PHYSICS

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 15	16 - 28	29 - 39	40 - 49	50 - 59	60 - 69	70 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 27	28 - 38	39 - 47	48 - 57	58 - 66	67 - 100

Internal assessment

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 8	9 - 16	17 - 22	23 - 27	28 - 33	34 - 38	39 - 48

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 8	9 - 16	17 - 22	23 - 27	28 - 33	34 - 38	39 - 48

The range and suitability of the work submitted

There was ample evidence that most schools are providing comprehensive practical programs, covering a wide range of investigations. The use of ICT is now commonplace, and the majority of student reports are word-processed and graphs are presented using appropriate software. Teachers clearly understand the administrative and IA expectations, and this makes the moderation process run smoothly. IA Samples were nicely organized and easy to follow. The required hours of practical work seem to be no problem, and there is evidence of good syllabus coverage. Teachers are reminded that investigations can be on topics not found in the syllabus.

Some schools still have students provide a hypothesis for their design investigations; although this is not penalized it can inhibit the open-ended nature of the student's design. Also, when students already know the relevant theory and equations, assessing design is not always appropriate.

Teachers must be careful when giving the dependent variable in the design prompt, as there were a few cases where students were also given the independent variable. The group 4 project seems to be well integrated into the practical programs. Once again, a few schools provided evidence of this but evidence is not required (only an indication of the date and hours on the 4/PSOW form).

Candidate performance against each criterion

Design

Teachers have mastered the art of giving design prompts. In a few cases, however, the prompts were not appropriate, such as asking students to design an investigation to measure gravity. Good design prompts are ones that have students looking for a function between two variables, not a specific value. Students need to be reminded that for a complete under design that variables need to be defined (and vague statement like “I will measure the time” needs to be clarified as to just how this will be done). Operational definitions help in the design of a method as well. This comes under the ability to control variables.

Data Collection and Processing

Students tend to have the most success with DCP. Raw data always has uncertainty. Moderators are looking for a brief statement to why the student gives a particular value of uncertainty, and this holds for both raw and processed data. When assessing DCP students are expected to have produced graphs. There were some cases where graphs would have been relevant but students just made calculations. These cases cannot earn complete for DCP aspect 3. Teachers need to be aware of this expectation. Also, it is important that the student (and not the teacher) decides what quantities to graph and how to process the data.

Conclusion and Evaluation

This can be the most difficult criterion to earn full marks, especially aspect 1. Students need to think beyond the given data in order to provide a justification based on a reasonable interpretation of the data. Such insight might look at the extremes of the data range, the origin of the graph, the y-intercept, for some physical meaning. Students might even give the overall relationship some physical interpretation (perhaps a hypothesis). Teachers need to look for this when awarding aspect 1 a complete, as many times moderators had to change a ‘complete’ to a ‘partial’. Finally, if students perform a standard and well established physics lab, and CE is assessed, then it is unlikely that they can really come up with weaknesses or improvements. CE is best assessed when students also have designed and performed the investigation themselves.

Recommendations for the teaching of future candidates

Students need a clear understanding of the IA criteria. To help this the teacher might give students a copy of a really good IA, one that earned all completes.

Students need to be trained in achieving the IA aspects. Group work, teacher guidance, even peer review can help but of course in such cases the teacher would not mark the IA for an IB grade on the 4/PSOW.

It is important that when practical work is assessed a student works alone. This does not mean, however, that another student cannot help, say, release a ball from a given height while the other student measures the time. All measurements must come from the student being assessed. Occasionally moderators find identical data sets and then they are suspicious.

Further comments

November 2010 was a most successful year for IA moderation. Most teachers were assessing appropriate work and awarding appropriate marks. Moreover, most students were working hard and producing good high school physics lab reports. Indeed, there were a few schools producing amazing work, almost like a miniature extended essays. However, teachers are reminded a design investigation is not meant to be research project.

This last section contains the advice that is given to physics IA moderators. Overall, moderators normally keep the teacher’s marks, but occasionally they raise or lower marks. If the teachers have applied the criteria to appropriate tasks in good faith then the moderation system should support them. Moderators are not here to apply their own pet theories and practices as teachers, but to ensure that the schools are using the criteria within acceptable bounds according to the official descriptors. In other words, moderators are **looking for the systematic error beyond the random error in the application of the aspects of the criteria**. The following advice is given to the moderators.

When moderators mark down

Design

The moderator will mark down when the teacher gives a clearly defined research question and/or the independent **and** controlled variables. The teacher may give the student the dependent variable (as long as there is a variety of independent variables for the student to identify). Giving the student the general aim of the investigation is fine if the students have significantly modified the teacher prompt or question (e.g. made it more precise, defined the variables). The moderator will mark down when a method sheet is given which the student follows without any modification *or* **all** students are using identical methods. Standard laboratory investigations are not appropriate for assessment under Design.

Data Collection and Processing

The moderator will mark down when a photocopied table is provided with headings and units that are just filled in by students. If the student has not recorded uncertainties in any quantitative data then the maximum given by the moderator is ‘partial’ for first aspect. If the student has been *repeatedly inconsistent* in the use of significant digits when recording data then the most a moderator an award is ‘partial’ for first aspect. In physics data is always quantitative. Drawing the field lines around a magnet does not constitute DCP.

The moderator will mark down when a graph with axes already labelled is provided (or students have been told which variables to plot) or students follow structured questions in order to carry out data processing. For assessment under DCP aspect 3, students are expected to construct graphs. For a complete, the data points on the graph should include uncertainty bars, and the uncertainty in the best-straight line gradient needs to be calculated. The method for this is often the minimum and maximum gradients using the first and last data points.

