Physics higher level and standard level

Contents

Grade boundaries

Higher level overall

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 25	26 - 37	38 - 47	48 - 57	58 - 68	69 - 100

Standard level overall

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 12	13 - 21	22 - 30	31 - 40	41 - 50	51 - 61	62 - 100

Internal assessment

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

Higher level paper one

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 13	14 - 16	17 - 19	20 - 23	24 - 26	27 - 40

Standard level paper one

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 9	10 - 11	12 - 13	14 - 15	16 - 17	18 - 30

Higher level paper two

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 9	10 - 19	20 - 28	29 - 39	40 - 49	50 - 60	61 - 95

Standard level paper two

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

Higher level paper three

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

Standard level paper three

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 8	9 - 11	12 - 15	16 - 19	20 - 24	25 - 35

Internal assessment

The range and suitability of the work submitted

Mechanics was by far the most popular topic. Standard labs included investigations with a simple pendulum, with the Barton's pendulum, and the bifilar pendulum as well as the Atwood pulley. Different approaches to projectile motion were also popular. The coefficient of restitution of a bouncing ball was approached from a number of different perspectives. The effect of temperature on elasticity, electrical resistance, and other physical properties was also studied, sometime successfully and other times not. Electricity and magnetism was also a popular topic, as well as various thermal investigations. There were several investigations to determine the charge of an electron using a computer simulation. There was also a variety of investigations relating sugar or salt concentrations in water to the refractive index of light. Some of these studies were well done and others were quite poor. There were very few database labs. Although investigating the gauss magnetic gun could be an appropriate IA, the majority of examples of this proved to be uninformed and misdirected.

Almost any physical property could be an appropriate topic of investigation if the student demonstrates a sound understanding of the key issues, is able to define a well-focused and quantifiable research question and develops a workable method. The importance of basic research and an appreciation of the physics relevant to the investigation are essential features of suitable work.

Candidate performance against each criterion

Personal Engagement

When a student report demonstrates independent thinking, initiative or creativity, or when there is some personal significance, interest and curiosity relating to the research question, or when there is personal input in the design or implementation or presentation of the investigation, then and only then has the student addressed the criterion of personal engagement. PE is assessed holistically, not in a section or paragraph with the heading Personal Engagement. It was encouraging to see that some students had modified a traditional investigation or designed their own investigation, thus demonstrating independent and creative thinking. Performing an investigation with a standard method and standard analysis but in a thoughtful and competent way often earned one mark for PE. Only the most insightful and thoughtful investigations demonstrated the qualities expressed by the top PE descriptors. Here, students would demonstrate a thorough and detailed analysis, a deep understanding of the issues, and a dedication to quality scientific work.

Exploration

There were a number of interesting and challenging investigations. These always included a single and well-defined independent variable and a quantifiable dependent variable. Appropriate investigations made use of known scientific concepts and relevant equations, and they would establish a relationship or function between two variables or determine an important scientific constant. Issues of safety, ethical and environmental concerns were mentioned when appropriate. There were also several successful investigations on the nature of large amplitude pendulums (as there were in previous years) where theory and experiment were compared. The key in all of these examples was that the student understood the physics of their investigation and established some relevant and interesting conclusions from data analysis. Assessment of the Exploration criterion was occasionally over-marked by teachers. It is this aspect of an IA that is most important for the possibility of a student's success. Too many times students would select multiple independent variables, perhaps thinking this would enrich the investigation when it fact it inhibited it. Often the known context of a research question was not addressed but would have been helpful to the student to focus and clarify their work. Academic research is expected.

Analysis

This criterion 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 raw data, including uncertainties. In most cases, data tables were clear and consistent with scientific notation. Processing was often detailed, with sample calculations of complex computations. Samples of simple calculations are not required. Graphs were nicely presented often with error bars. Occasionally, graph scales were printed with only one significant figure, thus reading a scale range of 0, 0, 0, 0, 1, 1. Both student and teacher must carefully read the text before uploading. Some data tables were confused and hard to understand. Column headings should include the quantity, units and uncertainty with units. Some graphs lacked appropriate detail, and others were too small to appreciate, or had too much information entered on a single graph. The terms 'proportional' and 'linear' were not always understood correctly. The construction of minimum and maximum gradients, when the gradient was meaningful, was often done in an unrealistic and extreme way. Students need to appreciate what their data does and does not reveal. A number of times a student graphed relevant data where the data scatter suggested a curve and yet the student forced a linear fit. The linear fit was then used to establish a bogus conclusion. Often a forced linear fit would imply a meaningless or impossible physical result when one axis quantity was zero. In most cases, graphs should have zero-zero origins. Occasionally students would fill pages with formal or purely mathematical error analysis without reference to the physical meaning of their data. The focus needs to be on physics.

Evaluation

The evaluation criterion addresses how well the data aligns with the research question. An appreciation of the assumptions of the methodology helps evaluation. Students need to demonstrate an understanding of physics here. Simply stating that their experiment proved the research question fails to appreciate the nature of scientific studies. Often students would construct a meaningless polynomial equation without giving any physical meaning to the results. A comparison of the conclusion and accepted theory was often missing. One exploration concluded that refractive index changes with incident angle. Too often students would simply quote the terms 'random' and 'systematic' errors without evidence of how these related to their data. The evaluation criterion is the most difficult for students to achieve high marks, and it is often the most over-marked by teachers. Specific attention to all the evaluation indicators must be given.

