



General Certificate of Education

Physics 6451

Specification A

PA04 Waves, Fields and Nuclear Energy

Report on the Examination

2007 examination - June series

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Set and published by the Assessment and Qualifications Alliance.

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General Comments

The shift in the entry pattern for Unit 4, which was noted last year, has stabilised in 2007. The number of candidates entered for PA04 in January again increased this year, but by only about 70, whilst the June paper was taken by about 150 fewer candidates than in 2006. Almost 3300 candidates were involved in June 2007, as opposed to nearly 3900 in January. The statistical data from pre-testing exercises showed the two objective tests set in 2007 to be of comparable difficulty. But in Section A of the examination proper, the June candidates performed marginally better than those in January. Candidates' responses in Section B also seemed to show that the June candidates were better prepared for the examination than those who had taken the January 2007 PA04 paper.

Section A

The keys to the objective test questions were:

| | | | | | | | | | | | | | | |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| C | B | A | C | A | B | D | C | B | C | D | B | D | C | 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 67%, compared with 62% and 65% respectively in June 2006 and January 2007. The facility for individual questions ranged from 83% for question 11 to 47% for question 5.

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 was 0.44, which is slightly higher than the values produced by the two previous tests.

Ten of the questions (Questions 1 to 4, 6 to 8, 11, 12 and 15) proved to be easy, with facilities over 65%, whilst no question was found to be difficult. Three of the questions had been used in earlier Unit 4 tests, whilst one had appeared previously in an Advanced Supplementary level end-of-course examination. Candidates' performance on the old AS question was much better than when it had appeared previously, whilst their performance on the re-used Unit 4 questions was broadly similar (except for one question on which it was notably improved).

The mean facility of the questions increased by 12% over the pre-test values. An improvement of 11% was achieved in January 2007.

The answer to **Question 1** came easily to the candidates who remembered that, in simple harmonic motion, the maximum velocity $v_{\max} = 2\pi fA$. Because the amplitude A remains constant, it follows that $v_{\max} \propto f$. The doubling of v_{\max} was realised by just over 70% of the candidates. The most common wrong answer was distractor B (chosen by 12%), which would imply that, in shm, energy \propto frequency f (when in fact energy $\propto f^2$).

Question 2 tested candidates' understanding of the effect of damping on the amplitude and period of simple harmonic oscillations. Graph B, the correct response, showed exponential decay of the amplitude with the period unchanged. 73% of the candidates made this choice, but 19% selected distractor A, where both the amplitude and the period were shown to be decreasing. This question was not a very effective discriminator between the abilities of the candidates.

Question 3 required candidates to choose an **incorrect** equation involving the period, frequency, wavelength and speed of a wave motion. The four equations were not in a form that

would normally be familiar, and it is pleasing that the facility turned out to be almost 80%. Since $c = f \lambda$, the speed c cannot be equal to $T \lambda$ – as would be implied by distractor A. This question had appeared in a previous PA04 examination, when slightly fewer than 70% of the candidates made the correct choice. The discrimination of the question remained just as good as it had been previously.

Question 4 required an understanding of how phase varies with distance along a transverse wave, followed by correct application of the wave equation $c = f \lambda$. The essential connection was the association of a distance of $\lambda / 4$ with a phase change of $\pi/2$, leading to a wavelength of 1.6m and a speed of 640ms^{-1} . Around two-thirds of the candidates had this correct. The most popular incorrect response was distractor B, which follows from associating a distance of $\lambda / 2$ with a phase change of $\pi/2$.

The most demanding question in this paper was **Question 5**, the facility of which barely changed from its pre-examination value of 47%. Many less able candidates chose distractor D, which had been much less popular when the question was pre-tested. Unusually for this type of test, slightly more candidates selected the incorrect response (D) than the correct one (A). The coherence of two sources indicates that they must have the same frequency and the equation $E = h f$ links the frequency of a wave uniquely with photon energy. The confusion of candidates may have arisen because $E = h f$ is taught as part of the AS course, and had therefore become a distant memory. The question was nevertheless an effective discriminator.

