Mark schemes

1 (a) (i) $\left(g = -\frac{\Delta V}{\Delta x}\right)$ $19 = (-)\frac{\Delta V}{10}$ gives $\Delta V = 190$ **(1)** J kg^{-1} **(1)**

(ii) $W(= m\Delta V) = 9.0 \times 190 = 1710$J [or $mgh = 9.0 \times 19 \times 10 = 1710$J] **(1)**

(iii) on mountain, required energy would be less
because gravitational field strength is less **(1)**

max 3

(b) $g \propto \frac{1}{r^2}$ (or F $\propto \frac{1}{r^2}$ or correct use of $F = \frac{GMm}{r^2}$) **(1)**

$\therefore g' = \frac{19}{2^2} = 4.75$(Nkg^{-1}) **(1)**

2

[5]

2 (a) attractive force between two particles (or point masses) **(1)**
proportional to product of masses and inversely proportional to square of separation [or distance] **(1)**

2

(b) (for mass, m, at Earth's surface) $mg = \frac{GMm}{R^2}$ **(1)**

rearrangement gives result **(1)**

2

(c) $M_{moon}\left(= \frac{gR^2}{G}\right) = \frac{1.62 \times (1.74 \times 10^6)^2}{6.62 \times 10^{24}}$ **(1)**

$= 7.35 \times 10^{22}$ kg **(1)**

$\frac{M_{moon}}{M_{earth}} = \frac{7.35 \times 10^{22}}{6.00 \times 10^{24}}$ (= 0.0123) $\therefore$ 1.23%

3

[7]

3 (a) (i) (Minimum) Speed (given at the Earth's surface) that will allow an object to leave / escape the (Earth's) gravitational field (with no further energy input)

Not gravity

Condone gravitational pull / attraction

B1

1

(ii) $\frac{1}{2} mv^2 = \frac{GMm}{r}$

B1

Evidence of correct manipulation

At least one other step before answer

B1

2

(iii) Substitutes data and obtains $M = 7.33 \times 10^{22}$(kg)

or

Volume = $(1.33 \times 3.14 \times (1.74 \times 10^6)^3$ or 2.2×10^{19}

or $\rho = \frac{3v^2}{8\pi G r^2}$

C1

3300 (kg m^{-3})

A1

2

(b) (Not given all their KE at Earth's surface) energy continually added in flight / continuous thrust provided / can use fuel (continuously)

B1

Less energy needed to achieve orbit than to escape from Earth's gravitational field / it is not leaving the gravitational field

B1

2

[7]

4 (a) direction changing, velocity vector

B1

1

(b) Newton's law equation

M1

centripetal force equation

M1

cancel mass of Triton

A1

3

(c) $\omega = 2\pi f$ or $\omega = 2\pi/T$

M1

$\omega^2 r^3$ = constant or $\omega^2 = \frac{GM}{r^3}$

M1

$\frac{T_T^2}{T_P^2} = \frac{r_T^3}{r_P^3}$ **or** statement of Kepler III for B3

$\frac{T_T}{T_P} = \sqrt{\frac{(3.55 \times 10^8)^3}{(1.18 \times 10^8)^3}}$ = 5.2(2)

M1

4

[8]

5 (a) (i) force per unit mass/force per kg

B1

(ii) N kg^{-1} **not** ms^{-2} alone

B1

2

(b) (i) GM/R^2 seen

C1

$GM_Q/(3R)^2$ seen

C1

mass of Q = 9*M*

A1

(ii) passes through (3*R*, *g*) and falls off in curve

M1

two further points checked e.g., (6*R*,*g*/4) (12*R*, *g*/16)

M1

overall line quality – single smooth line (both Ms for this)

A1

6

[8]

6

(a) period = 24 hours or equals period of Earth's rotation **(1)**
remains in fixed position relative to surface of Earth **(1)**
equatorial orbit **(1)**
same angular speed as Earth or equatorial surface **(1)**

max 2

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

$T = \frac{2\pi}{\omega}$ **(1)**

$r\left(= \frac{GMT^2}{4\pi^2}\right)^{1/3} = \left(\frac{6.67\times10^{-11}\times6\times10^{24}\times(24\times3600)^2}{4\pi^2}\right)^{1/3}$ **(1)**

(gives $r = 42.3 \times 10^3$ km)

