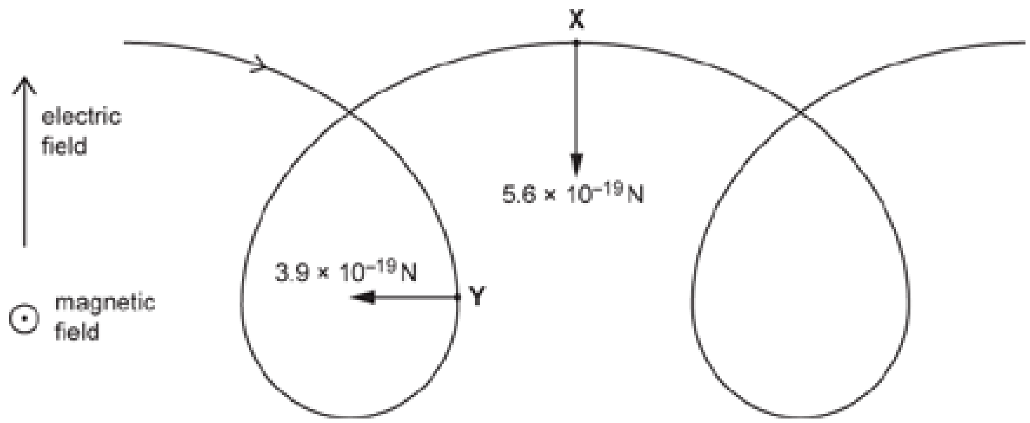
1(a). The figure below shows the path of a proton moving in a region occupied by both an electric field and a magnetic field.

The direction of the electric field lines is perpendicular to the direction of the magnetic field lines.



The uniform electric field is directed upwards, with electric field strength E = 0.90 N C^{-1}.

The uniform magnetic field is directed out of the plane of the paper, with magnetic flux density $B = 5.0 \times 10^{-5}$ T.

At point **X** the proton is moving horizontally to the right. The magnitude of the **magnetic** force at **X** is 5.6×10^{-19} N.

At point **Y** the proton is moving vertically downwards. The magnitude of the **magnetic** force at **Y** is 3.9×10^{-19} N.

The **electric** forces acting on the proton at **X** and **Y** are **not** shown in the figure.

Show that the magnitude of the constant **electric** force acting on the proton is about 10^{-19} N.

[1]

(b).

i. Suggest why the **magnetic** force acting on the proton has a different magnitude at **X** than at **Y**.

____

____

____ **[1]**

ii. At **X**, the motion of the proton is instantaneously equivalent to motion in a circle at a constant speed.

Calculate the radius of this circular motion.

radius = ... m **[4]**

iii. **1** Calculate the magnitude of the resultant force on the proton at **Y**.

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

2 Explain why the motion of the proton at **Y** is **not** instantaneously equivalent to motion in a circle at a constant speed.

[2]

2(a). A satellite of mass *m* is in a circular orbit around a planet of mass *M*. The radius of the orbit from the centre of the planet is *r*.

The gravitational potential V_g at a point a distance *r* from the centre of the planet is given by the equation

$$V_g = -\frac{GM}{r}.$$

i. By considering the cause of the centripetal force on the satellite, show that the kinetic energy of the satellite is equal to half the magnitude of its gravitational potential energy.

[2]

ii. A tiny satellite of mass 1.0 kg is to be launched from rest from the surface of the Earth into a low Earth orbit. The gravitational potential at any point in this orbit is −56 MJ k^{-1}.

The value of the gravitational potential at the Earth's surface is −63 MJ kg^{-1}.

Show that the satellite must gain more than 30 MJ of **total** energy to achieve and remain in orbit.

[2]

(b). Large satellites are often launched by rockets from sites near the equator. The rotation of the Earth increases the initial kinetic energy of the rocket and satellite.

A new strategy is to launch using a smaller rocket from a high-flying aircraft.

Using the information in part (ii) of the previous question and the data below, evaluate the advantages and limitations of this strategy. Use calculations to support your evaluation

Rotational speed at the equator	460 m s^{-1}

Typical aircraft operating altitude	10,000 m
Aircraft cruise velocity (relative to the ground)	230 m s^{-1}

[6]

3. Spherical filament lamps are manufactured by a process where they are filled with a gas at 290 K and low pressure.

When the filament lamp is switched on, the filament reaches a constant temperature of 2400 K. At this temperature, the pressure inside the filament lamp is 120 kPa.

i. Explain, in terms of energy transfers, why the temperature of the filament does **not** increase beyond 2400 K. You are **not** expected to refer to the electrical characteristics of the filament lamp.

