1 A spherical planet of uniform density ρ has radius *R*.

Which line, **A** to **D**, in the table gives correct expressions for the mass of the planet and the gravitational field strength at its surface?

	mass of planet	**gravitational field strength at surface**
A	$\frac{4\pi R^2 p}{3}$	$\frac{4\pi GRp}{3}$
B	$\frac{4\pi R^3 p}{3}$	$\frac{4\pi GRp}{3}$
C	$\frac{4\pi R^2 p}{3}$	$\frac{4\pi Gp}{3}$
D	$\frac{4\pi R^3 p}{3}$	$\frac{4\pi Gp}{3}$

(Total 1 mark)

2 The gravitational potential at the surface of the Earth, of radius *R*, is V. What is the gravitational potential at a point at a height *R* above the Earth's surface?

A $\frac{V}{4}$

B $\frac{V}{2}$

C V

D $2V$

(Total 1 mark)

3 A satellite is in orbit at a height h above the surface of a planet of mass M and radius R. What is the velocity of the satellite?

A $\sqrt{\dfrac{GM}{(R+h)}}$

B $\sqrt{\dfrac{GM\,(R+h)}{R}}$

C $\dfrac{\sqrt{GM\;(\sqrt{R+h})}}{R}$

D $\dfrac{\sqrt{GM}}{(R+h)}$

(Total 1 mark)

4 Masses of *M* and 2*M* exert a gravitational force *F* on each other when the distance between their centres is *r*. What is the gravitational force between masses of 2*M* and 4*M* when the distance between their centres is 4*r*?

A 0.25 *F*

B 0.50 *F*

C 0.75 *F*

D 1.00 *F*

(Total 1 mark)

5 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)

6 At the surface of the Earth the gravitational field strength is *g*, and the gravitational potential is *V*. The radius of the Earth is *R*. An object, whose weight on the surface of the Earth is *W*, is moved to a height 3*R* above the surface. Which line, **A** to **D**, in the table gives the weight of the object and the gravitational potential at this height?

	weight	**gravitational potential**
A	$\frac{W}{16}$	$\frac{V}{4}$
B	$\frac{W}{4}$	$\frac{V}{3}$
C	$\frac{W}{4}$	$\frac{V}{4}$
D	$\frac{W}{16}$	$\frac{V}{3}$

(Total 1 mark)

7 A satellite of mass *m* travels in a circular orbit of radius *r* around a planet of mass *M*. Which one of the following expressions gives the angular speed of the satellite?

A $\sqrt{GMr}$

B $\sqrt{Gmr}$

C $\sqrt{\frac{Gm}{r^3}}$

D $\sqrt{\frac{GM}{r^3}}$

(Total 1 mark)

8 The gravitational force between two uniform spheres is 3.1×10^{-9} N when the distance between their centres is 150 mm. If the mass of one sphere is 2.5 kg, what is the mass of the other?

A 0.043 kg

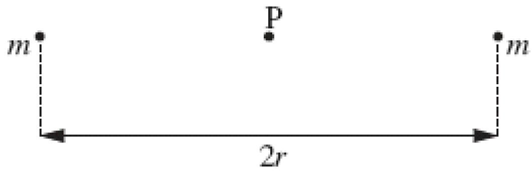
B 0.42 kg

C 2.8 kg

D 4.1 kg

(Total 1 mark)

9 The diagram shows two point masses each of mass m separated by a distance $2r$.



What is the value of the gravitational field strength at the mid-point, P, between the two masses?

A $\frac{4Gm}{r^2}$

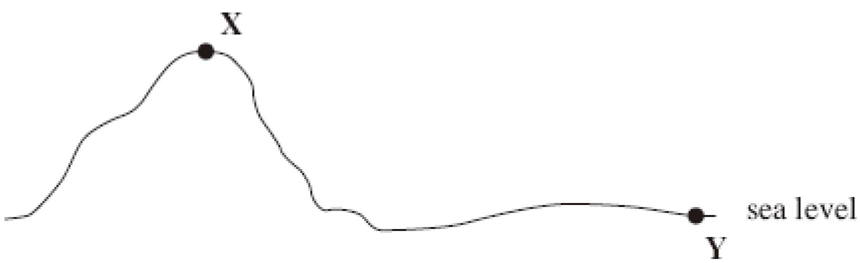
B $\frac{2Gm}{r^2}$

C $\frac{Gm}{2r^2}$

D zero

(Total 1 mark)

