A-LEVEL

PHYSICS A

PHYA4 – Fields and Further Mechanics
Report on the Examination

2450
June 2014

Version: 1.0

General Comments

2014 has been the first year in the lifetime of the current specification during which the Unit 4 examination has been offered only in June. This has had an effect on the profile of the students taking the June examination, and on how well they have prepared for it. Just over 15,200 candidates took the June 2013 Unit 4 test In 2013 the number of students taking the corresponding tests was almost 12,000 in January and around 8,900 in June. Roughly two-thirds of the June 2013 entrants were re-sitting the test; the high proportion of re-sitting students meant that the in June 2013 the students produced a somewhat lower average performance than in January.

In 2014 the outcome of the June examination benefitted from the greater maturation of those students who would otherwise have taken the test rather prematurely in January.

The mean pre-test facility of this Section A objective test was 51%, the same as that of both 2013 tests. In the 2014 examination itself, the mean mark achieved in this section was 16.7 out of 25; in 2013 the mean mark was 16.5 in the January test and 15.1 in June.

Section A – Objective Test Questions

The keys to the objective test questions were:

1	D	**2**	A	**3**	B	**4**	C	**5**	D
6	B	**7**	C	**8**	D	**9**	A	**10**	C
11	C	**12**	B	**13**	B	**14**	C	**15**	C
16	D	**17**	A	**18**	A	**19**	B	**20**	B
21	B	**22**	D	**23**	D	**24**	A	**25**	C

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 66.8%. The facility for individual questions ranged from 97% for Question 2 to 37% for Question 17. 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 56% when last used. The eighteen new questions had all been pre-tested and had a mean pre-test facility of 49%. Students always 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 19%. 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 candidates. The mean point biserial for this paper in the examination was 0.37.The new questions had a mean pre-test point biserial of 0.33, whilst the value for the re-banked questions was 0.42. On average there was therefore an overall improvement in the discrimination of the questions.

Fourteen of the questions (Questions 1, 2, 4, 5, 6, 7, 9, 10, 12, 14, 16, 22, 23 and 25) proved to be easy, with facilities over 65%, whilst none was difficult (i.e. had a facility less than 35%).

Question 1 was answered correctly by almost 95% of the students, who clearly recognised that the area under the graph was "force × time = impulse = change in momentum". The surprising feature of this question is that when in was pre-tested in 2008 fewer than 60% of the students gave the correct response.

Question 2 was a numerical test of "force × time = change in momentum", the same topic as Question 1. This topic was not examined in Section B. Outwardly this question is more demanding than the previous one, but an even higher percentage of the answers were correct. Consequently this was the easiest question in the test. The ability of a question to distinguish the ablest students usually suffers when the facility is high (97% in this case); hence this was also the least discriminating question in the test.

Question 3, involving the momentum of a column of water emerging from a garden hose, had been used in a previous examination, when just over 40% of the students gave the correct answer. This time 61% did so, probably showing the benefit of practising on past papers. The most common incorrect response was distractor C, chosen by 19%, where the students had omitted to consider the cross-sectional area of the body of water leaving the pipe per second.

Question 4 had a facility of 65%, up from 59% when used previously. Its subject was angular speed and its effect on the linear displacement of a model car moving around a circle. In 6.0s, the car would travel through an angular displacement of 3π radians, taking it round the circle 1½ times and therefore to the opposite end of a diameter. An incorrect answer of 2.4π m (the distance travelled) would have been understandable, but it was not on the list of distractors. The common incorrect answers were distractors B (the distance travelled after 1.0s) and D (the distance travelled after 4.0s).

In ***Question 5*** most students realised that the centripetal force on the mass acts towards the centre of the circle in which it moves, and very few were distracted by the weight of the mass. 73% of the responses were correct. This question had been used in a 2010 examination, when 9% fewer students chose the correct answer.

Question 6, on circular motion in a vertical circle, produced correct responses form almost 70% of the students. The most popular incorrect choice was distractor C, made by 26%. This error follows from the wrong resolution of forces when applying $F_{res} = ma$. $T = mg + mv^2/r$ leads to T = 17N whereas $T + mg = mv^2/r$ gives T = 13N.

