Mark schemes

1

(a) work done per unit mass in bringing object from infinity to point

B1

potential at infinity zero by definition

B1

work has been done by the field so potential at all points closer than infinity negative

B1

3

(b) use of point on graph allow within ± small square

C1

substitution into $V = -\frac{GM}{r}$

C1

range from 590 – 6.90 × 10^{24} (kg)

A1

3

(c) (i) $\Delta E_p = -\frac{GMm}{R_E + h} + \frac{GMm}{R_E}$

C1

addition of radius of Earth to give 7.25 × 10^{6} (m)

C1

1.54 × 10^{10} (J)

A1

3

(ii) equates $\frac{mv^2}{r}$ and $G\frac{mM}{r^2}$

C1

to give $\Delta E_K = G\frac{mM}{2}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

C1

1.25×10^9 J

A1

positive or increase

B1

4

(iii) (lower altitude so) gpe decreases ke increases

C1

loss of gpe is twice gain in ke

A1

2

[15]

2 (a) mass depends only on the amount of matter present owtte

B1

weight is force between body and Earth/depends on *g/mg*/ gravitational field strength or answers in terms of Newton's gravitational law

B1

g (etc) varies at different points on and above the Earth or is different on different planets etc

B1

3

(b) (i) reference is ‘infinity’ where potential is 0

B1

energy has to be put in/work has to be done to move mass to infinity or a bodies energy/PE decreases as a body moves from infinity towards the Earth

B1

2

(ii) need to show *Vr* to be constant, clear from algebra or final statement

B1

two sets of data used correctly

B1

all three sets of data used correctly (4.02, 4.025, 4.028)

B1

3

(iii) energy change per kg = $(5.36 - 3.22) \times 10^7$ (J)

B1

total change = 963 (960) $\times 10^7$ J

B1

2

(c) (i) $GMm/r^2 = mv^2/r$ or $v = \sqrt{(GM/r)}$

C1

$v^2 = 3.2 \times 10^7 m^2s^{-2}$ or $v = 5670\ ms^{-1}$

C1

use of KE = ½ mv^2 using their v

C1

7.2 GJ

A1

4

(ii) KE changes by 4.8 GJ (allow ecf, 12 – their ci)

B1

1

(iii) total energy (supplied) = (4.8) GJ (cnao)

(allow 5.2 GJ using 10 GJ for change in E_p)
(allow variations due to rounding off if physics is correct in previous parts)

B1

1

[16]

3 (a) $\omega \left(= \frac{2\pi}{T}\right) = \frac{2\pi}{97 \times 60}$ [or $\omega \left(= \frac{360}{T}\right) = \frac{360}{97 \times 60}$]

$= 1.1 \times 10^{-3}$ (1.08×10^{-3}) **(1)** [= 6.2 (6.19) $\times 10^{-2}$]

rad s^{-1} [accept s^{-1}] **(1)** [degree s^{-1}]

3

(b) (i) $\frac{GMm}{r^2} = m\omega^2 r$ **or** $r^3 = \frac{GM}{\omega^2}$ **(1)**

gives $r^3 = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.08 \times 10^{-3})^2}$ **(1)**

$\therefore r = 6.99 \times 10^6$ (m) **(1)**

3

(ii) F (= $m\omega^2 r$) = $1.1 \times 10^4 \times (1.08 \times 10^{-3})^2 \times 6.99 \times 10^6$ **(1)**

= 9.0×10^4 (8.97×10^4) (N) **(1)**

[**or** $F\left(= \frac{GMm}{r^2}\right) = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1.1 \times 10^4}{(6.99 \times 10^6)^2}$ **(1)**

= 9.0×10^4 (8.98×10^4) (N) **(1)**]

2

[8]

4 (a) force of attraction between two point masses (or particles) **(1)**

proportional to product of masses **(1)**

inversely proportional to square of distance between them **(1)**

[**alternatively**

quoting an equation, $F = \frac{GM_1M_2}{r^2}$ with all terms defined **(1)**

reference to point masses (or particles) **or** r is distance between centres **(1)**

F identified as an attractive force **(1)**]

max 2

(b) (i) mass of larger sphere M_L (= $\frac{4}{3}\pi r^3 \rho$) = $\frac{4}{3}$ π × $(0.100)^3 \times 11.3 \times 10^3$ **(1)**