Conclusion and Evaluation

If the teacher provides structured questions to prompt students through the discussion, conclusion and criticism then, depending on how focused the teacher's questions are and on the quality of students' response the maximum award is *partial* for each aspect the student has been guided through. The moderator judges purely on the students input. The difference between a partial and a complete for CE aspect 1 involves the justification of their interpretation of the experimental results. This is a difficult task, and it can involve physical theory.

When moderators do not mark down

In the following cases the moderator will support the teacher's stance, as they are aware of their own expectations of the students.

Design

Moderators do not mark down when the independent and controlled variables have been clearly identified in the procedure but are not given as a separate list (we mark the whole report and there is no obligation to write up according to the aspect headings). Moderators do not mark down when there is a list of variables and it is clearly apparent from the procedure which is independent and which are controlled.

Moderators do not mark down when similar (but not word for word identical) procedures are given for a narrow task. The moderator will make a comment though on the poor suitability of a task on 4/IAF form. Moderators do not only mark the equipment list, they give credit for equipment clearly identified in a stepwise procedure. Remember moderators look at the whole report. Moderators do not insist on +/- precision of apparatus to be given in the apparatus list. This has never been specified to teachers and the concept of recording uncertainties is dealt with in DCP. Moderators do not downgrade a teacher's mark if something as routine as safety glasses or lab coats are not listed. Some teachers consider it vital to list them each time and some teachers consider them such an integral part of all lab work that they go without saying. Moderators support the teacher's stance here.

Data Collection and Processing

In a comprehensive data collection exercise possibly with several tables of data the student has been inconsistent with significant digits for just one data point or missed units out of one column heading, then the moderator will not mark this minor error down. If the moderator feels the student has demonstrated that they were paying attention to these points and made one careless slip then the moderator can still support maximum marks under the 'complete not meaning perfection' rule. This is an important principle since good students responding in full to an extended task unfairly get penalized more often than students addressing a simplistic exercise. The student is not marked down if they have not included any qualitative observation(s) and the moderator cannot think of any that would have been obviously relevant. The moderator does not mark down if there is no table title when it is obvious what the data in the table refers to. Often students do all the hard work for DCP and then lose a mark from the class teacher because they did not title the table. Except for extended investigations it is normally self-evident what the table refers to.

The expectation for the treatment of errors and uncertainties in physics is described in the Course Guide and the TSM. Both standard level and higher-level students are assessed on the same syllabus content and the same standard of performance.

All raw data is expected to include units and uncertainties. The least count of any scale or the least significant digit in any measurement is an indication of the minimum uncertainty. Students may make statements about the manufacture's claim of accuracy, but this is not required. When raw data is processed, uncertainties need to be processed (see the Course Guide, syllabus section 1.2.11)

Students can estimate uncertainties in compound measurements (± half the range), and they can make educated guesses about uncertainties in the method of measurement. If uncertainties are small enough to be ignored, the candidate should note this fact.

Minimum and maximum gradients should be drawn on linear graphs using uncertainty bars (using the first and last data points) for only one quantity. This simplified method becomes obscured when both graph quantities contain uncertainty bars. Other uncertainty analysis is expected when graphs are non-linear.

If the student has clearly attempted to consider or propagate uncertainties then moderators support the teacher's award even if they may feel that the student could have made a more sophisticated effort. If propagation is demonstrated in part of the lab then full credit can be awarded even if error analysis is not carried through in every detail (as long as the student has demonstrated an appreciation of uncertainty then they can earn a complete).

Moderators **do not** punish a teacher or student if the protocol is not the one that you teach i.e. top pan balance uncertainties have been given as +/- 0.01g when you may feel that if we consider the tare weighing then it should be doubled. Moderation is not the time or place to establish a favoured IB protocol.

Conclusion and Evaluation

Moderators often apply the principle of 'complete' not meaning perfect. For example, if the student has identified the most sensible sources of systematic error then the moderator can support a teacher's award even if the moderator can identify one more. Moderators are a bit more critical in the third aspect that the modifications are actually relating to the cited sources of error. If the moderator feels a task was too simple to truly meet the spirit of the criteria, then comments on the 4IAF as to the unsuitability of the task giving full justifications will be provided in feedback but the moderator will not necessarily downgrade the student. Yes, this does mean that students could get high DCP marks for some quite brief work on limited data but, if they have fulfilled the aspect's requirements within this small range, then the moderator will support the teacher's marks.

The most challenging aspect of CE is the differentiation between a partial and a complete under aspect 1: "States a conclusion, with justification, based on a reasonable interpretation of the data." A justification may be a mathematical analysis of the results, one that includes an appreciation the limits of the data range, but it might also be an analysis that includes some physical meaning or theory, even an hypothesis (though a hypothesis is not required). It is difficult to earn a complete in CE (aspect 1) because serious and thoughtful comments are required, something beyond "the data reveal a linear and proportional relationship". See the last paragraph in the Conclusion and Evaluation comments in section B above.

General comments on the written papers

IB multiple choice physics papers are designed to have, in the main, questions testing knowledge of facts, concepts and terminology and the application of the aforementioned. These Assessment objectives are specified in the Guide. It should be noted that multiple-choice items enable definitions and laws to be tested without full recall, but requiring understanding of the underlying concepts.

Although the questions may involve simple calculations, calculations can be assessed more appropriately in questions on Papers 2 and 3. Calculators are therefore neither needed nor allowed for Paper 1.

In Papers 2 and 3, candidates are sometimes asked to write short paragraphs so that their understanding of topics may be assessed. It is clear that, from many answers, candidates have been trained to give definitions and to perform calculations, but have little understanding of the underlying physics. It is this lack of understanding that prevents candidates from achieving the higher grades.