[3]

ii. Calculate the pressure of the gas within the filament lamp during manufacture.

pressure = ... kPa **[2]**

4(a). This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy. Electromagnetic radiation is collected from Nu Persei by a sensor with an efficiency of 11% and cross-sectional area 1.0×10^{-4} m^2.

The radiant power collected by the sensor is 7.0×10^{-15} W.

i. Show that the radiant power per unit area arriving at the sensor is about 6×10^{-10} W m^{-2}.

[2]

ii. By the time the electromagnetic radiation from Nu Persei reaches Earth, the radiation from Nu Persei is evenly distributed over a spherical area with radius equal to the distance between Nu Persei and Earth.

Calculate the distance of Nu Persei from Earth in light years.

distance = ... light years **[4]**

(b). This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy. The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. *L* is the luminosity of a star and *L* is the luminosity of the Sun.

The temperature data from earlier in this question is repeated in the table below.

Star	**Surface temperature / K**
Sun	5800
Nu Persei	6300

Comment on the uncertainty in your value, calculated in **part (ii) above**, of the distance of Nu Persei from Earth. You may write on the diagram as part of your answer.

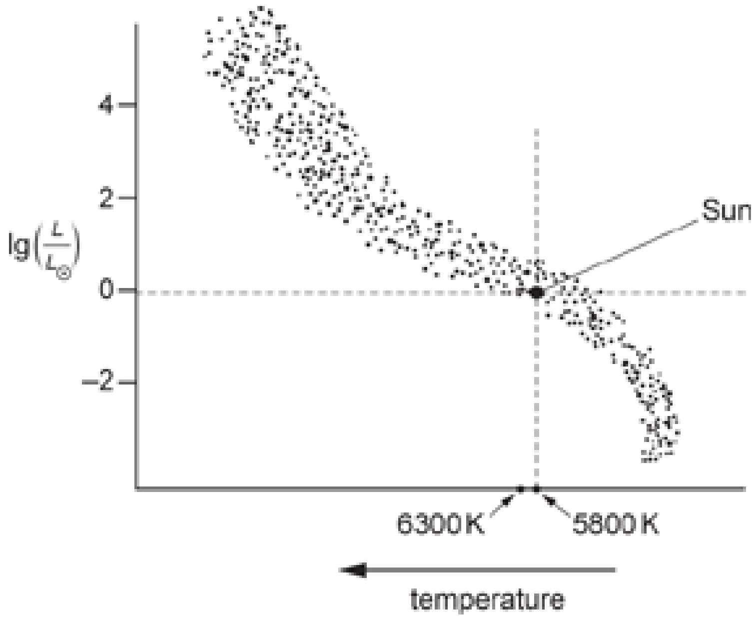


Fig. 21.2

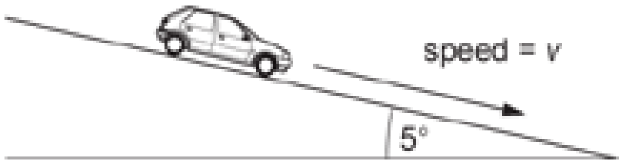
[3]

5(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

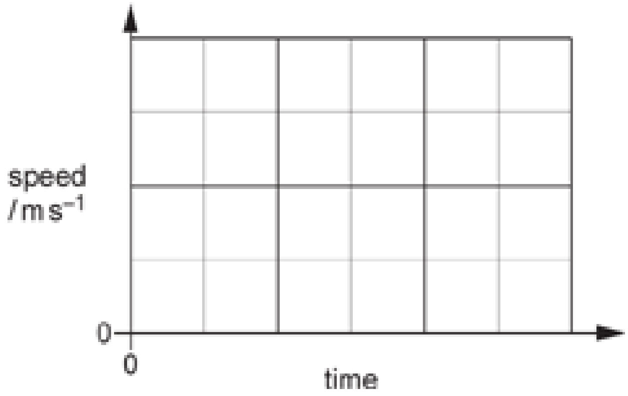
$F = kv^2$

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]

6. An object is released from rest and oscillates with simple harmonic motion. The maximum kinetic energy is *U*.

The object is stopped and the process is repeated with the initial displacement doubled.