= 47(.3) (kg) **(1)**

[**alternatively**

use of M µ r^3 gives $\frac{M_L}{0.74} = \left(\frac{100}{25}\right)^3$ **(1)** (= 64)

and $M_L = 64 \times 0.74 = 47(.4)$ (kg) **(1)**]

2

(ii) gravitational force F $\left(= \frac{GM_L M_S}{x^2}\right) = \frac{6.67 \times 10^{-11} \times 47.3 \times 0.74}{0.125^2}$ **(1)**

= 1.5×10^{-7} (N) **(1)**

2

(c) for the spheres, mass µ volume (or µ r^3, or $M = \frac{4}{3}\pi r^3 \rho$) **(1)**

mass of either sphere would be 8 × greater (378 kg, 5.91 kg) **(1)**

this would make the force 64 × greater **(1)**

but separation would be doubled causing force to be 4 × smaller **(1)**

net effect would be to make the force (64/4) = 16 × greater **(1)**
(ie 2.38×10^{-6} N)

max 4

[10]

5 (a) (i) *g* gravitational field strength, *G* gravitational constant

C1

g force on 1 kg (on or close to) Earth's surface

A1

G universal constant relating attraction of any two masses to their separation/constant in Newton's law of gravitation

A1

3

(ii) equates *w* and cancels *m*

B1

1

(iii) substitutes values into equation

B1

correct calculation 5.99×10^{24}

C1

answer to two significant figures 6.0×10^{24} (kg)

A1

3

(b) (i) 1 day/24 hours/86400 (s)

B1

1

(ii) 4.24×10^{7} (m)

B1

1

(iii) $v = 2\pi r/T$ or equivalent

C1

conversion of period to seconds (allow in (b)(i))

C1

3.08 (cao)

A1

3

(iv) communication/specific example of communication (eg satellite TV/weather)

B1

1

(v) avoids dish having to track/stationary **footprint**

B1

1

[14]

6 (a) (i) relationship between them is $E_p = mV$ (allow $\Delta E_p = m\Delta V$) [or V is energy per unit mass (or per kg)] **(1)**

1

(ii) value of E_p is doubled **(1)**

value of V is unchanged **(1)**

2

(b) (i) use of $V = -\frac{GM}{r}$ gives $r_A = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{12.0 \times 10^6}$ **(1)**

$= 3.3(2) \times 10^7$ (m) **(1)**

2

(ii) since $V \propto (-)\frac{1}{r}\left(\text{or } \frac{r_A}{r_B} = \frac{v_B}{v_A} = \frac{36.0}{12.0} = 3\right) r_B = \frac{3.32 \times 10^7 \text{ m}}{3}$ **(1)**

(which is ≈ 1.1×10^4 km)

1

(iii) centripetal acceleration $g_B = \frac{GM}{r_B^{\,2}} = \frac{6.67\times10^{-11}\times5.98\times10^{24}}{(1.11\times10^{7})^2}$ **(1)**

[allow use of 1.1×10^7 m from (b)(ii)]

= 3.2 (m s^{-2}) **(1)**

[**alternatively**, since $g_B = (-)\frac{v_B}{v_a}$, $g_B = \frac{36.0\times10^6}{1.11\times10^7}$ **(1)**

= 3.2 (m s^{-2}) **(1)**]

2

(iv) use of $\Delta E_p = m\Delta V$ gives $\Delta E_p = 330 \times (-12.0 - (-36.0)) \times 10^6$ **(1)**

(which is 7.9×10^9 J or ≈ 8 GJ)

1

(c) *g* is not constant over the distance involved

(**or** *g* decreases as height increases
or work done per metre decreases as height increases
or field is radial and/or not uniform) **(1)**

1

[10]

7 **A**

[1]

8 **A**

[1]

9 **C**

[1]

10 C

[1]

Examiner reports

1 Most students realised that, in part (a), the potential at infinity is zero but few could elucidate why the values are negative. Even fewer students mentioned that potential is work done per unit mass in bringing a small test mass from infinity to the various points. Many students suggested that 'gravitational potential is a negative force' – there appears to be much confusion over why gravitational potential is negative.

Those students who understood what to do in part (b) usually gained full marks – and this was the clear majority. Those choosing points at the extremes of the graph often were outside the accepted tolerance for the mass as a result of making an imprecise estimate of the coordinates of their chosen point.

Most students made good attempt at part (c) (i). The most common error was to forget to add the radius of the Earth to height of the satellite's orbit.

