# Physics GA 3: Written examination 2

## GENERAL COMMENTS

This examination provided a fair and reliable test of the material studied in Unit 4, with both students and teachers alike being quite positive about the style, depth and quality of the questions. The average score for the exam was 46.3/90, or 51.4% (the female mean was 48.5 and the male mean 45.8). It should be noted that the mean for the equivalent examination in 1999 was 54/90.

The cut-off score for a grade of A+ was 75/90 (compared with 82/90 in 1999). However, this also gave the students in the upper band of performance a better opportunity to demonstrate their understanding of the Unit 4 content.

The examination was clearly accessible to most students, as evidenced by the mark distribution. The entire scale of the 0–90 mark scheme was achieved across the broad spectrum of students. It was particularly pleasing to note that six students were able to score the full 90 available marks, a tribute to their understanding of the physics content and the preparation that went into their Unit 4 studies.

As always, the quality of the upper band of student responses was particularly impressive. It is quite apparent that many of our physics students graduate not only with a good understanding of physics concepts, but also with the ability to express these ideas via explanations, diagrams and numerical calculations.

A few concerns to note are:

- Students neglecting to show working when part marks are often awarded for such working, or, some students obtaining the correct numerical answer by incorrect physics.
- The inability of students to calculate answers arising from simple equations suggests that more practice in calculating numerical answers is needed.
- Poor quality written explanations or explanations which simply lack sufficient detail in cases where 2 or more marks are to be awarded.
- Students not answering the specific question asked, but rather giving a broad explanation suggestive of the student grasping at pre-prepared material from the A4 sheet that they bring with them to the exam. Teaching students to use this A4 sheet as a resource, particularly in the early stages of revising for the exam, rather than for direct application is an issue that teachers need to address. An emphasis on the value of the preparation process for the A4 sheet, rather than the end product, should continue to be a combined focus for students and teachers alike.

## SPECIFIC INFORMATION

### Area 1 – Motion

The average score for Questions 1 and 2 was 2.94/4, indicating that most students found the first two questions of the paper quite straightforward.

#### Question 1

The acceleration of the car was calculated from the equations for uniform acceleration to be 3.1 m s$^{-2}$.

The most common error here was first to calculate the average velocity (25 m s$^{-1}$) and then use this value in one of the equations for uniform acceleration. This resulted in an incorrect value for the acceleration of 1.56 m s$^{-2}$. This was a remarkably common error.

#### Question 2

The speed of the car was calculated via the equations for uniform acceleration, resulting in an answer of 50 m s$^{-1}$. There were a number of correct consequential answers for students who obtained the incorrect answer to Question 1.

This question was usually correctly answered, either directly or consequentially. The most common error was to calculate the average velocity (25 m s$^{-1}$).

#### Question 3

The change in momentum is defined as *final momentum – initial momentum.* Subtracting the initial momentum vector from the final momentum vector resulted in vector D as the change in momentum vector.

The average mark for this question was 0.29/1, a disappointing result for what was expected to be a fairly straightforward question. The most common incorrect answer, A, appears to have resulted by students ignoring the vector nature of momentum.

### Question 4

In order to explain why the surfboard continues forward, students needed to address these points:

- a statement of Newton's First or Second Law was required;
- the surfboard was initially moving at 10 m s$^{-1}$ and needed to decelerate to rest, in order to remain with the car;
- the deceleration of the surfboard requires a net force – this force would normally be provided by the roof straps, which clearly cannot happen if the straps are broken.

The average mark was a disappointing 1.14/2, an indication that students do not have a complete grasp of the meaning of Newton's Laws when applied to a particular physical situation. Students were usually able to state the first law, gaining 1 mark, but unable to apply it to the case of the surfboard and the roof strap. Another common problem occurred when students tried to 'creatively' use Newton's Third Law. Some students confused the subsequent vertical motion under gravity with the horizontal aspects relevant to the question.

The average mark for Questions 5 and 6 was 2.97/5. However, it was pleasing to note that nearly half of the students scored the full 5 marks for both questions. This indicated that students either fully understood or had very little idea about the horizontal component of projectile motion. It was disappointing to observe that 30% of students scored zero for both questions.

