Physics – Timezone 2

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 - 46	47 - 56	57 - 66	67 - 100

SL

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 12	13 - 21	22 - 33	34 - 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.

The majority of 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, more often than not students would copy images from textbooks or online sources and not give references. Instead, they would list a number of 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 the impact speed from free fall at different heights. An inappropriate RQ 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 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 gravity as 9.8 (units) but 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

A number of 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 - 9	10 - 19	20 - 30	31 - 39	40 - 48	49 - 57	58 - 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

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

Our thanks are due to the many teachers who took the trouble to complete the G2 forms. These gave us an excellent feeling of how the students regarded the papers.

Every year there are occasional comments from teachers that either paper 1 or paper 2 are unbalanced in terms of syllabus coverage. 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 in order to succeed at multiple choice questions are described in the final section of this report.

The HL(SL in brackets) paper was regarded as being of appropriate difficulty by about 70%(80%) of the respondents with 30%(20%) finding it too difficult. Over 30%(25%) of centres regarded it as being more difficult than last year's paper with 45%(45%) saying it was the same and 20%(20%) claiming it was easier. Both papers were regarded as having good, or better, 'clarity of wording' by around 80% of respondents; and about 90% or teachers judged the presentation to be good, or better.

The G2 comments were copious with many teachers praising the quality of the paper. There were, however two critical themes that ran through the comments, those of time and trickiness.

Time

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

For a few teachers, the reason why the time was insufficient was the wordiness of the questions. For some this put ESL students at a particular disadvantage. The questions are peer-reviewed before publication to ensure that the stem in each question fully described the situation without any superfluous words. Students should read the questions carefully – each question is unique and students should beware of jumping to conclusions as to what is being asked.

There were many comments this year that the calculations took up a lot of time. This issue is dealt with later in this report, but students should know that if they find themselves spending time on calculating they have probably missed the point of the question. Multiple choice questions will only contain simple numbers, that cancel and multiply easily, and if the candidate knows the concept behind the question there will never be a necessity for long calculations.

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.

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	1831	487	1069	4859	23	58.76	0.53
2	764	5933	954	553	65	71.75	0.41
3	1224	3583	2296	1141	25	13.80	0.19
4	804	1695	3658	1965	147	44.24	0.25
5	761	6189	1102	201	16	74.85	0.19
6	1364	998	3489	2334	84	28.23	0.37
7	1247	1337	1634	3977	74	48.10	0.59
8	994	389	6465	400	21	78.18	0.37
9	2738	996	2942	1541	52	33.11	0.45
10	4412	2763	737	307	50	33.41	0.35
11	1167	685	398	6006	13	72.63	0.39
12	1235	2772	3712	515	35	33.52	0.36
13	3112	3752	277	1106	22	37.63	0.43
14	689	388	5064	2084	44	61.24	0.37
15	314	6036	255	1625	39	73.00	0.35
16	265	2793	3385	1799	27	33.78	0.20
17	4560	2676	700	309	24	55.15	0.39
18	3361	1251	2325	1195	136	14.45	0.10
19	5114	1155	1533	401	66	61.85	0.38
20	670	634	6716	230	19	81.22	0.37
21	847	958	3835	2564	65	46.38	0.34
22	575	5339	1313	1009	33	64.57	0.46
23	6280	1286	317	372	14	75.95	0.30
24	517	931	2684	3963	174	47.93	0.14
25	335	770	633	6490	41	78.49	0.32
26	2858	2305	2591	483	32	31.33	0.51
27	2489	1557	1507	2687	29	32.49	0.39
28	670	3426	3528	598	47	42.67	0.28
29	307	414	3159	4375	14	52.91	0.47
30	563	5672	1486	515	33	68.59	0.28
31	3739	2170	1379	880	101	26.24	0.09
32	483	727	6822	214	23	82.50	0.30
33	473	3826	2314	1590	66	46.27	0.30
34	4076	569	3330	223	71	49.29	0.35
35	1124	2663	2817	1599	66	34.07	0.14
36	4275	3025	665	243	61	51.70	0.42
37	1121	1013	5111	954	70	61.81	0.56
38	2541	3064	839	1698	127	30.73	0.39
39	3315	1578	2111	1019	246	40.09	0.41
40	2132	455	4823	757	102	25.78	0.29

Number of candidates: 8342

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Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1805	667	1201	2447	13	39.90	0.54
2	622	1259	301	3944	7	64.31	0.31
3	1523	2999	633	955	23	48.90	0.50
4	707	3386	1379	578	83	55.21	0.35
5	495	4237	1051	342	8	69.09	0.29
6	4083	498	1367	133	52	66.57	0.36
7	1886	3276	614	326	31	53.42	0.56
8	1722	2318	1360	718	15	37.80	0.25
9	1277	1006	2552	1215	83	19.81	0.15
10	1087	1308	1468	2252	18	36.72	0.56
11	998	578	4039	490	28	65.86	0.42
12	1203	792	2130	1968	40	19.62	0.23
13	1508	889	608	3106	22	50.64	0.49
14	3733	1236	406	746	12	60.87	0.37
15	664	1537	3417	497	18	25.06	0.32
16	1671	2562	438	1442	20	27.25	0.22
17	643	451	3297	1713	29	53.76	0.23
18	1237	1656	2827	385	28	46.09	0.52
19	298	2009	2154	1639	33	32.76	0.16
20	417	2878	2339	447	52	38.14	0.19
21	1679	1286	1698	1443	27	27.38	0.20
22	3384	1509	356	830	54	55.18	0.45
23	985	2501	1638	969	40	26.71	0.07
24	4677	344	305	784	23	76.26	0.34
25	194	436	4752	695	56	77.48	0.37
26	1041	945	3796	280	71	61.89	0.51
27	1009	2803	1278	981	62	45.70	0.48
28	4064	997	519	508	45	66.26	0.41
29	519	1112	1572	2813	117	45.87	0.20
30	508	670	828	4043	84	65.92	0.34

Number of candidates: 6196

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.

The difficulty index varies from about 15% in HL and 20% in SL (relatively 'difficult' questions) to about 80% in both HL and SL (relatively 'easy' questions).

A difficulty index of 50% indicates that half of the students chose the correct option for that item. This was the case for 18 of the HL questions and 15 of the SL 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.

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. This was achieved for about 90% of the questions.

A low discrimination index may not necessarily result from an unreliable question. It could indicate a common misconception amongst candidates or a question with a high difficulty index.

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'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.

Candidates must develop the habit of reading the responses as part of the question. Multiple choice questions test a different aptitude to that tested in papers 2 and 3. The student who calculates the answer then searches the responses for a fit will always be short of time. Instead they should first visualise the situation after a careful reading of the stem and then ask themselves "which of the responses makes sense – and which are clearly absurd?"

The questions test concepts, not calculations.