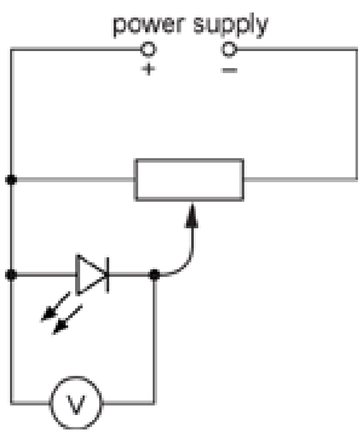
What is the new maximum kinetic energy?

A *U*
B 1.4*U*
C 2*U*
D 4*U*

Your answer **[1]**

7. A student carries out an investigation to determine the value of the Planck constant, *h*.

They use the circuit shown below



Initially the LED emits no light.

The student slowly increases the p.d. across the LED.

They record the p.d. V on the voltmeter when the LED just starts to emit light.

The measurement is repeated for LEDs that emit light with different frequencies f.

One of the LEDs emits red light. Another of the LEDs emits blue light.

The red LED emits 3.3×10^{15} photons per second.

The blue LED emits light with frequency 6.38×10^{14} Hz.

The manufacturer lists the power rating of each of the LEDs as 1 mW.

The student states that there are more photons emitted per second from the blue LED than from the red LED.

Deduce, by calculation, whether the student is correct.

Use $h = 6.63 \times 10^{-34}$ J s.

[3]

8. A student investigates the motion of falling objects.

The student releases a heavy ball and allows it to fall from a height of 2.0 m.

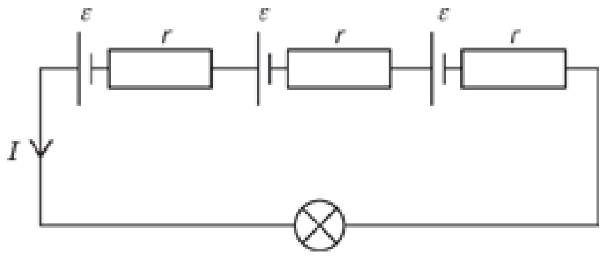
Calculate its expected speed when it hits the ground.

Assume that air resistance is negligible.

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

9. A torch uses three identical cells connected in series to a bulb.

Each cell has e.m.f. ε and internal resistance r.



Suggest why a torch battery with a large internal resistance may be undesirable.

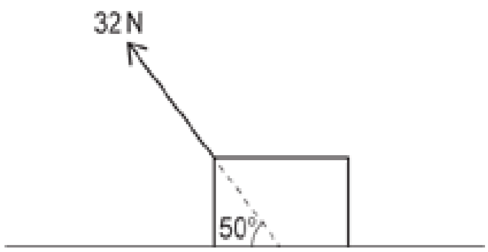
[2]

10. A lab technician is moving boxes.

The technician pulls a box using a rope with a force of 32 N.

The force acts at an angle of 50° to the horizontal.

The box moves a horizontal distance of 3.5 m along the floor in a time of 6 s.



Calculate the power of the technician as they move the box along the floor.

power = ... W **[3]**

11. A 3D printer can manufacture small objects.

Some 3D printers use polylactic acid (PLA). PLA is supplied in the form of long filaments. The 3D printer melts the PLA and builds up the shape of the desired object in layers.

The electrical supply to the heater in the printer has an e.m.f., ε, of 12 V. The power of the heater is 40 W.

The specific latent heat of fusion of PLA is 9.4×10^4 J kg^{-1} and its melting point is 160°C.

i. Define **specific latent heat of fusion**.

[1]

ii. Calculate the **maximum** mass *m* of PLA that the heater could melt in one minute.

m = ... kg **[2]**

iii. Explain why the printing process is slower in practice than your answer to **(ii)** suggests.

[2]

iv. **Fig. 6.1** shows the initial and final temperature of the PLA during the printing process.

Initially (point **A**), the solid PLA is at 20°C and is just entering the heater. Later (point **B**), the PLA has been added to the object and is solid again.

