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Physics A PHYA4

(Specification 2450)

Unit 4: Fields and further mechanics

Report on the Examination

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GCE Physics, Specification A, PHYA4, Particles, Quantum Phenomena and Electricity

General Comments

Around 7200 candidates took the June 2011 unit 4 examination. The number of candidates for the January examination was in the region of 10000, so it is clear that (as in 2010) a large proportion of the June entry consisted of candidates who were re-sitting the test in order to improve their total UMS mark and overall grade.

The mean pre-test facility of the Section A objective test was very similar to those for the corresponding tests in June 2010 and January 2011. The mean mark achieved in this test was slightly lower than in June 2010 and significantly lower than in January 2011.

Section A

Keys to Objective Test Questions

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
D	B	D	A	A	D	C	B	C	A	C	A	D

14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
B	C	D	D	C	A	C	C	B	B	B	A

The *facility* of a question is a measure of all candidates attempting a question who choose the correct option. The mean facility of this paper was 58%. The facility for individual questions ranged from 83% for question 5 to 33% for question 12. For the purpose of monitoring standards over time, objective tests contain a proportion of questions that are re-banked after satisfactory use in an earlier examination. This test contained seven of these questions, with a mean facility of 64% when last used. The eighteen new questions had all been pre-tested and had a mean pre-test facility of 45%. Candidates invariably produce higher facilities for the questions in a real examination than in the pre-testing situation. The improvement achieved on this paper for these new questions on average was 9%. The mean facility of all of the re-banked questions improved by an average of 3%.

The *point biserial index* of a question is a measure of how well the question discriminates between the most and least able candidates. The mean point biserial for this paper was 0.37. The new questions had a mean pre-test point biserial of 0.35, whilst the value for the re-banked questions was 0.41. This amounts to a very modest improvement in the discrimination of the new questions, whilst all but one of the re-banked questions gave poorer discrimination this time.

Eight of the questions (questions 5, 7, 11, 13, 17, 19, 20 and 25) proved to be easy, with facilities over 65%; question 12 alone was difficult (ie had a facility less than 35%).

The principal hurdle in **Question 1** was to decide whether the moment of a force is a scalar or a vector. The vector nature of momentum was known by almost all. Nearly two-thirds of the candidates realised that a moment has an associated direction and gave the correct response. Over a quarter chose distractor B, where moment is a scalar and momentum a vector.

Question 2 was the most discriminating question in the test. It's facility was 51%. Distractor C accounted for 30% of the responses, probably because the candidates involved failed to notice that the force was 5 N (rather than 15 N) for the initial 0.5 s on the force-time graph.

It is surprising that only 49% of the candidates arrived at the correct answer in **Question 3**. Identifying the rate of change of momentum with force, and the unit of force with (mass $\times$ acceleration), ought to be relatively straightforward piece of physics for candidates at the end of an A level course. Distractors A and C (where in each case the answer is a unit of momentum) were both chosen by about 20% of the candidates.

Question 4, on circular motion, had been used in a previous examination. The facility this time was 62%, an increase of 7% over the previous result. The most common incorrect choices were distractors C and D, each getting 15% of the responses. The popularity of C was probably caused by a failure to understand that momentum is a vector.

Knowledge of circular motion was also tested in **Question 5**, where familiarity with $F = m\omega^2 r$, was the key to success. This turned out to be the easiest question on the paper, with 83% of the candidates giving correct responses; when pre-tested only 44% of answers were correct.

Question 6 was a sterner test of motion in a circle, because it was a two-stage calculation with algebraic distractors. Just over half of the candidates arrived at the correct result by combining $a = v^2/r$ and $T = 2\pi r/v$. Almost a quarter of the responses were for distractor C, in which the square-rooted expression (r/a) is inverted. This is likely to have been caused by careless rearrangement of the algebra.

Simple harmonic oscillation was the topic tested by **Question 7** (which had been used before) and **Question 8**. 79% of the responses to Question 7 were correct, which was 8% better than when it was last used. This shows that $v_{max} = 2\pi fA$ is well known. Question 8 was much more demanding because it required application of the relationship between mass and density for a uniform sphere, as well as $g = GM/R^2$. Just 41% of the responses were correct.

Candidates for this test were slightly less familiar with the direction of the damping force acting on a vibrating system, required in **Question 9**, than those in 2005 when this question was last used. On both occasions about three-fifths of candidates made the right choice. Incorrect responses were fairly evenly spread across the other distractors.

Question 10 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.

Question 11, 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.