(ii) $\Delta V = GM\left(\frac{1}{R} - \frac{1}{r}\right)$ **(1)**

$= 6.67 \times 10^{-11} \times 6 \times 10^{24} \times \left(\frac{1}{6.4 \times 10^{6}} - \frac{1}{4.23 \times 10^{7}}\right)$

$= 5.31 \times 10^{7}$ (J kg^{-1}) **(1)**

$\Delta E_p = m\Delta V$ (= 750 × 5.31 × 10^7) = 3.98 × 10^{10} J **(1)**

(allow C.E. for value of ΔV)

[alternatives:

calculation of $\frac{GM}{R}$ (6.25 × 10^7) or $\frac{GM}{r}$ (9.46 × 10^6) **(1)**

or calculation of $\frac{GMm}{R}$ (4.69 × 10^{10}) or $\frac{GMm}{r}$ (7.10× 10^9) **(1)**

calculation of both potential energy values **(1)**
subtraction of values or use of $m\Delta V$ with correct answer **(1)**]

6

[8]

7 (a) (i) $M = \frac{4}{3}\pi R^3 \rho$ ✓

combined with $g_s = \frac{GM}{R^2}$ (gives $g_s = \frac{4}{3}\pi GR\rho$) ✓

Do not allow r instead of R in final answer but condone in early stages of working.

Evidence of combination, eg cancelling R^2 required for second mark.

2

(ii) $R = \left(\frac{3g_s}{4\pi G\rho}\right) = \frac{3 \times 8.87}{4\pi 6.67 \times 10^{-11} \times 5.24 \times 10^{3}}$ ✓

gives R = 6.06 × 10^6 (m) ✓
answer to **3SF** ✓

SF mark is independent but may only be awarded after some working is presented.

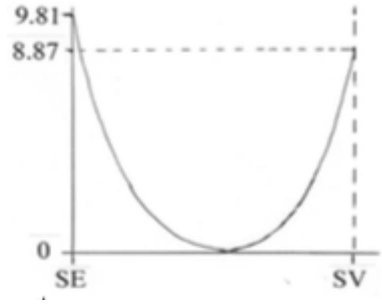
3

(b) line starts at 9.81 and ends at 8.87 ✓

correct shape curve which falls and rises ✓

falls to zeo value near centre of and to right of centre of distance scale ✓

[*Minimum of graph in 3rd point to be >0.5 and <0.75 SE-SV distance]*



For 3rd mark accept flatter curve than the above in central region.

3

[8]

8 (a) (i) –31 MJ kg^{-1} **(1)**

(ii) increase in potential energy = $m\Delta V$ **(1)**

$= 1200 \times (62 - 21) \times 10^6$ **(1)**

$= 4.9 \times 10^{10}$ J **(1)**

(4)

(b) (i) $g = -\dfrac{\Delta V}{\Delta x}$ **(1)**

(ii) g is the gradient of the graph = $\dfrac{62.5 \times 10^6}{4 \times 6.4 \times 10^6}$ **(1)**

$= 2.44$ N kg^{-1} **(1)**

(iii) $g \propto \dfrac{1}{R^2}$ and R is doubled **(1)**

expect g to be $\dfrac{9.81}{4}$ = 2.45 N kg^{-1} **(1)**

[*alternative (iii)*

$g \propto \dfrac{1}{R^2}$ and R is halved **(1)**

expect g to be 2.44 × 4 = 9.76 N kg^{-1} **(1)**]

(5)

[9]

9 (a) (i) h (= ct) (= $3.0 \times 10^8 \times 68 \times 10^{-3}$) = $2.0(4) \times 10^7$ m **(1)**

(ii) $g = (-)\frac{GM}{r^2}$ **(1)**

r (= $6.4 \times 10^6 + 2.04 \times 10^7$) = 2.68×10^7 (m) **(1)**

(allow C.E. for value of h from (i) for first two marks, but not 3rd)

$g = \frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{(2.68 \times 10^7)^2}$ **(1)** (= 0.56 N kg^{-1})

4

(b) (i) $g = \frac{v^2}{r}$ **(1)**

$v = [0.56 \times (2.68 \times 10^7)]^{½}$ **(1)**

= 3.9×10^3m s^{-1} **(1)** (3.87×10^3 m s^{-1})

(allow C.E. for value of r from a**(ii)**

[or $v^2 = \frac{GM}{r}$ = **(1)**

$v = \left(\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{2.68 \times 10^7}\right)^{1/2}$ **(1)**

