1 A planet has a radius half the Earth's radius and a mass a quarter of the Earth's mass. What is the approximate gravitational field strength on the surface of the planet?

A 1.6 N kg^{-1} ☐

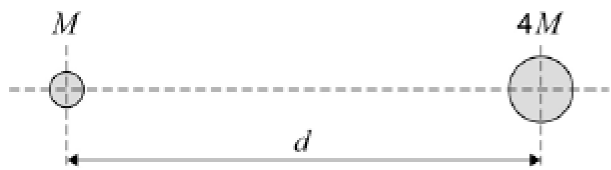
B 5.0 N kg^{-1} ☐

C 10 N kg^{-1} ☐

D 20 N kg^{-1} ☐

(Total 1 mark)

2 Two stars of mass M and $4M$ are at a distance d between their centres.



The resultant gravitational field strength is zero along the line between their centres at a distance y from the centre of the star of mass M.

What is the value of the ratio $\frac{y}{d}$?

A $\frac{1}{2}$ ☐

B $\frac{1}{3}$ ☐

C $\frac{2}{3}$ ☐

D $\frac{3}{4}$ ☐

(Total 1 mark)

3 Which of the following statements about Newton's law of gravitation is correct?

Newton's gravitational law explains

A the origin of gravitational forces. ⬭

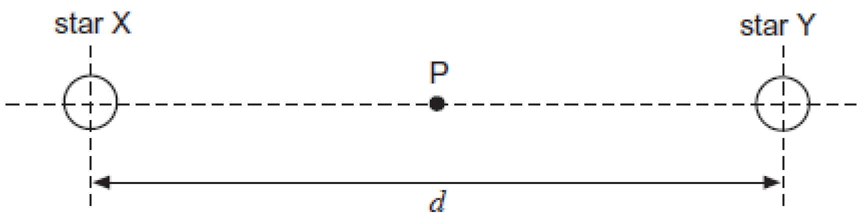
B why a falling satellite burns up when it enters the Earth's atmosphere. ⬭

C why projectiles maintain a uniform horizontal speed. ⬭

D how various factors affect the gravitational force between two particles. ⬭

(Total 1 mark)

4 X and Y are two stars of equal mass M. The distance between their centres is d.



What is the gravitational potential at the mid-point P between them?

A $\frac{GM}{2d}$

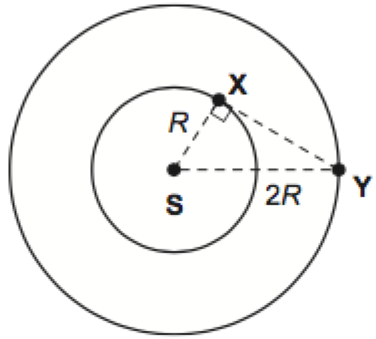
B $-\frac{GM}{d}$

C $-\frac{4GM}{d}$

D $-\frac{8GM}{d}$

(Total 1 mark)

5 Two planets **X** and **Y** are in concentric circular orbits about a star **S**. The radius of the orbit of **X** is R and the radius of orbit of **Y** is $2R$.



The gravitational force between **X** and **Y** is F when angle **SXY** is 90°, as shown in the diagram.

What is the gravitational force between **X** and **Y** when they are nearest to each other?

A $2F$
B $3F$
C $4F$
D $5F$

(Total 1 mark)

6 A geosynchronous satellite is in a constant radius orbit around the Earth. The Earth has a mass of 6.0×10^{24} kg and a radius of 6.4×10^{6} m.

What is the height of the satellite above the Earth's surface?

A 1.3×10^{7} m
B 3.6×10^{7} m
C 4.2×10^{7} m
D 4.8×10^{7} m

(Total 1 mark)

7 The gravitational constant, G, is a constant of proportionality in Newton's law of gravitation. The permittivity of free space, ε_0, is a constant of proportionality in Coulomb's law.

When comparing the electrostatic force acting on a pair of charged particles to the gravitational force between them, the product $\varepsilon_0 G$ can appear in the calculation.

Which is a unit for $\varepsilon_0 G$?