### Question 5

The time for the surfboard to hit the water was calculated using the equations for uniformly accelerated motion, with an acceleration of 9.8 m s$^{-2}$ and an initial velocity in the vertical direction of zero. This resulted in a time of 4.04 s. The most common error was to take the initial velocity in the vertical direction as 10 m s$^{-1}$. Another common error was an answer of 16.3 s, obtained as a result of students omitting to take the square root when applying the correct equation.

### Question 6

To calculate the horizontal distance travelled students needed to be aware that the horizontal component of motion was a constant speed of 10 m s$^{-1}$. This resulted in an answer of 40.4 m. This question was generally well answered.

### Question 7

This question required students to understand that the area under a force-distance graph represented the work done, or the change in kinetic energy of the driver's head. The area under the graph was calculated as 900 J, resulting in a compression distance of 0.15 m (15 cm).

The average mark for this question was a disappointing 1.16/4, with the most common error being to interpret this question as relating to impulse-momentum rather than work-energy. It was clear that students were so used to analysing collisions in terms of impulse-momentum, that this change in emphasis caught them quite unawares. The most common incorrect answer was 0.02 m, which was simply the end point of the scale on the graph. Another incorrect method was to calculate the initial momentum (120 kg m s$^{-1}$) and then treat this as a force. It was disappointing to note that approximately 15% of students showed no working at all, giving only the final answer, which was sometimes correct but often not.

### Question 8

Collision with the hard surface of the steering wheel would result in a shorter compression distance. In order for the area under the graph to remain as 900 J, the retarding force would need to be much larger. Hence, graph A best represents the graph of retarding force versus compression distance.

The average mark for this question was 1.44/2. The most common incorrect response was graph B. It appeared that most of the correct answers were based on choosing the graph with the largest force.

### Question 9

The specific reasons for choosing graph A needed to cover:

- a collision with a harder surface would result in a smaller compression distance
- the area under the graph remains constant (900 J) no matter whether the collision is with the air bag or steering wheel
- hence, the required graph must have a shorter compression distance and a larger force.

Alternatively, students could have addressed this answer via an understanding that harder surfaces are 'stiffer' and have a steeper force-distance graph gradient. The aspect of the area under the graph remaining at 900 J was essential no matter which method students used.

The average mark here was a disappointing 1.04/3, indicating that students found this concept to be quite difficult. Very few students noted that the area under the force-compression graph had to be the same (900 J) as in the original problem. Most students attempted to address this via an impulse-momentum approach, which made it difficult for them to gain full marks.

### Question 10

Students needed to understand that work done equals change in kinetic energy. If a car is travelling at twice the speed then it will have four times the kinetic energy and the brakes will need to do four times as much work in bringing it to rest. Hence, for the same braking force the stopping distance will be about four times as far. Distance C (40 m) was the best estimate of the stopping distance.

The average mark for this question was 1.15/2. The most common incorrect response was A, obtained by students assuming a linear relationship between speed and stopping distance.

The average mark for the combined Questions 11 and 12 was 2.9/5. Thirty per cent of students obtained the full 5 marks for both questions, but it was disappointing to observe that 10% of students scored zero for both questions.

### Question 11

Direct application of Newton's Second Law resulted in an answer for the net force of $2.75 \cdot 10^{3}$ N.

This question was quite well answered, as would be expected for such a fairly straightforward question.

### Question 12

Application of Newton's Second Law for the caravan alone resulted in an answer of $1.125 \cdot 10^{3}$ N for the tension in the coupling. Students needed to be aware that the driving force for the caravan was provided solely by the tension in the coupling.

This question appeared to be the more difficult of the two. Students appeared to understand the concept and scored the full 3 marks, or had little idea. The most common error (one-third of students) was to find the tension by subtracting *ma* for the caravan from *ma* for the car, resulting in an answer of 500 N. Most correct answers involved students treating the caravan alone, rather than the slightly more complicated method of the car alone.

### Question 13

Constant velocity implies a net force of zero. Hence, the driving force must be equal and opposite to the retarding forces, that is, 2400 N.

