2004 Physics GA 3: Written examination 2

GENERAL COMMENTS

The examiners and assessors felt that this examination provided a fair and reliable test of the material studied in Unit 4. The response from both students and teachers was quite positive, and the context, style, depth and quality of the questions were deemed to be both relevant and suitable. The examination was clearly accessible to the majority of students, as evidenced from the mark distribution. A 90-mark scale was used, and it was pleasing to note that six students scored the full 90 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 and assessors found these papers a delight to mark. It is very clear that many of our physics students graduate with not only a good understanding of physics concepts, but with the ability to express these ideas via explanations, diagrams and numerical calculations. This examination again proved to be one that, although accessible, provided reasonable discrimination across all of the grading scale.

Some concerns to note:

- students continued to use the radian mode of their calculator rather than degree mode for calculations involving angles in degrees. This is despite repeated warnings to both teachers and students to check this aspect after graphics calculators have been cleared
- students still experienced problems when using their calculators to evaluate some of the more complex calculations. Many students did not seem to understand the use of brackets or the order of multiplication and division operations when entering numerical data into their calculators
- students still sometimes forgot to convert centimetres or kilometres into metres, or forgot to convert tonnes into kilograms
- students often neglected to show working when part marks may have been awarded and/or when specifically required
- written explanations often lacked sufficient detail, especially in cases where two or more marks were to be awarded
- free-body force diagrams were often poorly drawn, with forces and their point of application clearly not well understood. This point was well illustrated in the poor quality of answers to the questions involving friction as a driving and braking force
- the concepts of weightlessness and gravitational forces confused many students
- the setting out and working shown for the torque problems in the ‘Structures and materials’ section was frequently of poor quality. Students should be encouraged to indicate the points about which they are taking torques.

SPECIFIC COMMENTS

Area 1 – Motion

Question 1

Marks	0	1	2	Average
%	32	3	65	1.4

The speed on the straight road was constant, so there was zero acceleration. Hence, the net force on the system was zero. To achieve a net force of zero, the driving force must balance out the retarding forces of 1400 N and 1200 N respectively. Hence, the driving force was calculated as 2600 N.

The average score indicates this was a reasonably straightforward question to start off the examination. The only mistakes involved students either adding the weight force to the resistance force or treating the case of zero acceleration as zero driving force.

Question 2

Marks	0	1	2	3	Average
%	21	9	8	62	**2.2**

The distance was calculated by substituting into one of the equations for uniform acceleration ($v^2 = u^2 + 2as$). However, before substituting it was necessary to convert the initial and final speeds from the unit of km h^{-1} into the unit of m s^{-1}. This calculation resulted in a distance of 208 m.

The average score indicates that this was another straightforward question following on from Question 1. The most common errors were omitting to convert the unit km h^{-1} into m s^{-1} or incorrectly carrying out this conversion.

Question 3

Marks	0	1	2	3	Average
%	59	6	2	33	**1.1**

The simplest method for calculating the tension in the coupling was to consider the forces on the trailer alone. The tension in the coupling provided the driving force for accelerating the trailer. Application of Newton's 2nd Law resulted in the equation $T - 1200 = ma$. Substitution for the mass (1200 kg) and acceleration (1.20 m s^{-2}) resulted in a tension of 2640 N.

The average score for Question 3 indicates that this was a fairly difficult question. In fact, almost 60% of students scored zero for this question, a most disappointing response for what should have been a fairly standard physics concept. Most incorrect answers were related to students not considering the forces on the trailer alone. It was quite apparent that students were not at all sure about the application of Newton's Laws to combinations of two (or more) masses.

Question 4

Marks	0	1	2	3	Average
%	44	3	3	50	**1.7**

This question could be addressed by either impulse-momentum or work-energy. The fact that the crumple distance was stated in the question meant that the work-energy approach was simpler. Substitution into the work-energy equation $Fd = \Delta E_K = ½\ mv^2 - ½\ mu^2$ resulted in an average force of 4.0×10^5 N.