= 3.9×10^3 m s^{-1} **(1)**]

(ii) $T\left(= \frac{2\pi r}{v}\right) = \frac{2\pi \times 2.68 \times 10^7}{3.87 \times 10^3}$ **(1)**

= $4.3(5) \times 10^4$s **(1)** (12.**(1)** hours)

(use of $v = 3.9 \times 10^3$ gives T = 4.3**(1)** × 10^4 s = 12.0 hours)

(allow C.E. for value of v from (I)

[alternative for (b):

(i) $v\left(\frac{2\pi r}{T}\right) = \frac{2\pi \times 2.68 \times 10^7}{4.36 \times 10^4}$ **(1)**

$= 3.8(6) \times 10^3$ m s^{-1} **(1)**]

(allow C.E. for value of *r* from (a)(ii) and value of *T*)

(ii) $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ **(1)**

$\left(= \frac{4\pi^2}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}} \times (2.68 \times 10^7)^3\right) = (1.90 \times 10^9$ (s^2) **(1)**

$T = 4.3(6) \times 10^4$ s **(1)**

5

[9]

10 (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 $g_B = \frac{GM}{r_B^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(1.11 \times 10^7)^2}$ **(1)**

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

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

[**alternatively**, since $g_B = (-)\frac{v_B}{v_a}, g_B = \frac{36.0 \times 10^6}{1.11 \times 10^7}$ **(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]

11 (a) the radius/diameter of the planet **not** 'size'

B1

the mass (or density) of the planet

B1

2

(b) (i) volume of the granite = 4/3π r^3
or
radius of the granite = 0.2 km (may be seen in an incorrect equation)

B1

200^3 or 4/3π 0.2^3 or 3.35×10^7 m^3

B1

Mass = density × volume used with any density and their volume
(Volume may be in formula form)
If they use correct volume then either 1.24×10^{11} or 7.37×10^{10} gets the mark)

B1

(3700-2200) × 3.35×10^7 **or** 1500 × 3.35×10^7 kg
or (1.24×10^{11} –7.37×10^{10}) **or** 5.025×10^{10}
or 5.03×10^{10} seen
Condone rounding off early leading to 4.6×10^{10} kg

B1

4

NB
1) the fourth mark is not for 5.0×10^{10} – all working must be shown
2) those who do not show conversion of radius from km to m in the calculation but otherwise correct will get 3

(ii) Gravitation field strength $g = GM/r^2$
or
uses distance of 0.4 km for r

C1

Substitution for extra field strength
$= 6.7 \times 10^{-11} \times 5.0 \times 10^{10}/(0.4\times10^3)^2$
Condone $r = 0.4$ for this mark

C1

Correct substitution for the extra field strength
with **correct**
powers of 10

C1

2.1×10^{-5} N kg^{-1} (condone m s^{-2})
or
1.9×10^{-5} if 4.6×10^{10} carried forward from (i)

A1

4

(iii) Correct general shape always below original curve

B1

1

Alternative scheme for different approach to (ii)

(ii) Gravitation field strength $= GM/r^2$
or
uses distance of 0.4 km for r

C1

Correct substitution for field strength for granite (or soil)
$6.7 \times 10^{-11} \times 1.24 \times 10^{11}/(0.4\times10^3)^2$ or $6.7 \times 10^{-11} \times 7.37 \times 10^{10}/(0.4\times10^3)^2$
Condone r = 0.4 for this mark

C1

Correct substitution for field strength for soil (or granite)

C1

2.1×10^{-5} N kg^{-1} (condone m s^{-2})

A1

4

[11]

12 (a) attractive **force** between point masses **(1)**
proportional to (product of) the masses **(1)**
inversely proportional to square of separation/distance apart **(1)**

3

(b) $m\omega^2 R = (-)\dfrac{GMm}{R^2}\left(\text{or} = \dfrac{mv^2}{R}\right)$ **(1)**

(use of $T = \dfrac{2\pi}{\omega}$ gives) $\dfrac{4\pi^2}{T^2} = \dfrac{GM}{R^3}$ **(1)**

G and M are constants, hence $T^2 \propto R^3$ **(1)**

3

(c) (i) (use of $T^2 \propto R^3$ gives) $\dfrac{365^2}{(1.50 \times 10^{11})^3} = \dfrac{T_m^2}{(5.79 \times 10^{10})^3}$ **(1)**

