Mark schemes

1 (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)**

= 2.2×10^{-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 μ (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 parallel to 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 greatest when ωt = 90° or 270°] **(1)**

max 3

[8]

2 (a) (i) 60 (degrees) ✓

1

(ii) angle required is 150° ✓

which is $5\pi / 6$ [**or** 2.6(2)] (radians) ✓

Correct answer in radians scores both marks.

2

(b) (i) (magnitude of the induced) emf ✓

Accept "induced voltage" or "rate of change of flux linkage", but not "voltage" alone.

1

(ii) frequency $\left(=\frac{1}{T}\right)=\frac{1}{40\times10^{-3}}$ ✓ (= 25 Hz)

no of revolutions per minute = 25 × 60 = 1500 ✓

1500 scores both marks.

Award 1 mark for 40s → 1.5 rev min^{-1}.

2

(iii) maximum flux linkage *(=BAN)* = 0.55 (Wb turns) ✓

angular speed $\omega\left(=\frac{2\pi}{T}\right)=\frac{2\pi}{40\times10^{-3}}$ ✓ (= 157 rad s^{-1})

peak emf (= $BAN\omega$) = 0.55 × 157 = 86(.4) (V) ✓

[**or**, less accurately, use of gradient method ✓

{e.g $\varepsilon\left(=\frac{\Delta(N\Phi)}{\Delta t}\right)=\frac{0.5-(-0.5)}{(16-4)\times10^{-3}}=\frac{1.0}{12\times10^{-3}}$ } = 83 (± 10) (V) ✓ ✓

(max 2 for (iii) for values between 63 and 72 V or 94 and 103V)]

3

(c) sinusoidal shape of constant period 40 ms ✓

Mark sequentially.

Graph must cover at least 80ms.

correct phase (i.e. starts as a minus sin curve) ✓

For 2nd mark, accept + sin curve.

Perfect sin curves are not expected.

2

(d) $BAN=$ 0.55 ∴ flux density $B=\frac{0.55}{4.0\times10^{-3}\times550}$ ✓

= 0.25(0) (T) ✓

OR *by use of ε from (b)(iii) and f from (b)(ii) substituted in ε = $BAN(2\pi f)$.*

2

(Total 13 marks)

3

(a) Φ (= BA) = 45 × 10^{-3} × π × (70 × 10^{-3})^2 **(1)**
= 6.9 × 10^{-4} Wb **(1)** (6.93 × 10^{-4} Wb)

2

(b) (i) $N\Delta\Phi$ (= NBA – 0) = 850 × 6.93 × 10^{-4} **(1)**

= 0.59 (Wb turns) **(1)** (0.589 (Wb turns))

(if Φ = 6.9 × 10^{-4}, then 0.587 (Wb turns))

(allow C.E. for value of Φ from (a))

(ii) induced emf (= $N \frac{\Delta\Phi}{\Delta t}$) = $\frac{0.589}{0.12}$ **(1)**

= 4.9 V **(1)** (4.91 V)

(allow C.E. for value of Wb turns from (ii)

4

[6]

4

(a) 1000 km hr^{-1} = $\frac{1000 \times 10^3}{3600}$ m s^{-1}

flux cut per second = B × area swept out per second $\left[\text{or } 4.5 \times 10^{-5} \times 42 \times \frac{10^4}{36}\right]$ **(1)**

= 0.52Wb **(1)**

(b) induced e.m.f. equals flux cut per second [or equation and symbols defined] **(1)**
$\therefore E$ = 0.52V **(1)**

(c) direction of p.d. reversed **(1)**

[6]

5

(a) deflects one way **(1)**
then the other way **(1)**

2

(b) (i) acceleration is less than g [or reduced] **(1)**
suitable argument **(1)** (e.g. correct use of Lenz's law)

(ii) acceleration is less than g [or reduced] **(1)**
suitable argument **(1)** (e.g. correct use of Lenz's law)

4

(c) magnet now falls at acceleration *g* **(1)**
emf induced **(1)**
but no current **(1)**
no energy lost from circuit **(1)**
[or no opposing force on magnet, or no force from magnetic field or no magnetic field produced]

3
QWC 2

[9]

