Physics timezone 2

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-14	15-25	26-36	37-46	47-56	57-66	67-100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-12	13-21	22-31	32-41	42-51	52-61	62-100

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

The range of work submitted was from the basic (e.g. confirming Hooke's law for a rubber band, measuring electrical resistance of putty) to the sophisticated (e.g. measuring the earth's magnetic field, real and theoretical gravity turning points for a water rocket). Some topics, such as the Gauss gun, projectile motion, temperature and viscosity, and resonance of a musical string, were performed many times. Results varied from very poor work to outstanding work. Although the chosen topic is important, how the student approaches the topic and what they do with it is most important for a successful investigation. Most of the investigations were traditional hands on: mechanics, waves, electricity, and fluids were the most popular topics. There were a few database labs, but these followed predictable research questions or copied TSM samples. There were a few computer simulations, some of these also copied existing TSM samples. Some investigations that were not successful were those that included multiple independent variables, investigations that padded their report with two or three separate but topic related investigations, and investigations where the physics background was simply made up by the student when there was established textbook theory. The most successful investigations had well-defined research questions, clearly identified variables and an

appropriate means to measure and relate the variables, and an appropriate and known scientific background. Most importantly, the successful investigations were scientifically interesting and relevant to the IB curriculum and showed genuine student involvement.

Candidate performance against each criterion

Personal Engagement Strengths

When a student report demonstrates independent thinking, initiative or creativity, or when there is some personal significance, interest and curiosity relating to the research question, or when there is personal input in the design or implementation or presentation of the investigation, then and only then has the student addressed the criterion of personal engagement. PE is assessed holistically, not in a section or paragraph with the heading Personal Engagement. 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 top PE descriptors. Here, students would demonstrate a thorough and detailed analysis, a deep understanding of the issues, and a dedication to quality scientific work.

Personal Engagement Weaknesses

Students would often over-emphasize 'personal significance' by writing what seemed to be artificial comments about their interests. Moreover, their background interest would not be related to a specific research question. For example, the love of music is not related to an investigation into the speed of sound. Why then full a page of personal history playing a musical instrument? Teachers need to encourage students to demonstrate their curiosity and insight in the investigation itself, in the nature of the 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. Personal engagement in an exploration should demonstrate student input and initiative in the design, implementation or presentation of the investigation, where there is significant independent thinking, initiative or creativity in the work. Because PE is assessed in a holistic way, students must not add a sub-title section "Personal Engagement."

Exploration Strengths

There were a number of interesting and challenging investigations. These always included a single and well-defined independent variable and a quantifiable dependent variable. Appropriate investigations made use of known scientific concepts and relevant equations, and they would establish a relationship or function between two variables or determine an important scientific constant. Issues of safety, ethical and environmental concerns were mentioned when appropriate. Some successful investigations included variable mass and the Atwood machine, metronome synchronization, wind speed and lift force on a flat roof, the Earth's magnetic field, temperature and resistance using a Wheatstone bridge, a filament light bulb as a black body radiator. There were some interesting database investigations, including mass-life relationship

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for stars. Mathematical modelling investigations included a study of rocket launch fuel efficiency and the gravity turning point. Computer simulation investigations included discharge of a capacitor, intensity of reflected light and incident angle, and double-axial symmetry balance analysis. There were also several successful investigations on the nature of large amplitude pendulums where theory and experiment were compared. The key in all of these examples was that the student understood the physics of their investigation and established some relevant and interesting conclusions from data analysis.

Exploration Weaknesses

Assessment of the Exploration criterion was occasionally over-marked by teachers. It is this aspect of an IA that is most important for the possibility of a student's success. Too many times students would select multiple independent variables, perhaps thinking this would enrich the investigation when it fact it inhibited it. Often the known context of a research question was not addressed but would have been helpful to the student to focus and clarify their work. Academic research is expected. Made up physics-like explanations do more harm than good. Historical background is not relevant. Two pages on the history of the guitar when investigating how tension affects the frequency of a guitar string is irrelevant information. Students need to explain their methodology and assumptions as well as the scope and limit of their investigation, but they do not need to give pedantic step-by-step instructions. There were numerous investigations about viscosity and temperature, projectile motion without any depth of understanding, formation of craters, and the most popular of all, refractive index of water with salt or sugar solution. A number of students were fascinated by the Gauss gun and attempted mediocre investigations. Please make sure students understand the topic they want to study. There were some meaningless investigations too: relating the distance covered by a wheel in one rotation as a function of the wheel diameter; investigating how the time to run up a flight of stairs relates to the power exerted; or how mass affects the moment of inertia. In these cases, the independent variable is also the assumed dependent variable.

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. Most students demonstrated a sound mastery of analysis. The majority of students demonstrated the ability to obtain and record data, including raw uncertainties. In most cases, data tables were clear and consistent with scientific notation. Processing was often detailed, with sample calculations of complex computations. Samples of simple calculations are not required. Graphs were nicely presented often with error bars. Most student graphs were computer generated, and in most cases known theory directed the appropriate graph representations. Occasionally students used more advanced methods of error analysis, and this was successful.

Analysis Weaknesses

Some data tables were confused and hard to understand. Column headings should include the quantity, units and uncertainty with units. Some graphs lacked appropriate detail, and others were too small to appreciate or had too much information entered on a single graph. The terms 'proportional' and 'linear' were not always understood correctly. The construction of minimum

and maximum gradients, when the gradient was meaningful, was often done in an unrealistic and extreme way. Students need to appreciate what their data does and does not reveal. A number of times a student graphed relevant data where the data scatter suggested a curve and yet the student forced a linear fit. The linear fit was then used to establish a bogus conclusion. Often a forced linear fit would imply a meaningless or impossible physical result when one axis quantity was zero. In most cases, graphs should have zero-zero origins. There were occasional inconsistent expressions of significant figures. What is the physical meaning of an uncertainty of 27.853%? The general rules should apply: (1) No calculation can improve precision. The result of addition and/or subtraction should be rounded off so that it has the same number of decimal places (to the right of the decimal point) as the quantity in the calculation having the least number of decimal places. That is to say, a sum or difference is not more precise than the least precise number. (2) Significant figures in the result of multiplication and/or division should be rounded off so that it has as many significant figures as the least precise quantity used in the calculation. A product or quotient has no more significant digits than the number with the least number of significant digits. Teachers need to ask students to understand what they are saying. Occasionally students would fill pages with formal or purely mathematical error analysis without reference to the physical meaning of their data. The focus needs to be on physics.