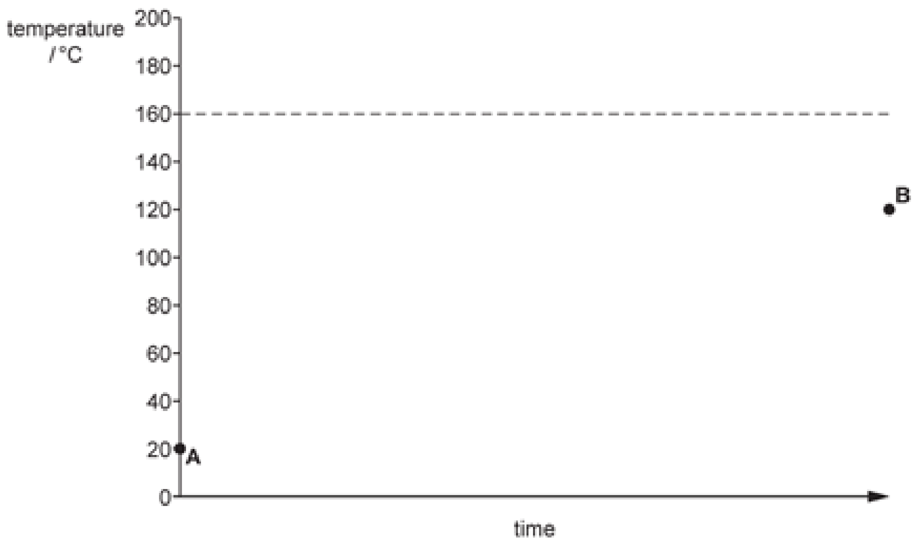


Fig. 6.1

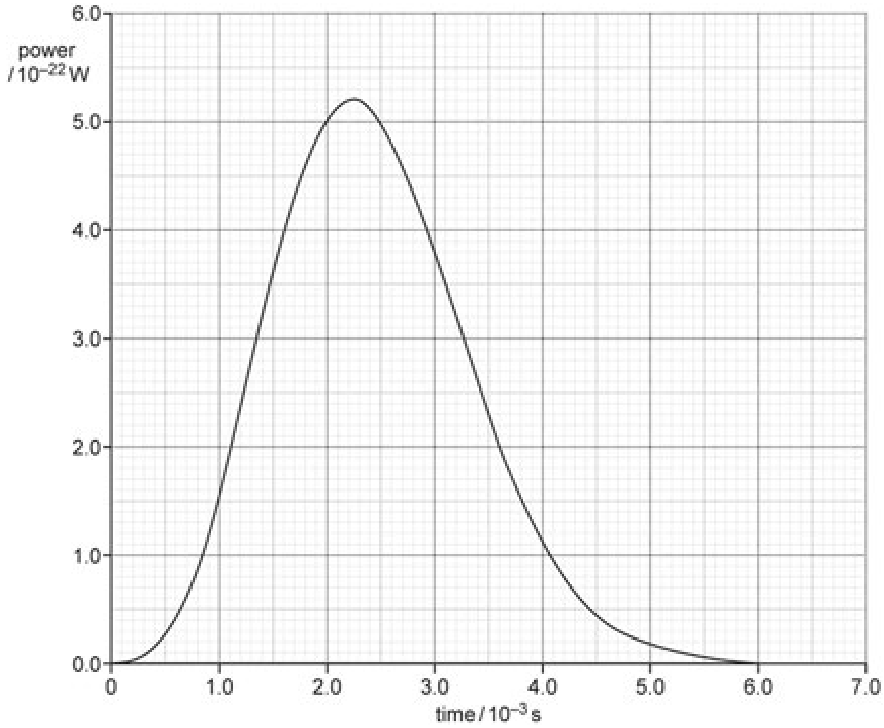
Complete **Fig. 6.1** to show how the temperature of the PLA changes between **A** and **B**.
You are **not** required to label the time axis.

[3]

12. A pulsar is a rapidly rotating neutron star that emits radio waves.

An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



i. By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

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

ii. The surface area of the telescope is about 3000 m^2.

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

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

13. Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

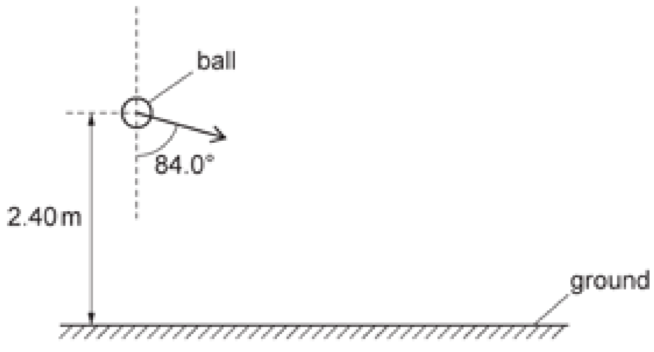
- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

[2]

14(a). A student throws a ball of mass 0.210 kg. The hand of the student is a vertical distance of 2.40 m above the ground. The ball leaves the student's hand with a velocity of 22.3 m s^{-1} at an angle of 84.0° to the vertical as shown in the diagram.



