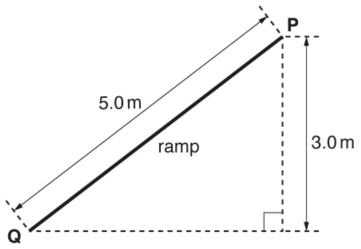
Work Energy and Power

1. Define the *work done* by a force.

[1]

2. An object is at the top of a ramp at point **P**. The gravitational potential energy of the object at **P** is 100 J. The object is released from rest at **P**. It travels down the ramp. The kinetic energy of the object at the bottom of the ramp at point **Q** is 60 J.



What is the average resistive force acting on the object as it travels down the ramp?

A 8.0 N

B 10 N

C 12 N

D 20 N

Your answer **[1]**

3. A sodium lamp is rated at 40 W. About 12% of the power is emitted as yellow light of wavelength 5.9×10^{-7} m.

How many photons of yellow light are emitted per second from this lamp?

A. $1.4 \times 10^{19}\ s^{-1}$
B. $1.2 \times 10^{20}\ s^{-1}$
C. $3.6 \times 10^{27}\ s^{-1}$
D. $1.0 \times 10^{40}\ s^{-1}$

Your answer

[1]

4. The de Broglie wavelength of a proton is 160 pm.

The kinetic energy of this proton is doubled.

What is the de Broglie wavelength of the proton now?

A 80 pm

B 110 pm

C 230 pm

D 320 pm

Your answer **[1]**

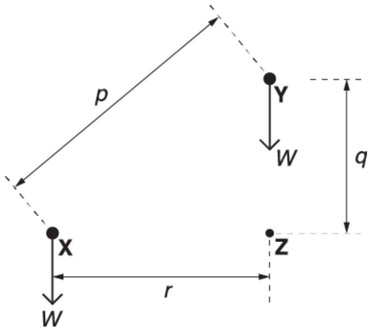
5. An object of mass 0.12 kg is lifted through a height of 0.60 m at a constant speed 3.0 m s^{-1}.

What is the minimum power needed to lift the object?

A 0.36 W
B 0.54 W
C 3.5 W
D 4.1 W

Your answer ☐ **[1]**

6. A crane is used to lift a load directly from point **X** to point **Y**.



The weight of the load is *W.*
p, q and *r* are distances between points **X**, **Y** and **Z** as shown in the diagram.

What is the work done against the weight?

A *Wp*
B *Wq*
C *Wr*
D *W(q + r)*

Your answer ☐

[1]

7. An object is travelling along a horizontal surface with kinetic energy 16J and speed *v*.
A force acts against the motion of the object. The work done by this force is 4.0J.

What is the final speed of the object in terms of *v*?

A 0.75*v*
B 0.87*v*
C 1.1*v*
D 1.3*v*

Your answer ☐ **[1]**

8. The watt is the SI unit for power.

Which is the correct definition for the watt? A watt is ....

A the rate of work done.
B the work done per second.
C a joule per second.
D a joule per unit time.

Your answer ☐

[1]

9. A 6.0 N force is applied to a spring which extends vertically downwards by a distance 5.0 cm. The force is suddenly removed so that the spring flies vertically upwards. The spring has mass 9.0 g.

What is the maximum height reached by the spring?

A. 0.085 m
B. 0.17 m
C. 1.7 m
D. 3.4 m

Your answer ☐

[1]

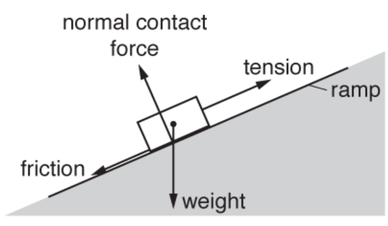
10. The kilogram, metre and second are SI base units.

Determine the unit for *power* in terms of these SI units.

unit for power = ... **[1]**

11. A block moves at **constant** speed up a ramp.

The diagram below shows all the forces acting on the block.



Which force does no work on, or against, the object as it travels up the ramp?

A weight
B friction
C tension
D normal contact force

Your answer ☐ **[1]**

12. The intensity of a laser beam is 2.0 W m^{-2}. The cross-sectional area of the beam is 1.0 mm^2.

What is the energy delivered by the laser beam in a time of 100 s?

A 2.0×10^{-6} J

B 2.0×10^{-4} J

C 2.0×10^{-1} J

D 2.0×10^{1} J

Your answer [1]

13 (a). A spring of negligible mass and natural length 20 cm has a 0.60 kg mass attached. The mass-spring system oscillates for a short time and then settles in an equilibrium position (Fig. 21).

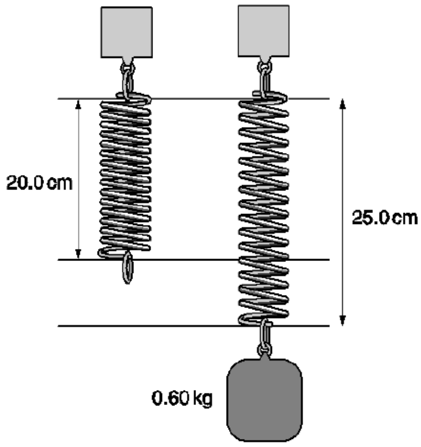


Fig. 21

Calculate the change in gravitational potential energy E_p of the mass when it finally comes to rest in its equilibrium position with length of 25.0 cm.

E_p = ... J **[1]**

(b). Show that the elastic potential energy in the stretched spring in its equilibrium position is 0.15 J.

[2]

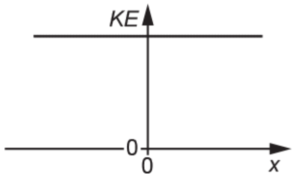
(c). A student compares the values calculated in **(a)** and **(b)** and concludes that "energy has not been conserved". State the energy transfers that occur as the spring oscillates and comes to rest and explain why the student is wrong.

[3]

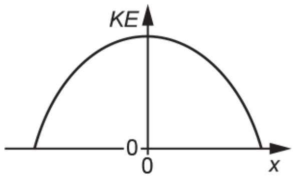
14. An oscillator is executing simple harmonic motion.

Which graph of kinetic energy *KE* against displacement *x* is correct for this oscillator?

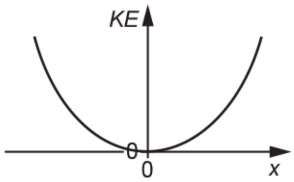
A



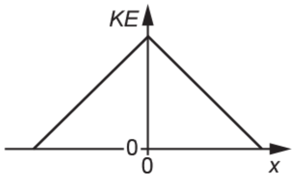
B



C

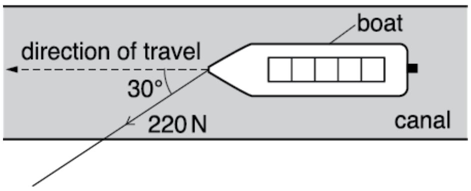


D



Your answer [1]

15. A canal boat is pulled by a single rope.
The tension in the rope is 220 N. The rope makes an angle of 30° to the direction of travel.
The speed of the boat is 1.8 m s^{-1}.



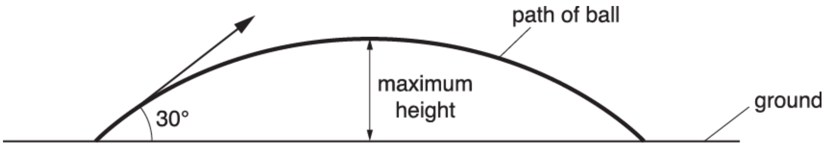
What is the work done per second by the 220 N force in the direction of travel?

A 61 J s^{-1}
B 200 J s^{-1}
C 340 J s^{-1}
D 400 J s^{-1}

Your answer

[1]

16. A ball is thrown at an angle of 30° to the horizontal. The initial kinetic energy of the ball is *K*. Air resistance has negligible effect on the motion of the ball.



What is the kinetic energy of the ball at the maximum height?

A 0
B 0.25 *K*
C 0.75 *K*
D 0.87 *K*

Your answer ☐

[1]

17. A ball is thrown vertically upwards with a speed of 5.0 m s^{-1}.
Ignore air resistance.

What is the maximum height reached by the ball?

A 0.3 m
B 0.8 m
C 1.3 m
D 2.5 m

Your answer ☐

[1]

18. An athlete is running at a speed of about 5 m s^{-1}.

What is a reasonable estimate for the kinetic energy of this athlete?

A 12 J
B 100 J
C 900 J
D 800 000 J

Your answer ☐ **[1]**

19. A student uses a motion sensor to investigate the motion of a trolley crashing into a soft barrier. Fig. 21 shows the displacement *s* against time *t* graph for the trolley in one experiment.

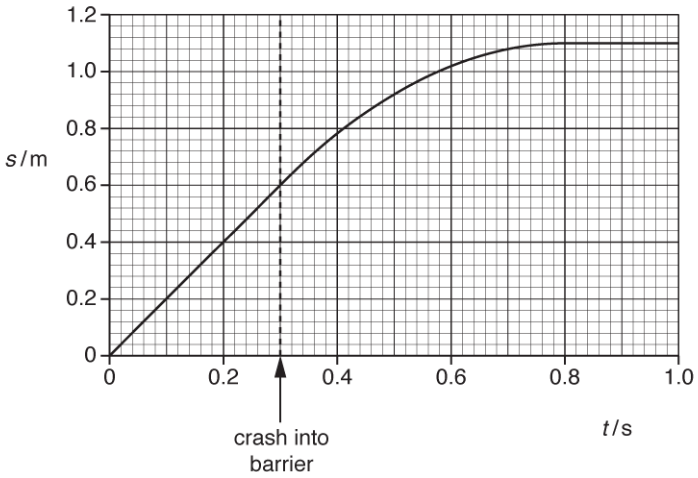


Fig. 21

Calculate the initial kinetic energy of the trolley.

kinetic energy = ... J **[1]**

20. A sodium lamp is rated at 40 W.
12% of the power is emitted as yellow light of wavelength 5.9×10^{-7} m.

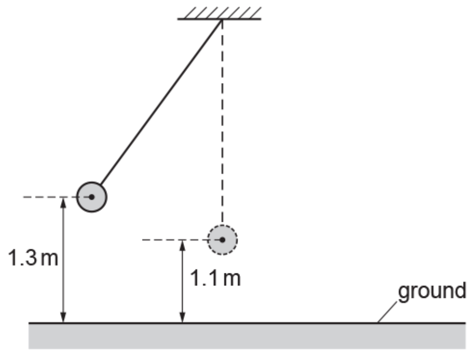
How many photons of yellow light are emitted per second from this lamp?

A. 1.4×10^{19}
B. 1.2×10^{20}
C. 3.6×10^{27}
D. 1.0×10^{40}

Your answer ☐

[1]

21. A pendulum bob is oscillating in a vacuum.
The maximum height of the bob from the ground is 1.3 m and its minimum height is 1.1 m.