Communication

Like Personal Engagement, the communication criterion is assessed holistically. This means that the overall clarity, flow and focus of the report are assessed. The best reports made it clear in the first paragraph what the specific investigation was about, how it was conducted and what results were found. The best reports stayed focused on the research question and related physics and did not ramble on with generalities about the student's interest, historical background or unnecessary pedantic details. A title page is not needed, but a descriptive title at the beginning of the student report is recommended. A table of contents should not be needed if the report is concise and flows logically. Any picture or image copied from a source must be referenced, not just a listing in the bibliography. Only resources that are referenced and used should be included in the bibliography. Padding the bibliography does not impress the moderator. Communication is not penalized for lack of references but rather when this occurs it becomes a serious IB issue of academic honesty and possible plagiarism. Finally, it is important to note that many students are writing in a second language, so when there is an ambiguity in the text, moderators often give the student the benefit of doubt. Communication often earned high marks, usually in the 3-4 mark-band.

Recommendations and guidance for the teaching of future candidates

- It is important that teachers provide guidance during the entire IA investigation process, and not only when they read a draft.
- Students need to acknowledge and appreciate the physics that is already known about their research question. Too often students made-up common-sense physics or failed to appreciate well-known theories.
- Teachers should encourage students to include a descriptive title to their report and to make sure the research question is identified and explained within the first paragraph. A title page or a table of contents is not necessary when a report is concise and focused.
- All images (pictures, diagrams) and any ideas that are copied must be referenced. A bibliography at the end should only include sources that were used and properly referenced within the text.
- Research questions are most appropriate for assessment when they address a function or relationship between two variables, or where they experimentally measure an important constant in nature. Research questions should be both challenging and scientifically interesting. The purpose of the investigation can be expressed as a research task, and not necessarily in a form of a question.
- Students should not assume that data scatter graphs must be forced into a best-fit linear line. In many cases the physics meaning of doing this goes against known theory and common sense. For example, forcing a linear line fit on a Newton cooling curve graph. If, however, a proper function is found, then such quantities can be graphed in a linear way. Computer fitted polynomials can fit any data scatter, and students need physical reasons for selecting a complicated best-fit line.

- It is important that students have a sound knowledge of the assessment criteria. Teachers can discuss extensions to class investigations or ideas relating to topics studied throughout the school year, so when students are expected to come up with their own research topic, their minds are full of exciting possibilities.
- Make sure students use physics terms correctly. The change in temperature is not temperature, velocity is not average speed, distance is not displacement.
- Students should not copy existing IAs as published by the IB as teacher support material or follow detailed worksheets as published by commercial IB support companies or purchase so called teacher marked IA reports.

Further comments

- Teachers application of the assessment criteria is mostly in line with IB standards, but occasionally, when teachers' over-mark or under-mark the student's script, then the examination team needs to moderate the student's total. When this happens, the schools receive feedback. If the teacher's assessment is within tolerance, however, then there is no feedback to the school.
- When teachers upload a student's IA and enter criteria marks there is additional space for entering comments about their assessment of the student's work. Teachers should take advantage of this aspect and share with the examiner their reasons or evidence for the awarded marks. Alternatively, teachers can add comments throughout the report or, preferably, at the end of the report. It is best not to simply copy the official five pages of IA criteria and checkmark the assessed levels.
- Teachers should realize that issues of uncertainty and error analysis appear under the Exploration, Analysis and the Evaluation criteria. However, each time the issues are addressed from a different perspective. In Exploration, students should take into consideration significant factors that may influence the quality of work. Under Analysis, students need to appreciate the impact of uncertainties, and this is a quantitative appreciation. Under Evaluation, students should discuss the limitations of the data, as well as the sources of errors and uncertainties.
- Under the criterion of Evaluation, procedural and methodological issues are distinguished. Procedural issues (mark band 1-2) are a fixed set of steps, not a generalization. They are a subset of methodological issues. For example, taking more data, or extending the range of data, are both procedural issues. In mark bands 3-4 and 5-6, methodological issues are mentioned, and these issues address the assumptions in the method, and may include suggestions on new ways to measure the quantities or alternative approaches to the research question.

Paper one

General comments

A very low number of G2s were submitted this year compared to last year. While this return rate may indicate a general level of satisfaction with the papers, we strongly encourage teachers to take the time to provide us with thoughts about the papers and the individual questions. The G2 comments are always carefully considered and they do inform the grade award process and future writing.

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

The HL paper was regarded as being of appropriate difficulty by about 87% of the respondents with 13% finding it too difficult. The HL paper was deemed to be of a similar standard to the previous year's paper by 53% of respondents, with 26% of HL respondents judging it to be more difficult. All HL respondents felt that the paper had good or better 'clarity of wording', and presentation of the paper was similarly judged as good or better by all respondents.

There was a feeling expressed in the G2 comments that this paper required more elaborate algebraic manipulation that typical in past papers. It was also suggested that this may have led to time being more of an issue this year for students as they worked to complete the paper. The low number of blanks from HL candidates suggested that time may not have been a significant factor for the majority of HL candidates. In contrast, the number of blank answers increased significantly for SL candidates towards the end of the paper suggesting that candidates may have been more pressed for time. (See discussion of 'Blank' responses 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 accepted answer is indicated by a shaded cell.