10 The diagram shows two positions, **X** and **Y**, on the Earth's surface.



Which line, **A** to **D**, in the table gives correct comparisons at **X** and **Y** for gravitational potential and angular velocity?

	gravitational potential at X compared with Y	**angular velocity at X compared with Y**
A	greater	greater
B	greater	same
C	greater	smaller
D	same	same

(Total 1 mark)

11 What would the period of rotation of the Earth need to be if objects at the equator were to appear weightless?

radius of Earth = 6.4×10^6 m

A 4.5×10^{-2} hours

B 1.4 hours

C 24 hours

D 160 hours

(Total 1 mark)

12 As a comet orbits the Sun the distance between the comet and the Sun continually changes. As the comet moves towards the Sun this distance reaches a minimum value.
Which one of the following statements is **incorrect** as the comet approaches this minimum distance?

A The potential energy of the comet increases.

B The gravitational force acting on the comet increases.

C The direction of the gravitational force acting on the comet changes.

D The kinetic energy of the comet increases.

(Total 1 mark)

13 Two protons are 1.0×10^{-14} m apart. Approximately how many times is the electrostatic force between them greater than the gravitational force between them?
(Use the Data and Formulae booklet)

A 10^{23}

B 10^{30}

C 10^{36}

D 10^{42}

(Total 1 mark)

14 A 10 mF capacitor is charged to 10 V and then discharged completely through a small motor. During the process, the motor lifts a weight of mass 0.10 kg. If 10% of the energy stored in the capacitor is used to lift the weight, through what approximate height will the weight be lifted?

A 0.05 m

B 0.10 m

C 0.50 m

D 1.00 m

(Total 1 mark)

15 A projectile moves in a gravitational field. Which one of the following is a correct statement about the gravitational force acting on the projectile?

A The force is in the direction of the field.

B The force is in the opposite direction to that of the field.

C The force is at right angles to the field.

D The force is at an angle between 0° and 90° to the field.

(Total 1 mark)

16 The gravitational potential difference between the surface of a planet and a point P, 10 m above the surface, is 8.0 J kg^{-1}. Assuming a uniform field, what is the value of the gravitational field strength in the region between the planet's surface and P?

A 0.80 N kg^{-1}

B 1.25 N kg^{-1}

C 8.0 N kg^{-1}

D 80 N kg^{-1}

(Total 1 mark)

17 An artificial satellite of mass *m* is in a stable circular orbit of radius *r* around a planet of mass *M*. Which one of the following expressions gives the speed of the satellite?
G is the universal gravitational constant.

A $\left(\frac{Gm}{r}\right)^{\frac{1}{2}}$

B $\left(\frac{GM}{r}\right)^{\frac{1}{2}}$

C $\frac{Gm}{r}$

D $\left(\frac{Gm}{r}\right)^{\frac{3}{2}}$

(Total 1 mark)

18 Two identical spheres exert a gravitational force *F* on each other. What is the gravitational force between two spheres, each twice the mass of one of the original spheres, when the separation of their centres is twice the original separation?

A F

B $2F$

C $4F$

D $8F$

(Total 1 mark)

19 A planet of mass *M* and radius *R* rotates so rapidly that loose material at the equator only just remains on the surface. What is the period of rotation of the planet?

G is the universal gravitational constant.

A $2\pi\sqrt{\frac{R}{GM}}$

B $2\pi\sqrt{\frac{R^2}{GM}}$

C $2\pi\sqrt{\frac{GM}{R^3}}$

D $2\pi\sqrt{\frac{R^3}{GM}}$

(Total 1 mark)

20 The radius of a certain planet is *x* times the radius of the Earth and its surface gravitational field strength is *y* times that of the Earth.

Which one of the following gives the ratio $\left(\frac{\text{mass of the planet}}{\text{mass of the Earth}}\right)$?