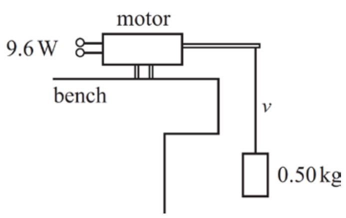


What is the maximum speed of the pendulum bob?

A 2.0 m s^{-1}
B 3.9 m s^{-1}
C 5.1 m s^{-1}
D 26 m s^{-1}

Your answer **[1]**

22. A small electric motor is 20% efficient. Its input power is 9.6 W when it is lifting a mass of 0.50 kg at a steady speed *v*.



What is the value of *v*?

A. 0.39 m s^{-1}
B. 2.0 m s^{-1}
C. 2.8 m s^{-1}
D. 3.8 m s^{-1}

Your answer

[1]

23. A proton has kinetic energy 8.00×10^{-17} J.

Which is the correct expression for the de Broglie wavelength *λ* of the proton?

A $\lambda = \dfrac{6.63 \times 10^{-34}}{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}$

B $\lambda = \dfrac{6.63 \times 10^{-34}}{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}$

C $\lambda = \dfrac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}}$

D $\lambda = \dfrac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}}$

Your answer ☐ **[1]**

24. The frictional force acting on an object falling vertically through water is directly proportional to its speed squared.

What is the correct relationship between *P*, the rate of work done against the frictional force, and the speed *v* of the object?

A $P \propto v^{-1}$
B $P \propto v$
C $P \propto v^{2}$
D $P \propto v^{3}$

Your answer ☐ **[1]**

25. An electron with initial kinetic energy of 100 eV and initial speed of 5.9×10^{6} m s^{-1} is **accelerated** through a potential difference of 250 V.

What is the final speed of this electron?

A 5.9×10^{6} m s^{-1}
B 7.3×10^{6} m s^{-1}
C 9.4×10^{6} m s^{-1}
D 1.1×10^{7} m s^{-1}

Your answer ☐ **[1]**

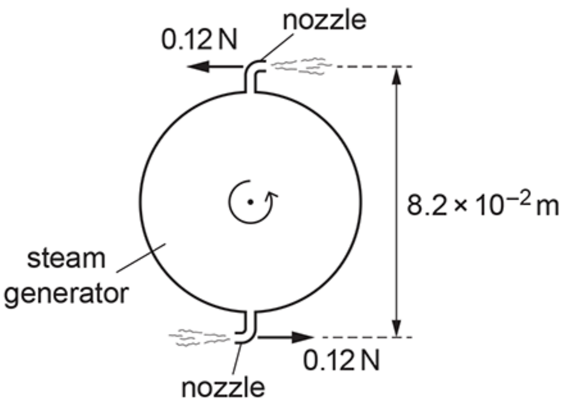
26. A force of 12 N moves an object at an angle θ to the force. The object travels 9.6 m and the work done by the force is 52 J.

What is the angle θ ?

A 1.1°
B 27°
C 63°
D 90°

Your answer [1]

27. The diagram below shows a rotating steam generator.



The steam ejected from the nozzles provides a couple. The force at each nozzle is 0.12 N. The perpendicular distance between the nozzles is 8.2×10^{-2} m.

What is the work done by the forces as the steam generator completes one revolution?

A 0 J
B 9.8×10^{-3} J
C 3.1×10^{-2} J
D 6.2×10^{-2} J

Your answer [1]

28. A trolley of mass 1.0 kg is moving on a horizontal surface at a constant velocity of 2.0 ms^{-1}. A force of 3.0 N is applied to the trolley in the opposite direction to its motion for a time of 1.5 s and then the force is removed.

What is the magnitude of the final momentum of the trolley?

A 2.0 kg ms^{-1}
B 2.5 kg ms^{-1}
C 4.5 kg ms^{-1}
D 6.5 kg ms^{-1}

Your answer [ ] **[1]**

29. A plastic kettle is filled with 0.60 kg of water at a temperature of 20°C.
A 2.2 kW electric heater is used to heat the water for a time of 4.0 minutes.

Calculate the total energy supplied by the heater during the time of 4.0 minutes.

energy = ... J **[2]**

30 (a). Fig. 16 shows a hydraulic jack used to lift a car which has a mass of 1200 kg. A mechanic exerts a downwards force of 400 N on the handle of the jack, moving it 80.0 cm downwards. As he moves the handle, the car rises 2.0 cm.

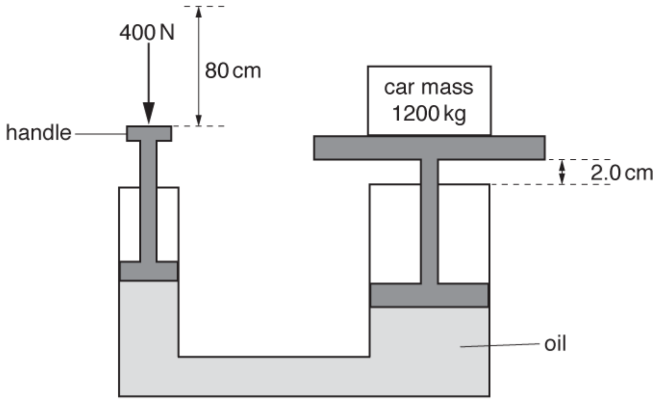


Fig. 16

Calculate the work done by the 400 N force exerted by the mechanic.

work done = ... J **[2]**

(b). Calculate the ratio

$$\frac{\text{speed of handle moving down}}{\text{speed of car moving up}}.$$

ratio = ... **[2]**

(c). Calculate the useful work done on the car and hence the percentage efficiency of the jack.

efficiency = ... % **[2]**

31. An archer fires an arrow towards a target as shown below.

The diagram is **not** drawn to scale.

The centre of the target is at the same height as the initial position of the arrow.
The target is a distance of 90 m from the arrow.
The arrow has an initial velocity of 68 m s^{-1} and is fired at an angle of 11° to the horizontal.

Air resistance has negligible effect on the motion of the arrow.

Describe how the kinetic energy of the arrow changes during its journey from when it is fired until it reaches its maximum height.

[2]

32. Wind turbines convert the kinetic energy of the wind into electrical energy.
Fig. 18 shows a wind turbine.

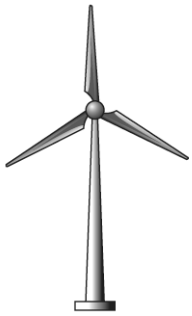


Fig. 18

When the wind speed is 8.0 m s^{-1}, the kinetic energy of the air incident at the turbine per second is 1.2 MJ s^{-1}.
Calculate the mass of the air incident at the turbine per second.

mass per second = kg s^{-1} **[2]**

33. A crane raises a mass of 3000 kg through a height of 12 m in 40 seconds with an efficiency of 60%.

Calculate the total input energy to the crane.

total input energy .... J **[2]**

34.

Use the equations for momentum and kinetic energy to derive an expression for the kinetic energy E_k of a particle in terms of its momentum p and mass m.

[2]

35. Fig. 22.1 shows the circular track of a positron moving in a uniform magnetic field.

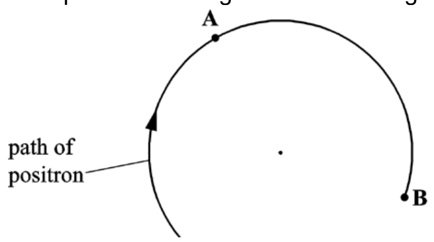


Fig. 22.1

The magnetic field is perpendicular to the plane of **Fig. 22.1**.
The speed of the positron is 5.0×10^7 m s^{-1} and the radius of the track is 0.018 m.

State the direction of the force acting on the positron when at point **A** and explain why this force does **not** change the speed of the positron.

[2]

36 (a). Fig. 4.1 shows an arrangement used by a student to determine the acceleration of free fall.

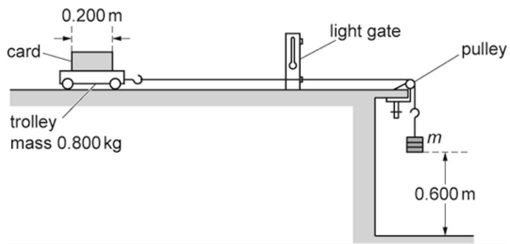


Fig. 4.1

A trolley is attached to a variable mass *m* by a string which passes over a pulley.

The mass *m* is released from rest and falls through a fixed height of 0.600 m accelerating the trolley of mass 0.800 kg. When the mass *m* hits the floor, the trolley then continues to move at a **constant** velocity *v*.

This constant velocity *v* is determined by measuring the time *t* for the card of length 0.200 m to pass fully through a light gate connected to a timer.

Frictional forces on the trolley and the falling mass *m* are negligible.

Show that the relationship between *v* and *m* is

$$v^2 = \frac{1.20mg}{(m + 0.800)}$$

where *g* is the acceleration of free fall.

[2]

(b). The student records the information from the experiment in a table. The column headings and just the last row for m = 0.600 kg from this table are shown below.

m / kg	t / 10^{-3} s	$\frac{m}{(m + 0.800)}$	v / m s^{-1}	v^2 / m^2 s^{-2}
0.600	90 ± 2	0.429	2.22 ± 0.05	

i.

Complete the missing value of v^2 in the table including the absolute uncertainty. **[2]**

ii. Fig. 4.2 shows some of the data points plotted by the student. Plot the missing data for m = 0.600 kg on Fig. 4.2 and draw the straight line of best fit.

[2]

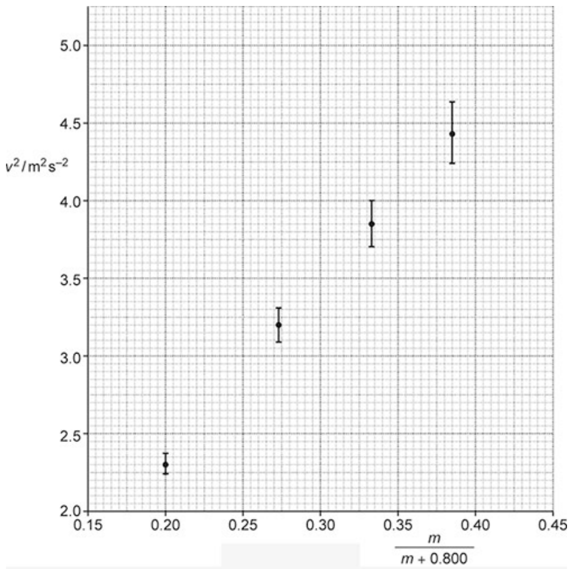


Fig. 4.2

(c).

i. Use the equation given in **(a)** to show that the gradient of the graph of v^2 against $\frac{m}{(m + 0.800)}$ is equal to 1.20 g.

[1]

ii. Assume that the best-fit straight line through the data points gives 9.5 m s^{-2} for the experimental value of *g*. Draw a worst-fit line through the data points on Fig. 4.2 and determine the absolute uncertainty in the value for *g*.

absolute uncertainty = ± ms^{-2} **[4]**

(d). It is suspected that the card on the trolley did not pass at right angles through the light beam.