T_m = 87(.5) days **(1)**

(ii) $\dfrac{1^2}{(1.50 \times 10^{11})^3} = \dfrac{165^2}{R_N^3}$ **(1)** (gives $R_N = 4.52 \times 10^{12}$ m)

ratio = $\dfrac{4.51 \times 10^{12}}{1.50 \times 10^{11}}$ = 30(.1) **(1)**

4

[10]

13 (a) zero potential at infinity (a long way away)

B1

energy input needed to move to infinity (from the point)
work done by the field moving object from infinity
potential energy falls as object moves from infinity

B1

2

(b) Any pair of coordinates read correctly

C1

±1/2 square

Use of E_p or $V = (-)\dfrac{GM}{r}$

C1

Rearrange for M

6.4 (±0.5) × 10^{23} kg

A1

3

(c) Reads correct potential at surface of Mars = −12.6 (MJ)

C1

or reads radius of mars correctly (3.5 × 10^{6})

equates to ½ v^2 (condone power of 10 in MJ)

C1

use of v = √(2GM/r) with wrong radius

5000 ± *20* m s^{-1} (condone 1sf e.g. 5 km s^{-1})

A1

e.c.f. value of M from (b) may be outside range for other method 6.2 × 10^{-9}x √their M

3

(d) Attempts 1 calculation of *Vr*

B1

Many values give 4.2.... so allow mark is for reading and using correct coordinates but allow minor differences in readings
Ignore powers of 10 but consistent

Two correct calculation of *Vr*

B1

Three correct calculations with conclusion

B1

3

[11]

14 (a) (centripetal) force = $m\,r\,(2\,\pi\,/\,T)^2$ Or m r $(\omega)^2$

(is given by the gravitational) force = $G\,m\,M\,/\,r^2$ ✓ (mark for both equations)

(equating both expressions and substituting for ω if required) $T^2 = (4\pi^2\,/\,GM)\,r^3$ ✓ ($4\pi^2\,/\,GM$ is constant, the constants may be on either side of equation but T and r must be numerators)

First mark is for two equations (gravitational and centripetal)

The second mark is for combining.

2

(b) (use of $T^2 \propto r^3$ so $(T_P\,/\,T_E)^2 = (r_P\,/\,r_E)^3$)

$(T_P\,/1.00)^2 = (5.91 \times 10^9\,/1.50 \times 10^8)^3$ ✓ (mark is for substitution of given data into any equation that corresponds to the proportional equation given above)

($T_P^2 = 61163$)

$T_P = 250$ (yr) ✓ (247 yr)

Answer only gains both marks

The calculation may be performed using data for the Sun in $T^2 = (4\pi^2\,/\,GM)\,r^3$ easily spotted from $M_s = 1.99 \times 10^{30}$ kg giving a similar answer 247 – 252 yr.

2

(c) using $M\,(= g\,r^2\,/\,G) = 0.617 \times (1.19 \times 10^6)^2\,/\,6.67 \times 10^{-11}$ ✓

$M = 1.31 \times 10^{22}$ kg ✓

answer to 3 sig fig ✓ (this mark stands alone)

The last mark may be given from an incorrect calculation but not lone wrong answer.

3

(d) Initial KE = ½ (m) $1400^2 = 9.8 \times 10^5$ (m) J✓
Energy needed to escape = 7.4×10^5 (m) J ✓
So sufficient energy to escape. ✓

OR For object on surface escape speed given by $7.4 \times 10^5 = ½ v^2$
✓
escape speed = 1200 m s^{-1} ✓ (if correct equation is shown the previous mark is awarded without substitution)
So sufficient (initial) speed to escape. ✓

OR escape velocity = $\sqrt{\frac{2GM}{R}}$ substituting *M* from part (c) ✓
escape speed = 1200 m s^{-1} ✓ (1210 m s^{-1})
So sufficient (initial) speed to escape. ✓

OR escape velocity = $\sqrt{2Rg}$ substituting from data in (c) ✓
Third alternative may come from a CE from (c)
(1.06 × 10^{-8} × $(1.06 \times 10^{-8} \times \sqrt{\text{answer(c)}})$*)*
Conclusion must be explicit for third mark and cannot be awarded from a CE

3

[10]

15 (a) (i) force per unit mass (allow equation with defined terms)