Questions 7 and 8 concerned the equations of simple harmonic motion. In Question 7, the selection of the correct algebraic terms for amplitude and frequency from the equation $x = P \cos Qt$ was carried out correctly by three-quarters of the students. Difficulties with algebra are likely to have caused 17% to select distractor B (where frequency = $2\pi Q$ instead of $Q/2\pi$). Question 8 was rather more demanding, with a facility of 58%. Successful solutions required an understanding that $v_{max} = 2\pi fA$ and recognition that the numerical values in the alternative answers were given in mm s^{-1}, not m s^{-1}. Failure to notice the latter point caused one third of the students to select distractor B, where the value was given as 0.32π mm s^{-1} rather than the correct 320π mm s^{-1}.

The effect of heavier damping on the amplitude of vibration of an oscillating object when close to resonance was the subject tested by ***Question 9***. 74% of the students appreciated correctly that the amplitude would be reduced at all frequencies, but 18% considered that heavier damping would be effective only at frequencies above resonance (distractor C).

Direct application of Newton's law of gravitation easily gave the answer in ***Question10***, which had a facility of 78%. A very small number of incorrect responses came from assuming that the law gives $F \propto (1/r)$ – represented by distractors A and D. Rather more (14%) chose distractor B; these students probably added the two component forces acting on the spacecraft instead of subtracting them.

Question 11 tested students' knowledge of gravitational potential. 61% of the answers were correct. Each incorrect answer attracted a significant proportion of the responses, the most common being distractor D (19%). This choice came from confusing the correct unit of gravitational potential, J kg^{-1}, with the unit of field strength (N kg^{-1}).

Questions 12 and 13 were both on Coulomb's law. In Question 12 the incorrect statements were readily identifiable by those who had understood the topic. The correct one could then be found by a process of elimination, without necessarily working out that the electrostatic force could be measured in $C^2\,F^{-1}m^{-1}$. 80% of the answers were correct; perhaps it is remarkable that only 51% of the responses were correct when this question was pre-tested. Question 13 presented students with considerable mathematical demands, following from understanding that the electrostatic force obeys $F \propto (1/r^2)$. Since the force between the charges is doubled from 0.5F to F, their separation must be decreased to $1/\sqrt{2}$ of 20mm, i.e. to 14.1mm. 61% of the responses were correct, with incorrect ones fairly evenly spread amongst the other distractors.

In ***Question 14***, 66% of the students knew that an electric field can change both the magnitude and the direction of a moving charge, in the same way that a gravitational field can for a moving projectile. Confusion with the effect of a magnetic field on a moving charge may have caused 20% of the responses being for distractor B (direction can be changed but magnitude is unaffected).

Question 15 required an understanding of electric potential as a scalar, so that the contributions of the two charges to the total potential at any point around them can be found by simple addition. Combined with an appreciation that $V \propto (1/r)$, it follows that the potential at the mid-point due to one charge is 12.5V – and that this becomes 25V when the distance is decreased to 1.0m, and 8.3V when increased to 3.0m. Therefore the resultant potential at the required point is 33.3V. Distractors B and D each attracted about one-fifth of the responses.

Question 16 was the first of the two questions in this test where the students had to select a "wrong" statement. This always highlights the need for careful reading of the question. When a charge is moved completely around a closed path in an electric field the net work done is zero; this *correct* statement was given in distractor C, which was chosen by 26%. Distractor D – the correct response – directly contradicts distractor C. 67% made the right choice.

Question 17, with a facility of 37%, turned out to be the most demanding question in the test. Understanding that plate **X** was at a higher potential than plate **Y** should have enabled students to deduce that the electric field direction was from **X** to **Y**, and that an electron would experience an electrostatic force directed towards **X**. Hence an electron travelling from **X** to **Y** would be decelerated; its E_k would decrease and its E_p would increase. Therefore ΔE_p would be +30eV. Each of the distractors B and D received about 25% of the responses.