A $C^2\ kg^{-2}$
B $C^2\ m^{-2}$
C $F\ kg^2\ N^{-1}\ m^{-2}$
D it has no unit

(Total 1 mark)

8 Two identical uniform spheres each of radius R are placed in contact. The gravitational force between them is F.

The spheres are now separated until the force of attraction is $\frac{F}{9}$.

What is the distance between the **surfaces** of the spheres after they have been separated?

A $2R$

B $4R$

C $8R$

D $12R$

(Total 1 mark)

9 A satellite of mass m is in a circular orbit at height R above the surface of a uniform spherical planet of radius R and density ρ.

What is the force of gravitational attraction between the satellite and the planet?

A $\frac{\pi \rho G m R}{3}$

B $\frac{2\pi \rho G m R}{3}$

C $\frac{\pi \rho G m R^2}{3}$

D $\frac{2\pi \rho G m R^2}{3}$

(Total 1 mark)

10 The following data refers to two planets, P and Q.

	Radius / km	**Density / kg m^{-3}**
planet P	8000	6000
planet Q	16 000	3000

The gravitational field strength at the surface of P is 13.4 N kg^{-1}.
What is the gravitational field strength at the surface of Q?

A 3.4 N kg^{-1}

B 13.4 N kg^{-1}

C 53.6 N kg^{-1}

D 80.4 N kg^{-1}

(Total 1 mark)

11 Which one of the following statements about gravitational potential is **incorrect**?

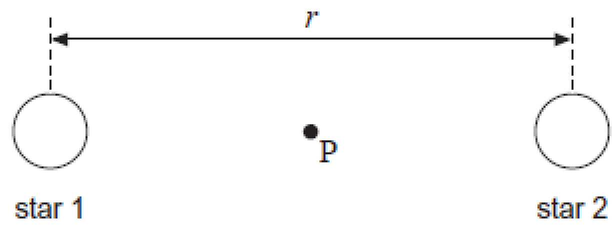
A It is analogous to the electric potential at a point in an electric field.

B It is equal to the gravitational potential energy of a mass of 1 kg.

C It is a vector quantity.

D The difference in gravitational potential between two points at different heights above the Earth depends on the position of the points.

12 The diagram shows an isolated binary star system. The two stars have equal masses, M, and the distance between their centres is r.



The point P is half-way between the two stars.
What is the gravitational field strength at P?

A zero

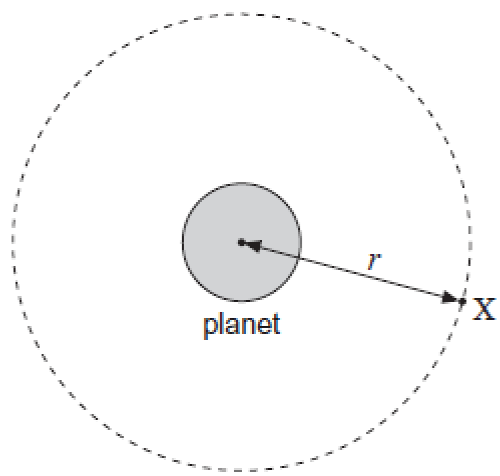
B $-\frac{GM}{r^2}$

C $-\frac{2GM}{r^2}$

D $-\frac{4GM}{r^2}$

(Total 1 mark)

13 A satellite X is in a circular orbit of radius r about the centre of a spherical planet of mass M.



Which line, **A** to **D**, in the table gives correct expressions for the centripetal acceleration a and the speed v of the satellite?

	Centripetal acceleration a	Speed v
A	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{2r}}$
B	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{r}}$
C	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{2r}}$
D	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{r}}$

(Total 1 mark)

14 A satellite orbiting the Earth moves to an orbit which is closer to the Earth.

Which line, **A** to **D**, in the table shows correctly what happens to the speed of the satellite and to the time it takes for one orbit of the Earth?

	Speed of satellite	Time For One Orbit Of Earth
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

(Total 1 mark)

15 In the equation $X = \frac{ab}{r^n}$, X represents a physical variable in an electric or a gravitational field, a is a constant, b is either mass or charge and n is a number.

