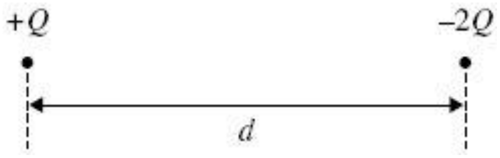
Fields and Lots of it!

109 minutes

79 marks

Q1.



The diagram shows two particles at a distance *d* apart. One particle has charge +*Q* and the other –2*Q*. The two particles exert an electrostatic force of attraction, *F*, on each other. Each particle is then given an additional charge +*Q* and their separation is increased to a distance 2*d*.
Which one of the following gives the force that now acts between the two particles?

A an attractive force of $\frac{F}{4}$

B a repulsive force of $\frac{F}{4}$

C an attractive force of $\frac{F}{2}$

D a repulsive force of $\frac{F}{2}$

(Total 1 mark)

Q2. 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)

Q3. 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)

Q4. 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)

Q5. 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*

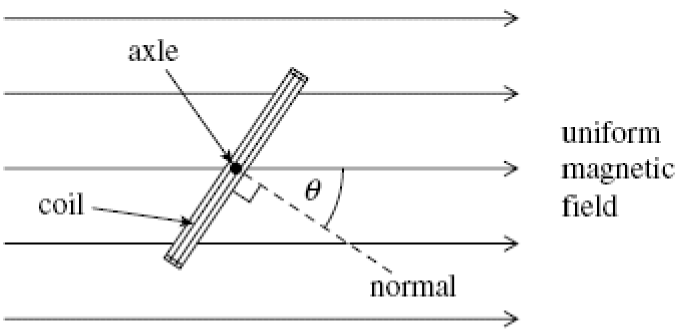
B 2*F*

C 4*F*

D 8*F*

(Total 1 mark)

Q6. The figure below shows an end view of a simple electrical generator. A rectangular coil is rotated in a uniform magnetic field with the axle at right angles to the field direction. When in the position shown in the figure below the angle between the direction of the magnetic field and the normal to the plane of the coil is θ.



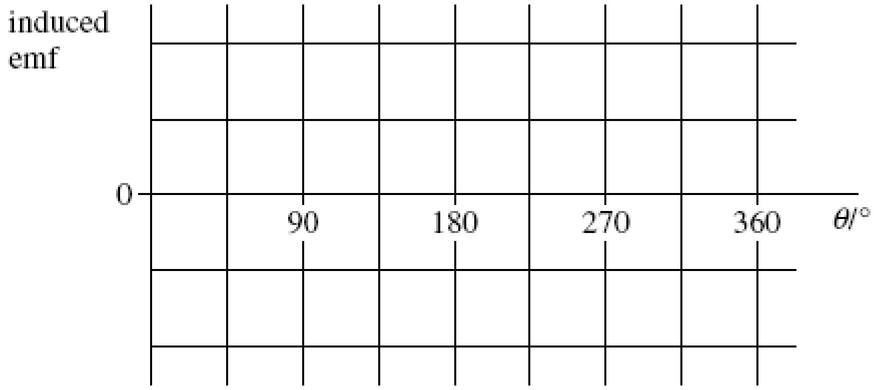
(a) The coil has 50 turns and an area of 1.9×10^{-3} m^2. The flux density of the magnetic field is 2.8×10^{-2} T. Calculate the flux linkage for the coil when θ is 35°, expressing your answer to an appropriate number of significant figures.

answer = ... Wb turns

(3)

(b) The coil is rotated at constant speed, causing an emf to be induced.

(i) Sketch a graph on the outline axes to show how the induced emf varies with angle θduring one complete rotation of the coil, starting when θ = 0. Values are not required on the emf axis of the graph.



(1)

(ii) Give the value of the flux linkage for the coil at the positions where the emf has its greatest values.

answer = ... Wb turns

(1)

(iii) Explain why the magnitude of the emf is greatest at the values of θ shown in your answer to part (b)(i).

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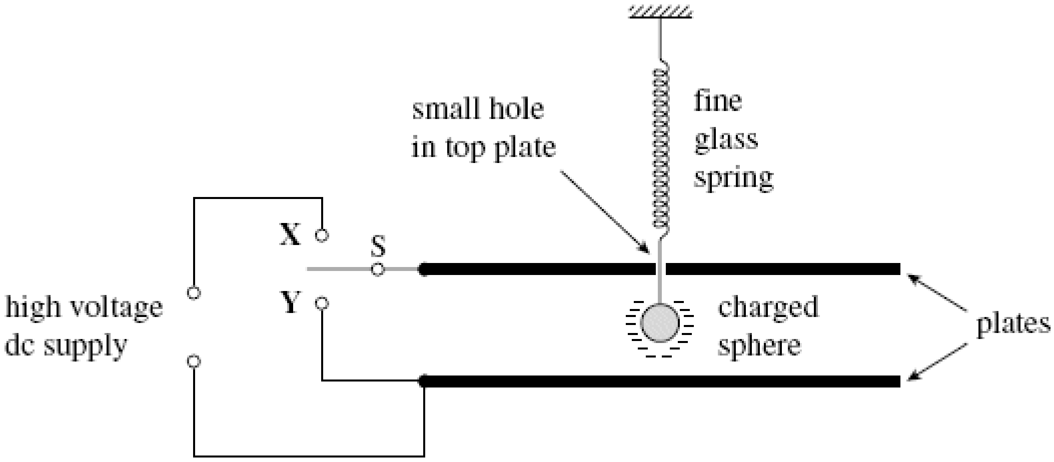
(3)
(Total 8 marks)

Q7. A small negatively charged sphere is suspended from a fine glass spring between parallel horizontal metal plates, as shown in the figure below.