Evaluation Strengths

The evaluation criterion remains one of the most demanding. Teachers often over-mark this criterion. Students should describe in detail and justify a conclusion for their investigation based on the original research question and their data analysis. Focus is the key here. Appreciation of the quality and range of data should be included. The propagation of uncertainties is relevant. When there is a known scientific context or accepted value, then students need to compare their result with the accepted value. When there is no such value then a reasonable interpretation of the accepted scientific context should be given. For example, a student claimed that the refractive index of water at 85°C was 5.2. The student never thought this might be wrong, as their data was thought to show this. Another difficult component of the evaluation criterion is an appreciation of the strengths and weaknesses of the methodology involved in the investigation. The more successful student reports showed an appreciation for any assumptions of their methodology. Finally, students need to suggest realistic and relevant improvements as well as possible extensions of their investigation. These need to be specific and based on an evaluation and appreciation of the weaknesses or limits. Significant improvements can be understood as an extension.

Evaluation Weaknesses

Often students stated they 'proved' their hypothesis about their research question without re-stating it in the context of their data and methodology. An appreciation of the scope and limit, the methodology and any theoretical assumptions should be addressed when evaluating a conclusion. Too often students made general and qualitative comments only: "I am pleased with my results; I proved my hypothesis." 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 graph they would have seen the senseless meaning of such an equation. Students need to appreciate the physical meaning of the quantities under investigation, and so they need to interpret the data correctly. The graph of one student investigating mass and period of a SHM oscillator claimed

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that with zero mass the system would oscillate with a period of 4 seconds. There is more to a graph than a simple equation. Finally, evaluations were often superficial, blaming human error or friction, or systematic error when the best-fit line was an inappropriate and meaningless line fit. Suggesting a more precise rule would result in more accurate measurements seems artificial.

Communications Strengths

The Communications criterion more often than not successfully earned marks in the 3-4 mark-band. 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 and did not ramble on with generalities about the student's interest, historical background or unnecessary pedantic details. The best reports had descriptive titles, like "How temperature affects the refractive index of water" and not titles like "Bending light" or "Bouncing balls." The majority of reports used correct and relevant scientific notation, equations and units. MS Word has a built-in equation editor, and students are expected to present equations properly. The majority of reports were within the 12-page expectation. It has becomes clear that ten pages is a perfectly reasonable length for a focused and concise IA report. Occasionally, however, an extended report flowed well and wasted no space, and as such, for example, a 16-page report was not penalized under Communications. Reasonable margins, spacing, appropriate scales of graphs and data tables, all help the communications criterion. It is best to avoid 8-point font and single-spaced text. Most students consistently and appropriately provide references to their work (in a variety of consistent and acceptable ways). Any picture image copied from a source must be referenced, not just a listing in the bibliography. Academic research is expected. Research questions and hypotheses need to be supported by relevant scientific information, relevant to the investigation and not just historical background.

Communications Weaknesses

A number of students omitted any sort of investigation title. Titles should be descriptive. For example, "Using a conical pendulum to determine gravity" is appropriate but a title like "Gravity" or "Physics Investigation" is not appropriate. A cover sheet or title page is not necessary. A table of contents may give the reader an overview but is not necessary either. Several pages of the history of physics or standard textbook theory not directly related to the research task wastes space and demonstrate a lack of focus. Although the moderator needs to know how the student performed the investigation, they do not need simplistic and obvious comments like: "Set up the equipment, turn on the computer….." Often students include photographs when a clear sketch would have been better. Colour photographs of a metre rule, or a stopwatch, or electrical wires do not help the understanding of the work and is a waste of space; superfluous text distracts the reader from the flow and logic of the investigation. A good individual investigation does not need to resemble a cookbook approach. Too often images taken from books or the Internet were not referenced. Communications does not penalize for lack of references but rather when this occurs it becomes a serious IB issue of academic honesty and possible plagiarism. Simply listing a number of texts or websites at the end of the report without using them is not referencing. Some students padded their investigations with artificial research references that were never used.

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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 a draft.
- Students need to acknowledge and appreciate the physics that is already known about their research question. Too often students made up common sense physics or failed to appreciate well-known theories.
- Teachers should encourage students to include a descriptive title to their report and to make sure the research question is identified and explained within the first paragraph. A title page or a table of contents is not necessary when a report is concise and focused.
- All images (pictures, diagrams) and any ideas that are copied must be referenced. A bibliography at the end should only include sources that were actually used and properly referenced within the text.
- Research questions are most appropriate for assessment when they address a function or relationship between two variables, or where they experimentally measure an important constant in nature. Research questions should be both challenging and scientifically interesting. The purpose of the investigation can be expressed as a research task, and not necessarily in a form of a question.
- Students should not assume that data scatter graphs must be forced into a best-fit linear line. In many cases the physics meaning of doing this goes against known theory and common sense. For example, one student forced a linear line fit on a Newton cooling curve graph. If, however, a proper function is found then such quantities can be graphed in a linear graph. Computer fitted polynomials can fit any data scatter, and students need physical reasons for selecting a complicated best-fit line.
- It is important that students have a sound knowledge of the assessment criteria. Teachers can discuss extensions to class investigations or ideas relating to topics studied throughout the school year, so when students are expected to come up with their own research topic, their minds are full of exciting possibilities.
- Make sure students use physics terms correctly. The change in temperature is not temperature, velocity is not average speed, distance is not displacement.
- Students should not copy existing IAs as published by the IB as teacher support material or follow detailed worksheets as published by commercial IB support companies or purchase so called teacher marked IA reports.

Further comments

- Teachers application of the assessment criteria is mostly in line with IB standards, but occasionally, when teachers' over-mark or under-mark the student's script, then the examination team needs to moderate the student's total. When this happens, the schools receive feedback. If the teacher's assessment is within tolerance, however, then there is no feedback to the school.
- When teachers upload a student's IA and enter criteria marks there is additional space for entering comments about their assessment of the student's work. Teachers should take advantage of this aspect and share with the examiner their reasons or evidence

for the awarded marks. Alternatively, teachers can add comments throughout the report or, preferably, at the end of the report. It is best not to simply copy the official five pages of IA criteria and checkmark the assessed levels.

- Teachers should realize that issues of uncertainty and error analysis appear under the Exploration, Analysis and the Evaluation criteria. However, each time the issues are addressed from a different perspective. In Exploration, students should take into consideration significant factors that may influence the quality of work. Under Analysis, students need to appreciate the impact of uncertainties, and this is a quantitative appreciation. Under Evaluation, students should discuss the limitations of the data, as well as the sources of errors and uncertainties.
- Under the criterion of Evaluation, procedural and methodological issues are distinguished. Procedural issues (mark band 1-2) are a fixed set of steps, not a generalization. They are a subset of methodological issues. For example, taking more data, or extending the range of data, are both procedural issues. In mark bands 3-4 and 5-6, methodological issues are mentioned, and these issues address the assumptions in the method, and may include suggestions on new ways to measure the quantities or alternative approaches to the research question.
- For the May 2018 exam session, Standard Level IA totals earned on average between a high grade 4 to low grade 5, while Higher Level IA totals earned on average from a low grade 5 to a high grade 5.

