November 2016 Physics

Physics

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 26	27 - 39	40 - 49	50 - 58	59 - 67	68 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 13	14 - 23	24 - 32	33 - 42	43 - 53	54 - 63	64 - 100

Internal assessment

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 3	4 - 6	7 - 10	11 - 13	14 - 16	17 - 19	20 - 24

The range and suitability of the work submitted

There was a wide range of investigations, ranging from the simplistic (determining the spring constant of a rubber band) to a sophisticated mathematical model (the most efficient way to heat a house). There were many traditional investigations, many of which were thoroughly done. Some investigations were too complex, involving multiple independent variables or consisting of two distinct investigations. This should be avoided. Some investigations had unquantifiable independent variables, and this too should be avoided. Students need to focus on one well-defined investigation and go into the depth required to earn good marks.

Most student work involved hands-on investigations, with primary data collection in the school laboratory. This approach allowed addressing all the assessment criteria. Mechanics was the most popular topic, but electricity and magnetism, and waves (mechanical standing waves and optical refractive index), were common too. A surprisingly low number of investigations were mathematical models, computer simulations and database investigations.

Candidate performance against each criterion

Personal Engagement Strengths:

When a student report demonstrates independent thinking, initiative or creativity, and when there is personal significant, interest and curiosity in the chosen research question, and when there is personal input in the design or implementation or presentation of the investigation, then the student has addressed the personal engagement criterion. PE is assessed holistically.

It was encouraging to see that some students had modified a traditional investigation or designed their own investigation, thus demonstrating independent and creative thinking. Performing an investigation with a standard method and standard analysis but in a thoughtful and competent way often earned one mark for PE. Only the most insightful and thoughtful investigations demonstrated the qualities expressed by the PE descriptors.

Personal Engagement Weaknesses:

Students would often over-emphasized ‘personal significance’ by writing what seemed to be artificial comments about their interests. Teachers need to encourage students to demonstrate their curiosity and insight in the investigation itself, in research question, in the details of methodology and analysis, and in other contributions made by the student to their individual investigation. Teachers often over marked PE thinking that an interest in the general topic was enough to earn full marks. Because PE is assessed in a holistic way, students must not add a sub-title section “Personal Engagement.”

Exploration Strengths:

Many students produced interesting and challenging investigations. These always included a single and well-defined independent variable and a quantifiable dependent variable. Appropriate investigations often made use of known scientific concepts and equations to their work. Thus, analysis was focused in a relevant way. Issues of safety, ethical and environmental concerns were mentioned when appropriate. Moderators were impressed by the degree of student engagement and imagination.

Exploration Weaknesses:

Some students had vague research questions, never defining the key issues. Some investigations had multiple independent variables. This usually harmed the quality of the investigation as it took the student’s attention away from a more focused study. Some students made up a scientific context, following common sense when there was relevant theory but never realized by the student. Occasionally students thought that a history of physics provided background when in fact all it did was distract the focus of the investigation. Some investigations were too simple and the research question too obvious, like finding the relationship between frequency and wavelength for standing waves on a vibrating string. Determining the spring constant of an elastic band is too simple too, but how temperature affects the spring constant of an elastic band would be an appropriate research question. Most appropriate research questions look for a function or relationship between two quantifiable variables, or the research questions uses a known equation or relationship to establish an important constant of nature.

Analysis Strengths:

Analysis includes the traditional scientific skills that assess data collection, data processing, appreciation of errors and uncertainties, the scope and limit of the data, graphing and methodological issues. These are traditional scientific skills, and most students demonstrated a sound mastery of analysis. Most students demonstrated the ability to obtain and record data, including raw uncertainties. Data tables were clear and consistent with scientific notation. Processing was often detailed, with sample calculations. Graphs were nicely presented often with error bars. Most student graphs were computer generated. In most cases theory and hypothesis directed the appropriate graph representation. Often students used more advanced methods of error analysis, and this was successful.

Analysis Weaknesses:

Occasionally raw data was incorrectly recorded, omitting uncertainties. Column headings should include the quantity name, units and uncertainty values with units. Occasionally incorrect units, such as feet and minutes, were used. Claiming a metre rule could measure distances to 0.01 mm is unlikely to be true. Some graphs lacked appropriate detail, and some graphs were too small to appreciate. This affects the Communications assessment. Occasionally a linear fit was used to establish a bogus conclusion. One student thought they established a linear relationship between the length of a pendulum and the period. Teachers should ask students what relevant theory applies and how the graph should look. Dimensional analysis or the use of logarithms could here. Students need to appreciate the physical meaning of a graph including the intercept. Students need to be careful when claiming results prove something. There should always be a range and limit to the meaning of a given investigations, and complex polynomials and statistical analysis require physical interpretation.

Evaluation Strengths:

The evaluation criterion remains one of the hardest criterions to address for many students. Focus is the key here and students who justified a conclusion for their investigation based on the original research question often did well. The propagation of uncertainties was a key part for successful students. When there is a known scientific context or accepted value, then students who compared their result with the accepted value did better. When there is no known context, then a reasonable interpretation involving relevant scientific principles is acceptable. The more successful student reports showed an appreciation for any assumptions in their methodology.

Evaluation Weaknesses:

Students need to be careful with statements about proving a hypothesis. An appreciation of the scope and limit, the procedures, the methodology as well as any theoretical assumptions should be addressed when evaluating a conclusion. Often the terms proportional and linear were confused. Often students would construct a meaningless polynomial equation to fit their data and then assert a conclusion described by the equation, without giving any physical meaning to the results. If the student had extended the range of the graph they would have seen the senseless meaning of such an equation. Too often students would force data to fit a linear graph and then state this as a conclusion with the linear line as the justification. In an Evaluation students need to appreciate the physical meaning of the quantities under investigation, so they need to interpret the data correctly. Many times, students failed to appreciate the physical quantities under study and so they failed to appreciate what they have established. There is more to a graph than an equation.

Communications Strengths:

Communications, like Personal Engagement, is assessed holistically. This means that the overall clarity, flow and focus of the report are assessed. The best reports made it clear in the first paragraph what the specific investigation was about, how it was conducted and what results were found. The best reports stayed focused on the research question and related physics content. The best reports had specific titles, like “How the temperature affects the refractive index of water” and not generic titles like “Investigating Sound.” Most reports used correct and relevant scientific notation, equations and units. Most reports were within the 12-page expectation. Reasonable margins, spacing and appropriate scales of graphs and data tables, all help the communication criterion. Most students consistently and appropriately provide references to their work (in a variety of consistent and acceptable ways). Academic research is expected. Research questions and hypothesis need to be supported by relevant scientific information, relevant to the investigation (and not historical background or how much a student enjoys physics class).

Communications Weaknesses:

A number of students omitted any sort of investigation title. Some students wrote “IA Investigation” or vague titles like “Investigating Light.” A cover sheet is not necessary. A table of contents may give the reader an overview but is not necessary either. Significant sections relating to personal interest and the history of science often contributed little to the achievement of the student.

