May 2017 subject reports

Physics – Timezone 1

Overall grade boundaries

To protect the integrity of the examinations, increasing use is being made of timezone variants of examination papers. By using variants of the same examination paper candidates in one part of the world will not always be taking the same examination paper as candidates in other parts of the world. A rigorous process is applied to ensure that the papers are comparable in terms of difficulty and syllabus coverage, and measures are taken to guarantee that the same grading standards are applied to candidates' scripts for the different versions of the Examinations papers. For the May 2017 session, the IB has produced timezone variants of Physics SL/HL Papers 1, 2 and 3.

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 25	26 - 36	37 - 47	48 - 58	59 - 69	70 - 100

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 12	13 - 21	22 - 32	33 - 43	44 - 54	55 - 65	66 - 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. Impressive investigation included a study of bungee jumping, the size of a super moon, Doppler effects, resonance in a wine glass, temperature and internal resistance of a battery, depth and buoyant force, pendulum damping, stress in a plastic bag, and many other interesting topics. What makes a good investigation is not the topic or research question as such but it is rather the depth of understanding demonstrated by the student and a well-focused research question on a scientifically interesting topic. For example, one student investigated how the coefficient of restitution of a tennis ball varied with temperature and they earned low marks. They included two pages of the history of tennis. Another student had the same research question but demonstrated an innovative method, insight to the relevant theory, and wrote an interesting and focused report that earned full marks.

Determining a spring constant is too basic, but investigating how temperature affects a spring constant is interesting and worthy of an investigation. Too simplistic investigations included determining the relationship of impact speed and height of a dropped ball, investigating series and parallel resistors, asking whether the change in current increases or decreases the electromagnetic field. Often students followed standard and well-established investigations. There is nothing wrong with this but teachers are encouraged to challenge students to find innovative approaches or variations on traditional themes or to truly understand the theory and the method.

Most student work involved hands-on investigations, with primary data collection in the school laboratory. Mechanics was the most popular topic, but electricity and magnetism, waves, and astrophysics were common too. A surprisingly low number of investigations were mathematical models, computer simulations and database investigations. Most popular investigations include measuring the refractive index with varying solutions, investigating the restitution of a bouncing ball, and the formation of craters by dropping a ball.

Unlike previous years, there were a few science essays submitted as IAs. In these cases, the student simply wrote about a physics topic. There was no selection of variables, no data and no analysis. Such essays are not appropriate for IA. Although data logging is an excellent method for collecting data, one student included 170 pages of such data, and this was inappropriate. Only a sample of data is needed. Finally, often students would copy images from textbooks or online sources and not give references. Instead, they would list several books or online links at the end of the essay. Only work that is directly referenced should be listed at the end of the report, and all copied images must have specific referencing.

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, 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-emphasized ‘personal significance’ by writing what seemed to be artificial comments about their interests. This was a waste of time and space, and lacked the focus of a good report. For example, a student wanted to measure the refractive index of salt water but wrote two pages about their love of the ocean and their summer holiday to the beach. Such an expression of personal interest earns no credit. 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. 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 relevant equations. As a result, 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. There were a number of good investigations relating temperature to the performance of a bouncing ball, a semiconductor, a spring constant, the electro-motive-force of a battery, and so on. Several students investigated the limitations of the standard textbook equation for a simple pendulum. These and other focused and interesting physics topics earned high marks.

Exploration weaknesses

Some students had vague research questions, never defining the key issues. Some investigations had multiple independent variables although the student did not realize this. Multiple independent variables only 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 that the student never realized. For example, one student hypothesized that the period of a simple pendulum was directly proportional to the pendulum string length. Some investigations included unquantifiable variables, such as comparing the rebound height of a ball dropped onto different surfaces (wood, grass, ice, etc.). Some investigations were too simple and the research question too obvious, like finding the spring constant for a rubber band or investigation of the impact speed from free fall at different heights. An inappropriate research question was “What is relationship of voltage and current in a resistor? Or, “What ball is best for tennis: tennis ball, Ping-Pong ball, golf ball, or hand ball?” Qualitative investigations, like mixing colors of light, are not appropriate for assessment. More appropriate research questions look for functions or relationships between two variables, or to determine an important constant in nature. Occasionally students thought that a history of physics provided background when in fact all it did was distract the focus of the investigation. Two pages on the history of the pencil when investigating the resistivity of the lead in a pencil did not constitute appropriate background. A page and a half on the history of tennis did not constitute background information for the measurement of the coefficient of restitution for a tennis ball.

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. Data tables were clear and consistent with scientific notation. Processing was often detailed, with sample calculations of complex computation. Graphs were nicely presented often with error bars. All 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. Some data tables were confused and hard to understand. Column headings should include the quantity, units and uncertainty with units. Occasionally incorrect units, such as feet and minutes, were used. One student claimed a wooden metre rule could measure distances to 0.01 mm. Some graphs lacked appropriate detail, and some graphs were too small to appreciate. This would affect the Communications assessment. 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. 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 to the trend line and how the graph should look. Ask the student what the *x* and *y* intercepts mean in terms of the physical properties under study. Again, a number of graphs were force fit with meaningless polynomials, and students thought the equation answered their research question. Students need to realize that science never proves anything. There is always a scope and limit to the meaning of a given investigation. Too many significant figures were often quoted by the student, such as an uncertainty of ±0.3476554% or a speed of 4.8233683533333 metres per second. Occasionally students used 9.8, then made calculations of weight or free fall speed to 8 significant figures. 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 student to understand what they are saying.