SL and HL common questions

SL Question 9 and HL Question 6

There were some G2 comments that the candidates may not know what a force sensor was. But the graph shows the way a force changes with time (candidates should always check the axes on a graph!). Typically graphs have areas and gradients. In this case the gradient clearly has no relevance. The area gives a force x a time, which yields a change in momentum.

This gives the correct answer as D.

The skill of cancelling and dealing quickly with powers of ten are essential for the effective and quick solution of multiple choice questions. They are skills that many candidates find difficult given their normal dependence upon calculators.

SL Question 15 and HL Question 12

This is an area of the curriculum that regularly scores poorly. The key to successful understanding of wave mechanics is visualisation and linking this with the graphical representation.

If we want a centre of a compression for a longitudinal wave then the particles to the right of this centre will be to the left of their equilibrium position and those to the left of the centre of compression will be found to the right of their equilibrium position. This is shown graphically by response B.

This is a difficult idea to express in words but easy to see for candidates who have a good visual understanding of waves.

SL Question 16 and HL Question 13

There were a few G2 comments that the term 'transmitted light' in the stem was ambiguous as the light was transmitted through both filters. But the diagram is very clearly labelled – and if the question were about the light transmitted through the first filter then this would have rendered the second filter irrelevant to the question.

The discrimination index showed that the better candidates read the question correctly and gave the only possible answer, A.

SL Question 17 and HL Question 14

Two quick sketches of the pipes and the wave representations within them would allow the candidate to see that the wavelength has doubled indicating that the frequency has halved – C. No equations or calculations are needed.

SL Question 19 and HL Question 16

Current electricity seems to be a mystery to many candidates.

Students will never understand current electricity (and the concept of potential difference, which wasn't being tested here) unless they have an effective conceptual model. This may be that of traffic flow, or of termites making their way through the forest floor, or of water in a pipe, or of students running around a classroom track. However it is done, the students need to be able to visualise the flow of charge. When this has been achieved questions relating to speed and current (and, indeed, potential difference) become trivial.

The correct answer, B, was a minority option and the discrimination index indicated that there may have been quite a bit of guessing.

SL Question 27 and HL Question 22

There were a few G2 comments to the effect that the pion was not examinable. But candidates are expected to be familiar with them as itemised in the second bullet point understanding of 7.3 in the *Guide*. It was good to see that the candidates preferred option was the correct answer at both HL and SL.

SL Question 29 and HL Question 24

There were many G2 comments about the exact physics of this question, but in context there can only be one correct answer.

Clearly the rate of energy loss depends upon the temperature of the plate and of the surroundings. So '3' must feature in the answer, and it must be subtracted since elevating it would result in a smaller rate of energy loss.

So, D is the only conceivably correct answer.

Teachers should encourage students to see equations as dynamic descriptions of a physical reality. Even when introducing a topic for the first time a variety of equations can be surmised or invented, some of which are clearly wrong. This question would provide an excellent introduction to thermal radiation (8.2) to get the students thinking.

SL Question 30 and HL Question 25

Nature of Science is an integral part of the course and teachers should make sure that the philosophical context of the physics they are teaching is understood by their students. It is not an add-on. Teachers are well advised to take account of the Nature of Science section in the *Guide* (page 6 onwards) throughout their teaching and when preparing students for the assessments.

We recognise that the wording of this question was clumsy but it was good to see that most candidates at both HL and SL chose the correct response.

Future candidates can continue to expect NoS questions in both paper1 and 2.

HL-only questions

Question 3

This had the lowest difficulty index of the paper meaning that it was the most difficult question.

The candidates need to personalise the situation. If they imagine they (and a friend) are pulling on the ends of the string providing the tension then clearly as the angle to the horizontal gets smaller then they will need to pull harder. So clearly the tension is greater than something. So the only reasonable answer is D. The other responses all involve the tension being less than some value.

Personalisation and visualisation are powerful tools when solving multiple choice questions.

Question 4

This was a question that demanded a quick force diagram. Paper 2 questions consistently reveal that candidates are very poor at isolating a body and identifying the forces acting upon it. Once they have the force diagram, though, the application of $F = ma$ is easy.

Here the only force acting on the trolley is provided by the friction from the block. This is 1.0 kg x 10 N kg^{-1} x 0.3. Apply $F = ma$ to give the correct response of C.

Note that the quantities are chosen to make the use of a calculator unnecessary. Teachers should regularly encourage their students to perform quick mental arithmetic, cancelling and estimating where necessary.

Question 7

The responses may be summarised as:

A.   Much much bigger than v

B.   v

C.   A little bit less than v

D.   Very much smaller than v.

If the candidate now personalises the situation such that s/he is the polonium nucleus and a basketball is the alpha particle, it should be clear that their recoil velocity will be very small.

No numbers or calculations are necessary. The answer can only be D.

Question 9

Many G2 comments deemed this to be a tricky question. Granted the question needs to be read carefully – it requires us to compare the energies of the molecules. There were no square roots (or squares!) in the responses, so it was clear that the examiner was not trying to trick the candidates into thinking the question was about velocities.

Unfortunately the most common response was the incorrect C. But there was a high discrimination index which indicated that the best candidates were not fooled.

Question 10

Candidates should imagine doing this. They block the end of a syringe and reduce its volume by a third. This will treble its pressure. They then heat it up slightly. The pressure will increase slightly. The only answer acceptable is something just slightly more than 300kPa – Response B.

Note that no calculations are needed. Such questions should take less than a minute for a candidate who is thinking physically – rather than mathematically.

Question 18

This is another question that demands that the candidates imagine that they are whirling the weight in the circle. They will then realise that it needs to have some speed at the top if it is going to continue in a circle and not just fall.

So it must have more than enough energy at the bottom to get to the top. The energy to get from X to the top is clearly 2WR. Only option D indicates an amount greater than this so it must be the correct response.

Note that if there had been a distractor of 3WR then this would have been a difficult question requiring calculation and time. But if candidates are encouraged to step back from the problem, personalise the situation and ask themselves: 'What is going on?' then they will find that the distractors are chosen such that the correct response is obvious.

Question 19

This is another item that has an obvious answer when the situation is correctly visualised.

Both A and B are saying 'a fraction less than one, whereas C and D give a fraction greater than one. So clearly C and D are unreasonable as we know that the Earth is more massive than the Moon.

The relationship between mass and distance involves Newton's inverse square law, so we would expect squareds. There are no square roots in the responses so we can safely identify A as the correct response.

Question 26

This item had a high discrimination index but with A being the most popular answer. It is incorrect.

No equations or maths is needed to solve this question. The candidates are invited to choose between:

A. Very much less than the original energy

B. half the original energy

C. More than half of its original energy

D. Its original energy.

A candidate visualising the situation will see a mass slowing down from its equilibrium position. So D is impossible. In travelling from its equilibrium position to the half way point the force it is having to 'fight against' is on average smaller than the second half of its journey to its maximum displacement.