Paper one

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0-10	11-13	14-17	18-20	21-24	25-27	28-40

SL

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.

Slightly more of the total number of teachers or the total number of centres taking the examination returned G2's this session but it was still only a small percentage. For SL, there were 141 responses from 1032 centres and for HL there were 226 responses from 1018 centres. While this return rate may indicate a general level of satisfaction with the papers, we strongly encourage teachers to take the time to provide us with thoughts about the papers and

the individual questions. The G2 comments are always carefully considered and they do inform the grade award process and future question writing.

The HL (SL in brackets) paper was regarded as being of appropriate difficulty by about 83% (80%) of the respondents with 17% (19%) finding it too difficult. The papers were deemed to be of a similar level of difficulty as the previous year's paper by 47% (48%) of respondents, although it should be noted that both papers were considered more difficult than the previous years by 33% (32%). 77% of respondents at both levels felt that the paper was deemed to have good or better 'clarity of wording' and 86% of respondents at both levels judged the presentation to be good, or better.

It must be stressed that this very positive feedback was from only about 14%(22%) 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 most of the questions met with general approval.

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

Time

The syllabus specifies that 50% of multiple choice questions will require AO3 skills and students should expect some questions to be answered in well under a minute allowing extra time for questions of greater complexity.

There is evidence from the number of blanks that both SL and HL candidates may have struggled a bit 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 14 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. There is very little that needs to be memorized 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.

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

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Statistical analysis

HL

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Multiple Choice Analysis Report

PHYSICS HL PAPER 1 (MCQ) Timezone 2 MAY 2018 in Question order

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1109	1610	5385	608	33	61.58	0.37
2	798	6867	708	324	48	78.52	0.26
3	100	52	264	8318	11	95.12	0.10
4	1293	4334	2335	679	104	49.56	0.48
5	2189	5137	668	737	14	58.74	0.52
6	2687	2928	2630	389	111	33.48	0.32
7	622	4062	585	3452	24	39.47	0.38
8	6839	1038	428	409	31	78.20	0.28
9	3783	3003	1146	736	77	34.34	0.27
10	1990	1371	1481	3794	109	43.38	0.40
11	1442	1521	885	4881	16	55.81	0.38
12	5099	2165	710	761	10	58.31	0.41
13	2214	2300	3112	1029	90	26.30	0.18
14	381	657	6995	701	11	79.99	0.30
15	793	676	3144	4106	26	35.95	0.39
16	431	629	5928	1742	15	67.79	0.51
17	1307	1587	520	5279	52	60.37	0.39
18	3144	1634	830	3090	47	35.33	0.29
19	5987	1117	1034	539	68	68.46	0.47
20	497	5937	1091	1194	26	67.89	0.42
21	692	699	1347	5966	41	68.22	0.58
22	5601	1000	1323	794	27	64.05	0.35
23	4966	1882	1447	423	27	56.79	0.40
24	133	4524	162	3896	30	44.55	-0.09
25	957	6796	449	531	12	77.71	0.37
26	2242	1012	1991	3436	64	39.29	0.47
27	5286	1856	643	891	69	60.45	0.41
28	3158	960	2996	1546	85	34.26	0.25
29	3968	3449	755	524	49	45.37	0.17
30	543	1120	5154	1888	40	58.94	0.26
31	765	2064	4786	1096	34	54.73	0.40
32	274	837	7297	303	34	83.44	0.34
33	623	3282	2845	1942	53	32.53	0.24
34	2083	1342	1091	4163	66	23.82	0.34
35	3008	2930	1471	1159	177	34.40	0.30
36	459	853	5022	2347	64	57.43	0.48
37	1698	4699	1581	581	186	19.42	0.19
38	1379	5381	1401	493	91	61.53	0.53
39	1449	2722	4022	428	124	31.13	0.26
40	2053	1456	3947	1161	128	45.13	0.25

Number of candidates : 8746

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SL

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Multiple Choice Analysis Report

PHYSICS SL PAPER 1 (MCQ) Timezone 2 MAY 2018 In Question order

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1294	1771	2017	388	33	36.65	0.25
2	1409	510	605	2963	16	53.84	0.55
3	663	3790	733	271	46	68.87	0.32
4	94	46	590	4769	4	86.66	0.24
5	1193	1927	1585	709	89	35.02	0.33
6	2182	2047	566	697	11	37.20	0.39
7	187	568	4221	517	10	76.70	0.41
8	897	1160	1659	1707	80	16.30	0.11
9	1015	803	2273	1393	19	41.30	0.34
10	399	2771	1902	415	16	50.35	0.56
11	3703	899	477	400	24	67.29	0.37
12	2673	873	806	1128	23	48.57	0.30
13	2784	552	1962	194	11	50.59	0.47
14	1318	1254	1179	1683	69	30.58	0.33
15	1121	1079	889	2399	15	43.59	0.37
16	2615	1585	697	589	17	47.52	0.41
17	672	2448	1844	495	44	33.51	0.36
18	1179	2319	694	1260	51	22.90	0.27
19	449	868	3536	629	21	64.26	0.44
20	646	828	1216	2770	43	22.10	0.11
21	1302	1456	1043	1681	21	30.55	0.27
22	1623	1327	821	1630	102	29.62	0.44
23	1965	679	1836	994	29	18.06	0.15
24	1558	1519	713	1641	72	29.82	0.16
25	2707	1062	1048	609	77	49.19	0.47
26	347	1149	3112	817	78	56.55	0.52
27	442	952	2837	1224	48	51.55	0.46
28	847	791	1355	2418	92	43.94	0.60
29	4199	751	113	382	58	76.30	0.22
30	1219	2454	913	756	161	44.59	0.40

Number of candidates : 5503

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 accepted answer is indicated by a shaded cell.

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 24% in HL and 22% in SL (relatively 'difficult' questions) to about 84% in HL and 77% 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. In both papers, there was an even range of difficulties amongst the questions, which led to a normal distribution

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of marks. This meant that both papers were effective assessment tools with the mean mark being slightly higher for HL (1.2%) and slightly lower for SL (1.05%) than the previous May.

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.

The majority of questions had a positive value for the discrimination index (only HL 24 had a negative index). Ideally, the index should be greater than about 0.2. Five HL and four 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.

SL and HL common questions

4 HL, 5 SL

This question has a good discrimination index at HL with more candidates choosing the correct response at both levels. The popularity of responses followed the same order B,C,A,D suggesting that the most common mistake was in finding the area under the graph followed by forgetting to account for the mass.