6

(a) Induced current such as to opposes the change producing it✓

Switch on current increases the flux through Y✓

Current opposite direction / anticlockwise to create opposing flux✓

Switch off flux thorough Y due to X decreases so current travels clockwise to create flux to oppose the decrease✓

one marks for Lenz's law statement

two for explaining what happens at switch on ***OR*** *switch off adequately*

one for completing the argument for switch on and off adequately

4

(b) Determines correctly in the calculation two of V_{pk}(5.6±1 μV) , *A* (0.096 m^2) and *ω*(9.4 rad s^{-1})β✓

Substitutes all three in $v = BAn\omega$ ignoring powers of 10 and calculation errors for *A* and / or ω provided they have been attempted with working shown✓

B_H = 12.4 nT✓

Allow 2 or 3 sf

3

[7]

7

(a) direction of induced emf (or current) ✓
opposes change (of magnetic flux) that produces it ✓

2

(b) (i) (volumes are equal and mass of Q is greater than that of P) density of steel > density of aluminium ✓

Allow density of Q greater (than density of P).

1

(ii) use of $s = ½\, g\, t^2$ gives $t^2 = \frac{2 \times 1.0}{9.81}$ (from which $t = 0.45$ s) ✓

Backwards working is acceptable for 1st mark

(vertical) acceleration [**or** acceleration due to gravity] is independent of mass of falling object
[**or** correct reference to $F = mg = ma$ with m cancelling] ✓

2 nd mark must refer to mass.

Do not allow "both in free fall" for 2 nd mark.

2

(c) (i) moving magnet [**or** magnetic field] passes through tube ✓ there is a change of flux (linkage)(in the tube)

[**or** flux lines are cut **or** appropriate reference to $\varepsilon = N\,(\Delta\phi / \Delta t)$] ✓

In this part marks can be awarded for answers which mix and match these schemes.

[**Alternative:**
(conduction) electrons in copper (or tube) acted on by (moving) magnetic field of Q ✓
induced emf (or current) is produced by redistributed electrons ✓]

2

(ii) emf produces current (in copper) ✓
this current [*allow* emf] produces a magnetic field ✓
this field opposes magnetic field (or motion) of Q
[**or** acts to reduce relative motion **or** produces upward force] ✓
no emf is induced by P because it is not magnetised (or not magnet)
[**or** movement of P is not opposed by an induced emf or current] ✓

***Alternative** to 3 rd mark:*
current gives heating effect in copper and energy for this comes from ke of Q ✓

max 3

(d) time for P is unaffected because there is still no (induced) emf
[**or** because P is not magnetised
or because there is no repulsive force on P] ✓
time for Q is shorter (than in (c)) ✓
current induced by Q would be smaller ✓
because resistance of brass ∝ resistivity and is therefore higher
[**or** resistance of brass is higher because resistivity is greater] ✓
giving weaker (opposing) magnetic field
[**or** less opposition to Q's movement] ✓

Condone "will pass through faster" for 2nd mark.
If emf is stated to be smaller for Q, mark (d) to max 2.

max 3

[13]

8

(a) (i) meter deflects then returns to zero ✓

current produces (magnetic) field / flux ✓

change in field / flux through Q induces emf ✓

induced emf causes current in Q (and meter) ✓

Deflection to right (condone left) then zero is equivalent to 1st mark.

Accept momentary deflection for 1st point.

"Change in field / flux <u>induces</u> current in Q" is just ✓ from the last two marking points.

max 3

(ii) meter deflects in opposite direction (or to left, or ecf) ✓

field / flux through P is reduced ✓

induces emf / current in opposite direction ✓

Ignore references to magnitude of deflection.

max 2

(b) (i) flux linkage (= $n\Phi = nBA$) = $40 \times 0.42 \times 3.6 \times 10^{-3}$

$= 6.0(5) \times 10^{-2}$ ✓

Unit mark is independent.

Allow 6×10^{-2}.

Wb turns ✓

Accept 60 mWb turns if this unit is made clear.

Unit: allow Wb.

