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Physics A PHYA4

(Specification 2450)

Unit 4: Fields and further mechanics

Report on the Examination

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General Comments

Around 7900 students took the June 2012 Unit 4 test, an increase of about 10% over the number of students who took the corresponding test in June 2011.

The mean pre-test facility of the Section A objective test was very similar to those for the Unit 4 tests in June 2011 and January 2012. In the examination itself, the mean mark achieved in this section was higher than that in June 2011 but lower than that in January 2012.

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 students attempting a question who choose the correct option. The mean facility of this paper was 63%. The facility for individual questions ranged from 86% for question 20 to 39% for question 13. 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 six of these questions, with a mean facility of 60% when last used. The nineteen new questions had all been pre-tested and had a mean pre-test facility of 48%. Students 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 14%. The mean facility of the re-banked questions improved by an average of 7%.

The *point biserial index* of a question is a measure of how well the question discriminates between the most able and the least able students. The mean point biserial for this paper was 0.39. The new questions had a mean pre-test point biserial of 0.33, whilst the value for the re-banked questions was 0.45. On average there was therefore an overall improvement in the discrimination of the questions, but only two of the re-used questions actually showed any improvement in discrimination.

Twelve of the questions (Questions 1, 3, 5, 6, 8, 12, 15, 17, 19, 20, 22 and 25) proved to be easy, with facilities over 65%; none was difficult (i.e. had a facility less than 35%).

Question 1 was an easy starter that required the application of “change of momentum = area under force/time graph”. This question discriminated well, and just over two-thirds of the students gave the correct answer. The most popular incorrect response was distractor D, no doubt because the students who chose it overlooked the factor of ½ when calculating a triangular area.

Students often find that questions in which the result of a calculation is shown algebraically are harder than ones in which the calculation is purely numerical. This was the case in **Question 2**, where the recoil speed after an explosion was to be found in terms of kinetic energy. Just under half of the students arrived at the correct expression, and the question did not discriminate very well. 27% of the students selected distractor B, because they regarded the mass of the daughter nucleus still to be M (instead of $M - m$) after it had emitted the α particle.

Question 3 tested basic facts concerning the quantities that are conserved when two bodies – two skaters in this question – separate from each other with a release of kinetic energy. Almost 70% of the students gave the correct response. The most common incorrect response was distractor B, the students involved not realising that kinetic energy must increase when two stationary bodies start to move.

Students' understanding of circular motion was tested by the next three questions.

Question 4, where the purpose was to calculate the Earth's orbital speed, combined circular motion with gravitation. 62% of the students were successful, whilst incorrect answers were spread fairly evenly between the three incorrect responses.

Over 70% of the students gave the required answer in **Question 5**, but over 20% of them considered that a centripetal acceleration acts along a tangent to the circular path (distractor D).

Question 6 had been used in a previous examination. Its facility this time was 67%, a marginal improvement over the value obtained when last used. Problems with algebra led to almost one quarter of the students selecting distractor D, where g appeared in the numerator instead of the denominator of the required fraction.

Question 7 required students to identify the point (or points) at which the resultant force is a *minimum* when a mass on a spring moves with simple harmonic motion. Almost 60% of them recognised that this could only be at the central point of the oscillation. The most common incorrect response was distractor D (top and bottom of the oscillation), suggesting that there was confusion between the *minimum* and the *maximum* resultant force.

Question 8 was a fairly direct test of $T = 2\pi\ (m/k)^{1/2}$ for a mass-spring system, but the spring constant k had to be determined first. The question turned out to be remarkably easy, with over 80% of students giving the correct response. When this question was pre-tested, only half of the students had done so.

Question 9, about removing a simple pendulum and a mass-spring system from the Earth to another planet and determining the revised time periods, was a re-banked question from an earlier examination. Its facility in 2012 was 63%, which was a substantial improvement over the previous occasion, but its discrimination was slightly worse this time. Distractor B, chosen by 20% of the students, was the most popular incorrect choice.

Question 10 presented students with four amplitude-frequency graphs for a resonant system, from which they were to select the best illustration of light damping. Around half of the students had this correct; incorrect answers were evenly distributed around the distractors.