The loss of kinetic energy going from the equilibrium point to $\frac{x_0}{2}$ will be smaller than from $\frac{x_0}{2}$ to x_0. So it will have more than half of its kinetic energy left – C.

Again, no equations are needed; just a clear understanding of the concepts involved.

Question 31

Some teachers regarded the sign reversal as 'tricky' in this item.

First, though, a brief look at the units show that the answer must be either A or B (gravitational potential is measured in Jkg^{-1} and the question demands an answer in Joules.

So the only thing this item is testing is whether the candidate knows the difference between 'work done on' and 'work done by'.

A gives a positive answer, while B gives a negative answer.

Work done by a gravitational field will be positive if a mass is falling in the field. Here we are doing the work (not the gravitational field) so the answer will be negative – B.

Question 35

This is a very standard question but the statistics indicated there was a lot of guessing.

If current electricity is correctly visualised then it should be clear that whatever charge left one of the inside plates must have moved to the other inside plate. So the charges on each of the capacitors must be the same. And as the capacitors have different capacitance then the potential difference across each plate must be different (capacitance is measured in CV^{-1}). Hence C is the correct answer.

Question 36

It was disappointing to see how many candidates selected B. A charged capacitor can crudely be modelled as a battery that runs out over a very short time period. So initially the current should be high and then die away.

Perhaps some candidates were trying to rely upon memory and/or equations rather than a conceptual understanding of the physics based upon a model.

Question 39

A quick glance at these expressions shows that each answer will have different dimensions. Only A, though, yields Joules.

Question 40

Exaggerate! This is always a good way of seeing which equation is physically reasonable.

Let $\lambda = 0$, ie the substance is not decaying at all. Then the answer should be zero. Only A and C yield this. Now let $\lambda = \infty$, ie the substance all decays immediately, in which case there will be N nuclei that decay in the first second. Only A gives this so it must be correct.

It is interesting that more than twice as many candidates chose the incorrect C to those who selected A. Perhaps they are relying too heavily on their data booklets?

SL-only questions

Question 7

Candidates are expected to be able to perform simple mental arithmetic.

Question 10

Most candidates realised that the answer had to be either C or D. That was the easy part! But it is a frequent conceptual error to equate specific heat capacity with 'responsiveness to being heated' (ie to the gradient of a *T/t* graph.

But students should have the mental image of specific heat capacity as 'the capacity to take the heat'. It's exactly as advertised on the tin. A high *c* indicates an ability to keep calm and carry on – in other words it is indicated by a low gradient on a *T/t* graph.

Question 14

Simple visualisation – imagining being there on the boat and watching the waves come by – leads to the correct answer as long as the candidate realises that time period is measured in minutes and not min^{-1}.

Question 20

As observed elsewhere candidates regularly display a poor conceptual understanding of current electricity.

Current is the flow of charge and it may help some students if they use their fingertips to trace the path of the current. When they get to Y they have a choice to get to town X across the fields which offer a high resistance or to take the motorway where there is negligible resistance. So clearly the current will bypass the resistor and a simple application of V = IR leads to the correct answer of C.

Recommendations and guidance for the teaching of future candidates

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

Above all multiple-choice questions focus upon concept, and will involve only simple calculations. All topics start with concepts, ideas and models of reality. Scientists think with models and they 'see' the way through a problem. It is evident also in papers 2 and 3 that candidates are much happier calculating an answer than they are explaining a situation.

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. They should also learn the art of estimation.

These skills – 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. 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. This visualisation will involve stepping back from the question and understanding what is happening. What is the physics of the situation? Plunging into the minutiae of a question, data booklet to hand, is a recipe for disaster.

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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:

Personalise the situation. This is particularly important in mechanics. If the student imagines they are there then the answer often becomes obvious.

Eliminate the clearly wrong responses.

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 added in one response and subtracted in another.

Draw or visualise 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 those students with weak language skills.

Distinguish between cos, sin and tan functions – mentally making the angle 90^0 will 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 make an attempt at every item. It should be emphasised that an incorrect response does not give rise to a mark deduction.

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

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

Candidates should consult the current Physics *Guide* during preparation for the examination, 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 memorised but the students should not expect to find many multiple choice questions based purely upon memory. The 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.* 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 - 19	20 - 30	31 - 39	40 - 48	49 - 57	58 - 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

This was the second May assessment for the new course and there was evidence that this year's candidates are more at home with the changed demands of the course.

The G2 comments were very favourable for both papers. At HL (*SL in brackets*) 198 (*143*) schools responded – roughly 20% of the cohort. 79% (*70%*) found the paper of a similar or easier standard than in 2016. Clarity of wording and presentation of the paper were both found to be good or better by 80% (*80%*). Many teachers regarded the papers as having interesting contexts and to represent the type of paper that should be set for candidates at this level. Only around 10 % (*10%*) found minor issues with accessibility.

At HL there was no evidence that candidates were short of time on the paper. If there were gaps they were likely to be anywhere in the paper – not just at the end. There were no dead marks on the paper and excellent attainment was seen from some candidates who wrote and evaluated at a high standard. In the work of these candidates, calculations were often clear and laid out in a very satisfactory way. However, this was not seen from all. There was the usual negligence in respect of units and candidates need to continue to work at this aspect of examination technique.

At SL the standard was more mixed. There were clearly some candidates who had a good grasp of the subject matter and could express it concisely, but far too many candidates struggled with the construction of a reasoned argument and its presentation.

Candidates at all levels would be well advised to take note of the command word in a question and try to demonstrate their very best physics when answering questions. In their own interests, candidates should write with precision and care.

This effective presentation of work is a skill with which many candidates struggle. Examiners cannot give credit for illegible statements. Work – whether written, algebraic, or numerical answers – is often poorly conveyed. The order of written material is ill-considered; numerical solutions are jumbled and incoherent. The standard of work is in many cases very poor indeed. Candidates are given enough space for answers provided they seek to lay the work out in a neat and obvious way. Numbers are frequently illegible to some degree. The numerals 4, 7 and 9 are often written so poorly that they are indistinguishable; powers of ten are poorly written – examiners will not give the benefit of the doubt in such cases. Many candidates take no pride in their work and in an assessment at this standard this is a serious indictment. They should seek to lay out work in a clear and unambiguous way, they should seek to write legibly, and they should ensure that the final answer is clear and obvious. These are small points that will gain some candidates many marks.

Too many candidates continue to work outside the scanned area (denoted in all case by the boxes rules around the answer lines and other working areas). When examiners see material sliding off into un-scanned areas or are directed to it by the candidates then they will do everything possible to find the answer. However, if invisible off-scan work is not flagged up, then examiners cannot be blamed for failing to consider it in the marking. The Instructions to candidates are very clear on this point.

Where a candidate is asked to 'show that….' examiners require a reasoned argument within the context of the question leading to the desired result. All algebra must be clear as well as any substitutions made. The answer should be given, in this case, to one more SD than declared in the stem to indicate that a calculation has been made as the final step in the argument.