Investigations need to refer to the research question early. Step by step instructions were too detailed, in some cases and unnecessary. Students do not need to include photographs of a metre rule or a stopwatch. This can lead to wasted space. Often reports with excessive content (e.g. 16 or 18 pages) inhibited the clarity of the report. Occasionally students would copy pictures from the Internet or a textbook and not give the reference. In some cases, this was obvious, but referencing is required for all material that is not original. Communications does not penalize for lack of references but rather when this occurs it becomes an issue of academic honesty.

Recommendations for the teaching of future candidates

It is important that teachers provide guidance during the entire IA investigation process, and not only when they read the first draft. Some of the problems that teachers could correct early on include multiple independent variables, unquantifiable variables, graphs with scatter data suggesting a curve but students forcing a linear fit, inappropriate units or even no units, and too simple a research question. Teachers could also make sure students include a descriptive title to their investigation, and that students do some academic research to find out the relevant known theory to their own work. A number of investigations could have been improved if the student had this support early on.

Further comments

Most schools are doing appropriate IA work and teacher's assessment is fair. Most teacher's marks were within the acceptable range. Students are working hard. There was a large range of work quality. The key to IA success is to have a well-defined and focused research question that is challenging and interesting to the student. Too simple or too ambitious can inhibit the student's success. Some teachers ask what topics or research questions are best for earning high marks and the answer is that is it not so much the topic or research question but how well the investigation is carried out.

Higher and standard level paper one

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 14	15 - 18	19 - 21	22 - 25	26 - 28	29 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 9	10 - 11	12 - 13	14 - 16	17 - 18	19 - 30

General comments

A proportion of questions are common to the SL and HL papers, with the additional questions in HL providing further syllabus coverage.

Every year there are occasional comments from teachers that either paper 1 or paper 2 are unbalanced in terms of syllabus cover. It should be noted, however, that these two papers *together* aim to provide valid assessment of the complete syllabus, both in content and skills. The specific skills that need to be engendered in the candidates to succeed at multiple choice questions are described in the final section of this report.

Only a small percentage of the total number of teachers or the total number of centres taking the examination returned G2's. For SL, there were 24 responses from 229 centres (10%) and for HL there were 28 responses from 289 centres (also 10%). This disappointing return may be the result of general satisfaction with the papers, but we would advise schools to offer comments, which are always carefully considered and they do inform the award and future question writing.

The HL (SL in brackets) paper was regarded as being of appropriate difficulty by about 89%(83%) of the respondents with 11%(17%) finding it too difficult. Over 25%(46%) of the respondents regarded it as being more difficult than last year's paper. The papers were deemed to have good, or better, 'clarity of wording' by around 93%(75%) of respondents; and over 96%(92%) of teachers judged the presentation to be good, or better.

There was also a feeling, by about 10% of the centres, that the wording was somewhat inaccessible for second language learners and those with learning difficulties.

It must be stressed that this very positive feedback was from only about 10% of the schools so it must be regarded with some caution. But, from the evidence gained from the G2 comments, the examiners were satisfied that the papers met with general approval.

There were only a few G2 general comments. Question-specific comments will be dealt with later in this report.

Time

There were a couple of comments that there was not enough time as the questions were more 'multi-layered' than in previous years. The new syllabus, however, specifies that 50% of multiple choice questions will require AO3 skills. This is a departure from pre-2016 practice and students should expect some questions to be done in well under a minute leaving extra time for those questions of greater complexity.

There is evidence from the number of blanks and the G2 comments that the SL candidates struggled with finishing the paper in good time. It should be noted that the common elements of the curriculum need to be taught to the same level of complexity and will normally be tested with the same multiple choice questions. In this session, there were 16 common questions which is in line with previous practice.

Trickiness

It is not the examiners intention to ‘trick’ students. But students cannot expect multiple choice questions to follow a familiar pattern. They should read the questions carefully and expect them to be different from those asked in previous years.

Physics involves the application of general principles to new situations. Indeed, a paper that just offers students familiar questions would not be a physics paper. There is very little that needs to be memorised in physics; instead time should be spent applying the underlying core ideas to observed phenomena. Sometimes, for example, a problem can be solved by a consideration of the dimensions of the responses rather than a detailed working of the algebra.

Wordiness

Paper writers and reviewers do their utmost to ensure that words are kept to a minimum and supplement the question with a diagram where helpful. But all the words in a multiple-choice question are important – there will be no distracting padding – so students must be encouraged to carefully read the question and visualise the situation rather than jumping to conclusions too early.

Other comments will be dealt with in the item analysis below.

Statistical analysis

The overall performance of candidates and the performance on individual questions are illustrated in the statistical analysis of responses. These data are given in the grids below. The numbers in the columns A-D and Blank are the numbers of candidates choosing the labelled option or leaving the answer blank.

The question key (correct option) is indicated by a shaded cell.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	145	392	617	69	10	50.04	0.44
2	39	149	951	94		77.13	0.21
3	205	936	27	64	1	75.91	0.42
4	426	191	550	65	1	44.61	0.48
5	787	138	114	192	2	63.83	0.47
6	319	330	179	404	1	32.77	0.21
7	53	734	365	76	5	59.53	0.54
8	7	99	60	1065	2	86.37	0.29
9	66	321	69	774	3	62.77	0.38
10	137	925	146	24	1	75.02	0.26
11	58	966	176	32	1	14.27	0.21
12	192	234	63	742	2	60.18	0.61
13	638	18	210	363	4	51.74	0.68
14	175	547	383	128		44.36	0.54
15	951	56	189	35	2	77.13	0.20
16	99	211	847	74	2	68.69	0.43
17	321	302	453	154	3	36.74	0.59
18	23	1015	31	161	3	82.32	0.39
19	774	37	120	298	4	62.77	0.50
20	621	72	55	484	1	50.36	0.43
21	169	743	232	87	2	60.26	0.51
22	188	176	715	131	23	57.99	0.49
23	1139	18	69	6	1	92.38	0.15
24	407	515	157	152	2	41.77	0.36
25	702	163	329	31	8	56.93	0.61
26	251	213	409	349	11	33.17	0.45
27	96	75	266	791	5	64.15	0.32
28	368	203	586	61	15	47.53	0.23
29	46	652	400	122	13	52.88	0.61
30	86	1065	36	39	7	86.37	0.24
31	160	970	65	36	2	78.67	0.29
32	770	100	265	88	10	62.45	0.59
33	286	150	188	604	5	48.99	0.26
34	568	430	156	68	11	46.07	0.32
35	110	146	621	347	9	50.36	0.42
36	875	115	86	155	2	70.97	0.57
37	50	245	313	616	9	49.96	0.42
38	150	102	123	844	14	68.45	0.55
39	226	568	228	204	7	46.07	0.57
40	104	126	182	813	8	65.94	0.54