B1

(1)

(ii) diagram of method that will work
(pendulum / light gates / solenoid and mechanical gate / strobe photography / video)

B1

pair of measurements (eg length of pendulum and (periodic) time / distance and time of fall – could be shown on diagram)

M1

instruments to measure named quantities (may be on diagram)

A1

correct procedure (eg calculate period for range of lengths, measure the time of fall for range of heights)

B1

good practice – series of values and averages / use of gradient of graph

B1

appropriate formula and how g calculated

B1

(6)

(b) (i) evidence of gr^2 being used

C1

values of 0.25, 0.11, 0.06(25)
no s.f. penalty here unless values given as fractions

A1

(2)

(ii) points correctly plotted on grid (e.c.f.)

B1

smooth curve of high quality at least to 10 × 10^7 m, no intercept on r axis

B1

(2)

(iii) attempt to use area under curve

B1

evidence of × 800 kg

B1

(4.3 – 5.3) × 10^9 J

B1

or

use of equation for potential $\Delta E_G = m(g_1 r_1 - g_2 r_2)$

B1

evidence of × 800 kg

B1

(4.7 – 4.9) × 10^9 J

B1

max 2 if assumed values of G and M used

allow calculation of GM from graph followed by substitution into $\Delta E_G = M_G(m / r_1 - m / r_2)$ for 3 marks

(3)

[14]

16 (a) the work done per unit mass ✓

in moving from infinity to the point ✓

2

(b) Gravitational potential is defined as zero at ∞ ✓

(Forces attractive) so work must be done (on a mass) to reach ∞ (hence negative) ✓

2

(c) $V = -GM / r = 6.67 \times 10^{-11} \times 5.97\ 10^{24} / 6.37 \times 10^6$ ✓

$= -6.25 \times 10^7$ J kg^{-1} ✓

2

(d) in the plane of the equator

always above the same location on the earth

having the same period as the earth / 24 hours

✓✓any two lines

2

(e) $V = -GM/r = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / 4.23 \times 10^{7} = -9.41 \times 10^{6}$ J kg^{-1} ✓

$E_p = \Delta V \times m = = (6.26 - 0.94) \times 10^{7} \times 1200$ ✓

$= 6.38 \times 10^{10}$ J ✓

3

(f) radius must increase ✓

velocity gets smaller ✓

reference to R^3 is proportional to T^2 ✓

reference (from circular motion) v^2 is proportional to $1/r$ ✓

4

[15]

17 (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]

18 (a) force is proportional to the product of the two masses

B1

force is inversely proportional to the square of their separation
(condone radius between masses)
or
equation M0 : masses defined A1 separation defined A1

B1

2

(b) (i) appreciation that potential x distance from centre of sun = constant
or calculation of Vr for two sets of values (1.33×10^{20})
or uses distance ratio to calculate new V or r

C1

calculation of all three + conclusion
or uses distance ratios twice+ conclusion
conclusion must be more than 'numbers are same'
(condone 'signs' and no use of powers of 10)

A1

2

(ii) $V = GM/r$ and $g = GM/r^2$
or

$g = V/r$ (no mark for E or $g= V/d$ or $E = V/r$)

B1

substitution of one set of data to obtain GM (1.33×10^{20})
or $19 \times 10^{10}/7 \times 10^8$ seen

B1

271 N kg^{-1} (m s^{-2}) (J kg^{-1} m^{-1})

B1

3

(iii) potential energy of the Earth = $(-)GMm/r$
or potential difference formula + $r^2 = \infty$
or potential at position of Earth = -8.87×10^8 J kg^{-1}
(from $Vr = 1.33 \times 10^{20}$)

C1

correct substitution (allow ecf for GM from (ii))
or
potential energy = potential x mass of Earth

C1

change in PE = 5.32×10^{33} J (cnao)
Fd approach is PE so 0 marks

A1

3

(iv) speed of Earth round Sun = $2\pi r/T$ or $\sqrt{\frac{GM}{r}}$
or 3.0×10^4 m s^{-1}

or KE= $\frac{GMm}{2r}$

B1

KE of Earth = ½ $6 \times 10^{24} \times$ their v^2 (2.68×10^{33}J)

B1

energy needed = difference between (iii) and orbital KE
(2.64×10^{33} J)

or KE in orbit = half total energy needed to
escape (−1 for AE)

B1

3

[13]