Which line, **A** to **D**, in the table provides a consistent representation of X, a and b according to the value of n?

The symbols E, g, V and r have their usual meanings.

	n	***X***	***a***	***b***
A	1	E	$\frac{1}{4\pi\varepsilon_0}$	charge
B	1	V	$\frac{1}{4\pi\varepsilon_0}$	mass
C	2	g	G	mass
D	2	V	G	charge

(Total 1 mark)

16 A spacecraft of mass m is at the mid-point between the centres of a planet of mass M_1 and its moon of mass M_2. If the distance between the spacecraft and the centre of the planet is d, what is the magnitude of the resultant gravitational force on the spacecraft?

A $\frac{Gm(M_1 - M_2)}{d}$

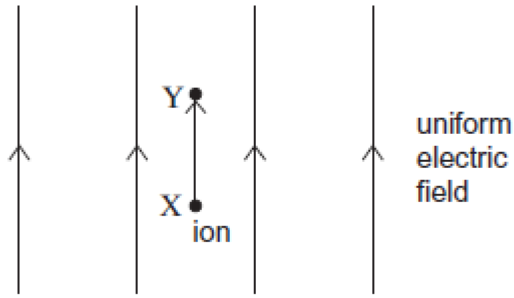
B $\frac{Gm(M_1 + M_2)}{d^2}$

C $\frac{Gm(M_1 - M_2)}{d^2}$

D $\frac{Gm(M_1 + M_2)}{d}$

(Total 1 mark)

17 A uniform electric field of electric field strength E is aligned so it is vertical. An ion moves vertically through a small distance Δd from point X to point Y in the field.
There is a uniform gravitational field of field strength g throughout the region.



Which line, **A** to **D**, in the table correctly gives the gravitational potential difference, and the electric potential difference, between X and Y?

	Gravitational potential difference	**Electric potential difference**
A	$g\Delta d$	$E\Delta d$
B	$g\Delta d$	$\frac{E}{\Delta d}$
C	$\frac{g}{\Delta d}$	$E\Delta d$
D	$\frac{g}{\Delta d}$	$\frac{E}{\Delta d}$

(Total 1 mark)

18 Which one of the following statements about gravitational potential is correct?

A gravitational potential can have a positive value

B the gravitational potential at the surface of the Earth is zero

C the gravitational potential gradient at a point has the same numerical value as the gravitational field strength at that point

D the unit of gravitational potential is N kg^{-1}

(Total 1 mark)

19 When a space shuttle is in a low orbit around the Earth it experiences gravitational forces F_E due to the Earth, F_M due to the Moon and F_S due to the Sun. Which one of the following correctly shows how the magnitudes of these forces are related to each other?

mass of Sun = 1.99×10^{30} kg
mass of Moon = 7.35×10^{22} kg
mean distance from Earth to Sun = 1.50×10^{11} m
mean distance from Earth to Moon = 3.84×10^{8} m

A $F_E > F_S > F_M$

B $F_S > F_E > F_M$

C $F_E > F_M > F_S$

D $F_M > F_E > F_S$

(Total 1 mark)

20 The gravitational field strengths at the surfaces of the Earth and the Moon are 9.8 N kg^{-1} and 1.7 N kg^{-1} respectively. If the mass of the Earth is 81 × the mass of the Moon, what is the ratio of the radius of the Earth to the radius of the Moon?

A 3.7

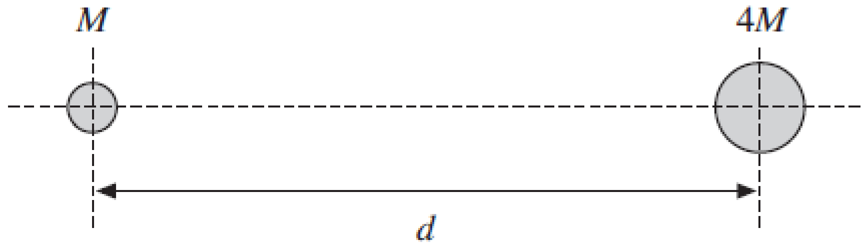
B 5.8

C 14

D 22

(Total 1 mark)

21 Two stars of mass M and $4M$ are at a distance d between their centres.



The resultant gravitational field strength is zero along the line between their centres at a distance y from the centre of the star of mass M.

