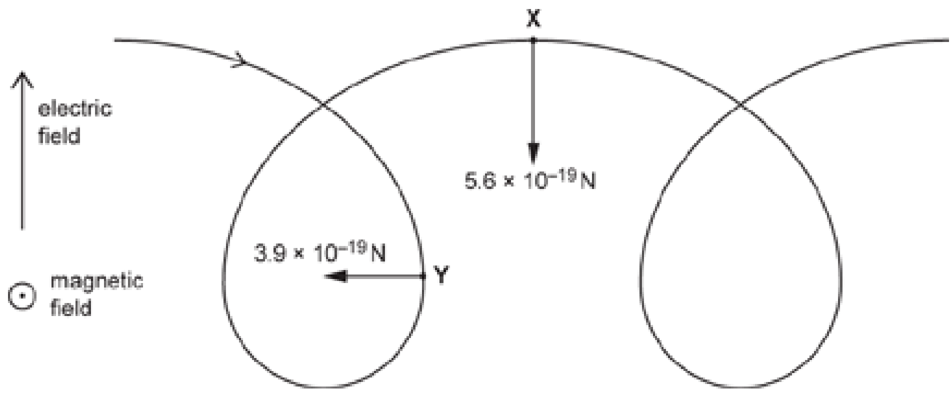
1(a). The figure below shows the path of a proton moving in a region occupied by both an electric field and a magnetic field.

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. A car drives over a bridge at speed v. The path of the car is part of a vertical circle of radius r. The mass of the driver is m.

At the top of the bridge the driver of the car experiences apparent weightlessness and no normal contact force from the car seat.

The acceleration of free fall is g.

Which statement is correct?

A $mg = 0$
B $v \geq gr$
C $v^2 \geq gr$
D $mv^2 \geq gr$

Your answer ☐ **[1]**

4. A rubber bung is attached to a string. The bung is whirled around in a horizontal circle of radius r. The rotational period of the bung is T. The tension in the string is kept constant as the bung is whirled around at different speeds.

Which relationship is correct for this whirling bung?

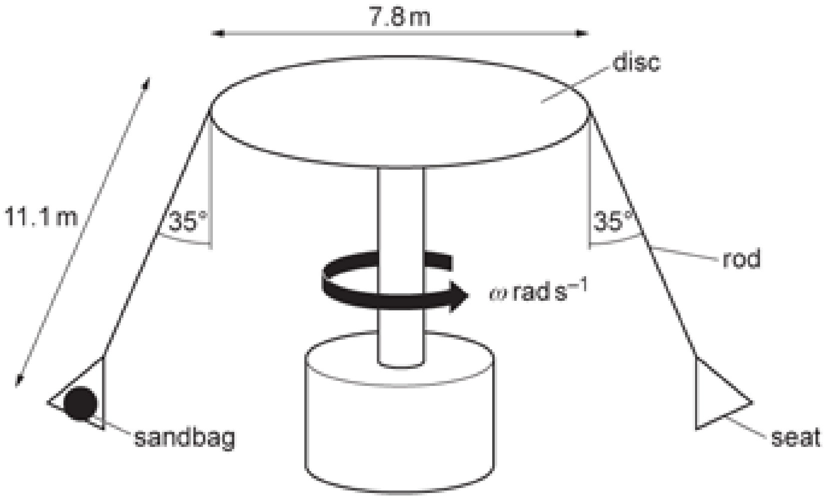
A $T \propto r$
B $T^2 \propto r$
C $T \propto r^2$
D $T \propto \sqrt{r}$

Your answer ☐ **[1]**

5(a). The diagram below shows a fairground ride. Each rider is secured in a seat suspended by a rod.

The distance from the top of the rod to the base of the seat is 11.1 m.

The rod is attached to the edge of a disc of diameter 7.8 m.



(not to scale)

To test the equipment a sandbag is attached to the seat and the ride is started.

The combined mass of the seat and the sandbag is 12 kg.

The rod makes an angle of 35° with the vertical.

i. Draw an arrow labelled T on the diagram to represent the tension in the rod.

[1]

ii. Show that the radius of the circular path followed by the sandbag is about 10 m.

[2]

iii. Calculate the tension *T* in the rod.

T = ... N **[3]**

iv. Show that the angular velocity of the ride is about 0.8 radians per second.

[2]

(b). When the seat is at its highest point the sandbag is 17 m above the ground. The sandbag is released from the seat to model an object being dropped by a rider.

i. Calculate *t*, the time taken for the sandbag to reach the ground.

t = ... s **[2]**

ii. Using your answer to **(a)(iv)**, determine the horizontal displacement *s* travelled by the sandbag before hitting the ground.

s = ...m **[3]**

iii. Determine, with reasons, the effect on the horizontal displacement travelled if the object released from the ride was a shoe from a rider.

[3]

6. A satellite is in geostationary orbit 36 000 km above the Earth's surface. The Earth has a radius of 6400 km.

At what speed is the satellite moving relative to the centre of the Earth?

A 0 m s^{-1}
B 490 m s^{-1}
C 2.6 km s^{-1}
D 3.1 km s^{-1}

Your answer ☐ **[1]**

7. The table shows some data on the planet Venus.

Mass / kg	4.87×10^{24}
Radius / km	6050
Density of atmosphere at surface / kg m^{-3}	65
Period of rotation about its axis / hours	5830

Two identical space probes, **A** and **B**, land on a flat surface on Venus.

Probe **A** lands at the north pole. Probe **B** lands on the equator.

Each probe has mass 760 kg and volume 1.7 m^3.

i. Calculate the centripetal acceleration *a* of probe **B** at the equator due to the rotation of Venus about its axis.

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

ii. The atmosphere exerts the same upthrust on each probe.

Using your answer to **(a)**, calculate the upthrust acting on each probe.

upthrust = ... N **[3]**

iii. Explain which probe will experience the greater normal contact force from the surface of Venus.

[3]

8.

A planet of mass *m* is in a circular orbit around a star of mass *M*.

Use the equation for Newton's law of gravitation and your knowledge of circular motion to show that the relationship between the orbital period *T* of the planet and its orbital radius *r* is $T^2 \propto r^3$.

[3]

END OF QUESTION PAPER