2

(ii) change in flux linkage = $\Delta(n\Phi)$= 6.05×10^{-2} (Wb turns) ✓

induced emf $\left(= \frac{\Delta(n\phi)}{\Delta t}\right) = \frac{6.05 \times 10^{-2}}{0.50}$ = 0.12(1) (V) ✓

Essential to appreciate that 6.05×10^{-2} is change in flux linkage for 1st mark. Otherwise mark to max 1.

2

[9]

9

(a) gravity or force acts towards centre **(1)**

force acts at right angles to velocity or direction of motion

[or velocity is tangential] **(1)**

no movement in direction of force **(1)**

no work done so no change of kinetic energy so no change in speed **(1)**

3

(b) (i) $B = (56^2 + 17^2)^{½} = 59\ \mu T$ **(1)**

(ii) $\tan\theta = \frac{17}{56}$ **(1)**

$\theta = 17°$ **(1)** (± 1°)

(iii) rod sweeps out or cuts (magnetic) flux
[or rod cuts field] **(1)**

4

[7]

10

(a) emf = Δ*(BAN) / t*
Change in flux = *A* × Δ*B* or 12 × (23 − 9) seen

C1

Substitution ignoring powers of 10

C1

1.2 V

A1

3

(b) Reduced

M0

Magnet will move (with the case)

A1

Increased

M0

Flux linkage increases or emf is proportional to *N*

A1

2

(c) (i) Formula used

$\frac{4\pi^2 \times 8 \times 10^{-3}}{2.6}$ seen

B1

0.348 / 0.349 seen to at least 3 sf

B1

2

(ii) Period consistent at 0.35 s or V_o = 8 V

B1

Shape shows decreasing amplitude

M1

At least 3 cycles starting at 8 V

A1

3

[10]

11 (a) *(Faraday's law)*
(induced) emf ∞ rate of change of flux (linkage) ✓
(Lenz's law)
direction of induced emf (or current) ✓
is such as to oppose the change (in flux) producing it ✓

In either order.

Allow "(induced) emf = rate of change of flux linkage".

Ignore incorrect reference to names of laws.

3

(b) (i) current in coil produces magnetic field or flux
(that passes through disc) ✓
rotating disc cuts flux inducing / producing emf **or** current (in disc) ✓
induced (eddy) currents (in disc) interact with magnetic field ✓
force on (eddy) currents slows (or opposes) rotation (of disc) ✓

Alternative *for last two points:*

(eddy) currents in disc cause heating of disc ✓

energy for heating comes from ke of disc or vehicle (which is slowed) ✓

max 3

(ii) *Advantage*: any one ✓

- no material (eg pads or discs or drums) to wear out
- no pads needing replacement
- no additional (or fewer) moving parts

Disadvantage: any one ✓

- ineffective at low speed **or** when stationary
- dependent on vehicle's electrical system remaining in working order
- requires an electrical circuit (or source of electrical energy) to operate whereas pads do not

Answers must refer to advantages and disadvantages of the electromagnetic brake.

Only accept points from these lists.

2

[8]

12

(a) (i) graph showing two pulses one at start and the other at the end with no emf between the pulses

Positive and negative pulses shown

Similar shaped 'curved' pulses : negative between 0 and 0.22 ± 0.02 s and positive pulse 0.58 ± 0.02 and 0.8

3

(ii) emf induced when the flux is changing or induced emf depends on the rate of change of flux

emf induced when flux changes between 0 and 0.2(2) s and / or between 0.6(0.58)s and 0.8 s
OR
no change in flux between 0.2 and 0.6 so no induced emf

Induced emf / current produces a field to oppose the change producing it.

Flux linking bracelet increases as the bracelet enters the field produced by C and decreases as it leaves so opposite emfs

4

(b) (Takes 0.21 s or 0.22 s for flux to change from 0 to maximum so)
diameter = 0.28 × 0.21 = 0.059 (0.588) (m)
or 0.28 × 0.22 = 0.062 (0.616) (m)

must be to at least 2sf

1

(c) Area of bracelet = 3.14×0.031^2

$B = 1120 \times 10^{-6} / (3.14 \times 0.031^2) = 0.38$ (T)
$B = 0.40$ T if 3 cm used for radius

Condone incorrect power of 10

Allow answers in range 0.38T to 0.41 T (depends on value used for r)

2

(d) Use of steepest gradient of graph or tangent drawn on Figure 2
Correct data from tangent or points on the steepest part of the graph
10 to 11 mV

3

[13]

Examiner reports

1 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.