When asked to "calculate" students should also give steps in a logical progression. It is only in this way that the student can guarantee to receive compensatory credit for errors that occur in the middle of the work. Thus, many candidates miss out on errors carried forward through this type of poor communication both within and between sub-sections of questions. It is not the role of the examiner to investigate the origin of mysterious numbers that appear and disappear in work. It is the candidate's job to communicate clearly.

Most calculations in Physics proceed from an equation that often needs to be re-arranged from a version in the Data Booklet. Then a numerical substitution is required before final calculation. These stages are, ideally, written beneath each other in a logical order. At both HL and SL, examiners find that too many candidates present a jumble of unrelated algebra and numbers with an answer appearing in some random position. Candidate who present their work in this way do themselves no favours.

An understanding of units is fundamental to Physics, yet many candidates seem to regard them as optional extras. While examiners do not penalise every unit omission, an error in multiplier prefixes (ms, MW, kg etc) *will* be penalised. Students should declare units for every final answer. Not only is it good Physics, but it can often lead a student to a correct solution*.*

It is always inappropriate to give numerical answers to more significant figures than are quoted in the question data. Multiple rounding within a question can lead to an answer that has drifted away from the expected result by an unacceptable amount. Answers should not be left in surd form or as multiples of π – such answers will be treated as though the candidate has omitted the evaluation stage.

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

- Conceptual understanding of basic electrical phenomena, e.g. the relationship between current in a circuit and charge flow
- Clear and complete descriptions of energy changes and processes
- Identification of standing waves effects
- Correct constant identification in gas-law calculations
- Qualitative explanation of photo-electric phenomena
- (SL only) Balancing simple nuclear equations
- (SL only) Understanding the need to specify a vector quantity completely
- (HL only) Alternating current calculations
- (HL only) simple determination of force direction on current-carrying wire
- The areas of the programme and examination in which candidates appeared well prepared
- Applying physics to new contexts
- Mechanics calculations
- Calculations involving harmonic motion
- Calculations involving exponential change
- Interference and diffraction explanations and calculations
- Field calculations (in context of gravitational potential) The strengths and weaknesses of the candidates in the treatment of individual questions.

Question 1

(a) Many candidates were able to give good and accurate solutions to this first straightforward kinematic problem. Failure points were to assume that the final speed was constant and arrive at double the correct answer. Alternatively, a small number of candidates took the final answer (148.5 m) and rounded it down. Accurate rounding is expected in problems.

(b) Again, well done by many but with a perceptibly lower success rate than (a). Two common failures were to ignore the resistive drag completely or to subtract it from the driving force rather than add it. A simple force diagram would have solved this problem but this was rarely seen.

(c) There are a number of ways to tackle this question. The method that seemed to give most success was to approach it from an *energy = force × distance* standpoint. Many candidates who used *power = force* x *speed* failed to realise that the speed here should be the average

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value and not the maximum value. The third method in which the final kinetic energy of the glider and the work done against friction are summed was rarely correct as many candidates failed to take account of the friction term and therefore lost full credit.

(d) HL and (e) SL The Physics *Guide* is very clear that students should be taught to label all forces on a free-body diagram. Although there was much success with the arrows themselves, labelling was often missing or misleading. 'Weight' is acceptable; 'Gravity' is not. 'Drag' is not the same as 'friction' and should not be used synonymously. Most diagrams appeared to have been drawn with a ruler and the examiners commend candidates for this and hope that this improvement in presentation will continue. It was disappointing to see how many candidates added 'speed' or 'momentum' as forces.   Adding components as separate forces is not acceptable.

SL only

1d (SL only) This was well done by most candidates with most, although not all, expressing the units correctly

1f (SL only) It was rare to find a candidate able to apply Newton's first law in a concise way to this simple situation. The main problem was to identify the component of the lift as being equal to the weight.

1g (SL only) This was generally well done, but many did not realise that velocity involves direction.

Question 2

2a (HL only) Very many could write convincingly about harmonic motion. Credit was lost where it was not clear about the direction of the acceleration.

2b(i) (HL only) There were a large number of accurate determinations of the maximum speed. Most of   those who failed here either could not get started at all or could only calculate the frequency of the motion or its time period.

2b(ii) (HL only) There was a clear need for candidates to understand the context of the whole question in order to answer the graphical question effectively. This is a continuing and new feature of the new course. They needed to recognise that there is no energy converted for half the cycle and that for the remaining time it is sinusoidal. There was latitude in the marking but far too many simply drew "rectified" sine curves or $\sin^2$ curves. Despite a clear flag in the question a considerable number failed to label the time axis in a satisfactory way.

HL and (b) & (c) SL

(i) There were two requirements for this answer: a good description of the energy transfers involved in the process of using a pumped-storage facility, and a rationale for the use of pumped storage in the first place. The first point was well understood, the second point rare. A small but significant number of candidates (erroneously) referred their answer to wave power or to a tidal barrage and scored little if any marks. Candidates are always encouraged to read the question carefully. *SL candidates frequently missed marks as they wrote vaguely about 'potential energy'*

without linking it to the water. Just saying potential energy transferred to kinetic energy received no credit. Note also that the term 'mechanical energy' is ambiguous and should not be used when describing energy transformations.

(ii)This simple calculation was well answered by many.

(iii) Another failure to read the question meant that a number of candidates did not notice that there were four generators in use. Power of ten errors also fooled a number because they could manipulate the exponents.

(iv) Examiners were looking for precision in expression and variety of example in this question where candidates were asked for the energy losses. Both the seat of the energy transfer and its energy type were required. Two distinct examples were needed: a good starting point would be a thermal resistive transfer and an electrical loss. However, too frequently candidates focussed on one type of transfer (eg mechanical resistance) and repeated it for the second example. More flexibility in thought is needed in questions such as this.

(d) (SL only) This was well done.

Question 3 (HL only)

(a) With the exceptions of those who forgot to square the pd or failed to operate their calculator correctly, many did this question well.

(b) It was good to see so many well presented and effective solutions to this problem. Candidates can clearly understand the problems involved and solve them with clarity.

c(i) This was a question where an accurate attempt at a unit was required with the answer. Too often candidates worked in grammes and then expressed the answer as a unit including kilogrammes (or vice versa). This was a comparatively straightforward unit question and it was sad to see so many candidates failing to make a sensible attempt at it.

c(ii) Candidate frequently made a good attempt at the first mark by suggesting a viable thermal energy loss and then many could go on to show what difference this makes to the final estimate *in the experiment*. However, lack of clarity in writing meant that many candidates were not awarded the second mark as it was unclear whether they were saying that the estimate was lower or higher than the accepted value of the specific heat capacity.