Number of candidates : 1233

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	309	542	508	197	28	32.07	0.35
2	344	501	369	336	34	31.63	0.23
3	120	315	1018	126	5	64.27	0.26
4	285	353	764	169	13	48.23	0.51
5	774	297	251	256	6	48.86	0.33
6	525	420	222	399	18	25.19	0.12
7	50	199	192	1125	18	71.02	0.39
8	243	561	170	601	9	35.42	0.27
9	592	246	163	578	5	36.49	0.29
10	142	463	210	755	14	47.66	0.41
11	283	1030	170	85	16	10.73	0.04
12	264	910	329	72	9	57.45	0.33
13	507	623	196	245	13	39.33	0.34
14	316	387	264	610	7	38.51	0.45
15	392	97	354	733	8	24.75	0.34
16	395	322	738	122	7	20.33	0.21
17	280	223	416	649	16	40.97	0.43
18	202	469	717	182	14	45.27	0.53
19	710	97	685	69	23	44.82	0.42
20	240	200	262	859	23	54.23	0.39
21	141	996	84	344	19	62.88	0.41
22	677	125	290	475	17	42.74	0.45
23	332	176	541	494	41	34.15	0.23
24	639	284	434	189	38	40.34	0.34
25	266	602	540	141	35	38.01	0.33
26	372	348	531	270	63	33.52	0.26
27	279	119	787	362	37	49.68	0.30
28	944	301	192	103	44	59.60	0.50
29	140	1102	94	211	37	69.57	0.30
30	1207	70	203	55	49	76.20	0.38

Number of candidates : 1584

Comments on the analysis

Difficulty

The *difficulty index* (perhaps better called facility index) is the percentage of candidates that gave the correct response (the key). A high index thus indicates an easy question.

Ignoring a couple of outliers, the difficulty index varies from about 30% in HL and 20% in SL (relatively 'difficult' questions) to about 90% in HL and 76% in SL (relatively 'easy' questions). The papers gave an adequate spread of marks while allowing all candidates to gain credit. This range of indices showed that the paper was accessible to students of all abilities.

Put in other words, over 50% of the HL students could do 70% of the questions successfully. For SL, the corresponding figure was 27%. In both papers, there was an even range of difficulties amongst the questions, which led to a good normal distribution of marks. This meant that both papers were effective assessment tools with the mean mark being broadly like the previous November.

Discrimination

The *discrimination index* is a measure of how well the question discriminated between the candidates of different abilities. In general, a higher discrimination index indicates that a greater proportion of the more able candidates correctly identified the key compared with the weaker candidates.

All questions had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. Only one HL and two SL questions fell below this standard. However, a low discrimination index may not result from an unreliable question. It could indicate a common misconception amongst candidates or a question with a high difficulty index.

‘Blank’ response

In both Papers, there were several blank responses throughout the test with a slight increase towards the end as in previous years. This may indicate that some candidates had insufficient time to complete their responses, while others left the questions they were unsure of. **Candidates should be reminded that there is no penalty for an incorrect response**. Therefore, if the correct response is not known, then an educated guess should be made. In general, some of the ‘distractors’ should be capable of elimination, thus increasing the probability of selecting the correct response. If candidates concentrate on selecting the correct response – instead of working out the correct answer (as they might in paper 2) then there should be adequate time to complete all the questions and check the doubtful ones.

It is interesting that in this session the rate of blanks was much higher amongst SL candidates (1.2%) compared to HL candidates (0.4%)

The strengths and weaknesses of the candidates in the treatment of individual questions

Candidate performance on the individual questions is provided in the statistical tables above, along with the values of the indices. For most questions, this alone will provide sufficient feedback information when looking at a specific question. Feedback will be given only on selected questions, i.e. those that illustrate a particular issue or drew comment on the G2’s.

SL and HL common questions

SL Q1 and HL Q1

Making reasonable estimates for everyday quantities should be common teaching practice at this level. If a boy is jumping from a 3m high wall, we can assume he is not a toddler! C is the only reasonable answer.

SL Q6 and HL Q6

This elegant question revealed several misconceptions. *Any* body in free fall has an acceleration of g. Therefore, A and B can immediately be discounted. In equilibrium (as shown in the diagram) the spring has a tension of $3g$, so after the thread is cut the unbalanced force on the 1 kg mass will be $2g$ giving D as the correct response.

Over 50% of the candidates chose either A or B. Perhaps they never visualised the situation and had to resort to making a quick guess.

SL Q10 and HL Q9

It is a common misconception that the gradient of a graph of temperature against time relates to the specific heat capacity (which is probably why many candidates opted for B). It is perhaps advisable initially to teach the concept of specific heat capacity as being equivalent to *insensitivity* to heat, so a body that can soak up a lot of heat energy without much response/temperature rise, has a *high* heat capacity.

SL Q11 and HL Q11

Over 70% of the candidates chose the incorrect response of B. This cannot be correct for the simple reason that n in the equation $pV = nRT$ stands for the number of moles in the gas. It is not the same as N, which is commonly used, as here, for the number of molecules.

A good revision exercise is for the students to randomly select equations from the data booklet and state a) the situation in which the equation would be useful, b) the meaning of the symbols, and c) the SI units of each quantity

A and D can be easily eliminated, leaving C as the only possible correct response.

SL Q14 and HL Q12

This question requires visualisation. Any candidate who 'sees' a body performing SHM (they can move their pencil tip backwards and forwards if they wish) will notice that within a period there will be *two* occasions when that the body is stationary. As kinetic energy cannot take a negative value, this gives D as the only possible correct response.

SL Q15 and HL Q13

C and D are logically equivalent so they must both be incorrect. B can be immediately discarded leaving A as the only possible correct response.

When teaching refraction, it is perhaps better to visualise the angles being 'big' and 'small' rather than angles of 'refraction/incidence'. In this way, we avoid changing the equations when the direction of the ray reverses.

SL Q22 and HL Q19

There were a couple of comments that we should have specified that the rod was on Earth. But if we are in outer space then there is no reason to specify that the circle is vertical.

Simple visualisation ('imagine you are the body on the end of the rod') leads clearly to the correct response of A.

SL Q26 and HL Q22

This elicited the largest number of blanks in both papers. Perhaps the candidates got bogged down in arithmetic and powers of ten and thought they would return to it later. But any students who have worked through questions on binding energy will have noticed that, for typical nuclei, they are of the order of magnitude of MeV's. So C is the only reasonable response.

At this level students should be able to recognise improbable magnitudes for nuclear and atomic events (just as they should be able to estimate the mass of a boy jumping off a wall as in Q1).

HL-only questions

Q3

This is an example of how units can be used to quickly give the correct response.

Q4

Where there is a selection of trigonometrical expressions in the responses, candidates should apply their knowledge of these functions. Knowing the sine, cosine and tangent of both 0^0 and 90^0, it should be clear that B and D are impossible (visualisation leads to a = 0 when θ = 0^0). And θ = 90^0 is impossible unless the acceleration is infinite. So C is the only possible response.

Q7

Work is being done by gravity upon the object. So *force* × *distance* will give the extra energy gained (100 J), giving B.

Q17

The responses chosen were quite equal but the discrimination index was very high. This would suggest that the better candidates understand simple circuit electricity while the rest resorted to guessing.

