Physics GA 3: Written examination 2

GENERAL COMMENTS

The examination provided a fair and reliable test of the material studied in Unit 4, with both students and teachers alike being positive about the style, depth and quality of the questions. The examination was clearly accessible to most students as evidenced by the mark distribution, with four students able to score the full 90 available marks. The mean score was 44/90 (49%).

The quality of the upper band of student responses was particularly impressive. The most successful students are graduating with not only a good understanding of physics concepts, but with the ability to express these ideas via explanations, diagrams and numerical calculations. The cut-off score for a grade of A+ was $\frac{75}{90}$, compared with $\frac{80}{90}$ in 2001, $\frac{75}{90}$ in 2000 and $\frac{82}{90}$ in 1999. While this indicates an examination that could be described as being on the more difficult end of the scale, it was one which provided good discrimination for the upper band of students.

Clearly some students spent more time than anticipated on the more difficult calculations for the Gravity and ***Structures and materials*** sections of the paper and so were pushed for time when attempting the final section of the examination.

A few concerns to note:

- using radian mode on calculators rather than degree mode for calculations involving angles in degrees. This was much less of a problem in 2002 compared with 2001 and so teachers have been successful in their efforts to advise students on this point.
- problems evaluating some of the more complex calculations needed in the ***Gravity*** and ***Structures and materials*** sections of the examination. Many students do not understand the use of brackets or the order of multiplication and division operations when entering numerical data into their calculators.
- the use of SI units is an issue with students forgetting to convert cm or km into m, or tonnes into kilograms
- neglecting to show working when it is asked for; part marks are awarded where possible for such working
- written explanations which are often of poor quality, or simply lacking sufficient detail in cases where two or more marks are to be awarded
- not answering the specific question asked but rather giving a broad explanation; perhaps grasping at pre-prepared material from the A4 sheet brought into the examination; particularly evident on the question about weightlessness and in the students' approach to describing the stresses on a beam that bends
- difficulty in using the A4 sheet as a resource – teachers need to emphasise the value of preparing the A4 sheet, particularly in the early stages of revising for the examination, rather than for direct application.

SPECIFIC INFORMATION

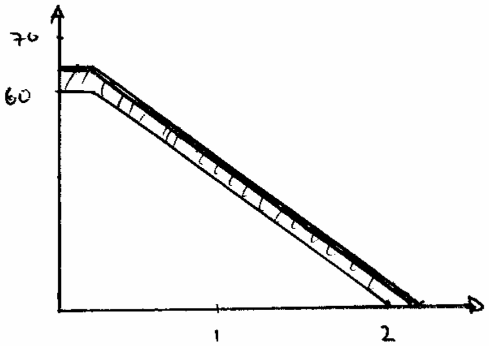
Area 1 – Motion

Question	Marks	%	Response
Questions 1 and 2	0/4 1/4 2/4 3/4 4/4 (Average mark 2.45)	20 4 27 9 40	**Question 1** This question was an example of uniformly accelerated motion and application of the equation $s = ut + \frac{1}{2} at^2$ resulted in an answer of 2.2 m s^{-2}. The most common error, committed by a large number of students, was to start by calculating the average speed via $\frac{400}{19}$ = 21.05 m s^{-1} and then calculate the acceleration as $\frac{21.05}{19}$ = 1.1 m s^{-2}. **Question 2** This question could be solved in a number of ways. The most common, and longest, method was to find the distance and time for each of the accelerating and braking phases and then divide the total distance by the total time for the average speed. A simpler method was to realise that the average speed for both sections (accelerating and braking) was the same and hence all one had to do was find the final speed for the accelerating section (42.1 m s^{-1}) and then halve it – giving an answer of 21 m s^{-1} for the average speed. Very few students recognised the symmetry of the uniform acceleration and braking sections and so took longer than anticipated in solving this question. A number of students chose 21.1 m s^{-1} as the maximum speed rather than 42.2 m s^{-1}. This reinforced the fact that many students are