Questions 12 and **13** continued the theme of gravitation. At first sight, question 12 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. Question 13, with a facility of 71%, required the angular speed of a satellite in circular orbit to be found and appeared to cause little difficulty.

Failure to realise that a negatively charged electron has an associated negative value of electric potential caused many candidates to go wrong in **Question 14**. As in gravitation, the force between an electron and a proton is attractive and so the potential is negative. 40% of the candidates made the correct selection, B. 26% selected distractor A; the only difference between A and B is the – sign in B.

Question 15 tested candidates' understanding of the mechanics of the motion of a positive ion as it passes through a uniform electric field. Quite a lot of calculation was needed to arrive at the correct response, but 57% were successful. Incorrect answers were evenly distributed amongst the other distractors.

Question 16 tested the relationship $V \propto 1/r$ for a point charge, but made appreciable mathematical demands because it required candidates to deal with a *change in V*. Rather fewer than half of the responses were correct, with distractor C as the most popular incorrect answer.

Questions 17 to **19** were all on capacitors and all three had appeared at various times in previous examinations. This time all three gave slightly inferior results to those obtained when last used. Question 17 involved finding the current when a capacitor is charged using a constant current, by combining $Q = CV$ and $Q = I\,t$. 68% of candidates chose the correct alternative. Question 18 was more demanding, with a facility of 49%. Here the energy and voltage of a capacitor had to be considered when the charge is increased by half; distractors A and B each attracted over 20% of the responses. Question 19, about factors affecting time constant in an *RC* circuit, was the easiest of the three with a facility of 75%.

In **Question 20**, candidates were required to determine the value of the time constant of an *RC* circuit from data on a Q - t graph. The answer could be found in various ways. Perhaps the quickest was to read off the time at which the charge had fallen to Q_0/e, 0.036 μC, but many candidates would have resorted to substituting values into $Q = Q_0\,e^{-t/RC}$. Almost 70% of responses were correct.

The remaining five questions were all set on section 3.4.5 of the specification, magnetic fields. **Question 21** concerned the time period of charged particles moving in a circular orbit in a magnetic field. It's facility was 55% but distractors A and B were each selected by more than 20% of candidates. Successful solutions required $mv^2/r = BQv$ to be combined with $T = 2\pi r/v$.

Question 22 required candidates to know that an induced emf is proportional to the *rate of change of flux linkage*. Almost one-third of the candidates considered it to be proportional to the *flux linkage*, distractor A. 56% of the responses were correct, whilst very few chose alternatives C or D.

There were similar problems in **Question 23**, which tested the same principle in a different context. A large proportion of candidates did not realise that the flux linkage increases to a constant value once the magnet is at rest inside the coil, and therefore selected the incorrect distractor A. 43% gave the correct response.

Electromagnetic induction continued to cause difficulty in **Question 24**, which had a facility of 40%. In this question, candidates should have noticed that, although the speed of rotation of the coil was doubled, the flux density was halved. This has the net effect of leaving the peak emf unchanged whilst the frequency is doubled. 30% of the candidates realised that the frequency would be doubled but thought the peak emf would also double (distractor D).

The facts about energy losses in transformers were well known in **Question 25**, where 73% of candidates gave the correct answer. The strongest incorrect distractor was C, suggesting that the energy losses caused by magnetic hysteresis are not always recognised.

Section B

General Comments

The paper began with two questions from section 3.4.1 of the specification. Many candidates did not produce satisfactory answers to question 1, which was on the mechanics of circular motion. In many cases this was because they had not understood that a resultant force has to act towards the centre of the circle. Candidates who understood this usually scored well. Question 2, dealing with the simple harmonic motion of a body between two springs, overall produced more successful responses. Question 3 dealt with energy storage by capacitors and cells. The principal obstacle here was knowledge of how to calculate the energy that can be delivered by a cell; this is a synoptic aspect, because the topic is covered in unit 1. Question 4 was concerned with the combined effects of magnetic and electric fields on a stream of ions. Responses showed that candidates continue to be challenged by the three-dimensional aspects of magnetic effects, and by the complexity of magnetic units. Question 5 tested candidates' understanding of transformers and their application in power distribution networks. Basic facts were generally known, but comprehensive knowledge of high voltage transmission systems was rarely encountered in part (c), where the quality of written communication was assessed.