Familiarity with $E = V/d$ should have enabled students to realise in ***Question 18***
that potential difference can be calculated from (field strength) $\times\ \Delta d$, for both gravitational end electric fields. 62% of students correctly gave answer A; the three other distractors were chosen fairly randomly by between 10% and 17% of the entry.

Question 19, with a facility of 45%, was concerned with energy storage by a capacitor and was one of the more demanding questions in the test. This is more likely to have been caused by mathematical difficulty than by lack of knowledge of $\frac{1}{2}CV^2$. A decrease in the applied pd of 2.0V caused the energy stored to decrease from 1600μJ to 400μJ. $E \propto V^2$, so the initial pd must have been 4.0V. Direct substitution of E = 1600μJ when V = 4.0V into $E = \frac{1}{2}CV^2$ then gives the value of C. Distractors C (20%) and D (25%) were both common incorrect choices.

Question 20 tested students' understanding of exponential decay as well as energy storage. The "half value period" of the *RC* circuit was 36ms; in this time the pd would decrease to $V/2$ and the energy stored would fall to $E/4$. In a further 36ms the energy stored would fall to $E/16$. 62% of the responses were correct. Distractor C was selected by 17% of the students.

Question 21, which had been used in an earlier examination, had a facility of 60% in 2014. On the previous occasion its facility was 55%. It may be readily seen that the radius of the path of a moving charged particle in a magnetic field is proportional to momentum p and inversely proportional to charge Q. When both p and Q are doubled, the charge will continue in a path of the same radius. Incorrect responses were evenly spread between distractors A, C and D. Question 21 was the most discriminating question in the test.

Question 22 required students to show an understanding of the meaning of the term *electromagnetic induction*. 69% were able to do so. Careful reading of the question was needed again here, because students had to choose an application where electromagnetic induction does not take place. 13% of the students considered that electromagnetic induction does *not* take place in power station generators (distractor A) – probably because they had mis-read the question.

The majority of the students knew that a faster moving magnet would induce a greater emf, and would pass through a vertical coil more rapidly, in ***Question 23***. The facility of this question was 65%. One fifth of the answers selected distractor C, where the emf was greater but the time unchanged.

Question 24 could be answered by knowing that the emf generated in a coil rotating in a magnetic field is given by $\varepsilon = BAN\omega \sin \omega t$, that and that $\omega = 2\pi f$. The maximum emf $\varepsilon_0 = BAN\omega$, which is (maximum flux linkage) $\times\ 2\pi f$. 59% of the answers were correct.

It is possible that the values chosen for three of the distractors in ***Question 25***, on transformer efficiency, were so obviously wrong that there was no need for the students to perform any calculation. However, only 54% gave the correct response when the question was pre-tested in 2009. The 2014 A level students made amends for this, because the facility of the question was 87% this time.

Section B – Written Test

Section B gave wide coverage of the specification; it gave students plenty of opportunities to recount what they had learned about the Unit 4 topics and to practise the techniques they knew. There were questions on gravitational fields and satellite motion from the second section of the specification, electric fields and magnetic fields from the third and fifth sections, simple harmonic motion from the first section, and capacitance from the fourth section. Question 1, on gravitation, was answered very well in general. Some parts of Question 2, on fields, caused greater difficulty. Parts of Question 3, where the topic was energy in a vertical mass-spring system, were also found to be demanding by many students. In Question 4 most students gained full marks on part (a)(i), but very few marks on part (a)(ii). Many were successfully guided by the bullet points in part (b) to give workmanlike answers in this communications exercise about capacitor charging and discharging processes.

Whilst a large amount of excellent work was seen, examiners were disappointed by the lack of care taken by some students in the presentation of their work. Particular problems arose with the poor legibility of the handwriting of many of them: writing that was sometimes too small or badly formed to be legible, and numbers (especially in the index x in 10^x) that were far too tiny to be read accurately.

The majority of students took care to show their full working in calculations, but a minority seemed unaware that they would lose marks when they omitted essential steps. There were many instances where marks for the correct substitution of numerical values into a formula could not be awarded because the answer shifted directly from a sketchy algebraic outline to a final value.