(a) Initially the plates are uncharged. When switch S is set to position **X**, a high voltage dc supply is connected across the plates. This causes the sphere to move vertically upwards so that eventually it comes to rest 18 mm higher than its original position.

(i) State the direction of the electric field between the plates.

....

(1)

(ii) The spring constant of the glass spring is 0.24 N m^{-1}. Show that the force exerted on the sphere by the electric field is 4.3×10^{-3} N.

(1)

(iii) The pd applied across the plates is 5.0 kV. If the charge on the sphere is -4.1×10^{-8} C, determine the separation of the plates.

answer = ... m

(3)

(b) Switch S is now moved to position **Y**.

(i) State and explain the effect of this on the electric field between the plates.

....

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....

(2)

(ii) With reference to the forces acting on the sphere, explain why it starts to move with simple harmonic motion.

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(3)
(Total 10 marks)

Q8. (a) State Newton's law of gravitation.

....

....

....

....

(2)

(b) In 1798 Cavendish investigated Newton's law by measuring the gravitational force between two unequal uniform lead spheres. The radius of the larger sphere was 100 mm and that of the smaller sphere was 25 mm.

(i) The mass of the smaller sphere was 0.74 kg. Show that the mass of the larger sphere was about 47 kg.

density of lead = 11.3×10^{3} kg m^{-3}

(2)

(ii) Calculate the gravitational force between the spheres when their surfaces were in contact.

answer = ... N

(2)

(c) Modifications, such as increasing the size of each sphere to produce a greater force between them, were considered in order to improve the accuracy of Cavendish's experiment. Describe and explain the effect on the calculations in part (b) of doubling the radius of both spheres.

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(4)
(Total 10 marks)

Q9. A 230 V, 60 W lamp is connected to the output terminals of a transformer which has a 200 turn primary coil and a 2000 turn secondary coil. The primary coil is connected to an ac source with a variable output pd. The lamp lights at its normal brightness when the primary coil is supplied with an alternating current of 2.7 A.

What is the percentage efficiency of the transformer?

A 3%

B 10%

C 97%

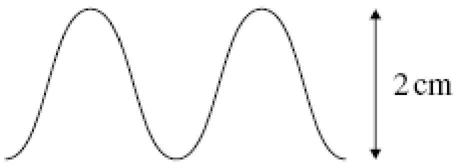
D 100%

(Total 1 mark)

Q10. A coil rotating in a magnetic field produces the following voltage waveform when connected to an oscilloscope.

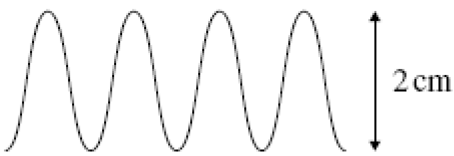
With the same oscilloscope settings, which one of the following voltage waveforms would be produced if the coil were rotated at twice the original speed?

A



B

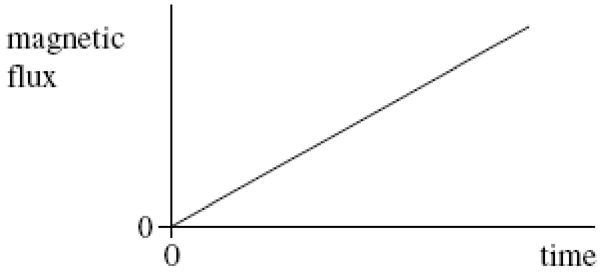
C



D

(Total 1 mark)

Q11. The graph shows how the magnetic flux passing through a loop of wire changes with time.



What feature of the graph represents the magnitude of the emf induced in the coil?

A the area enclosed between the graph line and the time axis

B the area enclosed between the graph line and the magnetic flux axis

C the inverse of the gradient of the graph

D the gradient of the graph

(Total 1 mark)

Q12. Which one of the following could **not** be used as a unit of force?

A A T m

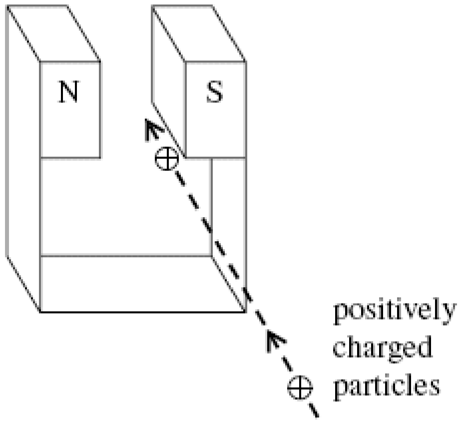
B W s^{-2}

C kg m s^{-2}

D J m^{-1}

(Total 1 mark)

Q13. A jet of air carrying positively charged particles is directed horizontally between the poles of a strong magnet, as shown in the diagram.



In which direction are the charged particles deflected?

A upwards

B downwards

C towards the N pole of the magnet

D towards the S pole of the magnet

(Total 1 mark)

Q14. An electron moving with a constant speed enters a uniform magnetic field in a direction at right angles to the field. What is the subsequent path of the electron?

A A straight line in the direction of the field.

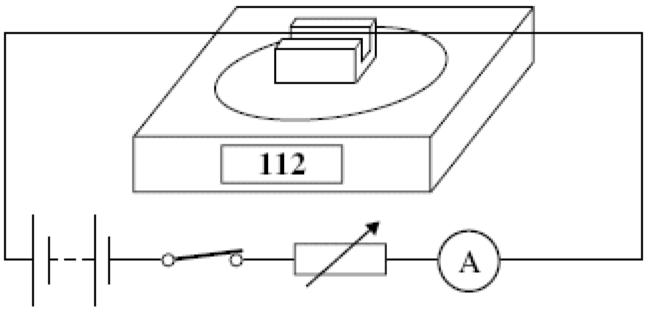
B A straight line in a direction opposite to that of the field.