Question 6 examined conditions for the formation of a dark fringe in two-slit interference, in terms of path difference and phase difference. 68% of the candidates appreciated that a path difference of $(m + \frac{1}{2})\lambda$ would give a phase difference of 180° , the required condition. The next most popular option was distractor C (19%), where the phase difference is correct but the path difference is not.

Question 7, on the diffraction grating, had been used in a previous PA04 examination. The 2007 candidates found it to be rather more demanding than their predecessors, because the facility (67%) was 3% worse than last time. However, the question was more discriminating than any other in this paper. Perhaps it was forgetting $n = (1 / d)$ that caused 18% of the candidates to choose distractor B, because the value of d in this question worked out at $2 \times 10^{-6}\text{m}$.

Question 8 required candidates to calculate the pd across a capacitor being charged by a constant current. The candidates who had pre-tested this question found it to be moderately difficult, but in the examination the facility improved by over 25%, to 76%. The charge stored after 25s is easily found from $Q = I t$, and a rearrangement of $C = Q / V$ then leads to the answer. Possibly the 15% of candidates who chose distractor A were successful with the first half of the calculation, but then used an incorrect equation such as $V = C / Q$.

Question 9 gave the candidates more to do than any of the other questions, in that there was a lot of material to read, as well as several separate concepts to deal with. Around 1.5% of the candidates failed to make any response to question 9, which is surprising when an outright guess would give a 1 in 4 chance of success. Recognising that E , the energy stored by a capacitor, is proportional to V^2 , was the initial key to clear thinking. The condition required by the question was therefore that the pd was to fall to $V / 4$. The simple characteristics of exponential decay indicate that this will take twice the time taken for the pd to fall to $V / 2$, i.e. 72 ms. Almost a quarter of the candidates chose distractor D, obtained by multiplying 36ms by 16.

Question 10, another re-used question from a previous PA04 examination, was concerned with the gravitational field strength between two point masses. The facility of 62% was very slightly greater than last time, but the question was rather more discriminating this time. Problems with algebraic rearrangement caused almost one in five of the candidates to choose distractor D, the inverse of the correct response.

The easiest question proved to be **Question 11**, which had a facility of 83%. Simple rearrangement of the equation giving g in terms of G , M and R (which was provided on the data sheet) was all that was necessary. The most common incorrect response was distractor B, probably because the candidates involved could not distinguish between g and G .

It has been noted in previous Reports on the Examination that present-day A level candidates are more proficient than those who took the old Advanced Supplementary examination. When **Question 12** was used in a previous AS examination, only about two-fifths of the candidates made the correct choice, whereas this time about two-thirds of them did so. Even so, almost a quarter of them selected the unit of gravitational field strength (distractor D) rather than that of gravitational potential.

Question 13 required calculation of the emf induced in a coil when there is a rate of change of the magnetic flux linked with it. The question had a facility of 64% and it discriminated well. Distractor B attracted 23% of the candidates, no doubt because they overlooked the 5 turns on the coil, which caused the emf to be 80mV rather than 16mV.

Question 14 was also on electromagnetic induction, but it was qualitative. A falling magnet takes a longer time to pass through a vertical tube when a larger current is induced by the change of magnetic flux through the tube. The largest current will be produced in the tube with the least resistance, or least resistivity (since the dimensions the tubes are identical). Hence the order in which the magnets emerge is rubber, lead, copper. 65% of the candidates made the correct choice, with 21% giving distractor A – exactly the opposite order of that expected. The question was much less discriminating than it had been when pre-tested.

Question 15, which tested candidates' familiarity with the features of the well-known binding energy per nucleon curve, needed them to select the *incorrect* statement from a list of four. Inevitably there are some candidates who are challenged by a question that is answered by a *wrong* statement when most of the others require the selection of a *right* statement. Two-thirds of the candidates knew that *fission* could not occur for nuclides of low nucleon number and therefore spotted that distractor A could not be a correct statement.

