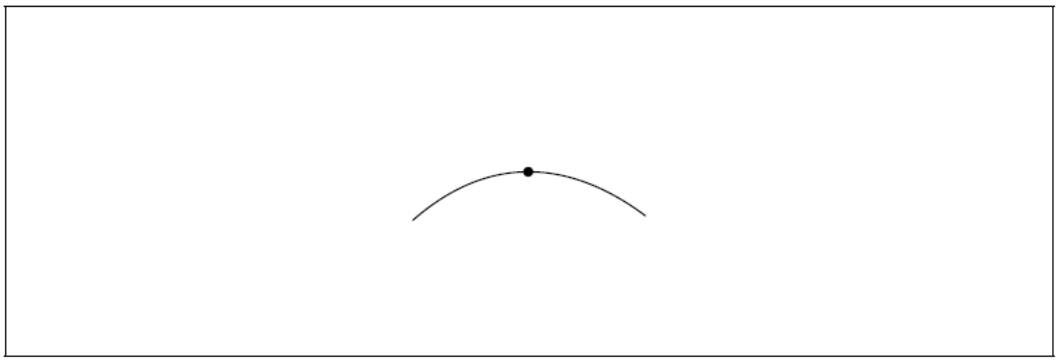
2c. The dot on the following diagram represents the skier as she passes point B. *[2 marks]*
Draw and label the vertical forces acting on the skier.



2d. The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. *[3 marks]*

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2e. The skier reaches point C with a speed of 8.2 m s^{-1}. She stops after a distance of 24 m at point D. *[3 marks]*

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected.

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At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed 9.6 m s^{-1}.

2f. Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. *[2 marks]*

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2g. Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. *[2 marks]*

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3a. (i) Define *gravitational field strength.* *[2 marks]*

(ii) State the SI unit for gravitational field strength.

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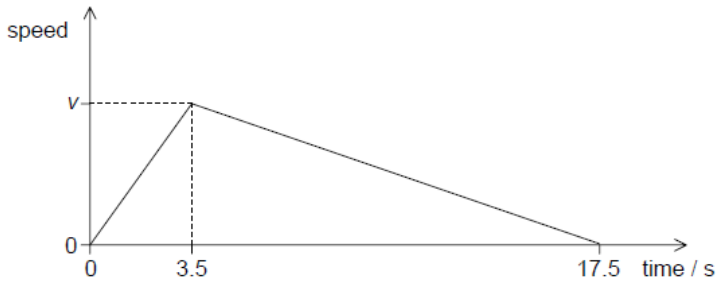
3b. A planet orbits the Sun in a circular orbit with orbital period *T* and orbital radius *R*. The mass of the Sun is *M*. *[4 marks]*

(i) Show that $T = \sqrt{\frac{4\pi^2 R^3}{GM}}$.

(ii) The Earth's orbit around the Sun is almost circular with radius 1.5×10^{11} m. Estimate the mass of the Sun.

Curling is a game played on a horizontal ice surface. A player pushes a large smooth stone across the ice for several seconds and then releases it. The graph shows the variation of speed of the stone with time.



The total distance travelled by the stone in 17.5 s is 29.8 m.

4a. Determine the coefficient of dynamic friction between the stone and the ice during the last 14.0 s of the stone's motion. *[3 marks]*

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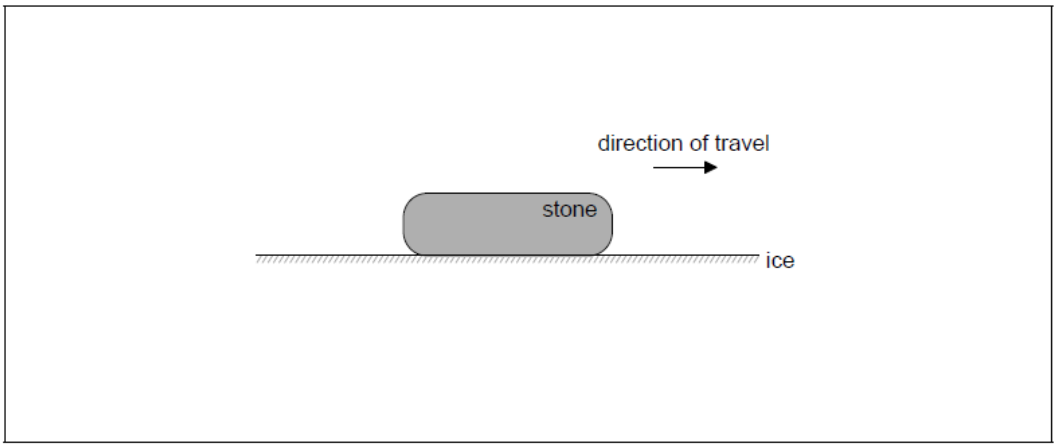
4b. The diagram shows the stone during its motion **after** release. *[3 marks]*



