3. Dynamics

3.2 Non-uniform motion

Paper 2

Question Paper

1 The drag force F_D acting on an object falling through air is given by

$$F_D = \frac{1}{2} C\rho A v^2$$

where A is the cross-sectional area of the object,
v is the velocity of the object in the air,
ρ is the density of the air and
C is a constant called the drag coefficient.

(b) Fig. 1.1 shows a sphere falling at terminal velocity in air.

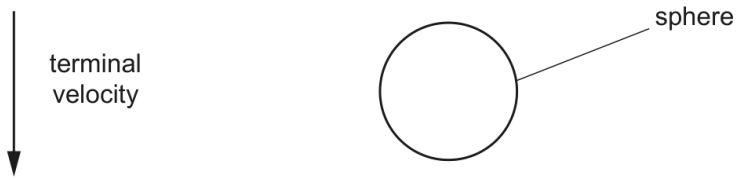


Fig. 1.1

Assume that the upthrust on the sphere is negligible.

On Fig. 1.1, draw and label arrows to show the directions of the **two** forces acting on the sphere. [2]

(c) The mass of the sphere is 49 g.

Calculate the drag force F_D acting on the sphere.

F_D = ... N [2]

(d) The sphere is falling in air at a terminal velocity of 25 in SI base units.
The density of the air is 1.2 in SI base units.
The diameter of the sphere is 0.060 in SI base units.

Use your answer in **(c)** to calculate the drag coefficient C for the sphere.

C = ... [3]

2 A skydiver jumps from an aircraft at time $t = 0$ and falls vertically downwards. The variation with t of her velocity v is shown in Fig. 2.1.

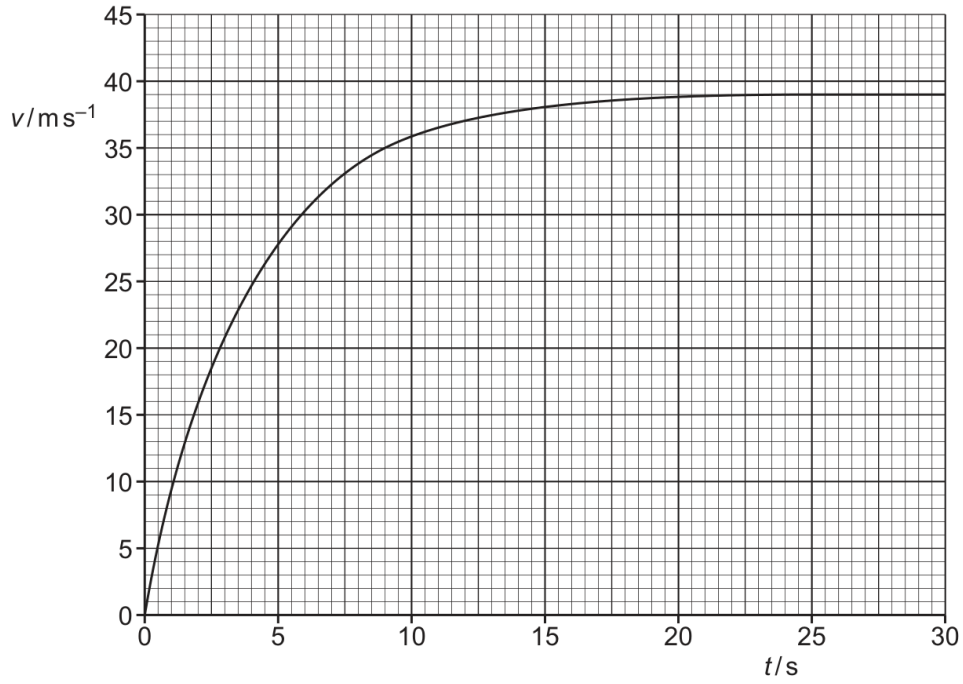


Fig. 2.1

(a) (i) Using Fig. 2.1, state the terminal velocity of the skydiver.

terminal velocity = ...m s^{-1} [1]

(c) The parachute is fully open at time t_2. At a later time t_3 the skydiver reaches a constant velocity of 5.7 m s^{-1}.