5 HL, 6 SL

This question gives good discrimination at HL with the correct response being the most popular. Response A was second most popular at HL and most popular by a small margin at SL. These candidates appear to have forgotten that not only is vertical motion considered where the speed at the highest point is in fact zero but the ball also has a constant speed in the horizontal direction.

10 HL, 14 SL

There was some concern expressed on the G2s that this question was too lengthy however it provided good discrimination at both levels with the correct response proving to be the most popular.

11 HL, 15 SL

Some G2s gave the opinion that the wording of this question was confusing and it is accepted that it is perhaps not in the style normally seen in this type of question. However, the correct response was the most popular and at both levels it gave good discrimination. The wording has been improved for publication.

15 HL, 20 SL

The most popular response was D at both levels with the correct answer C second. SL candidates had problems with this question with a difficulty index of 22 and discrimination index of 0.11 meaning that it was answered incorrectly more often by stronger candidates. The question asks about the electromagnetic force and the chosen answer suggests that many candidates were focussing on the 'magnetic' rather than the 'electric' portion of the name even though there is no magnetic field mentioned in the question. There were some comments in the G2s that the use of 'electromagnetic' was confusing but it is a term that is used in the guide and as such should be familiar to candidates.

18 HL, 24 SL

Responses A (incorrect) and D (correct) were equally chosen at HL with A, B and D almost equally popular at SL. Choosing response A implies that although candidates removed the background count to work out the remaining activity they then forgot that it would still have been present and needed to be added back to the final answer. Option B suggests that they ignored the background count completely.

19 HL, 25 SL

This question provided good discrimination at both levels with the correct response being the most popular.
21 HL, 28 SL

This question also provided good discrimination at both levels with 61% of the HL candidates choosing the correct response.

HL only questions

7

Option B was the most popular answer with candidates forgetting that momentum requires the consideration of velocity which becomes negative after rebounding from the wall whereas the graph gives them the variation of speed with time. This is a good example of a question that candidate's need to read carefully especially taking account of diagrams that are provided, they

are there to provide information that helps with answering the question, not just to make the paper look more attractive.

9

This proved to be a challenging question with Option A the most popular response. The question applies knowledge of the ideal gas equation but the answer chosen suggests that candidates were considering the volume of Q rather than the volume of the complete system.

13

The difficulty index suggests that candidates found this hard and a low discrimination index means that better candidates were often not getting it correct. Option C was the most popular response, perhaps students were considering half not full wavelengths. Students should approach this question by considering the second harmonic where $f = v/L$ and then the fourth harmonic, when the node is next in the centre of the string and $L = 2\lambda$, freq. $= 2v/L$ or $2f$ to reveal the pattern leading to answer B.

24

This has a negative discrimination index which indicated that more candidates scoring low marks overall are answering it correctly. The most popular answer is B. This is an example of a question where candidates have to think carefully about the overall situation. Considering the SHM only it is correct that the restoring force at B is zero because the displacement is zero but there is also a resultant force upwards (the tension force is greater than the gravitational force) so the <u>resultant</u> force is never zero. Another possibility is to realise that at the lowest point the bob is changing its velocity, in direction, and therefore the net force on it cannot be zero. This is a question that is worth discussing experimentally by observing a force meter at its maximum extension when the bob of a pendulum hanging from it goes over the lowest point in the oscillation.

25

There were some comments on the G2s asking what the angle θ represents. Most of the candidates answered this correctly but to aid clarity a label has been added to the diagram for publication.

28

Slightly more candidates chose A than the correct answer C. This is a question that can be answered simply by inspection, knowing that the gravitational potential is maximum closer to the smaller mass. It is also easy to remember if candidates realise that the value on the surface of the larger planet is much greater in absolute value and then the value will have to increase and then decrease to a much smaller absolute value on the surface of the smaller moon thus reaching a maximum close to the moon. It could also be calculated using GM/r^2 which gives a ratio of positions 20R:2R and their choice would imply that they have unfortunately taken the 2R as the distance from the planet rather than the moon.

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33

A large number choose D suggesting that candidates had problems with this question. The question can be answered by just considering Lenz's Law – the current in A causes an induced magnetic field which produces currents in B and C in such a way that they will oppose that changing magnetic field – considering the points where B, A and C are closest in the centre of the diagram, the current in A will point from top to bottom of page so the current in B and C will point from bottom to top of page. Also, the increasing current in A causes a magnetic field into the page across B and therefore current in B must flow to create a magnetic field pointing out of the page i.e. a North Pole if viewed from above. It is useful to remember that the shape of a letter N with arrows on its tips can help candidates to remember that current will flow anticlockwise in B.

34

Nearly half the candidates chose Option D. This is an example of a question where a candidate should pause and think about the question and then look carefully at the given answers to see which makes sense. Candidates should know that considering Faraday's Law no change in the magnetic field across the coil will produce no induced emf giving the emf as zero once within the field so D is the first answer to be discarded. Next, consider that the emf induced on moving into the field will be in the opposite sense to that induced on moving out and also that the change in field is constant so the induced emf is constant giving A as the only possible correct answer.

37

Candidates had some problems with this question with more choosing B than the others combined. This is the maximum kinetic energy of the electron at the surface of the photocathode ignoring the fact that there was a battery in the external circuit. Those who appreciated that 2eV provided by the 2V battery was also involved chose A and C in almost equal quantities implying that there may have been an element of guesswork involved. The battery is connected as a stopping potential so the correct answer is A with the 2V decreasing the energy of the photoelectrons by 2eV.

SL only questions

8

Candidates found this very difficult as shown by the low value for the difficulty index. The correct answer was the least popular of the options. If candidates had considered the four options carefully they may have realised that options C and D could be discounted because they give an incorrect unit. They also needed to realise that a **weight** was tied to the trolley whereas the relevant equations require the use of the **mass** or W/g.

17

This should have been a straightforward question but the most popular answer was 45° rather than 90°.

18

The most popular response was B with the correct answer D and option A very close in popularity. It would appear that candidates did not consider the varied length units in both the question and answer with sufficient care. Their choice of A also implies that they may have confused the meaning of the symbols in the relevant data booklet equation.

23

This was a question where 2 wrong answers were very popular. It is a slightly different version of the normal form of this question and candidates probably were looking for the answer 'continues along the tangent to the circle' and were surprised when it wasn't among the choices. When they are unsure of an answer it is a good idea to see if they can reject any of the answers immediately or in a situation like this try and form a mental picture of the mass and what will happen next.

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 warm up questions to stimulate discussion as well as for quick tests and should never be regarded as add-ons only to be practiced, a paper at a time, for the final examination session.