What is the value of the ratio $\frac{y}{d}$?

A $\frac{1}{2}$

B $\frac{1}{3}$

C $\frac{2}{3}$

D $\frac{3}{4}$

(Total 1 mark)

22 Mars has a diameter approximately 0.5 that of the Earth, and a mass of 0.1 that of the Earth. The gravitational potential at the Earth's surface is -63 MJ kg^{-1}.
What is the approximate value of the gravitational potential at the surface of Mars?

A -13 MJ kg^{-1}

B -25 MJ kg^{-1}

C -95 MJ kg^{-1}

D -320 MJ kg^{-1}

(Total 1 mark)

23 Two satellites P and Q, of equal mass, orbit the Earth at radii R and $2R$ respectively. Which one of the following statements is correct?

A P has less kinetic energy and more potential energy than Q.

B P has less kinetic energy and less potential energy than Q.

C P has more kinetic energy and less potential energy than Q.

D P has more kinetic energy and more potential energy than Q.

(Total 1 mark)

24 A small mass is situated at a point on a line joining two large masses m_1 and m_2 such that it experiences no resultant gravitational force. Its distance from the centre of mass of m_1 is r_1 and its distance from the centre of mass of m_2 is r_2.

What is the value of the ratio $\frac{r_1}{r_2}$?

A $\frac{m_1^2}{m_2^2}$

B $\frac{m_2^2}{m_1^2}$

C $\sqrt{\frac{m_1}{m_2}}$

D $\sqrt{\frac{m_2}{m_1}}$

(Total 1 mark)

25 Which one of the following gives a correct unit for $\left(\frac{g}{G}\right)^2$?

A N m^{-2}

B N kg^{-1}

C N m

D N

(Total 1 mark)

26 The gravitational field strength at the surface of the Earth is 6 times its value at the surface of the Moon. The mean density of the Moon is 0.6 times the mean density of the Earth.

What is the value of the ratio $\left(\frac{\text{radius of Earth}}{\text{radius of Moon}}\right)$?

A 1.8

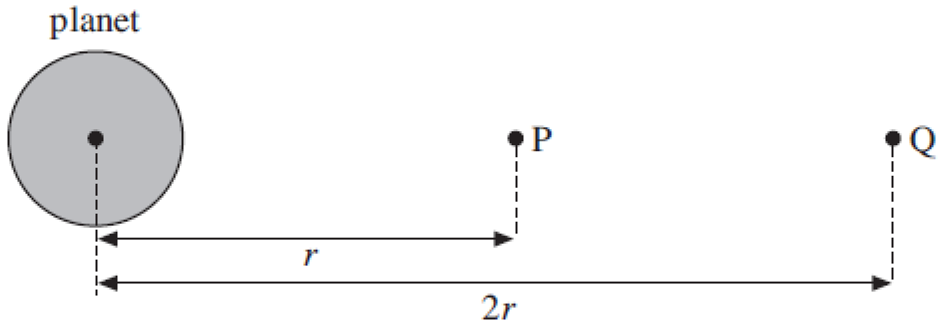
B 3.6

C 6.0

D 10

(Total 1 mark)

27 The diagram shows two points, P and Q, at distances r and $2r$ from the centre of a planet.



The gravitational potential at P is −16 kJ kg^{-1}. What is the work done on a 10 kg mass when it is taken from P to Q?

A – 120 kJ

B – 80 kJ

C + 80 kJ

D + 120 kJ

(Total 1 mark)

28 The Earth moves around the Sun in a circular orbit with a radius of 1.5×10^8 km.
What is the Earth's approximate speed?

A $1.5 \times 10^3 ms^{-1}$

B $5.0 \times 10^3 ms^{-1}$

C $1.0 \times 10^4 ms^{-1}$

D $3.0 \times 10^4 ms^{-1}$

(Total 1 mark)

29 When a charge moves between two points in an electric field, or a mass moves between two points in a gravitational field, energy may be transferred.
Which one of the following statements is correct?