Evaluation strengths

The evaluation criterion remains one of the most demanding criterions to address for many students. Teachers often over-mark this criterion too. Student's need to described 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. 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 weakness or limits. Significant improvements can be understood as an extension.

Evaluation weaknesses

Often students stated they ‘proved’ their hypothesis about their research question without restating it in the context of their data and methodology. As mentioned under Analysis, no experiment proves anything. An appreciation of the scope and limit, the methodology and 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 graph they would have seen the senseless meaning of such an equation. Too often students would force a linear graph without appreciating the meaning of such a function (see Analysis), 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, and 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 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.

Communications strengths

In the May session, the Communications criterion, more often than not, successfully earned marks of 3 and 4. 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, 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 the temperature of a metal spring affects the spring constant” and not titles like “Investigating Collisions” or “Momentum.” The majority of reports used correct and relevant scientific notation, equations and units. MS Word has a built-in equation editor. The majority of reports were within the 12-page expectation. 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). 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

Several students omitted any sort of investigation title. Some students wrote “IA Investigation” or vague titles like “Forces” or “The Physics of Sound.” Titles should be descriptive. A cover sheet is not necessary. A table of contents may give the reader an overview but is not necessary either. In most cases, a table of contents is superfluous. A ten to twelve-page lab report needs no table of contents if the text is focused. Two and a half pages on the history of the pencil adds nothing to a research question about the resistivity of pencil lead. Good reports remain focused on a well-defined research question. Too often an IA report would not explain its RQ until page 3, and too often graphs and data tables were confusing, and lacked focus. Students do not need to show how they found the average of four repeated measurements. And often too much detail was given. Step by step instructions are not required. One student wrote 48 steps to their investigation, starting with: “put on a lab coat, collect the required material, set up the equipment, and then…” This distracts the reader from the flow and logic of the investigation. A good individual investigation does not need to resemble a cookbook approach. Students do not need to include a photograph of a metre rule or a stopwatch. Wasted space lacks focus, and experience show that well a focused report can easily be written within the 6 to 12-page expectation. Often reports with excessive content (e.g. 16 or 18 pages) inhibited the clarity of the repot. 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.

Recommendations for the teaching of future candidates

Guidance

It is important that teacher provide guidance during the entire IA investigation process, and not only when they read the draft. Some of the weaknesses that teachers could have 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,

Research questions

Teachers should guide students into appropriate research questions, questions that relate to scientific principles and within a context of physics. Sometimes students would make up common sense physics instead of doing some basic research. One student thought that the period of a pendulum was directly proportional to the length of a pendulum. Their data graph even forced a linear relationship of length and period. The student never even looked in the textbook. The research question should be challenging to the student and not obvious or too simple. Confirming the action-reaction principle using a computer simulation, or finding the relationship of impact speed to drop height, are not challenging investigations. The key here is to ask if the investigation is interesting. Teachers should also make sure students include a descriptive title to their investigation, and that students do some academic research to find out the known theory relevant to their own work.

Method and analysis

Students need to make it clear to the moderator what their method was. This does not mean listing 48 steps and including pictures of a metre rule. Instead, a concise paragraph stating what they did and how they performed the investigation is appropriate. The key is that the reader understands how to reproduce the investigation; a cookbook approach is not needed. Students should reflect on the physical meaning of their data and not rely totally on some abstract mathematical model.

Further comments

Many students demonstrated enthusiasm and involvement in the IA work. This is admirable. Where students often go wrong, however, is when there is a lack of focus and an ill-defined research goal. Too often students attempt multiple independent variables. Teacher's guidance in the early stages could prevent this. Also, students often waste space and thought on writing the history or social dimension of the topic, adding nothing to the scientific rationale at hand. Another weakness is that often students make an overly mathematical analysis, forcing curved scatter data into a linear fit or imposing a meaningless polynomial equation and never attempting to understand the physical meaning of the data trend.

It is helpful to moderators when teachers add criteria comments with the mark input window. It is not helpful when teachers scan all the criteria pages from the Course Guide and just tick the indicators they feel are appropriate. Specific comments either on the text or summarized at the end about achievement levels judged by the teacher are useful to the moderator.

Teachers should note that if their assessment is within moderation tolerance then they would not receive feedback from the IB. Only schools where significant moderation was required receive feedback.

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Paper one

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 14	15 - 18	19 - 22	23 - 25	26 - 29	30 - 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.

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 75 responses from 551 centres (14%) and for HL there were 45 responses from 350 centres (13%). 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 82% (88%) of the respondents with 18% (12%) finding it too difficult. Roughly 9% (21%) 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 98% (95%) of respondents; and over 96% (90%) of teachers judged the presentation to be good, or better.

It must be stressed that this very positive feedback was from only about 14% 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.