Questions 11 to 14 tested knowledge and understanding of gravitational fields. 57% of the students selected the required *incorrect* statement in Question 11. One in five of them chose distractor A. This may have been caused by them thinking they were supposed to choose the *correct* statement, or it may have been caused by a general misunderstanding of gravitational potential that was also evident in Section B of this paper. Question 12, which had a facility of 70%, was an algebraic test of the relationship between the weight of an object at the surface of a planet and the mass and radius of that planet. This question discriminated well and had no particularly strong distractor. Question 13, which tested how g is connected to the diameter for two stars of similar density, was the most demanding question on the test – its facility was only 39%. Equating mg with GMm / R^2 and then substituting $(4/3)\ \pi\ R^3\rho$ for M ought to have shown that g is proportional to the product $R\rho$. Consequently, if ρ is taken to be the same, $g \propto R$. Yet 33% of the students suggested that g would be 100 times smaller (distractor A), and not 100 times bigger, when the diameter was 100 times larger. Question 14, with a facility of 41%, was also demanding. Here several factors – kinetic energy, weight, time period and speed – had to be considered for two satellites in different circular orbits. The three incorrect answers had a fairly even distribution of responses.

Questions 15 and 16 moved on to electric fields. Question 15, a direct algebraic test of Coulomb's law, had appeared in a previous examination. The 2012 students dealt with it much better than their predecessors, causing the facility to increase from 49% to 80%. Question 16 was also a re-banked question but the improvement in its facility was much less marked: from 62% to only 64% in fact.

The connection between the pd applied across a capacitor and the energy it stores was the subject of **Question 17**. Almost three-quarters of the students were able to see that a 100:1 capacitance ratio would imply a 1:100 ratio for V^2 if the energy was to be the same.

The students in 2012 found **Question 18** to be rather more demanding than those who faced this question when it appeared in a previous test, thus causing the facility to decrease from 69% to 64%. Students who were successful here had to understand the meaning and significance of the time constant of an *RC* circuit, and in particular that the pd would decrease to 1/e of its initial value after a time equal to one time constant.

Question 19, which required application of a knowledge of time constant by correctly using the equation $V = V_0 e^{-t/RC}$, discriminated between the strongest and weakest students better than any other question in this test. The facility of this question was 71%.

Question 20 was a test of $F = B\,I\,l$ that, with a facility of 86%, proved to be the least demanding question in this Section A. When the question was pre-tested just over half of the students selected the correct response.

Fleming's left hand rule, as applied to a beam of positive ions, was the topic in **Question 21**. 61% of the students could apply the rule correctly, but almost one quarter of them chose distractor B, where the magnetic field would have acted "down" into the page instead of "up" out of it.

Question 22, on the emf generated by a moving magnet and the consequences of Lenz's law, had been used in a previous examination. The facility of 67% this time was slightly better than when it was last used. Curiously, the most common incorrect response was distractor A (chosen by 18%), where the order in which the magnet would emerge is the exact opposite of the correct order.

Question 23 was a graphical test of the relationship between an induced emf and the rate of change of magnetic flux causing it. 59% of the students saw that the increasing gradient of the original graph had to imply that the emf would increase, and that therefore only graph D *could* be correct.   24% of the responses were for distractor B, where the emf is shown to decrease at an increasing rate.

Question 24 needed students to spot that the most rapid change of flux in a transformer circuit occurs when a current is suddenly interrupted, leading to a maximum emf and (in this case) the largest current in the secondary circuit. A conventional car ignition system, now increasingly rare, illustrates this principle most effectively.   The facility of the question was 43%, with 25% of the students opting for distractor B (when the primary current is steadily increased).

Question 25 amounted to a traditional transformer efficiency question, but it was set in the context of a mobile phone charger circuit with low efficiency. The facility of the question was 71%. There was no strong distractor, and the question discriminated much better than it had done when pre-tested.

Section B

General Comments

As was evident in the Unit 4 test in January 2012, many more students are now taking care to show their working in calculations. This facilitates the award of marks for intermediate stages, and makes it much clearer for examiners to locate the problem when final answers are incorrect.

