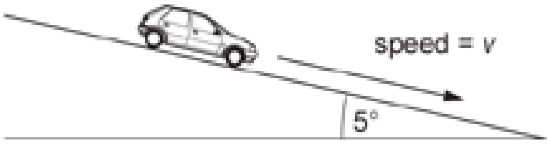
1(a). A car of weight 9300 N is moving at speed *v*. The total resistive force, *F*, acting against the motion of the car is given by the formula

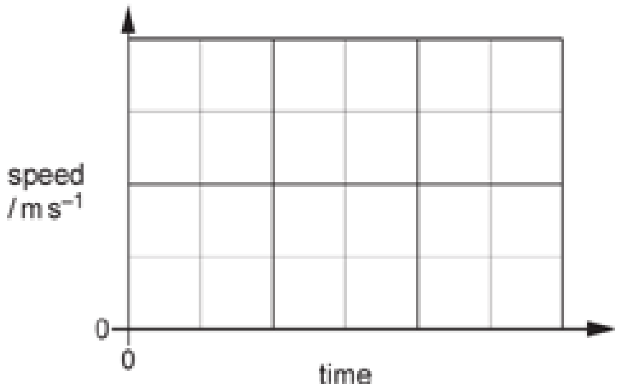
$F = kv^2$

where *k* is a constant.

The car is allowed to roll from rest down a slope of 5° to the horizontal. The engine of the car is not switched on. The car reaches a maximum speed of 30 m s^{-1}.



i. Sketch a graph on the axes below to show how the speed of the car changes over time. Add a suitable value to the vertical axis.



[2]

ii. Explain why the car reaches a maximum speed.

[2]

iii. Show that the value of *k* in the equation $F = kv^2$ is about 1.

[3]

(b). The car is now moving along a straight, level track. The engine of the car delivers a maximum power of 75 kW.

Calculate the maximum speed of the car.

maximum speed of car = ... m s^{-1} **[3]**

(c). Changes are made to the engine of the car so that it can produce double the original maximum power.

Explain why the maximum speed of the modified car is **not** doubled.

[2]

2. A student investigates the motion of falling objects.

The student releases a feather in air and allows it to fall.

The feather reaches a terminal velocity.

Explain this observation

[3]

3(a). A cloud is made up of droplets of water falling at terminal velocity.

Describe and explain the motion of an object falling at terminal velocity.

[3]

(b).

i. The terminal velocity v of a small sphere of density ρ_s and radius r falling through a fluid of density ρ_f is given by the formula:

$$v = \frac{2gr^2(\rho_s - \rho_f)}{9\eta}$$

where η is a constant for the fluid and g is the acceleration of free fall.

Water droplets of rain fall to the ground whereas water droplets in mist appear to float.

Use the formula above to suggest why.

[2]

ii. A student models water droplets falling through air using small solid spheres in a liquid.

The table shows properties of the materials available to the student.

Material	**Solid density, ρ_s / kg m^{-3}**	**Liquid density, ρ_f / kg m^{-3}**	**Approximate value of η / 10^{-3} kg m^{-1} s^{-1}**
Water (liquid)		1000	1
Sunflower oil (liquid)		920	50
Steel (solid sphere)	7 800		
Lead (solid sphere)	11 300		

Describe an experiment to verify the expression given in **(i)** as accurately as possible. As part of your answer, estimate the **lowest** terminal velocity if the student uses a solid sphere of diameter = 1 mm.

[6]

4. A student is investigating the motion of small metal balls falling from rest vertically through a liquid.

The student drops a ball of diameter *d* from rest at the surface of the liquid. The student determines the terminal velocity *v* of the ball in the liquid.

It is suggested that the relationship between the terminal velocity *v* and the diameter *d* is

$$v = \frac{(\rho - \sigma)gd^2}{18K}$$

where
ρ is the density of the metal
σ is the density of the liquid
g is the acceleration of free fall = 9.81 ms^{-2} and
K is a constant.

Describe, with the aid of a suitable diagram:

- how an experiment can be safely conducted to test this relationship between *v* and *d*, and
- how the data can be analysed to determine *K*.

Diagram

[6]

5(a). A soil scientist investigates how different types of soil particles fall through water.