Discuss, without doing any calculations, the effect this may have on the experimental value for the acceleration of free fall *g*.

[4]

37 (a). Electron diffraction provides evidence for the wave-like behaviour of particles. Electrons are diffracted by a thin slice of graphite.

In one experiment, electrons are accelerated from rest through a potential difference of 300 V.

Show that the final speed *v* of the electrons is 1.0×10^7 m s^{-1}.

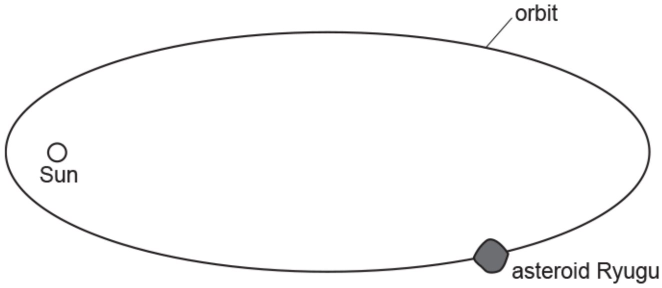
[3]

(b). Determine the de Broglie wavelength λ of the electrons.

λ = ... m **[2]**

38 (a). In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

The asteroid orbits the Sun in an elliptical orbit as shown below.



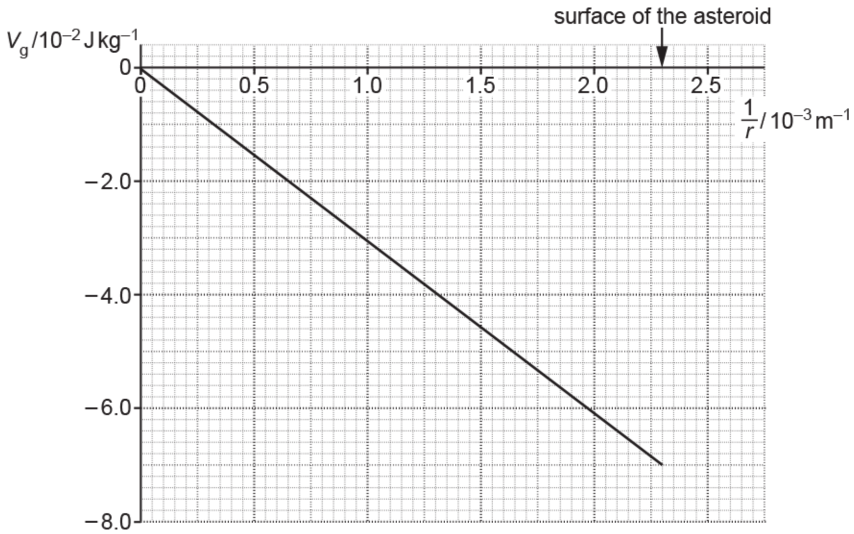
The diagram is **not** drawn to scale.

(i) Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed. **[1]**

1. Use Kepler's **second law** to explain your answer to **(a)(i)** .

[2]

(b). The gravitational potential at a distance *r* from the centre of the asteroid Ryugu is *V*g. The graph of *V*g against $\frac{1}{r}$ for the asteroid is shown below.



i. Define **gravitational potential** .

[1]

ii. Show that the magnitude of the gradient of the graph is equal to *GM*, where *M* is the mass of the asteroid and *G* is the gravitational constant.

[1]

iii. Use the gradient of the graph to show that the mass *M* of the asteroid is about 4.6×10^{11} kg.

M = ... kg **[2]**

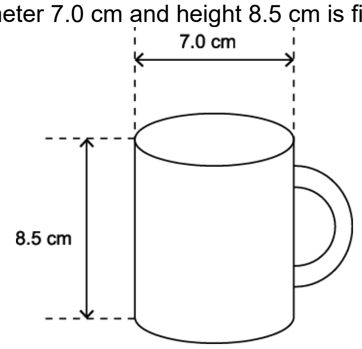
(c). In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from **(b)** to calculate the speed of the impact *v* when MASCOT landed on the surface of the asteroid.

v = ... m s^{-1} **[3]**

39 (a). A cylindrical cup of internal diameter 7.0 cm and height 8.5 cm is filled to the top with water.



The density of water is 1000 kg m^{-3}. The mass of one mole of water is 18 g. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

Show that the minimum time taken for a 0.50 kW camping kettle to bring a cup of water at 20 °C to boiling point is about 200 s.

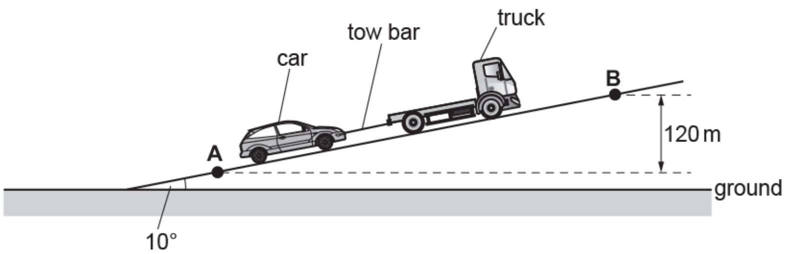
[3]

(b). In a laboratory test, the camping kettle was found to bring a cup of water to the boil in 320 seconds.

Explain why your previous answer is an underestimate and suggest **two** ways that you can refine the test to ensure that the time to boil is closer to 200 s.

[3]

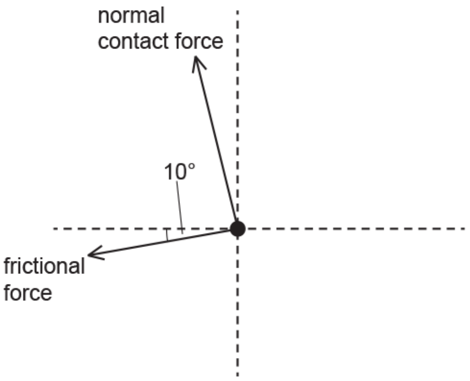
40 (a). A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.



The diagram is **not** drawn to scale.
The slope is 10° to the horizontal ground.
The mass of the car is 1100 kg.
The car travels from **A** to **B** . The vertical distance between **A** and **B** is 120 m.

There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

(b). Show that the component of the weight of the car *W*s acting down the slope is about 1900 N.

[1]

(c). The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

force = ... N **[1]**

(d). Calculate the work done by the force provided by the tow bar as the car travels from **A** to **B** .

work done = ... J **[3]**

(e). The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m.
The Young modulus of steel is 2.0×10^{11} Pa.
The force on the tow bar is 2200 N.

Calculate the extension x of the tow bar as the car travels up the slope.

x = ... m **[3]**

41 (a). A student investigates the motion of a tennis ball of mass 57 g which falls vertically from rest, then bounces once on a soft horizontal surface.
Fig. 1 shows the variation with time *t* of the velocity *v* of the tennis ball falling from rest until it hits the soft surface.

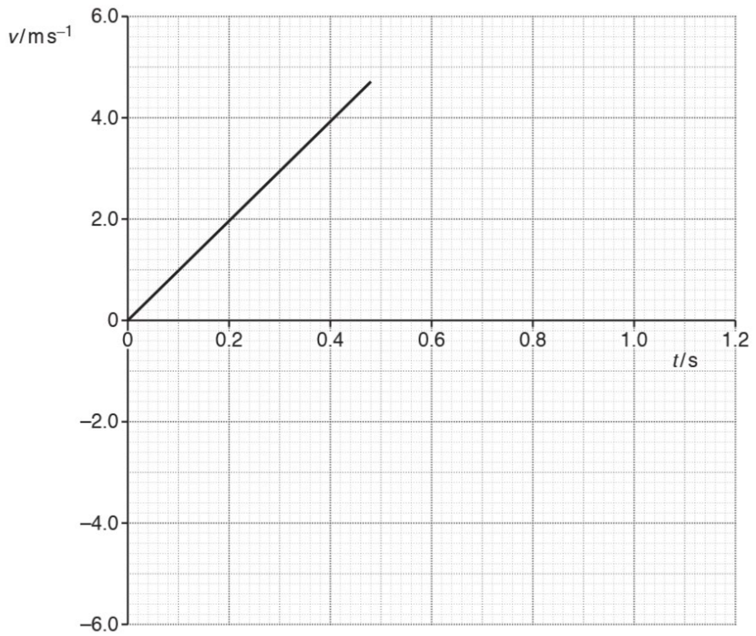


Fig. 1

Air resistance has a negligible effect on the motion of the tennis ball.

Use Fig. 1 to show that

i. the acceleration of the falling ball is about 10 m s^{-2}

[1]

ii. the kinetic energy of the ball just before impact with the surface is 0.63 J.

[2]

(b). The ball leaves the surface with 80% of the kinetic energy just before impact.

i. Calculate the magnitude of the velocity *v* of the ball as it leaves the surface.

v = ... m s^{-1} **[3]**

ii. Complete Fig. 1 to show the variation of the velocity of the ball after it leaves the surface until it is at rest again.

[2]

iii. Determine the maximum height h reached by the ball after it bounces.

***h* = ... m [2]**

(c). The student repeats the experiment with a different ball that is affected by air resistance.

Explain how the graph in Fig. 1 now appears from the time the ball is released to the time it hits the surface.

[2]

42 (a). When riding at a steady speed on the flat, a cyclist provides a constant power of 200 W to the rear wheel of his bicycle. The total mass of bicycle and rider is 120 kg.

The total resistive forces *R* acting against the motion of the bicycle and the rider vary with the velocity *v* of the bicycle as shown in Fig. 1.

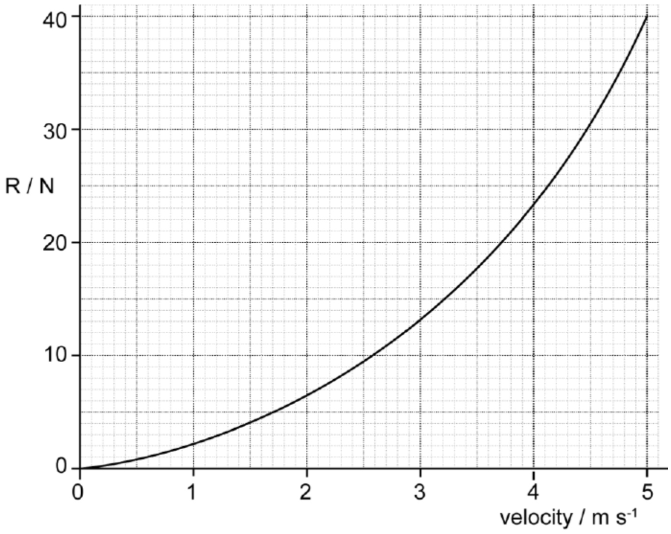


Fig.1

i. The cyclist starts from rest. He pedals steadily along a horizontal road. This exerts a constant forward force of 40 N on the bicycle.

Use Fig. 1 to state and explain how the acceleration and velocity of the bicycle vary as the cyclist travels along the road.