A xy

B x^2y

C xy^2

D x^2y^2

(Total 1 mark)

21 Which one of the following could be a unit of gravitational potential?

A N

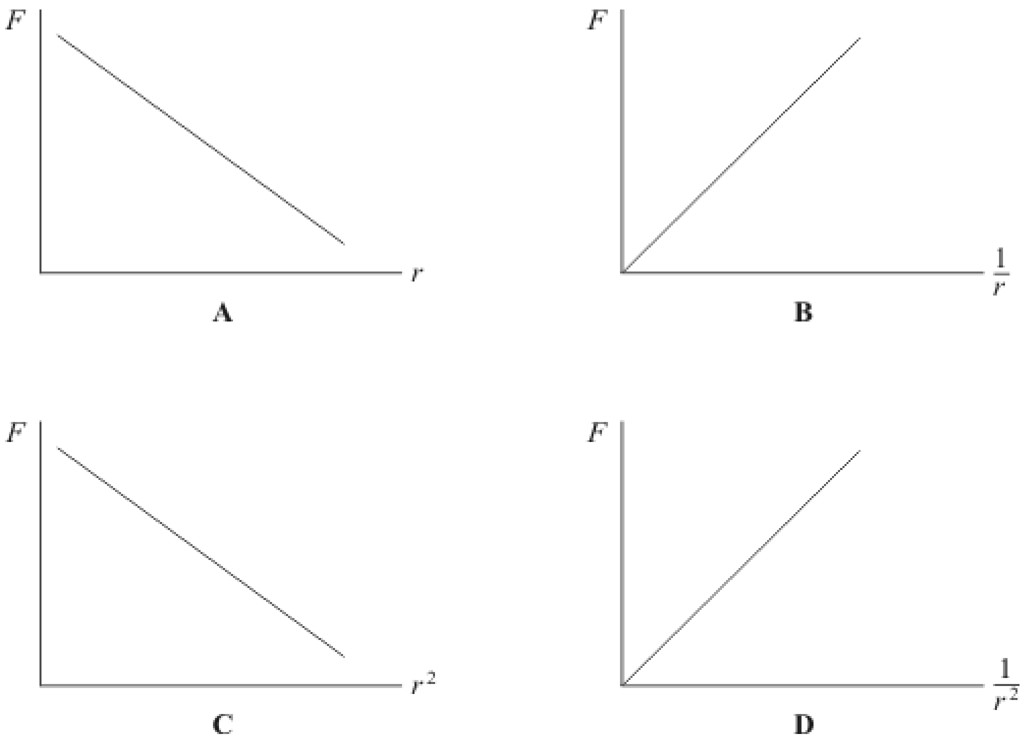
B J

C N kg^{-1}

D J kg^{-1}

(Total 1 mark)

22 Which one of the following graphs correctly shows the relationship between the gravitational force, *F*, between two masses and their separation *r*.



(Total 1 mark)

23 When at the surface of the Earth, a satellite has weight *W* and gravitational potential energy –*U*. It is projected into a circular orbit whose radius is equal to twice the radius of the Earth. Which line, **A** to **D**, in the table shows correctly what happens to the weight of the satellite and to its gravitational potential energy?

	weight	**gravitational potential energy**
A	becomes $\frac{W}{2}$	increases by $\frac{U}{2}$
B	becomes $\frac{W}{4}$	increases by $\frac{U}{2}$
C	remains *W*	increases by *U*
D	becomes $\frac{W}{4}$	increases by *U*

(Total 1 mark)

24 Two protons are 1.0×10^{-14} m apart. Approximately how many times is the electrostatic force between them greater than the gravitational force between them?

A 10^{23}

B 10^{30}

C 10^{36}

D 10^{42}

(Total 1 mark)

25 The diagram shows two positions, **X** and **Y**, at different heights on the surface of the Earth.

Which line, **A** to **D**, in the table gives correct comparisons at **X** and **Y** for gravitational potential and angular velocity?

	gravitational potential at X compared with Y	**angular velocity at X compared with Y**
A	greater	greater
B	greater	same
C	greater	smaller
D	same	same

(Total 1 mark)

26 A projectile moves in a gravitational field. Which one of the following is a correct statement for the gravitational force acting on the projectile?