Part (c) (ii) was not well understood, few students were able to calculate the change in kinetic energy either by calculating the velocities or relating the centripetal force to the gravitational attraction to obtain $E_k = G\frac{Mm}{2r}$ Again, many forgot to add the radius of the Earth to the satellite's altitude. Many students did not make it clear whether the change was an increase or a decrease.

Most realised that there was loss of potential energy and increase in kinetic energy in part (c) (iii). Of those students correctly obtaining the factor of two in the kinetic energy equation, few went on to say that the decrease in potential energy was twice the increase in kinetic energy.

2 In part (a), most candidates were able to make some reference to weight being mass multiplied by gravitational field strength although this was often expressed simply as $W = mg$ or, too loosely, as mass × gravity. Many did not go on to explain why gravitational field strength was not constant.

Relatively few stated that mass was dependent only on the matter that was contained in the object.

A few pointed out that, in fact, there could be relativistic increase in mass and these were rewarded.

A majority of the candidates identified zero potential at infinity in part (b)(i), but explanations of why this led to negative values closer to the Earth were often unconvincing. Candidates needed to say more than 'the field is attractive'.

Many candidates had difficulties with the straightforward exercise in part (b)(ii). Rather than simply analysing the data to show that Vr at each position produces a constant, many used the equation $V = GM/r$. Although candidates were not penalised for a correct approach using this method as long as they were thorough, the additional arithmetic often led to errors. In this type of question it is important that candidates give an appropriate reason why the analysis demonstrates consistency of the data with the law that is proposed. This was often not the case and responses were frequently a jumble of calculations from which the examiner was, presumably, required to draw their own conclusion.

Many candidates overcomplicated part (b)(iii) owing to inadequate understanding of the information that was provided in the table. Some candidates made no use of the table data at all and used $GMm(1/r_1 - 1/r_2)$. Although this was against the spirit of the question, candidates were allowed one of the available marks provided that this was completed successfully but many ran into problems with the arithmetic. Some used change in PE = *mgh.*

Part (c)(i) was done very poorly. Although knowing that they had to use ½ mv^2, many did not know that the speed of the satellite in an orbit can be found using $GMm/r^2 = mv^2/r$.

Because of their inability to produce an answer to part (c)(i) there were a high proportion of the candidates who omitted parts (c)(ii) and (c)(iii). Most of those who found an answer to (c)(i), even if incorrect, were able to score here by realising that the answer was the difference between 12 GJ and their answer to (c)(i).

There were few correct answers to part (c)(iii) because most candidates paid no attention to the signs of the changes, the KE change being a decrease and the 10 GJ PE change an increase.

3 This question as a whole was very rewarding for the candidates who were sufficiently familiar with the principles of gravitation to understand the mathematical conditions for a satellite in stable orbit, as required in part (b) (i). These candidates made good progress with all parts of the question, whereas many other candidates were only able to score well on parts (a) and (b) (ii). In part (a), the correct conversion of the orbital time of the Hubble satellite into seconds followed by correct use of $\omega = 2\pi/T$, with a correct unit for angular speed, brought full marks for the majority of the candidates. Confusion of angular speed ω with linear speed v continues to be a problem, and giving the unit of ω as m s^{-1} inevitably caused the loss of one mark.

Part (b) (i) required candidates to appreciate that the radius of the orbit of a satellite can be found from the orbit equation $GMm/r^2 = m\omega^2 r$. The angular speed ω had been determined in part (a), whilst the values for G and the Earth's mass M could be taken from the *Data and Formulae Booklet*. Because the question had indicated that the Hubble telescope is in orbit close to the Earth, some candidates assumed that the radius of its orbit would be that of the Earth, 6.37×10^6 m.

Another common unsuccessful response was to attempt to determine the answer using the orbit relationship T^2/r^3 = constant, incorrectly treating the surface of the Earth as a satellite orbit and using T = 24 hours and r = 6.37×10^6 m.

Candidates who used $F = m\omega^2 r$, or $F = GMm/r^2$, had very little difficulty in part (b) (ii), where both marks were still accessible to those who had worked out wrong values for ω and/or r in the earlier parts of the question. Attempts at this part using $F = mv^2/r$ were often incorrect because of inability to correctly work out the linear speed, v.