[3]

ii. Calculate

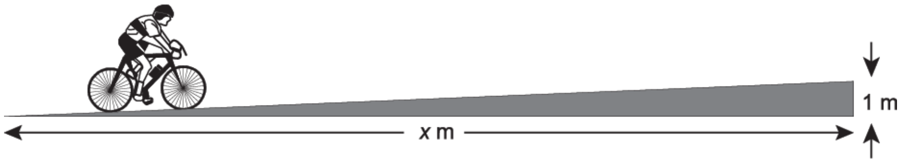
1. the initial acceleration of the bicycle

acceleration = ... $m\ s^{-2}$ **[1]**

2. the maximum speed of the cyclist.

maximum speed = ... $m\ s^{-1}$ **[2]**

(b). The cyclist reaches a hill.



The cyclist has to double the power provided to the rear wheel to maintain the same maximum speed reached on the flat road.

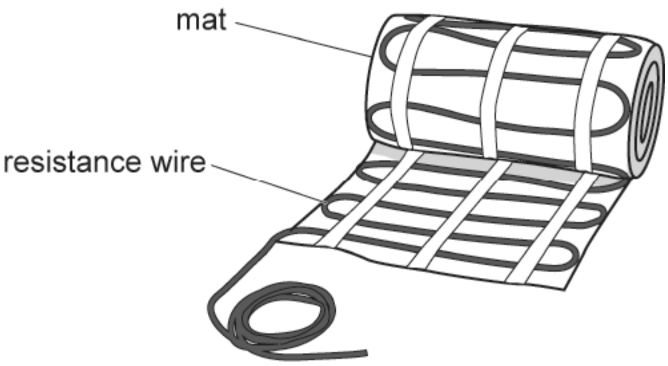
Assume that the total resistive force is unchanged.

The gradient of the hill is 1 in *x*.

Calculate x.

x = ... m **[3]**

43. The diagram below shows a mat used for underfloor heating.



Each mat has resistance wire. The wire has cross-sectional area 6.7×10^{-8} m^2, total length 25 m and resistance 180 Ω. Each mat dissipates 300 W when connected to the mains supply.

i. A total output power 1.2 kW is required for a room.
Calculate the number of mats required.

number of mats =... **[1]**

ii. Calculate the resistivity ρ of the material of the wire.

ρ = ... Ωm **[2]**

44 (a). Fig. 22.2 shows an arrangement used to investigate how the kinetic energy of a toy car varies with its distance *d* from the top of the ramp.

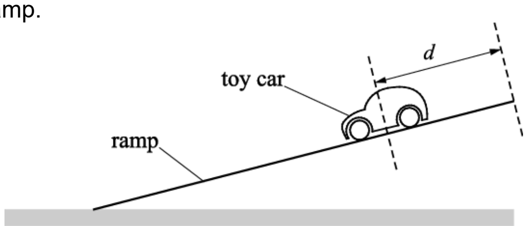


Fig. 22.2

The toy car is released from rest from the top of the ramp. The two graphs in **Fig. 22.3** show the variation of the gravitational potential energy E_p of the toy car and its kinetic energy E_k with distance *d* from the top of the ramp.

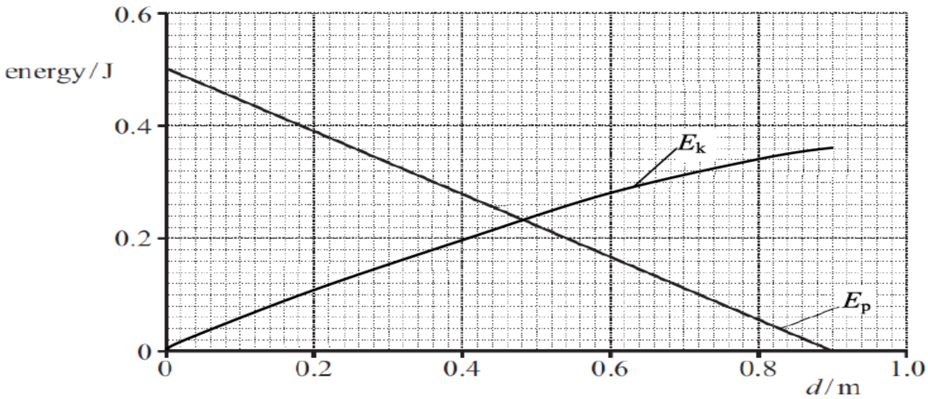


Fig. 22.3

The car travels a distance of 90 cm along the length of the ramp.

i. The variation of E_p with *d* is linear.
State why the E_k against *d* graph is **not** linear.

[1]

ii. Use **Fig. 22.3** to determine the average resistive force acting on the toy car.

force = ...N **[2]**

(b). Fig. 22.2 shows an arrangement used to investigate how the kinetic energy of a toy car varies with its distance *d* from the top of the ramp.

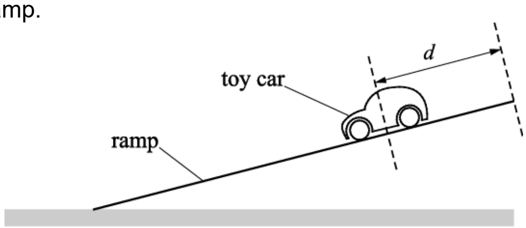


Fig. 22.2

Design a laboratory experiment to determine the kinetic energy of the car at one particular distance *d* from the top of the ramp.
In your description pay particular attention to

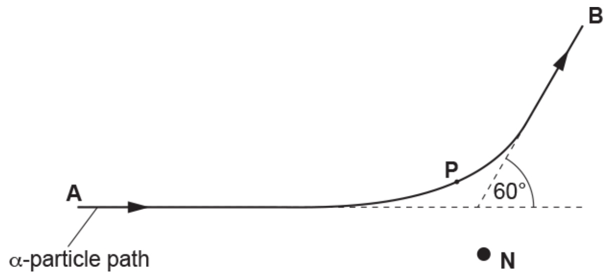
- how the apparatus is used
- what measurements are taken
- how the data is analysed.

[3]

45. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The initial kinetic energy of each α-particle is 5.0 MeV.

Show that the magnitude of the initial momentum of each α-particle is about 10^{-19} kg m s^{-1}.
Take the mass of the α-particle to be 6.6×10^{-27} kg.

[3]

46. In a hockey match a hockey ball is hit 18.0 m from the front of the goal. The ball leaves the hockey stick with initial velocity v at an angle θ to the horizontal ground. The ball passes over the goal at a maximum height of 2.0 m as shown in Fig. 3.

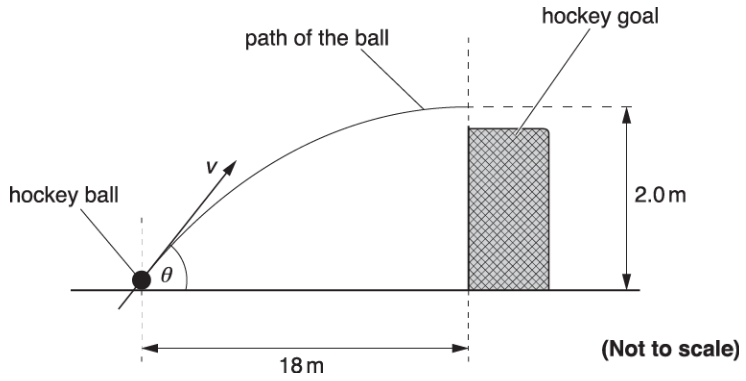


Fig. 3

The hockey ball has a mass of 0.160 kg.

i. Calculate the initial kinetic energy E_k of the ball as it leaves the hockey stick.

E_k = ... J **[1]**

ii. Calculate the change in gravitational potential energy E_p of the ball as it moves from the ground to the maximum height.

E_p = ... J **[1]**

iii. Calculate the kinetic energy of the ball at the maximum height.

kinetic energy = ... J **[1]**

47 (a). A hydrogen atom travelling at 500 m s^{-1} makes a head-on collision with a stationary carbon atom. The collision is perfectly elastic. After the collision the hydrogen atom bounces back with a speed of 420 m s^{-1}. Fig. 24.2 shows the atoms before and after the collision.

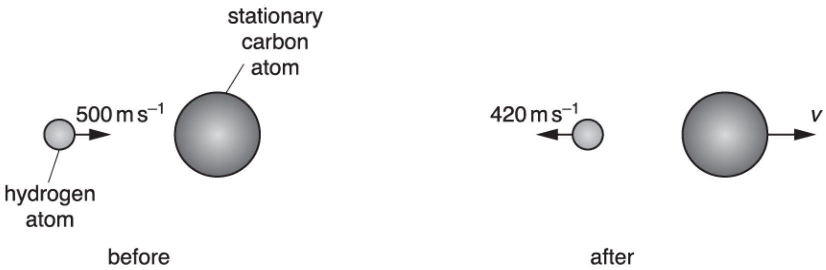


Fig. 24.2

The mass of the hydrogen atom is 1.7×10^{-27} kg and the mass of the carbon atom is 2.0×10^{-26} kg.
Calculate the speed *v*of the carbon atom after the collision.

v = ... m s^{-1} **[3]**

(b). A comet makes an inelastic collision with a small asteroid in space.

i. State **two** physical quantities conserved in this collision.

1

2

[1]

ii. Fig. 24.1 shows how the force *F* acting on the **comet** varies with time *t* during the collision.

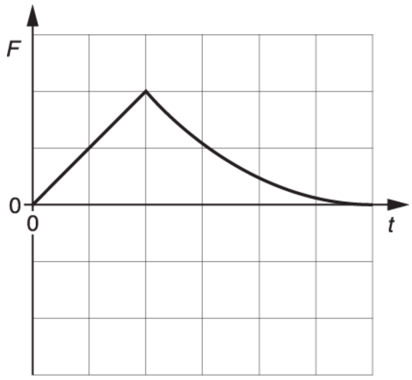


Fig. 24.1

Describe and explain how the force acting on the **asteroid** varies with time during this collision. You may sketch a suitable graph on **Fig. 24.1** to support your answer.

[2]

48 (a).

Electromagnetic radiation is incident on a negatively charged zinc plate. Electrons are emitted from the surface of the plate when a weak intensity ultraviolet source is used. Electrons are not emitted at all when an intense visible light from a lamp is used.

Explain these observations.

[4]

(b). The **maximum** wavelength of the electromagnetic radiation incident on the surface of a metal which causes electrons to be emitted is 2.9×10^{-7} m.

Calculate the maximum kinetic energy of electrons emitted from the surface of the metal when each incident photon has energy of 5.1 eV.

maximum kinetic energy = ... J **[3]**

(c). Electromagnetic radiation of constant wavelength is incident on a metal plate. Photoelectrons are emitted from the metal plate. Fig. 19.1 shows an arrangement used to determine the maximum kinetic energy of electrons emitted from a metal plate.