Candidates should be encouraged to give precise definitions for physical quantities. Definitions given partly or totally in terms of units are not acceptable.

Paper one

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 14	15 - 19	20 - 23	24 - 27	28 - 31	32 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 10	11 - 13	14 - 15	16 - 18	19 - 20	21 - 30

General comments

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

Only a small percentage of the total number of teachers or the total number of Centres taking the examination returned G2's. For example, at SL there were 16 responses from 162 Centres. Consequently, general opinions are difficult to assess since those sending G2's may be only those who feel strongly in some way about the Papers. The replies indicated that the November 2010 papers were generally well received. A majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level.

However, a few thought that both Papers were a little more demanding than in the previous year. Such changes in demand can be accommodated when grade boundaries are set. With one or two exceptions, teachers thought that the Papers gave satisfactory or good coverage of the syllabus. It should be noted that the balance of the paper is identical every year and is dictated by the balance of teaching hours as laid down in the syllabus.

When commenting on coverage, it should be borne in mind that this must be judged in conjunction with Paper 2.

All teachers felt that the presentation of the Papers was either satisfactory or good.

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 an asterisk (*). 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 *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. This may not, however, be the case where the difficulty index is either high or low.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	84	73	157	511*	1	61.86	0.65
2	98	339*	284	103	2	41.04	0.65
3	10	57	55	699*	5	84.62	0.34
4	99	502*	115	106	4	60.77	0.48
5	527*	81	142	75	1	63.80	0.54
6	366	90	80	289*	1	34.99	0.48
7	44	485*	103	191	3	58.72	0.31
8	500*	44	230	50	2	60.53	0.47
9	123	596*	75	31	1	72.15	0.37
10	138	206	178	297*	7	35.96	0.42
11	555*	175	68	26	2	67.19	0.48
12	174	202	40	407*	3	49.27	0.57
13	69	29	74	653*	1	79.06	0.34
14	209	28	38	550*	1	66.59	0.45
15	398	148	112*	165	3	13.56	0.13
16	539*	95	156	34	2	65.25	0.59
17	27	672*	74	53		81.36	0.35
18	34	78	499*	213	2	60.41	0.51
19	35	56	604*	131		73.12	0.46
20	10	22	740*	51	3	89.59	0.24
21	81	392*	129	219	5	47.46	0.36
22	63	60	83	620*		75.06	0.48
23	169	214	27	414*	2	50.12	0.56
24	507	55	213*	50	1	25.79	0.09
25	438*	339*	24	22	3	94.07	0.08
26	45	355*	160	263	3	42.98	0.25
27	453*	158	159	48	8	54.84	0.64
28	23	739*	44	20		89.47	0.19
29	179	87	503*	55	2	60.90	0.47
30	470*	119	138	98	1	56.90	0.55
31	275*	175	297	76	3	33.29	0.36
32	453*	145	102	121	5	54.84	0.61
33	232	480*	34	78	2	58.11	0.53
34	244	201	201*	174	6	24.33	0.18
35	80	245	430*	69	2	52.06	0.54
36	35	279	250	251*	11	30.39	0.28
37	741*	20	41	19	5	89.71	0.21
38	189	102	417*	111	7	50.48	0.30
39	95	428*	202	94	7	51.82	0.55
40	26	602*	53	140	5	72.88	0.40

Number of candidates: 826

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	96	128	218	351*	1	44.21	0.57
2	20	440*	252	79	3	55.42	0.42
3	94	597*	59	43	1	75.19	0.32
4	491*	41	26	236		61.84	0.43
5	111	86	295	298*	4	37.53	0.48
6	32	636*	115	10	1	80.10	0.32
7	438*	95	172	89		55.16	0.54
8	532	81	54	125*	2	15.74	0.09
9	427*	65	243	59		53.78	0.55
10	94	73	417*	208	2	52.52	0.28
11	58	51	574*	109	2	72.29	0.43
12	398*	190	50	155	1	50.13	0.44
13	158	110	431*	93	2	54.28	0.51
14	68	110	319*	296	1	40.18	0.07
15	287	39	45	422*	1	53.15	0.45
16	48	73	472*	201		59.45	0.54
17	11	48	620*	112	3	78.09	0.37
18	44	326*	300	119	5	41.06	0.37
19	319	299*	82	92	2	37.66	0.31
20	379*	340	30	43	2	47.73	0.34
21	111	91	171	419*	2	52.77	0.60
22	163	291*	151	180	9	36.65	0.24
23	174	122	428*	67	3	53.90	0.54
24	24	684*	69	17		86.15	0.20
25	526*	147	49	69	3	66.25	0.38
26	54	72	578*	90		72.80	0.39
27	106	282	311*	90	5	39.17	0.51
28	51	348	198	192*	5	24.18	0.13
29	194*	420	29	149	2	24.43	0.32
30	224	105	334*	126	5	42.07	0.25

Number of candidates: 794

Comments on the analysis

Difficulty

The difficulty index varies from about 13% in HL and 15% in SL (relatively ‘difficult’ questions) to about 90% in HL and 86% in SL (relatively ‘easy’ questions). The majority of items were in the range 30% to 70%. Thus, the Papers provided ample opportunity for all candidates to gain some credit and, at the same time, gave an adequate spread of marks.

Discrimination

All questions had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. This was achieved in the very large majority of questions. However, a low discrimination index may not result from an unreliable question. It could indicate a common misconception amongst candidates or a question with a high difficulty index. At both levels, about 50% of the coefficients of discrimination were above 0.40.