A '12 V battery' refers to the emf of the battery, not the terminal voltage. A sketch of the circuit shows that A, B and D can be easily discounted with only trivial calculation. So the correct response must be C.

Q20

D was a popular distractor, perhaps due to careless reading of the question.

Q26

This was poorly done. The question asks about energy and how it relates to displacement. So it is appropriate to sketch a graph showing the variation of force with displacement, which will be a straight line with the area yielding energy. This leads directly to C.

Q28

The number of maxima observed for a diffraction grating will always be odd. So A and B can be immediately discounted.

Q34

Most candidates correctly reasoned that there will be no reverse potential difference. Consideration of symmetry leads to the correct response of A.

Q38

D is given directly using units. *h* is in J s and J can be thought of as [*mass* × *velocity*^{2}]. So mass needs to cancel out (A and C must be incorrect); also there needs to be a velocity in the denominator, so r cannot be in the numerator. Hence B can also be eliminated.

SL-only questions

Q2

This is a straightforward question requiring manipulation of multipliers. Students should be able to quickly simplify combinations of multipliers, so $k^2 = M$; $\frac{1}{Mk} = n$; and $\mu M = 1$ etc.

The statistics suggest that there was much guessing! As the slit separation increases so the distance between the maxima decreases so the 1000 µm is in the denominator; hence the correct multiplier is given by $\frac{1000n \times M}{1000\mu}$ which gives $\frac{nM}{\mu}$ or k. Response B.

Q4

The examiners recognised that there was slight uncertainty in this question as there was no mention of the object's volume so the upthrust was indeterminate. But candidates are required to select the *best* response and as there were no <'s or >'s in the responses on offer C must be chosen in the assumption that the object was small.

The statistics showed that the better candidates were not distracted by the ambiguity in this question.

Q8

Momentum is a vector quantity so the angle and the direction are both relevant to the answer. Hence C and D can be eliminated. If $\theta = 90^0$, then the ball is just rolling down the wall and there is no change in momentum. Hence B is correct ($\cos 90^0 = 0$).

Q13

Many candidates selected the incorrect response A, perhaps transferring the negative sign from the definition of SHM. But quick visualisation of SHM using the end of a pencil will show that the correct response is B.

Q16

The table is frictionless so the most popular option, C, cannot be correct.

Q17

Speed is in m s^{-1} so A and B must be incorrect.

Q19

C was a commonly chosen distractor, but since the current is flowing in the same (clockwise) direction through both R_1 and R_3 then the two terms on the RHS for loop X must have the same sign. Hence C is incorrect.

Q23

This question involved using simple proportion. The radius of a planet is proportional to √mass and inversely proportional to √gravitational field strength. So the required ratio can be simplified as $\sqrt{(\frac{mass\ of\ Earth \times g\ of\ Mars}{mass\ of\ Mars \times g\ of\ Earth})}$which yields $\sqrt{\frac{10}{4}}$ ie response C.

Recommendations and guidance for the teaching of future candidates

Multiple Choice items are an excellent, motivating and highly time-efficient way of testing and promoting learning while a course is being taught. They can be used as warmers to stimulate discussion as well as for quick tests and should never be regarded as add-ons only to be practised, a paper at a time, for the final examination session.

A frequent criticism of multiple choice questions is that they give limited feedback to the teacher on the way the student is thinking. It is perhaps more helpful if the teacher collects in the jottings that the students do while solving the questions. It is also instructive if the students code each answer with their level of certainty (0: it was a complete guess; 1: it's a hunch; 2: I'm sure; 3: I'm certain).

Multiple choice questions test different skills to structured questions. In paper 2 students are expected to display their knowledge in a logical and communicative fashion. But multiple choice questions test quick thinking, insight and problem solving. In particular, students should be discouraged from reaching automatically for an equation and instead visualise the situation and assess the reasonableness of the responses on offer.

Students should be adept at dealing with powers of ten and multipliers quickly and efficiently. Total reliance upon a calculator for simple cancelling and combining the powers of ten can be a waste of valuable time.

Teachers frequently comment on unfair 'tricky' questions. But the physical world has a history of tricking scientists into false conclusions. In order not to be 'tricked', candidates must read the question very carefully to visualise the situation. The questions are carefully created to communicate the problem unambiguously and in as few words as possible; the words are both necessary and sufficient. After they have made their selection the candidates should make a habit to check back that they have indeed answered the question. Only then should they move on. There is evidence that many candidates are not 'back-checking' once they have made their selection.

There is no single most successful strategy with MCQs, so flexibility of thinking is needed. Students should be encouraged to develop strategies for spotting the correct answer – rather than working it out as they would in a paper 2. Among the strategies leading to successful completion of multiple choice questions are:

- Eliminate the clearly wrong responses.
- Use natural common sense, asking 'as such-and-such increases or decreases what is likely to happen'.
- Consider the units. There is much evidence that students are not being taught the power of and necessity for units. They are there to help the student not to burden them and will often lead to the identification of the correct response.
- If two responses are logically equivalent, then they must both be wrong.
- Exaggerate a variable – this will often point the candidate in the correct direction, especially if a variable is in the denominator in one response and the numerator in another.
- Model the situation while reading the stem. This can be done through visualisation, a simple sketch, or even by pushing a pencil over the desktop. These activities aid understanding and often lead the candidate to the correct response. This is particularly important for those students with weak language skills.
- Distinguish between cos, sin and tan functions – mentally making the angle 90^0 will often show which response is correct.
- Use proportion: *new quantity = old quantity* × *a fraction*, where the fraction depends upon the variables that have changed.
- Observe the axes on graphs and use units to attach meaning to the gradient and the area.
- If all else fails, make an intelligent guess ensuring that the response selected is at least reasonable.

Candidates should make an attempt at every item. It should be emphasised that an incorrect response does not give rise to a mark deduction.

Graphs, force diagrams and other means of illustration are a fundamental way in which physicists seek to model and understand the world. Candidates should be encouraged to sketch their answers to problems before they plunge into calculations. There is evidence, also from the written papers and extended essays, that this is not a skill shared by many candidates.

The stem should be read carefully. Inevitably some questions may appear at first sight similar to past questions, but students should not jump to conclusions. It appears that some candidates do not read the whole stem but rather, having ascertained the general meaning, they move on to the options. Multiple choice items are kept as short as is possible. Consequently, all wording is significant and important. They should also bear in mind that they are asked to find the **best** response. Sometimes it may not be strictly 100% correct but Physics candidates should be used to identifying and ignoring quantities that have negligible impact.

Candidates should consult the current Physics Guide during preparation for the examination, to clarify the requirements for examination success. Teachers should be aware that questions are constructed from the requirements of the syllabus – not from previous papers!

This Guide does invite the candidates to recall certain simple facts, although most of Physics is process orientated. Such facts lend themselves to Multiple Choice questioning so the teachers should not be afraid to require their candidates to occasionally memorise information. Definitions (which are universally poorly given in written papers) are perhaps best learned and tested with simple multiple choice questions, but MCQ papers will have about 50% AO3 questions involving higher order thinking skills.