The average score for this question indicates that a slight majority of the students understood the concept of work-energy. What was of concern though, was that approximately 40% of students scored zero for this question. It seemed clear that students were familiar with treating collisions from an impulse-momentum approach but less so with the work-energy method. It was also of concern to note that a number of students divided their final answer by two when determining the average.

Question 5

Marks	0	1	2	Average
%	33	3	63	**1.4**

The impact time could be calculated by two methods. The first was to apply the impulse-momentum equation using the average force calculated in Question 4. The second approach was to apply one of the equations of uniformly accelerated motion ($s = ½\ (u + v)t$). Either method resulted in an impact time of 0.06 s.

The average score for Question 5 indicates that a majority of students understood the method of solution. The most common method was to solve the question using the impulse-momentum approach.

Question 6

Marks	0	1	2	3	Average
%	30	27	31	12	**1.3**

This question required students to cover the following key points in order to score the three marks:

- the initial momentum of the van was 24 000 kg m s^{-1} south. The final momentum of the van was zero
- the change in momentum of the van was 24 000 kg m s^{-1} north
- momentum can only have been conserved if the system of the power pole and Earth gains a momentum of 24 000 kg m s^{-1} south.

The average score demonstrates that students did not have a thorough understanding of conservation of momentum in relation to collisions involving transfer of momentum to the earth. Most students were able to correctly calculate the initial and final momenta, and many had an understanding that momentum was transferred to the earth in this situation. However, the concept of momentum as a vector concept was not well understood. In particular, the direction of the change in momentum of the van was rarely addressed in answers to this question.

Question 7

Marks	0	1	2	3	4	Average
%	56	6	5	4	29	**1.5**

The motion of the motorcycle and rider could be treated as an example of projectile motion at a projection angle of 20^o. The solution required students to separate the motion into horizontal (constant velocity) and vertical (constant acceleration of *g*) components. Combining the equations for both components resulted in a minimum speed of 12.35 m s^{-1} needed to safely cross the gap.

The average score for Question 7 indicates that many students found this question to be quite difficult. It was interesting to note that a number of students solved the problem using the range formula. Even though this formula is not part of the standard physics formula sheet, it was clear that many teachers included it as part of their coverage of projectile motion. What was also apparent was that many students were not at all sure of how to separate the vertical and horizontal components of the motion and set up the appropriate equations to solve. A number of others solved for the time to reach the highest point of the motion and then incorrectly treated this as the time for the full motion.

Question 8

Marks	0	1	2	3	Average
%	41	32	10	17	**1.1**

For the car to accelerate forward there must be a net force acting on the car in this direction. This net force can only come from the frictional contact between the tyres and the road. Hence, students needed to sketch a frictional force acting forwards on the front tyre at the surface of the road. For friction to act there needs to be a normal contact force acting on the tyre, and this needed to be sketched acting in the upwards direction.

The average score for Question 8 indicates that the concept of friction as a driving force was poorly understood. While many students were aware that there had to be a net force acting forwards to accelerate the car, the origin and point of application of this force was rarely correctly sketched. In fact, many students still sketched the road–tyre friction force acting backwards so as to oppose the motion of the car. It was also disappointing to note the number of sketches that did not show the correct point of application of the weight, normal or frictional forces. It is quite apparent that VCE Physics students need more practice in drawing free-body force diagrams.

Question 9

Marks	0	1	2	Average
%	40	37	23	**0.9**

In order for the car to brake there must be a net force acting in the opposite direction to the motion. Again, this arises due to friction between the tyre and the road surface. However, this time the friction forces needed to be sketched acting in the direction opposite to the motion (at the interface between both tyres and the road surface). Normal contact forces, acting upwards on both tyres, also needed to be included in the sketch.

The average score for this question again indicates that students found this nearly as difficult as the previous question and that friction as a braking force was not thoroughly understood.