Another general weakness arose from the failure to read the wording of a question sufficiently thoroughly to be able to address its specific requirements. This could mean that the answers went beyond the scope of the question's intentions, such as in Question 3(a)(ii), or simply did not produce the details required in a diagrammatic response, such as in Question 3(b)(ii).

Question 1

The definition in part (a)(i) was well known. Because the quantity concerned is called gravitational field *strength*, there was frequent confusion as to whether it is a vector or a scalar, with many answers being crossed out and changed. Part (a)(ii) was also generally very rewarding. The main problem was a failure to show how the terms from the data booklet equations (m_1, m_2 and r) translated into the terms in the question (m, M, R and h). In the derivation, some students cancelled M instead of m. However, others had so little confidence in their use of algebra that they could make little progress even in a simple derivation such as this.

Part (b)(i) caused few problems and marks were generally high. Sometimes incorrect values had been extracted from the data booklet for the mass and radius of the Earth. Three significant figures were expected in the answer; therefore a minimum of three significant figures should also have been used in the substitution and working. When $h = 1.39 \times 10^7$ was used as the radius of the orbit one mark was lost and the value of the force thus obtained was carried forward to make most marks available in part (b)(ii). Part (b)(ii) offered a very wide range of approaches to enable students to show that the satellite would make three transits of Earth in every 24 hours. Apart from the three alternatives given in the mark scheme (all of which were frequently seen) a very concise calculation showed that a satellite with an angular speed of 2.19×10^{-4} rad s^{-1} would move through an angle of 18.9 rad in one day, equating to ($18.9/2\pi$ =) 3.01 transits.

Use of polar orbiting satellites for monitoring the Earth (weather forecasting, spying, surveying, etc.) were well known in part (c), although some students confused the application with an equatorial geosynchronous satellite. Explanations of the application were often less satisfactory: reference to the rotation of Earth beneath the orbit, allowing the whole surface to be scanned, was the key here. The ability to provide regular updates of the information obtained was also an acceptable explanation. Students who mentioned the use of the polar satellite for communications gained the first mark but were usually unable to point out its limitations, caused by intermittent contact.

Question 2

The direction of the force on the negatively charged ion in part (a)(i) was mainly correct. Explanations of the direction of the force were good and marks for this part were high.

At A2 level the students are expected to have retained a comprehensive knowledge of earlier work, which is tested by synoptic components within the questions. Part (a)(ii) was an example of this, because the simplest solution followed directly from "energy gained = work done = force × distance". This eluded most students, many of whom were completely defeated. Many of them became successful after taking a very roundabout route, involving calculation of the pd from $V = W/Q$, the field strength from $E = V/d$ and the force from $F = EQ$. Others produced answers based on the uniform acceleration equations and $F = ma$. When this was done using algebra the mass m of the ion could be cancelled and the answer was accepted. When a numerical value was chosen for m the mark that could be awarded was limited to 1 out of 2. There were fewer difficulties in part (a)(iii), where $E = F/3e$ gave the most direct answer but where $E = V/d$ offered an alternative method. Incorrect force values from part (a)(ii) were permitted for full credit in (a)(iii).

In part (b)(i) the successful application of Fleming's left hand rule readily showed the majority that the magnetic force on the wire would be downwards (or into the page). Most students gained both marks. It seemed that some students who thought too deeply about the direction of this force eventually got it wrong: their line of thought was that the force due to the current was downwards, but electrons carry a negative charge so the force on them must act upwards. It had not occurred to them that the force on the complete wire has to act in the same direction as the force on all of the free electrons within it.

The simple calculation that led to the number of free electrons in the section of wire was almost always worked out correctly in part (b)(ii). This was a "show that" question, so students should have realised that a more precise answer than 4×10^{22} (such as 4.07×10^{22}) would be expected before the mark became available. Part (b)(iii) offered two approaches to the value of the flux density B. By considering the average force on a single electron, $F = BQv$ could be used. Alternatively, by considering the force on the section of wire, $F = BIl$ could be used. In the latter method many got into difficulty by forgetting to consider the number of electrons in the wire.

