M1. D

[1]

M2. C

[1]

M3. (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]

M4.(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. $v^2 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{\text{any value of radius}}$

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]

M5.(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 × 10^4 s ✓

1

(c) $\lambda \left(= \frac{c}{f} = \frac{3.0 \times 10^8}{1100 \times 10^6}\right)$ =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) × 10^3 / 6400) ✓

0.30 rad (or 17°) ✓

Time taken = α / ω = 0.30 / 2.5(4) × 10^{-4} = 1.18 × 10^3 s

= 20 mins ✓

Alternative:

Speed of point on surface directly below satellite = ωR

= 2.5(4) × 10^{-4} × 6400 × 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 × 2.5 × 10^4 = 1.19 × 10^3 s ✓

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

or

Circumference of Earth = 2π × 6370 ✓

= 40023 km

Width of beam at surface = 1920 km ✓

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

$= 1180\ s = 19.6\ min$ ✓

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]

M6.(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) $F\left(=\frac{GMm}{(R+h)^2}\right) = \frac{6.67\times10^{-11}\times5.98\times10^{24}\times2520}{\left((6.37\times10^6)+(1.39\times10^7)\right)^2}$ ✓

$= 2.45 \times 10^3$ (N) ✓ to **3SF** ✓

1st 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.

*3rd mark: **SF mark is independent.***

3

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

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

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

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

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

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

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

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

gives time period T = 2.87×10^4s ✓]

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

number of transits in 1 day = $\dfrac{24}{7.97}$ = 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]

M7. C

[1]

M8. D

[1]