Well-constructed multiple-choice questions can be very beneficial in addressing student misconceptions about a particular topic. Looking through many of the questions on these papers it is easy to see that candidates who did not fully understand the topic or who held a common misconception would choose a particular answer over the correct response. This can be a very useful teaching tool, particularly when that information can be aggregated to determine how the class as a whole is understanding a particular concept.

Arithmetically the students should be adept at dealing with powers of ten quickly and efficiently. Total reliance upon a calculator for simple cancelling and combining the powers of ten can be a waste of valuable time. Overreliance on a calculator also can cause candidates to potentially panic on this paper when they are faced with a calculation in a question. The non-calculator mathematical skills of cancellation, estimation, mental arithmetic and dealing with powers of ten may need to be taught explicitly to students.

Teachers frequently comment on unfair 'tricky' questions. In order, not to be 'tricked', candidates must read the question very carefully to visualize the situation. This visualization will involve stepping back from the question and understanding what is happening. It can start with thinking about what core physics concepts are involved in the situation and what the candidate knows about those concepts. Plunging into the minutiae of a question or scouring

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the data booklet without first thinking about these steps first can cause students to fall into traps rather than see the correct answer.

There is no single most successful strategy with multiple choice questions, 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
- Consider the units. Paying attention to units can sometimes lead to the identification of the correct response
- Exaggerate a variable – this will often point the candidate in the correct direction
- Draw or visualize the situation while reading the stem. A simple sketch will aid in understanding and often lead the candidate to the correct response. This is particularly important for students who are not testing in their native language
- Distinguish between cos, sin and tan functions – mentally making the angle 0° or 90° will often show which is correct
- Use proportion: new quantity = old quantity x 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

Candidates should try every question. It should be emphasized that an incorrect response does not give rise to a mark deduction.

The stem should be read carefully to identify or highlight key words or phrases. 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, in order 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. Occasionally there are items in physics that need to be memorized but the students should not expect to find many multiple-choice questions based purely upon memory. That said, student understanding of core concepts and definitions often impacts how they read and answer multiple choice questions. It is also worth noting that current specifications require that about 50% of the items will be AO3 questions involving higher order thinking skills.

Candidates can expect the proportion of questions covering a particular topic to be the same as the proportion of time allocated for teaching that topic, as specified in the physics guide.

Paper two

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0-9	10-18	19-26	27-35	36-43	44-52	53-95

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0-3	4-7	8-10	11-15	16-20	21-25	26-50

General comments

HL

From the G2 comments 67.7% of respondents (from 226 forms) felt that the paper was of appropriate difficulty, while 32.3% felt it was too difficult. 46.5 % felt that it was of a similar standard to last year's or easier, while 55% felt it was harder.

SL

From the G2 comments 74.5% of respondents (from 141 forms) felt that the paper was of appropriate difficulty, while 25.5% felt it was too difficult. 56.0 % felt that it was of a similar standard to last year's or easier, while 44.0% % felt it was harder.

Candidates were able to show strengths in all areas of the syllabus tested by this exam paper. The sub-topics that provided the most blank answers at HL were capacitance and nuclear physics and at SL were EMF, internal resistance and binding energy.

Many candidates' answers were well structured and examiners commented that there were fewer issues when it came to following lines of arguments or calculations.

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

- resolving forces
- applying conservation of energy and momentum
- describing pressure in terms of the molecular motion of gases
- calculating the wavelength of a standing wave
- the concept of internal resistance
- (HL only) energy changes in gravitational fields
- (HL only) Bohr model of the atom

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- (HL only) Feynman diagrams

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

- circular motion
- graph sketching for SHM
- correct use of significant figures
- ideal gas calculations
- SHM calculations
- correct use of units
- (HL only) capacitor calculations

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

1

Although considered to be difficult, this proved to be an accessible question in an unfamiliar situation.

1ai

Many candidates recognised that the direction was towards the centre of the circle with the most common incorrect answer being towards the centre of the bowl. Some, particularly at SL, thought it was in the opposite direction to N.

1aii

Very few drew anything other than a vertical arrow downwards but often the arrow was too long. It was common to see an indication that it was the same length as N.

1aiii

This part often caused candidates difficulty. Many attempted to resolve the weight and then employed some dubious trigonometry to come up with the required result. Most of those who scored full marks did so from the first alternative in the markscheme rather than the second which required a fully labelled diagram.

1b

It was good to see that many candidates recognised the need to equate the expression for F from the previous question with the general expression for a centripetal force and the calculations were generally well presented. It was common to score 3 marks rather than the full 4 as a result of incorrectly substituting 8 m for the radius.

1c

Many candidates felt that the speed of the ball was key here and comments about it being fast enough or too slow were common. Examiners didn't accept 'mathematical' answers based on substituting an angle of zero into the expression in aiii) and stating that F is undefined.

1di HL

This was well answered by many candidates. Generally, mark schemes require a statement of proportionality and direction to define simple harmonic motion but here it was felt that for 1 mark the proportionality of force/acceleration and displacement was sufficient. It shouldn't be interpreted that this is what will be required in future mark schemes.

1dii HL

Answers that started with the formula for the time period of a simple pendulum weren't accepted however where it was unclear where the formula for the period came from candidates were able to score the second marking point. In general, in 'show' questions, it is expected that the final figure stated as the answer needs to be to at least 1 significant figure more than the 'show' value.

1diii HL

Many candidates scored 2 marks for drawing the graph but missed the third for having a correct amplitude which needed to be calculated.

1e SL d

The most common approach to this question was to equate the potential energy of one ball initially to the potential energy of 2 balls finally which ignores any effect of the collision between the balls. This approach is identified in the mark scheme as one that did not gain any credit.

2ai

Of the 3 alternatives in the mark scheme, alternatives 1 and 3 were the likeliest to score the mark. Those that wrote an ideal gas obeyed the ideal gas law often forgot to add 'at all pressures…'. It's important when answering in terms of energy, that the candidates state that it is the energy of the molecules/atoms/particles.

2aii

This was well answered by most candidates. The majority who didn't score the mark calculated the number of moles rather that the number of atoms.

2aiii

It was most common the work out the kinetic energy of a single atom and forget to multiply by the number of atoms.

2bi

This was generally well answered.

2bii

Examiners were looking for clear explanations here and precision in use of terms. Candidates were rewarded for saying that molecules made less frequent collisions with the walls of the container rather than just fewer collisions. Some were awarded the first marking point for stating that the average kinetic energy remained unchanged but very few mentioned a decreased rate of change of momentum at the walls.

3ai

A statement of the Principle of Superposition was insufficient here. The answer needed to include the idea of superposition as well as which waves were superposing.

The following question parts have been amended and re-numbered for publication.

3aii

The requirement for students to indicate the magnitude of the velocity was dropped here and candidates were able to score both marks for indicating the direction. The majority of candidates scored both marks.