‘Blank’ response

In both Papers, the number of blank responses tends to increase towards the end of the test. This may indicate that candidates did not have sufficient time to complete their responses, despite a lack of comments from teachers to this effect. Even so, this does not provide an explanation for ‘blanks’ early in the Papers. Candidates should be reminded that there is no penalty for an incorrect response. Therefore, if the correct response is not known, then they should use their judgement to make a decision. In general, some of the ‘distractors’ should be capable of elimination, perhaps by consideration of units, or by symmetry, thus reducing the element of guesswork.

Comments on selected questions

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

Higher Level and Standard Level common questions

SL Questions 8 and HL Question 6

A large majority of the candidates opted for A, indicating perhaps that they misunderstood the question as asking for the *change in the magnitude of momentums.* It is worth noting that such an interpretation has no physical significance, whereas the question being asked relates to the force of the ball on the wall.

SL Question 22 and HL Question 21

A surprising number of students were confused by this question, with the evidence being that many were simply guessing. Crossing an electric and a magnetic field is the basis of selecting the velocity of charged particles as can be readily seen by equating Bqv to qE. The charge cancels which means that if the electron is undeflected then the alpha particle will also be undeflected.

SL Question 28 and HL Question 36

Many candidates thought that the peaks of the curves being at the same intensity meant that the temperatures were the same (response B). It would appear that the family of curves representing bodies of different emissivities (but the same temperature) had not been widely taught.

Higher Level Questions

Question 15

The majority response of A showed a basic misconception of what these standing wave patterns represent. Indeed, the correct response was chosen by the fewest candidates! The standing wave is longitudinal with air molecules moving parallel to the sides of the pipe. At the antinodes they are moving with maximum amplitude, while at the nodes (X) they are not moving (amplitude is zero).

At adjacent antinodes the molecules are out of phase such that when a molecule to the left of X is moving to the left, then a particle to the right of X will be moving to the right creating a rarefaction at X; half a time period later the directions are reversed and a compression will be formed at X.

Teachers should emphasise the dynamic nature of the standing wave with the traditional representation being essentially a graph of amplitude against distance.

Question 23

Energy consideration (with the masses cancelling) leads to D as the correct response.

Question 24

Candidates had presumably seen a similar diagram showing the magnetic field lines around two anti-parallel currents. We can only assume that the majority chose A, as they 'saw' the two objects repelling each other and assumed they must be charges of the same sign.

Teachers should emphasise the different information that equipotentials and field lines give. They are related inasmuch as the *potential gradient* is the *field strength* and so field lines are always perpendicular to the equipotentials. Any candidate sketching the field lines onto the diagram will see immediately that the only answer can be C. Alternatively they could have seen that approaching the pair of objects from below is possible without crossing any equipotentials. Hence they must be opposite charges.

Question 25

Both A and B were allowed as the wording was slightly ambiguous. The symmetry of the situation as a test charge approaches from infinity should have led the candidates to the correct response of B, though.

The poor results of candidates on questions 24 and 25 indicate that more time needs to be spent on this topic.

Question 31

The *immediate* nature of photoelectricity is often overlooked in textbooks. It is, however, part of the evidence for the photonic nature of light.

Question 34

The statistics indicate that even the best candidates were guessing. The relationship between the wave function and the uncertainty in the momentum for a particle is on the syllabus (13.1.12/3) and needs to be taught.

Standard Level Questions

Question 14

A surprising number of candidates chose D, perhaps thinking that if it has less energy then it must necessarily be going slower. The energy of a wave, however, is a function of its amplitude – not its velocity.

If the wall had been rigid then 'III only' would have been a correct response, but as this was not available, C is the only possibility and we must assume the wall is not rigid.

Question 29

Most candidates opted for B. A clear distinction needs to be made between the melting of sea ice and the melting of fresh water ice when discussing the resulting rise of sea levels.

Recommendations and guidance for the teaching of future candidates

It is our belief that Multiple Choice Questions should be used extensively in the classroom. They can be used to efficiently check on the students' understanding of a concept; they can also be used to initiate group discussion before a topic has been taught. There is rarely one unique way of getting the correct answer, so they can be used to encourage lateral as well as logical thinking. Thinking 'backwards' as well as forwards, and weighing a number of possible options is an essential scientific skill.

Candidates should make an attempt at every item. Where they cannot provide the correct response, then they should always choose that option which, to them, appears to be the most likely. It should be emphasised that an incorrect response does not give rise to a mark deduction.

The stem should be read carefully. 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.

Having decided on the correct response, candidates should check that all other options are not feasible.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 11	12 - 23	24 - 32	33 - 42	43 - 52	53 - 62	63 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 6	7 - 12	13 - 17	18 - 22	23 - 26	27 - 31	32 - 50

Very few centres returned G2 forms for this examination (10 forms for HL; 14 SL) and this level of return makes it difficult for awarders to judge the response of centres to the papers. It continues to be important for those who mark and write papers to have a sense of the perception of both teachers and candidates. The awarders urge centres to complete and return these important pieces of information.

55% of returns at SL indicated that the P2 paper was at about the same standard as at November 2009. 27% found it a little more difficult while 9% found it to be much more difficult. The level of difficulty was adjudged to be appropriate to 86% of centres with 14% finding it too difficult.

Clarity of working was seen to be good by 65% of centres while 14% found it poor. Syllabus coverage responses indicated either satisfactory or good with paper presentation found good by 79%.

Similar views were expressed about the HL P2 paper. 45% found the standard to be similar with 11% and 33% finding it much more and a little more difficult respectively. The level of difficulty was found to be appropriate by 70% whilst syllabus coverage wording clarify and presentation were all judged good by at least 70% of the respondents.

The statistics of the examination bore out some of these perceptions. The mean mark on the components was somewhat lower than in November 2009, returning to the levels of November 2008 and earlier years.