C A circular arc in a plane perpendicular to the direction of the field.

D An elliptical arc in a plane perpendicular to the direction of the field.

(Total 1 mark)

Q15. The diagram shows a rigidly-clamped straight horizontal current-carrying wire held mid-way between the poles of a magnet on a top pan balance. The wire is perpendicular to the magnetic field direction.



The balance, which was zeroed before the switch was closed, reads 112 g after the switch is closed. If the current is reversed and doubled, what will be the new reading on the balance?

A –224 g

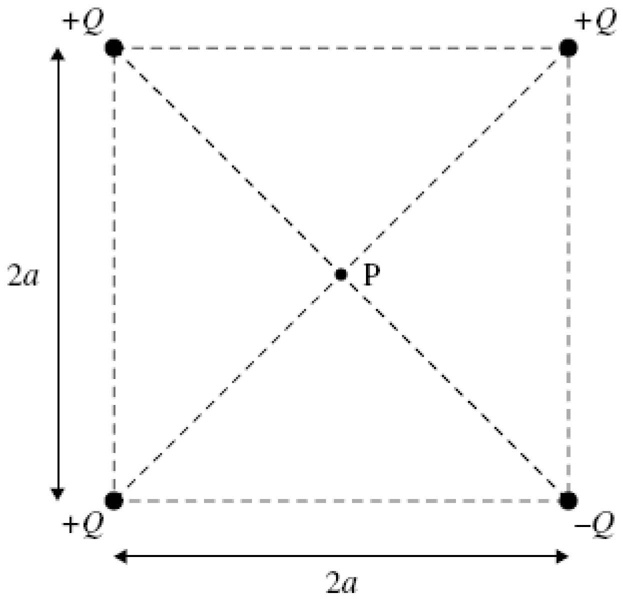
B –112 g

C zero

D 224 g

(Total 1 mark)

Q16. The diagram shows four point charges at the corners of a square of side 2*a*. What is the electric potential at P, the centre of the square?



A $\dfrac{Q}{2\sqrt{2}\pi\varepsilon_0 a}$

B $\dfrac{Q}{\sqrt{2}\pi\varepsilon_0 a}$

C $\dfrac{Q}{2\pi\varepsilon_0 a}$

D $\dfrac{Q}{4\pi\varepsilon_0 a}$

(Total 1 mark)

Q17.

The diagram shows two charges, +4 μC and –16 μC, 120 mm apart. What is the distance from the +4 μC charge to the point between the two charges where the resultant electric potential is zero?

A 24 mm

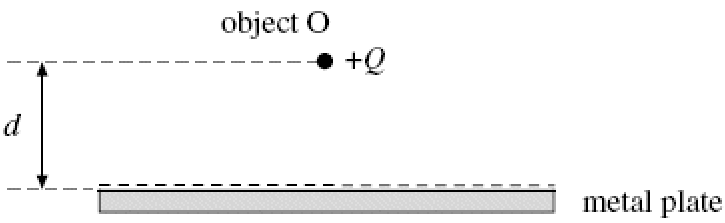
B 40 mm

C 80 mm

D 96 mm

(Total 1 mark)

Q18. A small object O carrying a charge +*Q* is placed at a distance *d* from a metal plate that has an equal and opposite charge. The object is acted on by an electrostatic force *F*.



Which one of the following expressions has the same unit as *F*?

A $\frac{\varepsilon_0 Q^2}{d}$

B $\frac{\varepsilon_0 Q^2}{d^2}$

C $\frac{Q^2}{\varepsilon_0 d}$

D $\frac{Q^2}{\varepsilon_0 d^2}$

(Total 1 mark)

Q19. 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)

Q20. 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)

Q21. 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.

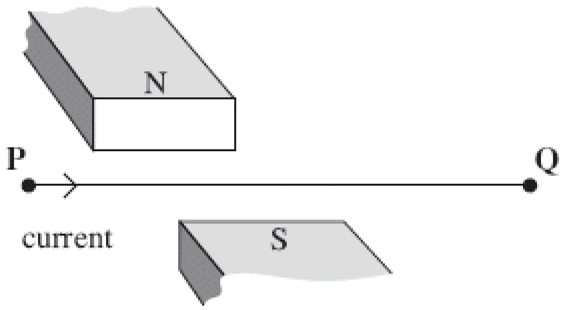
B The force is in the opposite direction to that of the field.

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)

Q22. The figure below shows a horizontal wire, held in tension between fixed points at **P** and **Q**. A short section of the wire is positioned between the pole pieces of a permanent magnet, which applies a uniform horizontal magnetic field at right angles to the wire. Wires connected to a circuit at **P** and **Q** allow an electric current to be passed through the wire.



(a) (i) State the direction of the force on the wire when there is a direct current from **P** to **Q**, as shown in the figure above.

....

(1)

(ii) In a second experiment, an alternating current is passed through the wire. Explain why the wire will vibrate vertically.

....

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....

....

....

....

(3)

(b) The permanent magnet produces a uniform magnetic field of flux density 220 mT over a 55 mm length of the wire. Show that the maximum force on the wire is about 40 mN when there is an alternating current of rms value 2.4 A in it.

(3)

(c) The length of **PQ** is 0.40 m. When the wire is vibrating, transverse waves are propagated along the wire at a speed of 64 m s^{-1}. Explain why the wire is set into large amplitude vibration when the frequency of the a.c. supply is 80 Hz.