Candidates can expect the proportion of questions covering a topic to be the same as the proportion of time allocated for teaching that topic, as specified in the Physics Guide. The common knowledge that most people have about certain areas of the Guide is not always sufficient to answer questions, which are not trivial.

Higher and standard level paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 20	21 - 31	32 - 40	41 - 48	49 - 57	58 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 12	13 - 17	18 - 23	24 - 28	29 - 50

General comments

About 10% of schools forwarded G2 statistics and G2 comment forms for the attention of the examiners. This was (as usual) disappointing, especially so given that this was the first November assessment of a new course. Senior examiners assume that schools are content with the assessment if no comments are forthcoming. All schools are encouraged to submit at least a G2 statistics form.

The forms submitted suggested that most schools (60% HL; 40% SL) felt that the papers were of a similar standard to previous years with the remainder at HL describing the papers as either a little harder or a little easier in about equal measure. The position was different at SL where another 40% felt that the papers were a little more difficult, with one school expressing the view that the papers were much easier than in the previous series. There were unfavourable comments in respect of the SL paper in some G2 comments but these were not reflected in unusually extreme scores in the G2 statistics. Papers at both levels were overwhelmingly regarded as clear and well presented. No special needs issues in the papers were flagged up by schools.

There were fewer G2 comments than usual, and these were very balanced for and against the new style of paper. Individual comments are reported with the question to which they refer.

There was evidence of completely omitted questions as candidates worked through the paper in a similar way to last summer. Nevertheless, most candidates could make some attempt at parts of the final questions 10 and 11. Spanish-language papers showed more evidence of being unfinished than those written in English. In general, Spanish-language scripts at both levels were significantly poorer than those in English.

There were two unfortunate typographic errors: HL P2 English Q5b. The word “be” was repeated in line 4. This did not impact on candidates. More seriously, SL P2 Spanish Q Q3 (b)(ii) had the volume quoted in the wrong units. The Spanish mark scheme was adjusted so that candidates were not penalised for the increased effort needed to answer the question.

Most candidates presented their answers inside the marking box provided and there was less use of extra sheets compared to recent years; these were welcome improvements in presentation. However, a generally poor standard of presentation continues to be an issue for candidates. Diagrams are poorly executed; the continuity of calculations or deductions is often unclear; in “show that” proofs, whether algebraic or numerical, candidates only rarely convince the examiner.

The areas of the programme and examination which appeared difficult for the candidates

- Drawing accurate force diagrams
- Accurate definitions of internal energy
- Accurate representations of nuclear changes using Feynman diagrams
- Explanation of nuclear mass changes
- Explanations of polarisation in the context of radio reception
- Gravitational field theory
- Dc electrical calculations and deductions
- Explanation of the generation of emf by an ac generator

The areas of the programme and examination in which candidates appeared well prepared

- Mechanics and kinematics, including frictional forces
- Radioactivity calculations (HL only)

- Resolution calculations
- Magnetic field theory (HL only)
- Calculations involving energy production topics
- Descriptions of the photoelectric effect

The strengths and weaknesses of the candidates in the treatment of individual questions

Q1 HL and SL

(a) Many candidates could calculate the maximum height and deduce that this was greater than the ceiling height. Main failures included using $15 \cos(50)$ for the vertical speed component or using plain 15 – ie no allowance made for the non-vertical initial velocity. Most energy approaches suffered from this latter error. Deductions for the final mark were usually clear.

(b) The force was correctly evaluated by most candidates.

(c) HL only. Although many had the correct idea, sometimes these ideas were poorly expressed. Self-evidently the force and its reaction are not "the same" as they must act in different directions. Examiners were looking for a clear statement that the force of the ball on the racket was equal in magnitude and in opposite direction to the force of the racket on the ball. It was common to see vague use of the words 'action' and 'reaction' with only tangential reference to the ball and the racket.

(c) SL only Candidates were well able to determine the dissipated energy that arises from the frictional force.

Q2 HL and SL

(a) Clear evidence of the physics used was required for the first mark, either as a statement that the answer was equivalent to the area under the graph or that the mean velocity was used. A common error was to obtain an answer of 1.7 m s^{-1} which received only one mark.

(b) This multi-step problem was beyond weaker candidates who typically evaluated the acceleration but little else. Even strong candidates sometimes gave a hazy third step to show that the friction coefficient was $\frac{0.243m}{9.81m}$ with an indicated cancellation of *m.* This explicit cancellation was frequently omitted or m was simply omitted from the start but the error was, on this occasion, condoned.

(c) Drawings of the forces acting on the stone were disappointing in both physics and overall quality. It should not be too much to expect candidates at this level to use a ruler and to give care to drawing. Errors observed by the examiners included: failure to recognise that there is no longer a force to the right acting on the stone (it had been released by the player by this stage), failure to show exactly where the friction force arises (the base of the stone), failure to draw the vertical forces accurately (vertical and broadly speaking in the centre of the stone), and careless non-physical labelling ("gravity").

Q3

(a) Although many were able to satisfy examiners that the internal energy is the sum (or total) of the kinetic and potential energies, too often candidates simply said “the kinetic and potential energies”. This is not enough to convince that a summation is intended; candidates need to be more careful with their expression. Only half of the candidates emphasised that there was an ensemble of atoms or molecules or even simply particles involved. The remainder usually talked about the “substance”. This recognition of an ensemble of particles is an important part of the understanding of this topic.

(b)(i) This was correctly answered by many.

(ii) Large numbers of correct answers were seen. Errors usually centred on quoting the answer in degrees Celsius or adding 273 to an answer that was already in kelvin.
(iii) Many candidates gave sensible responses to this Nature of Science question and showed that they fully understood the role of modelling in physics. No credit was awarded to those who continued to answer in terms of the kinetic theory as the question was clearly formulated in a general scientific context. This was not the case in Spanish language papers where many candidates struggled to say anything meaningful or relevant.

Q4 HL

(a) This was correctly answered for full credit by about half the candidates. Half of the remainder scored 1. Errors were usually seen in the calculation of strangeness and the baryon number.

(b) Many candidates recognised that a d quark becomes a u quark in beta decay. The involvement of a W^- particle was less frequent (commonly, the γ symbol was seen) and the arrow attached to the electron antineutrino was often in the wrong direction. One school in a G2 comment suggested that the Feynman diagram was drawn in a different way from usual. This was not the case, but in any event, examiners will be at liberty to draw the diagrams in either of the two main conventions and candidates should be prepared accordingly. Another respondent felt that the Guide was not sufficiently explicit as to the need for candidates to memorise the quark structure of protons and neutrons. However, this can be deduced using the Data Booklet and the simple knowledge that the two nucleons concerned are composed only of up and down quarks, three in number.

(c) This part was poorly and confusingly answered. Most candidates resorted to telling the examiner that the carbon and nitrogen nuclear masses were different (mentioned in the question). There was a general failure to recognise that (i) there are decay products, (ii) one of these has mass, both have energy, and (iii) that this mass/energy must have come from somewhere. This may be a logical link that needs more emphasis when teaching this topic. Candidates frequently wrote about “energy” as if it were some strange disembodied form. Whenever the word “energy” is used it needs to be qualified (as kinetic, thermal, etc) and placed in context (of the beta particle, turbine, etc). Examiners gave credit for reference to the kinetic energy of the decay products, but not to meaningless statements about ‘energy being released’.