3aiii

Calculating the wavelength proved difficult for many candidates but they were able to score an 'error carried forward' mark for calculating the frequency from their value for the wavelength. It is important to note that in most circumstances, to be awarded 'error carried forward' marks, candidates need to show workings rather than just writing down a bald value for the answer.

3bi

This was generally well answered with the answer often given to an appropriate number of significant figures.

3bii

Many candidates drew a diagram as though the waves were slowing down, i.e. that which they would draw for light.

4a

Even though this appears regularly in paper 2 questions it wasn't very well answered.

4bi

This was very well answered with the majority of candidates scoring both marks.

4bii

This proved more difficult, with many candidates thinking that as the current is zero the emf should be either 0 or 12 V.

4c HL

Very few candidates answered this correctly. Students find the concept of internal resistance a challenging one and this was reflected in the wide range of confused answers.

5 HL

5a

The most common answer to see here was a single slit diffraction pattern.

5b

Many candidates recognised the double slit pattern has equally spaced fringes and the majority were able to represent the spacing correctly. It was common to see the double slit pattern modulated by a single slit one which was perfectly acceptable and scored full marks provided that the spacing was correct as well as the peak intensity at x = 0.

5c

Most candidates answered this correctly.

6 HL

6ai

This was generally well answered however some candidates missed describing a small or test mass. A number of candidates wrote a definition of gravitational potential rather than field strength.

6aii

The solution required combining 2 equations available in the data booklet. Examiners were lenient when it came to candidates swapping backwards and forwards with letters representing distance e.g. r and R + h. Incorrect answers that involved starting with g = - delta V/delta r and then 'cancelling the deltas' did not gain any credit. These were actually quite common.

6aiii

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The general shape and sign of the graph were recognised by most candidates but often the y intercept was missed with the approaching it but not intersecting it.

6b

This was answered very well with appropriate SI units included. The negative sign was not required.

6c

It was common to see answer that assumed the asteroid was in orbit around the planet and used the equation for orbital velocity from the data booklet. This type of answer didn't gain any credit.
Examiners ignored negative sign errors in the workings for this question but it is not expected that this will always be the case.

6d

Many candidates calculated the force on the asteroid correctly using the approach in Alternative 1 in the mark scheme. Few then went on to comment that this is also the force on the planet. Very few candidates calculated the mass of the planet and then went on to calculate the force on the planet, but those that did adopt this approach were almost always successful in scoring both marks.

7 HL, SL 5

7ai

The term 'specific energy' was not one that was understood by many candidates and few scored marks on this question.

7aii

Many candidates scored the first mark for calculating the mass of water leaving the dam per second. Often then an incorrect height was used to calculate the average rate at which the GPE of the water decreases.

7aiii

This was answered correctly by almost all candidates who attempted it.

7b

The most common answers to this part involved ingenious ways of violating the conservation of energy. It was common to read descriptions of turbines placed in the upward flow of water that generated the energy required to pump the water back. Rain was another common solution.

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8 HL

8a

This was answered correctly by almost all candidates who attempted it.

8bi

Very well answered.

8bii

Very well answered.

8ci

Many candidates rounded their answer to the calculation of charge remaining to 2 significant figures and consequently their final answer to 2 significant figures. As mentioned earlier in this report it is normally required to give an answer to 1 more sf than the 'show' value.

8cii

This was answered well.

8d

Many answers here focused on the air between the Earth and the cloud or the spread of charge across the cloud rather than the surfaces.

9a HL, 6a SL

In some candidates answers there was confusion between describing the model of the atom and describing the experimental observations that led to it. It was most common to award marks for a positively charged nucleus and orbiting electrons. At SL many candidates confused Rutherford's model with the plum pudding model.

9b HL

It was most common to award a mark for electrons having discrete energy levels. Many candidates confused Bohr's model with Schrödinger's and even with Heisenberg's uncertainty principle.

9ci HL

This was well answered by those who attempted it as was 9cii and ciii).

9di HL

Many candidates calculated a value for the energy released in the decay and some recognised that an antineutrino gains some of this energy making the energy range of the electron continuous.

9dii HL

It was not enough here to state that the nucleus needed to lose energy. A reference to the diagram and it falling to the ground state was required.

9diii HL

A large number of candidates scored an 'error carried forward' mark here after using the wrong energy.

9ei HL, SL 6ci

The completion of the Feynman diagram caused many candidates difficulties. Often lines were drawn downwards from the vertex or incorrectly labelled. This question prompted a number of G2 comments about the direction of the time axis. It is common to see it drawn horizontally in some cases and vertically in others and this will be reflected in examination questions.

9eii HL, SL 6cii

This was generally answered successfully.

SL only

6bi

Although this was generally well answered a popular incorrect response was 'the energy required to bind the nucleus together.'

6bii

A common approach was to subtract one value of binding energy per nucleon from the other and then optimistically claim it was equal to 3 MeV. Examiners also saw some very complicated answers involving $E = mc^2$.

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Recommendations and guidance for the teaching of future candidates

paper three

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-12	13-18	19-22	23-27	28-31	32-45

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-8	9-13	14-16	17-20	21-23	24-35

General comments

- Reading the stem of each question part carefully. Many students tend to write everything they know about the topic of the question without really answering the question.
- *Highlighting* key phrases or data in a question.
- Knowing what the *symbols* represent in a data book formula or equation.
- Powers of 10 and unit multipliers. (The most common cause of accidental mark loss)
- Careless arithmetic and algebraic errors. Calculator mistakes are common.
- Distinguishing between $\pi r^2, 4\pi r^2, \frac{4}{3}\pi r^3$. (They are in the data booklet)
- Showing working *in full* in 'show that' questions. Proof of calculation is required.
- General layout of working in numerical questions - needs to be legible, planned and methodical. Students should write their answers keeping in mind that marks are allocated for the process. Some scripts were almost impossible to mark.
- Paying little attention to the number of marks awarded for each part question. Often candidates provide fewer key facts than required.
- Paying little attention to specific command terms - *determine, explain, outline* etc...
- Sequencing the presentation of facts to support an explanation or description. The answers should form logical and coherent arguments. The use of Bullet points was rarely seen, but is very helpful.

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

- Using the whole line when finding a gradient.
- Confusing linear with proportional when describing a relationship.

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- Manipulation of units (usually units are ignored by candidates, but they are still tested)
- Appreciating the nature of an intercept on a graph.
- Understanding the exact meaning of time dilation.
- Use of the spacetime interval and interpreting spacetime diagrams.
- Solving numerical rotational mechanics problems.
- Entropy change in the context of gas cycles.
- Damping.
- Completing a simple ray diagram.
- Cladding - core critical angle determination for optical fibres.
- The role of cladding for optical fibres.
- The formation of B scans.
- Using correct units and POT for v and d in Hubble's law calculations.
- Problems involving cosmological scale factor and the meaning of R and Ro.
- Describing the role neutron capture in creating heavier elements.
- The evidence for dark matter and how dark energy was hypothesised.