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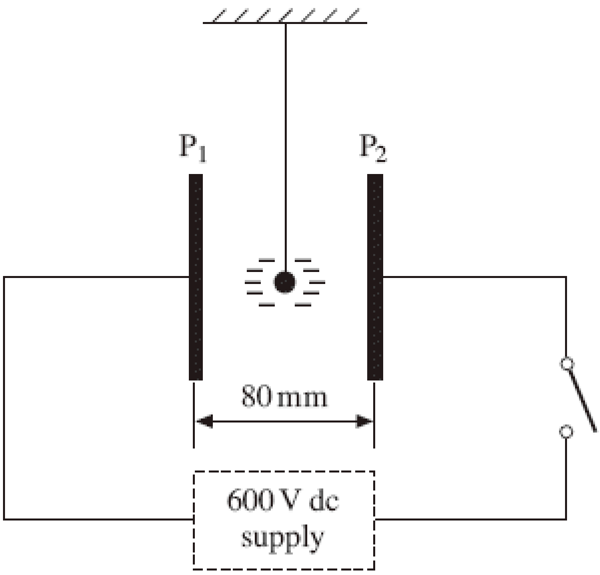
(3)
(Total 10 marks)

Q23. **Figure 1** shows a small polystyrene ball which is suspended between two vertical metal plates, $\mathbf{P_1}$ and $\mathbf{P_2}$, 80 mm apart, that are initially uncharged. The ball carries a charge of –0.17

μC.

Figure 1



(a) (i) A pd of 600 V is applied between $\mathbf{P_1}$ and $\mathbf{P_2}$ when the switch is closed. Calculate the magnitude of the electric field strength between the plates, assuming it is uniform.

answer = ...V m^{-1}

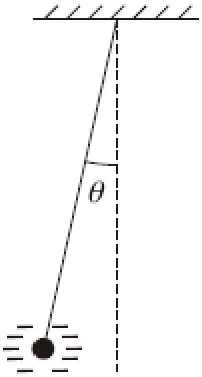
(2)

(ii) Show that the magnitude of the electrostatic force that acts on the ball under these conditions is 1.3 mN.

(1)

(b) Because of the electrostatic force acting on it, the ball is displaced from its original position. It comes to rest when the suspended thread makes an angle *θ* with the vertical, as shown in **Figure 2**.

Figure 2



(i) On **Figure 2**, mark and label the forces that act on the ball when in this position.

(2)

(ii) The mass of the ball is 4.8×10^{-4} kg. By considering the equilibrium of the ball, determine the value of θ.

answer = ... degrees

(3)

(Total 8 marks)

Q24. A transformer has 1200 turns on the primary coil and 500 turns on the secondary coil. The primary coil draws a current of 0.25 A from a 240 V ac supply. If the efficiency of the transformer is 83%, what is the current in the secondary coil?

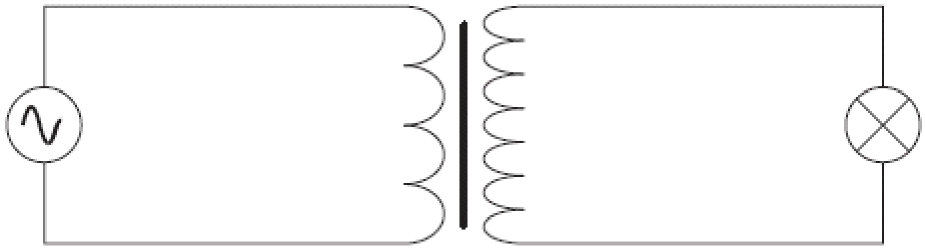
A 0.10 A

B 0.21 A

C 0.50 A

D 0.60 A

Q25. The primary coil of a step-up transformer is connected to a source of alternating pd.The secondary coil is connected to a lamp.

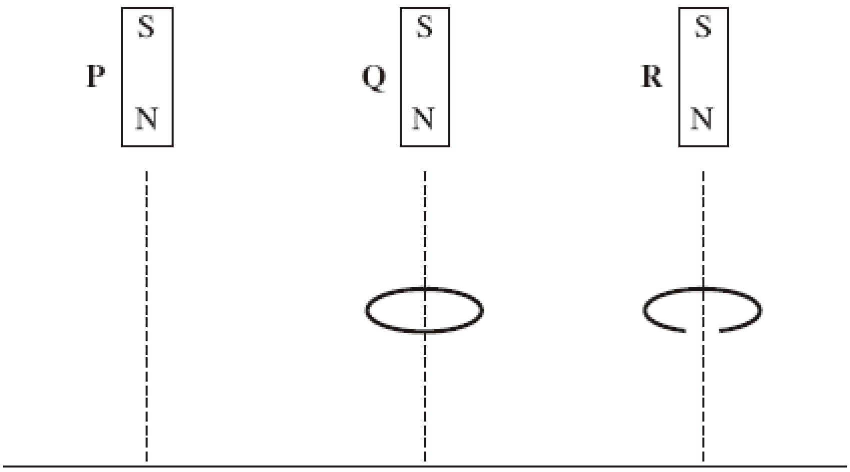


Which line, **A** to **D**, in the table correctly describes the flux linkage and current through the secondary coil in relation to the primary coil?

	$\frac{\text{secondary magnetic flux linkage}}{\text{primary magnetic flux linkage}}$	$\frac{\text{secondary current}}{\text{primary current}}$
A	>1	<1
B	<1	<1
C	>1	>1
D	<1	>1

(Total 1 mark)

Q26.



Three identical magnets **P**, **Q** and **R** are released simultaneously from rest and fall to the ground from the same height. **P** falls directly to the ground, **Q** falls through the centre of a thick conducting ring and **R** falls through a ring which is identical except for a gap cut into it. Which one of the statements below correctly describe the sequence in which the magnets reach the ground?

A **P** and **R** arrive together followed by **Q**.

B **P** and **Q** arrive together followed by **R**.