Use of an appropriate number of significant figures was specifically tested by the one mark available in question 3 (a)(i). However, candidates needed to be aware that careless use of significant figures can have knock-on effects elsewhere. Failure to work with sufficient significant figures throughout a calculation can lead to the final answer drifting away from an acceptable value, which could lead to a loss of marks. Also, care is needed when writing down final answers: in question 2 (b)(ii) the value expected was 0.73 s (to two significant figures) and an answer of 0.7 s (to one significant figure) would be penalised.

This time more candidates were willing to show their working in calculations, but some did miss out essential steps and were therefore penalised. For example, in question 4 (b)(iii), where four marks were available, a candidate who wrote down only the correct final answer, 4.3×10^{-3} T, with no supporting evidence, would receive only half marks.

In questions requiring description or explanation, candidates' limited ability to express ideas clearly sometimes restricted the mark that could be awarded or meant that no mark could be awarded at all.

Question 1

The context of this question may have been unfamiliar to many candidates. Although most had some awareness of the 'lift off' sensation when a vehicle passes over a hump-backed bridge, relatively few were able to give good answers to explain the mechanics involved. Attempts at part (a)(i) were often muddled by the introduction of arrows marked 'centripetal force', 'driving force', 'momentum' and so on. In a correct answer, two labelled vertical arrows acting through the same point on the parcel were all that was expected; the weight downwards and the reaction upwards. Frictional forces were not expected but their inclusion did not nullify the answer. Poor understanding was revealed by labels such as 'upthrust' and 'gravity'. The principal error in part (a)(ii) was to assume that the resultant (centripetal) force acts outwards, resulting in the incorrect equation $R - mg = mv^2/r$. Candidates doing this evidently did not understand that, for a body to move in a circular path, it has to experience a resultant force that acts *towards the centre* of the circle. This kind of incorrect response in part (ii) almost invariably meant that part (a)(iii) – where the calculation is based on the equation – would also be incorrect.

Some good answers were seen to part (b), but most only received partial credit. Good understanding of the mechanics of part (a) allowed more able candidates to see that at higher speeds, because mv^2/r increases but mg remains constant, R must decrease. They could then calculate R when v = 15 ms^{-1} and find it to be almost zero. The obvious deduction is that, with a slight increase in speed, R would become zero and the parcel would lose contact with the floor of the van. Very few candidates who carried out the calculation for speeds higher than 15 ms^{-1} were able to give a correct interpretation of the negative value they calculated for R. Less able candidates sometimes argued that the van would lift up vertically from the road surface at high speed because the upwards reaction would be greater than its weight. Candidates would be able to approach questions of this kind more successfully if more of them realised that 'centripetal force' (mv^2/r) really is 'mass × acceleration towards centre' rather than being an *actual force*, but that it is equal to the *real* resultant force ($mg - R$ here) acting towards the centre of the circle.

Question 2

The application of Hooke's law did not trouble candidates in part (a)(i), but full and complete explanations of why the resultant force is 3.6 N rather than 1.8 N were rarely presented. Examiners decided to accept very minimal explanations for the second mark, but explanations that pretended that the displacement of the trolley was 120 mm were not allowed. In part (a)(ii) the acceleration was easily found from $F = ma$, although some did not spot this and took the circuitous route via $a = (2\pi f)^2 x$ instead. Almost all candidates correctly identified the direction of the acceleration.

The two shm conditions expected in part (b)(i) – those which define shm – were less well known than had been anticipated. Common unacceptable answers were 'no external forces' and 'time period is constant'. Part (b)(ii) was generally answered well, but some candidates did not go beyond finding the frequency, assuming it to be the answer.

Part (c) was rewarding for most candidates. In questions where candidates are asked *to show* the numerical value of a quantity, it is essential for evidence of the calculation to be presented. In this case, the mark was not awarded when the substitution of values into the equation $f = (1/2\pi)\sqrt{2k/m}$ was missing. In final answers to numerical questions, it is expected that candidates will work out a result that is a pure number; answers containing surds etc, are not acceptable. Therefore, a final value of 200π did not receive the one mark available in part (c)(ii). The calculation in part (c)(iii) was a straightforward application of ½ mv^2, which led easily to the required answer provided the candidate remembered to square the value for v obtained in (c)(ii); failure to do so was common. An alternative approach to (c)(ii), adopted in a tiny minority of cases, was to apply ½ $(2k)A^2$, which is the maximum potential energy stored by the two springs.

Question 3

The data used in this question is realistic. A low voltage 70 F capacitor is available for back-up purposes, and there is a rechargeable cell with the specification quoted. Part (a)(i) was readily answered by the application of ½ CV^2. The choice of an inappropriate number of significant figures, typically three, caused the loss of a mark. Candidates should realise that a final value should only be quoted to two significant figures when the data in the question is given to no more than two significant figures.