(not to scale)

Assume that air resistance is negligible.

Show that the vertical component u_v of the velocity of the ball as it leaves the student's hand is about 2.33 m s^{-1}.

[1]

(b). Show that the vertical component v_v of the velocity of the ball as it hits the ground is about 7.25 m s^{-1}.

[2]

(c). Calculate the kinetic energy E_k of the ball as it hits the ground.

E_k = ...J **[3]**

(d). Explain why the momentum of the ball changes as the ball travels from the hand to the ground.

[2]

15. The figure below shows a stationary glider of mass *m* on an air track.

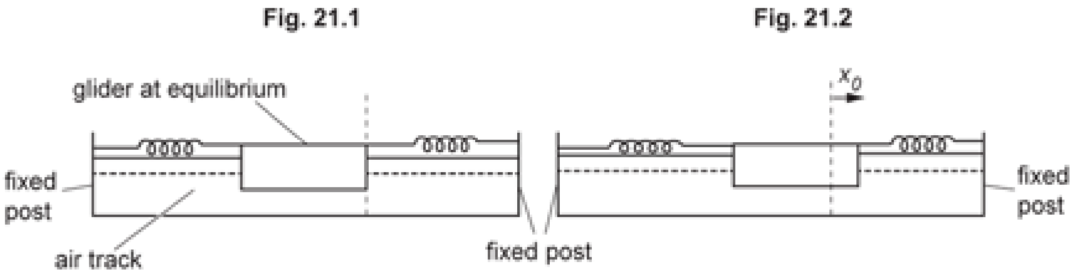
The glider has identical springs with force constant *k* attached to each end which are secured to fixed posts.

The air track blower is turned on and the glider is displaced a small distance x_0 , as seen in the figure. It is then released.

The glider moves horizontally in simple harmonic motion.

The springs remain in tension throughout the motion.

The time taken for 20 complete oscillations is measured, and the period *T* calculated.



The relationship between the period *T*, the mass of the glider *m* and the force constant *k* is described by the equation
$T^2 = \frac{2\pi^2 m}{k}$.

When the initial displacement is increased, one spring increases its extension while the extension of the other spring decreases.

Explain why the **maximum** kinetic energy of the motion increases.

[4]

16(a). The diagram shows a road where vehicles travel at high speeds.

Markings painted on the road surface are spaced 40 m apart.

Drivers are advised to keep at least two markings visible on the road between them and the vehicle in front.

The maximum speed vehicles travel at on the road is 110 km / hr. The table shows data from a driving manual for a vehicle travelling on a straight, horizontal road.

Speed (km / hr)	Braking distance (m)	Stopping distance (m)
110	75	96

i. Calculate the maximum speed *v* of vehicles on the road in S.I. units.

v = ...Unit = ...**[2]**

ii. A vehicle passes over one of the markings.

Calculate time taken to travel the 40 m distance between the two markings.

t = ...s **[1]**

iii. Using the table, explain why having markings 40 m apart helps prevent collisions.

[3]

(b). A vehicle with mass 1600 kg is travelling at 110 km / hr.
The driver sees an obstruction and applies the brakes to bring the vehicle to rest in 5.6 s.

i. Estimate the magnitude of the average resultant force *F* required to bring the vehicle to rest.

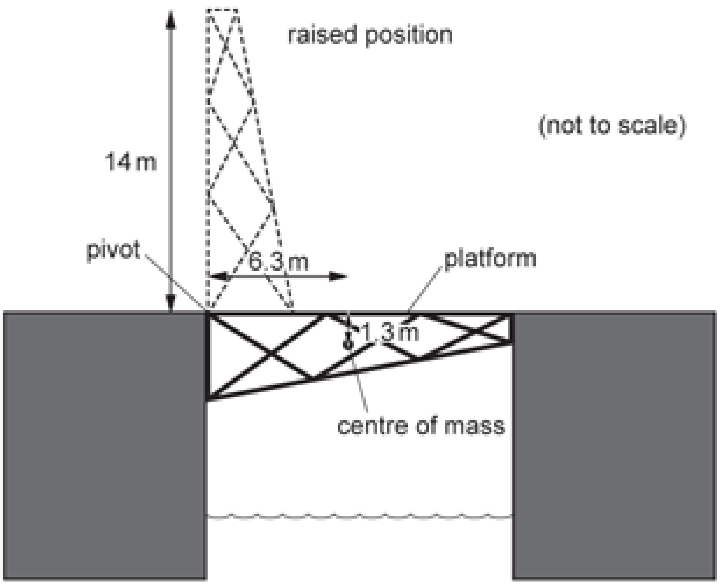
F = ...N **[2]**

ii. Explain the effect on the distance required to bring the vehicle to rest if the road has an upwards slope.