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

- Determining and processing uncertainties.
- Velocity addition in relativity and finding the Lorentz factor from velocity.
- Manipulation of the ideal gas equations.
- Use of the 1st law of thermodynamics.
- Finding the Reynolds number and interpretation its value.
- Solving problems involving one converging lens.
- Use of the attenuation formula.
- Hydrostatic equilibrium in main sequence stars.
- Simple calculations of luminosity.
- Determining the age of the Universe (despite many POT errors).

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

Section A

1a

Far too many candidates used equations of motion and assumed the value of g. They had not read the stem carefully - this was an experiment to determine g. Those that realised this fact often made careless errors and failed to simply subtract the diameter of the sphere from 654 mm.

1b

Many candidates knew how to find the absolute uncertainty in g correctly from the given equation, but were unsure about the number of digits to include in their answer. ECF marks

from part 1a were very often awarded. Working was often disorganised and scattered all over the page.

2a

This proof could fit on one line, but some needed an additional page for their working. Again untidy working was all too common, but a variety of acceptable proofs were seen.

2bi

The fact that C was the x-intercept was hardly ever seen in answers. Many students thought that the y-intercept was C, or used the gradient in an unnecessary calculation. If calculations were used units were often totally disregarded in working.

2bii

The given answer to 2a ($K = 2\sqrt{\frac{\pi}{P}}$) was expected to be used to find P from the gradient K.

Far too many candidates did not realise that K was the gradient. However, many did realise this, but got lost with units and POT. Others used the original equations and often made arithmetic or algebraic errors. Occasionally the points chosen were data points which were not on the line of best fit. Very few candidates scored 4 marks.

2c

Many candidates realised that the graph mentioned would not be straight. Fewer could state that finding C would be more difficult. Some common wrong answers included that the values would be smaller and that the graph would be more difficult to draw or that the uncertainties would increase.

Option A Relativity

(about 5% of candidates attempted this Option at SL and HL, so comments are tentative)

3ai

An easy mark, but a few gave 0.25c as an answer.

3aii

There were the usual problems with sign convention in the relativistic velocity addition formula, but correct answers were seen.

3b

If candidates obtained a correct answer for 3ai then they could usually answer this correctly by stating that v>c was impossible.

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4a

Correctly calculating v = 0.6c from γ was easy and seen in some scripts.

4b

These were fairly easy marks for many using time dilation.

4c

Very few correct answers were seen. Finding the time for the signal to reach Earth was usually not correct. Adding the time of sending the signal was usually overlooked.

4di

A few correct spacetime diagrams were seen and rulers were almost always used. Most errors occurred because the stem of the question was not read carefully and lines were drawn starting from the wrong point.

4dii

This question was usually not answered correctly. When answered correctly, the students rarely described appropriately the process used to find the answer. Measurements on the spacetime diagram were not often seen.

5a

A few candidates could explain the meaning of invariance.
5bi

The correct value of the spacetime interval was seen in less than half the answers seen.

5bii

No candidates seen used the answer to 5bi here. The use of γ to find the proper time was sometimes correct.
5c

Most candidates knew that time dilation had something to do with the time difference. However far too many thought that B's time was dilated in B's frame. B's time is dilated, but only when viewed from A's frame. A very common but incorrect explanation was 'time runs slow for B'.

HL only

6a

Most candidates were able to calculate the value of γ correctly.

6bi

Few students managed to get the 3 marks. It was often difficult to understand the process followed by the students as the answers were not structured.

6bii

Many students drew the arrow in the correct direction.

7ai

Most students had the correct idea but found it difficult to express the definition with the rigour and clarity expected.

7aii

Most students used the correct formula. A common mistake was to use the mass of the Sun.

7b

Most students realised that time is dilated more when close to the black-hole.

Option B Engineering Physics

(Chosen by about 20% of SL candidates and 26% at HL)

8ai HL, SL 6ai

Many candidates stated how to calculate moment of inertia instead of explaining what it

meant.

8aii HL, SL 6aii

Most candidates were able to write down the conservation of energy relationship for the falling cylinder. However, many mistakenly used the outer cylinder radius in their calculations.

8 HL, SL, 6aiii

The angular velocity was often correctly calculated. However, the wrong radius was again frequently used. ECF was often needed.

8 HL, SL 6bi

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The frictional force acts in the same direction as v, but still many said it would cause v to decrease. However, many correct answers were seen.

8a HL, SL 6bii

This time F creates a decelerating torque and this seemed to be more obvious to candidates.

9 HL, SL 7a

This was answered successfully by the majority of candidates using either Charles's law or

PV = nRT.

9 HL, SL 7b

Using PΔV most candidates had no trouble with this question as long as they used the correct POT for P.

9 HL, SL 7c

Another easy question using the 1st law, but few knew the simple relationship U= 3/2PV. Mostly good answers were seen.

9 HL, SL 7di

The PV diagram was mostly correctly annotated including arrow directions.

9 HL, SL 7dii

Many candidates just wrote that entropy decreases, especially at SL. 'Outline' requires a reason – less disorder at lower T. A few students tried to use the formula for entropy to justify their answers.

9 HL, SL 7e

Rather surprisingly the majority of candidates gave valid answers here. The most popular answer was that alternative forms of a law can be used in different physical situations.

HL only

10a

Most students realised that Bernoulli equation had to be used but very few could use it correctly. The working was often very disorganised and made it difficult to award marks as this is a show that question.

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10bi, bii

Both questions were generally well answered.

11a

About half of the students had the correct shape for the graph and the other half of the students drew sine-like graphs, showing that the students did not read the question carefully.

11b

Candidates who answered 11a correctly were generally able to answer this question correctly.

Option C Imaging

(Chosen by about 13% of SL candidates and 9% at HL)

12 HL, SL 8ai

Most found the focal length by calculation rather than by construction. An easy 2 marks.

12 HL, SL 8aii

Almost all answers for the magnification were correct.

12 HL, SL 8b

In describing chromatic aberration many candidates just repeated the information in the question. They were expected to draw on the diagram and refer to the greater speed or lesser refraction of red light compared to blue. Too often references to speed were not specific.

13 HL, SL 9a

The primary focus of the telescope mirror was usually correctly positioned.

13 HL, SL 9b

Few candidates realised that increasing f_O will increase magnification.

13c

Very few students managed to answer the question correctly and knew how to approach the question. Many students did not use any calculation to justify their answers.

SL only

9c

About half of all candidates could describe at least two features of the Newtonian mounting. A plane mirror at 45° or an eyepiece axis perpendicular to the principal axis were commonly mentioned.