19 (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 $v = (GM/r)$

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]

20 (a) Total mass of spacecraft = 3050 kg

Change in PE = $\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 3050}{6400 \times 10^3}$

1.9×10^{11}(J)

2 sf

condone errors in powers of 10 and incorrect mass for payload
Allow if some sensible working

4

(b) Chemical combustion of propellant / fuel or gases produced at high pressure

Gas is expelled / expands through nozzle

Change in momentum of gases escaping

equal and opposite change in momentum of the spacecraft

Thrust = rate of change of change in momentum

Max 3

N3 in terms of forces worth 1

3

(c) 0.031(4) (m s^{-2})

1

(d) Use of rocket equation

$v = 1200 \ln \frac{3050}{1330}$

996 (m s^{-1})

Condone 1000 (m s^{-1})

3

(e) (i) Use of correct mass 108 kg

$$F = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{13} \times 108}{(2 \times 10^{3})^{2}}$$

0.0198 N

Allow incorrect powers of 10 and mass

3

(ii) Use of $v = \sqrt{\frac{2GM}{r}}$

Correct substitution $v = \frac{2 \times 6.67 \times 10^{-11} \times 1.1 \times 10^{18}}{2 \times 10^{8}}$

0.86 (m s^{-1})

Recognisable mass – condone incorrect power of 10

3

(iii) Impulse = 25 N × 4.8 = 120 N s

(120 = 108 *v* so) Velocity = 1.1 m s^{-1}

Clear conclusion

ie explanation/comparison of calculated velocity with escape velocity from **(e)(ii)**

May use F = ma approach

3

[20]

21 (a) Equatorial orbit ✓

Moving west to east ✓

Period 24 hours✓

ANY TWO

2

(b) $T\left(=\frac{2\pi}{\omega}=\frac{2\pi}{2.5(4)\times10^{-4}}\right) = 2.5 \times 10^4$ s ✓

1

(c) $\lambda\left(=\frac{c}{f}=\frac{3.0\times10^8}{1100\times10^6}\right)$ =0.27 (3)m)✓

$\theta\left(=\frac{\lambda}{d}=\frac{0.27(3)}{1.7}\right)$ = 0.16(1) rad = 92 ° ✓

(linear) width = $D\theta$ = 12000 km 0.16(1) rad) = 1.9(3) × 10^3 km ✓

3

(d) Angle subtended by beam at Earth's centre

= beam width / Earth's radius = $1.9(3) \times 10^{3} / 6400$) ✓

0.30 rad (or 17°) ✓

Time taken = $\alpha / \omega = 0.30 / 2.5(4) \times 10^{-4} = 1.18 \times 10^{3}$ s

= 20 mins ✓

Alternative:

Speed of point on surface directly below satellite = ωR

= $2.5(4) \times 10^{-4} \times 6400 \times 10^{3}$)

= 1.63×10^{3} m s^{-1}✓

Time taken = width / speed

= 1.93×10^{6} m / 1.63×10^{3} m s^{-1} ✓

= 1.18×10^{3} s

(accept 1.2×10^{3} s or 20 mins) ✓

or

Satellite has to move through angle of 1900 / 6400 radian = 0.29 rad✓

Fraction of one orbit = 0.30 / 2 × 3.14✓

Time = $0.048 \times 2.5 \times 10^{4} = 1.19 \times 10^{3}$ s✓

Time= $\frac{17}{360} \times 2.5 \times 10^{4} = 1.18 \times 10^{3}$ s

or

Circumference of Earth = 2π × 6370 ✓

= 40023 km

Width of beam at surface = 1920 km ✓

Time = $\frac{1920}{40023} \times 2.48 \times 10^{4}$

= 1180 s = 19.6 min ✓

3

(e) Signal would be weaker ✓ (as distance it travels is greater)

Energy spread over wider area/intensity decreases with increase of distance ✓

Signal received for longer (each orbit) ✓

Beam width increases with satellite height/satellite moves at lower angular speed ✓)

4

[13]

22

(a) Idea that both astronaut and vehicle are travelling at same (orbital) speed or have the same (centripetal) acceleration / are in freefall

Not falling at the same speed

B1

No (normal) reaction (between astronaut and vehicle)

B1

2

(b) (i) Equates centripetal force with gravitational force using appropriate formulae