The G2 comments generally described this as a fair paper. 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. The order of the questions in the paper matches the order of the guide so students can be encouraged to tackle questions in areas of their strengths fist. 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. 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.

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1360	582	**1416**	543	14	36.17	0.35
2	356	**2672**	120	766	1	68.25	0.35
3	98	878	**2559**	376	4	65.36	0.50
4	1551	**1540**	365	450	9	39.34	0.55
5	**2312**	1101	339	143	20	59.05	0.48
6	93	491	275	**3049**	7	77.88	0.27
7	528	**3143**	132	98	14	80.28	0.25
8	**1922**	585	443	961	4	49.09	0.57
9	**1287**	718	1007	880	23	32.87	0.37
10	162	693	**2794**	260	6	71.37	0.36
11	**2860**	465	129	458	3	73.05	0.31
12	425	**2350**	660	427	53	60.03	0.28
13	198	134	**3226**	354	3	82.40	0.15
14	520	696	**1564**	1127	8	39.95	0.12
15	950	833	754	**1374**	4	35.10	0.39
16	1403	489	**1735**	268	20	44.32	0.51
17	328	1088	1644	**837**	18	21.38	0.30
18	**1562**	312	1380	654	7	39.90	0.40
19	**2327**	322	784	464	18	59.44	0.42
20	251	591	1268	**1789**	16	45.70	0.40
21	**1142**	368	1873	527	5	29.17	0.21
22	**677**	1222	1055	913	48	17.29	0.10
23	507	**2246**	600	558	4	57.37	0.45
24	1638	369	319	**1575**	14	40.23	0.32
25	1283	561	521	**1536**	14	39.23	0.55
26	547	374	**2141**	834	19	54.69	0.28
27	747	**2255**	235	666	12	57.60	0.19
28	**2272**	427	363	838	15	58.03	0.38
29	1262	**1340**	795	494	24	34.23	0.17
30	459	675	**2242**	513	26	57.27	0.45
31	1117	**2353**	209	217	19	60.10	0.30
32	415	712	1511	**1244**	33	31.78	0.35
33	657	**1908**	887	437	26	48.74	0.46
34	391	638	**2126**	730	30	54.30	0.26
35	556	**2164**	575	568	52	55.27	0.34
36	445	467	514	**2455**	34	62.71	0.40
37	**625**	632	1124	1481	53	15.96	0.16
38	814	1271	345	**1449**	36	37.01	0.50
39	982	718	558	**1597**	60	40.79	0.26
40	314	521	1680	**1356**	44	34.64	0.25

Number of candidates: 3793

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	2137	1412	**1867**	1086	40	28.54	0.20
2	901	858	**4174**	601	8	63.80	0.50
3	369	836	**3097**	2178	62	47.34	0.25
4	1078	**3712**	429	1315	8	56.74	0.40
5	**1589**	1680	2266	987	20	24.29	0.39
6	2992	**1824**	951	730	45	27.88	0.35
7	39	655	**5412**	432	4	82.73	0.21
8	271	1251	648	**4350**	22	66.49	0.39
9	**3044**	809	1647	1027	15	46.53	0.44
10	**2203**	1493	946	1890	10	33.67	0.54
11	**1655**	1397	1291	2149	50	25.30	0.23
12	387	1515	**4133**	488	19	63.18	0.38
13	**3918**	1315	439	861	9	59.89	0.37
14	502	**4018**	819	1184	19	61.42	0.36
15	**5055**	707	635	141	4	77.27	0.32
16	984	1301	**2637**	1551	69	40.31	0.13
17	1497	**3191**	515	1316	23	48.78	0.39
18	894	2083	**3285**	256	24	50.21	0.50
19	3054	1130	**1805**	503	50	27.59	0.35
20	704	1689	1990	**2051**	108	31.35	0.32
21	**1930**	985	2785	801	41	29.50	0.40
22	407	**2600**	1656	1837	42	39.74	0.35
23	**3352**	756	1637	730	67	51.24	0.39
24	1341	1163	1250	**2746**	42	41.97	0.38
25	**1918**	846	2815	928	35	29.32	0.21
26	**1112**	2248	1852	1233	97	17.00	0.11
27	869	2234	1610	**1717**	112	26.25	0.11
28	673	**4383**	761	672	53	67.00	0.20
29	2684	863	674	**2183**	138	33.37	0.24
30	389	1023	2980	**1974**	176	30.17	0.36

Number of candidates: 6731

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 20% in HL and 20% in SL (relatively 'difficult' questions) to about 80% in HL and 80% 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 two HL and three 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' responses

In both Papers, there were a number of 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.

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

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 Question 1 and HL Question 1

This turned out to be a middle difficulty question and unsurprisingly the incorrect answers were split quite evenly between the 2 possibilities that contained 'electrical' units. SL Question 6 and HL Question 4

Again, challenging as it was an AO3 question and a 2-stage calculation. The most common answer given was A, as candidates simply multiplied the mass by the acceleration given in the stem of the question.

SL Question 10 and HL Question 8

This was a medium difficulty question answered more successfully by HL candidates. At both HL and SL, the most common wrong answer was D, presumably by students who missed the first sentence of the question.