C **P** arrives first, follow by **Q** which is followed by **R**.

D All three magnets arrive simultaneously.

(Total 1 mark)

Q27. An aircraft, of wing span 60 m, flies horizontally at a speed of 150 m s^{-1}. If the vertical component of the Earth's magnetic field in the region of the plane is 1.0×10^{-5} T, what is the magnitude of the magnetic flux cut by the wings in 10 s?

A 1.0×10^{-5} Wb

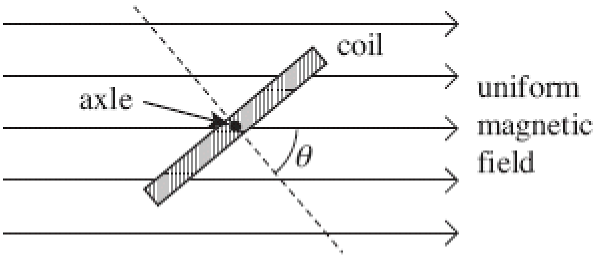
B 1.0×10^{-4} Wb

C 9.0×10^{-2} Wb

D 9.0×10^{-1} Wb

(Total 1 mark)

Q28.



A coil of 50 turns has a cross-sectional area of 4.2×10^{-3} m^2. It is placed at an angle to a uniform magnetic field of flux density 2.8×10^{-2} T, as shown in the diagram, so that angle $\theta = 50°$.

What is the change in flux linkage when the coil is rotated anticlockwise until $\theta = 0°$?

A The flux linkage decreases by 2.1×10^{-3} Wb turns.

B The flux linkage increases by 2.1×10^{-3} Wb turns.

C The flux linkage decreases by 3.8×10^{-3} Wb turns.

D The flux linkage increases by 3.8×10^{-3} Wb turns.

(Total 1 mark)

Q29. An electron moving with a constant speed enters a uniform magnetic field in a direction perpendicular to the magnetic field. What is the shape of the path that the electron would follow?

A parabolic

B circular

C elliptical

D a line parallel to the magnetic field

(Total 1 mark)

Q30. A negatively charged particle moves at right angles to a uniform magnetic field. The magnetic force on the particle acts

A in the direction of the field.

B in the opposite direction to that of the field.

C at an angle between 0° and 90° to the field.

D at right angles to the field.

(Total 1 mark)

Q31. 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)

Q32. 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)

Q33. What is the acceleration of an electron at a point in an electric field where the field strength is 1.5×10^{5} V m^{-1}?

A 1.2×10^{6} m s^{-2}

B 1.4×10^{13} m s^{-2}

C 2.7×10^{15} m s^{-2}

D 2.6×10^{16} m s^{-2}

(Total 1 mark)

Q34. The repulsive force between two small negative charges separated by a distance *r* is *F*.

What is the force between the charges when the separation is reduced to $\frac{r}{3}$?

A $\frac{F}{9}$

B $\frac{F}{3}$

C $3F$

D $9F$

(Total 1 mark)

Q35. 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)

M1. A

[1]

M2. D

[1]

M3. B

[1]

M4. D

[1]

M5. A

[1]

M6. (a) flux linkage (= $N\phi$ = $BAN\cos\theta$)

$= 2.8 \times 10^{-2} \times 1.9 \times 10^{-3} \times 50 \times \cos 35°$ **(1)**

$= 2.2 \times 10^{-3}$ (Wb turns) **(1)**

answer must be to **2 sf** only **(1)**

3

(b) (i) reasonable sine curve drawn on axes, showing just one cycle, starting at emf = 0 **(1)**

1

(ii) the flux linkage in these positions is **zero (1)**

1

(iii) induced emf $\propto$ (or =) rate of change of flux (linkage) **(1)**

flux (linkage) through the coil changes as it is rotated **(1)**

from maximum at θ = 0, 180° to zero at 90° and 270° **(1)**

rate of change is greatest when plane of coil is parallelto B [**or** reference to $\varepsilon = BAN\omega \sin \omega t$, **or** $\varepsilon = BAN\omega \sin \theta$] **(1)**

because coil then cuts flux lines perpendicularly[**or** $\varepsilon = BAN\omega \sin \omega t$ shows ε is greatestwhen ωt = 90° or 270°] **(1)**

max 3

[8]

M7. (a) (i) (vertically) downwards [**or** top to bottom, or down the page] **(1)**

1

(ii) force on sphere F (= kx) = $0.24 \times 18 \times 10^{-3}$ **(1)** (= 4.32×10^{-3} N)

1

(iii) **use of** $F = EQ$ gives $E = \dfrac{4.32 \times 10^{-3}}{41 \times 10^{-9}}$ **(1)** (= 1.05×10^{5} V m^{-1})

use of $E = \dfrac{v}{d}$ gives separation $d = \dfrac{5.0 \times 10^{-3}}{1.05 \times 10^{5}}$ **(1)**

= 4.8×10^{-2} (m) **(1)** (4.76×10^{-2})

3

(b) (i) electric field becomes zero (or ceases to exist) **(1)**

flow of charge (or electrons) from one plate to the other [**or** plates discharge] **(1)**

(until) pd across plates becomes zero [**or** no pd across plates, **or** plates at same potential] **(1)**

max 2

(ii) net downward force on sphere (when E becomes zero)[**or** gravitational force acts on sphere, **or** force is weight] **(1)**

this force extends spring **(1)**

force (or acceleration) is proportional to (change in)extension of spring **(1)**acceleration is in opposite direction to displacement(or towards equilibrium) **(1)** for shm, acceleration $\propto$ (−) displacement[**or** for shm, force $\propto$ (−) displacement] **(1)**

max 3

[10]

