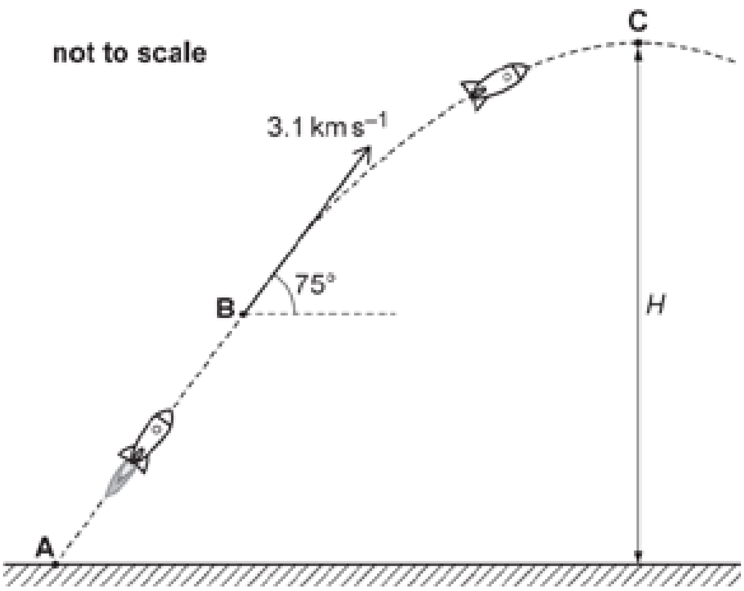
1. A scientist uses a rocket to study the Earth's atmosphere.

The scientist launches the rocket from rest at the point **A** at t = 0 seconds. The force produced by the rocket's engine causes it to accelerate.

At t = 50 seconds, the rocket's engine no longer produce an accelerating force as all of the fuel has been used. The rocket has reached point **B**. Its velocity is now 3.1 km s^{-1} at an angle of 75° to the horizontal.



The rocket reaches its maximum height at point **C**.

- Estimate the vertical displacement H between **A** and **C**. Assume that g = 9.81 m s^{-2} throughout.
- Clearly state any other assumptions required at each stage in your calculations.
- Evaluate the assumption that g = 9.81 m s^{-2} between **A** and **C**, supporting your discussion with a calculation. Assume that the radius of the Earth ≈ 6400 km.

[6]

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]

(c). A satellite in a geostationary orbit around the Earth appears to remain at the same point in the sky when viewed from the ground.

i. State **one** condition required for an orbit to be geostationary.

[1]

ii. Calculate the orbital radius of the geostationary satellite. The mass of the Earth is 6.0×10^{24} kg.

orbital radius = ... m **[3]**

3. At the surface of a planet with radius *r* the magnitude of the gravitational field strength is *g*.

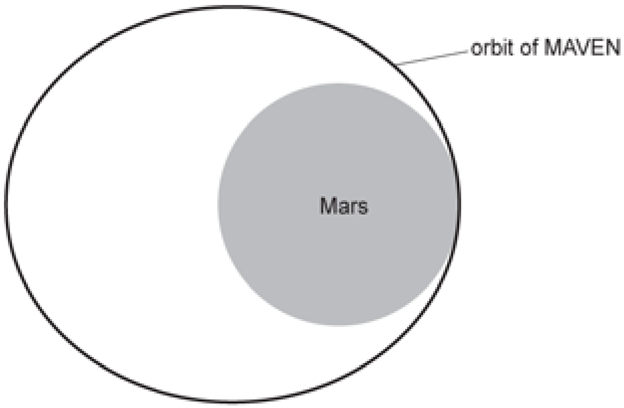
What is the escape velocity from the surface of the planet?

A $\sqrt{rg}$
B $\sqrt{2g}$
C $\sqrt{2rg}$
D $2rg$

Your answer ☐ **[1]**

4(a). The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

The diagram below shows the orbit of MAVEN around Mars.



i. Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration.

[1]

ii. Explain how Kepler's 1st law applies to MAVEN's orbit around Mars.

[2]

(b). The table shows data for four orbits around Mars.

Phobos and Deimos are moons of Mars.

An areostationary orbit for Mars is the equivalent of a geostationary orbit for Earth.

Orbit	Time period / hours	Average distance from centre of Mars / km
MAVEN	4.5	6 500
Phobos	7.7	9 400
Deimos	30	23 000
Areostationary	25	20 000

i. Show that Kepler's 3rd law applies to this data.

[2]

ii. Suggest **two** reasons why MAVEN was **not** placed in an areostationary orbit.

1 ______________________________

____

____

2 ______________________________

____

______________________________ **[2]**

5. A continuous stream of particles called a solar wind flows from the surface of the star into the surrounding space.

These particles include helium nuclei of mass 6.6×10^{-27} kg.

Assume that the atmosphere is modelled as an ideal gas.

i. Show that the typical kinetic energy of a helium nucleus in the atmosphere is about 10^{-16} J.

[2]

ii. The gravitational potential energy of a helium nucleus in the outer layer of the star is -2.3×10^{-16} J.

Calculate the gravitational potential energy *U* at the maximum distance from the star that a helium nucleus could reach.

U = ... J **[1]**

iii. Calculate the distance from the centre of the star reached by this helium nucleus.

distance = ... m **[3]**

iv. Explain why the star has a solar wind that reaches a much greater distance from the star than found in **(iii)**.

____

______________________________ **[1]**

6. Two identical spheres, each of mass 8700 kg, have a space of 3.6 m between their centres.

What is the magnitude of the gravitational force they exert on each other?

A 2.0×10^{-3} N
B 3.9×10^{-4} N
C 7.5×10^{-4} N
D 4.5×10^{-8} N

Your answer ☐ **[1]**

7. 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]**

8. 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

Calculate the magnitude of the gravitational field strength g at the surface of Venus.

Give your answer to **3** significant figures.

g = ... N kg^{-1} **[3]**

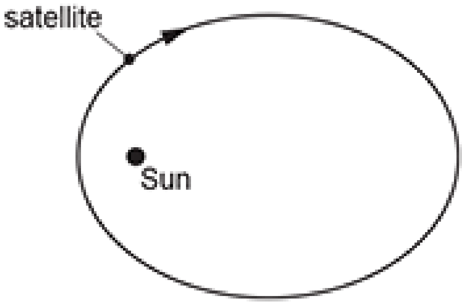
9(a).

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]

(b). 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]**

10. Which pair of quantities do **not** have the same, or equivalent, units?

A acceleration, gravitational field strength
B angular frequency, angular velocity
C gravitational potential, kinetic energy
D impulse, momentum

Your answer ☐ **[1]**

END OF QUESTION PAPER