			unable to distinguish between average and instantaneous velocity. Another common error was to assume that the braking time was the same as the accelerating time of 19 s.
Question 3	0/2 1/2 2/2 (Average mark 1.4)	30 0 70	Graph B best represented the velocity-time graph for the car for the entire journey. It showed a uniform increase in speed when accelerating and a uniform decrease in speed when braking. The most common incorrect response was to choose graph D.
Question 4	0/2 1/2 2/2 (Average mark 0.9)	55 0 45	Graph E best represented the distance-time graph for the car for the entire journey. There was a disappointing rate of correct responses for such a straightforward question. The most common incorrect response was to choose graph C or F.
Question 5	0/3 1/3 2/3 3/3 (Average mark 1.4)	49 3 5 43	This was an example of projectile motion. Students needed to separate the motion into two parts. The vertical motion represented vertical motion under gravity for an initial speed of zero. Hence, the time of fall was calculated to be 0.9035 s. The horizontal motion was then treated as motion at constant velocity for a time of 0.9035 s and a horizontal distance of 20 m. Hence, a minimum speed of 22 m s^{-1} was required for the car to land in building 2. The most common incorrect responses were to choose an initial speed of 22 m s^{-1}, rather than zero, for the motion in the vertical direction or to make a simple arithmetic error at some stage of the calculation.
Questions 6 and 7	0/4 1/4 2/4 3/4 4/4 (Average mark 2.17)	24 7 30 7 32	**Question 6** This question could be solved by at least two different methods. The first, and most common, method was to treat the motion in two parts and to calculate the vertical and horizontal components of the final velocity. The vertical component was calculated to be 8.85 m s^{-1} and the horizontal was given in the stem as 25 m s^{-1}. The vector addition of these components resulted in a velocity of magnitude 26.5 m s^{-1}. An alternative method was to apply a conservation of energy approach, relating the gain in kinetic energy to the loss in potential energy via the equation $\frac{1}{2}m \times 25^2 + m \times 9.8 \times 4 = \frac{1}{2}mv^2$. This resulted in the answer $\boldsymbol{v}$ = 26.5 m s^{-1}. Most students chose to answer using the vector method rather than the conservation of energy approach. A number of students did not recognise the vector nature of velocity and it was disappointing that many attempted to solve the problem by the use of the equation $v^2 = u^2 + 2as$. This showed a serious misunderstanding of the application of this equation. **Question 7** Application of the impulse-momentum equation $\Delta t = \Delta p$ resulted in an average force of 1.4 x 10^5 N. Many students did well on this question even those who struggled on previous questions. Clearly, students are quite confident about applying the impulse-momentum equation for a simple collision.
Question 8	0/3 1/3 2/3 3/3 (Average mark 1.4)	34 15 27 24	The explanation of how the crumple zone can minimise the extent of injuries experienced by the occupants could have been addressed by either an impulse-momentum or a work-energy approach. Students needed to address the following points in order to score marks: • the crumple zone extends either the time or distance of the collision • the change in momentum or the change in kinetic energy is a ‘fixed’ quantity for the collision. Each quantity depends only on the initial and final velocities • longer collision time/distance results in smaller force on the occupants and hence minimises the extent of injuries they may experience. Students were generally clear about the fact that the crumple zone increased the time or distance for the collision and this resulted in a lower force on the occupants. However, many students were unable to describe

			the fact that the change in momentum or kinetic energy was a 'constant' and how this was necessary for an understanding of the relationship between force and time or distance.
Questions 9 and 10	0/4 1/4 2/4 3/4 4/4 (Average mark 2.49)	21 3 25 7 44	**Question 9** Application of the equation for conservation of momentum resulted in a final speed for the joined trucks of 4.0 m s^{-1}. Most students were comfortable with this question and answered correctly. Some errors were made by students attempting to solve the problem using conservation of kinetic energy or by neglecting to consider the combined mass of the railway trucks. **Question 10** Students needed to realise that the impulse truck Y exerts on truck X equals the change in momentum of truck X. The change in momentum of truck X was then calculated to be $10 \times 10^3 \times 6.0 - 10 \times 10^3 \times 4.0 = 2.0 \times 10^4$ N s. A slightly easier method was to realise that the impulse exerted on truck X was equal and opposite to that exerted on truck Y, the change in momentum of truck Y being simpler to calculate. Students seemed to have a reasonable understanding of this question. Some common errors were: • students seemed to think Impulse = Δp applied to change in momentum for the whole system, which gave an answer of zero (i.e. they calculated $p_{final} - p_{initial} = 60\ 000 - 60\ 000 = 0$ Ns) Teachers need to emphasise that impulse is always the momentum transferred from one body to another or the change in momentum of one object not the whole system. • students confused p_{final} with Δp, calculating 15 000 x 4 = 60 000 N s or confused $p_{initial}$ with Δp $\therefore$ calculating 10 000 x 6 = 60 000 N s • students calculated total mass instead of mass on one truck only, $(m_1+m_2)\Delta v = 15\ 000 \times 2 = 30\ 000$ N s, or even used the difference in masses, $(m_2 - m_1)\ \Delta v = 5000 \times 2 = 10\ 000$ N s. (These students may have subtracted masses from the RHS in Question 9; they actually had the wrong formula written on their A4 sheets) • students correctly tried to find the change in momentum of one truck only, but used the mass of one truck multiplied by the change in velocity of the other truck (i.e. 5000 x 2 = 10 000 N s or 10 000 x 4 = 40 000 N s) • students used mg instead of just 'm' for the mass. By far the most common error was in neglecting to change the masses from tonnes to kilograms.
Question 11	0/3 1/3 2/3 3/3 (Average mark 1.5)	44 5 7 44	Students needed to understand that the definition of an inelastic collision related to the non-conservation of kinetic energy for the system. This needed to be supported by specific calculations showing: • initial kinetic energy = 1.8×10^5 J • final kinetic energy = 1.2×10^5 J. Hence, the final kinetic energy was less than the initial kinetic energy and so the collision was inelastic. Students had an understanding of the concept of an inelastic collision but many were unable to answer in sufficient detail. In particular, some common errors were: • using conservation of momentum and incorrectly stating that it was an inelastic collision because $p_{final} = p_{initial}$ • calculating the total change in momentum incorrectly and stating that some momentum was lost • not addressing the question and not doing any calculations, but simply stating that 'momentum was conserved but some kinetic energy was transformed into heat, sound etc.', or 'it was a sticky