International Baccalaureate

Multiple Choice Analysis Report

PHYSICS HL PAPER 1 (MCQ) NOVEMBER 2018 in Question order 99% of cohort

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	66	53	362	1082	4	69.05	0.56
2	41	193	1259	70	4	80.34	0.36
3	285	822	425	32	3	18.19	0.25
4	631	217	680	36	3	40.27	0.28
5	781	519	175	86	6	49.84	0.34
6	223	945	304	89	6	60.31	0.45
7	77	912	481	95	2	58.20	0.48
8	206	32	1268	60	1	80.92	0.39
9	410	256	567	322	12	36.18	0.58
10	123	189	1121	133	1	71.54	0.43
11	256	1108	37	163	3	70.71	0.43
12	175	1083	260	48	1	69.11	0.51
13	1079	133	145	200	10	68.86	0.57
14	134	139	836	449	9	28.65	0.39
15	863	220	257	224	3	55.07	0.60
16	47	988	476	51	5	63.05	0.37
17	195	161	596	602	13	38.03	0.30
18	942	227	170	218	10	60.11	0.52
19	187	712	438	225	5	45.44	0.51
20	154	1104	130	176	3	70.45	0.49
21	1309	97	62	93	6	83.54	0.31
22	295	937	169	162	4	59.80	0.52
23	286	62	63	1153	3	73.58	0.31
24	33	340	200	982	12	62.67	0.54
25	150	1229	142	42	4	78.43	0.33
26	255	67	1066	174	5	68.03	0.57
27	220	284	761	298	4	48.56	0.37
28	200	1067	168	123	9	68.09	0.45
29	320	63	135	1046	3	66.75	0.52
30	210	411	654	270	22	17.23	0.16
31	988	294	207	74	4	63.05	0.34
32	293	411	224	629	10	40.14	0.49
33	351	325	428	445	18	28.40	0.32
34	210	62	744	543	8	47.48	0.63
35	780	279	331	153	24	49.78	0.52
36	257	459	698	134	19	44.54	0.39
37	115	72	1203	165	12	76.77	0.51
38	124	112	354	964	13	61.52	0.55
39	301	263	215	751	37	47.93	0.45
40	932	238	154	220	23	59.48	0.50

Number of candidates : 1567

PHYSICS SL PAPER 1 (MCQ) NOVEMBER 2018 in Question order

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	606	388	211	**1305**	6	51.87	0.50
2	163	227	1063	**1035**	28	41.14	0.64
3	113	536	**1711**	140	16	68.00	0.44
4	**1727**	211	161	404	13	68.64	0.40
5	**334**	1390	632	153	7	13.28	0.07
6	**831**	272	813	588	12	33.03	0.32
7	**812**	1057	228	409	10	32.27	0.36
8	464	**1283**	539	190	40	50.99	0.20
9	615	488	735	**626**	52	24.88	0.10
10	158	430	**1479**	417	32	58.78	0.30
11	1314	450	**289**	415	48	11.49	0.18
12	424	581	**1126**	358	27	44.75	0.52
13	491	**1335**	225	454	11	53.06	0.35
14	590	**1069**	695	134	28	42.49	0.42
15	400	1337	244	**502**	33	19.95	0.33
16	663	541	**1026**	262	24	40.78	0.41
17	580	200	262	**1454**	20	57.79	0.21
18	**584**	767	826	311	28	23.21	0.42
19	147	**1038**	1055	231	45	41.26	0.31
20	477	425	**695**	862	57	27.62	0.18
21	**936**	585	589	347	59	37.20	0.38
22	548	**777**	681	453	57	30.88	0.26
23	371	462	**898**	703	82	35.69	0.28
24	578	**1043**	541	288	66	41.45	0.38
25	**1192**	552	398	285	89	47.38	0.45
26	448	668	576	**764**	60	30.37	0.41
27	518	**1045**	603	263	87	41.53	0.37
28	652	291	216	**1291**	66	51.31	0.28
29	232	892	541	**723**	128	28.74	0.34
30	273	**1214**	676	202	151	48.25	0.36

Number of candidates : 2516

Comments on the analysis

Significant SL cohort changes

It should be noted there is a 51% increase in the number of students in the SL component many of whom scored low marks or left responses blank. Comments largely refer to the smaller stable cohort and therefore may seem to contradict the data. Separate specific advice will be forthcoming for these new schools.

Difficulty

The syllabus specifies that 50% of multiple choice questions will require AO3 skills and students should expect some questions to be answered in well under a minute allowing extra time for questions of greater complexity. It should be noted that the common elements of the curriculum need to be taught to the same level of complexity and will normally be tested with the same multiple choice questions.

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 papers gave a reasonable spread of marks while allowing all candidates to gain credit. This range of indices showed that the paper was accessible to students of all abilities. In both papers, there was an even range of difficulties amongst the questions, which led to a normal distribution of marks. This meant that both papers were effective assessment tools with the mean mark being broadly like the previous November.

Discrimination

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

All questions had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. However, a low discrimination index will not always result from an unreliable question. It could indicate a common misconception amongst candidates or a question with a high difficulty index.

'Blank' response

Candidates should be reminded that there is no penalty for an incorrect response. If the correct response is not known, candidates should be able to eliminate some of the 'distractors', thus increasing the probability of selecting the correct response. In certain instances, the correct response can be selected through a consideration of relative magnitude or units of the responses rather than a detailed working of the algebra. In this manner, there should be adequate time to complete all the questions and check any uncertain responses.

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

In this paper there were 15 common questions which comparable to that seen in previous sessions.

SL & HL Common Questions

HL Question 1 and SL Question 2

This question was answered well, in particular at higher level. Some candidates neglected to multiply the length uncertainty by three in order to determine the percentage uncertainty in the volume when cubing the length.

HL Question 2 and SL Question 3

This question was very well answered. A small number of HL and SL candidates made a power of ten error leading to response B.

HL Question 3 and SL Question 5

This question had a particularly low difficulty index for both HL and SL, indicating that the majority of candidates selected an incorrect answer. The most common (incorrect) answer was B, suggesting that candidates did not recognize that distance was plotted on the x-axis rather than time. Since this was indicated in the stem of the question, candidates should be encouraged to read questions carefully, as well as noting the axes labels on graphs.

HL Question 6 and SL Question 8

The majority of candidates recognized response B as the correct response. A significant number of both SL and HL candidates selected responses A and C, suggesting that some candidates need practice when rearranging algebraic equations.

HL Question 9 and SL Question 11

Determining the proportionality between speed and mass, through kinetic energy and temperature, proved challenging for many candidates. It is important that candidates learn how to manipulate ratios, combining and rearranging formulas with several unknowns to obtain a desired value. This question had a good discrimination index, indicating that candidates who answered this question correctly generally scored higher overall on the paper.