Label the diagram to show the forces acting on the stone. Your answer should include the name, the direction **and** point of application of each force.

This question is in two parts. **Part 1** is about momentum. **Part 2** is about electric point charges.

Part 1 Momentum

5a. State the law of conservation of linear momentum. *[2 marks]*

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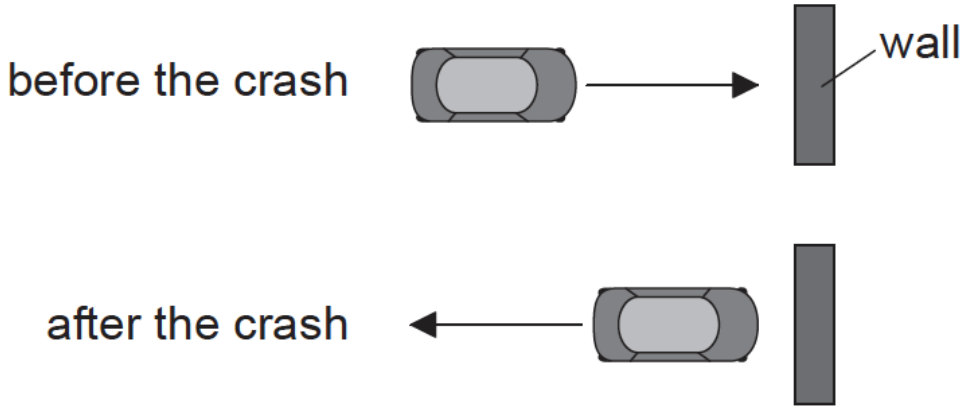
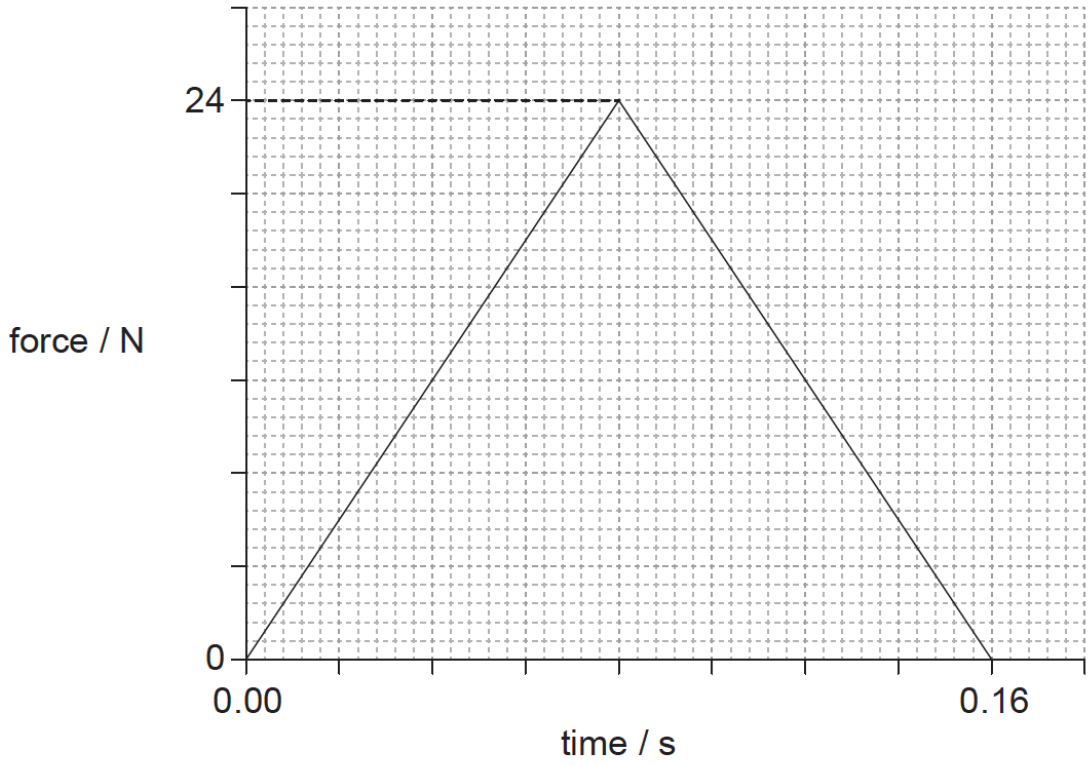
5b. A toy car crashes into a wall and rebounds at right angles to the wall, as shown in the plan view. *[9 marks]*