A The force is in the direction of the field.

B The force is in the opposite direction to that of the field.

C The force is at right angles to the field.

D The force is at an angle between 0° and 90° to the field.

(Total 1 mark)

27 The Earth has density ρ and radius R. The gravitational field strength at the surface is g. What is the gravitational field strength at the surface of a planet of density 2ρ and radius $2R$?

A g

B $2\,g$

C $4\,g$

D $16\,g$

(Total 1 mark)

28 Two protons, each of mass *m* and charge *e*, are a distance *d* apart. Which one of the following expressions correctly gives the ratio $\left(\frac{\text{electrostatic force}}{\text{gravitational force}}\right)$ for the forces acting between them?

A $\frac{4\pi\varepsilon_0 e^2}{Gm^2}$

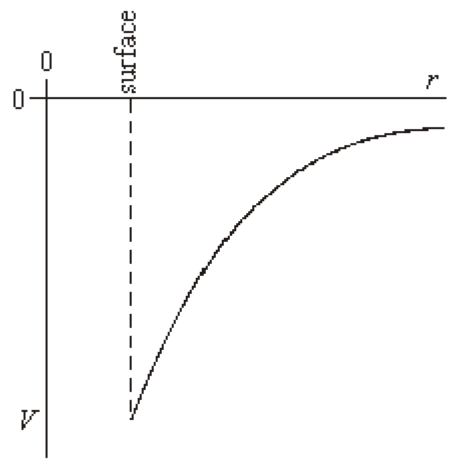
B $\frac{Ge^2}{4\pi\varepsilon_0 m^2}$

C $\frac{e^2 m^2}{4\pi\varepsilon_0 G}$

D $\frac{e^2}{4\pi\varepsilon_0 Gm^2}$

(Total 1 mark)

29 The graph shows how the gravitational potential, *V*, varies with the distance, *r* , from the centre of the Earth.



What does the gradient of the graph at any point represent?

A the magnitude of the gravitational field strength at that point

B the magnitude of the gravitational constant

C the mass of the Earth

D the potential energy at the point where the gradient is measured

(Total 1 mark)

30 The following data refer to two planets.

	radius/km	density/kg m^{-3}
planet P	8 000	6 000
planet Q	16 000	3 000

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)

31 Near the surface of a planet the gravitational field is uniform and for two points, 10 m apart vertically, the gravitational potential difference is 3 J kg^{-1}. How much work must be done in raising a mass of 4 kg vertically through 5 m?

A 3 J

B 6 J

C 12 J

D 15 J

(Total 1 mark)

32 What is the angular speed of a satellite in a geo-synchronous orbit around the Earth?

A 7.3×10^{-5} rad s^{-1}

B 2.6×10^{-1} rad s^{-1}

C 24 rad s^{-1}

D 5.0×10^{6} rad s^{-1}

(Total 1 mark)

33 A planet has a radius half of 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)

34 At a distance *R* from a fixed charge, the electric field strength is *E* and the electric potential is *V*. Which line, **A** to **D**, gives the electric field strength and electric potential at a distance 2*R* from the charge?

	electric field strength	electric potential
A	$\frac{E}{2}$	$\frac{V}{4}$
B	$\frac{E}{2}$	$\frac{V}{2}$
C	$\frac{E}{4}$	$\frac{V}{2}$
D	$\frac{E}{4}$	$\frac{V}{4}$

(Total 1 mark)

35 A small mass is situated at a point on a line joining two large masses m_l and m_2 such that it experiences no resultant gravitational force. If its distance from the mass m_1 is r_1 and its distance from the mass 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)