		collision which is inelastic because the trucks didn't bounce off one another', or 'it was an inelastic collision because velocity decreased' • confusing energy with velocity, for example, by stating that energy lost was 2 m s^{-1} • forgetting to convert tonnes into kilograms when calculating the initial and final kinetic energies.
Question 12	0/2 18 1/2 4 2/2 78 (Average mark 1.6)	Application of one of the equations for uniformly accelerated motion ($F = mv^2/r$) resulted in a net force of 1.125 N. There was a sound understanding of the equation for uniform circular motion. The main error was of an arithmetic nature; simply forgetting to square v when evaluating the equation.
Question 13	0/2 66 1/2 0 2/2 34 (Average mark 0.67)	Explanation B, stating that the track exerts a force in the direction ~~on~~ → the flange of wheel P, provided the best explanation of the force exerted on the wheels of the engine to round the curve. This was a demanding question with the most common incorrect response being F. Clearly students understood that the net force must be towards the centre of the circle, but did not understand the method by which vehicles corner on flat rails, as specifically mentioned in the study design. (Note: although girls performed better on the examination than boys, this was one question in which boys did better than girls).
Question 14	0/3 42 1/3 23 2/3 20 3/3 15 (Average mark 1.07)	The cyclist pushes against the pedals that results in the chain rotating the rear wheel in a clockwise direction. Hence, the rear wheel tends to rotate backwards relative to the ground and as a result of friction will push backwards against the ground. According to Newton's Third Law the ground pushes in the opposite direction (forwards) on the tyre and this results in a net force forwards on the bicycle to accelerate it forwards. Students needed to address the following key points: • the rear wheel rotates in a clockwise direction • friction between the tyre and road surfaces results in the tyre pushing backwards against the road surface • the road surface exerts an equal and opposite force, that is forwards, on the tyre • there is a net force forwards on the bicycle and so it accelerates forwards A force diagram was required, clearly showing a frictional force acting forwards on the rear tyre surface in contact with the road. This proved to be a demanding question and that the role of friction as a driving force is not well understood. The force diagram was poorly done. Often students showed friction acting both forwards and backwards and it was certainly clear that the concept of a free-body force diagram was not at all well understood, e.g. 'when the rider presses on the petals (sic) he causes a chain reaction'.

Question 15	0/2 1/2 2/2 (Average mark 1.65)	8 19 74	A graph starting with a speed of 65 km h^{-1}, showing the same reaction time of 0.2 s and the same gradient was required.  Students had a clear understanding of this concept. The most common error was to show a reaction time of greater than 0.2 s, indicating confusion between reaction time and reaction distance. Some students incorrectly drew a smaller gradient for the faster car, suggesting that they thought that a faster car would be harder to stop.
Question 16	0/2 1/2 2/2 (Average mark 0.92)	47 13 40	The stopping distance could have been determined by calculating the difference between the areas under the two graphs (see the shaded area in the graph of Question 15). This question was not done well. One major error was to consider the area difference for the section after the reaction time rather than the total area difference. Some students attempted to calculate the separate stopping distances even though such a calculation was not required.