2 It has long been clear that electromagnetism is a challenging topic for quite a lot of A level candidates, and that flux and flux linkage are regularly confused. Several parts of this question revealed these weaknesses once again. In part (a) the initial orientation of the coil in relation to the magnetic field has to be understood. It is also necessary to know that flux linkage is a maximum when the plane of the coil is perpendicular to the field, and that the emf through a rotating coil is a maximum when the flux linkage is a minimum. There were more correct answers to part (a)(i) than to part (a)(ii), although a significant number of candidates gave the wrong answer in (i) and the gave the right answer in (ii). Conversion of the angle from degrees to radians was a problem for some in (ii), whilst others had not noticed that the answer was required in radians in this part.

The majority of responses to part (b)(i) were correct, but part (b)(ii) caused more problems than expected. Answers of 1.5 revolutions per minute that had been reached by misreading the time axis of Figure 3 were allowed one of the two available marks. In part (b)(iii) the most accurate value for the peak emf can be found by reading the maximum flux linkage (0.55 Wb turns) from Figure 3 and then applying $\varepsilon_{max} = BAN \times 2\pi f$. Only a few candidates used this method, the majority choosing a gradient evaluation instead. Different tolerances were applied, depending on how far their answer for the gradient was away from the expected result of around 85 V. It was very clear from their calculations that many candidates had not understood that the *peak value* of the emf is represented by the *maximum* gradient, because a large number of the evaluations were closer to an average emf. Almost inevitably, there were candidates who resorted to the introduction of $\sqrt{2}$ into their calculation.

Plenty of good, carefully drawn -sine or sine curves were presented in part (c). These received both marks provided the graph covered at least two full cycles and had periods of 40 ms and consistent maxima. Good cosine curves were allowed one mark, but there was no credit for the triangular or square waves that were occasionally drawn.

3 The topic of electromagnetism continues to present greater difficulty than most of the remainder of the Unit 4 content. Candidates who had mastered the distinction between magnetic flux and flux linkage, and who appreciated that induced emf = (rate of change of $N\Phi$), readily gained all six marks. Only a small minority of the candidates came into this category, however. When finding the cross-sectional area presented to the flux, there was evidence of the usual confusion between diameter and radius, leading to the loss of one mark on the question. More worrying were those candidates who wrote the area of a circle as $2\pi r$, or as $2\pi r^2$. In part (b), examiners took the view that candidates should know that an emf is measured in V – final answers expressed in Wb turns s^{-1} were not accepted.

4 All but the below average candidates could calculate the flux cut per second in part (a). The commonest errors arose in changing km h^{-1} to m s^{-1} and in the final unit.

Many candidates went astray in part (b), not realising that the e.m.f. in V equalled the flux cut per second. Some candidates started again with Blv, others referred to the Hall effect or even gravitational potential. Correct statements of Faraday.s law in words were fairly common, although a number of candidates thought that an equation like $E = -\mathrm{N}\phi\,/\,\mathrm{d}t$, or even the name of the law , was enough. The equation was accepted only if the symbols were defined. The majority of candidates said that the only change in the p.d. would be a reversal in polarity. Some candidates, not always those who scored high marks, carefully pointed out that relative to an observer in the aircraft, there would be no change. Both answers were obviously accepted, but references to charges and currents were not.

5 This question was intended as a straightforward test of the “simple experimental phenomena” of electromagnetic induction and Lenz’s law, as required by Section 13.4.4 of the Specification. It is recognised that most A level candidates have difficulty with these topics and examiners were not very surprised by the many relatively weak answers that were written. Partial (or superficial) understanding of the phenomena appeared to be the main obstacle to progress. For example, in part (a) almost all candidates appreciated that the ammeter needle would deflect, but relatively few saw that it would move one way, and then the other way, before returning to zero. In this part, examiners sometimes wondered what was going through the minds of candidates who wrote things such as “the current through the ammeter would increase, and then return to its normal value”. Perhaps this suggests that these students had never previously encountered a centre zero instrument. Inappropriate use of English also handicapped some candidates in part (a) – typical of which were answers that began with “the ammeter moves to the right”.