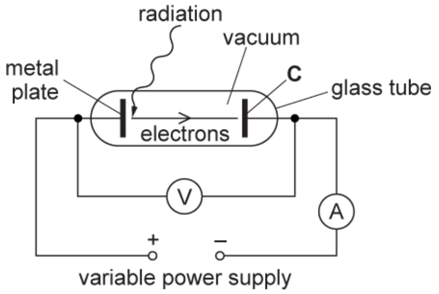


Fig. 19.1

The metal plate and the electrode **C** are both in a vacuum. The electrode **C** is connected to the negative terminal of the variable power supply.

Fig. 19.2 shows the variation of current *I* in the circuit as the potential difference *V* between the metal plate and **C** is increased from 0 V to 3.0 V.

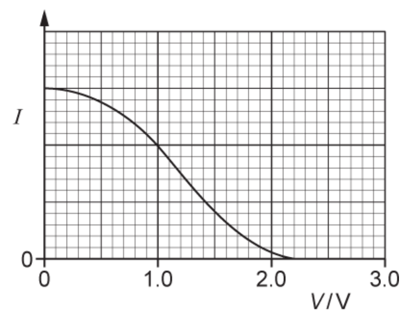


Fig. 19.2

Explain why the current decreases as *V* increases and describe how you can determine the maximum kinetic energy of the emitted electrons.

[3]

49. Fig. 21.2 shows the displacement *x* against time *t* graph of an oscillator damped in air.

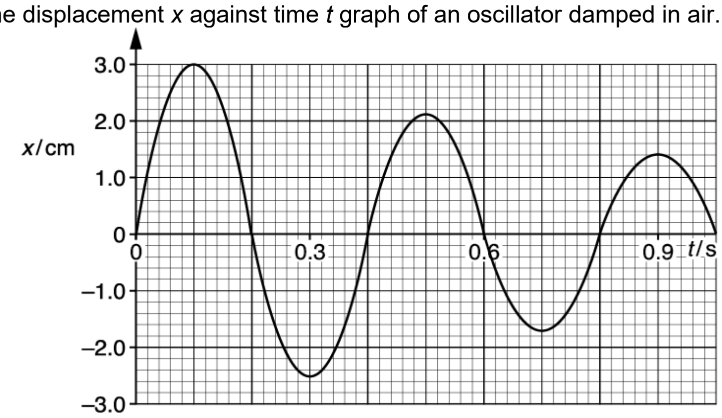


Fig. 21.2

i. According to a student, the amplitude of the oscillator decays by the same fraction every half oscillation. Analyse Fig. 21.2 to assess whether or not the student is correct.

[2]

ii. State and explain at which time the oscillator dissipates **maximum** energy.

[2]

50. Fig. 3.1 shows the design of a ‘mechanical’ torch.

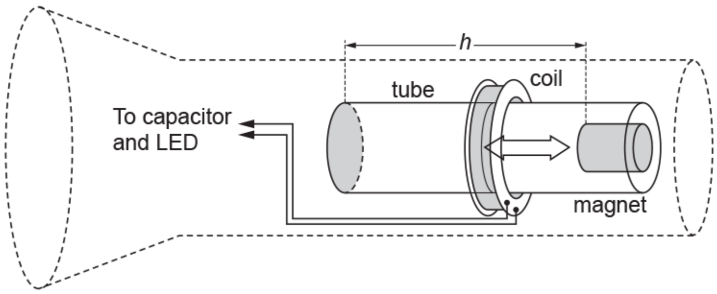


Fig. 3.1

There is no battery in the torch. Instead, when the torch is inverted, the magnet falls a short vertical distance *h* through the coil of wire, as shown in Fig. 3.2. This induces an electromotive force (e.m.f.) across the ends of the coil. The e.m.f. is used to store charge in a capacitor, which lights a light-emitting diode (LED) when it discharges.

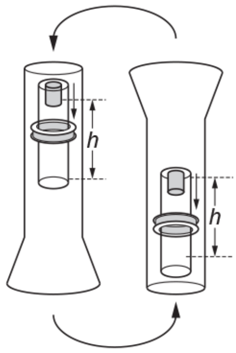


Fig. 3.2

Fig. 3.3 shows the variation with time of the e.m.f. generated as the magnet falls the distance *h.*

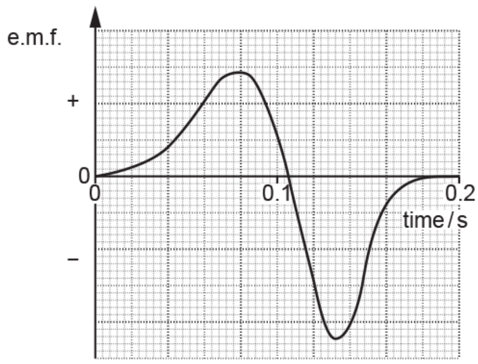


Fig. 3.3

When the torch is inverted, the pulses of e.m.f. shown in Fig. 3.3 cause a capacitor of capacitance 0.12 F to become charged.
Each positive **and** each negative pulse adds 9.0×10^{-3} C to the charge stored in the capacitor.

i. The torch is inverted 80 times.
Calculate the total energy stored in the capacitor.

total energy = ... J **[3]**

ii. When the torch is switched on, the energy stored in the capacitor lights a 50 mW LED. Estimate the time for which the LED lights.

time = ... s **[1]**

51 (a). This question is about a laser pen.

Green light from the laser pen passes through a pair of narrow slits S_1 and S_2 as shown in Fig. 5.1.

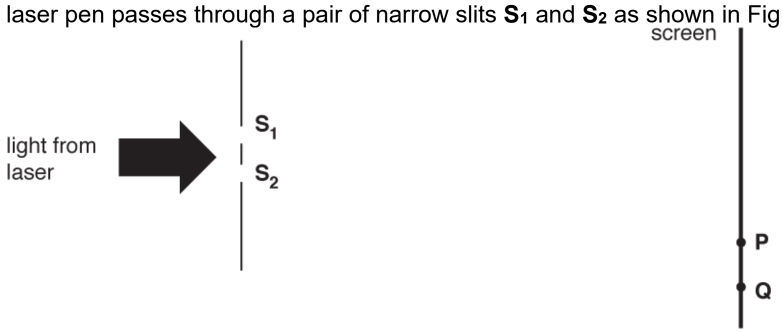


Fig. 5.1

A pattern is produced on a screen consisting of regularly spaced bright and dark lines as shown in Fig. 5.2.

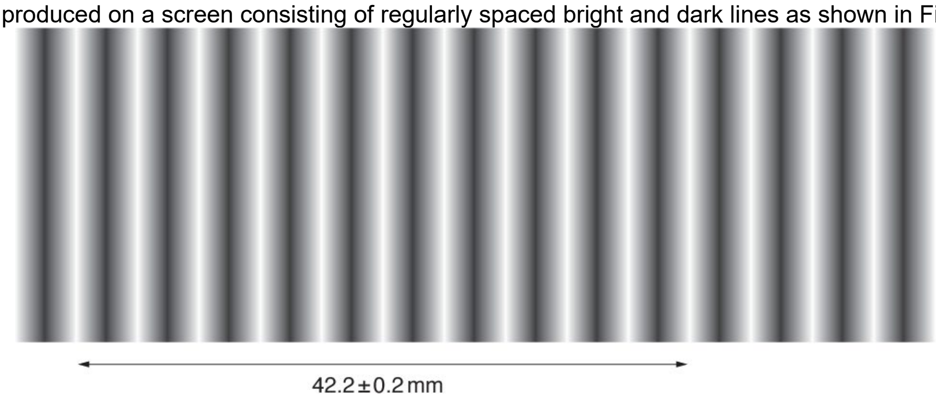


Fig. 5.2

i. Fig. 5.1 shows two points, **P** and **Q**, on the screen. Explain in terms of path difference why point **P** is a bright line and point **Q** is a dark line.

[2]

ii. The screen is at a distance of 4.50 ± 0.02 m from the slits and the slit separation is 0.56 ± 0.02 mm.

1. Use Fig. 5.2 to determine the wavelength λ of the light.

λ = ... m **[3]**

2. Determine the percentage uncertainty in λ.

percentage uncertainty = ... % **[2]**

(b). The power of the green light from the laser pen is 50.0 mW. It is now used in a demonstration of the photoelectric effect.

i. Calculate the number of photons *n* that the laser emits per second.

n = ... **[2]**

ii. The green light falls on a negatively charged metal plate with a work function of 2.6 eV. Explain whether photoelectrons will be emitted.

[2]

52. A metal plate is placed in an evacuated chamber. Electromagnetic radiation of wavelength 380 nm is incident on the plate. The work function of the metal is 1.1 eV.

i. Calculate the maximum speed of the photoelectrons emitted from the plate.

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

ii. State the change, if any, to the maximum speed of the emitted photoelectrons when the intensity of the incident electromagnetic radiation on the metal plate is doubled.

[1]

53. Some lasers are used in eye surgery.
One such laser emits a beam of light of wavelength 490 nm and power 230 mW.

Calculate

i. the energy of each photon of light from the laser.

energy = ... J **[2]**

ii. the number of photons of light emitted in each second.

number of photons = ... **[2]**

54 (a). On **Fig. 21.3** sketch a graph showing the variation of kinetic energy with time. Add a scale to the kinetic energy axis.

[2]

(b). A stabilising mechanism for electrical equipment on board a high-speed train is modelled using a 5.0 g mass and two springs, as shown in **Fig. 21.1**. For testing purposes, the springs are horizontal and attached to two fixed supports in a laboratory.

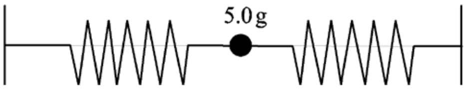


Fig. 21.1

Fig. 21.2 shows the graph of displacement against time for the oscillating mass.

