Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.

1a. Show that the energy of photons from the UV lamp is about 10 eV.  

Markscheme

\[ E_1 = -13.6 \text{ eV} \quad E_2 = -\frac{13.6}{4} = -3.4 \text{ eV} \]

energy of photon is difference \( E_2 - E_1 = 10.2 \approx 10 \text{ eV} \)

Must see at least 10.2 eV.

[2 marks]

1b. Calculate, in J, the maximum kinetic energy of the emitted electrons.  

Markscheme

\[ 10 - 5.1 = 4.9 \text{ eV} \]
\[ 4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19} \text{ J} \]

Allow 5.1 if 10.2 is used to give \( 8.2 \times 10^{-19} \text{ J} \).

[2 marks]

1c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate.  

[2 marks]
Markscheme

EPE produced by battery
exceeds maximum KE of electrons / electrons don't have enough KE

For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.

[2 marks]  

1d. The variable voltage can be adjusted so that no electrons reach the collecting plate.  [1 mark]
Write down the minimum value of the voltage for which no electrons reach the collecting plate.

Markscheme

4.9 «V»

Allow 5.1 if 10.2 is used in (b)(i).
Ignore sign on answer.

[1 mark]  

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.

1e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V.  [2 marks]
1f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. [2 marks]

Markscheme
kinetic energy at collecting plate = 0.9 «eV»
speed = «
\[ \sqrt{\frac{2 \times 0.9 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} \] = 5.6 \times 10^5 «ms^{-1}»

Allow ECF from MP1 [2 marks]

2a. A planet has radius \( R \). At a distance \( h \) above the surface of the planet the gravitational field strength is \( g \) and the gravitational potential is \( V \).

2a. State what is meant by gravitational field strength. [1 mark]

Markscheme
the «gravitational» force per unit mass exerted on a point/small/test mass [1 mark]

2b. Show that \( V = -g(R + h) \). [2 marks]
at height $h$ potential is $V = -\frac{GM}{(R+h)}$

field is $g = \frac{GM}{(R+h)^2}$

«dividing gives answer»

Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ and then cancels the deltas and substitutes $R + h$

[2 marks]

2c. Draw a graph, on the axes, to show the variation of the gravitational potential $V$ of the planet with height $h$ above the surface of the planet.

![Graph of gravitational potential vs height](image)

Markscheme

correct shape and sign
non-zero negative vertical intercept

[2 marks]

2d. A planet has a radius of $3.1 \times 10^6$ m. At a point P a distance $2.4 \times 10^7$ m above the surface of the planet the gravitational field strength is $2.2$ N kg$^{-1}$. Calculate the gravitational potential at point P, include an appropriate unit for your answer.

[1 mark]
**Markscheme**

\[ V = -2.2 \times (3.1 \times 10^6 + 2.4 \times 10^7) \rightleftharpoons 6.0 \times 10^7 \text{ J kg}^{-1} \]

*Unit is essential*

*Allow eg MJ kg\(^{-1}\) if power of 10 is correct*

*Allow other correct SI units eg m\(^2\)s\(^{-2}\), N m kg\(^{-1}\)*

[1 mark]

2e. The diagram shows the path of an asteroid as it moves past the planet. 

When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

**Markscheme**

*total energy at P = 0 / KE gained = GPE lost*

\[ \frac{1}{2}mv^2 + mV = 0 \rightleftharpoons v = \sqrt{-2V} \]

\[ v = \sqrt{2 \times 6.0 \times 10^7} \rightleftharpoons 1.1 \times 10^4 \text{ m s}^{-1} \]

*Award [3] for a bald correct answer*

*Ignore negative sign errors in the workings*

*Allow ECF from 6(b)*

[3 marks]

2f. The mass of the asteroid is \(6.2 \times 10^{12}\) kg. Calculate the gravitational force experienced by the planet when the asteroid is at point P.

[2 marks]
**Markscheme**

*ALTERNATIVE 1*

force on asteroid is \(6.2 \times 10^{12} \times 2.2 = 1.4 \times 10^{13}\) N

«by Newton’s third law» this is also the force on the planet

*ALTERNATIVE 2*

mass of planet = \(2.4 \times 10^{25}\) kg «from \(V = -\frac{GM}{(R+h)}\) »

force on planet « \(\frac{GMm}{(R+h)^2}\) » = \(1.4 \times 10^{13}\) N

*MP2 must be explicit*

[2 marks]

The diagram shows the gravitational field lines of planet X.

---

3a. Outline how this diagram shows that the gravitational field strength of planet X decreases with distance from the surface.