The average mark of 1.25/2, indicated that about 63% of students understood the concept. Any errors were due to students not realising that constant speed in a straight line implies a net force of zero.

### Question 14

With friction and air resistance forces being ignored, the gain in kinetic energy equals the loss in gravitational potential energy. Thus, when the energy equation was set-up and values for the initial and final speeds substituted, the height was calculated to be 24.3 m.

The average score of 1.35/3 indicated that most students experienced some difficulty with this concept. The most common error was in neglecting Jo's initial kinetic energy. However, most students seemed to be aware that they needed to apply the concept of conservation of mechanical energy. About 15% of students did not attempt this question.

### Question 15

The motion at the instant of point Y can be treated as uniform circular motion. Thus, the net force must be directed towards the centre of the circle, that is, upwards in the direction of arrow C. The net force can be calculated via the equation $F = mv^2/r$ resulting in a value of 2400 N.

The average score for this question was 1.55/3, indicating only a moderate understanding of this concept. The most common errors were in calculating the weight force $mg$ or the weight force less the centripetal force $mg - mv^2/r$. Students need to understand that 'centripetal force' is another name for 'net force'; it is not a force in its own right. Most students were able to choose C as the direction of the net force.

## Area 2 – Gravity

### Question 1

The magnitude of the sun's gravitational field at point P calculates to $1.33 \cdot 10^{-4}$ N kg$^{-1}$. This required a simple substitution into the field strength equation.

With an average score of 1.59/2, most students understood how to calculate the gravitational field strength. The most common error occurred as a result of students neglecting to square the distance; that is, they correctly wrote down the formula and substituted in values, but then forgot to square. It is also worth encouraging students to consider the likeliness of answers (forgetting to square the distance obtained an answer that was too large).

### Question 2

The increase in kinetic energy was determined from the area under the force-distance graph between the distance values of $1.0 \cdot 10^{11}$ m and $3.0 \cdot 10^{11}$ m. This could be achieved by estimating the area by square counting or by a suitable geometric approximation. This resulted in an increase of $7.5 \cdot 10^{20}$ J. (values between $7.0 \cdot 10^{20}$ J and $8.0 \cdot 10^{20}$ J were accepted as reasonable approximations).

The average mark for this question was 1.55/3. The most common method used by students was to count up the squares, although a small number of students used a triangulation method in order to estimate the area under the curve. The most common error was due to incorrect powers of 10, usually arising from the calculation of the area of a single square on the graph.

### Question 3

The parking orbit of Apollo 11 is an example of uniform circular motion in which the net force is provided by the gravitational force between Earth and Apollo 11. This resulted in a speed of $7.8 \cdot 10^{3}$ m s$^{-1}$.

The average mark of 1.76/3 demonstrates that just over 50% students had a reasonable grasp of this concept. In fact, about half of the students scored the full 3 marks for this question, but about 30% scored zero. The most common error was made by students forgetting to add the spacecraft's altitude to the radius of Earth when determining the radius of the orbit. Many students made simple errors when substituting in numerical values or when using their calculator.

### Question 4

In order to address whether Jane or Maria was correct students were expected to discuss the following points:

- a statement of Newton's First Law
- the velocity of Apollo 11 was changing (change in direction), hence it was accelerating
- a net force (gravitational force) was acting on Apollo 11.

The average score here was 1.16/3. It is clear that students are able to recall Newton's Laws but are unable to apply them in a particular physical situation. Very few students discussed the net force acting on Apollo 11 or the fact that it was accelerating.

### Question 5

The origin of the net force needed to support uniform circular motion of Apollo is that of the gravitational attraction exerted by Earth on Apollo 11. Hence, statement D was correct.

The average mark of 0.57/1 was a disappointing result for such a simple question.

### Question 6

Graph C best represents the variation of the net gravitational force acting on Apollo 11. The force decreases according to the inverse square law as Apollo 11 travels away from Earth, reaching zero at a point closer to the Moon. The direction of the force now changes as Apollo 11 experiences a net force directed towards the moon. The magnitude of this net force again increases as Apollo 11 approaches the Moon.