(i) Describe and explain the variation with time of the magnitude of her acceleration between time t_2 and time t_3.

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..... [2]

3 A hot-air balloon floats just above the ground. The balloon is stationary and is held in place by a vertical rope, as shown in Fig. 2.1.

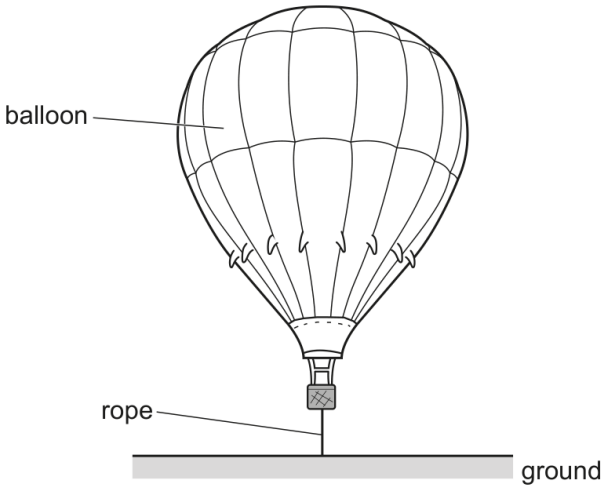


Fig. 2.1

The balloon has a weight W of 3.39×10^4 N. The tension T in the rope is 4.00×10^2 N.
Upthrust U acts on the balloon.
The density of the surrounding air is $1.23\,\text{kg}\,\text{m}^{-3}$.

(b) The balloon is stationary at a height of 500 m above the ground. A tennis ball is released from rest and falls vertically from the balloon.

A passenger in the balloon uses the equation $v^2 = u^2 + 2as$ to calculate that the ball will be travelling at a speed of approximately $100\,\text{m}\,\text{s}^{-1}$ when it hits the ground.

Explain why the actual speed of the ball will be much lower than $100\,\text{m}\,\text{s}^{-1}$ when it hits the ground.

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..... [3]

4 A high-altitude balloon is stationary in still air. A solid sphere is suspended from the balloon by a string, as shown in Fig. 2.1.

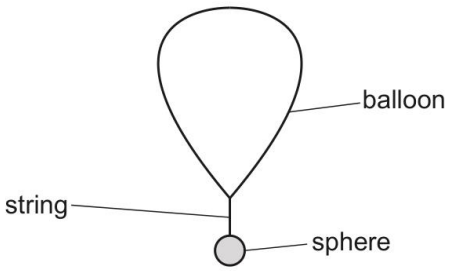


Fig. 2.1 (not to scale)

The volume of the balloon is 7.5 m^3. The total weight of the balloon, string and sphere is 65 N. The upthrust acting on the string and sphere is negligible.

(b) The string breaks, releasing the sphere.

(ii) State and explain the variation, if any, in the magnitude of the acceleration of the sphere when it is moving downwards **before** it reaches terminal (constant) velocity.

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..... [3]

5 **(c)** In practice, the planet in **(b)** does have an atmosphere that causes a viscous force to act on the moving rock.

State and explain the variation, if any, in the resultant force acting on the rock as it moves vertically upwards.

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..... [2]

6 A steel ball is projected horizontally from the top of a table, as shown in Fig. 2.1.

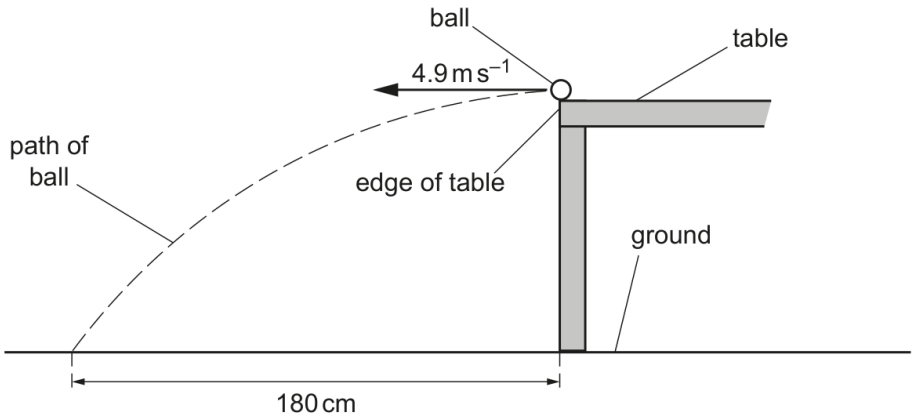


Fig. 2.1 (not to scale)