[2]

17. The figure below shows a bridge.

The bridge can be raised by an electric motor to allow tall ships to pass underneath.



The moving section of the bridge is 14 m long and has a weight of 120 kN.

The centre of mass of the structure is 6.3 m from the pivot.

i. Calculate the average power required to raise the bridge to a vertical position in 90 s.

power .... W **[2]**

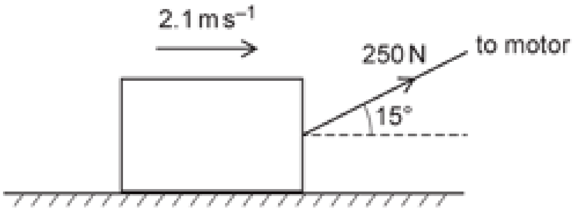
ii. Suggest why the actual electric motor used to lift the bridge has a maximum power output several times larger than the value calculated in **(i)**.

[1]

18. The diagram shows a motor pulling a load along a flat, horizontal surface.

The load is connected to the motor by a string at an angle of 15° to the surface. The tension in the string is 250 N. The load reaches a constant speed of 2.1 m s^{-1}.

The diagram does not show the other forces acting on the load.



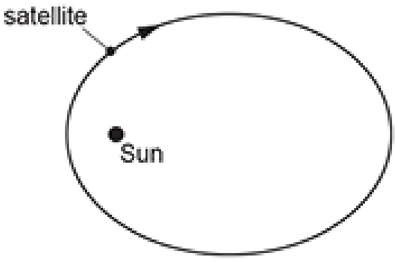
What is the output power of the motor?

A 120 W
B 140 W
C 460 W
D 510 W

Your answer ☐ **[1]**

19.

The Solar Orbiter satellite was launched in February 2020.
This satellite moves around the Sun in an elliptical orbit with a period of 168 days.
The diagram below shows the elliptical orbit of this satellite.



The closest distance of the satellite to the Sun is 4.20×10^{10} m and its furthest distance from the Sun is 1.37×10^{11} m.
The mass of the Sun is 2.0×10^{30} kg and the mass of the satellite is 209 kg.

i. The Earth has a mean orbital distance of 1.50×10^{11} m around the Sun and an orbital period of 365 days.

Use **Kepler's third la w** to calculate the mean orbital distance of the satellite from the Sun.

distance =.. m **[2]**

ii. The total kinetic and gravitational potential energy of the satellite in its orbit remains constant.

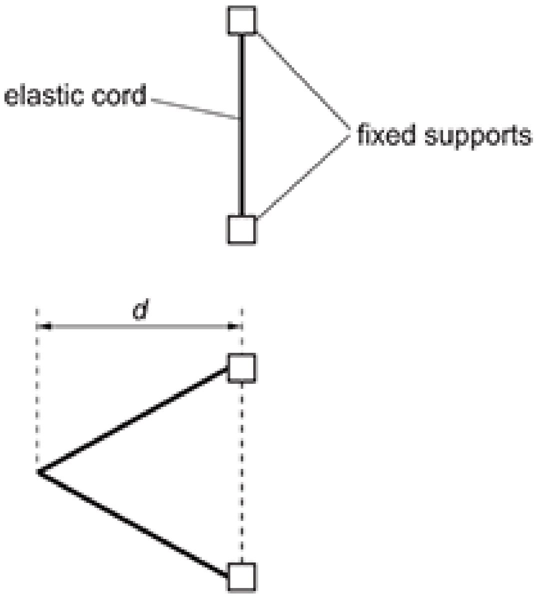
Calculate the change in the kinetic energy of the satellite as it travels from its furthest point from the Sun to its closest point to the Sun.

change in kinetic energy =... J **[3]**

iii. Suggest why the total energy of the satellite in its orbit around the Sun is not the same as the total energy of the satellite during its launch from the surface of the Earth.