Question 4 – HL and question 3 – SL

(a) This mark scheme for this question was designed to produce a ramp of difficulty and it achieved this. Almost all candidates were able to identify that superposition was the effect occurring here. Fewer candidates thought however to identify the maxima and minima as corresponding to constructive and destructive interference. Even fewer were able to link successfully the sensor behaviour with the interference effects themselves. Again, it comes back to a careful consideration of the question. Candidates were asked to link to the "voltage peaks" not to the "intensity peaks".

b(i) The sequence of three calculations was well done by many. Most now appear to grasp the (newly introduced) concept of interference fringes that are modulated by single-slit diffraction effects and can usually handle the ensuing calculations (with the reservation expressed in (c)(i) below) with precision and understanding.

b(ii) This was also well done; however, it was common to see 25 s rather than 25 ms for the graph time read-off. This was penalised.

c(i) (HL only) The final calculation was less well explained and examiners allowed considerable latitude in the explanation of the calculation. Candidates cannot always assume this level of generosity: for example, calculations with the correct answer stemming from $n\lambda = d\sin\theta$ were awarded credit. However, examiners might have taken the view that this solution stems from the use of the diffraction grating equation and considered it to be wrong physics. In only a few cases was there any consideration of n. It simply disappeared in most cases.

c(ii) (HL only) Candidates were asked to consider what interference effects are displayed in the region between the first and second diffraction minimum in the pattern. The answers are that all the peaks will be less than the corresponding peaks in the central region and that the fringe spacing is unchanged or that the train moves through peaks at an unchanged rate. The second point was rarely seen. This comes back to the point made earlier that candidates should not simply jump on the first bandwagon that passes but should consider all possibilities inherent in the context.

(d) HL and (c) SL Few candidates demonstrated a clear understanding that a standing wave was being observed in this question. There was more description of interference effects but as these generally failed to focus on the anti-nodal nature of the maxima full marks were rare and a common score was one mark for a basic description of the incident and reflected wave interfering. A significant number of candidates suggested that the Doppler effect was responsible for the intensity variation. Although there will be a very small Doppler shift in this case it is swamped by the standing wave phenomena – suggestions of Doppler were regarded as neutral.

Question 5 HL and question 4 SL

(a) The very straightforward first part was done well. Occasionally the emitted particle was identified as a beta particle and this poor physics lost the credit. The SL question was slightly different providing a reduced demand; this was also well done.

b(i) (HL only) Candidates scored well on this unusual question and were able to demonstrate with clarity what they were doing. Failure points included mixing units in the evaluation (eg decay constant in seconds with times evaluated in days) and a lack of final explanation leaving examiners in the dark as to what was going on. Again, candidates should take full account of the command word ("deduce" in this case) and where this corresponds to an Assessment Objective 3 task, full working and explanation must be given for full credit.

b(ii) (HL only) In this part, explanations were generally poorer but as candidates could establish their understanding by quoting the final answer to 2 significant figures or better high marks were scored.

HL and SL (b) and (c)

(i) Candidates should take care not to give a re-statement of the stem of the question. This was commonly seen here. Equally, statements of the obvious are unlikely to score. Examiners were looking for evidence of *physics*: a statement of the ionization power of the alphas, or their penetration power, or a crude description of the normal range of alphas was needed. But "so that they can get through" will not do.

(iii) Although many candidates (though not all) grasped the physical principles at work in this question, careless errors trapped many. A common (and predictable) mistake was a failure to convert the temperature into kelvin. A considerable fraction of the entry also struggled with the correct constant in the gas equation: is it R or is in k? The Data booklet gives some help here but many were struggling and a loss of a mark here was very common. At SL level it was common to see a jumble of figures without any underlying rationale. It is difficult for examiners to award ECF here.

(d) Statements of the basic physics (a transition from a high energy state to low) were commonly seen. About 50% of the candidates rightly mentioned the discrete nature of the energy levels as being important. It was however unusual to see the last and more difficult marking point where the energy level difference was clearly linked to the frequency of the emitted photon.

(e) The Nature of Science question turned on the idea of peer-review – an issue flagged up in the Guide. The point is that the review (and possibly experimentation) happens before the paper is accepted for publication by a journal; thus reducing the need for experimental repetition *after* publication. Many candidates however described the repeat experiments as happening post-publication or were vague about the timing. It was, though, good to see that many candidates had at least heard of the process and did not simply leave the answer space blank.

Question 6 HL and question 5 SL

(a) Most candidates were able to give an account of the electron as charge carrier and the reason why insulators and conductors differ. The standard of expression was however weak here. It was much less common to see some consideration of the role of the electric field. The field accelerates the electrons and the question flagged up the need for some statement reflecting this. The question clearly says 'with reference to charge carriers' but at SL it was rare to find candidates who made any reference to charge carriers in their response.

b(i) (HL only) Many candidates could demonstrate the use of the resistivity equation with complete success. Failures here were often due to incorrect quotation of the area equation for a circle ($2\pi r^2$ and $4\pi r^2$ were frequently seen).

b(ii) and b(iii) (HL only) There were widespread failures in these questions. Despite the careful description of the cable in the stem of the question including a diagram of its cross-section, candidates failed to appreciate that there were 32 individual strands in the cable each one of resistance 64 Ω. This gave rise to many variants of the answer in (ii). In (iii) the problems were more serious as many candidates had evidently not been introduced to the idea of power transmission through a cable and could not distinguish between the peak potential difference (pd) across the generator output (150 kV) and the pd across the length of the cable (about 1.4

kV). This was a serious error in physics and gave rise to some staggeringly large power dissipations per unit length in the cable (commensurate with the total transmitted power). This is an area of the Guide that teachers may wish to emphasise in their teaching.

SL only

b(i) Many candidates could demonstrate the use of the resistivity equation with complete success. Failures here were often due to incorrect quotation of the area equation for a circle ($2\pi r^2$ and $4\pi r^2$ were frequently seen).

b(ii) It was common to see 'R=....' without any indication of whether the R referred to the resistance of the cable, or of a wire, or of one meter of the wire etc. It is very difficult for the examiners to award ECF if the candidates do not make the line of reasoning clear and transparent.
The question invites the candidates to 'Show that....'. Many answers indicated that there was a desperate attempt to multiply/divide/add numbers to get the correct answer! This approach never receives credit. Similarly multiplying two incorrect numbers together and pretending they give 30W will always receive zero.

b(iii) This was generally well done. Candidates needed to state the correct equation and make the necessary substitutions, respecting the units of the temperature change.

(c) (HL only) Most candidates forgot that there are now two cables and that the current in them is therefore halved.

(d) (HL only) The forces between the cables in parallel vary in a number of ways and many candidates identified at least one way correctly. More able candidates wrote in clear terms about the current direction and deduced that the forces were always attractive. Others were able to describe the variation in force over one cycle of the alternating supply but usually with less clarity.

e(i) Finally the candidates were asked to consider the role of a step-up transformer in the power transmission process. Many were able to describe fluently the link between high pd and small current leading to smaller thermal losses and relating this to I^2R.

e(ii) Most candidates knew that laminating the core of the transformer reduces eddy currents. However, sometimes the focus on the core was missing and "wires" or the "coil" were mentioned (erroneously) in this context.