The ball is projected horizontally at a speed of $4.9\,m\,s^{-1}$. The ball lands on the ground a horizontal distance of 180 cm from the edge of the table.

Assume that air resistance is negligible.

(c) The steel ball is replaced by a polystyrene ball of the same diameter but of much lower mass. The spring is given compression x_0 and is then released.

Air resistance on this ball is **not** negligible after it leaves the spring.

Explain:

(ii) why this ball takes a longer time to reach the ground than the steel ball.

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7 A person uses a trolley to move suitcases at an airport. The total mass of the trolley and suitcases is 72 kg.

(c) The angle of the slope in **(b)** is constant. The frictional forces acting on the wheels of the moving trolley are also constant.

Explain why, in practice, it is incorrect to assume that the total resistive force opposing the motion of the trolley and suitcases is constant as the trolley moves between X and Y.

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..... [1]

8 A ball is thrown vertically downwards to the ground, as illustrated in Fig. 2.1.

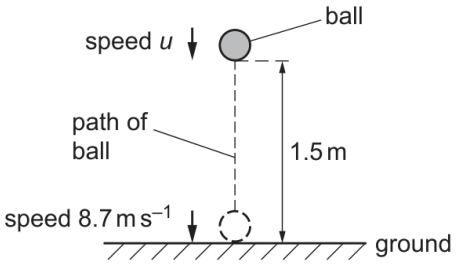


Fig. 2.1

The ball is thrown with speed u from a height of 1.5 m. The ball then hits the ground with speed 8.7 m s^{-1}. Assume that air resistance is negligible.

(e) In practice, air resistance is not negligible.

State and explain the variation, if any, with time t of the gradient of the graph in **(d)** when air resistance is not negligible.

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9 **(c)** Another parcel is accidentally released from rest by a different aircraft when it is hovering at a great height above the ground. Air resistance is now significant.

(i) On Fig. 2.2, draw arrows to show the directions of the forces acting on the parcel as it falls vertically downwards. Label each arrow with the name of the force.

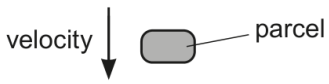


Fig. 2.2

[2]

(ii) By considering the forces acting on the parcel, state and explain the variation, if any, of the acceleration of the parcel as it moves downwards before it reaches constant (terminal) speed.

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..... [3]

10 **(c)** The ball in **(b)** is dropped at time $t = 0$ and hits the ground at time $t = T$. The acceleration of free fall is g.

On Fig. 3.1, sketch a line to show the variation of the acceleration a of the ball with time t from time $t = 0$ to $t = T$.

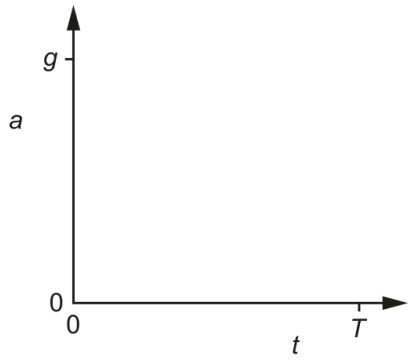


Fig. 3.1

[2]

11 **(c)** The cylinder in **(b)** is released from the string at time $t = 4.0\,s$. The cylinder falls, from rest, vertically downwards through the water. Assume that the upthrust acting on the cylinder remains constant as it falls.

(i) State the name of the force that acts on the cylinder when it is moving and does not act on the cylinder when it is stationary.

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(ii) State and explain the variation, if any, of the acceleration of the cylinder as it falls downwards through the water.