(d) (i) Although it was clear that candidates had a general idea about this question, answers were often too vague for credit. The points to emphasise were that because the number of C-14 nuclei is decreasing and because activity is proportional to the number present, therefore the activity decreases with time. It was rare to see a good statement of this simple physics.

(ii) Candidates are now well practised in the art of exponential decay calculations and many good examples were seen, either using $N = N_0 e^{-\lambda t}$ or work derived from $fraction\ remaining = 0.5^n$. However, the conversion to an "appropriate" number of significant figures was poorly done with a significant number of candidates simply ignoring this instruction – and throwing away an easy mark in the process.

Q4 SL

This question is covered in HL comments – almost identical questions with a similar level of performance.

Q5

(a) (i) Candidates seemed to be expert at suggesting the standard answer of "destructive interference" but were poor when it came to making statements about the actual context. There were many incorrect references to the equation for the required path difference $\left(n + \frac{1}{2}\right)\lambda$ with the $\frac{1}{2}$ omitted or in the wrong place. Technical language was very poor and confused in this question.

(ii) Many were able to arrive at a correct solution but in too many cases candidates omitted the factor of 2. Some are clearly at a loss as to the meanings of the symbols in this equation in the Data Booklet and cast around (usually incorrectly) to match symbol and number.

(b) Candidates had simply to suggest that the receiving antenna was parallel to *the plane of polarization* (too frequently they said parallel to the transmitting antenna – which they were told in the question) and then to go on to predict the effect of the antennae being parallel (maximises the received intensity). The most successful solutions used the Malus Law (alternative 3 on the mark scheme). Alternative 1 and 4 were rarely seen with Alternative 2 much used with only limited success. This was another example of a question where candidates should have taken a little time to plan a coherent answer before beginning to write.

(c) There was a G2 suggestion that the diagram was confusing. However, this was not apparent in the scripts in which large numbers scored well in questions that referred to the diagram. (i) Many had full control of the Malus Law and appreciated which values in the equation correspond to the initial and final intensities. Those who made mistakes in this respect usually gained 1 of the 2 marks.

(ii) This straightforward speed calculation was well done by the majority, but some evidently failed to appreciate the significance of the speed of electromagnetic radiation.

Q6 HL only

(a) (i) Answers were often confused and jumbled. It was sometimes difficult fully to understand what candidates were trying to say. Many were able to identify the frequency increase and those who recognised that the Doppler Effect was the cause scored the first mark too. Descriptions not involving a statement of the effect tended to ignore the relevance of the *relative* nature of the velocities. It was evident that many think in terms of a change in the absolute wave speed and this gained little if any credit given the complete inaccuracy of such a starting point.

(ii) Equally, a majority of the candidates believed that the factor 2 in the quoted equation arises from the need for the signal to cover twice the distance between the car and the radar gun. It was comparatively rare to see a convincing argument here in which there was a good description of the car as, first, an approaching observer and, later, as an approaching source.

(iii) The calculation simply required candidates to substitute into the quoted expression and then to evaluate the speed. The second mark required a comparison with the speed limit. Most candidates were able to score both marks in this simple question.

(b) This was also easy, but weaker candidates were not always able to negotiate the difficulties of (i) including 1.22 in the expression or (ii) manipulating the powers of ten successfully. A common error was to introduce a factor of 2 into the answer.

Q7 HL and Q6 SL

(a) Once again it was disappointing to see candidates failing to reproduce a standard piece of physics understanding. The first mark required a consideration of the work done per unit mass and the second a reference to the correct displacement of the test mass from infinity to the surface of the planet. Although condoned, it was sad to see the surface ignored by many and replaced by the concept of “infinity to the point”. It was clear that candidates were not reacting to the question itself but to a standard definition they have learnt. In this new series of assessments, candidates can expect to see questions phrased in terms of a (sometimes unfamiliar) context rather than a theoretical position and examiners will expect them to be able to react appropriately to the contextual stimulus.

(b) (i) The calculation, a standard piece of equation usage, was well done by many.

(ii) There were three points about the motion of the projectile (again it was a case of interpreting the context): The projectile is decelerating (considerable latitude was allowed in the way this was described and many took advantage of this latitude). The rate of deceleration decreases (this was ignored by most candidates). The velocity is constant when the projectile is beyond the effective gravitational field (latitude was *not* allowed here – candidates could not use the loose “constant speed” and this denied many the third mark). A G2 suggestion that this question was only worth two marks ignores the need in assessments at this level to provide a gradation in taxonomy. The first mark (above) is straightforward; the third tests the technical vocabulary of the candidates. The second mark is designed to be accessible by able candidates who are the most likely to have a good understanding of the true meaning of acceleration as rate of change of velocity. Candidates should always look carefully at the mark tariff to form a judgement of the complexity of the required answer.

(c) (i) Candidate errors apparent in earlier Diploma physics assessments were again evident here. Candidates do not explain their physics in an adequate way when instructed to "Show that...". In this example, it was crucial that examiners be completely satisfied as to the starting point of the physics. Simply launching into a series of equated expressions will not do. Examiners expected to see some recognition of the physics such as "centripetal force = gravitational force" or "speed of projectile = orbital speed" rather than the appearance of disjointed and confused algebra. Solutions where there was no clear indication of a starting point lost marks, only gaining partial credit for unexplained algebra.

(ii) Several issues appeared in what should have been another comparatively straightforward calculation. Many used the wrong time in the expression: 24 h instead of 1 year was common. There was a widespread failure to see (and even write) r^3 but then to use $(1.5 \times 10^{11})^2$ in the evaluation. Candidates at this level of assessment cannot expect credit for carelessness of this sort.

Q8 HL and Q7 SL

(a) (i) Many recognised that R_T increased with increasing current. However, for credit it was important to make it clear that this was linked to increase in current. A bald "increases" did not score, nor should it have.

(ii) This was well done, and shows that the candidates have a good grasp of the relationships between pd and current. This was a two-stage answer: because, for the quoted current, the pd across R is greater than the pd across T, therefore (as $R = \frac{V}{I}$) the resistance of R is greater than that of T. The other crucial step (that the current is the same in both R and T) was not insisted upon which was fortunate as most ignored it. Many candidates incorrectly correlated the gradient of the graph (or, here, its inverse) with the resistance.

(b) (i) This was well identified by most.

(ii) A minority were able to successfully reason that because the pd is the same for both resistors therefore the currents must be about 0.14 A and 0.06 A so that the pd is roughly 2 V. However, it was clear that a large number of candidates have no real conceptual grasp of the relationship between a circuit and the parameters that govern its behaviour. It was rare to see a correct solution to this problem at SL, where most candidates embarked on a series of fruitless calculations involving the resistance of parallel resistances. The invitation, though, was to "estimate" – not to "calculate".