HL Question 10 and SL Question 12

This question was very well answered by HL candidates. Candidates were required to use ratios to solve for the required answer.

HL Question 11 and SL Question 13

This question was well answered by both HL and SL candidates.

HL Question 12 and SL Question 14

This question was very well answered by HL candidates.

HL Question 16 and SL Question 19

While the correct response (response B) was the most frequent option selected by HL candidates, response C was also a popular response. Candidates appeared to be confused whether the change in length would half or double the resulting power.

HL Question 17 and Question 20

The majority of candidates (both HL and SL) selected response D as the correct answer. This answer represented the total current in the circuit, rather than the current passing through resistor X in the parallel branch of the circuit.

HL Question 19 and SL Question 22

Fewer than half of the candidates recognized Response B as the correct answer, however the large majority of candidates eliminated Responses A and D. This suggested many candidates understood the effect of charge on particle trajectory but were less familiar with the effect of particle speed.

HL Question 21 and SL Question 25

This question had the highest difficulty index for HL candidates, indicating that this question was very well answered. Answers were more divided for SL candidates, however the majority selected A as the correct answer.

HL Question 23 and SL Question 28

This question was very well answered by both HL and SL candidates.

HL Question 24 and SL Question 29

Most HL candidates correctly selected Response D. SL candidates were divided between Responses C and D, suggesting they were unsure whether the correct ratio was 3/4 or 4/3.

HL Question 25 and SL Question 30

This question was well answered by both HL and SL candidates.

HL Only Questions

Question 4

The majority of candidates (incorrectly) selected response C. This response would be correct in the absence of air resistance, but the asymmetry in the graph along with the numbers on the graph axis clearly indicates that air resistance is to be considered. Fewer than half of candidates correctly selected response A.

Question 5

Roughly half of the candidates correctly selected response A. Response B was the second most common answer, suggesting some candidates were unsure how to combine tension and the force of gravity.

Question 7

This question was generally well answered by candidates. Response C was the second most common answer; these candidates were likely focusing solely on equilibrium in the vertical (y-) plane.

Question 8

This question had a very high difficulty index, indicating that the majority of candidates selected the correct answer. Candidates (incorrectly) selecting response A likely assumed that the solid substance had not reached its melting point at the y-intercept, as is typically represented in heating curves.

Question 13

This question was well answered by candidates.

Question 14

The majority of candidates recognized that the waves would constructively interfere at point P, however responses were divided between response C and D. Students selecting response C (the most frequent response), did not recognize the relationship between amplitude and intensity.

Question 15

The majority of candidates recognized that response A was correct; incorrect responses were equally divided among the remaining options.

Question 18

This question was well answered by candidates.

Question 20

This question had a high difficulty index; the large majority of candidates correctly selected response B.

Question 22

This question was well answered by candidates.

Question 26

This question was very well answered by candidates.

Question 27

Fewer than half of the candidates correctly selected response C. Incorrect answers were evenly divided among the other answers.

Question 28

This question was well answered by candidates.

Question 29

This question was very well answered by candidates.

Question 30

This question had a very low difficulty index, indicating that this question was very challenging for students. Students should be aware of the formulas provided in the data booklet; recognizing the significance of the gradient makes the question substantially easier.

Question 31

This question was generally well answered by candidates. A surprising number of candidates selected responses B and C. Each had elements of the correct answer, but neither was fully correct.

Question 32

Response D was correct, and the most frequent selection by candidates. A number of candidates (incorrectly) selected response B, correctly recognizing the factor of $\sqrt{2}$ but mistaking its placement in the ratio.

Question 33

Candidate answers were fairly evenly distributed among responses, indicating a general lack of understanding. This question would be useful when teaching students about electromagnetic induction.

Question 34

The large majority of candidates correctly eliminated options A and B but were divided about the effect of frequency on peak power output. This question had a good discrimination index, indicating that candidates who answered this question correctly generally scored higher overall on the paper.

Question 35

This question was generally well answered by candidates.

Question 36

Fewer than half of candidates correctly selected response C suggesting that students could benefit from greater familiarity with capacitors in series and parallel.

Question 37

This question was very well answered by candidates.

Question 38

This question was well answered by candidates.

Question 39

Roughly half of candidates recognized response D as the correct answer. The remaining candidates were divided between the other three options.

Question 40

This question was correctly answered by the majority of candidates.

SL Only Questions

Question 1

This question was well answered by candidates. A surprising number of candidates selected response A, apparently calculating the units for acceleration.

Question 4

Unlike HL Q4, this question considers air resistance to be negligible. The majority of candidate correctly selected response A.

Question 6

Most candidates correctly recognized that direction of the friction vectors had to be opposite. While response A was correct, and the most frequent answer selected by candidates, response C was almost as frequent.

Question 7

Candidates were able to identify the direction of centripetal force acting in this question, however (the incorrect) response B was more frequent, suggesting that candidates struggled to identify the work done in circular motion.

Question 9

Approximately one-quarter of candidates recognized response D as the correct answer. Other answers were divided between the remaining options. As with other ratio-based questions, many SL candidates found this question particularly challenging.

Question 10

This question was answered very well, however some candidates incorrectly selected response D without considering the units.

Question 15

The majority of candidates (incorrectly) selected response B, likely missing the units on the time axis (ms).

Question 16

Roughly half of candidates recognized that response C was correct.

Question 17

This question was well answered by candidates.

Question 18

Candidate answers were fairly evenly distributed among responses. Again, the notion of ratios proved challenging for SL candidates. This question would be useful when teaching students about drift velocity.

Question 21

Fewer than half of candidates correctly selected response A.

Question 23

This question was difficult for many candidates. This is a good example of a question where certain responses (A and B) can quickly be eliminated without performing complex calculations.

Question 24

This question was generally well answered.