**Markscheme**

the field lines/arrows are further apart at greater distances from the surface
3b. The diagram shows part of the surface of planet X. The gravitational potential at the surface of planet X is \(-3\, V\) and the gravitational potential at point Y is \(-V\).

Sketch on the grid the equipotential surface corresponding to a gravitational potential of \(-2\, V\).

**Markscheme**

- circle centred on Planet X
- three units from Planet X centre

3c. A meteorite, very far from planet X begins to fall to the surface with a negligibly small initial speed. The mass of planet X is \(3.1 \times 10^{21}\) kg and its radius is \(1.2 \times 10^6\) m. The planet has no atmosphere. Calculate the speed at which the meteorite will hit the surface.
loss in gravitational potential = \( \frac{6.67 \times 10^{-11} \times 3.1 \times 10^{21}}{1.2 \times 10^6} \) 
\( \approx 1.72 \times 10^5 \text{ JKg}^{-1} \)
equate to \( \frac{1}{2}v^2 \) 
\( v = 590 \text{ m s}^{-1} \)

3d. At the instant of impact the meteorite which is made of ice has a temperature of 0 °C. [2 marks] Assume that all the kinetic energy at impact gets transferred into internal energy in the meteorite. Calculate the percentage of the meteorite’s mass that melts. The specific latent heat of fusion of ice is \( 3.3 \times 10^5 \text{ J kg}^{-1} \).

available energy to melt one kg = \( 1.72 \times 10^5 \text{ J} \)

fraction that melts is \( \frac{1.72 \times 10^5}{3.3 \times 10^5} = 0.52 \text{ OR 52%} \)

4a. Outline why the gravitational potential is negative. [2 marks]

potential is defined to be zero at infinity
so a positive amount of work needs to be supplied for a mass to reach infinity

4b. The gravitational potential due to the Sun at a distance \( r \) from its centre is \( V_S \). Show that [1 mark] 
\( rV_S = \text{constant} \).
4c. Calculate the gravitational potential energy of the Earth in its orbit around the Sun. Give your answer to an appropriate number of significant figures.

**Markscheme**

\[ V_s = -\frac{GM}{r} \] so \( r \times V_s = -GM \) = constant because \( G \) and \( M \) are constants

**4d. Calculate the total energy of the Earth in its orbit.**

**Markscheme**

**ALTERNATIVE 1**

work leading to statement that kinetic energy \( \frac{GMm}{2r} \), AND kinetic energy evaluated to be \( \approx 2.7 \times 10^{33} \text{ J} \)

energy \( \approx PE + KE \) = answer to (b)(ii) + \( 2.7 \times 10^{33} \) = \( \approx \) \( 2.7 \times 10^{33} \text{ J} \)

**ALTERNATIVE 2**

statement that kinetic energy is \( \approx -\frac{1}{2} \) gravitational potential energy in orbit

so energy \( \approx \frac{\text{answer to (b)(ii)}}{2} \) = \( \approx 2.7 \times 10^{33} \text{ J} \)

Various approaches possible.

4e. An asteroid strikes the Earth and causes the orbital speed of the Earth to suddenly decrease. Suggest the ways in which the orbit of the Earth will change.

**[2 marks]**
4f. Outline, in terms of the force acting on it, why the Earth remains in a circular orbit around the Sun. 

**Markscheme**

centripetal force is required
and is provided by gravitational force between Earth and Sun

*Award [1 max] for statement that there is a “centripetal force of gravity” without further qualification.*


5a. Explain what is meant by the gravitational potential at the surface of a planet. 

**Markscheme**

the «gravitational» work done «by an external agent» per/on unit mass/kg

*Allow definition in terms of reverse process of moving mass to infinity eg “work done on external agent by…”.*

*Allow “energy” as equivalent to “work done”*

in moving a «small» mass from infinity to the «surface of» planet / to a point

*N.B.: on SL paper Q5(a)(i) and (ii) is about “gravitational field”.*

5b. An unpowered projectile is fired vertically upwards into deep space from the surface of planet Venus. Assume that the gravitational effects of the Sun and the other planets are negligible.

The following data are available.

Mass of Venus = \(4.87 \times 10^{24}\) kg
Radius of Venus = \(6.05 \times 10^6\) m
Mass of projectile = \(3.50 \times 10^3\) kg
Initial speed of projectile = \(1.10 \times \text{escape speed}\)

(i) Determine the initial kinetic energy of the projectile.