Q9

(a) About half of the candidates identified the field direction (downwards on the diagram) correctly. Some showed edge effects (not expected, but welcome). Only a handful gave completely irrational answers, field at an angle or out of the page.

(b) Few failed to gain some credit here. Most received 2 marks, some 1 mark for a factor of 4 error.

(c) This was also well done but it was crucial that candidates wrote about the direction of the deflection and not just about the path shape.

Q10 HL and Q8 SL

(a) (i) A large number of correct answers were seen. Common errors involved using the wrong time or quoting an incorrect unit.

(ii) The calculation of CO_2 mass emitted was well done.

(iii) Candidates were expected to link the gas to the greenhouse effect and to give one global effect that results from it. Most were successful on both counts.

(iv) This was straightforward but many scored only 1 mark because they could not take the argument successfully beyond one of the number of transfers involved in this energy conversion. The popular correct response was the “kinetic energy of the turbine”. Some candidates wrote spuriously and without credit about the effect of gas or wind on the system; some were clearly thinking about wind turbines for some reason. SL candidates were universally poor at describing energy transformations. A statement that “thermal energy of the steam is transferred to kinetic energy of the turbine” would gain full credit, but “water is heated and the steam turns a turbine” receives zero as it fails to address the question.

(b) (i) There were a large number of failures in significant figure practice here. Only 2 sf was appropriate and allowed. Otherwise the calculation was well done by many apart from a significant minority who either incorporated efficiency on the wrong side of the equation or ignored it altogether.

(ii) The first mark was frequently seen, but often candidates failed to make the point that this is a thermal energy loss proportional to $current^2$. Statements that were far too loose and general in character failed to gain this mark.

(c) (i) Descriptions of the ac generator were generally very vague and unfocussed. It was rare to see three marks scored. 1 and 2 were seen in about equal numbers. This was another case where candidates’ language did not support the complexity of the physics. References to changes in flux linkage were rare and most contented themselves with reference to “changing field lines” (whatever that means in the context of a rotating coil and constant magnetic field). Students should be taught to develop a good command of the technical vocabulary of the subject and to use it accurately in a given situation.

(ii) Candidates who identified the situation and read the question carefully scored well here. But it was easy to lose the mark by assuming that the examiners required the emf in one coil or in all the turns.

(iii) Again, all candidates had to do was to multiply 160 but many had already invented their own question and did not score this mark.

Q11 HL only

(a) Descriptions of the photoelectric effect are regularly examined and candidates are now able to focus on the demands of the question and to write accordingly. Many complete and fluent answers were seen here. This was good to see in this complex and potentially confusing area of the subject.

(b) (i) The graph drawings were good with only a handful failing to gain the intercept mark. More found the higher plateau more difficult to judge with currents that were lower or equal to the original.

(ii) and (iii) These calculations were very mixed. In essence, candidates failed to read the questions carefully before considering their route through the physics. In (ii) many came to a halt having calculated a photon energy of 3.1 eV and then quoted this as the final answer. In (iii) the majority either gave up or subtracted the 2.50 eV failing to score the second mark.

Recommendations and guidance for the teaching of future candidates

Students should be encouraged to

- structure written answers in their heads before beginning to write
- develop a better understanding of the concepts that surround electricity theory
- develop a strategy for providing examiners with a standard description of a topic
- avoid slips in calculations, eg in powers of ten
- transcribe equations and values correctly from Data Booklet to answer book and from question to question
- appreciate the importance of including units in an answer coupled with the need to match the unit prefix to the power of ten of the answer
- recognise that, in assessments of the new course, there will be unfamiliar contexts presented and this is a deliberate part of the test

Higher and standard level paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 6	7 - 12	13 - 19	20 - 23	24 - 26	27 - 30	31 - 45

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 12	13 - 15	16 - 19	20 - 22	23 - 35

General comments

Both papers, HL and SL, matched the Physics guide and were well designed in terms of level of difficulty, curriculum coverage, understanding, application and skill coverage. The range of appropriate command terms was well used.

Section A was designed to measure mainly Topic 1, Measurement and uncertainties. The contexts, light refraction in question 1 and ideal gas laws in question 2 worked well. Candidates demonstrated that the contexts and experiments used in were understood well. Question 3 was designed around the context of well-known experiment, foam exponential decay which was well understood by many candidates.

The options in Section B were well balanced. Each of the options included questions measuring the level of the knowledge, understanding and skills of assessment objectives 1,2 and 3 as required by the syllabus. Questions from section B were set using suitable contexts and applications.

The candidates demonstrated they had enough time to complete the paper. Discrimination of the paper was at an appropriate level and the difficulty of the options the same. We could see many examples of good understanding in each question. Almost all candidates answered all questions from section A and all questions from one option selected. A clear majority of candidates kept responses in the answer boxes provided. Where extension sheets were used students referred to this within the answer box. Handwriting seems to be at a similar level as previous sessions, answers were legible.

The areas of the programme and examination which appeared difficult for the candidates

Some candidates demonstrated difficulty with command terms and did not read and then answer the questions correctly. Most students interpreted command terms well.

Difficulties related to the syllabus details:

1.1 fundamental and derived units; expression of units in term of base SI units

A.1 electromagnetic forces in relativity; determining whether a force on a charge or current is electric or magnetic in a given frame of reference

B1 and 2.2 Free body diagram and Newton second law applied to rotational motion

C1 and 4.4 Reflection and Ray diagrams

Other difficulties:

•Quite often there were arithmetic and algebraic mistakes or calculator mistakes

•The wrong units (sometimes even meter for time; not penalised in most of the questions)

•Powers of ten (POT) mistakes in calculations;

• Some candidates clearly read questions superficially and gave superficial answers or did not answer at all.

The areas of the programme and examination in which candidates appeared well prepared

The great majority of candidates have clearly seen the new Physics Guide and their studies were based on this document. Well prepared candidates could analyse the situations, present working in logical manner and use proper terminology, physical quantities and units. A majority of candidates demonstrated the ability to analyse situations in various contexts, to read and understand the questions. They demonstrated an understanding of the facts and concepts using them with proper terminology. Most of the candidates could clearly present well known facts in appropriate words and sentences. The layout of working in numerical questions and sequencing of facts to support an explanation and description was better in this exam session.

The strengths and weaknesses of the candidates in the treatment of individual questions

Section A. All questions were accessible to most candidates.

Q1

(a) The vast majority of candidates outlined the reason for greater percentage uncertainty of OY and calculated percentage uncertainty of the refractive index measurement. Some candidates omitted mentioning the same uncertainty in OX and OY (i). Some candidates experienced difficulty with fractional uncertainty in (ii).

(b) The majority of candidates answered (i) and (ii) well, the vast majority of candidates, did not realise the small angle approximation is used in the experiment. The refractive index in (ii) was usually calculated from one point or from a gradient based on two measured points; even if majority of candidates drew a line, only the best candidates used a suitable line and a gradient this line. Answers varied from 1.2 to 1.6.

Q2

The correct unit for the gradient of the pressure-time diagram in terms of SI base units was determined only by the best prepared candidates. Lots of answers contained derived units or incorrect base SI units. A high number of candidates did not answer (bi) well. Part (bii) was answered well..