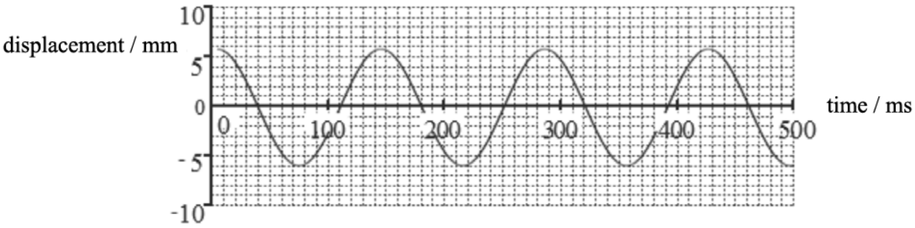


Fig. 21.2

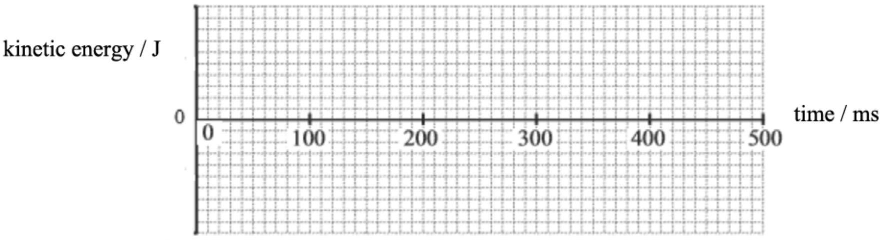


Fig. 21.3

i. Determine the maximum acceleration of the mass during the oscillations.

maximum acceleration = ... ms^{-2} **[2]**

ii. Calculate the maximum kinetic energy of the mass during the oscillations.

maximum kinetic energy = ... J **[2]**

55. Fig. 21.2 shows two parallel vertical metal plates connected to a battery.

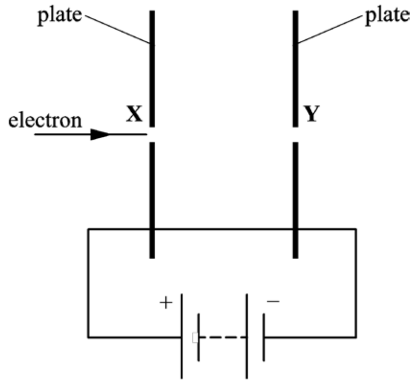


Fig. 21.2

The plates are placed in a vacuum and have a separation of 1.2 cm. The uniform electric field strength between the plates is 1500 V m^{-1}. An electron travels through holes **X** and **Y** in the plates. The electron has a horizontal velocity of 5.0×10^6 m s^{-1} when it enters hole **X**.

i. Draw five lines on **Fig. 21.2** to represent the electric field between the parallel plates.

[2]

ii. Calculate the final speed of the electron as it leaves hole **Y**.

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

56. Procyon is a star of radius 1.4×10^9 m. The total output power of the electromagnetic radiation from its surface is 2.7×10^{27} W. The average wavelength of the electromagnetic waves from Procyon is 5.0×10^{-7} m.

i. Show that the surface intensity of the radiation from Procyon is 1.1×10^8 W m^{-2}.

[2]

ii. Calculate the energy of a photon of wavelength 5.0×10^{-7} m.

energy = J **[2]**

iii. Estimate the total number of photons emitted per second from the surface of Procyon.

number per second = s^{-1} **[1]**

57. A cyclist moves along a horizontal road. She pushes on the pedals with a constant power of 250 W. The mass of the cyclist and bicycle is 85 kg. The total drag force is $0.4v^2$, where v is the speed of the cyclist.

i. Calculate the energy provided by the cyclist each minute when the overall efficiency of the cyclist's muscles is 65%.

energy = ... J **[2]**

ii. Calculate the drag force and hence the instantaneous acceleration of the cyclist when the speed is 6.0 ms^{-1}.

acceleration = ... ms^{-2} **[3]**

58. In an electron-gun, each electron is accelerated to a maximum kinetic energy of 210 eV.

i. Show that the final speed of each electron is about 9×10^6 ms^{-1}.

[3]

ii. Calculate the de Broglie wavelength λ of each electron.

λ = ... m **[2]**

59. The International Space Station (ISS) circles the Earth at a height of 4.0×10^5 m.

Its mass is 4.2×10^5 kg.

The radius of the Earth is 6.4×10^6 m.

i. Show that the speed of the ISS in orbit is about 8 km s^{-1}.

[3]

ii. Calculate the total energy of the ISS.

total energy = ... J **[2]**

60. Fig. 3.1 shows the design of a 'mechanical' torch.

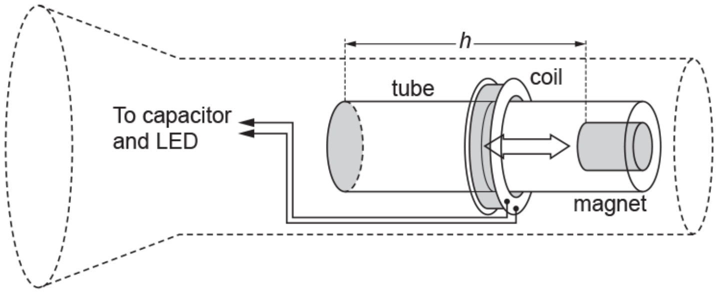


Fig. 3.1

There is no battery in the torch. Instead, when the torch is inverted, the magnet falls a short vertical distance *h* through the coil of wire, as shown in Fig. 3.2. This induces an electromotive force (e.m.f.) across the ends of the coil. The e.m.f. is used to store charge in a capacitor, which lights a light-emitting diode (LED) when it discharges.

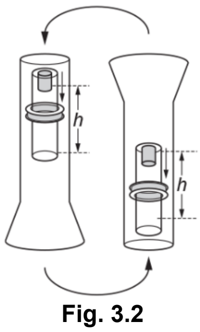


Fig. 3.2

Fig. 3.3 shows the variation with time of the e.m.f. generated as the magnet falls the distance *h.*

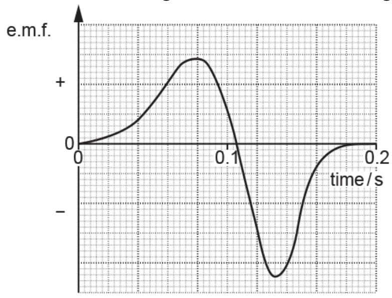


Fig. 3.3

In the torch, the gravitational potential energy of the magnet is converted into electrical energy supplied to the 50 mW LED.

You are asked to investigate whether the efficiency of this energy conversion depends on the number of inversions of the torch.

- Describe how you will make accurate measurements to collect your data. Assume that both the torch and the tube can be opened.
- Explain how you will use the data to reach a conclusion.

[6]

61 (a).

A metal ball is rolled off the edge of a horizontal laboratory bench. The initial horizontal velocity of the ball is *v*. The ball travels a horizontal distance *x* before it hits the level floor.

Use your knowledge of projectile motion to suggest the relationship between *v* and *x*. Describe how an experiment can be safely conducted to test this relationship and how the data can be analysed.

[6]

(b). A tennis ball is struck with a racket.
The initial velocity v of the ball leaving the racket is 30.0 m s^{-1} and it makes an angle of 70° to the horizontal as shown in Fig. 16.
Air resistance is negligible

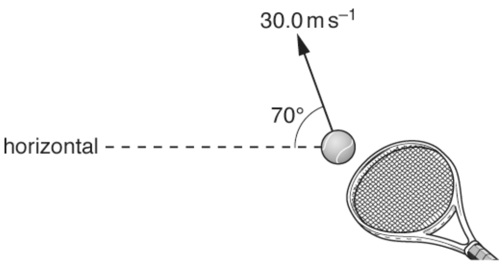


Fig. 16

i. Calculate the vertical component of the initial velocity of the ball.

vertical component = m s^{-1} **[1]**

ii. Use your answer in (**i**) to show that the ball reaches a maximum height *h* of about 40 m.

h = m **[2]**

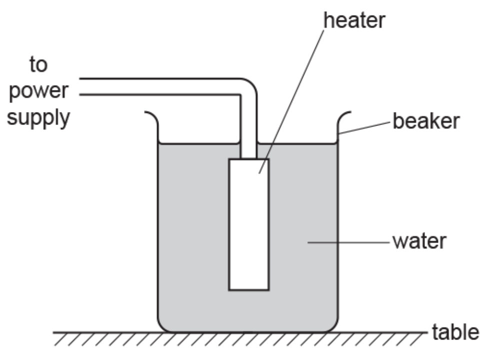
iii. Explain why the kinetic energy of the ball is not zero at maximum height.

[1]

iv. The mass *m* of the ball is 57.0 g.
Calculate the kinetic energy E_k of the ball when it is at its maximum height.

E_k = J **[2]**

62. A heater is used to heat water in a beaker.



i. Before switching on, the metal heater and the water are both at room temperature.
Describe the motion of the atoms of the metal heater and of the water molecules.

[3]

ii. The heater is now switched on.
The power of the heater is 200 W.
The mass of the water in the beaker is 500 g.
It takes 10.0 minutes to increase the temperature of the water in the beaker from 20 °C to 60 °C.

Calculate the energy transferred from the water to the **beaker and the surroundings** .

- specific heat capacity of water = 4200 J kg^{-1} K^{-1}

energy transferred = ... J **[3]**

63. Einstein derived the following equation to explain the photoelectric effect:

$$hf = \phi + KE_{max}$$

Electromagnetic radiation of frequency 1.2×10^{15} Hz is incident on the surface of a negatively charged aluminium plate. The work function of aluminium is 4.1 eV.

i. Show that the maximum speed of the electrons emitted from the surface of the aluminium is 5.5×10^5 m s^{-1}.

[4]

ii. State and explain what change, if any, occurs to the maximum speed of the emitted electrons when the intensity of the electromagnetic radiation is increased.

[2]

64. This question is about a photoelectric cell, which is an electronic device that detects photons.
Fig. 6 shows a cross-section through a simple photocell.

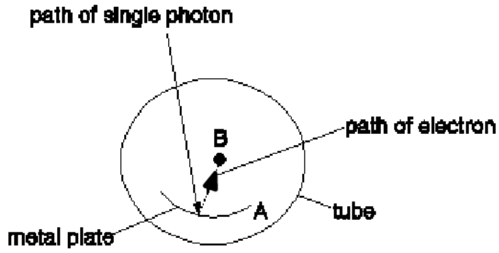


Fig. 6

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon of high enough energy, incident on the plate, can cause an electron to be released from the surface towards the collector rod **B**.

There is a potential difference of 12 V between plate **A** and rod **B** so that released electrons are accelerated towards and collected by rod **B**. **B** is 5.0 mm from **A.**
Light of wavelength 570 nm is incident on plate **A**.

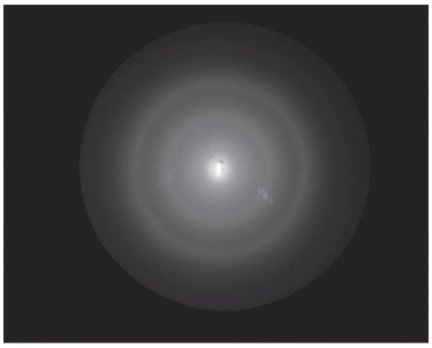
i. Calculate the speed v of electrons arriving at rod **B**.

v = ... ms^{-1} **[4]**

ii. Estimate the response time of the photocell, that is the time it takes for electrons to travel from **A** to **B**.

response time = ... s **[2]**

65. * A student is investigating electron diffraction. A beam of electrons is directed towards a thin slice of graphite in an evacuated tube.
The electrons are accelerated by a potential difference of 2000 V. The diagram below shows the pattern formed on the fluorescent screen of the evacuated tube.



Describe and explain how the pattern changes as the potential difference is increased. Include how the de Broglie wavelength λ of the electron is related to the potential difference V.

[6]

66 (a). Fig. 3 shows a swimmer of mass 65 kg, weight 640 N, being lifted vertically upwards from the sea by a cable of negligible mass compared to the swimmer.