Part (a)(ii) was answered poorly, usually because the calculation was approached from the capacitor energy equation (½ QV), instead of that giving the energy delivered by a cell (QV). Examiners were ready to penalise the candidates who, having started from the wrong principle, introduced a mysterious factor of two in order *to show* that the energy stored was 50× greater, rather than 25× greater.

In part (b) candidates' responses were often inadequate because of incompleteness, and/or an inability to express ideas sufficiently clearly. It was expected that satisfactory answers would relate to the use of the capacitor in a cordless telephone. 'A capacitor discharges quickly' is an incomplete answer; 'a capacitor would need recharging frequently' or 'a capacitor would only power the phone for a short time' were much more explicit in the context of the question. Other acceptable answers were that a 70 F capacitor would be too large to fit in the telephone, or that the voltage supplied by it would decrease continuously whilst in use.

Question 4

In part (a)(i) many candidates were unaware of the condition under which $F = BQv$ applies, which is given clearly in the specification. A common incorrect answer was to state that *the force* has to be perpendicular to B, without any reference to v. In part (a)(ii) the main difficulty proved to be the meaning of B; magnetic flux density was correct and the loose 'magnetic field strength' was not accepted. Some candidates thought that v represents voltage.

Part (b)(i) was a test of Fleming's left hand rule when applied to a stream of positive ions. Together with Figure 5, the first paragraph of part (b) defines 'downwards' as the direction towards the lower (negative) plate. The correct answer in (b)(i) is 'into the plane of the diagram', not downwards.

In part (b)(ii) candidates were expected to consider the force conditions applying to the undeflected ions. A common misconception was that the magnetic *field* is equal to the electric *field*. The main errors in part (b)(iii), where the numerical value obtained was often correct, were the omission of clear working and not knowing that the unit of B is T. Some candidates could only quote $F = BQv$ and were at a loss to make further progress without $F = EQ$ and $E = V/d$.

Many candidates were totally lost in part (c). Others correctly explained that the ions would now be deflected upwards because the magnetic force (which is proportional to v) increases whilst the electrostatic force (which is independent of v) remains constant.

Question 5

Most candidates could score only half marks in part (a). There was very little difficulty in (i), but the most common answers in (ii) and (iii) were 12 kW and 2.4% respectively. These incorrect answers were the result of just calculating the power dissipated in the cables, instead of the power transmitted to the factory by them. It seemed that only the most perceptive candidates appreciated that the power transmitted would be 500 – 12 = 488 kW and therefore the efficiency of transmission 97.6%.

In part (b)(i) answers which did not address constructional differences (ie referring to turns ratios) went unrewarded. The expected answer was that the secondary of a step-down transformer has fewer turns than the primary (whereas a step-up transformer has more secondary turns than primary turns). It was essential to make these comparisons for the same kind of transformer: answers such as 'a step-up has fewer secondary turns but a step-down has fewer primary turns' were not considered satisfactory.

Part (b)(ii) was generally answered well, with many candidates realising that thicker wire would have a lower resistance and hence reduce the power lost by heating of the secondary. It was quite rare to find an answer in which it was stated that this is important in a step-down transformer because the secondary carries a higher current than the primary. Frequent misapprehensions were that a thicker wire would have *greater* resistance (and thereby reduce the current), and that thicker wire would have a lower *resistivity*.

Part (c) was used to assess candidates' quality of written communication. In this type of question, a large proportion of candidates struggle when trying to present an organised and coherent piece of writing that answers the main issues raised by the question. Consequently, the marks awarded were generally low. Relatively few answers could be placed in the high level category of response. Perhaps this is to be expected when, as here, the communication question is attempted at the end of a fairly demanding examination. The main temptation appeared to be to devote most of the answer to energy losses in a transformer, which had been the topic tested by a communications question in a 2010 PHYA4 examination. Yet transformer losses are only one of the factors involved in the overall principles of power transmission. Clear statements that transformers will only work continuously with an ac supply and that power loss through heating of the cables can be reduced if the current is reduced (whilst maintaining the same power) by increasing the voltage, were uncommon. Good answers were expected to enhance this by referring to $P = I\,V$ and $P = I^2R$ and outlining the need for voltage reduction on safety grounds at the consumer's end, for low resistance cables etc. It appeared that in many centres, this topic has only been given a very superficial treatment. It was reassuring for examiners to occasionally come across a good answer, in which the principles involved in power transmission were discussed in a logical and organised manner.

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