General comments

Candidates continue to fail to take full account of the mark structure presented to them. This was evident in both written responses and those involving calculation. Candidates are advised carefully to consider the number of distinct points that they need to present in offering a chain of argument whether mathematical or descriptive.

Candidates do not always appear to be aware of the distinctions between the command terms used exclusively in the papers. There are significant differences between the demands of “state that / determine / explain” questions and those that ask candidates to “calculate / outline”. It is essential that in tests of assessment objective 3 material, candidates should give clear, well-reasoned and logical responses. Too often, mathematical material is jumbled, poorly arranged and negligent; work of this quality will not attract full credit.

Candidates need to be aware that some components of the physics examination are marked on-screen rather than in paper form. This has many implications for those taking the tests. Work must be presented in the indicated places on the paper and if a candidate needs to continue an answer on an additional sheet, he or she will be wise to indicate this to the examiner in a clear and unambiguous way.

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

The examining team identified the following areas: -

- resonance
- polarization (HL)
- centripetal force and acceleration
- the need to explain the steps in a calculation clearly
- calculations involving gravitational potential and potential energy (HL)
- current electricity concepts (SL)
- mechanics calculations

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

It was pleasing to see the following skills demonstrated: -

- understanding of the principles behind CD and DVD operation
- nuclear processes
- specific thermal capacity and specific latent heat calculations

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

There were many common questions between SL and HL. The comments below are arranged in the order that the questions appeared in HL.

Section A

A1 [HL and SL] Data analysis question

The context for this question was straightforward.

a) (i) This was well done with almost all candidates understanding the combination of errors.

(ii) Only the weakest candidates could not take the uncertainty value calculated in (a)(i) and transfer this correctly to the graph.

b) This was not well done. Too many candidates forced their lines through the printed origin, drew lines that lay outside the two error bars at each end of the range, or gave unrealistic abrupt changes of gradient.

c) Many understood the need to compare ratios in some way and identify that the ratios were not the same for n = 2 or 4. However, some candidates appeared unable to make any attempt at this question.

d) This is an example of a case where a clear and logical presentation is required so that examiners can understand what is in the candidate's mind.

A2 [HL] and B2 Part 2 [SL] Energy density

a) A handful of candidates defined energy density as energy converted per unit density, but most gave energy released per unit mass with a minority quoting energy released per unit volume.

b) (i) Again, this was done well by the majority with the usual smattering of significant figure penalties and mistakes in handling powers of ten.

[HL only]

(ii) Almost all could recognize that the temperature change was 20 K and could use their earlier value of power output. However the numerical manipulations were sometimes weak (often leading to ludicrously large air masses moving through the heater in 1 second.

[SL only]

(ii) Arguments were weak and poorly supported by calculation.

c) **[SL only]** Candidates found great difficulty in stating the differences between liquids and gases. They often focused on either molecular structure or motion, but not both as required in the question.

A2 [SL] Mechanics

a) Most candidates were able to score well on this part.

b) There were widespread failures to achieve the correct intermediate step of evaluating the acceleration in stage 2. The initial speed was often taken to be zero.

c) This very simple part caused problems for many who were unable to calculate the distances travelled in each stage, or add these together correctly.

A3 [HL] CD and DVD

a) Many candidates were able to score 3 or 4 marks on this well understood description.

b) The deduction of the result of a change in the laser wavelength that occurs when going from DVD to BluRay disc was poor. Most could only identify an increase in storage space, but the reasoning behind this was weak or spurious. Few made the point that the reduction in pit size leads to the possibility of more layers <u>and</u> closer tracks, preferring the vaguer "tracks are smaller".

A3 [SL] Current electricity

a) Circuit diagrams of the potential divider were very poor although most were able to predict the correct positions for the ammeter and voltmeter.

b) Most candidates achieved full marks here.

c) This question defeated all but the most able. Almost all assumed (falsely) that the resistance of X was unchanged at 0.83 Ω and carried through a calculation on this basis. There are a number of ways to solve the problem: perhaps the simplest is to recognize that when the current is 1.3 A, the pd across the 1.0 Ω resistor is 1.3 V and (from the graph) the pd across X is 0.7 V and that these added give 2.0 V, the emf of the supply.

A4 [HL] Induced emf

a) The chain of argument needed to be clear in answers. A correct statement of Faraday's Law should lead to the recognition that the current produces a magnetic field, that this field is changing, and that therefore a time changing flux exists inside the coil

b) Candidates could identify the similarity of frequency between graphs but the phase relationship usually defeated them.

c) Candidates failed to rise to the challenge of this question or indeed to read it correctly. They were asked to explain how the voltmeter can be used to compare the values of currents in different cables. This involves making both the distance from the centre of the cable and the orientation common to both sets of measurements. It also involves the recognition by the candidate that the current is directly proportional to the reading on the voltmeter.

A5 [HL] and B1 Part 2 [SL] Rutherford model of the atom

a) Candidates who rely on a diagram rather than a written description must ensure that their sketches give all the required information unambiguously. In this type of question it is also common to see candidates repeating part of the question itself back to the examiner; this will not gain credit. Candidates needed to distinguish between those alpha particles passing close to and those far away from a nucleus, and then to give the deduced properties of the nucleus from these observations. Descriptions were often illogical and repetitive.

b) Most candidates could write with confidence about the repulsive nature of the proton-proton interaction and the attractive nature of the strong nuclear force. Few gave good accounts of the balance between these two forces or described the energy situation (a better way to answer). Weak candidates could not name the strong nuclear force adequately.

c) **[HL only]** Many were able correctly to identify the particles in the interaction, but a sizeable minority listed positrons and neutrinos.