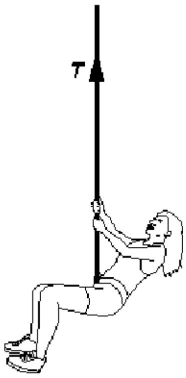


Fig. 3

The tension **T** in the cable from the time that she leaves the water at t = 0 until t = 1.5 s is 670 N. At t = 1.5 s **T** reduces to and remains constant at 640 N.

i. Use Newton's laws to describe qualitatively the motion of the swimmer for the first 4.0 s of her ascent.

[2]

ii. Show that at t = 4.0 s her height h above the water is more than 2 m and that she is rising at about 0.7 m s^{-1}.

speed = ... m s^{-1}

h = ... m **[4]**

(b). The cable is attached to a winch rotated by an electric motor in a rescue helicopter. The electric supply to the motor has an e.m.f. of 28 V. The circuit has a total resistance of 0.11 Ω. When the swimmer is rising at 0.70 m s^{-1} the motor draws a current of 30 A from the supply.

Under these conditions calculate:

i. the power lost in the electrical circuit

power lost = ... W **[2]**

ii. the efficiency of the motor

efficiency = ... **[4]**

67. A satellite is in a circular geostationary orbit around the centre of the Earth. The satellite has both kinetic energy and gravitational potential energy.

The mass of the satellite is 2500 kg and the radius of its circular orbit is 4.22×10^7 m.
The mass of the Earth is 5.97×10^{24} kg.

- Describe some of the features of a geostationary orbit.
- Calculate the **total** energy of the satellite in its geostationary orbit.

[6]

68. This question is about a space probe which is in orbit around the Sun.

The space probe has mass 810 kg. The orbital radius of the space probe is 1.5×10^{11} m. The orbital period of the space probe around the Sun is 3.16×10^{7} s. The mass of the Sun is 2.0×10^{30}kg.

i. Show that the magnitude of the gravitational potential energy of the space probe is about 7×10^{11} J.

[2]

ii. Show that the kinetic energy of the space probe is half the value of your answer to **(i)**.

[3]

iii. Calculate the total energy of the space probe.

total energy = ... J**[1]**

69.  A student wishes to determine experimentally the efficiency of a small low-voltage DC motor. The motor is used to lift light loads.

Describe with the aid of a suitable diagram how an experiment to determine the efficiency of the electric motor can be safely conducted, and how the data can be analysed.

[6]

70. A linear air track is used to investigate the collision of two gliders **A** and **B**, as shown in **Fig. 3.1**.

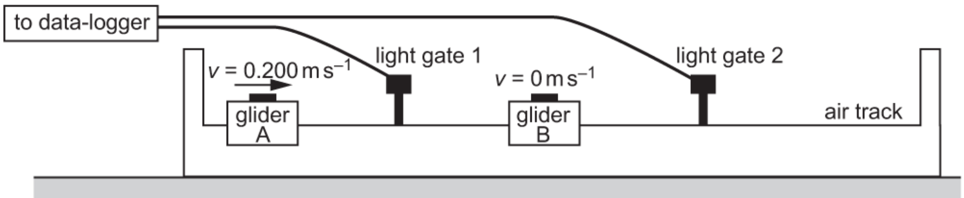


Fig. 3.1

Light gates 1 and 2 are connected to a data-logger to determine the speed of the gliders. Glider **A** has a mass of 0.75kg and glider **B** has a mass of 1.25 kg.

Two experiments are carried out.

Experiment 1

- Glider **B** is initially at rest between light gates 1 and 2.
- Glider **A** passes light gate 1 at a speed of 0.200 m s^{-1}.
- Glider **A** collides with glider **B**.
- Glider **A** rebounds and passes light gate 1 at a speed of 0.050ms^{-1} and glider **B** passes light gate 2 at a speed of 0.150 m s^{-1}.

Experiment 2

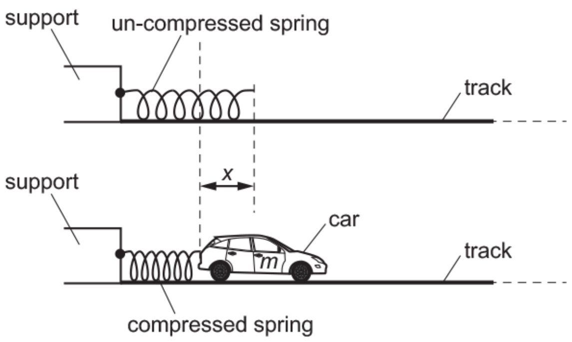
- Glider **B** is initially at rest between light gates 1 and 2.
- Glider **A** passes light gate 1 at a speed of 0.200 m s^{-1}.
- Glider **A** collides with glider **B**.
- Glider **A** sticks to glider **B**.
- Both gliders pass light gate 2 at a speed of 0.075 m s^{-1}.

With the help of calculations and the terms below, explain the results of the two experiments.

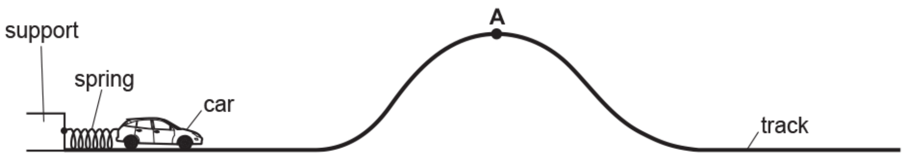
[6]

elastic **inelastic** **momentum**

71. One end of a spring is fixed to a support.
A toy car, which is on a smooth horizontal track, is pushed against the free end of the spring.
The spring compresses. The car is then released. The car accelerates to the right until the spring returns back to its original length.



The arrangement is used to propel the toy car along a smooth track.



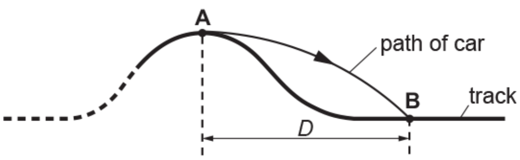
i. Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

All the elastic potential energy of the spring is transferred to gravitational potential energy of the car.

Calculate the initial compression *x* of the spring.

x = ... m **[3]**

ii. At a specific speed, the car leaves point **A** horizontally and lands on the track at point **B**.
The horizontal distance between **A** and **B** is D.



Air resistance has negligible effect on the motion of the car between **A** and **B**.

1 Explain how the time of flight between **A** and **B** depends on the speed of the car at **A**.

[2]

2 Explain how the distance *D* depends on the speed of the car at **A**.

[2]

72. Fig. 19 shows a crane lifting a car of mass 850 kg at constant velocity through a height of 12 m in a time of 40 s. The crane has a working efficiency of 60 %.

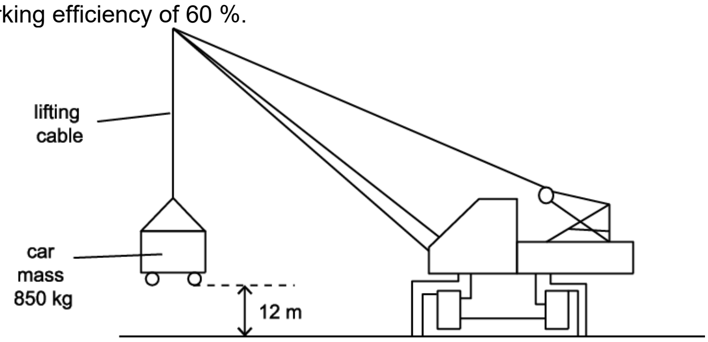


Fig. 19

i. Calculate the tension in the lifting cable.

tension = ...N **[1]**

ii. Calculate the total input power required by the crane to lift the car.

total input power = ...W **[4]**

iii. Suggest and explain **two** ways the crane can be modified to improve its efficiency.

[2]

73. Wind turbines convert the kinetic energy of the wind into electrical energy.
Fig. 18 shows a wind turbine.

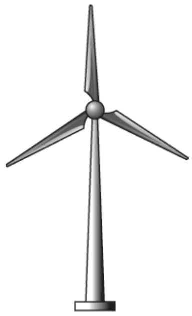


Fig. 18

A group of engineers are investigating the design of wind turbines.
The maximum **input** power P from the wind is given by the equation

$$P = \frac{1}{2}\rho A v^3$$

where *A* is the area swept out by the rotating blades, *ρ* is the density of air and *v* is the speed of the wind.

i. Show that the equation is homogeneous with both sides of the equation having the same base units.

[3]

ii. The input power to the wind turbine is 1.2 MW when the wind speed is 8.0 m s^{-1}.
The density of air is 1.3 kg m^{-3}.

Calculate the length *L* of the turbine blades.

L = m **[2]**

iii. A wind farm is required to produce an output power of 50 MW when the average wind speed is 8.0 m s^{-1}. The efficiency of each wind turbine is 42%.

Calculate the minimum number *N* of wind turbines required to meet this demand.

N = **[2]**

74. Fig. 1 shows a high-speed electric train.

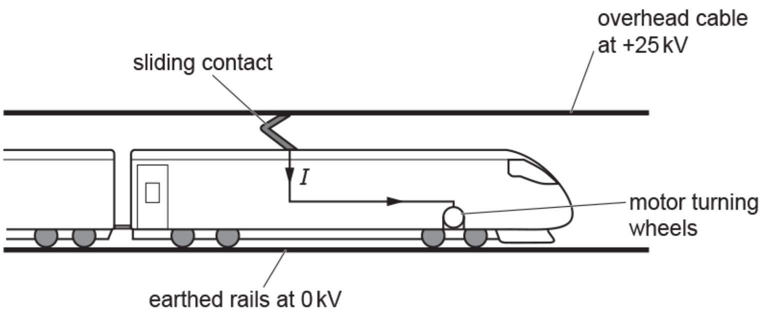


Fig. 1

The potential difference between the overhead cable and the rails on the ground is 25 kV.
The sliding contact on the top of the train constantly touches the overhead cable.
The overhead cable supplies a current I to the electric motor of the train.
The motor turns the wheels. The train experiences a **resultant** forward force *F*.

The total mass of the train is 2.1×10^5 kg.

The train accelerates from rest. The value of F is 190 kN for speeds less than 6.0 m s^{-1}.

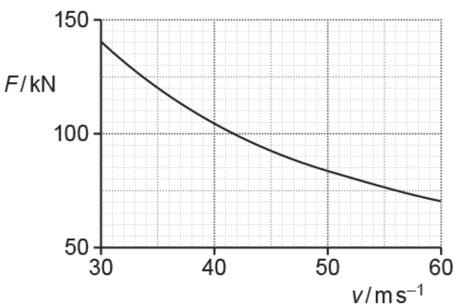
i. Show that the train's acceleration is about 1 m s^{-2}.

[1]

ii. Calculate the distance s that the train travels to reach a speed of 6.0 m s^{-1}.

s = ... m**[2]**

iii. The speed of the train is v.
During one period of its journey, the train accelerates from v = 30 m s^{-1} to v = 60 m s^{-1}.
The graph of *F* against v for this period is shown below.