9d

In answering this question candidates did not often refer to radiation. Many described radio waves as something visible. Few mentioned an antenna at the dish focus.

14 HL, SL 10a

Almost no candidates could attempt this question. Usually they just found the critical angle for the cladding-air interface rather than the fibre core-cladding boundary. Nobody knew that cladding restricted rays to be almost parallel to the fibre axis so that dispersion was reduced.

14 HL, SL 10bi

The majority of candidates were able to determine the allowed attenuation in the optic fibre.

14 HL, SL 10bii

Candidates were less sure about the calculations required to find the number of amplifiers needed. Frequently they just divided the answer to 10bi by 12dB without considering the 37dB loss along the cable.

14 HL, SL 10biii

Very rarely was there a mention of red and blue light traveling at different speeds or taking different times to travel along the cable. Material dispersion was hardly ever referred to.

14 HL, SL 10c

Almost everyone could give an example of the benefits of optical fibres.

HL only

15a

Most students had difficulties even getting one mark showing that a poor understanding of B scans. Most students seemed to confuse different techniques in their answers.

15bi

Generally well answered but many students did not include the quantity that halves (intensity).

15bii

Few students could calculate the change of intensity from each layer and then combine them correctly. A common mistake was to use the energy of the beam for the incoming intensity.

15biii

Answers were often poorly structured and students often wrote contradictory ideas.

Option D. Astrophysics

(Chosen by about 62% of candidates)

16 HL, SL 11a

The equilibrium between inward gravitational forces and outward radiation forces was very frequently mentioned. Many answers were too verbose and contained superfluous information.

16 HL, SL 11b

The majority of candidates were able to find the relative luminosity of star P.

16 HL, SL 11ci

Using σAT^4 large numbers of candidates could determine the luminosity of Gacrux. However, many used the wrong formula for the star's surface area, omitted POT or made calculator errors. Often candidates then forgot to divide by solar luminosity especially at SL.

16 HL, SL 11cii

A very easy question. Stellar parallax limits are well known.

16 HL, SL 11di

Most could draw a band or line to represent main sequence stars on the HR diagram.

16 HL, SL 11dii

Star P was usually correctly located at the correct luminosity on the main sequence.

16 HL, SL 11diii

Star G was often misplaced as the temperature of 3600K was overlooked.

16 HL, SL 11e

Most candidates referred to the evolution of Gacrux to red giant and to white dwarf. The mass reduction after the planetary nebula stage was not usually mentioned. Many students wrote what they knew about stellar evolution without making any reference to mass change. There were frequent incorrect references to an increase in mass after Gacrux moved away from the main sequence. Answers which assumed that Gacrux was a super red giant were also accepted. Most answered showed that candidates have roughly the correct idea but can get confused when expressing the details of the processes.

17 HL, SL 12a

Most candidates knew that they had to use the gradient or inverse gradient of the Hubble diagram to determine the age of the universe. POT errors were common in using galactic velocity. Further mistakes were often made in converting Mpc to metres. However, large numbers of candidates found T correctly.

17 HL, SL 12b

The assumption is that H has always been the value obtained in 12a - ie the expansion rate of galaxies does not change over time. Most candidates did not seem to know this.

17 HL, SL 12c

Many correct answers using z to determine R/R_O were seen. However very few then went on to find R_O/R. This may be due to a variation in interpretation of the two symbols. In the data booklet R is the scale factor for the current time and R_O the value in the past. So $R_O < R$.

HL only

18a

Many quoted the Jeans mass formula and correctly stated it was the minimum or critical mass for star formation. The idea that magnitude of PE> KE seems well known. There were some good arguments explaining why hot diffuse stars may not meet the criterion. A common mistake was to say that a cold dense gas has a higher mass than a hot diffuse gas.

18b

Too many candidates simply repeated the question. To gain marks it was necessary to explain that neutron capture produces an unstable isotope and that β decay then occurs with an increase in Z. Many students confused mass number and atomic number or tried to explain the difference between the r and s process.

19a

Most students knew that rotation curves for galaxies provide some evidence for dark matter but many answers were not specific or did not address the question directly (evidence for the location of dark matter).

19b

Most students knew that dark energy provides an explanation for the accelerated expansion of the universe. Candidates often failed to mention type 1a supernovae. There is no real evidence that candidates understand what it is about these stars that was unexpected. Many students seemed to confused dark matter and dark energy.

Recommendations and guidance for the teaching of future candidates

Section A of Paper 3 contains questions that can be practised frequently in class or assessed practical sessions. It is clear that some candidates are very familiar with data response questions - some less so. Almost certainly Question 1 or 2 will involve at least one graph. Candidates need to be familiar with gradient determination and to choose the largest triangle possible to find a gradient. They also need to master the interpretation and determination of both x and y intercepts with the appropriate units. Uncertainties may be asked for as absolute, fractional or %. Manipulating these should be second nature as candidates should be using uncertainties routinely in their assessed practical work. Question 2 will usually be focused on one of the standard practicals, so it is worth putting variations of all of them in the practical scheme of work. In fact, given that each investigation can lead to more than one practical, it is possible to build an entire practical course around them. The following experiments are taken from the *Applications and skills* section of the Subject Guide:

- 2.1 Determining the acceleration of free-fall experimentally.
- 3.1 Applying the calorimetric techniques of specific heat capacity or specific latent heat experimentally. 3.2 Investigating a minimum of one gas law experimentally.
- 4.2 Investigating the speed of sound experimentally.
- 4.4 Determining refractive index experimentally.
- 5.2 Investigating one or more of the factors that affect resistance experimentally.
- 5.3 Determining internal resistance experimentally.
- 7.1 Investigating half-life experimentally (Simulation or teacher lead practical).
- 9.3 AHL Investigating Young's double-slit experimentally.
- 11.2 AHL Investigating a diode bridge rectification circuit experimentally.

Now that candidates are allowed to answer questions from only one of the four options it is vital that schools select an option that is popular and suited to the abilities of both candidates and teaching staff. Some option topics may include material that staff have never taught or even seen before. These new option topics are set in stone for the foreseeable future and it would appear that the majority of schools have selected the same one. It is important that sufficient time is allocated for the learning of the additional higher level material of the options.

It seems that many students would benefit from being shown more samples of logically structured answers, it is important to remind students that the mark scheme is a marking tool for examiners and not an example of model answers.

School G2 comments sometimes complain that questions test information that is not in the Subject Guide. It is important to remember that the Subject Guide provides a framework - a list

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of aims, objectives and assessment statements - it is not meant to be a definitive list of facts. There are several excellent IB textbooks that interpret the various objectives. Physics department's schemes of work will usually make use of many additional online sources of information.