Area 2 – Gravity

Question	Marks	%	Response
Question 1	0/3 1/3 2/3 3/3 (Average mark 1.58)	38 7 13 42	The required launch energy was calculated by determining the total area under the graph. Square counting resulted in approximately 13 squares, with each square representing a work done of 3 x 10^9 J. Hence, the total energy required was 13 x 3 x 10^9 = 3.9 x 10^{10} J. Allowing for a variation in the number of squares counted, a range of values 3.3 to 4.4 x 10^{10} J, was accepted. Most students recognised that the area under the graph was the key to answering this question. The most common error was incorrectly calculating the area of each square on the graph, usually by neglecting the 10^6 for the height axis. Others made an error in their estimation of the number of squares, usually in counting too few squares. Area estimation may need reviewing for some students. Some students lost a mark due to multiplying their calculated area by 700 kg, obviously being confused between force and field. It should be noted that the study design specifically mentions that it is force-distance graphs only that are to be examined in this context.
Question 2	0/2 1/2 2/2 (Average mark 0.71)	58 12 29	True weightlessness occurs when the total gravitational force on the object is zero. There was some confusion between the concepts of weightlessness and apparent weightlessness. In fact, nearly half the students incorrectly gave an answer based on ‘freefall’, apparent weightlessness or that the normal reaction force was zero. Many students gave an answer that stated ***g* = *0***, but then went on to say that this meant that the normal reaction was zero and so it represented apparent weightlessness.
Question 3	0/4 1/4 2/4 3/4 4/4 (Average mark 2.05)	29 12 14 12 32	The expected answer for this question involved subtracting the gravitational field due to Saturn from that due to Jupiter according to the equation. This resulted in a value for the gravitational field strength of 4.7 x 10^{-7} N kg^{-1} $g = GM_J/R_J^2 – GM_S/R_S^2$. It was not expected that students would include the gravitational field of the sun even though this turns out to be significantly greater at about 2 x 10^{-4} N kg^{-1} at this point

			(students who did include the effect of the sun were fully rewarded). The most common error was to calculate the field values and then add them rather than subtract. Another common error, becoming quite frequent in the past few years, is to neglect to square the radius value in the calculation. A number of students made arithmetic errors at some stage of the calculation.
Questions 4 and 5	0/2 1/2 2/2 (Average mark 1.18)	22 37 41	**Question 4** Students were expected to show an arrow in the direction ⟶ at the position Cassini. A common error was to draw two arrows, a small one to the left and a larger one to the right. **Question 5** To remain above the same point on Saturn's equator the satellite would be required to have a period of 10.7 hours, or 3.85 x 10^4 s. The main difficulties were to either assume a 24-hour day or to make an arithmetic error in the calculation.
Question 6	0/3 1/3 2/3 3/3 (Average mark 1.23)	49 9 11 31	Application of Newton's Law of Universal Gravitation for the force between two masses along with the relation for uniform circulation motion resulted in the equation: $GMm/R^2 = m4\pi^2R/T^2$ Substitution of the appropriate values resulted in a radius of 1.1 x 10^8 m for the stationary orbit. Many students experienced difficulty with the concept of a stationary orbit. Others had difficulty getting started, often starting with Newton's Law of Universal Gravitation but were unable to combine this with the circular motion equation involving the period. Students are more comfortable with the relation mv^2/R but not so familiar with $m4\pi^2R/T^2$. For those who could successfully write down and substitute into the formula, many made arithmetic errors. The final stage of taking the cube root to find R was very poorly done.