1. Use the graph to show that output power of the electric motor during this period is constant at about 4 MW.

[3]

2. Calculate the current *I* in the electric motor when the train is travelling at 50 m s^{-1}.

I = ... A**[2]**

75. Fig. 20.1 shows an electric motor used to lift and lower a load.

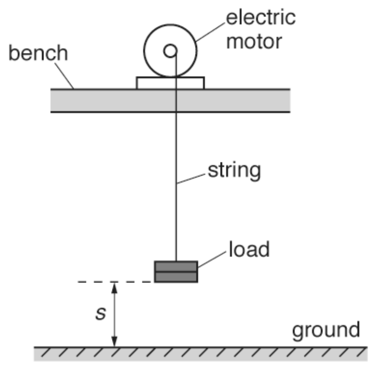


Fig. 20.1

At time *t* = 0 the load is on the ground with displacement *s* = 0.
Fig. 20.2 shows the variation of the displacement *s* of the load with time *t*.

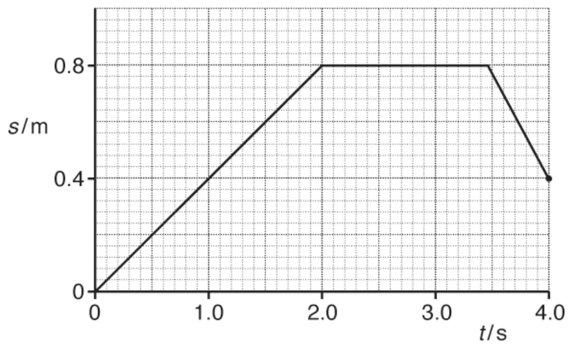


Fig. 20.2

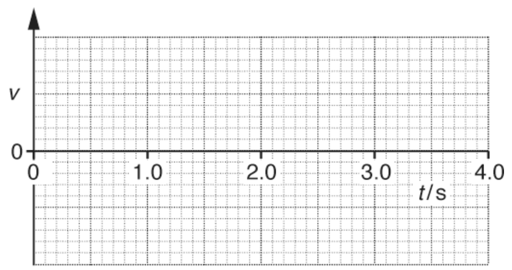


Fig. 20.3

i.

On Fig. 20.3, sketch a graph to show the variation of the velocity v of the load with time *t*.
You do not need to insert a scale on the *v* axis.

[3]

ii. Describe how the kinetic energy and the gravitational potential energy of the load varies from $t = 0$ to $t = 2.0$ s.

[2]

iii. During the **downward** journey of the load, the string breaks at $t = 4.0$ s. It then falls vertically towards the ground. The mass of the load is 120 g.
Air resistance is negligible.

1 Calculate the velocity *V* of the load just before it hits the ground.

V = ms^{-1}
[2]

2 The load hits the ground and comes to **rest** in a time interval of 25 ms.

Calculate the average force F exerted by the ground on the load.

F = N **[2]**

76. Fig. 1.1 shows a train of mass 1.9×10^5 kg travelling at 61 kmh^{-1} along a level track.

Fig. 1.1

i. Show that the train is travelling at about 17 ms^{-1}.

[1]

ii. The brakes of the train are applied and the train is brought to rest in a distance of 310 m. Calculate

1. the initial kinetic energy E_k of the train

E_k = ... J **[2]**

2. the average deceleration a of the train

a = ... ms^{-2} **[3]**

3. the average braking force F on the train.

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

iii. Fig. 1.2 shows a similar train travelling at 61 kmh^{-1} up an incline.

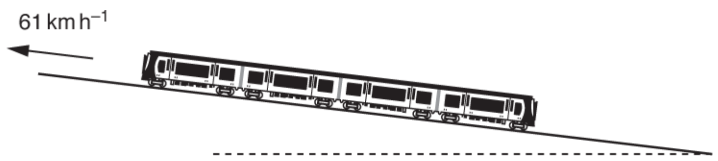


Fig. 1.2

The brakes of the train are applied with the **same** average braking force.
State and explain how the distance that the train travels, from when the brakes are applied until the train stops, compares with when the train is travelling on level track.

[2]

77 (a). The ball-release mechanism of a pinball machine is shown in Fig. 17.1.

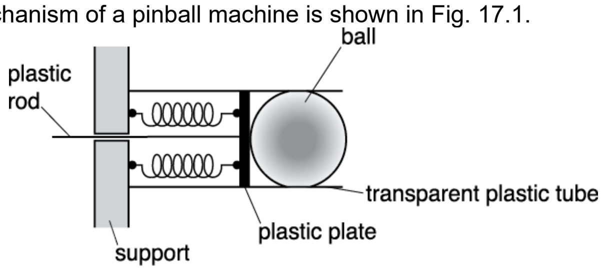


Fig. 17.1

A pair of identical compressible springs are fixed between a plastic plate and a support. The springs are in parallel. A plastic rod attached to the plate is pulled to the left to compress the springs. A ball, initially at rest, is fired when the plate is released.

A group of students are conducting an experiment to investigate the ball-release mechanism shown in Fig. 17.1. The students apply a force *F* and measure the compression *x* of the springs.
The table below shows the results.

***F* / N**	***x* / cm**
1.1 ± 0.2	2.0
2.0 ± 0.2	4.0
2.9 ± 0.2	6.0
4.0 ± 0.2	8.0
5.1 ± 0.2	10.0

Fig. 17.2 shows four data points from the table plotted on a *F* against *x* graph.

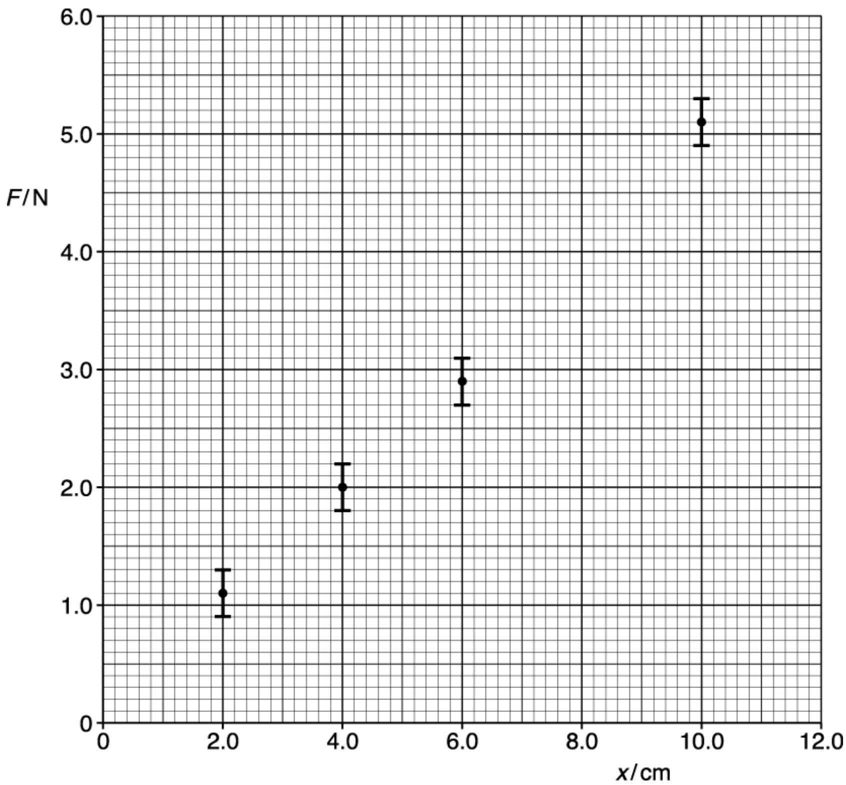


Fig. 17.2

i. Plot the missing data point and the error bar on Fig. 17.2.

[1]

ii. Describe how the data shown in the table may have been obtained in the laboratory.

[2]

iii. Draw the best fit and the worst fit straight lines on Fig. 17.2.
Use the graph to determine the force constant *k* for a **single** spring and the absolute uncertainty in this value.

k = ... ± .... N m^{-1} **[4]**

iv. State the feature of the graph that shows Hooke's law is obeyed by the springs.

[1]

v. The mass of the ball is 0.39 kg.

Use your answer from **(iii)** to calculate the launch speed *v* of the ball when the plastic plate shown in Fig. 17.1 is pulled back 12.0 cm.

v = ... m s^{-1} **[3]**

(b). A new arrangement for the ball-release mechanism using three identical springs is shown in Fig. 17.3.

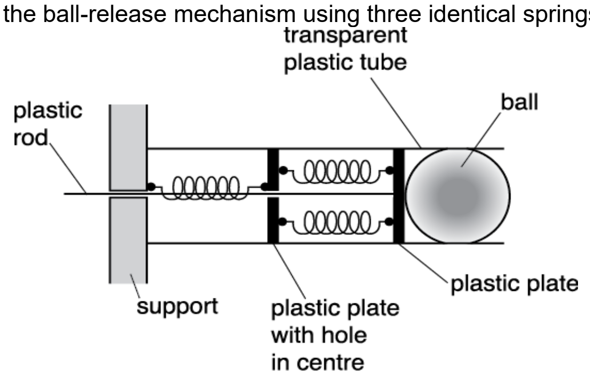


Fig. 17.3

The force constant of each spring is *k*.
The same ball of mass 0.39 kg is used. The plastic rod is pulled to the left by a distance of *x*.

Show that initial acceleration a of this ball is given by the equation

$$a = 1.7\,kx.$$

[2]

78. This question is about helium in the atmosphere of the Earth.

Experiment shows that most of the Earth's atmosphere is contained within a very thin shell around the surface of the Earth. Less than 0.0001% of this is helium.

The height of the atmosphere is negligible compared with the radius R of the Earth.

i. Show that the minimum speed v_E required for an atom or molecule to escape from the top of the Earth's atmosphere is given by the expression

$$v_E = \sqrt{2gR}\,.$$

[3]

ii. The radius R of the Earth is 6.4×10^6 m. Calculate this escape speed v_E.

v_E = ... m s $^{-1}$ **[1]**

iii. Calculate the temperature T in kelvin required at the top of the Earth's atmosphere for the root mean square speed $c_{r.m.s.}$ of the helium atoms there to equal this escape speed.

Molar mass of helium = 0.004 kg mol^{-1}

T = ... K **[3]**

iv. Fig. 1 shows the distribution of the speeds of the atoms of an ideal gas.

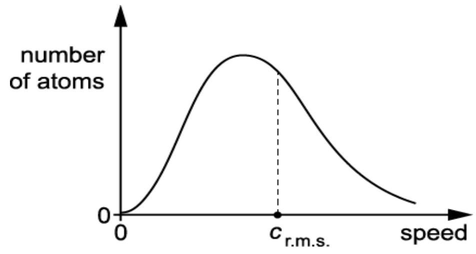


Fig. 1

Use your knowledge of the kinetic theory of gases to describe the shape of this distribution and explain why some helium is able escape from the Earth.

[4]

v. Over a very long period of time all of the helium should have escaped from the Earth. Suggest why there is still a small amount of helium, about 0.0001%, in the Earth's atmosphere.

[2]

END OF QUESTION PAPER