Definitions were generally well known, although imprecise use of language often limited the mark that could be given. Many answers to questions requiring explanation also suffered in the same way.

The topic of movement through gravitational fields (tested in Question 4 (c)), which was used for the assessment of written communication, was rather better understood than most topics used for this purpose in previous Unit 4 tests. Consequently marks tended to be slightly higher, although the proportion of students who were able to give a high level answer remained very small.

Some students appeared unaware of the fact that the Unit 4 test has to include synoptic content. In Question 2 (c)(i) knowledge of how the energy of a photon relates to the wavelength, and of the electron volt, was required. This should have been familiar to students from their study of Unit 1 of AS Physics.

Question 1

In part (a), the relationship was well known. The principal failings were omission of the word *change* in “change of momentum” and unclear references to time. “Change of momentum over a period of time”, with the period of time undefined, is not as satisfactory as “change of momentum divided by the time taken for change to occur”. Most correct answers quoted the familiar “force equals the rate of change of momentum”.

Either energy considerations or the equations for uniform acceleration offered a route to the answer in part (b)(i), where most attempts were correct. Some students tried to get the required 5.6 m s^{-1} by ingenious misuse of the numbers in the question, typically 1.60 m $\div$ 0.300 kg s^{-1} (which is 5.33). Calculation of the momentum that arrives per second in part (b)(ii) caused little difficulty.

This contrasts with part (b)(iii), where relatively few fully acceptable answers were seen. The majority of students readily saw that the balance reading must be at least 3.65 kg – their problem was to account for the extra 0.17 kg, reflecting the force produced by the change of momentum of the sand as it arrived in the container. Answers which got to 0.17 kg by dividing 1.68 N (from part (b)(ii)) by 10 were discounted, because the 10 usually referred to a time of 10.0 s rather than a value for the gravitational field strength. Examiners expected to see 1.68 divided by either 9.81 (the data booklet value) or 9.8 to arrive at a mass of 0.171 kg. Perhaps the most convincing answers were those that converted the 3.65 kg mass into a force of 35.81 N, and then added the 1.68 N, before dividing by 9.81 N kg^{-1} to obtain 3.82 kg.

Only a few answers to part (c) deserved all three marks. The numbers in part (b)(iii) should have made it clear that the balance had not been tared, so a horizontal line at a finite mass value (i.e. 0.65 kg) was expected over the first 5 s. The horizontal line between 25 and 30 s, and a line of constant positive gradient between 5 and 25 s, were usually drawn correctly. The features of this graph that caused most difficulty were the abrupt increase in reading at 5 s, and corresponding abrupt decrease at 25 s, caused by the momentum of the falling sand and its sudden cessation.

Question 2

Parts (a) and (b) of this question, about forces and accelerations of charged particles in electric fields, was more demanding than expected. The direction of the arrow in part (a)(i) was frequently wrong, and was often shown in a vertical direction. A clear force arrow, starting on the electron and directed horizontally to the left, was expected. However, in part (a)(ii) most students recognised that this situation produces a constant force; the explanation that the force is caused by a constant electric field strength was sometimes less clear.

More careful consideration of the wording of the questions, and subsequent review of the answers they had written, would have benefitted many students when answering part (b). For example, it was common for a student's attempt at part (i) to try to answer the issues raised in part (iii). Students should know that a force has two attributes, magnitude and direction. Both had to be addressed in satisfactory answers to part (i), where both particles are at exactly the same point in an electric field of exactly the same field strength. In part (ii) the relationship between forces and accelerations was usually well understood and both marks were usually awarded. Failure to discuss the accelerations of the proton and electron separately was common in part (iii), leading to many wrong answers. Parabolic and circular motion were often referred to here. Some of the less able students stated that the electron would decelerate, probably because they were unable to distinguish between deceleration and decreasing acceleration.