4 Many correct statements of Newton's law of gravitation were seen in part (a). Some candidates referred to just one aspect of the law ($\propto M_1M_2$, or $\propto 1/r^2$, not both together) and only received one mark. A reference to point masses – which helps when explaining the meaning of r – was not common. In fact a clear understanding of the meaning of r was expected in satisfactory answers. The common inadequate responses, when neither was more fully explained, were 'radius' and 'distance' Candidates who tried to rely simply on quoting $F = GM_1M_2/r^2$ were awarded a mark only when the terms in the equation were correctly identified; a further mark was available to them if they gave a clear definition of r or referred to the nature of the force as attractive.

Part (b) (i) could be approached using either ‘mass = volume × density’ or ‘mass $\propto r^3$. The first method was far more common, and most answers were satisfactory. On this paper, this was the first example of a question requiring candidates to ‘show that…’ Convincing answers to this type of question should include the fullest possible working, in which the final answer is quoted to one more significant figure than the value given in the question. Here, for example, a value of 47.3 kg was convincing. Part (b) (ii) also proved to be very rewarding for most candidates.

Common errors here were failing to square the denominator, or to assume that surfaces in contact meant that $r = 0$ (whilst still arriving at a finite numerical answer!).

Whilst many correct and well argued answers were seen in part (c), it was clear that some candidates had not read the question with sufficient care. Two requirements for a satisfactory answer ought to be clear from the wording of the question: the need to give a quantitative answer, and to confine the answer to the effect on the calculations in part (b). ‘Calculations’ (plural) was a strong hint that the mass of both spheres would be affected, but there were many answers in which it was assumed that the masses would not be changed. This meant that a maximum mark of 1 out of 4 could be awarded, for the $1/r^2$ relationship alone. The incorrect use of language sometimes also limited the mark that could be awarded for the answers here: candidates who stated that doubling the separation would reduce the force ‘by one quarter’ could not be credited with a mark.

5 In part (a) (i), nearly all candidates correctly identified *g* and *G*; few were rigorous in their explanations of what the quantities mean.

Few candidates did not equate the two equations in part (a) (ii), cancel *m* and rearrange into the form shown.

The vast majority of candidate performed the calculation in part (a) (iii) correctly, but a significant number quoted the final answer to either one or three significant figures (instead of the correct two). A small minority of candidates forgot to square the radius of the Earth.

In part (b) (i), most candidates recognised that the period would be 24 hours.

Difficulty was had by some candidates in part (b) (ii) who struggled to add the quantities written in different forms.

Part (b) (iii) was done well either by candidates dividing the circumference of the obit by the period in seconds or else using the mass of the Earth calculated in part (a) (iii).

Most candidates gave an appropriate use for geostationary satellites in part (b) (iv), however GPS and ‘mobile phones’ were not accepted.

In part (b) (v) few candidates were able to discuss the avoidance of dishes tracking by having geostationary satellites.

6 Many very good answers were seen in part (a) (i), expressed either fully in words or simply by quoting $E_p = mV$. The corresponding equation for an incremental change, $\Delta E_p = m\Delta V$, was also acceptable but mixed variations on this such as $E_p = m\Delta V$ (which showed a lack of understanding) were not. The consequences of doubling *m* were generally well understood in part (a) (ii), where most candidates scored highly, but some inevitably thought that E_p would be unchanged whilst *V* would double.

Candidates who were not fully conversant with the metric prefixes used with units had great difficulty in part (b), where it was necessary to know that 1 MJ $=10^6$ J, 1 GJ $=10^9$ J, and (even) 1 km = 10^3 m. Direct substitution into $V = (–)\ GM/r$ (having correctly converted the value of *V* to J kg^{-1}) usually gave a successful answer for the radius of orbit **A** in part (b) (i). A similar approach was often adopted in part (b) (ii) to find the radius of orbit **B**, although the realisation that $V \propto 1/r$ facilitated a quicker solution. Some candidates noticed that $V_B = 3\ V_A$ and guessed that $r_B = r_A/3$, but this was not allowed when there was no physical reasoning to support the calculation.

Part (b) (iii) caused much difficulty, because candidates did not always appreciate that the centripetal acceleration of a satellite in stable orbit is equal to the local value of *g*, which is equal to GM/r^2. This value turns out to equal to V/r, which provided an alternative route to the answer. Many incredible values were seen, some of them greatly exceeding 9.81 m s^{-2}.

Part (c) was generally well understood, with some very good and detailed answers from the candidates. Alternative answers were accepted: either that *g* is not constant over such large distances, or that the field of the Earth is radial rather than uniform.