Mark schemes

1 B **[1]**

2 B **[1]**

3 A **[1]**

4 A **[1]**

5 C **[1]**

6 A **[1]**

7 D **[1]**

8 B **[1]**

9 D **[1]**

10 B **[1]**

11 B **[1]**

12 A **[1]**

13 C **[1]**

14 A **[1]**

15 A **[1]**

16 A **[1]**

17 B **[1]**

18 A **[1]**

19 D **[1]**

20 B **[1]**

21 D **[1]**

22 D **[1]**

23 B **[1]**

24 C **[1]**

25 B **[1]**

26 A **[1]**

27 C **[1]**

28 D **[1]**

29 A **[1]**

30 B **[1]**

31 B **[1]**

32 A **[1]**

33 C **[1]**

34 C **[1]**

35 C **[1]**

Examiner reports

1 The algebra required to relate the density of a planet to its mass and gravitational field strength in this question did not prove to be an obstacle to most students because 79% of them gave the correct combination from the table.

2 Appreciation that gravitational potential V is proportional to $1/r$ was all that was required to arrive at the correct response in this question which had a facility of 71%. The most common incorrect choice was distractor A, where the students may have thought V is proportional to $1/r^2$.

3 This question three quarters of the students were successful when dealing with the algebra giving the velocity motion of a satellite in stable orbit of radius ($R + h$). This question had appeared in a 2002 examination, when the students found it marginally harder and it was slightly less discriminating.

4 This was a fairly demanding calculation on the inverse square law of gravitation, in which candidates had to consider the effect of changing both the size of the attracting masses and their separation. Just over half reached the correct conclusion. No doubt it was errors in rearranging the arithmetic and/or algebra that caused 34% of candidates to opt for distractor B, where the new force was double what it ought to be.

5 This question, on the gravitational field strength at the surface of a planet, made similar mathematical demands to the previous question but was answered more successfully. The facility was 72%, an improvement of over 10% on the result when this question last appeared in an examination. The question was also an effective discriminator.

6 This question continued the theme of gravitation. At first sight, it should be easy. In fact it was the most demanding question in the test, with a facility of only 33%. Marginally more candidates chose the incorrect distractor D than the correct answer. This was a fairly simple test of inverse square proportion for force and inverse proportion for potential. Candidates made matters difficult by confusing the distance from an external point to the centre of the Earth with the distance to the surface of the Earth.

7 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.

8 This question, involving a rearrangement of the force equation from Newton's law, had a facility of 77%.

9 This question was about the value of the gravitational field strength at the mid-point between two equal masses; surprisingly, only 60% of the candidates knew that this would be zero.

10 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 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.

12 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.

13 Another reused question combined Coulomb's law with Newton's law of gravitation and needed candidates to take data from the *Data and Formulae Booklet*. The incorrect responses were distributed fairly evenly across the three remaining distractors.

14 This question had been used in an earlier examination. Its facility of 58% this time was a slight improvement on that achieved previously. Either arithmetic errors, or failure to account for the 10% efficiency, were probably responsible for almost a quarter of the candidates choosing distractor C (0.50 m) rather than the correct 0.05 m.

15 The candidates in 2010 found this question to be slightly easier than their predecessors, with the facility advancing from 55% to 59%. One in four candidates demonstrated their confusion with magnetic fields by opting for distractor C, where the force was perpendicular to the field.

16 This question was a direct test of the equation connecting field strength and potential gradient, $g = -\Delta V/\Delta r$. The outcome from this question was very similar to when it was last used; the facility was 72% and there were no particularly strong distractors.

17 In this question, equating the centripetal force on a satellite with the gravitational force on it should lead easily to a correct algebraic expression for the speed. Two thirds of candidates were successfully able to do this.

18 This question was about gravitational forces. Application of the inverse square law was completed successfully by 70% of the candidates in the former question.

19 This question was about gravitational forces. Application of the inverse square law was completed successfully by 70% of the candidates in the former question. Candidates had to appreciate that the condition described would be met when the centripetal force acting on material is just equal to its weight, so $\omega^2 R = GM/R^2$. Only 48% of them were successful, but the question discriminated very well.

20 The correct algebraic rearrangement of $g = GM/R^2$ would deliver a correct answer in this question, achieved by 62% of the candidates.

21 The unit of gravitational potential was known correctly by 71% of the candidates in this question. However, one in five selected distractor C – N kg^{-1} – which is the unit of gravitational field strength.