Question 7 HL only

a(i) Few were unable to calculate the wavelength of the light correctly.

a(ii) This response was very mixed. Good descriptions of the interaction of the photon with the surface were rare with much muddling of the process with some sort of atomic excitation. The link to the small (zero) kinetic energy of the photoelectron was poorly made by most even though some credit was awarded. As in past years it is clear that candidates find photoelectricity a demanding topic and it is one that teachers are recommended to emphasise in their teaching.

(b) Most could carry through this calculation of the maximum photoelectron velocity.

c(i) It is a standard question to ask what is the effect of increasing the frequency of the incident photons when keeping the intensity constant. Most failed to realise that the number of photons emitted per second falls (because the energy per photon increases). There seemed to be a wide misunderstanding of the meaning of intensity even though this is clearly required in Topic 4 for the *Guide*. Candidates must expect concepts to cross Topics now.

c(ii) However, all physical reasoning disappeared in the next part as candidates demonstrated a very shaky understanding of basic current electricity. Candidates had no clear understanding that the current in the photocell depends only on the number of electrons emitted per second (and then travelling across the cell). Many candidates suggested that because the energy of the emitted photoelectron is greater and so the speed is greater and thus the current is greater.

Question 8 HL only

(a) Suggestions as to why the gravitational potential is negative were usually unsatisfactory. Any convincing explanation needs to begin with the knowledge that the potential is defined to be zero at infinity and to continue with a consideration of the nature of the work done on the object as it moves to this distant point. Candidates produced muddle and ambiguous responses that attracted little credit. Too often (here and later) candidates confused the concept of gravitational potential with that of gravitational potential energy.

b(i) Examiners needed to see separate statements that both *G* and *M* are constant here – not just references to the product.

b(ii) and b(iii) These linked calculations were, on the whole, well done. Candidates were either able to manipulate the equations with some facility or (in b(iii)) had learnt the relationship between total gravitation energy of a planet and the kinetic energy of the planet in its orbit.

b(iv) Only the best candidates could show that the decrease in orbital speed leads to a reduction in the orbital radius and hence (paradoxically) a subsequent increase in the orbital speed. The mistake was the failure to link the decrease in orbital speed to the total energy changes (a decrease) which explains the radius change. Most candidates failed to grasp this point. There are other changes including a change in the eccentricity of the orbit, and some candidates identified this change (but not necessarily in these words) for credit. Contradictory statements within the answer were common and penalised.

(c) Most candidates realised that examiners wished to see some consideration of the centripetal nature of the resultant force acting on the Earth due to the gravitational interaction between it and the Sun. This was well done.

Recommendations and guidance for the teaching of future candidates

- Give equal weight to the development of skills involving writing and explaining not simply facility with calculations
- Develop candidate skills in applying physics they understand well to new contexts

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- Emphasise the phenomena that lead to the flow of charge in an electrical circuit and to its consequences
- (HL only) Develop a sound knowledge of the factors involved in ac power transmission
- (HL only) Develop a good understanding of the photoelectric effect – its causes and consequences.

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 - 11	12 - 14	15 - 18	19 - 21	22 - 35

General comments

Most candidates made a serious effort to attempt the required number of questions and appeared to have ample time to complete the paper. Virtually no candidates attempted more than one option.

Relatively few candidates allowed answers to flow outside the boxes provided on the question paper. However, there are still too many candidates who do not know how to present answers in an organised way. This session saw a huge number of extension sheets used - possibly by 40% of candidates.

Some candidates believe that the more that they write, the better is their chance of saying something that will earn marks. The reverse is often true. Examiners appreciate concise answers that are not contradictory and do not deviate from the question.

There were frequent occasions when poor handwriting made marking difficult. In particular powers of ten and decimal points were not always clear. Very often examiners had difficulty in deciphering the candidate's reasoning within a calculation - and frequently this reasoning was completely absent. Errors with units and powers of ten were alarmingly frequent.

Nearly 200 schools provided G2 HL P3 feedback on this examination. These comments are very useful in the design of future examination papers and teachers are encouraged to provide timely feedback via their IB coordinator. 91% of schools thought that the paper was of *appropriate* difficulty. 70% of schools thought the paper was of similar difficulty to last year; 23% thought it more difficult (the mean score was 2 marks lower) , 7% thought it was easier. 85% of schools thought that the clarity of the wording and the presentation of the paper was good to excellent. 98% commented that there was no significant cultural, religious or ethnic bias. The overall comments on the individual options suggests that the majority of schools responding

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were satisfied with the balance and facility of the paper. The marks showed an almost perfect normal distribution.

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

General weaknesses for the M17 and earlier papers

- *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 πr^2, $4\pi r^2$ and $\underline{4}\ \pi r^3$. (They are in the latest 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 *planned* and
- *methodical.*
- Use of a ruler in drawing diagrams.
- 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, estimate etc...
- Sequencing the presentation of facts to support an explanation or description. Definitions are generally poor and not learnt well.

Weaknesses specific to the M17 question paper. (* = HL only)

- Referring to *line of best fit* or to *error bars* when describing a relationship. Confusing *linear* with *proportional* when describing a relationship.
- Fundamental units.
- Appreciating the nature of an *intercept* on a graph.
- The effect of a *systematic error* on the gradient of a graph. The nature of *E and B fields* in different reference frames.
- Lorentz transformations.
- **Relativistic* momentum, *γmv.*
- *Application of the *equivalence principle. Entropy* in the context of a PV diagram.
- *Application of the *Bernoulli effect.*
- **Realisation that pressure acts on *cross-sectional* area.
- **Phase relationships* at resonance. Completing diagrams involving *wavefronts.*
- Application of the *magnifying power* of a telescope. Ray angle determinations for *optical fibres.*
- *Ultrasound imaging frequencies.
- *Stellar density* calculations from an HR diagram.
- Giving a concise outline of the Big Bang model.
- Using kms-1 in Hubble's law calculations.
- *Problems involving cosmological scale factor.
- *The minute anisotropies in CM.

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

Noted improvements for the M17 paper

- Determining fractional and % uncertainties.
- Using a **large** triangle when finding gradient (but still too few use the whole line).
- Describing and explaining the *muons on the mount* experiment.
- *Rotational* mechanics.
- Manipulation of the *ideal gas equation*.
- *Damped resonance* curves.
- *Q factor* calculations.
- Attenuation calculations in *optical fibres.*
- *Nuclear magnetic resonance* explanations.
- The nature and use of *type1a supernovae* (however at SL this was a weakness)
- *Explaining the significance of *galactic rotation curves* and *dark matter.*

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

Section A

Question 1 Radio waves

In (a) many mentioned the origin, which is irrelevant. A common correct simple answer was *'a straight line cannot be drawn through all the error bars*'. Parts (bi) and (bii) were often correct, but a surprising number of candidates could not locate the correct point on the graph or read the value of d. In (ci) there were many correct answers, strangely however the units for b were identified correctly far more often than the ones for a. Candidates usually failed to realise that even 1 small square on the λ axis was equal to 100,000m, which at 3kHz is certainly not a *very high frequency electromagnetic wave*. Hence in (cii) many candidates did not use the *d2* intercept or put *λ=0* into the equation. Even when candidates had the correct process power of ten errors were often made.