(ii) Describe the subsequent motion of the projectile until it is effectively beyond the gravitational field of Venus.
**Markscheme**

i
escape speed
*Care with ECF from MP1.*

\[
v = \sqrt{\left( \frac{2GM}{R} \right)} = x \text{ or } 1.04 \times 10^4 \text{ m s}^{-1}
\]

*or «1.1 \times 10^4 \text{ m s}^{-1}» = 1.14 \times 10^4 \text{ m s}^{-1} »

KE = «0.5 \times 3500 \times (1.1 \times 10^4 \text{ m s}^{-1})^2 = 2.27 \times 10^{11} \text{ J} »

*Award [1 max] for omission of 1.1 – leads to 1.88 \times 10^{11} \text{ m s}^{-1}. Award [2] for a bald correct answer.*

ii
Velocity/speed decreases / projectile slows down «at decreasing rate»

«magnitude of» deceleration decreases «at decreasing rate»
*Mention of deceleration scores MP1 automatically.*

velocity becomes constant/non-zero

*OR*
deceleration tends to zero

*Accept “negative acceleration” for “deceleration”.*

*Must see “velocity” not “speed” for MP3.*

6a. Outline what is meant by escape speed. [1 mark]

**Markscheme**

speed to reach infinity/zero gravitational field

*OR*
speed to escape gravitational pull/effect of planet’s gravity

*Do not allow reference to leaving/escaping an orbit.*
*Do not allow “escaping the atmosphere”.*

6b. A probe is launched vertically upwards from the surface of a planet with a speed \(v = \frac{3}{4}v_{\text{esc}}\) [3 marks]

where \(v_{\text{esc}}\) is the escape speed from the planet. The planet has no atmosphere.

Determine, in terms of the radius of the planet \(R\), the maximum height from the surface of the planet reached by the probe.
6c. The total energy of a probe in orbit around a planet of mass $M$ is $E = -\frac{GMm}{2r}$ where $[3\text{ marks}]$ $m$ is the mass of the probe and $r$ is the orbit radius. A probe in low orbit experiences a small frictional force. Suggest the effect of this force on the speed of the probe.

**Markscheme**

energy reduces/lost
radius decreases
speed increases
*Do not allow “kinetic energy reduces” for MP1*

---

This question is in **two parts. Part 1** is about electric fields and radioactive decay. **Part 2** is about waves.

**Part 1** Electric fields and radioactive decay

An ionization chamber is a device which can be used to detect charged particles.

The charged particles enter the chamber through a thin window. They then ionize the air between the parallel metal plates. A high potential difference across the plates creates an electric field that causes the ions to move towards the plates. Charge now flows around the circuit and a current is detected by the sensitive ammeter.

7a. On the diagram, draw the shape of the electric field between the plates. \[[2\text{ marks}]\]
The separation of the plates \( d \) is 12 mm and the potential difference \( V \) between the plates is 5.2 kV. An ionized air molecule \( M \) with charge \( +2e \) is produced when a charged particle collides with an air molecule.

7b. Calculate the electric field strength between the plates. [1 mark]

**Markscheme**

\[ 4.3 \times 10^5 \text{ (NC}^{-1}) \]

7c. Determine the change in the electric potential energy of \( M \) as it moves from the positive to the negative plate. [3 marks]

**Markscheme**

\[ \Delta E_P = q\Delta V \text{ or } 3.2 \times 10^{-19} \times 5.2 \times 10^3; \]
\[ 1.7 \times 10^{-15} \text{ (J)}; \]
\[ \text{negative/loss}; \]

Radium-226 \( (^{226}\text{Ra}) \) decays into an isotope of radon \( (\text{Rn}) \) by the emission of an alpha particle and a gamma-ray photon. The alpha particle may be detected using the ionization chamber but the gamma-ray photon is unlikely to be detected.

7d. Construct the nuclear equation for the decay of radium-226. [2 marks]

\[ ^{226}\text{Ra} \rightarrow \quad \text{Rn} + \quad \text{He} + \quad ^{0}_0\gamma \]

**Markscheme**

\( (^{226}\text{Ra} \rightarrow ^{222}\text{Rn} + ^{4}_2\text{He} + ^{0}_0\gamma) \)
\( ^{222}\text{Rn} \text{ or } ^{4}_2\text{He} ; \)
\[ \text{numbers balance top and bottom on right-hand side}; \]

7e. Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to 5% of its original activity. [3 marks]
**Markscheme**

\[ \lambda = \frac{\ln 2}{1600} = 4.33 \times 10^{-4} \text{ (yr}^{-1}) \];

\[ 0.05 = e^{-\lambda t} ; \]

6900 (years);

*Award [3] for a bald correct answer.*

*Award [2 max] for \(2.18 \times 10^{11}\) (s).*

*Award [1 max] to a candidate who identifies time as about 4.3 half-lives but cannot get further or gives an approximate reasoned answer.*

*However award [3] if number n of half-lives is calculated from \(0.05 = 2^{-n} = 4.32\) usually from use of log2 working) and time shown.*