M8. (a) force of attraction between two point masses (or particles) **(1)**

proportional to product of masses **(1)**

inversely proportional to square of distance between them **(1)**

[**alternatively**

quoting an equation, $F = \frac{GM_1M_2}{r^2}$ with all terms defined **(1)**

reference to point masses (or particles) **or** r is distance between centres **(1)**

F identified as an attractive force **(1)**]

max 2

(b) (i) mass of larger sphere M_L (= $\frac{4}{3}\pi r^3\rho$) = $\frac{4}{3}$ π × $(0.100)^3$ × 11.3 × 10^3 **(1)**
= 47(.3) (kg) **(1)**

[**alternatively**

use of $M \propto r^3$ gives $\frac{M_L}{0.74} = \left(\frac{100}{25}\right)^3$ **(1)** (= 64)

and M_L = 64 × 0.74 = 47(.4) (kg) **(1)**]

2

(ii) gravitational force F $\left(= \frac{GM_L M_S}{x^2}\right) = \frac{6.67 \times 10^{-11} \times 47.3 \times 0.74}{0.125^2}$ **(1)**

= 1.5 × 10^{-7} (N) **(1)**

2

(c) for the spheres, mass $\propto$ volume (or $\propto r^3$, or $M = \frac{4}{3}\pi r^3\rho$) **(1)**

mass of either sphere would be 8 × greater (378 kg, 5.91 kg) **(1)**

this would make the force 64 × greater **(1)** but separation would be doubled causing force to be 4 × smaller **(1)**

net effect would be to make the force (64/4) = 16 × greater **(1)**(ie 2.38 × 10^{-6} N)

max 4

[10]

M9. C

[1]

M10. C

[1]

M11. D

[1]

M12. B

[1]

M13. B

[1]

M14. C

[1]

M15. A

[1]

M16. A

[1]

M17. A

[1]

M18. D

[1]

M19. B

[1]

M20. A

[1]

M21. A

[1]

M22. (a) (i) (vertically) downwards **(1)**

1

(ii) force F is perpendicular to both B and I [**or** equivalent correctexplanation using Fleming LHR] **(1)**

magnitude of F changes as size of current changes **(1)**

force acts in opposite direction when current reverses[**or** ac gives alternating force] **(1)**

continual reversal of ac means process is repeated **(1)**

max 3

(b) appreciation that maximum force corresponds to peak current **(1)**

peak current = 2.4 × $\sqrt{2}$ = 3.39 (A) **(1)**

F_{max} (= $B\ I_{pk}\ L$) = 0.22 × 3.39 × 55 × 10^{-3} **(1)** (= 4.10 × 10^{-2} N)

3

(c) wavelength (λ) of waves = $\left(= \frac{c}{f}\right) = \frac{64}{80}$ = 0.80 (m) **(1)**

length of wire is λ/2 causing fundamental vibration **(1)**

[**or** λ of waves required for fundamental (= 2 × 0.40) = 0.80 m **(1)**

natural frequency of wire $\left(= \frac{c}{\lambda}\right) = \frac{64}{0.80}$ = 80 (Hz) **(1)**]

wire resonates (at frequency of ac supply) [**or** a statement that fundamental frequency (or a natural frequency) of the wire is the same as applied frequency] **(1)**

3

[10]

M23. (a) (i) $E\left(=\frac{V}{d}\right)=\frac{600}{80\times10^{-3}}$ **(1)**

$= 7.5 \times 10^3$ (V m^{-1}) **(1)**

2

(ii) force *F* (= *EQ*) = $7500 \times 0.17 \times 10^{-6}$ **(1)** (= 1.28×10^{-3} N)

1

(b) (i) correct labelled arrows placed on diagram to show the threeforces acting;

- electric force *F* (or 1.3 mN) horizontally to left **(1)**
- *W* (or *mg*) vertically down **and**
- tension *T* upwards along the thread **(1)**

2

(ii) $F = T\sin\theta$ and $mg = T\cos\theta$ give $F = mg\tan\theta$ **(1)**
(or by triangle or parallelogram methods)

$\tan\theta\left(=\frac{F}{mg}\right)=\frac{1.28\times10^{-3}}{4.8\times10^{-4}\times9.81}(=0.272)$ **(1)**

gives θ = 15(.2) (°) **(1)**

3

[8]

M24. C

[1]

M25. A

[1]

M26. A

[1]

M27. D

[1]

M28. B

[1]

M29. B

[1]

M30. D

[1]

M31. A

[1]

M32. C

[1]

M33. D

[1]

M34. D

[1]

M35. A

[1]

E1. Coulomb's law had to be applied in this question. 66% of the candidates realised that doubling the separation would have the effect of reducing the force by a factor of four, whilst the changes to the charges would mean that they would become $+2Q$ and $-Q$, so that the force would remain one of attraction. Distractor C was selected by 22% of candidates; this could be because they thought that $F \propto 1/r$ instead of $F \propto 1/r^2$.

E2. 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.

E3. The correct algebraic rearrangement of $g = GM/R^2$ would deliver a correct answer in this question, achieved by 62% of the candidates.

E4. 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.

E5. This question was about gravitational forces. Application of the inverse square law was completed successfully by 70% of the candidates in the former question.

E6. A large proportion of the answers to part (a) were completely correct but to give three significant figures in the final answer. Other frequent mistakes were to use sin 35° instead of cos 35°, to calculate cos 35 in radians instead of degrees, or to omit the cos 35° factor completely.