The graph shows the variation with time of the force acting on the car due to the wall during the collision.

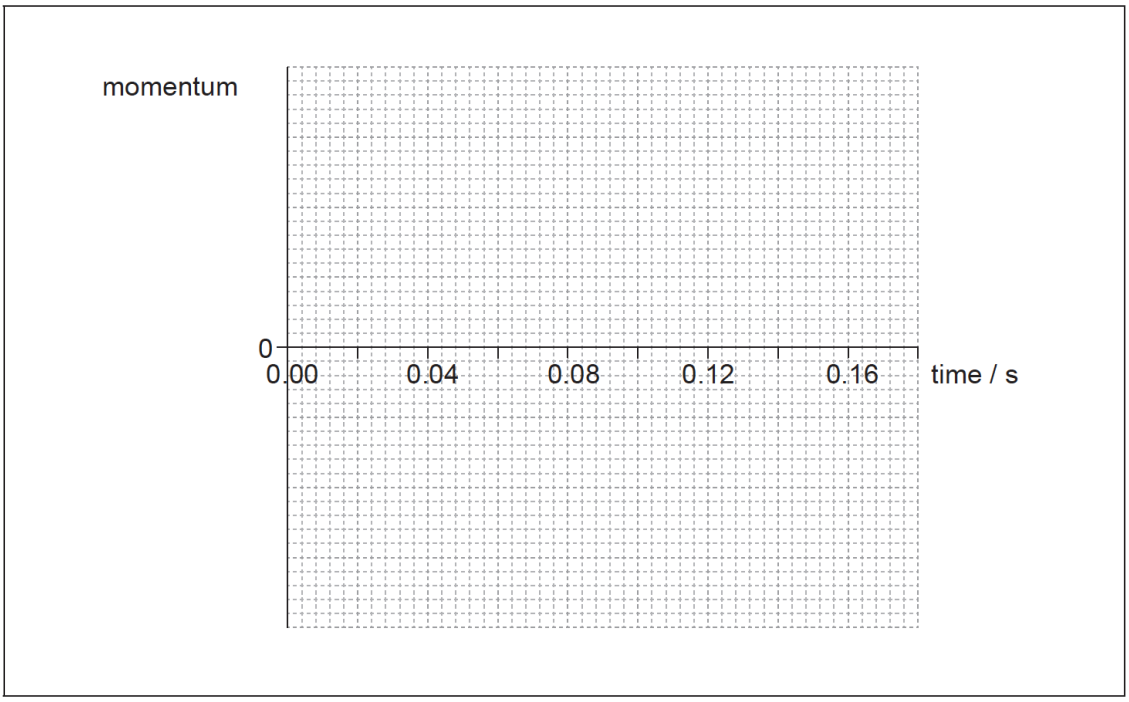


The kinetic energy of the car is unchanged after the collision. The mass of the car is 0.80 kg.

(i) Determine the initial momentum of the car.

(ii) Estimate the average acceleration of the car before it rebounds.

(iii) On the axes, draw a graph to show how the momentum of the car varies during the impact. You are not required to give values on the y-axis.