A No energy is transferred when the movement is parallel to the direction of the field.

B The energy transferred is independent of the path followed.

C The energy transferred is independent of the start and finish points.

D Energy is transferred when the movement is perpendicular to the field lines.

(Total 1 mark)

30 Which one of the following statements about gravitational fields is **incorrect**?

A Moving a mass in the direction of the field lines reduces its potential energy.

B A stronger field is represented by a greater density of field lines.

C Moving a mass perpendicularly across the field lines does not alter its potential energy.

D At a distance *r* from a mass the field strength is inversely proportional to *r*.

(Total 1 mark)

31 An object on the surface of a planet of radius *R* and mass *M* has weight *W*.
What would be the weight of the same object when on the surface of a planet of radius 2*R* and mass 2*M*?

A $\frac{W}{4}$

B $\frac{W}{2}$

C *W*

D 2*W*

(Total 1 mark)

32 The gravitational field strength on the surface of a planet orbiting a star is 8.0 N kg^{-1}. If the planet and star have a similar density but the diameter of the star is 100 times greater than the planet, what would be the gravitational field strength at the surface of the star?

A 0.0008 N kg^{-1}

B 0.08 N kg^{-1}

C 800 N kg^{-1}

D 8000 N kg^{-1}

(Total 1 mark)

33 Two satellites, P and Q, of the same mass, are in circular orbits around the Earth. The radius of the orbit of Q is three times that of P. Which one of the following statements is correct?

A The kinetic energy of P is greater than that of Q.

B The weight of P is three times that of Q.

C The time period of P is greater than that of Q.

D The speed of P is three times that of Q.

(Total 1 mark)

34 Which one of the following statements about Newton's law of gravitation is correct?

Newton's law of gravitation explains

A the origin of gravitational forces.

B why a falling satellite burns up when it enters the Earth's atmosphere.

C why projectiles maintain a uniform horizontal speed.

D how various factors affect the gravitational force between two particles.

(Total 1 mark)

35 If an electron and proton are separated by a distance of 5×10^{-11} m, what is the approximate gravitational force of attraction between them?

A 2×10^{-57} N

B 3×10^{-47} N

C 4×10^{-47} N

D 5×10^{-37} N

(Total 1 mark)

Mark schemes

1 C **[1]**

2 B **[1]**

3 D **[1]**

4 **C** **[1]**

5 **B** **[1]**

6 **B** **[1]**

7 **A** **[1]**

8 B **[1]**

9 A **[1]**

10 B **[1]**

11 C **[1]**

12 A **[1]**

13 D **[1]**

14 C **[1]**

15 C **[1]**

16 C **[1]**

17 A **[1]**

18 C

[1]

19 A

[1]

20 A

[1]

21 B

[1]

22 A

[1]

23 C

[1]

24 C

[1]

25 A

[1]

26 B

[1]

27 C

[1]

28 D

[1]

29 B

[1]

30 D

[1]

31 B

[1]

32 C

[1]

33 A

[1]

34 D

[1]

35 C

[1]

Examiner reports

4 This question turned to gravitational potential. At the mid-point P between the two identical stars, the gravitational potential due to one of the stars must be $-GM/0.5d$, which is $-2GM/d$. The total gravitational potential due to both stars must therefore be $-4GM/d$. This was realised by 62% of the students. Faulty algebraic work probably caused 28% of the students to choose distractor B ($-GM/d$).

5 This question tested the gravitational inverse square law in the context of two planets orbiting a star. Application of Pythagoras' theorem shows that $(XY)^2 = 3R^2$. When the planets are closest, their separation is reduced to R; thus the force increases from F to $3F$. The facility of the question was 58%, with one in five of the responses being for distractor C ($4F$).

6 If calculated from first principles from the data given in the question, about the height of a geosynchronous satellite, it is a demanding question for the time available in an objective test. Nevertheless 53% of the responses were correct; perhaps some students had rehearsed the calculation and committed the result to memory. The question asked for the height of the satellite *above the Earth's surface,* and it is not surprising that the most common incorrect response was distractor C (the radius of the satellite's orbit). 24% of the students made this mistake.