The confusion between flux linkage and rate of change of flux linkage was so widespread that the answers to part (b) were usually very poor. In part (b) (i), a majority of the candidates seemed to prefer to draw a cosine graph rather than the required sine (or – sine) curve. Responses to part (b) (ii) were split fairly evenly between zero and 2.66×10^{-3}. In part (b) (iii), the candidates who had drawn a cosine graph in part (i) could only refer usefully to the induced emf being proportional to the rate of change of flux linkage; everything else in their answers was nonsensical because of the wrong graph. Good, fully-reasoned answers, that referred to the changing flux linkage as the coil rotated and to the correct angles at which the rate of change would be maximised, were remarkably rare. Even when a sine curve had been drawn, examiners frequently came across a statement that 'the emf is greatest when the coil is perpendicular to the magnetic field'. In truth, the emf is greatest when the *plane of* the coil is parallel to the magnetic field.

E7. Far fewer correct answers were seen to part (a) (i) than might have been expected. Deducing the correct direction for the electric field involved spotting that the electrostatic force on the sphere acted upwards, and that the sphere carried a negative charge. The vast majority of answers to part (a) (ii) showed that students had not forgotten Hooke's law from Unit 2 of AS Physics; 0.24×0.018 readily gave 4.32×10^{-3} N. Part (a) (iii) was also well answered, either by combining $F = EQ$ and $E = V/d$ before inserting numbers, or by working out E, and then d, separately.

Attempts to answer both sections of part (b) showed that many candidates had little understanding of what would happen when switch S was moved to position **Y**. The fact that the immediate effect would be to short out the plates, causing them to discharge and therefore reduce the field strength to zero, escaped a very large number of candidates. Common answers to part (b) (i) were that the field was reversed, or that the field became an alternating one. Answers which suggested that an electric force would still be acting received no further credit in part (b) (ii). What was required here was an understanding that, when the field was removed, the sphere would fall under its own weight, extending the spring downwards. The resultant force on the sphere would be proportional to the change in the extension of the spring, producing an acceleration that was proportional to the displacement from equilibrium but acted in the opposite direction to the displacement ie the condition for shm.

E8. Many correct statements of Newton's law of gravitation were seen in part (a). Some candidates referred to just one aspect of the law ($\propto M_1M_2$, or $\propto 1/r^2$, not both together) and only received one mark. A reference to point masses – which helps when explaining the meaning of *r* – was not common. In fact a clear understanding of the meaning of r was expected in satisfactory answers. The common inadequate responses, when neither was more fully explained, were 'radius' and 'istance' Candidates who tried to rely simply on quoting $F = GM_1M_2/r^2$ were awarded a mark only when the terms in the equation were correctly identified; a further mark was available to them if they gave a clear definition of r or referred to the nature of the force as attractive.

Part (b) (i) could be approached using either 'mass = volume × density' or 'mass $\propto r^3$'. The first method was far more common, and most answers were satisfactory. On this paper, this was the first example of a question requiring candidates to 'show that…' Convincing answers to this type of question should include the fullest possible working, in which the final answer is quoted to one more significant figure than the value given in the question. Here, for example, a value of 47.3 kg was convincing. Part (b) (ii) also proved to be very rewarding for most candidates.

Common errors here were failing to square the denominator, or to assume that surfaces in contact meant that $r = 0$ (whilst still arriving at a finite numerical answer!).

Whilst many correct and well argued answers were seen in part (c), it was clear that some candidates had not read the question with sufficient care. Two requirements for a satisfactory answer ought to be clear from the wording of the question: the need to give a quantitative answer, and to confine the answer to the effect on the calculations in part (b). 'Calculations' (plural) was a strong hint that the mass of both spheres would be affected, but there were many answers in which it was assumed that the masses would not be changed. This meant that a maximum mark of 1 out of 4 could be awarded, for the $1/r^2$ relationship alone. The incorrect use of language sometimes also limited the mark that could be awarded for the answers here: candidates who stated that doubling the separation would reduce the force 'by one quarter' could not be credited with a mark.

E9. Knowledge of the efficiency of a transformer was tested in this question, which had a facility of 58%. The output power from the transformer must have been 60 W, because the lamp was lit at its normal brightness. The turns ratio indicated that the primary voltage was 23 V, whilst the question stated that the primary current was 2.7 A. Hence the input power could be found using 2.7 × 23 = 62.1 W. 25% of the candidates chose the incorrect distractor B.

E10. A coil which was rotating in a magnetic field was the subject being tested in this question. This was successfully answered by 57% of the candidates. Incorrect answers were almost equally divided between distractors A and B, with very few for distractor D.

E11. This question was easy, with a facility of 73%. It was a direct test of $\varepsilon = N\ (\Delta\Phi/\Delta t)$ in a graphical context. The most common incorrect answer was distractor A.

E12. This question contained a synoptic element, because two of the unit combinations quoted were mechanical. The facility of the question was 44%.

Overlooking the word not in the stem of the question presumably caused 34% of the candidates to choose distractor A, where $F = B\,I\,l$ ought to have shown that A T m is a correct unit of force.

E13. This question could be answered by applying Fleming's left hand rule to a beam of positive ions. Around half of the responses were correct, but a quarter were for distractor A (which was upwards, instead of downwards).

E14. The principles of the magnetic deflection of an electron beam by a magnetic field were well understood in this question, where 73% of the candidates made the correct choice. Almost one in five candidates chose distractor D, an obvious confusion over the shape of the curved path.

E15. This question involved a basic current balance and assumed familiarity with $F = B\,I\,l$. The simple idea here was that reversing the current and doubling it would produce a force in the opposite direction that would be twice the original. This eluded so many of the candidates that only 41% of them could select the correct response, whilst many of them chose distractors C or D.