SL Question 11 and HL Question 9

This question prompted a number of teachers to comment on the level of difficulty here. At HL, the most common answer was the correct answer, but not so at SL. The difficulty lay in finding the correct expression for the area.

SL Question 16 and HL Question 14

Most students appreciated that either polarizing sheet could be rotated.

SL Question 19 and HL Question 16

This was answered well at HL but not so well at SL.

SL Question 23 and HL Question 19

This question was answered well at both HL and SL.

SL Question 25 and HL Question 21

A definition often asked about, but the question wasn't answered well at either level. The most common answer at both levels was C with students associating the unified atomic mass unit with nuclear physics.

SL Question 26 and HL Question 22

This question turned out not to be a good discriminator at either HL or SL and probably resulted in a lot of guessing from candidates. Examiners believe the framing of the question put a lot of candidates off.

SL Question 29 and HL Question 24

This was a challenging question as it was an AO3 one. It required candidates to interpret two aspects of black body radiation at the same time. They had to appreciate that the peak wavelength for planet X had to be at a longer wavelength and that the dotted line had to be beneath the solid line.

HL-only questions

Question 3

This was a challenging question requiring candidates to realise the change in speed was the area under the graph. The indices indicate that this was a hard question, answered well by candidates who did well on the paper.

Question 7

This was a straightforward question answered well by many candidates as they realised the resultant force is the rate of change of momentum.

Question 17

This was one of only 7 questions at HL where the most common answer was not the correct one. The discrimination index was not very high suggesting that a lot of candidates guessed the answer to this one. It required students to link the current to the movement of the electrons and comments from the G2 forms suggest that teachers thought this fair.

Question 20

Most candidates recognised that given the relative size of the half-lives, the ratio had to be less than 1.

Question 23

If candidates realised that the Moon has no atmosphere so convection can't happen, there is only one possible answer. Again, a question answered well by candidates who did well overall.

Question 25

The difficulty here was mainly for candidates who weren't sure whether the albedo was the amount absorbed or reflected. Consequently, most answers were A or D.

Question 27

This question was answered well by candidates of all abilities.

Question 29

Many candidates answered A for this question. A could have been dismissed by simply looking at the diagram to see that V isn't constant.

Question 33

It was disappointing to see that a straightforward question on units scored a difficulty index of 48.74.

Question 36

Examiners were surprised that the answer of D wasn't more obvious to candidates.

Question 37

Clearly most students hadn't learnt the appropriate relationship. D was the most popular answer, probably because there is a distinct jump from C to D.

Question 40

Clearly most candidates knew X is a neutron and then it was just a question of neutrino or antineutrino.

SL-only questions

Question 2

Not surprisingly one of the easiest questions on the paper.

Question 3

Some teachers have expressed concerns over the wording of this question and the use of 'fourth second'. Most candidates picked the correct answer but examiners have noted the concerns for future papers.

Question 5

The most popular answer for this question was C followed by B. Presumably candidates missed the required link between resultant force and constant speed. There were no G2 comments suggesting that the wording of this question could have caused confusion.

Question 7

This question had the highest number of correct answers.

Question 9

This question was only about knowing the meaning of the word inelastic.

Question 24

Some G2 comments suggested that this was not included in the guide but the first two points of ‘Understandings’ in section 7.3 cover knowledge of positrons and neutrinos. Beta plus decay is important in scanners in modern nuclear medicine. The most common answer was the correct one although there appears to have been a fair bit of guessing.

Question 28

For this question, there were a high number of correct answers. It only required knowledge that crude oil isn’t a secondary source to identify the correct answer.

Question 30

Many students appreciated that the ratio had to be less than 1.

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 pretty 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:

Encourage students to start with the questions in topics that they feel confident. The questions are broadly in the same order as the topics are in the guide.

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 attempt 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 particular 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.

Paper two

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 9	10 - 18	19 - 27	28 - 38	39 - 49	50 - 60	61 - 95

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 8	9 - 14	15 - 20	21 - 25	26 - 31	32 - 50

General comments

Candidates were able to show strengths in all areas of the syllabus tested by this exam paper. The one area which did cause concern was particle physics and there was evidence from blank responses to question 5 and from student comments on some scripts that this section hadn't been covered by all centres.

It was good to see the continued improvement in the way candidates laid out their responses to numerical calculations and, even though units are required in very few situations in terms of the mark schemes, the improved knowledge of relevant units.

Knowledge of key terms in physics remains an issue and even though there is less emphasis on learning definitions students must be able to use the vocabulary of physics effectively.

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

- key terms when describing superposition
- single slit diffraction pattern
- particle physics
- relevant formulae used for motion in gravitational field
- interpretation of displacement distance graph for oscillatory motion, specifically longitudinal wave motion
- Faraday's law of induction
- explanations of the observations of the photoelectric effect
- describing specific types of energy

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

- calculations in the mechanics section
- energy efficiency calculations
- correct use of significant figures

- differences between solar heating panels and photovoltaic cells
- SHM calculations
- Correct use of units
- graph of results of photoelectric effect experiment

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

Question 1

1a(i) Many candidates were able to answer this successfully but most didn't initially cancel the mass as the markscheme anticipated. Some tripped up over the final answer by truncated 11.88 ms^{-1} to 11.8 ms^{-1} or not completing the final calculation at all and just stating 12 ms^{-1}. It is important to stress to candidates that when they have to show that a variable has a particular value they should complete the calculation and quote the answer to at least one more significant figure than the 'show that' value. Use of $g = 10\ ms^{-2}$ should be discouraged.