Question 3

Part (a)(i) offered an easy mark for naming the two types of potential energy involved in an oscillating suspended mass-spring system. “Gravitational potential energy” is clear and unambiguous, but a variety of terms appeared to be in use for the energy stored by a stretched spring. “Elastic potential energy” was the expected term, but “strain energy” was equally acceptable. For obvious reasons “stored energy” (when unqualified) was not.

Those who had concentrated on the wording of the question in (a)(ii) – especially on “energy *changes*”, “one complete oscillation” and “starting at its lowest point” – were able to give good concise answers. Far too many of the students attempted to consider the absolute values of elastic and gravitational energies during an oscillation, which usually led them into confusion and irrelevance. Many answers stated that elastic potential energy would increase as the mass moved above the equilibrium position because the spring would be compressed. Inevitably a lot of answers described only half of an oscillation: if the energy types and changes were correctly described even this was given 1 mark. Answers which did not refer to the kinetic energy of the system were not credited.

In part (b)(i) those who appreciated that the total potential energy of the system passes through two maxima per oscillation, one at each amplitude, came up with the expected 0.8s. Because they did not understand this, getting on for half of the students gave 0.4s. There were consequences in the later parts of Question 3, where incorrect values from part (b)(i) were generally accepted as a basis for the work that followed. A small minority of the graphs drawn in (b)(ii) were triangular, but the majority represented some form of sinusoidal variation. Whether this agreed with the expected period (0.8s), and was a negative cosine curve, proved to be more testing issues.

The time period calculation in part (c)(i) was straightforward. This was rewarding for those who could substitute mass and period values correctly and then calculate the expected value. N m^{-1} was the only answer accepted for the unit of k. The amplitude calculation in the final part of the question was often done well. Students who had made an error over the time period earlier were unable to show that the value of the amplitude would be about 40mm, so were limited to a mark of 3 out of 4. Working from T = 0.4s, many of these answers arrived at a value of 21.5 mm before the students introduced a mystery factor of 2 to end up with “about 40 mm”!

Question 4

The capacitance calculation in part (a)(i) rewarded most students with full marks. Answers to part (a)(ii) made a distinct contrast, because relatively few students were able to progress. Correct answers were rare. The circuit in Figure 5 is one in which the *current is maintained constant* by reducing the resistance as the capacitor is charged. Consequently the large number of attempted solutions that introduced exponential decay equations were totally inappropriate. An understanding of the principle that in a series circuit the sum of the voltages across components is equal to the applied voltage was essential. Many of the efforts progressed as far as establishing that the pd across the capacitor at 30s would be 2.2V, but then went on to find what is effectively “the resistance of the capacitor” by dividing 2.2V by the current.

The final question in this examination, part (b), concerned a *C-R* circuit is which *R* is constant and charging/discharging *are* exponential processes. Apart from testing this subject content, the question was also used to assess the communications skills of the students. The guidance given in the bullet points helped most students to organise their answers systematically. A very good spread of marks was seen, ranging from students who clearly knew everything that happens during charging and discharging to ones who understood little or nothing about capacitors. A large number of correct statements about the factors listed in the bullet points for both charging and discharging constituted a high level answer (5/6 marks). Fewer correct statements about either charging or discharging put answers into the intermediate level (3/4 marks) whilst even fewer correct statements put answers into the low level (1/2 marks). Contributing also to the overall assessment was examiners' consideration of the incorrect statements made in the answers, and how satisfactorily the answers had been had been written. There were many instances of answers in which it was stated that electrons passed directly from plate **Q** across the gap to plate **P** – these tended to condemn the knowledge of the student concerned. A common misapprehension concerning this circuit was that the reduction in current is caused by an increase in the *resistance of the capacitor* rather than by a decrease in the net potential difference as the capacitor charges or discharges. A large proportion of the students chose to ignore the advice given to refer in their answers to points **A**, **B**, **P** and **Q** in the circuit. This omission usually made their answers somewhat more difficult to assess.

Mark Ranges and Award of Grades

Grade boundaries and cumulative percentage grades are available on the Results Statistics page of the AQA Website.

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UMS conversion calculator www.aqa.org.uk/umsconversion