22 This question was a graphical test of inverse proportionality, as represented by the universal law of gravitation. The facility of the question was 65%, but one quarter of the candidates were tempted into choosing distractor C.

23 This question revived a question used in an Advanced Supplementary examination almost ten years ago. The topics, gravitational force and gravitational potential energy for an Earth satellite, were better known in 2006 than by the previous candidates: the facility increased from 39% in 1997 to 54% on this occasion. Distractor D was chosen by 22% of the candidates; increasing the gravitational potential energy of the satellite by U would in fact remove it to infinity. Distractor A was chosen by the 15% of candidates, thinking that both force and potential are proportional to $1/r$.

24 Data for *e*, m_P, ε_0 and *G* had to be extracted from the Data Sheet before the correct response to this question could be decided. This defeated almost half of the candidates, for the facility of the question was 51%. Around one fifth of the candidates selected each of the incorrect distractors A and B.

25 The angular velocity of the Earth was also to be considered in this question, but for points at different heights and therefore at different gravitational potentials. This question was very demanding, as is shown by its facility of only 51%. The common value of ω for the whole Earth was not always appreciated. Over one-fifth of the candidates chose distractor A, where the higher point was supposed to have a greater value of ω, whilst almost as many selected distractor C (a smaller ω at the higher point).

26 The direction of forces in gravitational, electric and magnetic fields continues to be an area of misunderstanding, as illustrated by the responses in this question, which had a facility of 55%. Despite the fact that this question was about gravitational fields, just over a quarter of the candidates selected distractor C, where the force is supposed to be at right angles to the field. This confusion with a magnetic field is no more understandable than that of the 11% who chose distractor B, where the force would be in the opposite direction to the field. Perhaps this latter group were thinking of electrons in an electric field. Such incorrect responses suggest that candidates were not always reading the questions with sufficient care.

27 The candidates found this question, with a facility of 41%, to be the most demanding on the test. The pre-test facility of this question had been rather higher. Candidates continue to have difficulty with algebraic questions such as this, which require two separate quantities (here field strength and density) to be combined. Practically half of the responses were divided almost equally between incorrect distractors A and B.

28 This question raised similar demands to the previous question, in that they required more than one concept to be combined to give an algebraic result. In this question, electrostatic and gravitational forces had to be considered together. The facility was 64%, and this question was the best discriminator in the test. Over one-fifth of the responses were for distractor A, which has ($4\pi\varepsilon_0$) in the numerator instead of the denominator of the required expression.

29 This question was a direct test of $g = -\Delta V/\Delta r$. This was easy, with 69% of the candidates making the correct response. There seems to be no logical reason to account for distractor B, which was chosen by one fifth of the candidates.

30 This question had been used previously in a linear A level examination, when 62% gave the correct response. Several linked ideas were necessary to obtain the required value: the dependence of *g* on radius and mass, and the connection between mass, density and volume. Fewer of the 2004 cohort were able to progress through this, because only 58% responded correctly this time. Since 21% chose distractor A, and 18% chose C, it is probable that many resorted to guessing.

31 This question, which was a test of $\Delta E_p = m\,\Delta V$, had been used in an earlier AS paper. The 2004 facility of 65% was a slight improvement on the previous occasion. Incomplete reading of the question – not realising that the distance involved was 5m rather than 10m – may account for the 25% who chose distractor C.

32 The geo-synchronous satellite in this question did not seriously trouble many of the candidates, since the facility was 80%. Wrong responses were almost evenly split between the remaining three distractors, with none attracting more than 8% of the candidates.

33 The gravitational field strength at the surface of a planet and its relation with radius and mass was the subject tested by this question. 61% of the candidates selected the correct response, a 10% improvement over the pre-test facility. Distractor B, the most common wrong response, was chosen by just over one in five of the candidates.

34 This question, with a facility of 66%, examined the variations of electric field strength and electric potential with distance in a radial field. Distractor D was hardly ever chosen, with wrong answers divided mainly between distractors A and B.

35 Gravitation was the subject being tested in this question, on the inverse square law, which had a facility of 61% but did not discriminate as well as it had when used in a previous AS level examination.