E16. There is no doubt that this question made appreciable mathematical demands, but it is surprising that the facility declined from 38% when pre-tested to 28% in this examination. This made it the most demanding question on the paper. Candidates should have seen that the contributions to V from the charges at top left and bottom right would effectively cancel. This then meant that the total potential would be double that due to one of the remaining charges. Application of Pythagoras leads to the distance r being $\sqrt{2}\,a$. Guesswork is probably the explanation for as many as 32% of the responses being for distractor D, which was no more than the simple potential equation $V = Q / 4\pi\varepsilon_0 r$ with $r = a$.

E17. This question required candidates to appreciate that, for the total potential to be zero at the chosen point, the magnitude of V due to the +4 µC charge should be the same as the magnitude of V due to the –16 µC charge. This required (Q/r) to be the same and should give a distance ratio of 1:4. 58% of the candidates were able to work this out correctly, which is 5% lower than when this question was last used in an examination. Almost one in four of the candidates chose distractor B, suggesting that the distance ratio would be 1:2. This question was the worst discriminator in this examination.

E18. This question represented a slightly unfamiliar situation for the students. Normally they would be much more accustomed to dealing with the force between point charges than with the force between a point charge and a charged plate. The clue to a correct answer came from the equation representing Coulomb's law, $F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$. 64% of candidates spotted this.

E19. 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.

E20. 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.

E21. 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.

E22. Most candidates were able to use Fleming's left hand rule in order to give the correct force direction in part (a) (i). Sometimes a candidate's answer was contradictory and went unrewarded, for example 'downwards towards the S pole'. Most answers to part (a) (ii) were reasonably good when explaining why the wire would vibrate, but rarely explained why these vibrations are vertical. An explanation by reference to the mutually perpendicular field, current and force directions was required in a complete answer. The reversal of force direction with change of current direction was well understood.

Fewer candidates made reference to the continuous current reversals brought about by ac causing the process to repeat, or to the fact that the size of the current affects the magnitude of the magnetic force.

It was evident that a large number of candidates had made a second, more enlightened, attempt at part (b) once they had realised that direct substitution of $I = 2.4$ A into $F = BIL$ did not lead to the value of force (about 40 mN) they had been asked to show. Once they realised that the maximum force is caused by the peak current, it became a straightforward matter to secure three marks.

The final part of the question, part (c), involved the resonance effect observed when the wire is supplied with ac current at the frequency of its fundamental vibration. Resonance was usually mentioned, but fewer candidates used the values provided in the question together with $c = f\lambda$ to give a wholly convincing account of why the wire would vibrate in its fundamental mode at 80 Hz.

A large number of candidates had forgotten that the fundamental condition would be $L = \lambda/2$ (this should be studied in unit 2). After using $c = f\lambda$ with $\lambda = 0.40$ m, they concluded that the frequency of waves on the wire would be 160 Hz. These candidates then attempted to argue that resonance would occur at 80 Hz because 80 is one half of 160, not understanding that if 160 Hz was the fundamental frequency, no frequency lower than 160 Hz could possibly set the wire into resonance.

E23. Calculation of the electric field strength in a uniform field by using $E = V/d$ were known well in part (a) (i), as was finding the force on a charge using $F = EQ$ in part (a) (ii). Most candidates therefore achieved full marks in these parts. Answers to the force diagram in part (b) (i) were much less satisfactory. Examiners were expecting to see three clearly labelled force arrows, starting on the ball, showing the electrostatic force to the left, the weight of the ball downwards and the tension acting upwards along the thread. Careless drawing and inadequate labelling caused marks to be lost in a majority of answers. When labelling the downwards force, 'weight', '*W*' or '*mg*' were acceptable, whereas 'gravity', 'mass' or '*g*' were not. The tension force was often omitted, whilst additional horizontal forces such as 'centripetal force' were sometimes shown.

In part (b) (ii), some evidence was expected for the appearance of the equation $F = mg \tan \theta$.

This could be from a consideration of the resolved components of the forces acting, or from a force diagram showing θ clearly. Many good answers were seen, but a large proportion of the candidates could make little or no progress.

E24. Transformers were also the subject under test, where 68% of the responses were correct. This was a fairly straightforward calculation involving transformer efficiency.

E25. A fairly demanding test of candidates' knowledge of transformers; slightly fewer than half of them selected the correct answer. Among the incorrect responses, distractor C was a common choice (23%), showing that the flux linkage ratio was better understood than the current ratio.

E26. This question had been used in a previous examination. Its facility in 2011 was 82%, an improvement on the previous result of over 10%. Evidently, the candidates this time readily recognised that the falling magnet would lose energy to the conducting ring only when the ring was complete, enabling the emf induced in it to cause a current.

E27. The most common incorrect response was distractor C, which accounted for 25% of the answers. This wrong choice is likely to have been caused by trying to work out the emf across the wing tips of a moving aircraft using the equation $E = B\,L\,v$, rather than finding the magnetic flux cut by the wing of a moving aircraft, as required by the question. However, 59% of the candidates chose the correct answer. This question discriminated well between the most able and the least able candidates.

E28. This was the most demanding question in the test, about the change in flux linkage when a coil is rotated in a magnetic field. 40% of the responses to this question were correct. Distractors C and D were each selected by almost a quarter of the candidates; this is probably because they considered the flux linkage to be zero when the plane of the coil was perpendicular to the magnetic field.

E29. This question, with facilities of 62%, was about charged particles moving at right angles to a magnetic field. Distractor A (parabolic path) attracted 29% of the responses.

E30. This question, with facilities of 67%, was about charged particles moving at right angles to a magnetic field. Relatively few candidates chose any one of the incorrect responses in the question.

E31. 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.

E32. 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.

E33. This question, requiring a combination of $F = EQ$ and $F = ma$, was the most discriminating question in the test; its facility was 67%.

E34. Almost three quarters of the candidates chose the correct answer in this question, which was a fairly direct test of Coulomb's inverse square law.

E35. 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.