Question 26

Roughly one-third of candidates recognized D as the correct answer, suggesting that students would benefit from further discussion of beta (positive and negative) decay.

Question 27

This question was generally well answered.

Recommendations and guidance for the teaching of future candidates

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

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

Arithmetically the students should be adept at dealing with powers of ten quickly and efficiently. Total reliance upon a calculator for simple cancelling and combining the powers of ten can be a waste of valuable time. Overreliance on a calculator can also cause candidates to potentially panic on this paper when they are faced with a calculation in a question. The non-calculator mathematical skills of cancellation, mental arithmetic and dealing with powers of ten may need to be taught explicitly to students. It is also important that students be able to work with ratios, combining equations to determine the effect of a stated change in one of the variables.

Teachers frequently comment on unfair 'tricky' questions. In order not to be 'tricked', candidates must read the question very carefully to visualize the situation. This visualization will involve stepping back from the question and understanding what is happening. It can start with thinking about what core physics concepts are involved in the situation and what the candidate knows about those concepts. Plunging into the minutiae of a question or scouring the data booklet without first thinking about these steps first can cause students to fall into traps rather than see the correct answer.

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

- Eliminate the clearly wrong responses.
- Consider the units. Paying attention to units can sometimes lead to the identification of the correct response.
- Exaggerate a variable - this will often point the candidate in the correct direction.
- Draw or visualize the situation while reading the stem. A simple sketch will aid in understanding and often lead the candidate to the correct response. This is particularly important for students who are not testing in their native language.
- Distinguish between cos, sin and tan functions - mentally making the angle 0° or 90° will often show which is correct.
- Use proportion: new quantity = (old quantity) x (a fraction), where the fraction depends upon the variables that have changed.
- Observe the axes on graphs and use units to attach meaning to the gradient and the area.
- If all else fails, make an educated guess.

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

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

Candidates should consult the current physics guide during preparation for the examination, in order to clarify the requirements for examination success. Teachers should be aware that questions are constructed from the requirements of the syllabus - not from previous papers.

The guide does invite the candidates to recall certain simple facts, although most of physics is process oriented. Occasionally there are items in physics that need to be memorized but the students should not expect to find many multiple-choice questions based purely upon memory. That said, student understanding of core concepts and definitions often impacts how they read and answer multiple choice questions; for example, the topics of nuclear binding energy and the photoelectric work function where critical in correctly answering questions on this paper. It is also worth noting that current specifications require that about 50% of the items will be AO3 questions involving higher order thinking skills.

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

Paper two

General comments

HL

From the G2 comments 40% of respondents felt that the paper was of appropriate difficulty, while 60% felt it was too difficult. 26.7% felt that it was of a similar standard to last year's or easier, while 73.3% felt it was harder.

SL

From the G2 comments 40% of respondents felt that the paper was of appropriate difficulty, while 60% felt it was too difficult. 33.3% felt that it was of a similar standard to last year's or easier, while 66.7% felt it was harder.

Candidates were able to show strengths in all areas of the syllabus tested by this exam paper. The sub-topics that provided the most blank answers at HL were diffraction gratings, nuclear physics and solar radiation. At SL they were solar radiation and electron energy levels.

Many candidates' answers were well structured, and examiners commented that again there were fewer issues when it came to following lines of arguments or calculations than in previous sessions. There were issues, however, with reading some powers of ten and the need to make these numbers clear should be pointed out to students.

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

- explanations involving electrical circuits
- energies of molecules in gases and liquids
- (HL only) eddy currents
- (HL only) diffraction gratings
- (HL only) details of beta decay

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

- force and momentum
- electricity calculations
- correct use of significant figures
- motion of particles in a longitudinal standing wave at HL, but less so at SL
- calculations of photon energies
- (HL only) calculation of decay constant
- (HL only) capacitor calculations
- (HL only) Kepler's third law

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

Question 1

1(a) This calculation was completed correctly by many candidates. The most common incorrect approaches were those based on an attempt to use kinematics equations or conservation of energy.

1(b) (i) Given the level of success in (a) it was surprising how many students struggled with this part. Successful answers were seen based on both alternatives given in the mark scheme.

1(b) (ii) HL only. Examiners were looking for a link between mass change and acceleration or force and acceleration. Many candidates didn’t gain this mark as they recognised e.g. that the mass changes but didn’t link that to acceleration.

1(b) (iii) The most common answer here was that estimates made calculations easier.

1(c) (i) Many candidates suggested that the ions repelled each other and of those most attributed this to them having the same sign charge. Common reasons given which didn’t gain credit were that the ions were being diffracted through the gap at the rear of the spacecraft and or that they were spreading out because space is a vacuum.

1(c) (ii) Many answers discussed components of momentum parallel and perpendicular to the direction of the spacecraft and how this affected the acceleration. In fact, the forces between the ions don’t have an effect on the spacecraft and this was recognised by very few candidates.

It should be noted that the wording of the question in the published version has been changed to ‘Explain what affect, if any, this spreading has….’

Question 2

2(a) This calculation was done successfully by many candidates and most recognised the need to give an answer to 2 significant figures. The significant figure mark was awarded even if the numerical answer was incorrect. Power of ten errors were common here.

2(b) This calculation was generally very well done with the majority of candidates realising the need to round down for the final number of lamps. At HL some candidates calculated the peak power and then calculated the number of lamps which yielded an answer of twice the number. Examiners didn’t allow ECF for the second marking point as a nonsensical answer for the first marking point would lead to ½ for this question being awarded for simply rounding down. ECF marks are generally awarded in all questions unless where stated.

2(c) Many candidates did not give responses that were explicitly about the differences between series and parallel circuits – instead they made comments that could possibly be true for series circuits as well e.g. in parallel the brightness of the bulbs would be the same. Also, quite a few discussed the change in resistance which led to many incorrect conclusions. The mark scheme shows many possible ways of scoring the one mark available and this reflects the many ways in which candidates answered this question.