1a(ii) At HL this was well answered by candidates describing the internal energy as being the total of the KE and PE of the individual molecules and temperature as being a measure of the average KE. The markscheme didn't require that PE was mentioned for internal energy, although most successful candidates did this. Molecules/particles/atoms had to be mentioned at least once to gain both marks. At SL students found this more demanding and the question was not as well answered.

1b(i) Examiners were surprised about the generally poor quality of the diagrams produced here. It was rare to see arrows drawn with a ruler and too often the arrow wasn't connected to the dot which represented the skier. The vertical nature of many arrows left a lot to be desired, especially as the question asks candidates to consider the vertical forces. The labelling of the forces generally met with standard conventions, but it was rare to see the weight force drawn longer than the reaction force with any conviction. Examiners were asked not to award credit for lengths of arrows that required them to get a ruler out to measure. Candidates should be encouraged to draw scaled force diagrams throughout their preparation.

1b(ii) This section was generally very well answered with candidates often scoring at least 2 marks. The calculations for centripetal force or acceleration were most commonly seen and most could then use their values to justify that the skier would not lose contact with the ground.

1c Again well answered but with inconsistent use of negative signs which candidates weren't penalised for, in this case.

1d(i) Many scored both marks here and it was good to see correct units being used.

1d(ii) Most candidates recognised the longer stopping time for the safety net but then didn't include enough detail to be awarded the second mark for relating this to the smaller force on the skier.

Question 2

2a This was poorly answered at both SL and HL. Most answers gave vague descriptions of constructive or destructive interference or talked about the addition of amplitudes.

2b This was well answered by most candidates with many realising the need for 2 significant figures.

2c Again well-answered with most candidates making the link between wavelength and fringe separation even if they couldn't remember whether green light has a shorter or longer wavelength than red.

2d A significant number of candidates sketched an intensity/angle graph but few were appropriately labelled. It was more common to award marks for written answers describing the bright central maximum and subsidiary maxima. Candidates could also be rewarded for discussing the relative widths of the maxima as in previous years' markschemes.

Question 3

3a At HL this was well answered by many ensuring that they used the term 'energy', but at SL there were a lot of vague answers that didn't connect to energy.

3b A straightforward calculation which most managed competently.

3c(i) This was a more challenging calculation which had a number of pitfalls. Firstly, the area calculation had to be completed and some candidates substituted 8.5 m for the radius rather than 17 m. Secondly the formula for power output of a wind turbine needed to be used and all too frequently candidates forget to cube the wind speed. Lastly the candidates needed to calculate the number of turbines needed for the required power output and the majority appreciated that they needed to round up to an integer value.

3c(ii) There were too many vague answers to this part which only mentioned turbines not being 100% efficient without tackling the physics of why that should be. When discussing energy losses, it is important that candidates address the form of energy that is lost e.g. thermal energy due to friction in a named part of the turbine.

Question 4

4a(i) A straightforward calculation that stumped a lot of candidates. The most common incorrect answers involved dividing 240 V by the resistivity to produce an enormous value for the current.

4a(ii) It was common to see a power of ten error here as candidates were unable to convert the cross-sectional area from mm^2 to m^2.

4a(iii) (HL only) This was generally well done with many scoring error carried forward from previous question parts.

4b Many candidates scored the first and third marking points on this section but rather than discussing a reduction in drift velocity talked about it being harder for the electrons to get through the wire. A common misconception was that as the temperature of the cable increases the electrons gain kinetic energy, move faster through the wire and so the resistance decreases.

4c This tended to be an all or nothing question with candidates answering it very well or hardly making a start. Many assigned a correct unit, either mass flow or volume flow, and it wasn't required that this matched the numerical answer.

Question 5

5a A significant number of candidates seemed not to have studied the particle physics section and this resulted in many weak answers here. Most who made a reasonable attempt at question 5 scored both marks.

5b(i) Bald answers of the weak interaction were not accepted here as the questions asks candidates to explain which interaction is responsible. There were roughly equal numbers who explained it in terms of a change in quark flavour as those who explained it by strangeness not being conserved. At SL, it was noticeable that a lot of candidates simply described the diagram rather than referring which interaction was involved.

5b(ii) This was well answered.

5b(iii) This was also well answered by those who realised that the weak interaction is responsible for the decay. Very few omitted the minus sign from the W boson. Those who didn't realise guessed one of the particle symbols in the diagram.

5c Examiners saw some very vague answers to this part about it costing less rather than costing less per nation or having more people involved. Common misconceptions were that it will bring energy production from fusion closer and that it would provide a greater area of land for building large accelerators.

HL-only questions

Question 6

6a This was generally answered well with candidates recognising that it is the spacing of the lines that is important rather than the direction of the arrows.