Question 10

Marks	0	1	2	Average
%	34	33	33	**1.0**

There were a number of acceptable suggestions that could make it safer for trucks travelling around the bend. These included the following:

- increasing the radius of the circular bend
- banking the curve
- lowering the centre of gravity of the truck.

In order to score the full two marks for this question, any of these suggestions needed to be supported by a suitable explanation that outlined the physics principles behind it.

The average score for Question 10 was one mark out of a possible two. Most students were able to suggest a suitable method of making the curve safer but were unable to convincingly explain the physics underpinning their suggested method.

Question 11

Marks	0	1	2	3	Average
%	34	19	23	25	**1.5**

Softer collisions mean a smaller net force or smaller magnitude of deceleration. Extending the contact time or extending the crumple distance of the airbag can achieve this. The physics principles underlying this are either work-energy or impulse-momentum, and students needed to describe one of these principles in their answer.

The average score for Question 11 shows that most students understood that a softer collision involved either extending the contact time or distance. Many also understood that impulse-momentum or work-energy needed to be applied to this situation, but very few discussed the fact that the change in momentum, or change in kinetic energy, was a fixed quantity when they tried to explain why extending the time or distance resulted in a reduced contact force.

Question 12

Marks	0	2	Average
%	26	74	**1.5**

Expression A gave the speed of the car at point Y.

The average score for Question 12 indicates a satisfactory understanding of the conversion of gravitational potential energy to kinetic energy.

Question 13

Marks	0	2	Average
%	39	61	**1.3**

Statement B correctly describes the horizontal component of the velocity of the car at Z.

Question 14

Marks	0	2	Average
%	30	70	**1.4**

Expression C gave the speed of the car just before hitting the water at point Z.

Area 2 – Gravity

Question 1

Marks	0	1	2	3	4	Average
%	37	9	7	3	45	**2.2**

The formula that relates the orbit radius and period of a satellite is $\frac{GMm}{r^2} = \frac{4\pi^2 r}{T^2}$. Substitution into this equation, using a period of 2.0 h (7200 s), results in a value for the orbit radius of 8.06 x 10^6 m. Subtracting the radius of the earth from this results in a height of 1.7 x 10^6 m as required.

Most students understood that the gravitational force between the two masses provided the net force, but some were unable to relate this to the net force needed for uniform circular motion. A common error was neglecting to convert the unit for the period from hours into seconds.

Question 2

Marks	0	1	2	Average
%	39	11	50	**1.2**

The speed of the satellite can be calculated via substitution into the equation $v = \frac{2\pi r}{T}$. The value of the period was previously given (7200 s) and the radius was calculated in the previous question. This resulted in an orbit speed of 7.0×10^3 m s^{-1}.

The average score was disappointing for what was a very straightforward question. Common errors were in using the height as the radius or again in neglecting to convert the unit for the period into seconds.

Question 3

Marks	0	1	2	3	4	5	Average
%	39	10	10	40	1	1	**1.7**

The energy needed to place the satellite in orbit was the sum of the gravitational potential energy needed to raise the satellite to the orbit height and the kinetic energy necessary for the orbit. The area under the graph represents the work done per kilogram to raise the satellite to this orbit height. Hence, the final expression for the energy required was: Energy = 400 x area under graph + ½ 400 v^2.

This resulted in a total energy of approximately 1.55×10^{10} J. A range of answers between $1.5 – 1.6 \times 10^{10}$ J was accepted in order to compensate for approximations to the area under the graph.

The average score for Question 3 indicates that this was a question that many students found quite challenging. In fact, just over one per cent of students scored the full five marks for this question, clearly demonstrating just how difficult it was. Many students understood that the area under the graph was involved in answering this question, but often still made an error. Very few students realised that they had to multiply the area by the mass in order to correctly determine the work done in order to overcome the gravitational potential energy deficit. Even fewer realised that they needed to also provide for the kinetic energy of the orbiting satellite.