E.g. $\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $mr\omega^2$

B1

Correct substitution seen e.g. $v^2 = \frac{6.67\times10^{-11}\times5.97\times10^{24}}{\text{any value of radius}}$

B1

(Radius of) 7.28×10^6 seen or $6.38 \times 10^6 + 0.9 \times 10^6$

B1

7396 (m s^{-1}) to at least 4 sf

Or $v^2 = 5.47 \times 10^7$ seen

B1

4

(ii) $\Delta PE = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} (1 / (7.28 \times 10^{6}) - 1 / (6.78 \times 10^{6}))$

C1

-6.8×10^{10} J

C1

$\Delta KE = 0.5 \times 1.68 \times 10^{4} \times (7700^2 - 7400^2) = 3.81 \times 10^{10}$ J

C1

$\Delta KE - \Delta PE = (-)\ 2.99 \times 10^{10}$ (J)

A1

OR

Total energy in original orbit shown to be (−)$GMm / 2r$
or $mv^2 / 2 - GMm / r$

C1

Initial energy
$= -\ 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} / (2 \times 7.28 \times 10^{6})$
$= 4.59 \times 10^{11}$

C1

Final energy
$= -\ 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^{4} / (2 \times 6.78 \times 10^{6})$
$= 4.93 \times 10^{11}$

3.4×10^{10}(J)

Condone power of 10 error for C marks

A1

4

[10]

23 (a) (i) force per unit mass ✓
a vector quantity ✓

Accept force on 1 kg (or a unit mass).

2

(ii) force on body of mass m is given by $F = \frac{GMm}{(R+h)^2}$ ✓

gravitational field strength $g\left(= \frac{F}{m}\right) = \frac{GM}{(R+h)^2}$ ✓

For both marks to be awarded, correct symbols must be used for M and m.

2

(b) (i) $F\left(= \frac{GMm}{(R+h)^2}\right) = \frac{6.67\times10^{-11}\times5.98\times10^{24}\times2520}{\left((6.37\times10^6)+(1.39\times10^7)\right)^2}$ ✓

= 2.45 × 10^3 (N) ✓ to **3SF** ✓

1^{st} mark: all substituted numbers must be to at least 3SF.
If 1.39 × 10^7 is used as the complete denominator, treat as AE with ECF available.
*3^{rd} mark: **SF mark is independent.***

3

(ii) $F = m\omega^2 (R + h)$ gives $\omega^2 = \frac{2450}{2520 \times 2.03 \times 10^7}$ ✓

from which $\omega = 2.19 \times 10^{-4}$ (rad s^{-1}) ✓

time period $T\left(= \frac{2\pi}{\omega}\right) = \frac{2\pi}{2.19 \times 10^{-4}}$ **or** = 2.87 ✓ 10^4 s ✓

[**or** $F = \frac{mv^2}{R+h}$ gives $v^2 = \frac{2.45 \times 10^3 \times ((6.37 \times 10^6) + (13.9 \times 10^6))}{2520}$ ✓

from which v = 4.40 ✓ 10^3 (m s^{-1}) ✓

time period $T\left(= \frac{2\pi(R+h))}{v}\right) = \frac{2\pi \times 2.03 \times 10^7}{4.40 \times 10^3}$ **or** = 2.87×10^4 s ✓]

[**or** $T^2 = \frac{4\pi^2 (R+h)^3}{GM}$ ✓

$= \frac{4\pi^2 ((6.37 \times 10^6) + (13.9 \times 10^6))^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}$ ✓

gives time period T = 2.87×10^4s ✓]

$= \frac{2.87 \times 10^4}{3600}$ = 7.97 (hours) ✓

number of transits in 1 day = $\frac{24}{7.97}$ = 3.01 (≈ 3) ✓

Allow ECF from wrong F value in (i) but mark to max 4 (because final answer won't agree with value to be shown).

First 3 marks are for determining time period (or frequency). Last 2 marks are for relating this to the number of transits.

Determination of f = 3.46×10^{-5} (s^{-1}) is equivalent to finding T by any of the methods.

5

(c) acceptable use ✓

satisfactory explanation ✓

e.g. monitoring weather **or** surveillance:

whole Earth may be scanned **or** Earth rotates under orbit

or information can be updated regularly

or communications: limited by intermittent contact

or gps: several satellites needed to fix position on Earth

Any reference to equatorial satellite should be awarded 0 marks.

2

[14]

24 (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]