[SL only] Most were able to identify the other particle correctly.

Section B

B1

Part 1 [HL and SL] Simple pendulum

a) (i) and (ii) Identifications of points A and V were mixed. About half the candidates received both marks here.

b) This was poorly done with many misapprehensions evident. The main problem was that candidates failed to associate the effect with the presence of a centripetal force and also unable to consider it in terms of the directions and additions of the various forces in the situation.

c) (i) This was well done by many. However a use of a *suvat* equation is not appropriate in this case as the acceleration is not uniform.

(ii) Candidates who kept a clear head were able to arrive at a correct answer even if they had failed in part (b)

d) (i) Graphs were poor in general with few gaining both marks and many candidates unable to make any progress. Graphs often showed a decreasing amplitude against time despite the frequency label on the *x*-axis.

(ii) Few understood the meaning of the term “resonance” sufficiently to be able to describe it in terms of the graph.

e) Again, few candidates referred their answer to the graph. Some were able to gain credit for discussing changes in amplitude.

B1 Part 2 [HL only] de Broglie hypothesis

a) Although many understand that the hypothesis ascribes wave properties to mass, many lost the second mark through failing to define the symbols they quoted.

b) Candidates answered this well and had been well schooled in the demands of this calculation. However a significant number wrote solutions that were completely unintelligible to the examiners.

c) Candidates were required to use the graph of electron beam intensity against scattering angle to show that the scattering aperture diameter was commensurate with the electron wavelength. About half the candidates could achieve this, but some lost marks through omitting the 1.22 factor in the circular aperture equation.

B2

B2 Part 1 [HL only] and B2 Part 1 [SL only] Lightning discharges

a) Many omitted the reference to a test charge that is positive.

b) Common errors were to draw the field lines in the wrong direction, to omit edge effects, and to fail to draw field lines that touch the plates.

c) **[HL only]**

(i) and (ii) These parts were well done.

(iii) There was a general failure to recognise that the average pd during the discharge is half the maximum (starting) value and this lost a mark.

[SL only]

(i) This part was well done.

(ii) Most candidates could only identify one assumption made in the calculation.

(iii) The estimation of discharge time was well done.

(iv) There was a general failure to recognise that the average pd during the discharge is half the maximum (starting) value and this lost a mark.

B2 Part 2 [HL] Microwave radiation

a) Few were able to give complete and convincing explanations of the formation of the standing wave. Common errors were to omit the consequence of the reflection at the metal plate. Superposition was often poorly or even not described. Details of the phase relationships were also poor.

b) (i) and (ii) Candidates were very comfortable with these calculations although the number of wavelengths in (i) was often incorrect. Errors from (i) were carried forward to (ii) allowing many cases of full credit in this second part.

c) Examiners saw very few good descriptions of the polarization demonstration. A number of techniques are available but it is clear that candidates have either not discussed these or find the concept difficult.

B3 [HL] and B3 Part 1 [SL] Nuclear fission

a) (i) A common incorrect answer was 2.

(ii) Candidates were often able to carry this calculation through to a correct conclusion. It was a "show that" and a high level of explanation was required by examiners and was – in many cases – demonstrated.

(iii) Reponses here were mostly correct. However, the answer "It has a higher energy" was common. Candidates need to be reminded of the imprecision of such a statement. Is "It" the initiating neutron or the emitted neutron?

b) Weaker candidates could not distinguish between the role of the moderator and that of the control rods.

c) Many good calculations were seen but weaker candidates usually arrived at recognition that the required power from the reactor is 40 MW and could go no further.

[HL only]

(ii) Although there was a vague awareness that plutonium-239 is generated in the presence of uranium-238 this was usually expressed in loose physics and scored relatively poorly.

[HL only]

(iii) Answers often centred on the use of plutonium in a nuclear weapon.

d) **[HL only]**

(i) The meanings of Q and W were often expressed poorly and incompletely.

(ii) Some candidates are confused about the statement of the first law of thermodynamics and quoted the second. Others gave vague and uncreditworthy accounts that showed that they were not answering in the context of the reactor heat exchanger. There was no real attempt by most candidates to arrive at four points in the answer, despite the fact that there are two exchanges going on in the reactor.

(iii) As in part (ii) some candidates did not focus on the context intended. The failure to identify all exchanges and entropy changes was common as in part (ii).

B4

B4 Part 1 [HL] B3 Part 2 [SL] Collisions

a) When the question is "State the principle of conservation of momentum." an answer of "momentum is conserved" will attract no marks. The examiner needs to know what "conserved" means. Many omitted the statement that external forces do not act (or similar)

b) (i) Careful examination of solutions showed that about one-third of candidate forgot to add the mass of the pellet to the final total mass of the block.

(ii) This two-stage calculation attracted the same error as part (i) and many power of ten errors through a failure to note the units of mass in the question.

c) **[HL only]**

(i) Candidates were required to determine the time taken to fall to the floor and then use this time to evaluate the distance travelled horizontally. Many managed this with more or less success.

(ii) Many candidates produced poor attempts at the sketch. Initial trajectories were not horizontal and the general shapes of the curves were usually not quasi-parabolic.

[SL only]

Descriptions of the energy transformations were incomplete and poorly described. There was a general failure to recognise that the pellet transfers its kinetic energy into a number of distinct forms. Candidates are too quick to ascribe energy loss to “friction” without indicating the seat of this energy loss.

d) **[SL only]**

Most candidates were able to complete this calculation or to get close to it. Some forgot to evaluate the square root having arrived at the speed squared.