Question 4

Marks	0	1	2	3	Average
%	39	17	20	24	**1.4**

The key to understanding why the astronauts appear to be ‘floating’ inside the spacecraft involves an understanding of apparent weightlessness. The key point here is that both the astronauts and spacecraft are in free fall; that is, they are both accelerating towards Earth at *g*. Furthermore, this implies that there will be no normal contact force between the astronaut and the spacecraft in this situation.

The average score for this question indicates that apparent weightlessness continued to cause difficulties for many students. Most students understood that the spacecraft was accelerating towards Earth and that the astronauts were also accelerating towards Earth. However, many omitted to mention that they were both accelerating at *g* and hence were both in free fall. It was pleasing to note the number of answers that provided a calculation to show that the normal contact force between an astronaut and the spacecraft was zero.

Area 3 – Structures and materials

Question 1

Marks	0	1	2	3	Average
%	28	17	35	20	**1.6**

The explanation of the features of the bridge structure which ensure that it is strong needed to cover the following points:

- concrete is much stronger under compression than tension
- steel is strong in both compression and tension
- the arch structure is such that it places the concrete on the lower surface of the arch under compression and also assists in transferring the loads into greater vertical components at the end supports.

The majority of students were able to address the properties of concrete and steel. However, a number of students interpreted the structure as an example of a cantilever rather than part of an arched bridge structure, and this led to some problems in terms of regions of compression and tension.

Question 2

Marks	0	1	2	3	4	Average
%	36	5	6	8	45	**2.3**

The tension in the cables was calculated by setting up an equation by taking torques about either end of the structure. This resulted in values for the tensions of 2.4×10^6 N and 5.9×10^5 N respectively.

From the responses noted, it was clear that students either knew they had to use the method of torques and then did so correctly, or else they did not know how to begin to solve for the forces. It remains apparent that many students still did not understand how to calculate torques and this is disappointing to note. Other errors involved neglecting to convert a mass in tonnes to a weight force in newtons and using incorrect lengths when calculating torques.

Question 3 & 4

Marks	0	1	2	3	4	Average
%	3	16	25	9	48	**2.9**

Material A was stronger. The reason for this was that it fractured at a greater tensile stress (200×10^6 N m^{-2}) compared with material B (120×10^6 N m^{-2}). Material A is also tougher, as indicated by a greater area under the stress-strain graph than for material B.

Most students understood that material A was stronger, and gave the correct reason. In some cases an incorrect reason was provided; for example, saying that material A was stronger because it had a steeper gradient.

Most students also understood that material A was tougher and gave the correct reason. But again, some gave an incorrect reason, confusing toughness with the need for a plastic region or a steeper gradient.

The average score for Questions 3 and 4 indicates that strength and toughness of materials, as determined from stress-strain graphs, was reasonably well understood.

Question 5

Marks	0	1	2	3	Average
%	16	15	14	55	**2.1**

The ratio for the Young's moduli was calculated by the ratio of the gradients of the linear sections of the graphs for each material. This resulted in a ratio of 2.7, or $\frac{8}{3}$.

The average score for Question 5 indicates a satisfactory understanding of this concept. The main error noted was that some students calculated the gradient of material A to the fracture point rather than the linear section only. This error indicates that some students were not clear about the definition of Young's Modulus.

Question 6

Marks	0	1	2	3	Average
%	80	5	5	10	**0.5**

The tension in the cable could be calculated via the equation derived from taking torques about the edge of the stadium roof. This resulted in a value for the tension of 1.4×10^5 N.

The average score for Question 6 clearly demonstrates that, as noted in the comments for Question 2, many students did not fully understand the concepts of torque and rotational equilibrium. By far the most common error was made by students who simply resolved forces and treated the structure as a point particle.

Question 7

Marks	0	1	2	3	Average
%	34	6	6	55	**1.9**

The distance that the cable stretches was calculated via the equation $\varepsilon = \frac{\sigma}{E}$ and this resulted in a value for the strain of 1.0×10^{-6} m. Further substitution into the equation for strain of $\varepsilon = \frac{\Delta 1}{1}$ resulted in a value for Δl of 1.6×10^{-5} m.