2(d) (i) HL only. Many candidates recognised that eddy currents result in thermal energy loss, but ideas about their location or how they are formed were patchy. Only a few candidates described then as being induced. Few candidates made the connection between the eddy currents decreasing output power specifically for MP3.

2(d) (ii) HL only. Many candidates made a good attempt at this calculation scoring marks for correct answers or from ECF marks. Examiners were able to award ECF marks from an incorrect power or number of lamps from b) and from a number of steps in this calculation.

Question 3

3(a) HL only. This was very well answered.

3(b) (i) HL only. This was very well answered. Examiners were looking for candidates to show their working and to produce a final answer with at least 2 significant figures i.e. 1 more significant figure than was given in the 'show that' value in the question.

3(b) (ii) HL only. Many candidates answered this well for the first 3 marks but then neglected to include the weight of the egg when calculating the total force.

3(b) (iii) HL only. This was well answered with answers seen using both alternatives in the markscheme. Some candidates, however, just discussed the 'hardness' of the concrete.

Question 4

4(a) (i) HL only. Many candidates tried to draw a line that was familiar to them on a diagram of a standing wave and drew the mirror image of the line in the diagram.

4(a) (ii) SL 4(a). There have been similar questions in recent years asking students to interpret the motion of particles in a longitudinal standing wave and their displacements to the left and to the right. This question was answered with much more success than previous ones with most candidates discussing left/right motion rather than up/down motion.

4(b) This was answered well with the most common mistake being the calculation of the wavelength. In addition, some candidates substituted a value for the speed of sound they had memorised. Many included the appropriate unit.

4(c) (i) This proved difficult for many candidates. Common answers were to continue the original ray from the transmitter through the wall or to draw a solid line over the dotted line. Another common answer was to draw a very similar situation but move the position of the image to the left.

4(c) (ii) Many candidates recognised that the effect would be caused by interference/superposition for the first mark. For the second mark examiners were looking for the condition for a maximum or minimum to be formed in terms of path difference or phase.

It was decided to ignore the π phase change on reflection from the wall as this would lead to too high an expectation for an answer in terms of path difference. Had such an answer been seen the mark would have been awarded.

Question 5

5(a) (i) SL 5(a). This was very well answered by the majority of candidates. Full credit was awarded for answers for the 488 nm, 435 nm and 410 nm lines as these could all, in some sense, be described as 'blue'. Candidates who chose the 656 nm line didn't score the first mark. For publication the question will be amended so that only one possible correct answer remains.

5(a) (ii) SL 5(b). This was often well answered with arrows matching the calculation. Some arrows were in the wrong direction.

5(a) (iii) SL 5(c). Key points here were the difference in energy levels equalling the energy of the photon and the downward arrow indicating energy being emitted. Candidates were able to score marks here even if their answers to the previous 2 parts were incorrect. Similarly, ECF marks could be awarded.

5(b) (i) HL only. Although this was well answered by many, some candidates were sloppy in their use of powers of ten and assumed that their answer of 1813 rounded to the required 'show that' value given in the question.

5(b) (ii) HL only. This question provided a very good example of candidates being unaware of what the equations in the data booklet mean. Almost every equation containing θ was attempted here. If the correct equation was chosen almost invariably the correct answer was obtained. The only exception being if the second-order was missed for the violet line. Answers were accepted in degrees and radians. Bald correct answers weren't allowed in this question nor were ECF marks for the third marking point. If this were not the case a candidate could have guessed 2 angles and scored 1/3 by working out the difference between them.

5(b) (iii) HL only. There were sharp contrasts in answers to this question with some candidates providing a detailed description of what the appearance would be and some trying to quote details of answers involving e.g. the appearance of a single slit pattern for monochromatic light. To help with the answer to this it was useful to think about the equation used in the previous part of the question.

Question 6

HL only.

6(a) (i) Most answers assumed that as the number of nucleons increases so does the density.

6(a) (ii)This was very well answered.

6(b) (i) This was very well answered.

6(b) (ii) This was answered well by able candidates. As ever there was confusion with the equations for energy and electric field strength. It was common to see the charge on the electron omitted.

6(c) A significant number of candidates answered this question as though the beta particle emitted was one of the atom's electrons e.g. discussing discrete energy levels, how close the electron was to the nucleus. Those candidates that knew an antineutrino is emitted generally scored both marks.

6(d) (i) This was surprisingly badly answered. Many candidates attempted to describe half-life, or activity in general, while others talked in very vague terms about the process of decay being constant.

6(d) (ii) This was answered surprisingly well with many candidates scoring full marks.

Question 7

HL only.

7(a) This was well answered.

7(b) This was well answered by most candidates who attempted it. Sometimes the third was omitted and sometimes squared was forgotten but in general attempts were largely successful.

7(c) For the first mark candidates needed to recognise that the capacitance would be halved and for the second mark recognise what effect this would have on the energy stored and consequently the height. For the second mark they could use decreased rather than being specific about halving. Examiners awarded ECF marks from an incorrect answer about how the capacitance changed. It was very rare to see answers that addressed the change in time for the mass to rise. "To make this question clearer, the published version has been changed to 'Comment on the effect this change has on the height and time taken to raise the 45 g mass.'"

Question 8

8(a) (i) HL only. This was well answered with more students than usual including the small/test/point mass. Some candidates confused it with gravitational potential.

8(a) (ii) HL only. Many candidates gained the second marking point for this, with fewer gaining the first.

8(b) (i) HL only. This was surprisingly well answered with many candidates able to provide a suitable starting point and work through the algebra required without mistake.

8(b) (ii) HL only. This was well answered with candidates either calculating the radius first or combining everything in one calculation.