The average mark here was 1.17/2, which was reasonable for what was anticipated to be a more difficult question.

## Area 3 – Structures and materials

The average mark for Questions 1 and 2 was 3.36/5.

### Question 1

The force constant can be calculated from the gradient of the force-compression graph. This resulted in an answer of $2.0 \cdot 10^4$ N m$^{-1}$.

Most students who attempted this question obtained the correct answer.

### Question 2

The area under the graph represents the strain energy stored in the spring, which in this case was 400 J. Inspection of the graph, or use of the spring potential energy relation $\frac{1}{2}kx^2$, resulted in a force of 4000 N.

The most common error was an inability to solve the equation $\frac{1}{2}kx^2 = 400$, either by incorrectly transposing the $\frac{1}{2}$ factor or neglecting to take the square root when calculating the value of $x$.

The average mark for Questions 3 and 4 was a disappointing 1.25/3.

### Question 3

The cross-section of beam A would be most appropriate for this application.

The most common incorrect answer was cross-section B, perhaps indicating that students had certainly seen this shape before.

### Question 4

The reasons for selecting cross-section A should have included some of the following:

- the lower surface of the beam will be under tension
- the upper surface of the beam will be under compression
- cast iron is weaker under tension than under compression
- the beam needs greater strength in the region that it is weakest, that is, on the lower surface
- a larger cross-sectional area in the lower region reduces the stress in the beam in this region
- cross-section A gives strength in the regions where it is most needed, but with least total mass.

Many of the explanations lacked detail or clarity, particularly when discussing the regions of tension or compression. It was also clear that many students could not visualise the beam when it was in use supporting the roadway. That is, they either treated the beam as the roadway itself or treated the beam as an isolated structure. Very few students sketched the bending of a beam, showing tension on the lower surface and compression on the upper.

### Question 5

Students were required to understand that torque can be calculated by use of the equation:

Torque = lever arm x force
$= 35 \cos 30^0 \cdot mg$
$= 107 \cdot 10^3 \cdot 9.8 \cdot 35 \cdot \cos 30^0$
$= 3.2 \cdot 10^7$ N m

The average score of 0.89/3 indicates that most students found the torque concept to be quite difficult. In fact, only 15% of students scored the full 3 marks for this question and just under half of the students scored zero. It has been apparent for a number of years now that torque has been poorly understood and this question simply confirms that view.

Of the 50% of students who had at least an idea that torque was determined by the force and lever arm, there were many errors made. These errors involved the use of sin$30^0$ rather than cos$30^0$, using $60^0$ rather than $30^0$, or simply forgetting about the angle altogether. Other errors included using the mass rather than the weight for the force, forgetting to convert tonnes to kilograms and using the entire length of the beam rather than the distance to the centre of mass.

### Question 6

Students needed to understand that total upward force exerted by the ropes balanced the weight forces of the painter and plank. This resulted in an answer for the weight of the painter of 588 N, corresponding to a mass of 60 kg.

The average score of 1.4/2 indicates that students found this to be reasonably straightforward. Most students seemed clear that they needed to equate forces to give a net force of zero. The most common error was in neglecting to convert a weight force of 588 N into a mass of 60 kg.

### Question 7

Students were required to equate clockwise and anticlockwise torques about the point P. This resulted in an answer of 2.5 m for the painter's distance from point P.

The average score of 1.62/4 demonstrates that, students were not at all confident about questions that require an understanding of torques as part of the solution process. Over half of the students scored zero for this question, yet about 30% of students scored the full 4 marks, with very few students able to score part marks. Students were either absolutely clear about this concept, or had little grasp of it.

### Question 8

Toughness refers to the strain energy per unit volume stored in the material. This is related to the area under the stress-strain graph. The graph for material B has a greater area and hence it is tougher than material A.

The average score for this question was 1.47/2 indicating a reasonable degree of understanding of this concept. The main issue with this question was due to students giving explanations that were not specific enough or which were ambiguous. Some students gave explanations that mixed up the concepts of toughness, elasticity, stress, strain and stiffness.

### Question 9

Brittle materials fracture close to their elastic limit or have a smaller plastic region. Inspection of the respective graphs reveals that material A is the more brittle.