7 This was an unusual question on combinations of electrical units. 54% of the responses were correct, whilst 18% selected distractor C and 20% distractor D (no unit). The latter must have been tempting because both $\boldsymbol{\varepsilon_0}$ and **G** are constants.

8 This question was on Newton's law, in particular the realisation that it is an inverse square relationship. Reduction in the force of attraction from F (when in contact at separation $2R$) to $F / 9$ implies that the separation of centres has increased by a factor of 3, from $2R$ to $6R$. Hence the distance between the surfaces of the spheres would be $4R$. 58% of the students gave this, with 21% choosing distractor A (which was $2R$).

9 This question was an algebraic test of Newton's law involving the use of density and the volume of a sphere to determine mass. Slightly more than one half of the students succeeded with this, although more than a quarter of them selected distractor B, where the force would be twice the expected value.

10 This question turned to gravitational field strength. This question had been used in a previous examination, when slightly less than half of the responses were correct. This time 65% were correct and the discrimination was also much improved. The basis of the calculation of g at the surface of the second planet ultimately depended on the ratio of the relative $R \times \rho$ values (which happened to be 1.0).

11 Features of gravitational potential were tested by this question, in which students had to choose an *incorrect* statement. Questions in this format always present a challenge to students, since they would normally expect to select *correct* statements. Consequently this question, with a facility of 44%, was one of the most difficult questions in this test. Students ought to be familiar with the fact that, whilst field strength is a vector quantity, potential is a scalar. Therefore statement C (potential is a vector) cannot be correct and is the required answer.

12 This question distracted only 13% of the students away from the correct answer. When the question was pre-tested only 68% of the responses were correct. Yet it should not have been too demanding for students to appreciate that the field strength would be zero at the mid-point between two identical stars.

13 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.

14 This question tested students' understanding of the effect of the descent towards a planet on the speed and orbit time. 74% of them knew that the speed would increase and the orbit time would decrease, because $v \propto r^{-1/2}$ whilst $T \propto r^{3/2}$.

15 This question proved to be somewhat easier, despite the rather abstract phrasing of the stem. 85% of the students knew that only alternative C gave a consistent expression i.e. $g = GM / r^2$.

16 Direct application of Newton's law of gravitation easily gave the answer in this question, which had a facility of 78%. A very small number of incorrect responses came from assuming that the law gives $F \propto (1 / r)$ – represented by distractors A and D. Rather more (14%) chose distractor B; these students probably added the two component forces acting on the spacecraft instead of subtracting them.

17 Familiarity with $E = V / d$ should have enabled students to realise in this question that potential difference can be calculated from (field strength) × Δd, for both gravitational end electric fields. 62% of students correctly gave answer A; the three other distractors were chosen fairly randomly by between 10% and 17% of the entry.

18 This question tested students' knowledge of gravitational potential. 61% of the answers were correct. Each incorrect answer attracted a significant proportion of the responses, the most common being distractor D (19%). This choice came from confusing the correct unit of gravitational potential, J kg^{-1}, with the unit of field strength (N kg^{-1}).

19 In this question the candidates had to decide about the relative magnitudes of the forces from the Earth, the Moon and the Sun acting on a spacecraft when close to the Earth. Values for the relevant masses and distances were provided in case candidates needed to perform a calculation, or to carry out a check on their intuition. Obviously the spacecraft would not be in orbit around Earth if F_E was smaller than either of the other two forces. Hence F_E must be the largest of the three forces. The relative sizes of F_M and F_S then comes down to the ratio M / R^2, because the local gravitational field strength caused by each of the masses is GM / R^2. The facility of the question was 56%. 29% of the candidates chose distractor C; they appreciated that F_E is largest but thought that F_M would be greater than F_S.

20 In this question there were two further tests of gravitational field strength which candidates found demanding, with facilities of 46% and 50% respectively. The question required candidates to find the ratio $R_E : R_M$ when $g_E : g_M$ are in the ratio 9.8:1.7 and M_E is 81 × M_M. Forgetting to take the square root of $(R_E / R_M)^2$2 when applying the equation $g = GM / R^2$ was probably responsible for the incorrect response of the 27% of the candidates who chose distractor C.