Area 3 – Structures and materials

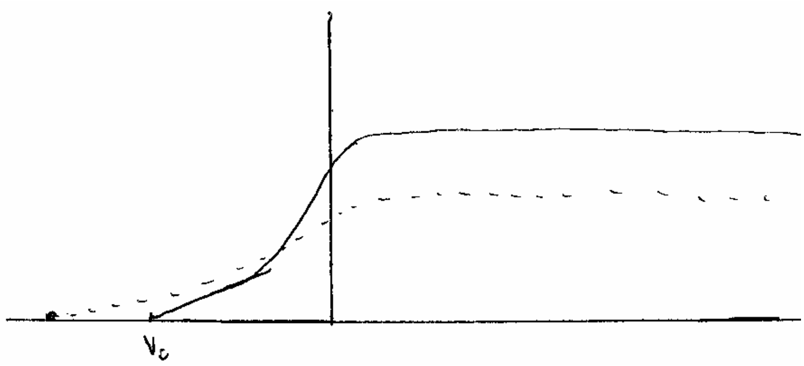
Question	Marks	%	Response
Question 1	0/3 1/3 2/3 3/3 (Average mark 1.4)	28 28 18 26	The vertical component of one wire was 5000 cos30^0 = 4330 N. Hence, the combined vertical component of the three wires was 1.3 x 10^4 N. The total downward force exerted on the radio mast will be due to the three wires plus the weight of the mast, that is: 1.3 x 10^4 N + 1.96 x 10^4 N = 3.3 x 10^4 N. The upthrust force by the ground on the mast must be equal and opposite the total downward force by the mast on the ground and so also has a magnitude of 3.3 x 10^4 N. Generally, students had an understanding of the concept being tested, but often made errors or omissions. Many simply calculated the weight of the radio mast only, others forgot to convert the mass of the mast into a weight in newtons, some assumed that there must be one or four wires rather than three and others confused sine and cosine when calculating the vertical component. While not as common as last year, some students forgot to change their calculator out of radian mode.
Question 2	0/3 1/3 2/3 3/3 (Average mark 1.53)	20 33 21 26	Stress = Force/Area = $5000/\pi x 0.005^2$ = 6.4 x 10^7 Pa. Most students understood that they had to calculate Force/Area. The most common errors were in forgetting to change the radius of the wire into metres or in using the diameter rather than the radius. Some students used the vertical component of the tension in the wire rather than the actual tension of 5000 N.
Question 3	0/4 1/4 2/4 3/4 4/4 (Average mark 2.12)	35 9 7 8 42	Students needed to set up a torque equation for a net torque of zero. For example, taking torques about the right-hand bridge support resulted in the torque equation: $N_1 \times 30 = 20 \times 10^3 \times 9.8 \times 15 + 6 \times 10^3 \times 9.8 \times 10$ and so N_1 = 1.2 x 10^5 N Similarly, taking torques about the left-hand bridge support resulted in N_2 = 1.4 x 10^5 N.

			There was improvement on previous years with this sort of question and the understanding of torques is improving. The main problem is that student working is often very difficult to follow. Students are encouraged to show neat and clear setting out of their work. A number of students neglected to change tonnes into kilograms or to change mass into a weight force so as to calculate the normal reactions in newtons.
Question 4	0/3 1/3 2/3 3/3 (Average mark 2.01)	18 13 17 51	When heavy vehicles cross the bridge it will bend in such a way as to have the lower surface in tension and the upper surface in compression. Because concrete is weak under tension then the bridge will need to be reinforced on the lower surface by a material that is strong under tension, for example steel. An alternative method would be to have supporting cables or superstructure to the bridge that will prevent it from bending in the first place. The concept of stresses on a bent beam and the properties of concrete were quite well understood by most students. Some answers lacked sufficient detail to score full marks. Very few students suggested design improvements that reduced the amount of bending in the first instance.
Question 5	0/3 1/3 2/3 3/3 (Average mark 1.38)	39 8 27 26	Reading from the graph it could be seen that a stress of 35 MPa for structural steel corresponds to a strain of 0.1%. Hence, the rod will extend by 0.1% of 3.0 m, that is $3\times10^{-3}m$ or $0.003m$. Most students knew how to get started and the most common problem was in forgetting to change the strain from a % to a decimal fraction.
Question 6	0/3 1/3 2/3 3/3 (Average mark 1.45)	31 21 20 28	Direct comparison from the graph showed that rail steel is indeed stronger (yield 45.7 MPa compared with 26.7 MPa; and fracture of 67 MPa compared with 36 MPa). It is also stiffer, as can be seen by comparison of the gradients (Young's Modulus) for the separate graphs – the rail steel gradient is steeper and hence it must be a stiffer material than structural steel. The concepts of strength and stiffness seemed reasonably clear to students and the main problem encountered was omitting the reasons for the manufacturer's claims. Few students were prepared to support their answers by specifically referring to values from the graphs. Some students simply referred to Young's Modulus when discussing stiffness and they failed to relate this to the gradient of the stress-strain graph.
Question 7	0/3 1/3 2/3 3/3 (Average mark 1.73)	34 8 9 49	Students were expected to realise that toughness was related to the total area under the stress-strain graph. Comparison of the two areas suggests that the area under the structural steel graph is somewhere about 30% to 50% larger than rail steel and so structural steel was tougher than rail steel. Most students were aware that toughness is related to the area under the stress-strain graph and answered that structural steel was tougher than rail steel. The main problem was that they did not specifically refer to the separate areas under the graphs and made general comments about toughness rather than comparing the separate areas in an approximate manner so as to justify their answer. The question specifically asked students to refer to the graph.