-- **[1]**

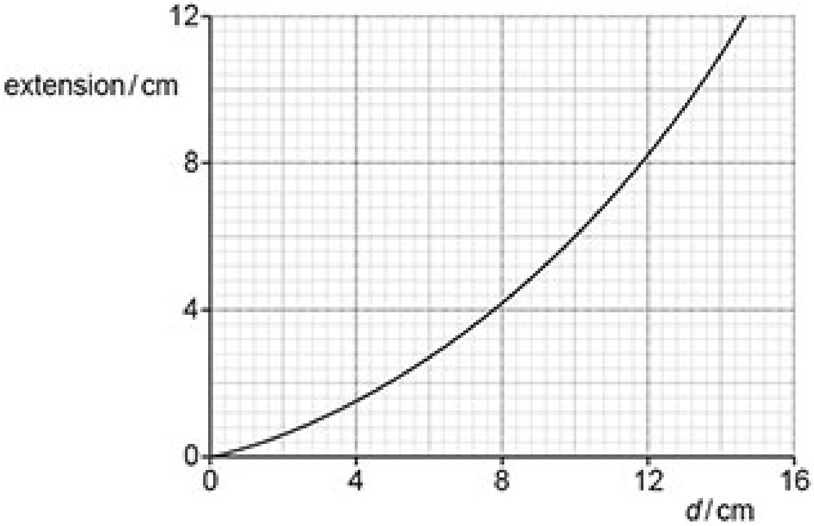
20. A simple catapult is made by an elastic cord fixed to two supports, as shown below.



The unstretched length of the cord is the same as the distance between the supports.
The distance that the centre of the cord has been pulled back is *d*.

The cord has a force constant of 500 Nm^{-1}.

The variation of the extension of the cord with distance *d* is shown below.



A small ball of mass 30 g is placed at the centre of the cord and drawn back with *d* = 10 cm.

The ball is released and launched horizontally from a height of 1.5 m above the horizontal ground.

i. Use the graph to show that the elastic potential energy *E* in the cord is about 1 J.

[3]

ii. Show that the maximum speed at which the ball leaves the catapult is about 8 ms^{-1}.

[2]

iii. Calculate the horizontal distance *R* travelled by the ball before it strikes the horizontal ground. Ignore the effects of air resistance in your calculation.

R = ... m **[3]**

iv. Explain how the value of *R* calculated in **(iii)** compares with the actual value.

[2]

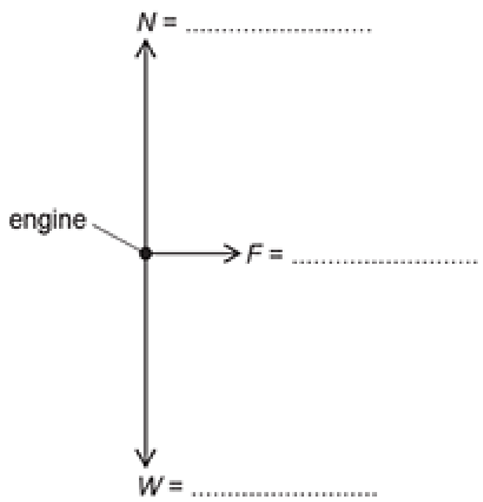
21(a). An electric engine of mass 17 000 kg has a constant power output of 280 kW and it can reach a maximum speed of 42 ms^{-1} on horizontal rails. The maximum kinetic energy of the engine is 15 MJ.

The engine is initially at rest on long horizontal rails.
Show that the minimum time taken for the engine to reach its maximum speed is about 1 minute.

[1]

(b). The engine is moving along the horizontal rails at the constant maximum speed of 42 ms^{-1}.
The weight of the engine is *W*, the total normal contact force from the rails is *N* and the total friction between the wheels and the rails is *F*.
F is responsible for the motion of the engine to the **right**.

Complete the free body diagram for the engine by showing a missing force, and the magnitudes of all the forces. There is space for you to do any calculations below the diagram.



[3]

(c). The speed of the engine is 42 ms^{-1}.

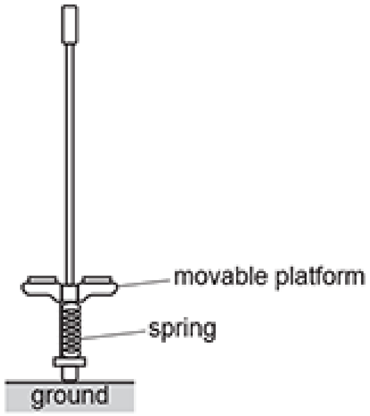
The driver sees an obstruction 167 m from the front of the engine. The engine is switched off and the brakes are applied.
The constant force opposing motion is 120 kN. The reaction time of the driver is 0.40 s.

