Mark schemes

1 D **[1]**

2 D **[1]**

3 B **[1]**

4 D **[1]**

5 D **[1]**

6 B **[1]**

7 A **[1]**

8 D **[1]**

9 B **[1]**

10 C **[1]**

11 (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)**

$= 6.67 \times 10^{-11} \times 6 \times 10^{24} \times \left(\frac{1}{6.4\times10^6}-\frac{1}{4.23\times10^7}\right)$

$= 5.31 \times 10^7$ (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]

12 (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** ✓

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 $\omega^2 = \frac{2450}{2520 \times 2.03 \times 10^7}$ ✓

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]

13 (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]

14 (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]

15 (a) (i) Use of $F – GMm/r^2$

C1

Allow 1 for
-correct formula quoted but forgetting square in substitution

Correct substitution of data

M1

-missing m in substitution

491 (490)N

A1

-substutution with incorrect powers of 10

Condone 492 N,

(ii) Up and down vectors shown (arrows at end) with labels

B1

allow W, mg (not gravity); R
allow if slightly out of line / two vectors shown at feet

up and down arrows of equal lengths

B1

condone if colinear but not shown acting on body

In relation to surface W ≤ R (by eye) to allow for weight vector starting in middle of the body

Must be colinear unless two arrows shown in which case R vectors ½ W vector(by eye)

(b) (i) Speed = $2\pi r / T$

B1

Max 2 if not easy to follow

2π6370000 / (24 × 60 × 60)

B1

463 m s^{-1}

B1

Must be 3sf or more

(ii) Use of $F = mv^2/r$

C1

Allow 1 for use of $F = mr\omega^2$ with ω= 460

1.7 (1.66 – 1.68) N

A1

(iii) Correct direction shown
(Perpendicular to and toward the axis of rotation)
NB – not towards the centre of the earth

B1

(c) Force on scales decreases / apparent weight decreases
Appreciates scale reading = reaction force

C1

The reading would become 489 (489.3)N or reduced by 1.7 N)

A1

Some of the gravitational force provides the necessary centripetal force

B1

or $R = mg - mv^2/r$

[14]

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

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

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

3

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

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

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

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

4

[10]

17 (a) (i) h (= ct) (= 3.0 × 10^8 × 68 × 10^{-3}) = 2.0(4) × 10^7 m **(1)**

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

r (= 6.4 × 10^6 + 2.04 × 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^{3}m 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) × 10^{4}s **(1)** (12.**(1)** hours)

(use of v = 3.9 × 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 × 10^9 **(s^2) (1)**

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

5

[9]

Examiner reports

1 This question, also on circular motion, involved a calculation. Candidates were rather less successful with this question and the facility was 65%. However, the same question had been used in the 1995 A level examination, when the facility was only 59%. Almost a quarter of the 2004 candidates chose distractor C.

2 This question where the purpose was to calculate the Earth's orbital speed, combined circular motion with gravitation. 62% of the students were successful, whilst incorrect answers were spread fairly evenly between the three incorrect responses.

3 This question required the angular velocity of the Earth's surface. This proved to be one of the easiest questions, with a facility of 79%. The remaining candidates split their responses almost equally between distractors A, C and D. The question gave good discrimination.

5 This question was about satellites. The former required correct algebraic expressions for the centripetal acceleration and speed of a satellite in circular orbit around a planet. Just over four-fifths of the responses were correct.

6 This question required familiarity with the idea that a body appears to become weightless when its centripetal acceleration is just equal to the local value of the acceleration due to gravity. Hence, if this were to happen at the surface of the Earth, $\omega^2 R$ would have to equal 9.81 m s^{-2}. The question had a facility of 55%, but one in five candidates selected distractor A.

7 This question required candidates to select an incorrect statement about what would happen to a comet as it approached the Sun. Distractor C was chosen by 31% of the candidates; this suggests they thought that the comet would make a line-of-centres approach instead of looping around the Sun.

8 This question, with a facility of 71%, required the angular speed of a satellite in circular orbit to be found and appeared to cause little difficulty.

9 This question was a re-banked question about the gravitational potential and angular velocity at two points whose height above the Earth's surface was different. The outcome was a very similar facility to that obtained on the previous occasion, with half of the candidates appreciating that the point at greater height would have greater V but the same ω. More than a quarter of responses were for distractor C (greater V, smaller ω) and almost a fifth for distractor A (both V and ω greater).

11 Two appropriate features of a geo-synchronous orbit were usually given by the candidates in part (a), but the marks for them were often the last that could be awarded in this question. The required radius in part (b)(i) came readily to the candidates who correctly equated the gravitational force on the satellite with $m\omega^2 r$, applied $T = 2\pi/\omega$, and completed the calculation by substituting $T = 24$ hours and the values given in the question. Other candidates commonly presented a tangled mass of unrelated algebra in part (b)(i), from which the examiners could rescue nothing worthy of credit.

In part (b)(ii) an incredible proportion of the candidates assumed that it was possible to calculate the increase in the potential energy by the use of mg Δh, in spite of the fact that the satellite had be raised vertically through almost 36,000 km. These attempts gained no marks. Other efforts started promisingly by the use of $V = -GM / r$, but made the crucial error of using $(4.23 \times 10^7 - 6.4 \times 10^6)$ as r in the denominator. Some credit was available to candidates who made progress with a partial solution that proceeded along the correct lines, such as evaluating the gravitational potential at a point in the orbit of the satellite. Confusion between the mass of the Earth and the mass of the satellite was common when doing this.