Area 4 – Ideas about light and matter

Questions 1 and 2	0/4 1/4 2/4 3/4 4/4 (Average mark 1.76)	34 7 32 3 24	**Question 1** The wavelength of 70 keV X-rays was to be calculated via the equation: $E = hc/\lambda$ Substitution of the relevant values resulted in a wavelength of 1.77×10^{-11} m. Most students understood they needed to use the equation to calculate the wavelength, but a number got lost in the algebraic manipulations or the arithmetic. Others forgot to convert keV into eV and hence were out by a factor of 10^3. **Question 2** Students were meant to observe that the separation of lines for the

			electron and X-ray patterns were the same and so their wavelength must also be the same. This implied that students were expected to understand that the separation of lines in an interference pattern was directly proportional to wavelength. Hence, the de Broglie wavelength of the electrons must also be 1.77 x 10^{-11} m. This question was poorly done and few students answered correctly. Many did not understand that the similar spacing of the diffraction patterns implied a similar wavelength. Others calculated a de Broglie wavelength using an electron speed of 3 x 10^{8} m s^{-1}.
Question 3	0/4 1/4 2/4 3/4 4/4 (Average mark 0.64)	79 3 3 3 12	The calculation for the kinetic energy followed: 1. Calculate the momentum of the electrons from their de Broglie wavelength as determined in the previous question. (resulting in a momentum of 3.7 x 10^{-23} kg m s^{-1}). 2. Calculate the kinetic energy of the electrons via application of the formula $E_K = p^2/2m_e$. (resulting in a kinetic energy of 7.7 x 10^{-16} J). 3. Convert the kinetic energy from J into eV. 7.7 x 10^{-16} J converts to 4800 eV and hence the expected answer was 4.8 keV. The most demanding question on the examination and most students did not understand the required concept. This probably followed on in part from the difficulty they experienced with the previous question. Students tended to choose the electron speed as the speed of light, probably because they did not understand the relationship between de Broglie wavelength and momentum for the electron. Very few students really knew how to proceed.
Question 4	0/2 1/2 2/2 (Average mark 1.18)	41 0 59	Statement B best explained why it was possible to compare X-ray and electron diffraction patterns. Diffraction represents a wave phenomenon and so it can only be explained for electrons if they can be considered to have wave properties. Statement A, that X-rays exhibit particle-like properties was the most common incorrect answer.
Question 5	0/3 1/3 2/3 3/3 (Average mark 0.89)	44 32 16 9	Students were expected to answer along the lines: • Pat was correct – a white band was expected in the centre • the light bands on the screen represent places of constructive interference • the position of the bands of an interference pattern is directly related to wavelength • the central band corresponds to a path difference of zero and hence is independent of the wavelength. This means that the central band is a maximum for all wavelengths and so will be white. Students found this to be quite a demanding question, and were evenly split about whether Pat or Robyn was correct. Those choosing Pat usually mentioned constructive interference, antinode, a path difference of nλ or crest meeting crest. However, very few students mentioned a path difference of zero for the central band and that it was therefore independent of wavelength. Many students mentioned that a white band represented the overlap of all the different colours/wavelengths.
Question 6	0/3 1/3 2/3 3/3 (Average mark 0.77)	67 8 6 19	Students experienced difficulty with this question and the concepts that it was testing. Many students did not attempt this question, possibly due to running out of time towards the end of the examination. The major problem was in interpreting the threshold frequency in terms of the work function. Some students gave an answer corresponding to 2.59 eV, which is the energy of a blue light photon or 2.28 eV, the value of the work function. Application of Einstein's equation $E_{Kmax} = hf - W$ results in a maximum kinetic energy for the photoelectrons of 0.31 eV. This corresponds to a cut-off potential of 0.31 V.

Question 7	0/2 1/2 2/2 (Average mark 0.92)	32 43 24	The expected curve needed to be of the form shown below.  Most students sketched a curve with a lower maximum current as expected, but not many showed the cut-off potential to the left of V_0.