6b Many drew a semicircle centred on planet X to score the first mark, but few had a radius of curvature of 3 units and selected 4 so that it passed halfway between the planet's surface and the point Y.

6c There were a good number of successful answers to this part, but also some misconceptions. A number of students started with the expression for escape velocity which examiners accepted as it is essentially the reverse of the situation here and so yields the correct answer. No credit was awarded for answers which were based on orbital motion. Examples include starting from the expression for orbital velocity or the total energy of an orbiting object. Some candidates used the formula for gravitational potential but believed that the V stood for velocity and used that as their final answer.

6d This was well answered with many students achieving the correct answer or gaining full ECF marks from an incorrect *v* from the previous question part.

Question 7

7a Examiners were surprised that this question part was poorly by a lot of candidates. There were many vague answers about the object needing to move backwards and forwards, have a constant amplitude or no air resistance.

7b This calculation was done well by the majority of candidates.

7c This was also done well but with some slipped up by missing the ‘squared’ from the amplitude and neglecting to convert from cm to m.

7d Few candidates worked through this part to score full marks. For those who made a good attempt it was common to award the first 2 marks but they then didn’t make the connection between the fractional uncertainty in T being greater and so the fractional uncertainty in m being greater.

7e(i) Most candidates chose correctly.

7e(ii) This part had to be answered by discussing the direction of motion of the coils either side of P. Many candidates discussed the points on the graph rather than making a connection to the motion of the spring. Bald answers of rarefaction weren’t credited.

Question 8

8a A significant number of candidates thought that Faraday’s law of induction was an expression of the turns ratio of a transformer and the relative size of the voltages. Many also confused Faraday’s law with Lenz’s law.

8b A significant number of answers only addressed the final marking point about the number of turns and the size of the voltages. Many candidates who realised that a 4-mark answer requires more than one point of physics made effective attempts at describing how a transformer works. Some candidates who attempted to write a more complete answer however often ran into two issues. The first was that they didn’t appreciate that the magnetic fields/flux linkages needed to be varying in time and the second was that Faraday’s law specifically refers to emf and not current.

8c Many candidates scored the first mark for discussing the fact that a laminated core reduces eddy currents but didn’t go on to talk about what sort of energy was lost.

8d As in the previous question part, the first mark was often awarded but not the second as there was no further expansion about the type of energy loss.

Question 9

9a The first part of question 9 caused candidates a lot of difficulty even though they coped very well with the rest of the question. The main issues were that the points they were making were generally not fully explained. For example, for observation 1 they realised that the photons didn't have enough energy but did not relate this to their frequency or the work function of the metal. It was difficult to award any of the marking points if the candidates didn't mention energy in their response. Many candidates used 'threshold frequency' as a stand-in for energy, rather than connecting the concept of photon energy to frequency.

9b(i) This was done very well and examiners saw very few bald answers of Planck's constant taken from the data booklet.

9b(ii) Most candidates had the right idea but some missed out the 'minimum' or 'least tightly bound' aspect.

9b(iii) A lot of candidates came up with a correct answer in J but didn't convert to eV.

9c The vast majority scored at least one mark for the parallel nature of the line and it was usually drawn in the correct position.

Recommendations and guidance for the teaching of future candidates

- Ensure adequate coverage of all areas of the guide.
- Encourage candidates to learn the meanings of command words.
- Encourage candidates to read the examination questions carefully.
- Encourage candidates to try to use key terms in their answers.
- Encourage candidates to use specific energy terms.
- Encourage candidates to take care when drawing and labelling diagrams.

Paper three

Component grade boundaries

HL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 5	6 - 11	12 - 16	17 - 20	21 - 25	26 - 29	30 - 45

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 3	4 - 6	7 - 9	10 - 13	14 - 17	18 - 21	22 - 35

General comments

The paper is designed in accordance with the physics guide. Section A is prepared for summative assessment of core material, mainly of Topic 1 Measurement and uncertainties. The contexts for the assessment are selected appropriately, one quite straightforward – simple pendulum experiment and another quite demanding – isothermal process experiment.

Options in section B are well balanced. In each of the options are included questions measuring the level of knowledge, understanding, skills and others of the assessment objectives 1,2 and 3 required by the syllabus. In the line of the Physics guide, the paper presupposes also knowledge on core (for SL and HL) and AHL (for HL) material.

Questions in section B are set to well selected contexts and applications. The candidates proved that they had enough time for work. Discrimination of the paper is at the appropriate level, difficulties of all the options are almost the same. Among answers we can see many examples of good understanding in each of the questions. 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 and if they used additional answer sheets, they referred to this within the answer box. Handwriting seems to be at the same level as previous sessions, the answers were legible, and there was no problem with marking in black-and-white.

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

The most difficult in this paper was utilisation of physics knowledge on core material in questions focused to topic 1 Measurement and uncertainties. In the design of P3 in this syllabus are questions on Topic 1 set to contexts of core material and it is presupposed to carefully read the situation, the stem of the question. The questions should be answered using whole knowledge of core material.