A soil scientist measures the terminal velocity of soil particles in water. He fills a tall glass cylinder with water and places a small sample of soil into the water. He uses a video camera, with a known frame rate, to measure the time taken for a particle in the soil to fall a measured distance.

The scientist records the total distance that the particle falls every 0.1 s.

Time / s	Total distance / cm
0.0	0.0
0.1	1.2
0.2	3.5
0.3	6.2
0.4	8.9
0.5	11.6

Use the information in the table to explain why using a video camera to measure the time is more appropriate than a stopwatch in this investigation.

[2]

(b). Suggest one other precaution that the scientist should take to ensure that the terminal velocity is determined as accurately as possible.

[1]

(c). Use the scientist's results to show that the terminal velocity is about 0.3 m s^{-1}.

[2]

(d). Soil scientists classify soil samples according to the diameter of the particles, as shown in the table below.

Soil sample	Range of diameter / mm
clay	< 0.002
silt	0.002 − 0.05
sand	0.05 − 2.0
gravel	>2.0

The terminal velocity of a spherical particle of radius *r*, falling in water is given by

$$v = \frac{2r^2 g(\rho_s - \rho_w)}{9\eta}$$

ρ_w = density of water = 1000 kg m^{-3}
ρ_s = density of soil particle = 1500 kg m^{-3}
η = constant for water = 1.0 × 10^{-3} Pas
g = acceleration of free fall = 9.81 ms^{-2}

Determine which soil sample was used by the scientist in this investigation.

soil sample = ... **[3]**

6(a). A tent is secured by 3 ropes along each of its long sides, as shown in **Fig. 18. 1**.

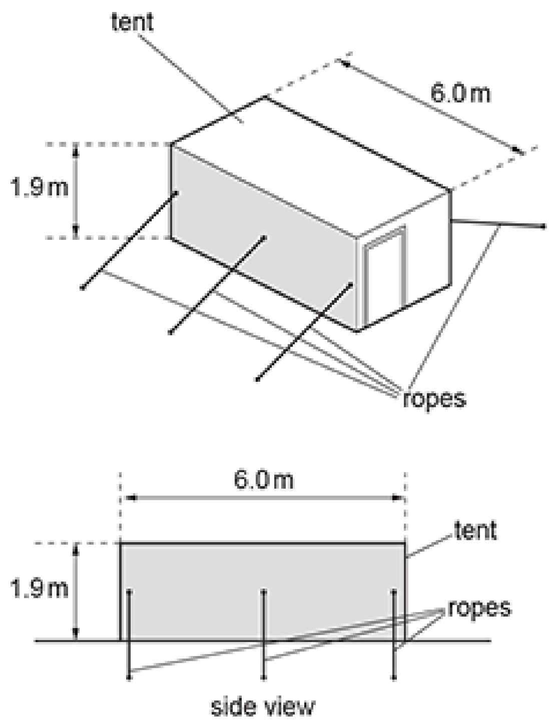


Fig. 18.1

Wind of speed 12 ms^{-1} blows at right angles to the **shaded** side of the tent for 3.0 s. The density of air is 1.2 kg m^{-3}.

i. Show that the mass of air which hits the tent in this time is about 490 kg.

[3]

ii. All of the air incident on the shaded side of the tent is deflected at 90° to the original direction as shown in **Fig. 18. 2**.

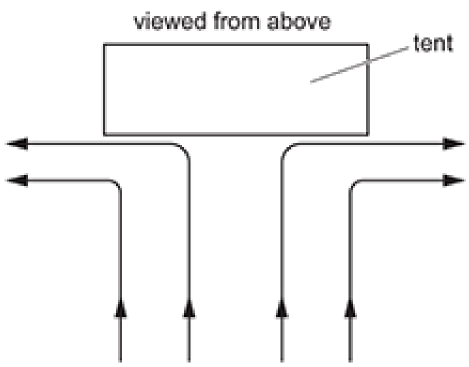


Fig. 18.2

Use the information given in **(a)(i)** to calculate the magnitude of the force *F* exerted by the wind on the shaded side of the tent.

F = ... N **[2]**

(b). *When the wind speed exceeds 20 ms^{-1} the ropes securing the tent break.

