6 A proton can be considered to be both a point charge and a point mass. There is an electric field and a gravitational field associated with the proton.

Which of the following statements about the fields is **not** correct?

☒ **A** Field strength is a vector.

☒ **B** Potential is always less than 0.

☒ **C** Potential is proportional to $\frac{1}{\text{distance from proton}}$

☒ **D** Field strength is proportional to $\frac{1}{(\text{distance from proton})^2}$

(Total for Question 6 = 1 mark)

7 A pendulum of length l with a bob of mass m oscillates with frequency f.

(Total for Question 7 = 1 mark)

(Total for Question 8 = 1 mark)

16 Astronauts on the 1971 Apollo 14 mission to the Moon brought back many rock samples. It is now believed that one of these contains a piece of rock that originated on Earth about 4 billion years (4×10^9 years) ago.

The piece of rock is believed to have been launched into space when an asteroid struck the Earth.

(a) The rock sample contains uranium. The radioactive decay of uranium allows it to be used to determine the time since the rock was formed on the Earth.

(i) The uranium isotope $^{238}_{92}U$ becomes the lead isotope $^{206}_{82}Pb$ through a series of radioactive decays.

Calculate the number of α particles and the number of β particles emitted for one nucleus of $^{238}_{92}U$ to decay to become a nucleus of $^{206}_{82}Pb$.

(2)

.....

.....

.....

.....

Number of α particles = ...

Number of β particles = ...

(ii) The half-life of $^{238}_{92}U$ is 4.47×10^9 years.

The half-lives of the other stages in the decay to $^{206}_{82}Pb$ are relatively so short that they can be ignored.

There was no lead in the rock when it formed, so all the $^{206}_{82}Pb$ in the sample is a product of $^{238}_{92}U$ decay. In the sample, for every 103 uranium nuclei present at the start, 50 are now lead nuclei.

Show that the age of the sample is about 4×10^9 years.

(3)

(b) The gravitational potential between the Earth and the Moon due to the combined effect of their gravitational fields increases to a maximum value of $-1.28\,\text{MJ kg}^{-1}$ at a point between them.

Calculate the minimum speed at which a rock would have to leave the Earth in order to reach the Moon.

In your calculation, you may assume the rock has zero kinetic energy when it has maximum potential energy.

mass of Earth = 5.97×10^{24} kg
radius of Earth = 6370 km

(4)

Minimum speed = ...

(c) Four billion years ago, the Moon had a different orbital period, because it was closer to the Earth than it is today.

Calculate the period of the Moon's orbit four billion years ago, when the radius of its orbit was 1.34×10^8 m.

mass of Earth = 5.97×10^{24} kg

(3)

Period = ...

(Total for Question 16 = 12 marks)

(Total for Question 7 = 1 mark)

8 The acceleration of free fall at the surface of the Earth is $9.81\,\text{m s}^{-2}$.
The mass of the Earth is M and the diameter of the Earth is D.

Which of the following gives the acceleration of free fall, in m s^{-2}, at the surface of a planet with diameter $\frac{D}{2}$ and mass $\frac{M}{9}$?

☒ **A** $\frac{9.81 \times 2}{9}$

☒ **B** $\frac{9.81 \times 4}{9}$

☒ **C** $\frac{9.81 \times 2}{3}$

☒ **D** $\frac{9.81 \times 9}{4}$

(Total for Question 8 = 1 mark)

17 Astronomers observing stars at the centre of our galaxy have suggested that many of them are orbiting a supermassive black hole. The mass of this black hole is 9.2×10^{36} kg.

(a) Calculate the orbital period for a star in a circular orbit at a distance of 1.9×10^{14} m from a black hole of this mass.

(3)

Orbital period = ...

(b) The star S0-2 is in a highly elliptical orbit around the position of the black hole.

At its point of closest approach, S0-2 is at a distance of 1.8×10^{13} m from the centre of the black hole.

At the most distant point of its orbit, S0-2 is 2.7×10^{14} m from the black hole.

(i) Show that the change in gravitational potential between the closest and most distant points in this orbit is about 3×10^{13} J kg^{-1}.

(2)

(ii) At its point of closest approach, the star is travelling at a speed of $8.1 \times 10^6\,m\,s^{-1}$.

Calculate the speed of S0-2 at the furthest point in its orbit using the change in gravitational potential.

mass of S0-2 = 2.4×10^{31} kg

(3)

Speed = ...

(c) Trigonometric parallax and Hubble's law are two methods used to determine astronomical distances.
Explain whether either of these methods is suitable to determine the distance to S0-2.

(3)

(Total for Question 17 = 11 marks)

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 A skydiver steps out of an aeroplane and falls from rest, towards the ground. Her parachute opens a short time after she reaches terminal velocity.

Which of the following statements is correct for the vertical acceleration a of the skydiver until her parachute opens?

☒ **A** a decreases to zero

☒ **B** a increases to a maximum

☒ **C** a is constant and equal to g

☒ **D** a is constant but less than g

(Total for Question 1 = 1 mark)

(Total for Question 2 = 1 mark)

12 In February 2021 the spacecraft Perseverance Rover landed on Mars. When the spacecraft was 11.0 km above the surface of Mars, parachutes opened to slow the descent. The parachutes detached from the spacecraft when it was 2.1 km above the surface of Mars.

Calculate the change in gravitational potential energy of the spacecraft during the parachute section of its descent.

mass of spacecraft = 1030 kg
mass of Mars = 6.39×10^{23} kg
radius of Mars = 3390 km

Change in gravitational potential energy of the spacecraft = ...

(Total for Question 12 = 3 marks)