B4 Part 2 [HL] Gravitational field of Mars

a) Some candidates gave a definition of gravitational potential, i.e. they related the energy to that of a unit mass.

b) Throughout this part candidates were instructed to use the graph, those who used other non-graphical methods were penalised.

(i) There were many good evaluations with complete and well presented solutions.

(ii) Use of the Data Booklet equation for gravitational field strength without reference to the graph was common.

c) Examiners were looking for recognition that a change from R to $4R$ involves a factor of 16 increase in g.

d) This was poorly explained. Candidates were vague as to whether the gravitational potential at the surface of Earth is larger or small than that of Mars and were confused by the signs. Most were able to discuss the relative sizes of the escape speeds, but with very unconvincing arguments.

Recommendations and guidance for the teaching of future candidates

There is a lack of precision in written answers. Candidates should be encouraged to define the terms and symbols.

The examination team continues to recommend working through past papers (and the associated mark schemes) as a good preparation for the examination. The candidates need to be made more aware of the nuances of the command terms. They need a better understanding of the level of detail required, as well as the skills that are being assessed. Candidates must also be encouraged to write clearly and legibly, to avoid the use of a pencil and always to have a ruler with them during the examination.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 6	7 - 13	14 - 19	20 - 24	25 - 29	30 - 34	35 - 60

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 3	4 - 7	8 - 12	13 - 16	17 - 19	20 - 23	24 - 40

General comments

Only 16 G2's were received from SL teachers and 9 from HL teachers. This is, unfortunately a very small number particularly when one considers the number of centres entering the exam – 814 SL and 854 HL. It is therefore difficult to draw any meaningful conclusions from this number of replies but at SL, 9 teachers thought to paper to be of a similar standard to last year, 4 a little more difficult and one thought it more difficult. 12 teachers thought the level appropriate and 4 thought it too difficult. All thought the syllabus coverage either satisfactory or good. Only one teacher thought that the clarity of wording was poor and all thought that the presentation of the paper as either satisfactory or good.

At HL 4 teachers though the paper of the same standard as last year and 5 thought it more difficult. 7 teachers thought the level of difficulty to be appropriate and 2 thought it too difficult. Only one teacher thought the syllabus coverage poor with 6 thinking it to be good. All 9 teachers thought that the clarity of wording and presentation of the paper as either satisfactory or good.

In the Option questions paper there was the usual balance between calculation and explanation. These involve different skills. The former were done well, but it was evident from wordy responses that the students did not know how to express themselves clearly and as a result marks were dropped unnecessarily. It should also be noted that students can achieve useful marks through learning definitions correctly. However, most students appeared not to be aware of the importance of rigorous and concise definitions.

There was significant difference in the choice of options. At SL Option B was popular but not C . At both levels, the different combinations of Option E (Astrophysics), G (Electromagnetic waves) and H (Relativity) were chosen by a large number of centres, with options F (Communications) being rarely chosen., At HL I (Medical physics) and J (Particle physics) were not popular choices being chosen in similar proportions by a few schools only.

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

The areas identified by the examination team as being difficult were as follows:

- Schmitt trigger
- Population inversion of laser
- Derivation of condition for maximum of diffraction grating
- Thin-film interference
- Galilean transformation leading to time dilation derivation
- Relativistic momentum and energy
- the standard model
- Asymptotic freedom of quarks
- Dealing with ratios
- Providing sufficient depth and detail in questions with a mark allocation of more than one mark. This was particularly true in those questions involving the action verbs "explain", "outline" and "describe".

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

- Straightforward calculations
- Factual recall

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

SL only

Option A – Sight and wave phenomena

A1 The eye

(a) Many candidates did not define the near point and far point or defined them incorrectly in terms of distance from the eye. However, in (b), many candidates recognised the role played by the (ciliary) muscles in altering the shape of the eye lens but did not always go on to say that this alters the focal length of the lens.

A2 Diffraction and Resolution

(a) Intensity distributions were often drawn well but quite a few candidates did not have their graphs in contact with the θ axis. Candidates' working was often difficult to follow in the calculation part of this question.

In part (b) very few candidates recognised the role played by diffraction in the resolution of the planet as a disc.

A3 Standing waves and organ pipes

(a) Most candidates knew a difference between a standing and travelling wave but diagrams of the fundamental and second harmonic were often poor. The manipulation of ratios in (c) defeated a lot of candidates and very few recognised that there must always be either a node or antinode at each end of the pipes.

Option B – Quantum physics and nuclear physics

B1 Wave-particle duality

In (a) (i) many candidates showed clearly that they understood the concept of the Einstein model and the existence of a threshold frequency. However, a significant minority of candidates had very little understanding of the topic. Those who answered (i) well had no problem in answering part (ii) correctly.

In (b) the problem on maximum kinetic energy was often done well but the standard calculation of the de Broglie wavelength was often done poorly with many candidates unable to make a start.

B2 Spectrum of atomic hydrogen

In part (a) very few candidates knew how a spectrum can be produced and observed in the laboratory. The conclusion reached by the Examining Team was that few candidates had seen this demonstrated.

The calculation in (b) was often correctly done.

B3 Radioactive decay

A surprisingly large number of candidates in (a) were unable to correctly identify the products of beta plus decay In (b), unit errors were often made in (i) and in (ii) there was often some very strange arithmetic to be seen

Option C Digital Technology

It was rare to see this Option answered well.

C1 CD’s and CCD’s

Part (a), which dealt with CD’s, was usually the best answered part of this question. In part (b) (i) a surprisingly large number of candidates did not define capacitance correctly and in (ii) only a few candidates completed the problem correctly; many candidates did not even start.

C2 Operational amplifier and Schmitt trigger

Candidates who took this option had clearly not been sufficiently exposed to solving problems involving circuits incorporating operational amplifiers.