Question 2 Internal resistance

(a) The ammeter and voltmeter were almost always correctly labeled. The graph in (b) is from a standard practical yet few could write down its equation: $V = E - Ir$ and so identify $-r$ as the gradient. Many could determine that $r = 0.6\Omega$, but sometimes using read-offs that were too close together or, particularly at SL, by simply using R=V/I. Common mistakes included obtaining more than one value for r or obtaining a negative answer**.** The definition of *a zero error* in (c) produced some amusing answers, but most were correct. In (cii) the strongest candidates realised that a systematic error in I does not affect the gradient.

Section B

HL & SL: Approximate percentage popularity of the Options: A 5%; B 25%; C 10%; D 60%

As SL questions were identical to the core HL questions all comments are listed together. If there were distinct differences in performance between the two levels they have been mentioned. SL question numbers are in brackets [ ].

Option A – Relativity

Question 3 Fundamentals of relativity

The invariance of c in (a) was an easy answer. However the answers to (b) were generally very poor with few coherent arguments. Most candidates thought that there would be a magnetic force on the proton in its rest frame. Almost none, at both HL and SL, knew that if there was no resultant force in frame X then there would be no resultant force in frame Y.

Question 4 Muons on the mount

At HL there were many good answers to this question. Most viewed the situation from the Earth frame and determined the transit time of the muons and compared it to the dilated half-life of the muons. Hence they were able to explain that significant numbers of muons reached the ground. However at SL candidates often gained 1 or 2 marks by making a correct calculation but too rarely explained in which reference frame they were working, making it difficult to interpret the answers.

Question 5 The rocket and spacestation

Part a(i) (length contraction) was an easy 2 marks. In a(ii) there were quite a few candidates who were careless with the

+ or - directions in the velocity addition formula. At SL particularly, quite a large number of candidates did not use the relativistic formula for velocity addition. Parts b(i) and b(ii) were not well answered with most candidates incorrectly opting for Lamp1 turning on first (because Lamp1 is closer to the rocket, presumably). The spacetime coordinates were almost always correctly labeled in c(i). But in c(ii) only the best candidates were able to explain that ct

$> ct'$ since t' is a proper time. The spacetime interval equation was often mentioned but poorly used in (ciii) as most did not realise that $x'=0$ for the event.

Relativistic momentum

This question was not done well. Many assumed the value of gamma for the proton was the same as gamma for the pion, which made the question pointless. A few of the most able candidates used conservation of relativistic momentum correctly.

General relativity

Most candidates could define *event horizon* in a(i) and derive the given equation in a(ii). Making sensible use of the equation in a(iii) was a little more difficult. Almost no candidates gained full marks in (b) - there is no overall frequency shift in either frame. Had they looked at the situation from the box frame the question would have been easier. In the Earth frame redshifts and blueshifts cancel.

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Option B Engineering physics

Question 8 Rotational mechanics

Part (ai) saw many HL candidates give non- zero answers. They obviously paid no attention to the fact that the question was worth only 1 mark and had little space for an answer. At SL the vast majority of candidates gave non-zero values and often used the value found to answer the subsequent questions. The resultant torque on the probe in a(ii) was found correctly by nearly everyone. Part (b) was a 'show that' question - this means full working must be shown to gain marks. Although easy, many candidates did not provide sufficient evidence. Both parts of (c), concerning angular momentum and rotational kinetic energy, were answered quite well at HL. Working was, however, often scattered all over the answer box. However at SL (cii) was often incorrect as many candidates chose the wrong mass or angular velocity or forgot to square the velocity when making the calculation.

Question 9 A Thermodynamic cycle

Part a(i) was easy, many candidates could show that $Q=W$. In a(ii) There were many approaches. Sometimes $TV\gamma-1= Constant$ was derived or stated, or Pc first calculated to find Tc. Working was often a mess. Candidates rarely labeled the symbols used with a subscript, for example many candidates referred to T without mentioning whether it was the temperature at A, B or C. This made marking particularly difficult. Part a(iii) saw similarly varied approaches, but was found to be more difficult even though the answer of *330J* was given.

Surprisingly few candidates were able to determine the efficiency of the cycle $\left(\dfrac{Qin - Qout}{Qin} \right)$ in a(iv), even though all the necessary data were given in the question. Many found the Carnot efficiency which gained no marks. Identifying which point in the cycle had the

greatest entropy was not easy in part (b). The relationship $\Delta S = \dfrac{\Delta Q}{T}$ was rarely used as justification. Instead temperature was often used as the sole criteria and A wrongly identified as the answer. Many answers made little sense.

The Bernoulli effect

This question was poorly answered. In part (ai) many could find the pressure difference between the top and bottom of the ball. None could use cross-sectional area to find the force. A downward arrow was correctly drawn by less than half of the candidates in part (aii). In (b) laminar flow (or no turbulence) was occasionally correctly stated.

Damped oscillations

In part (a) the resonance curve was usually correctly shown lower with the peak to the left. In part b(i) very few candidates

(c)   identified the phase difference of $\dfrac{\pi}{2}$ at resonance. The Q factor calculation

(d)   was mostly correctly answered in part (bii), but with quite a few candidates

(e)   reading the period incorrectly.

Option C Imaging

Question 12 Lenses

Parts (a) and (b) were poorly answered. Tracing the paths of wavefronts through a lens is clearly not familiar to most candidates. Subject guide C.1.8. Candidates were confused between wavefronts and rays and, particularly at SL, the answers to (b) often referred to rays. Furthermore, the explanations given in part (b) often failed to mention changes in wave-speed, refractive index or wavelength. In part (c) there were many correct answers (*8cm*) but few correct explanations that the lenses had common foci.

Question 13 The astronomical telescope

At HL part (a) was done reasonably well, although many tried to use the lens equations rather than the simple relationships between *fo* and *fe* . At SL when candidates identified the two correct equations they were often unable to solve them correctly. A minority of candidates made a good attempt at finding the diameter of the moon in part (b), many forgot to divide the angle given by *17* to find *D* by triangulation.

In (c) most candidates could give at least one advantage of satellite telescopes over Earth based telescopes. A common wrong answer, especially at SL, was that the satellite telescopes are closer to the object in space.