Another difficult area is mathematical requirements. Many weaker candidates failed in calculations, manipulation with exponential functions, use of direct and inverse proportions.

Generally, phrases as define, show that, compare, distinguish between... were followed by candidates much better than in last sessions.

Difficulties related to the syllabus details:

- Solving problems using gas laws (3.2).
- Differences between real and ideal gases (3.2).
- Interpret graphs (mathematical requirements, p.22).
- Direct and inverse proportion, linear function and direct proportion (mathematical requirements, p.22).
- Spacetime - reference frames (A.1).
- Invariant quantities - spacetime interval (A.2).
- Spacetime diagrams and their use (A.3, especially in SL).
- Particle acceleration (A.4).
- Conservation of angular momentum (B.1).
- Rotation involving kinetic energy (B.1, especially in SL).
- Buoyancy (B.3).
- Attenuation in optic fibre (C.3).
- Magnification of a telescope and explaining chromatic aberration (C.1, especially in SL).
- Explaining the origin of the emission of signal in NMR (C.4).
- Calculating from data presented in terms of the Sun, rather than absolute values (D.1).
- How the CMB provides evidence for the Hot Big Bang (D.3 in SL).

Other difficulties:

- arithmetic and algebraic mistakes;
- wrong units;
- power of ten (POT) mistakes in calculations; sometimes leading to unrealistic results, e.g. few volts in Q5a, some km s^{-1} in Q9c, few K in Q14 a(iii);
- working with constants in linear equations, e.g. linear simultaneous equations and direct proportions;
- layout of working in numerical questions, in a bad layout and wrong answer it is sometimes hard to see where the mistake occurred and award partial or ECF marks;
- carry out manipulations with simple algebraic equations.

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

The best candidates clearly presented good understanding. Well prepared candidates can analyse the situations, present working in logical manner and use proper terminology, physical quantities and units. Majority of candidates presented ability to read and understand questions. They demonstrated understanding of facts and concepts and could use them with proper terminology. Also presented well developed competences to use knowledge and ability related to mathematics. Most candidates proved the ability to clearly present well-known facts in words and sentences. Amazing is, that in this paper well prepared candidates proved ability to work with phenomena lasting from 10^{-7} s to 10^{10}s, with phenomena very real to very abstract, with physics very practical an also with pure theories.

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

Section A

Both questions are accessible to well-prepared candidates. However, many candidates failed in different parts of the questions.

Question 1 Isothermal process experiment

1a is the most difficult question, well answered only by the best prepared candidates. When the volume is reduced, the work is done so the student must wait to allow thermal exchange with surroundings to have constant temperature. Many average prepared candidates tried to answer this question in terms of oscillations, distributing pressure within the gas column, often by changes propagating by the speed of sound. Such phenomena are not observable with the apparatus presented, without extremely fast sampling.

1b was quite well answered. Common mistakes were power of ten mistake and unit mistake. Common incorrect unit was Pa m^{-1}.

1c was well done by candidates well prepared to write conclusions in their lab reports (p. 146 of the physics Guide). The ideal gas model predicts the graph, as the student measured. And the task was to outline, so give a brief account of this.

1d was well done by most averagely prepared candidates, however a few candidates incorrectly used Avogadro's number approach.

1e This question is directly connected to the requirement of the Physics Guide, differences between ideal and real gases, and this was recognised only by better prepared candidates. Liquefying of the gas was sometimes well mentioned. Some answers went to breaking the apparatus, which was not accepted, as the question was not about measuring at such high pressures, but only about extrapolating data measured at lower pressures.

Question 2 Simple pendulum experiment

2a Most of the candidates well calculated the value of acceleration. However, quite high number of average candidates made a mistake in calculation and their result presented a value far from the well-known accepted value. Most well-prepared candidates calculated a value of uncertainty, but some did not recognise the need to multiply the percentage error in T.

2b Well done by average and better candidates. Most of the candidates reached an answer of 22°, some an acceptable 20°. Many weaker candidates did not attempt to answer this question.

Option A – Relativity

Attempted by about 20% of the candidates

Question 3 Charged particle and a wire

In (a) many candidates do not clearly enough present the time coordinate and presents only three coordinate axes. In (b) much more candidates than last sessions distinguished differences of this simple electromagnetic interaction from two different reference frames and their answers were much clearer. Relativistic contraction was the most difficult in b(ii), but reasonable number of candidates well identified and presented also this crucial idea in their explanations.

Question 4 Train in a tunnel

This 14-mark question was answered quite well. The most difficult parts are d(ii) and d(iv). The ability to clearly, in logical manner formulate the ideas is significant in d(ii). The idea of invariant in Lorenz transformation is not understood by many candidates. In (b) many candidates did not use the ratio, as in the markscheme, and instead they used more complicated solutions, which in many cases resulted in simple arithmetic mistakes.

Q5 (HL only) Accelerated proton

Potential difference was calculated well by most of prepared candidates, but momentum of the photons produced after annihilation was determined only by the best candidates. This question well discriminated the best candidates in this option.

Q6 (HL only) Gamma rays in a gravitational field

This question was well answered by many candidates, but some of them wrote only vague ideas in (b), not clear enough explanation.