Students who had revised their AS Physics, and who presented their working fully, were well rewarded in part (c)(i). Part (c)(ii), although it is basically a simple question, proved to be much more challenging. The common acceptable approach was to calculate the strength *E* of the uniform electric field and then divide 1.91 (or 2) V by *E*. A slightly longer procedure was divide the energy calculated in part (i) (3.06×10^{-19} J) by the force on the electron – which had to be calculated. However the question could be answered using simple ratios: (2 / 4500) of 180 mm is 0.080 mm.

Question 3

It was rare for all four marks to be awarded in part (a). The essence of this question was well understood, but poor use of English and an inability to write logically limited the mark that could be given. An alarming proportion of answers made no reference at all to the magnetic field; these students appeared to be answering a more general question about circular motion. Many of the students evidently thought that the purpose of the magnetic force (presumably acting *outwards*) was to *balance* the centripetal force, rather than to *provide* it. Relatively few correct solutions were seen that used $r = mv / BQ$ to show that r is constant when B and v are constant.

The common error in part (b)(i) was failure to deduce the radius of the path of the protons from the 27 km circumference of the LHC. This only meant the loss of one of the three marks, however, provided the principles of the rest of the calculation were correct. Careless arithmetic such as failure to square v, and/or forgetting to convert km to m, was also a frequent source of loss of marks. $F = BQv$ was usually applied successfully in part (b)(ii), where the unit of magnetic flux density was quite well known. Almost inevitably, there was some confusion between *flux density* and *magnetic flux*.

The fact that had to be appreciated in part (c) was that in the LHC the radius of the path of the charged particles must remain constant as they are accelerated. A large proportion of students thought that it was necessary to maintain a constant centripetal force for this to happen, whereas it ought to have been clear to them that F must increase as v increases if r is to be constant.

Question 4

In the definition of gravitational potential (part (a)) the common failings were the omission of *per unit mass* and a wrong direction of displacement – from a point in the field to infinity instead of in the opposite direction. The calculation in part (b)(i) was usually well rewarded. The number of significant figures to be quoted in the final answer should have been limited to the smallest number of significant figures provided in the data, which was 2 in this case. Not all students realised that, in order to reach the Moon, the minimum increase in gravitational potential required was the difference between the values at X and at the Earth's surface, some thinking that the probe had to be given an increase of 62.6 MJ kg^{-1} (which would be enough to remove it to infinity).

Part (b)(ii) had a high proportion of correct answers, usually given in terms of field strength or gravitational force rather than gravitational potential. A common error here was to state that the Earth's field had no effect beyond X. Very few answers to part (b)(iii) scored both marks and most received no credit at all. The simplistic, incorrect answer – that V is proportional to $1/r$ implied that the potential would be negligible at large r – was given by many. The question had informed students that near the Earth the value of gravitational potential due to the Sun is –885 MJ kg^{-1}, which is certainly not negligible! The important facts in this part were that the Earth-Moon distance is much less than the Earth-Sun distance, so the *change in V* due to the Sun is negligible over the distance moved by the probe.

To merit a mark of 5 or 6 (a high level answer) in part (c) the students were expected to make detailed correct references to all of the four factors mentioned in the question: forces, field strengths, potentials and the significance of point X. Few were able to do this, and so the majority of answers fell to the intermediate or low level. The understanding of gravitational potential was particularly weak, compounded by misinterpretation of the negative sign in a scalar quantity. It was commonly stated that the gravitational potential of the Earth is *greater* than the gravitational potential of the Moon; in fact the values are –62.6 and –3.9 MJ kg^{-1} respectively, so it appears that a large proportion of A level students did not understand that 0 is greater than a negative number. Most answers concentrated on the Earth's gravitational field being larger than the Moon's because of their different masses. Many answers reiterated the question, without explaining the reasons satisfactorily, and in a coherent, sequenced, well organised way. Students should have been able to explain why X is closer to the Moon than to Earth, that work has to be done on the probe only as far as X, and that the larger distance from the Earth to X, and the average larger force required to get there, imply that more work has to be done on the probe when travelling to the Moon than when returning to Earth. Loose use of terminology was a frequent detractor when making these answers: "the Earth's larger potential pulls the probe back to Earth", etc. References to escape speed, which is not very relevant in the context of this question, were fairly common.

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