The average mark of 1.57/2 demonstrates that over 75% of students clearly understood the concept of a brittle material.

### Question 10

Students needed, first to determine the stress in each material for a strain of 0.002. This was determined to be $160 \cdot 10^6$ N m$^{-2}$ and $40 \cdot 10^6$ N m$^{-2}$ respectively. The next step was to interpret stress in terms of force/area, for the case of a common force. This finally resulted in an answer for the area ratio of $\frac{1}{4}$ or 0.25.

The average mark of 0.95/3 provides clear evidence that this was a moderately difficult question. While 23% of students were able to answer this question correctly, over half of the candidates scored zero for this question. Some students derived the ratio by calculating Young's Modulus as the gradient of the stress-strain graph, leading to an answer of 0.286; this answer was marked as correct. It was also disappointing to observe that a number of students had difficulty obtaining values from the graph.

## Area 4 – Ideas about light and matter

The average mark for Questions 1 and 2 was 2.7/4, indicating that most students had a clear understanding of both charged parallel plates and the work done on a charged particle in an electric field.

### Question 1

The electric field between two parallel plates can be calculated directly by substitution into the equation $E = V/d$. This resulted in an answer of $3.3 \cdot 10^{6}$ V m$^{-1}$.

This question was generally well done with the main error being due to a failure to convert mm to m.

### Question 2

The work done on the electron was $1.6 \cdot 10^{-15}$ J.

This question was not as well done as Question 1, although all it required was a simple application of a formula provided in the data sheet. The most common error was to try to use the value of the electric field calculated in the previous question as though it provided some form of hint as to how to proceed. Some students used a work-energy approach based on $W = qEd$, which was quite reasonable, if a touch more cumbersome.

### Question 3

The energy of a photon of 450 nm light is 2.76 eV.

The average mark for this question was 1.82/3. The main error was a failure to convert nm to m when using the wavelength in the formula for photon energy.

The average mark for both Questions 4 and 5 was a disappointing 1.37/5, indicating that students had a poor understanding of the photoelectric effect, particularly in regard to the concept of work function. In fact, only 10% of students were able to score the full 5 marks for both questions.

### Question 4

In order to explain the meaning of the term 'work function' students needed to describe it as the energy required to remove a surface electron or the minimum energy to eject an electron from the metal.

This question was not well done and about half of the students scored zero. The most common problems involved a discussion of ionisation or general and rambling explanations involving threshold frequency intercepts on a graph.

### Question 5

In order to calculate the work function for potassium, students needed to apply the Einstein equation $E_{Kmax} = hf - W$, where $W = 0.47$ eV as obtained from the graph in Figure 3. This resulted in an answer of 2.29 eV for the work function.

This was not well done, with most students scoring zero. A few students realised that they needed to use the value of 0.47 eV in some way, but could not proceed from there. Quite a number of students experienced problems with powers of 10, usually due to confusing the units of J and eV within the same equation.

### Question 6

When the wavelength is doubled, the energy of each photon is halved. At the original wavelength of 450 nm the photon energy was 2.76 eV. Thus, for a wavelength of 900 nm, each photon will have an energy of 1.38 eV. This value is now less than that of the work function (2.29 eV) and hence, no electrons will be ejected and no current will flow. Graph B was clearly the best correct answer.

As indicated by the average score of 0.2/2, this proved to be a difficult and demanding question. The most common incorrect answer was graph D, at least indicating that students were aware that the incident photon energy was less than in the original situation.

### Question 7

In order to explain the pattern of rings on the photographic film students should have addressed the following points:

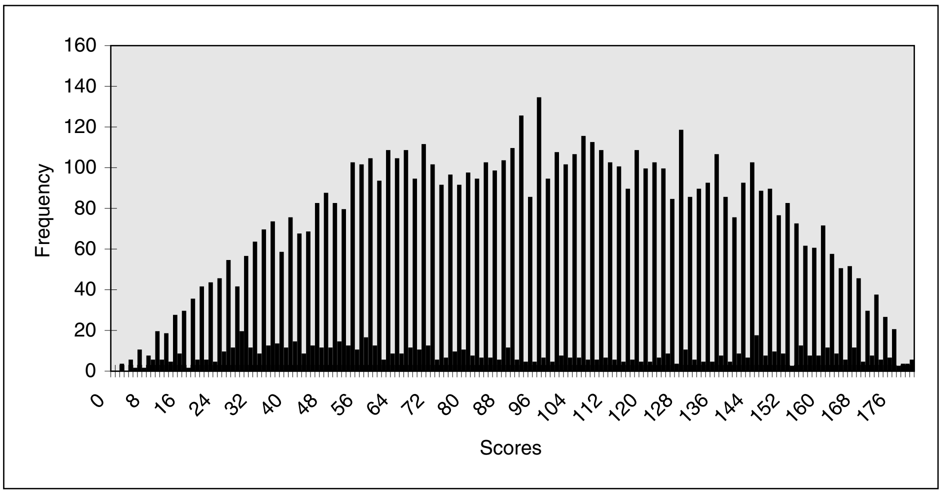
- the ring pattern was an interference/diffraction pattern formed by the X-rays passing through the metal
- the rings themselves represented positions of constructive interference
- the interference pattern occurs because the metal foil atoms/crystal planes act like a set of sources and a path difference results for the different scattered waves
- the pattern occurs because the wavelength of the X-rays is similar to that of the atomic spacing of the metal crystal.

The average mark for this final question on the paper was 0.8/2, with only 23% of students scoring the full 2 marks, with a further 43% scoring zero. A number of students recognised this as a diffraction phenomenon, but did not explain much more than this. Very few students discussed the atoms or crystal planes as scattering sites. Quite a few discussed the ratio of wavelength to gap size, but did not relate it to the context in which the question was asked.

GA PH033 PHYSICS WRITTEN EXAMINATION 2

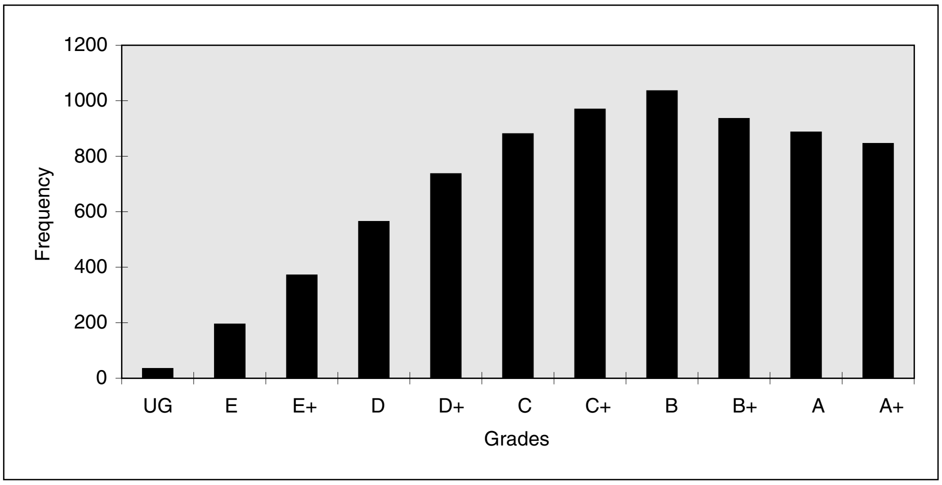
HISTOGRAM OF TOTAL SCORES 2000

Count 7427 Mean 94.24 Standard Deviation 42.08 NA Result 237



HISTOGRAM OF TOTAL GRADES 2000

Count 7427 Mean 6.30 Standard Deviation 2.50 NA Result 237



| ENROLMENTS | | % |
|---|---|---|
| Female | 1986 | 25.9 |
| Male | 5678 | 74.1 |
| Total | 7664 | |

## GLOSSARY OF TERMS

| | |
|---|---|
| **Count** | Number of students undertaking the assessment. This excludes those for whom NA was the result. |
| **Mean** | This is the 'average' score; that is all scores totalled then divided by the 'Count'. |
| **Standard Deviation** | This is a measure of how widely values are dispersed from the average value (the mean). |