Show with the help of calculations, that the engine will stop before reaching the obstruction.

[4]

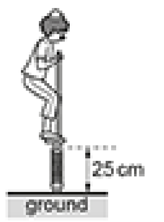
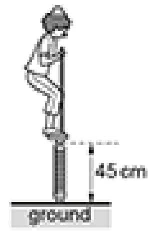
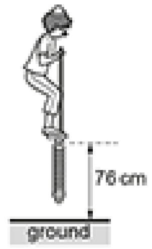
22(a). A pogo stick is a spring-based toy used by a circus clown for jumping vertically up and down.

A **compression** spring is fixed to the bottom of the pogo stick. The upper end of the spring is attached to a movable platform.



The force constant of the spring is 1.7×10^4 N m^{-1}.
The mass of the clown is 68 kg.
The mass of the pogo stick is negligible compared with the mass of the clown.

The table below shows the state of the spring and the clown in three different positions.

	Position A	**Position B**	**Position C**
			
State of spring	fully compressed	original length	original length
State of clown	stationary	Moving vertically upwards at maximum speed	stationary
Height of platform above the ground / cm	25	45	76

A student uses the following expression to determine the maximum speed v of the clown in position **B**:
maximum energy E stored in the compressed spring = $\frac{1}{2} \times 68 \times v^2$.

Explain why this expression is incorrect. You are not expected to do any calculations.

____

____ **[1]**

(b). Describe the energy changes taking place between positions **B** and **C**.

____

____ **[1]**

23. An electric motor is used to lift a weight of 4.0 N through a vertical height of 0.90 m in 1.8 s. The efficiency of the motor is 20%.
What is the electrical power supplied to the motor?

A 0.40 W
B 2.0 W
C 3.6 W
D 10 W

Your answer ☐ **[1]**

24. A car of mass 1000 kg is travelling on a straight and horizontal road. The driver applies the brakes.
The speed of the car decreases from 20 m s^{-1} to 15 m s^{-1} in 2.4 s.
What is the average power dissipated by the brakes?

A 1.0×10^3W
B 5.2×10^3 W
C 3.6×10^4 W
D 8.3×10^4 W

Your answer ☐ **[1]**

25(a).

A ball of mass 0.16 kg is dropped from rest from a height of 2.5 m above the ground.

Assume air resistance is negligible.

Calculate

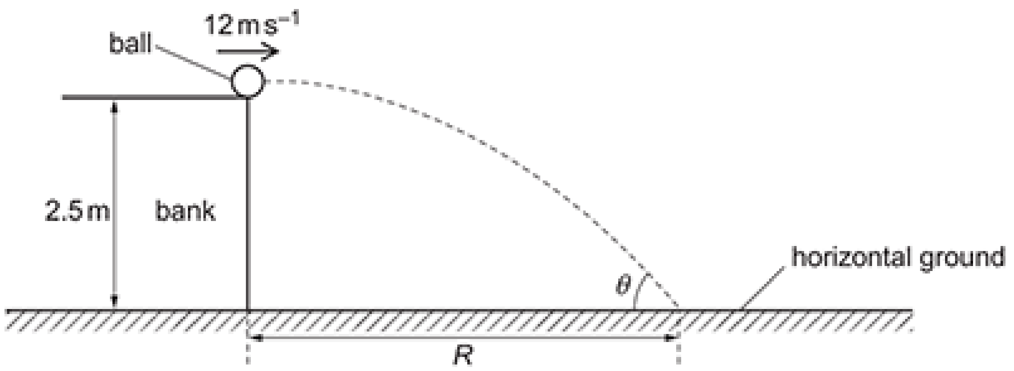
i. the change in gravitational energy E_p

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

ii. the velocity *v* of the ball as it reaches the ground.

v = ... ms^{-1} **[2]**

(b). The ball from **(a)** is now fired horizontally with a speed of 12 ms^{-1} from a bank.
The height of the bank is 2.5 m.
The time for the ball to travel from the edge of the bank to the horizontal ground is 0.71 s.
The path of the ball is shown in the diagram.
The ball hits the horizontal ground a distance *R* from the bottom of the bank.
Assume air resistance is negligible.



Calculate

i. *R*

R = ... m **[1]**

ii. the kinetic energy E_k of the ball as it reaches the ground

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

iii. the angle *θ* between the ground and the direction of the ball as it reaches the ground.

θ = ... ° **[1]**

END OF QUESTION PAPER