Section B

Section B once again gave candidates excellent opportunities to show what they had learned. Excellent answers were seen to all parts of all of the questions, but relatively few candidates were able to combine exemplary answers to all five. All parts of all of the questions were usually attempted and it was rare to find a script in which there were several unanswered questions. Most candidates had a reasonable knowledge of the majority of the topics that appeared in the paper, the poorest area proving to be electric fields (Question 4).

Some of the calculations turned out to be demanding, particularly those in Questions 1 (b) (ii) and 3 (c). The clarity of the working in calculations often left much to be desired, in that the work presented lacked progression and made it difficult for examiners to follow the thoughts of the candidates. The importance of retaining a sufficient number of significant figures during the intermediate stages of calculations again needs to be stressed.

The parts of the questions that relied on the interpretation of knowledge, such as Question 1 (a), or the explanation of physical effects, such as Questions 2 (a) and 3 (b), were often done very well. The inability of some candidates to write coherent sentences, to spell common words correctly, or to write an organised answer clearly, inevitably limited the mark that could be awarded for the quality of written communication. In this paper it was especially disappointing to encounter so many scripts in which the words *nucleus* and *nuclei* were spelt incorrectly, used indiscriminately, or confused with *nucleon*.

Incorrect units were penalised most often in Question 4 (a) (iii) – for electric potential given in anything other than V or J C⁻¹. The part causing most significant figure penalties was Question 5 (b), where examiners required at least two significant figures in the final answer.

Question 1

Inserting P, Q and R at acceptable points on the graph in Figure 1 was a relatively straightforward task for many candidates. Q was often shown incorrectly at a point of zero velocity but positive gradient, these candidates not appreciating that in simple harmonic motion the velocity changes from positive to negative when the displacement has its maximum positive value. Sometimes Q was omitted completely, perhaps because the candidate had not read part (i) fully. Explanation of the reasoning for the choice of position for R was often given convincingly, either in terms of gradient or an appreciation that *a* is a maximum when *v* is zero. Arguments in terms of displacement alone (e.g. $a \propto -\text{displacement}$) were less successful.

In part (b), calculation of the static extension of the spring caused little difficulty for the majority of the candidates. Finding the maximum potential energy stored by the spring during the first oscillation was much more testing, and correct answers were very rare. The energy exchange sequence of the mass-spring system is much more complex than that of a simple pendulum, because the mass-spring system stores potential energy at its equilibrium position, and also there are two kinds of potential energy involved. Candidates who realised that energy stored = $\frac{1}{2} F e$ could be applied, and who substituted the correct force of 5.6 N and extension of 0.20 m, rapidly reached a correct answer. Other approaches to this energy problem were possible but proved to be much too demanding for most candidates.

Question 2

The principles of circular motion were generally understood well by the great majority of candidates. The main errors that occurred in part (a) concerned some candidates being unable to identify which of the quantities involved are scalars and which are vectors. In part (b), the application of $F = m \omega^2 r$ led to the most straightforward solution for those who could relate the frequency of rotation to the angular speed ω . A common error was to consider the period of rotation to be 1.3 s instead of $(1/1.3)$ s, but the candidates who did this were still able to obtain marks for the rest of their calculation. Approaches which attempted to make use of $F = m v^2 / r$ were often less successful, because of the difficulty this caused when relating the speed v to the frequency of rotation. Problems in rearranging the algebra (or the arithmetic) were another common cause of wrong answers.

Question 3

Whilst the appearance of nodes and antinodes seemed to be familiar to candidates answering part (a), their ability to describe these features accurately was more limited. Explanations of node were often more satisfactory than those of antinode. The principal errors here concerned candidates being unable to appreciate that, at an antinode, the particle displacement is continuously variable but has the maximum *amplitude* of vibration. A common incorrect response from many candidates was 'at an antinode the particle displacement is a maximum'. This is incorrect because the particle displacement is variable and, indeed, is zero at two instants per cycle.