8(c) (i) SL 6(a). A straightforward calculation but a surprising number of candidates used a value for the solar constant that they had memorised rather than using the value in the data booklet. This led to scoring 1 of the 2 possible marks.

8(c) (ii) SL 6(b). Most candidates missed the factor of 4 here but scored 1 mark ECF.

8(c) (iii) It was common to see thorough answers describing the greenhouse effect with only a token effort to connect this to Mars' atmosphere, thus only scoring the first mark.

Question 9

9(a) As ever with this type of question a good deal of confusion was shown with the PE and KE in gaseous and liquid states. Many candidates thought the KE was greater in the gaseous state even though the temperature is the same. Many came up with vague answer such as the energy is mostly KE in a gas and PE in a liquid. In common with previous mark schemes it was necessary to refer to particles/molecules/atoms to be able to score full marks.

9(b) (i) This was well answered but powers of ten mistakes were common here with candidates calculating a value in watts and then writing kW after it.

9(b) (ii) This was well answered.

9(c) The most common answer here was no intermolecular forces. Candidates who tried to repeat answers referring to energy from a) did not score the mark. Candidates were expected to refer to the gas they were discussing i.e. an ideal gas or oxygen.

SL only

Question 1

1(d) (ii) Generally well answered. Incorrect answers tended to be circular, stating that the law of gravitation required point masses.

Question 3

3(a) Same as 3(b) (ii) at HL. Same comment applies.

Question 6

6(c) Many candidates described the greenhouse effect without reference to the relative concentration/abundance of CO_2 in the atmosphere. As a result, no marks were earned.

Question 7

7(b) (ii) This question was generally well answered, with some POT errors.

Recommendations and guidance for the teaching of future candidates

Many of these recommendations have been made in previous reports:

- Encourage candidates to read the examination questions carefully.
- Encourage candidates to look at the number of marks available and judge how much detail is required in their answer.
- Encourage candidates to show workings in calculations, in particular so that examiners have the opportunity to award ‘error carried forward’ marks.
- Encourage candidates to show a sufficient number of significant figures in their answers to ‘show’ questions. In other words, at least one more than the ‘show’ value given in the question. In addition, they should show their working rather than giving bald answers.
- Encourage candidates to have a thorough knowledge of the symbols used in the data booklet.

- Encourage candidates to use values of constants from the data booklet rather than a rounded value they have memorised.

Paper three

General comments

The paper was designed in accordance with the Physics guide. Section A was prepared for summative assessment of core material, mainly of Topic 1 Measurement and uncertainties. The contexts for the assessment – harmonic oscillations and specific latent heat of vaporisation were used appropriately; both are well known by the candidates.

Options in Section B were quite well balanced. Each of the options included questions measuring the level of knowledge, understanding, skills and other of the assessment objectives 1,2 and 3 required by the syllabus. In line with the Physics guide, the questions in each of the options presupposes knowledge on core material and AHL where appropriate.

Questions in section B used carefully selected contexts and applications. The candidates proved that they had enough time for the paper. Discrimination of the paper is at the appropriate level and the difficulty level of options is appropriate.

Among answers, we can see many examples of good understanding in each of the questions. Almost all candidates answered all questions from section A and all questions from one option selected.

The vast majority of candidates kept responses in the answer boxes provided and if using additional answer sheets they referred to this within the answer box. Handwriting seems to be at the same level as previous sessions, the answers were legible, and there was no problem with marking in black-and-white.

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

The most difficult area of the programme is the area around Aim 4, develop an ability to analyse, evaluate and synthesize scientific information. Average prepared candidates had difficulty in clarity of their explanations and in application of their knowledge in new situations. Showing working in full in "show that" questions is often omitted.

Main difficulties related to the syllabus:

- Powers of 10 and unit multipliers (SL mainly)
- Using the whole line when finding a gradient. Amazingly some use far less than half the line (1.2)
- Explaining how random and systematic errors can be identified and reduced (1.2)
- Manipulation with units (SL mainly) (1.1)
- Use Galilean transformation equations (A.1)
- Free body diagrams (2.2) and rigid bodies (B.1)
- Kinetic energy of rotational motion (B.1)
- Thermal efficiency (B.2)
- Application of the Bernoulli equation (B.3)
- The role of cladding (SL mainly) (C3)

- Describing the role of mass in stellar evolution (D.2)

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

The well-prepared candidates can analyze the situations, present their working in a logical manner, and use proper terminology, physical quantities and units. They demonstrated understanding of facts and concepts and were able to use them with proper terminology. Most candidates demonstrated the ability to clearly present well-known facts in words and sentences. Many candidates were able to discuss the work of their peers.

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

Section A

Question 1

Oscillating rod. Most candidates are able to work with units of physical quantities. Better candidates could identify the method of reducing error, weaker candidates had difficulty in identification of the method presented in the stem of the question. Identification of direct proportion was grasped well and most of candidates were able to use the slope of the graph in (d). Surprisingly, quite a high number of candidates referred to twenty measurements of one period and taking an average value.

Many SL candidates provided rather rambling or vague answers in part (b) and confused d with 1/d in their working in part (d). Some candidates used very small triangles in part (d).

Question 2

Latent heat of vaporization. More than half of candidates were able to outline the main parameters of the experiment presented in the stem of this question. The most difficult part (c), was answered well by the best candidates, weaker candidates tried to use the concept of multiple experiments and finding an average.

Section B

Option A – Relativity

This was not popular option this session.

HL and SL Question 3

Moving box, Galilean relativity. This question was well answered by about half of candidates, and in (b) (i) many candidates were not able to explain the information given clearly enough, many candidates used only vague, simplistic arguments. Many candidates failed to mention primed and unprimed frames.

HL and SL Question 4

Probe in a rocket. Many candidates calculated the speed in (a) and the time according to an observer at rest in the rocket. Only the best candidates were able to work in the frame at rest on the ground in (b) (i).