12 The definition in part (a)(i) was well known. Because the quantity concerned is called gravitational field *strength*, there was frequent confusion as to whether it is a vector or a scalar, with many answers being crossed out and changed. Part (a)(ii) was also generally very rewarding. The main problem was a failure to show how the terms from the data booklet equations (m_1, m^2 and r) translated into the terms in the question (m, M, R and h). In the derivation, some students cancelled M instead of m. However, others had so little confidence in their use of algebra that they could make little progress even in a simple derivation such as this.

Part (b)(i) caused few problems and marks were generally high. Sometimes incorrect values had been extracted from the data booklet for the mass and radius of the Earth. Three significant figures were expected in the answer; therefore a minimum of three significant figures should also have been used in the substitution and working. When $h = 1.39 \times 10^7$ was used as the radius of the orbit one mark was lost and the value of the force thus obtained was carried forward to make most marks available in part (b)(ii). Part (b)(ii) offered a very wide range of approaches to enable students to show that the satellite would make three transits of Earth in every 24 hours. Apart from the three alternatives given in the mark scheme (all of which were frequently seen) a very concise calculation showed that a satellite with an angular speed of 2.19×10^{-4} rad s^{-1} would move through an angle of 18.9 rad in one day, equating to ($18.9 / 2\pi =$) 3.01 transits.

Use of polar orbiting satellites for monitoring the Earth (weather forecasting, spying, surveying, etc.) were well known in part (c), although some students confused the application with an equatorial geosynchronous satellite. Explanations of the application were often less satisfactory: reference to the rotation of Earth beneath the orbit, allowing the whole surface to be scanned, was the key here. The ability to provide regular updates of the information obtained was also an acceptable explanation. Students who mentioned the use of the polar satellite for communications gained the first mark but were usually unable to point out its limitations, caused by intermittent contact.

13 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.

14

(a) Most candidates were able to correctly answer this part.

(b) Although the majority of candidates were able to quote either the Newton's law of gravitation or centripetal force equation only the better candidates equated these and showed that the mass of Triton cancelled.

(c) Only the best candidates were able to show this in a convincing way. A limited number of candidates gained a little credit for stumbling through one or two appropriate relationships.

15

(a) (i) Most candidates were able to make good progress with this calculation and there were many correct answers.

(ii) Many attempts were unconvincing and frequently carelessly drawn. Weight and reaction forces were often shown as not being collinear. Some showed a reaction force at one of the feet but not the other. That the length of a vector should represent magnitude was not realised by many candidates.

(b) (i) A good proportion of correct approaches were seen but many candidates seemed unsure what equation to use so quoted some that were not relevant. Good structure in a mathematical argument is an important skill in all problems but even more so in 'show that' type questions were marks are awarded for each step.

(ii) Again there was a good proportion of correct response. Some candidates used $F = mr\omega^2$; and 460 m s^{-1} for ω.

(iii) Misunderstanding about centripetal force was common here and there were relatively few correct answers. The majority showed the force acting toward the centre of the Earth. Whilst a component of this force provides the centripetal force, the direction of the centripetal force is toward the centre of rotation which in the diagram is perpendicular and toward the axis of rotation of the Earth.

(c) There were very good answers from candidates who understood that the scales read the reaction force.There were many who knew the formula $mg - R = mv^2 / r$ but thought that the scales would record mg and assumed R to remain constant so that the centripetal force increased the scale reading.

16

It was rare for all three marks to be awarded in part (a). Most answers made at least some reference to the proportionality and inverse proportionality involved in Newton's law, but references to point masses or to the attractive nature of the force were scarce.
The essential starting point in part (b) was a correct statement equating the gravitational force with $m\omega^2R$; the more able candidates had little difficulty in then applying $T = 2\pi/\omega$ to derive the required result, and three marks were usually obtained by them.

Both halves of part (c) followed directly from the $T^2 \propto R^3$ result in part (b), and the candidates who realised this usually made excellent progress. Unfortunately, a large proportion tried to go back to first principles and tied themselves in knots with the algebra and/or arithmetic, often getting nowhere. Confusion over which unit of time to employ in the different parts caused much difficulty, especially for candidates who had calculated a constant of proportionality in part (i). Some very elegant solutions to part (ii) were seen, where the result emerged swiftly from $(165)^{2/3}$. The most absurd efforts came from candidates who made the implicit assumption that the Earth, Mercury and Neptune all travel at the same speed in their orbits, leading to wrong answers of 141 days and 165 respectively.

17 Most candidates scored the mark in part (a) (i) and went to use their answer correctly in part (ii). A small number of candidates however, failed to add the height calculated in part (i) to the Earth's radius or added the radius in km to the height in m. They were usually able to gain some credit for knowing the correct equation to use.

In part (b) (i), many candidates gave a clear and correct expression, using either the expressions for centripetal acceleration or the speed in terms of the mass of the Earth. Weaker candidates confused the symbols for speed and gravitational potential on the data sheet and attempted to calculate the speed using the expression for gravitational potential. Most candidates who completed part (i) went on to complete part (ii) successfully, although some lost the final mark as a result of giving the answer to too many significant figures. Some candidates in part (ii) successfully related the time period to the radius of orbit and thus gained full credit. A small minority of candidates gained no credit as a result of misreading part (b), attempting to provide answers based on a time period of 24 hours.