The situation described in part (b) of the question is probably more familiar as a demonstration of double-source interference phenomena, as in Young's slits, than as something that shows stationary waves. In the main, candidates were not put off by this and a large number of very good answers were seen. Some of the less able candidates attributed the formation of stationary waves to the progressive waves generated by one dipper being bounced off the other (or off the edges of the ripple tank). This is presumably because these candidates had only encountered stationary waves when reflected waves were involved.

Errors in interpreting the data in part (c) meant that many attempts made little progress. A large number of the candidates seemed to have misread the question, by taking the frequency of one of the vibrations to be 2.0 Hz in their answers. The need to express the original frequency as f and the other as $(f + 2)$ escaped many of the candidates. Most candidates deduced that the wavelengths of the progressive waves involved were 24 mm and 20 mm respectively, whilst the application of $c = f \lambda$ in part (c) (ii) turned out to be rewarding for those who associated the original frequency with the longer wavelength.

Question 4

The total marks for this question were lower than for any other question on this paper. Many candidates were obviously uncertain about the meanings of electric field, electric potential and electric potential energy; therefore they did not know which equation to use. In part (a), most candidates realised that the charge of the α particle is $+2e$, and that of the gold nucleus is $+79e$, but the application of these values was often confused. For instance, $+2e$ was substituted for the charge in part (iii) – where the potential due to the gold nucleus was to be considered – and $+79e$ was substituted into $F = EQ$ in part (ii) – where the force on the α particle was to be considered. In many scripts there was a preference to use the Coulomb's law equation in part (ii) and this was perfectly acceptable. Answers to part (iii) which made use of the equation $V = E r$ only received credit when the reason why this equation might be used was explained, i.e. by showing that $(Q / 4\pi\epsilon_0 r^2) \times r = (Q / 4\pi\epsilon_0 r)$.

In part (b), examiners insisted on a reference to an increase in the *electric* potential energy as the α particle approached the nucleus, and on the change back to kinetic energy as it receded. Part (b) (i) was intended to lead the candidates into part (ii), because the initial kinetic energy of the α particle must be equal to its electrical potential energy when at point P. Attempts to answer this part by using $\frac{1}{2} m v^2$, with v assumed to be the speed of light c (or something approaching c) were very common. Inability to distinguish electric potential from electric potential energy was another problem in part (ii).

Question 5

Many excellent answers to part (a) were seen, but the reasons why fusion and fission processes release energy was not always understood. The concept of binding energy is one that candidates continue to struggle with, because many of them imagine that it is energy that a nucleus possesses (rather than energy which is released when a nucleus is formed). Examiners were looking for a reference to an increase in the binding energy per nucleon when fusion and fission take place, or for reference to the fact that the final mass(es) of the nucleus in fusion (or nuclei in fission) is/are less than the initial mass(es) of the nuclei in fusion (or nucleus in fission). Reference to a mass defect alone was not considered to be sufficient, because all nuclei except ^1H have a mass defect; in a satisfactory response an *increase* in mass defect was expected.

It is regretted that there was an error in the data given in part (b), and that this led to a misleading value for the energy released in α decay. The mass of the ^{216}Po nucleus should have been given as 215.95572 u, whereupon the mass difference produced by fission would have been 0.00688 u. The corresponding energy release would then have been 6.41 MeV ($1.03 \times 10^{-12}\text{J}$), which is within the expected range for the α decay process. The physical principles being tested in (b) were not affected by the incorrect data, and there was no evidence in the scripts that candidates had been in any way troubled by this unexpectedly large energy release. The energy release calculation proved to be easy and, apart from arithmetical errors, the only significant difficulty came with incorrect attempts to convert the energy unit from MeV to J.

Mark Ranges and Award of Grades

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