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5c. Two identical toy cars, A and B are dropped from the same height onto a solid floor without rebounding. Car A is unprotected whilst car B is in a box with protective packaging around the toy. Explain why car B is less likely to be damaged when dropped. *[4 marks]*

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Part 2 Electric point charges

5d. Define *electric field strength* at a point in an electric field. *[2 marks]*

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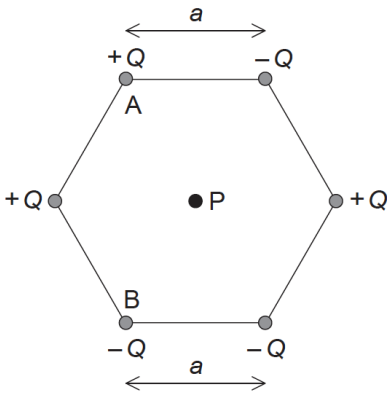
5e. Six point charges of equal magnitude Q are held at the corners of a hexagon with the signs of the charges as shown. Each side of the hexagon has a length a. *[8 marks]*



P is at the centre of the hexagon.

(i) Show, using Coulomb's law, that the magnitude of the electric field strength at point P due to **one** of the point charges is

$$\frac{kQ}{a^2}$$

(ii) On the diagram, draw arrows to represent the direction of the field at P due to point charge A (label this direction A) and point charge B (label this direction B).

(iii) The magnitude of Q is 3.2 μC and length a is 0.15 m. Determine the magnitude and the direction of the electric field strength at point P due to all six charges.

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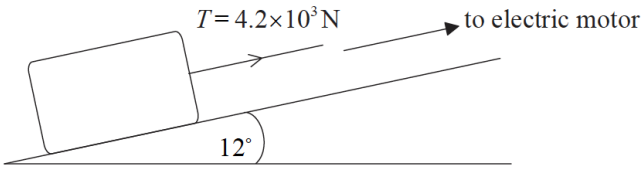
This question is about forces.

A stone block is pulled at constant speed up an incline by a cable attached to an electric motor.



The incline makes an angle of 12° with the horizontal. The weight of the block is 1.5×10^{4} N and the tension T in the cable is 4.2×10^{3} N.

6a. On the diagram draw and label arrows that represent the forces acting on the block. *[2 marks]*

6b. Calculate the magnitude of the friction force acting on the block. *[3 marks]*

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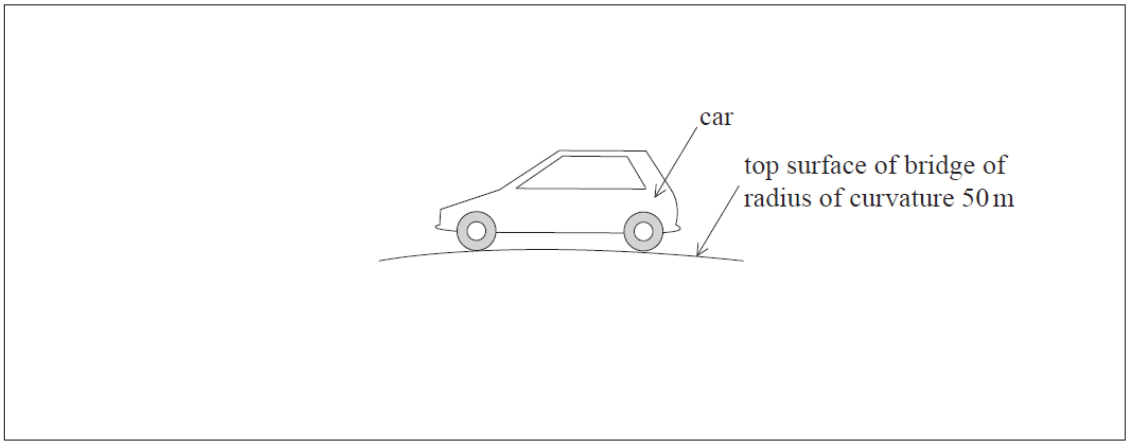
This question is about circular motion.

The diagram shows a car moving at a constant speed over a curved bridge. At the position shown, the top surface of the bridge has a radius of curvature of 50 m.



7a. Explain why the car is accelerating even though it is moving with a constant speed. *[2 marks]*

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7b. On the diagram, draw and label the vertical forces acting on the car in the position shown. *[2 marks]*

7c. Calculate the maximum speed at which the car will stay in contact with the bridge. *[3 marks]*

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