HL and SL Question 5

A rod in two frames, spacetime diagrams. About half the candidates proved able to use spacetime diagrams in (a) and (b). The most complex problem, moving rod in the spacetime diagram, in (c) (i) was well answered by only the best HL candidates and almost no SL candidates. Length contraction was well calculated in (c) (ii) also by many candidates.

HL Question 6

Collision of electron and positron. In (b) (i) some candidates had difficulty in application of law of conservation of momentum and energy.

HL Question 7

Event horizon. This was the easiest question of this option. Most of the candidates were able to perform the complex calculation in (b).

Option B – Engineering physics

This option was answered by about 20 % of the candidates

HL Question 8 and SL Question 6

A rod pivoted at one end. Candidates proved able to use basic knowledge in rigid body mechanics, but many were not able to apply concept of torque in (a) and (b) (ii), and energy conservation in (c) (i). In (c) (i) many candidates tried to use the formula, which was in (b) (ii) identified as not useful for this problem. Very few candidates used conservation of energy in (c) (i). Angular momentum in (c) (ii) was calculated by most of the candidates.

HL Question 9 and SL Question 7

Heat engine. This problem was grasped well by a majority of the candidates and in (b) they showed no difficulty in calculating the thermal energy transferred. In (c) (i) only the best candidates were able to calculate the efficiency of the cycle, most used Q1/Q2 instead of (Q1-Q2)/Q2.

HL Question 10

(a) Floating Ice cube. Some candidates clearly understood this well-known problem. Other candidates used the Archimedes principle and suggested that the level of water will not change. Some weaker candidates suggested a lowering or rising of the water surface, referring to different densities of ice and water.

(b) Water flow in a cylinder. Most candidates referred to the continuity equation, but in (b) (ii) many average candidates omitted the flow of water in the cylinder, this would be reasonable only if the speed in the cylinder was negligible compared to the speed in the pipe.

HL Question 11

Forced vibration. This question highlighted a lack of knowledge of phase relationship between driving frequency and forced oscillations and concept of Q factor for a large number of candidates.

Option C – Imaging

This option was answered by slightly less than 20% of the candidates

HL Question 12 and SL Question 8

12 HL, 8 SL Lens - chromatic aberration. The topic of chromatic aberration is well mastered by most of the candidates. Some improvement can be made in the clarity of presentation of the suggestion in (b) (i).

HL Question 13 and SL Question 9

Optical compound microscope. More than half of the candidates constructed a suitable final image in (a). In (b) (i) most of the candidates produced part of the calculation and the better candidates found the distance between the lenses. Also, in (b) (ii), most candidates gained one mark for partially correct working and the best candidates determined the magnification.

HL Question 14 and SL Question 10

Waveguide dispersion. Parts (a) and (b) (i) discriminated between weaker and average prepared candidates. Some weaker candidates incorrectly calculated the index of refraction of cladding slightly higher than index of refraction of fibre. The time delay in (b) (ii) was often poorly calculated using the speed of light in vacuum, instead of speed of light in the fibre. Answers in b (iii) were often vague, only the best candidates demonstrated a deep understanding of waveguide dispersion. Many SL candidates said that the cladding kept most rays inside the fibre, when the opposite is true, the large critical angle only permits rays which are almost parallel to the axis to be transmitted.

HL Question 15

NMR. This question discriminated between the best and average prepared candidates. Only the best candidates proved able to outline and describe how the information about the body is gathered from the signals gained during NMR.

HL Question 16

Intensity of ultrasound. Most candidates were able to use mathematics in the calculation of attenuated intensity of ultrasound. Some candidates omitted in (b) that ultrasound incident on the muscle-bone boundary is attenuated.

Option D – Astrophysics

This option is very popular.

HL Question 17 and SL Question 11

Constellation Orion. In (a) candidates compared constellation and open cluster often vaguely, only the best candidates clearly explained differences. Question (c) was answered well by all candidates.

HL Question 18 and SL Question 12

A main sequence star. Quite a high number of candidates had difficulty with the sequences of facts and algebra operations to support their ideas in “show that” questions (a) (iii) and (b). Applying mass-luminosity relation to compare lifetimes on the main sequence in (c) was difficult for candidates.

HL Question 19 and SL Question 13

Age of universe. In (a) about one third of candidates proved difficulty in outlying, how recessional velocities of galaxies were measured by Hubble. Far too many candidates (especially SL) wrote that Hubble used Hubble’s law to measure recessional velocity. The age of the universe based on the information given by graph was well calculated by average prepared candidates.

HL Question 20

Dark energy. This question proved difficulty in clear presentation of knowledge in the topic of dark energy. Many candidates well mentioned rotational motion of galaxies, topic explicitly stated in the guide and used in previous sessions. Only the best candidates formulated clear answers.

HL Question 21

Cosmic scale factor. Cosmic scale factor is a well known concept, but part (a) was quite difficult for average prepared candidates.

Recommendations and guidance for the teaching of future candidates

- Students should always check if the calculated answer is reasonable. Answers like age of universe in milliseconds, Schwarzschild radius about 1m should be suspicious.
- Practice use of the language of Physics, Physics concepts in explanations, eg “proportional” rather than “as one goes up so does the other”, use of energy, force, pressure, power, correctly and precisely, distinguish between power and energy in qualitative explanations.
- Answers to questions requiring ‘show that’ should be laid out carefully, showing relevant steps and reasoning, where relevant also appropriate mathematics.
- Sequence presentation of facts to support an explanation or description. The answers should form logical, concise and coherent arguments.
- Definitions are at the very heart of Physics must be known and practiced.
- Round off at the end of a string of calculations, not at each step.

- As this is a Physics examination: explain the physics involved rather than write generalised statements.
- The practice of removing constants from equations before substituting values when a ratio is required would simplify working and reduce arithmetical errors.