Failure to address the question was the main difficulty encountered in most answers to part (b). Instead of stating clearly that the acceleration of the magnet decreased, candidates usually preferred to resort to woolly descriptions of the effect on the motion of the magnet. Responses such as “the magnet slows down” and “it decelerates” were rejected. “The acceleration slows down” was not a preferred response but it was accepted. The major problem in part (b)(ii) was the failure of candidates to read the question properly: this was about the effect on the acceleration of the magnet *as it left* the coil, not *after it had left* the coil. Consequently a large number of candidates followed a broadly correct deduction in (i) by an incorrect one in (ii): they thought that the acceleration would increase. The two explanation marks in part (b) escaped all but the most knowledgeable candidates. Some understanding of what was induced and why, was almost a prerequisite to progress here. Bald reference to Lenz’s law was not considered to be adequate.

Even after presenting indifferent answers to the earlier parts of this question, many candidates salvaged most of the three marks in part (c). Most appreciated that an incomplete circuit meant that no current could flow, but many candidates wrongly thought that the missing ammeter would also prevent the induction of an emf.

7 Acceptable statements really needed to refer to both the direction of the induced emf (or current) and to the change (in magnetic flux) that produces the effect. In part (b)(i) an explanation of the greater mass of Q was required, so a simple statement that density was involved was inadequate; candidates had to state that steel (or Q) has a greater density than aluminium (or P). In part (b)(ii) the time of 0.45s was usually justified through the application of $s = ut + \frac{1}{2} at^2$, although some candidates made no attempt to justify this value. Backwards working, such as showing that the distance fallen is approximately 1.0m when the time of fall is 0.45s, was accepted. Explanations of why the two times are equal were expected to refer to acceleration due to gravity being independent of the mass of a falling body.

There was widespread misunderstanding in candidates’ attempts to answer part (c). In part (i), clearly Q is a moving magnet passing through a conducting tube and so the magnet’s flux lines are cut by the tube – hence an emf is induced. A significant number of responses stated that Q would be cutting through the flux lines of the tube. The tube was regularly referred to as a magnet. A very common misapprehension was that when a current is induced in the tube, it is the current that causes the emf. In part (c)(ii) many answers were too trivial, such as ones which referred to the repulsion of poles, or were simply wrong, such as attributing the effect to induced *charges*. Some responses even suggested that the induced electromotive force acts as a mechanical force to oppose the falling magnet. Examiners were pleased to encounter logical answers stating that the induced emf caused a current to flow in the copper, which then produced a magnetic field to oppose the movement of the falling magnet Q by opposing the magnet’s own field. Relatively few answers made any reference as to why cylinder P would fall without opposition.

Full marks were regularly awarded in part (d), where it was usually seen that the time for P would be unaffected (an explanation was needed for the mark) but that for Q would be shorter. Some candidates thought that the increased resistance of the tube would cause a reduced emf; these answers were subjected to a two mark maximum.

8 The topic of electromagnetic induction continues to challenge the understanding of A level students, as well as their ability to describe a sequence of processes systematically. Part (a) was set in the context of two coils linked by an iron bar, where the first coil acts as an electromagnet and the second is subject to magnetic flux changes produced by current changes in the electromagnet. Relatively few students stated in part (i) that the centre-zero meter would deflect *and then return to zero* when the current in coil P was switched on. There were frequent references to current flowing through the iron bar from P to Q and also to “ac batteries” and alternating currents. Only the best students described the processes sequentially and coherently: current in P produces magnetic flux, change in flux induces emf in Q, emf causes current in Q and meter, current falls to zero when flux becomes steady.

In part (a)(ii) more answers attempted to address the magnitude of the induced current than its direction. The effect on the magnitude could not in fact be determined, because there is no indication in the question of how rapidly the slider of the resistance is moved. What could be deduced is that a reduction in the electromagnet’s current would reduce the flux linkage and that this change would induce an emf in the opposite direction. This would cause a momentary deflection of the ammeter in the opposite direction to that in part (i).