The average score for Question 7 indicates that this concept was reasonably well understood. The most common errors occurred when students simply calculated the strain only or used an incorrect formula for either strain or change in length.

Question 8

Marks	0	1	2	3	4	Average
%	63	10	9	6	12	**1.0**

The area under a stress-strain graph gives the energy per unit volume stored in a stretched cable. Using the stress value of 2.0×10^5 N m^{-2} and the strain value calculated in Question 7 (1.0×10^{-6}), the energy per unit volume was determined to be 0.1 J m^{-3}. This value was then multiplied by the volume of the cable, resulting in a total energy stored in the cable of 2.0×10^{-3} J.

The average score indicates that this was a difficult question. In fact, 63% of students scored zero. It was disturbing to note the number of students who confused Young's Modulus with the spring constant, which resulted in many of these students attempting to treat this as an example of Hooke's Law. Many students also neglected to multiply the energy per unit volume by the volume of the cable so as to calculate the total energy.

Area 4 – Ideas about light and matter

Question 1 & 2

Marks	0	1	2	3	4	Average
%	23	7	13	4	53	**2.7**

The energy of a photon is calculated using the formula $E = \frac{hc}{\lambda}$, resulting in the energy for a photon of green light of 2.3 eV. Maximum kinetic energy of photoelectrons is calculated via the formula $E_{K\max} = hf - W$. Substitution into this equation resulted in a maximum kinetic energy of 0.16 eV.

Many students calculated the frequency first and then calculated the energy of the photon rather than using the formula $E = \frac{hc}{\lambda}$ in a one-step process.

The calculation for the maximum kinetic energy of the electrons was quite well understood. It was disappointing to observe that some students recalculated the frequency and sometimes made an arithmetic error.

The average score for Questions 1 and 2 indicates that photon energy and Einstein's equation for the maximum kinetic energy of photoelectrons were reasonably well understood.

Question 3

Marks	0	1	2	3	Average
%	47	9	3	41	**1.5**

In order to calculate the maximum speed of the photoelectrons it was first necessary to convert the unit for the maximum kinetic energy from electron-volt to joule. This then resulted in a speed calculation of 9.9×10^5 m s^{-1}.

The main error in this question was in neglecting to convert the energy unit from eV into J.

Question 4

Marks	0	1	2	Average
%	16	2	82	**1.7**

Electric field strength is calculated by substitution into the formula $E = \frac{V}{d}$. This resulted in an electric field strength of 5000 V m^{-1}.

This was a straightforward question.

Question 5

Marks	0	1	2	3	4	Average
%	50	7	4	4	34	**1.7**

The de Broglie wavelength is calculated using $\lambda = \frac{h}{p}$. However, before the electron momentum can be determined the kinetic energy needed to be calculated by applying the formula $E_K = qV$. This could then be used to calculate the electron speed as 5.9 x 10^{6} m s^{-1}, resulting in a de Broglie wavelength of 1.2 x 10^{-10} m.

The average score for this question indicates that many students found this to be a difficult question. The majority of students knew the formula for the de Broglie wavelength, but many experienced difficulty in understanding the method for calculating the speed of the electron. The most common errors involved either taking the speed of the electron as c (speed of light) or as 100 (confusing the '*V*' symbol for voltage with that for speed). It was clear that many students did not understand that they needed to determine the speed of the electron from kinetic energy gained in crossing the potential difference of 100 V. On the other hand, it was pleasing to see quite a number of students calculating the momentum directly via use of the equation $E_K = \frac{p^2}{2m}$.

Question 6

Marks	0	1	2	3	Average
%	38	7	13	41	**1.7**

The possible energy for each transition involving an atom initially in the 2nd excited state was 1.8 eV, 4.9 eV and 6.7 eV respectively.

The major errors here involved omitting either the 1.8 eV or 4.9 eV transitions for the two-part transition.