Option B - Engineering physics

Quite a popular option, attempted by about 30% of candidates.

Question 7 (SL5) Rotating bar

This is a not easy question, with the most difficult part at the beginning, a (i). Quite relevant number of candidates just pretended working in a(ii) and (iii) and as an answer repeated formulas from the question. However, many well-prepared candidates provided clear well-structured answers to all sub questions. It was quite difficult for students to conceptualise the situations. Part (b) was answered slightly better than (a). In b(i) many candidates missed including (3/4). In b(ii) even weaker candidates could convert radians into revolutions.

Question 8 (SL6) Carnot cycle

Question with great variety of difficulty among sub questions. The most accessible sub questions are (b) and c(i). The most difficult is (e). In this sub question candidates tried to write some vague attempts, but only the best candidates could state the reason required.

Question 9 (HL only) Air bubble in a liquid

This is a question with average difficulty. The origin of the buoyancy force was explained mostly very vaguely, but the best candidates could provide clear logical explanations. In (b) many candidates did not reference the ratio, even if calculated both forces. The terminal speed was attempted by most candidates and better candidates gained correct value. Quite common mistake here was POT mistake.

Question 10 (HL only) Damped oscillator

This question was generally answered well only by the best candidates. In (a) vague sentences related to amplitude was presented by weaker candidates. Part (b) is the most difficult, for candidates it was not easy to apply the formula from data booklet.

Option C - Imaging

Attempted by about 10% of candidates

Question 11 (SL7) Microscope and telescope

Well balanced question with calculations and explanations. The most difficult part, discriminating between the best and average candidates, is b(i). For candidates, it is not easy to explain the facts, which they know, but the best candidates did well here. The explanation in (c) is slightly less demanding, also average prepared candidates released that chromatic aberration is connected to refraction, not reflection. In b(ii) many weaker candidates proved that they do not understand the term angular diameter. In SL, many candidates were not able to define virtual image and quite common not acceptable answer was "an image on the same side as object". Part a(iv) was identified as extremely difficult for SL candidates.

Question 12 (SL8) Optic fibre

In a(i) many candidates gained at least one mark, the most popular answers were “longer distance without amplification” and “cannot easily be interfered with”. Part a(ii) belongs to the most difficult in this paper, only small portion of candidates have this knowledge. Part (c) was almost inaccessible for SL candidates.

Question 13 (HL only) X-ray image and NMR

Most average prepared candidates proved developed ability to manipulate and use exponential equations. Part (c) is well structured to scaffold explanations of role of segments of NMR. The most difficult was explanation of the role of non-uniform field in c(iii).

Option D – Astrophysics

The most popular option selected by more than 33% of candidates

Question 14 (SL9) Theta 1 Orionis

Well balanced question with many correct clear answers. For weaker candidates, it was a problem to calculate from the data presented in terms of the Sun, rather than SI units, and many candidates made a mistake related to constants (especially 4 π) in the formulas used. Part (c) was accessible for HL candidates and quite hard for SL candidates. Only a few SL candidates mentioned a “planetary nebula” stage, a lot of SL candidates mentioned only stages of the Sun and did not mention the stages of Orionis.

Question 15 (SL10) The size of the Universe

This question was well done by better prepared HL candidates. For SL candidates, it was difficult to describe how CMB provides evidence for the Hot Big Bang model. In part (b) they wrote only some irrelevant or vague ideas. In c(i) many candidates made a POT error between km and m. In c(ii) a reasonable number of average and weaker candidates were unable to read the question.

Question 16 (HL only) Star evolution

Many average candidates could outline star formation and discuss the layered structure of a massive star after leaving the main sequence. In (b) the better candidates proved that they can use large numbers and provided well-structured, clear and correct answers.

Question 17 (HL only) Dark energy

Average difficulty question. Many clear and correct answers can be seen, but also some candidates left part of this question blank.

Recommendations and guidance for the teaching of future candidates

Based on the evidence gathered from the responses this session I can offer the following recommendations.

Candidates score better in Paper 3, if they:

- study the option before the revision of core physics, to see connections among topics;
- use the Data Booklet when solving multistep, complex problems;
- spend most of the course learning Physics and prepare for the final exam as a minor part of the course;
- practise past papers;
- understand and apply, but also remember precise formulations of definitions, especially of physical quantities used only in options;
- study the option in a group of students and with the teacher, not by their own;
- are trained to express their ideas in written form, in logical manner, in proper layout, showing each step, even if “fully clear”;
- are encouraged to write some words explaining their working also in calculations,

derivations and other use of formulas; especially in not fully correct answers or alternative answers this can be helpful and candidates can gain some marks for partly correct working; also, candidates can find their own mistake in derivation, or calculation and can amend their answer;

- think again about a result in a complex numerical calculation and check possible POT mistake;
- do not neglect units, sporadically we see mistakes, e.g. calculated distance and time unit used; or calculated energy and unit of power used;
- are encouraged to be careful with the difference between "equal" and "proportional".
- Candidates must be reminded that every word must be readable, that the process is two ways – it is not enough to write the answer, somebody must be able to read and assess the answer. Answers should be in the box or on additional sheets.