Most students found the calculation of flux linkage in part (b)(i) to be routine. Both marks were usually awarded. The unit of flux linkage caused problems for some. The accepted unit for flux linkage is Wb turns. Some text books omit “turns” (which anyway is a dimensionless quantity) and quote flux linkage values in Wb. Either Wb turns or Wb were therefore considered to be acceptable; derived units such as T m^2 were not. Calculation of the emf induced when the coil was rotated by 90° was required in part (b)(ii). This tempted many students to attempt their solution by using the equation in the data booklet for a uniformly rotating coil, $\boldsymbol{\varepsilon} = BAN\omega \sin\omega t$, which does not apply in this case. Correct solutions should have started from $\boldsymbol{\varepsilon} = \Delta(N\Phi) / \Delta t$, and it should therefore have been clear that the induced emf is derived from the change in flux linkage rather than just one value of flux linkage. Almost inevitably, a few students confused flux with flux linkage.

9 In part (a) the large majority of candidates knew that the force on the satellite acted towards the centre of the Earth and that the direction of motion or velocity of the satellite was at right angles to the force. However, few of them were able to use these facts to explain adequately why the speed remained constant. Little or no reference was made to the absence of work done or zero change in potential or kinetic energy.

There were many correct calculations in parts (b)(i) and (ii), but some candidates did confuse the two components when calculating the angle in part (ii). In the final part, correct explanations for the induced emf were usually given in terms of the rod cutting the non-radial component of the Earth's magnetic field.

10 (a) Many candidates omitted the area in the formula, and there was some confusion over powers of 10.

(b) Very few candidates were able to give a satisfactory reason for the reduced emf when the spring stiffness increased. Of those who mentioned the magnet, most stated that it would move less, seemingly unaware that previously it did not move at all.

(c) (i) Well done by most.

(ii) Apart from some poor scripts where no scale was attempted, most answers gained at least 2 marks. The commonest errors were to start the graph at 0 instead of 8V and to draw fewer than 3 cycles.

11 Examiners were looking for precise statements of Faraday's and Lenz's laws, in the most general forms, in part (a). In Faraday's law, for instance, the induced emf is *proportional* to the rate of change of flux, but is *equal* to the rate of change of flux linkage. In statements of Lenz's law it was necessary to refer to the *direction* of the induced emf (or current), and to the *change* producing it, for full credit.

In some cases the operation of the electromagnetic brake in part (b)(i) was well understood, but in most cases it was not. Common errors were to consider the metal disc as a permanent magnet that would induce a current in the coil, or to suggest that the pole pieces would clamp onto the disc in the manner of brake pads, or to consider the current in the coil as an alternating one. Many answers just gained the first mark by understanding that the current in the coil would create a magnetic field across the disc. Recognition of the flux cutting by the rotating disc that would give an emf and current in the disc was much rarer, or less explicit. The exact cause of the force on the disc – the force on the disc's induced currents in the field of the electromagnet – was seldom identified. Attempts to apply Lenz's law were usually much too vague to deserve credit. The retardation of the disc can also be explained by an argument based on energy: the currents in the disc cause heating, dissipating the kinetic energy of the disc and vehicle, but this approach only appeared in the most exceptional examples.

In part (b)(ii) the clear principal advantage of an electromagnetic brake over the conventional friction brake is that it does not contain parts such as disc pads that wear out, needing replacement. Most students were able to make reference to this, however obscurely. Its clear disadvantage, that the electromagnetic brake becomes less effective as the speed drops, was hardly mentioned at all, but many were able to spot that it relies on an electrical circuit that is functioning.

12 (a) (i) A difficult question for most students who did not realise the emf pulses occur as the bracelet enters and leaves the magnetic flux of the coil.

(ii) Since most of the graphs for (a)(i) were incorrect it was difficult or impossible to explain the shape correctly. However, marks were awarded for correct statements of the Faraday and Lenz laws.

(b) Few students knew how to tackle this one marker. Many incorrect times were chosen.

(c) Some did not read the graph scale correctly, others used $area = \pi d^2$ and there were many power of 10 errors. A final answer of 0.4 T (1 sf) was penalised.

(d) The vast majority of answers incorrectly used the average emf for the first 0.22 s, instead of using the gradient of the steepest part of the graph to find the maximum emf.