Q3

Most candidates answered (a) well, some candidates did not realise that the time should be determined and only the corresponding half height identified. In (b) a nice variety of correct answers were seen, most of them mentioned in the mark scheme.

Section B.

Option A. Relativity

Q4

Frame of reference was properly defined only by the better candidates. In (b), length contraction for the proton separation is clearly not understood; it can be hard to find correct answer here.

Q5

Generally (a) and (b) were both well answered, though proper length was defined quite clumsily sometimes. Part (c) was well answered by only the best candidates.

Q6

The angle of the worldline was correctly determined by about three quarters of the candidates and most of the candidates also correctly drew the axis. The coordinates of the event were properly constructed by only the best candidates.

Q7

(a). Most students found this quite an easy question, but many candidates considered only half of the journey here.
(b) The time taken in the reference frame of twin B was generally determined well by using gamma.
(c and d) The standard spacetime diagram for the twin paradox was seen only from the best candidates and generally was not used in the answer to (d). In (d) many candidates omitted to mention, how the paradox arises.

Q8 (HL only)

In (a) only the best candidates referred to conservation of momentum. Calculation of the speed of incoming electron was well grasped by about half of the candidates and quite often with errors in details. Less than a quarter of candidates calculated the answer to (c) correctly.

Q9 (HL only)

The GPS time delay was well attempted by only the best candidates.

Option B Engineering physics

HL Q10, SL Q8

Well answered only by average and better prepared candidates, (c ii) only the best. Most of the candidates omitted that a falling object is being accelerated.

HL Q11, SL Q9

Generally good ideas presented, but often not in detail or not clearly enough.

HL Q12, SL Q10

(a) Very easy data booklet question, quite a high number of candidates omitted Kelvins transformation.

(b) Many failed to release that Carnot efficiency is only theoretical.

(c) Many calculation errors can be seen here, only the best candidates gained all three marks.

(d) Most candidates had difficulty in answering questions of the “discuss” type. Most of them wrote quite vague answers.

Q13 (HL only)

(a) In (i) many candidates calculated only mass, not weight. In (b) finding the proportion of the cube above the surface was difficult for average candidates, most of the best candidates calculated this in a quite straightforward way and very clearly.

(b) Continuity equation and Bernoulli effect were used by average and best candidates correctly. Many candidates did not mention the height/pressure dependence, what was necessary in this complex problem.

Q14 (HL only)

(a) (i) was answered well, most of the candidates connected energy and amplitude. 14 (a ii) was answered well by only a few candidates who noticed that energy is still being added, but at the same time is lost due to damping.

(b) About half of the candidates understood that the graph for critical damping goes to zero in less than one cycle and does not go negative.

Option C — Imaging

HL Q15, SL Q11

(a). This question was correctly answered by only a very few candidates. Making the angles of incidence and reflection equal was rarely seen. The best candidates used a normal and constructed a reflected ray using a second ray parallel to incident ray.

(b)(i) and (b)(ii) were easy questions and usually correctly answered in terms of spherical aberration and use of a parabolic mirror. A few candidates mistakenly referred to chromatic aberration.

HL Q16, SL Q12

Generally a well answered question. In (a) an easy mark for stating converging lens; in (b) the majority of answers were correct, though many candidates got into difficulty by starting with $v/u = -4$. In (c) most correctly found $f=0.96\text{m}$, ECF was applied if the answer to (b) was wrong.

(d) Easy 2 marks. Quite a few mistakenly described the image on the screen as virtual.

HL Q17, SL Q13

(a) A relatively easy question.

(b) No problems identified here.

(c)(i) Very few candidates referred to IR having lower energy photons. Answers were allowed in terms of power collected or resolution.

(c)(ii) Quite well answered. Many candidates knew about telescope arrays and radio interferometry.

(d) The number of candidates who knew that the intermediate image in compound microscope should be between the microscope eyepiece and f_e was disappointingly small.

(e) There were plenty of correct answers, but also many which referred to chromatic aberration and assumed that UV light was monochromatic.

HL Q18, SL Q14

(a and b) Generally quite well answered, although candidates sometimes failed to mention the direction in which refractive index decreases in graded index fibre.

Q19 (HL only)

(a) A few candidates misread the log scale, but there were many correct answers for this 'show that' question.

(b) Generally quite well attempted, with ECF sometimes needed if the log scale was misread.

(c) Not an easy mark, only the better prepared candidates realised and suggested that the image would lack contrast.

Q20 (HL only)

(a and b) Answers to both parts showed that candidates have become quite good at answering MRI questions. Some of them did not realise that they should focus their answers to gradient field and resonance and wrote unnecessary information about MRI.

Option D — Astrophysics

HL Q21, SL Q15

(a) Answered well by many candidates, a common inadequate answer was 'two stars orbiting each other'.

(b) (i) The majority of candidates realised that *d* was the same for both stars and so the ratio of brightness was the same as the ratio of luminosities.

(b) (ii) Reasonably well attempted, though many weaker candidates experienced difficulty with the formula for the surface area of a sphere.

(c) Many candidates did not point out that the temperatures of the two stars were similar.

(d) Very well answered question.

(e) The position and evolution of the star on the HR diagram was usually correct, weaker candidates often placed the present position too high in the HR diagram, some of them did not use the data given.

HL Q22, SL Q16

Candidates were required to read values from 2 graphs. Many mistakes were made, especially with the log graph. ECF was frequently used in marking. Many weaker candidates did not give answer in pc, which was required.

HL Q23, SL Q17

(a) Many candidates found this question difficult, weaker candidates recalled CMB radiation but only the best were able identify that the CMB radiation is homogenous, isotropic and is a black body radiation.

(b) The red shifted value for the spectral line was correctly given by the better candidates.

Q24 (HL only)

(a) Candidates, who knew enough about type 1a supernovae, had no problem describing how white dwarf stars become supernovae. Weaker candidates wrote some partially correct ideas.

(b) Candidates usually stated that they have a known luminosity, but only the best explained a reason for that.

(c) The fact that some distant type 1a supernovae are dimmer than expected was explained by only the best candidates and that this leads to dark energy.

Q25 (HL only)

(a) This question was well answered but too many candidates forgot to convert kpc to m when determining the rotation velocity of stars.

(b) The rotation curve evidence for dark matter was generally well argued.

Recommendations and guidance for the teaching of future candidates

Strategies regarding the initial reading of a problem should be emphasized and practiced. Many answers go on to address the topic as it has probably been learnt without a careful understanding of the context and therefore the subtle points of a specific text of the question.

Candidates should be given more opportunities during the course to practice examination style problems. They should also be familiar with mark schemes as to try to guide their answers linked to the number of marks allocated.

Candidates should be provided with, and given assistance with, the list of action verbs as specified in the guide.

When using a diagram to help answer a question, candidates should be encouraged to pay attention to the precision of the diagram.

Enough time should be devoted to cover in depth the Option chosen. Core physics should also be considered in answering questions in options.