21 In this question there were two further tests of gravitational field strength which candidates found demanding, with facilities of 46% and 50% respectively. The question required candidates to find the ratio $R_E : R_M$ when $g_E : g_M$ are in the ratio 9.8:1.7 and M_E is 81 × M_M. Forgetting to take the square root of $(R_E / R_M)^2$ when applying the equation $g = GM / R^2$ was probably responsible for the incorrect response of the 27% of the candidates who chose distractor C. This question was concerned with the position of the point between masses of M and $4M$ at which there would be no resultant field strength; distractor D was the choice of 26% of the candidates.

22 In this question the subject was gravitational potential. This question had been used in a previous examination; the facility of 65% this time was no different to when it was last used. Successful solutions involved arriving at $V_M / V_E = M_M R_E / M_E R_M$ and then applying the given data. More than one fifth of the candidates chose distractor B.

23 This question provided poorer discrimination between candidates' abilities than any other question in this test. Candidates ought to know that satellites speed up as they move into lower orbits, and therefore gain kinetic energy if their mass is unchanged. It should also be clear that satellites lose gravitational potential energy as they move closer to Earth. Therefore it is surprising that only 55% of the candidates gave the correct answer. The fairly even spread of responses amongst the other distractors suggests that many candidates were guessing.

24 This question, which involved determining the position of the point between two masses at which there would be no resultant gravitational force, was repeated from an earlier examination. Two thirds of the responses were correct, the most common incorrect one being distractor D – the inverse of the required expression.

25 This question was on gravitational effects. Rearrangement of possible units to obtain the ratio of the quantities g^2 / G was required; almost 70% of the candidates could do this correctly but 20% chose distractor B (N kg^{-1} instead of N m^{-2}).

26 This question was more demanding algebraically and involved use of a density value to determine the ratio of Earth's radius to the Moon's radius. Slightly under half of the candidates chose the correct value; incorrect responses were fairly evenly spread between the other distractors and the question discriminated poorly. This suggests that many were guessing.

27 Candidates found this question, on gravitational potential, a little easier, because its facility was almost 60%. Whether the work done was positive or negative must have troubled many, because distractor B (-80 kJ rather than +80 kJ) was the choice of 28%.

28 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.

29 This question turned out to be the hardest in the test, with a facility less than 40%, possibly because it required rather abstract thinking about energy transfer in fields. More than one quarter of the candidates did not spot that the displacement described in distractor D amounts to movement along an equipotential line, and so selected this as the correct answer.

30 This question tested knowledge and understanding of gravitational fields. 57% of the students selected the required *incorrect* statement in this question One in five of them chose distractor A. This may have been caused by them thinking they were supposed to choose the *correct* statement, or it may have been caused by a general misunderstanding of gravitational potential that was also evident in Section B of this paper.

31 This question which had a facility of 70%, was an algebraic test of the relationship between the weight of an object at the surface of a planet and the mass and radius of that planet. This question discriminated well and had no particularly strong distractor.

32 This question which tested how g is connected to the diameter for two stars of similar density, was the most demanding question on the test – its facility was only 39%. Equating *mg* with GMm / R^2 and then substituting (4/3) π R^3ρ. for *M* ought to have shown that *g* is proportional to the product *Rρ*. Consequently, if *ρ* is taken to be the same, $g \propto R$. Yet 33% of the students suggested that *g* would be 100 times smaller (distractor A), and not 100 times bigger, when the diameter was 100 times larger.

33 This question with a facility of 41%, was also demanding. Here several factors - kinetic energy, weight, time period and speed - had to be considered for two satellites in different circular orbits. The three incorrect answers had a fairly even distribution of responses.

34 This question involving statements about Newton's law of gravitation, had a facility of 85%. When pre-tested, this question had been found appreciably harder but was more discriminating than on this occasion.

35 Data for the gravitational constant and the masses of the electron and proton had to be extracted from the Data Sheet (see Reference Material) for use in this question where the topic was the gravitational force between two particles. Over four-fifths of the students succeeded with this.