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..... [2]

12 **(c)** The ball in **(b)** leaves the toy at point A and moves vertically upwards through the air. Point B is the position of the ball when it is at maximum height *h* above point A, as illustrated in Fig. 3.2.

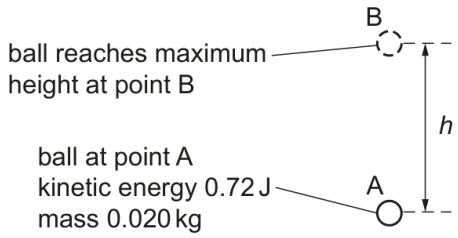


Fig. 3.2 (not to scale)

The gravitational potential energy of the ball increases by 0.60 J as it moves from A to B.

(iii) When there is air resistance, the ball takes time *T* to move from A to B.

State and explain whether the time taken for the ball to move from A to its maximum height will be more than, less than or equal to time *T* if there is **no** air resistance.

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..... [1]

13 **(d)** Two types of force, X and Y, can act on an oil drop when it is in air, but cannot act on an oil drop when it is in a vacuum. Force X can act on an oil drop when it is stationary or when it is moving. Force Y can only act on an oil drop when it is moving.

State the name of:

(ii) force Y.

.....[1]

14 **(b)** A steel ball of diameter 0.080 m is released from rest and falls vertically in air, as illustrated in Fig. 2.1.

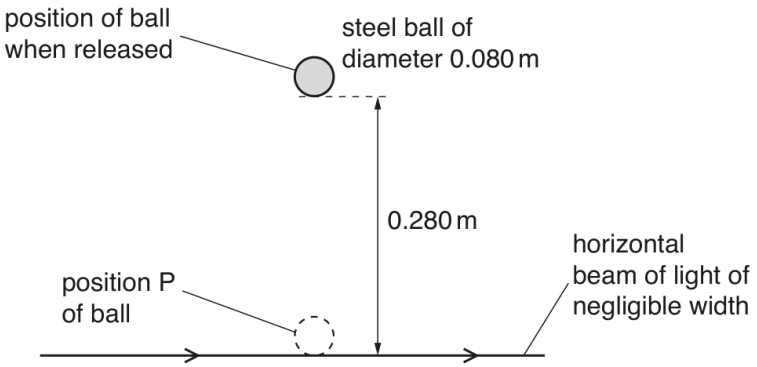


Fig. 2.1 (not to scale)

A horizontal beam of light of negligible width is a vertical distance of 0.280 m below the bottom of the ball when it is released. The ball falls through and breaks the beam of light.

(i) Explain why the force due to air resistance acting on the ball may be neglected when calculating the time taken for the ball to reach the beam of light.

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(c) A different ball is released from the same position as the steel ball in **(b)**. This ball has the same diameter but a much lower density. For this ball, the force due to air resistance cannot be neglected as the ball falls.

State and explain the change, if any, to the time interval during which the beam of light is broken by the ball.

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..... [2]

15 **(a)** A sphere in a liquid accelerates vertically downwards from rest. For the viscous force acting on the moving sphere, state:

(i) the direction

..... [1]

(ii) the variation, if any, in the magnitude.

..... [1]

16 A golfer strikes a ball so that it leaves horizontal ground with a velocity of $6.0\,m\,s^{-1}$ at an angle θ to the horizontal, as illustrated in Fig. 1.1.

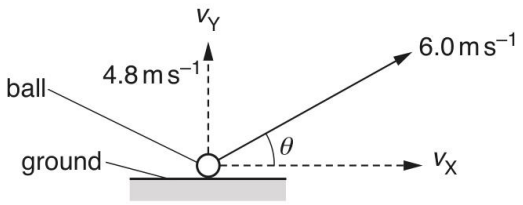


Fig. 1.1 (not to scale)

The magnitude of the initial vertical component v_Y of the velocity is $4.8\,m\,s^{-1}$.
Assume that air resistance is negligible.

(e) In practice, significant air resistance acts on the ball. Explain why the actual time taken for the ball to reach maximum height is less than the time calculated when air resistance is assumed to be negligible.

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