Question 14 Optical fibres

Part (a) proved to be very difficult. Few candidates were able to start from the critical angle within the fibre and work backwards to the refraction at the air/fibre boundary. Most candidates used the formula for the critical angle of the air/core boundary without thinking whether it applies to this situation or not. In part (bi) most candidates identified the wider pulse as evidence of dispersion, but could not identify the smaller pulse *area* as the evidence for attenuation. The attenuation calculation in (bii) was done very well.

Ultrasound imaging

In part (a) the range accepted was *1 to 20MHz*. About 30% knew this. If candidates understood the question in part (b) then many could usually identify the *piezoelectric* effect as being the important crystal property. Fewer could explain the application of an AC pd to produce ultrasonic vibrations. The impedance calculations in part (c) were both done reasonably well, but with the usual number of careless arithmetic errors.

NMR imaging

This has been tested many times over the years, but this question was slightly different. Candidates found it quite difficult to stay focused on the question and not just write all they knew about NMR. There were many good quality answers, but scripts scoring 3 marks were rare.

Option D Astrophysics

This is by far the most popular option.

Question 17 Stars

In part (a) the majority of candidates knew the two *most abundant* elements composing a *typical* main sequence star (eg the Sun). Part (b) was possibly the most difficult question to mark on the paper. Working was strewn far and wide and many candidates got completely lost. Finding the ratio of the masses of stars X and Y proved the most problematic. The proportionality in the luminosity-mass relationship was rarely understood and many candidates assumed that the proportional sign can be replaced by an equal sign. When finding the volume of the star many candidates used the formula for the surface area of a sphere or circle. These formulae are now given in the 2017 update to the data booklet. Please contact your IB Coordinator if you have not received a copy. Error carried forward (ECF) was frequently needed. In part (ci) many knew that Star X evolves to a red supergiant and moves right on the HR diagram. Markers ignored any further paths. It may be worth mentioning that it is IBO practice to place arrows on the axes of graphs without grids. This also applies to the HR diagram. There was no intention to suggest that temperature increased from left to right and no evidence that candidates interpreted the T axis in this way. In (cii) many candidates could identify *neutron degeneracy pressure* or mentioned the *Pauli exclusion principle*. The luminosity calculation in part (ciii) was often correct, but there were many POT errors and errors from not using $4\pi r^2$ for the area of a sphere. In (civ) the wavelength was *2.9nm*. The vast majority of candidates got this part correct, but then mistakenly identified the radiation as UV ($\lambda_{uv} > 10nm$). Confusion between the electromagnetic spectrum and spectral class was also common at SL.

Question 18 Cosmology

In part (a) candidates could have gained 2 marks for saying '*Matter/energy/space/time created from a point/singularity and then expanding'.* Particularly at SL many candidates seemed to think that the big bang was the result of a star or galaxy exploding. Answers were often very verbose but worthy of marks. If candidates conceptualised answers as *bullet points* then perhaps conciseness would improve. The best candidates give brief answers which are sharply focused on the question. So one example of an ideal answer to the characteristics of CMB question is (b): *CMB is isotropic; with wavelength stretched by expansion;* [2]. The question command term was '*state*'. Part (ci) was generally well answered but many candidates did not work in *kms-1* when using Hubble's law. At HL there were many completely correct answers to (cii) concerning the use of type 1a supernovae. However, at SL very few candidates could identify that a type 1a supernova has known luminosity and is used to calculate distance. The SL section of the guide requires a qualitative description of type1a supernovae as indicators of

an accelerating universe (where their brightness and distance measurement suggests that they are further away than expected)

CMB

In part (ai) an ideal answer would have been: *(redshift) λ=kR, (Wien's law) λ= k'/T, hence R = k''/T.* Alarmingly, far too many candidates made fruitless use of *Ho = 1/T.* Others wrote line after line seeking a proof. Part (aii) was easy, although many gave the correct answer of *3080K* more by luck than judgement. The significance of CMB anisotropies was not well known in (b).

Dark matter

In part (a) most candidates could state that dark matter is invisible, but fewer went on to mention its gravitational interactions. If candidates understood the question in part (b) the algebra was usually perfectly correct. Part (c) was about galactic rotation curves - many candidates have been well taught for this new topic and there were some well-focused answers.

Recommendations and guidance for the teaching of future candidates

The new option topics allow candidates to experience some of the more challenging and interesting areas of Physics. In general candidates tend to perform less well on the descriptive parts of questions, these are often the cause of the difference between a mediocre and good grade. In setting private study exercises it is helpful for candidates to be given not only numerical questions but also plenty of extended response questions which are marked rigorously. Very often extended responses in descriptive questions are too verbose. The concise use of bullet points is a way of reducing unnecessarily wordy answers.

Many candidates assume that units do not matter - because the incorrect or missing unit in a final answer is often not penalised. This is a dangerous assumption because mistakes with units, within the calculation, will obviously lead to an incorrect numerical value or power of ten error. These mistakes **are** penalised. Rigorous treatment of units is a fundamental and essential part of any Physics course, but based on current evidence units are still not well handled by a large percentage of candidates - although some improvement is evident. Teachers are encouraged to set exercises involving the manipulation of units wherever possible and to ensure that units feature prominently in any worked examples provided. The Subject Guide places greater emphasis on the teaching of units, unit multipliers and powers of ten than before.

Past papers provide the opportunity for essential practice with the style of questions candidates will face. Giving candidates model answers allows them to understand the level of response that is expected. These are often provided in IB Physics textbooks. In many schools, model answers to homework exercises are routinely provided. The highlighting of key phrases in a question should be encouraged as so often an instruction or piece of information is missed. The mark for a question, given in the margin of the paper, is a useful indicator of the detail required in a response.

All candidates can benefit from being given the *IB Physics Subject Guide* and *Data Booklet* (updated in 2017). Both are useful learning tools and revision checklists. The subject guide and

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data booklet can be provided in teacher – annotated form, with textbook page references, web-site links and past paper question references. Although time consuming, it is so easy to do since both documents are in digital format. If they cannot be provided in this form at the beginning of the course, then the annotations can be added by candidates as the course progresses. Teachers are advised to have sessions, during revision, to explain the use of every equation and all items of data in the Data Booklet. A simple search for IB Physics revision notes will return useful resources including unofficial annotated data booklets. Please remember that these resources are not IBO approved.

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 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 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:

Investigation

- 2.1 Determining the acceleration of free-fall experimentally.
- Applying the calorimetric techniques of specific heat capacity or specific latent heat experimentally.
- Investigating a minimum of one gas law experimentally.
- 4.2 Investigating the speed of sound experimentally.
- 4.4 Determining refractive index experimentally.
- Investigating one or more of the factors that affect resistance experimentally.

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 <u>one</u> 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.

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 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 the many additional online sources of information. More information can be found on the Programme Resource Centre.

There are a huge number of unofficial IB Physics resources online including complete video courses covering the new syllabus. These provide a wealth of relevant and inspirational material for use in class or as private study exercises. They can be organised by teachers into a very valuable learning resource to supplement textbook.

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