Describe, and explain in terms of forces, how the ropes and the shape of the tent could be modified to withstand wind speed exceeding 40 ms^{-1}.

[6]

7(a). A student investigates the motion of a steel ball in oil in a laboratory.

The radius *r* of the ball is 8.1 mm.

The student uses a measuring cylinder and a digital balance to determine the density of the oil.
The student records the following measurements:

- mass of empty measuring cylinder = 96 g
- volume of oil added to measuring cylinder = 87 cm^3
- total mass of measuring cylinder and oil = 169 g

Show that the density of the oil is about 840 kg m^{-3}.

[2]

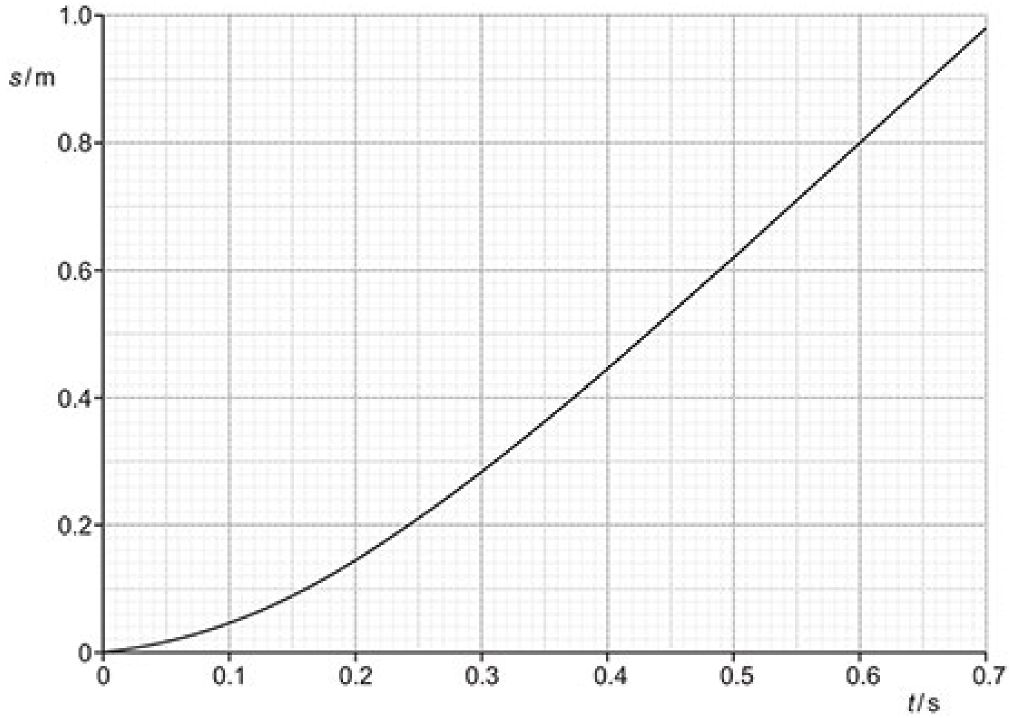
(b). The steel ball is submerged in the oil.

Show that the upthrust acting on the steel ball is 1.8×10^{-2} N.

[2]

(c). The student fills a long tube with the oil.
The student drops the steel ball from rest at the surface of the oil at time $t = 0$.
The displacement s of the ball is measured from the surface of the oil.

The graph shows the displacement s against time t for the steel ball from the instant it enters the oil.



i. The terminal velocity v of the steel ball is 1.8 m s^{-1}.

Describe and explain how this can be determined from the graph.

____

____

____

____ **[3]**

ii. Use the graph to calculate the velocity *u* of the steel ball at time *t* = 0.20 s.

u = ... m s^{-1} **[2]**

(d). The mass of the steel ball is 17 g.

The drag *F* acting on the steel ball falling through the oil is given by the equation $F = 6\pi\eta rv$

where η is a constant for the oil, *r* is the radius of the steel ball and *v* is the speed of the steel ball through the oil.

At $v = 1.8$ ms^{-1}, the force *F* is equal to the **difference** between the weight of the steel ball and the upthrust acting on the steel ball.

Calculate η.

Include an appropriate unit.

η = ... unit .... **[3]**

END OF QUESTION PAPER