Apart from part (a) (i), the voltage characteristic, this question was rarely answered well with most candidates showing little or no knowledge of the topic.

Option D – Relativity and particle physics

D1 See H1

D2 See J1

SL and HL combined

Option E – Astrophysics

E1 Procyon A and Procyon B

This was probably the most popular Option.

In (a) a large number of candidates were able to correctly distinguish between a constellation and a stellar cluster but there were many confused answers to part (b) in attempting to explain why P_A is much brighter than P_B and also much more luminous. The main difficulty would seem to be deciding which data from the table was relevant to a correct explanation. Answers often suggested that many candidates were confused as to the exact meaning of apparent magnitude, absolute magnitude and apparent brightness.

Many candidates had problems with the calculation in part (c) not recognising that all was needed was to show that $m - M$ is the same for each star. Most candidates recognised the reasons why P_A and P_B might be binary stars.

Answers to part (e) again showed the inability of many candidates to handle ratios. An approach often seen was to calculate L_A and L_B separately making for a very laborious calculation.

Instead of taking note of the given data there was much guesswork in positioning P_A and P_B on the H-R diagram in part (f). However, many candidates correctly identified the nature of P_B correctly.

E1 [HL only]

If part (f) had been answered correctly then evolutionary paths in (h) were often correctly drawn

Some candidates struggle with the manipulation of logs in part (i) but a significantly large number of candidates in (j) recognised that Betelgeuse might become a neutron star and that neutron degeneracy pressure would account for its final stability.

E2 Big Bang Model and red-shift

Many candidates in (a) knew what is meant by the Big Bang Model but an understanding of CMB in part (b) and its relevance to the Big Bang Model was only demonstrated by a minority of candidates. In (b) (ii) it was not sufficient to say that galaxies are moving away from Earth; a statement to the effect that the universe is expanding was required.

E2 [HL only]

Candidates should note that if, equations are quoted in explanations, then terms in the equation should be defined. In part (c), too many candidates lost marks by not defining the symbols in the Hubble Law. Part (d) was usually answered correctly.

Option F – Communications

F1 Modulation

A small number of candidates took this option.

In part (a) most candidates were able to state what was meant by modulation but using the data from the graph in part (b) to determine various aspects of a signal and carrier wave was rarely done well and often not answered.

Part (c), an advantage of frequency modulation over amplitude modulation, was more confidently answered.

F2 Optical fibres

In part (a) material dispersion was often confused with modal dispersion and this confusion carried through to answers to part (b) and c(ii).The calculations in part (d) were often done poorly or not done at all. Part (e), the confidential transfer of data, was usually answered well.

F3 [HL only] [SL C2] Operational amplifier and Schmitt trigger

Candidates who took this option had clearly not been sufficiently exposed to solving problems involving circuits incorporating operational amplifiers.

Apart from part (a)(i), the voltage characteristic, this question was rarely answered well with most candidates showing little or no knowledge of the topic.

Option G – Electromagnetic waves

G1 Lasers

In part (a) most candidates knew what was meant by the terms monochromatic and coherent. However, in (b) the role played by the metastable state in the production of laser light was not appreciated by many candidates. The problem in part (iv) was usually answered correctly.

G2 Astronomical telescope

In part (a), as in past papers, ray diagrams were often poor. Many candidates failed to identify the correct locations of the two focal points. In part (b) candidates who recognised that the power of a lens is the reciprocal of its focal length had little difficulty with the problem on angular magnification. Most candidates were aware of chromatic and spherical aberration in part (c).

G3 Diffraction grating

It was clear from the answers to part (a) that a large number of candidates were not familiar with the derivation of the diffraction formula. However, the application of the formula in part (b) was often done well.

G4 (HL only) X-ray diffraction

Quite a few of the candidates in part (a) viewed the crystal as some sort of transmission grating, and/or were under the impression that refraction was taking place. Calculations of the lattice spacing in (b) were often correctly done.

G5 (HL only) Thin film interference

A significant number of candidates did not attempt this question or made very poor attempts at answering. Candidates who gave good answers often used, correctly, a similar triangles approach to determining the diameter of the hair in part (c).

HL only

Option H – Relativity

H1 [SL D1]

Most candidates were able to draw the correct path of the light in part (a). Parts (b), (c) and (d) effectively dealt with the derivation of the time dilation formula and here many candidates had problems often relying on guesswork and half-remembered proofs rather than follow the logical development of the questions. The calculation was often done well but with the usual confusion between the times.

Parts (f) and (g) were HL only with the length contraction usually done correctly in (f). There were, however, many confused ideas in the discussion of muon decay and it's bearing on time dilation and length contraction. Rarely were there any attempts to identify the two reference frames involved, that of the muons and that of the Earth. Many candidates as in previous years still have the idea that there is an absolute reference frame and so talk about time going more slowly for moving objects.

H2 Pair production and relativistic mechanics

It was rare to see correct solutions to the calculations in this question. Candidates, as in previous years did not seem familiar with handling the units MeV c-1 and MeV and became confused.

H3 General Relativity

Generally speaking**,** candidates had much more success with this question although the ideas of the shortest path in space time in (b)(i) and of extreme curvature in (b)(ii) were often missed.

The substitution in (c) was usually done correctly.

Option I – Medical physics

This was not a popular option.

I1 Sound intensity

The definition of intensity in (a) (i) was usually correct but definitions of intensity level in (ii) often lacked precision

In (b) most candidates knew the two methods by which sound pressure at the ear drum is amplified. However, although there were some complete solutions to the problem in (c) many candidates did not make a start.

I2 X-rays

Most candidates were able to correctly define half-value thickness in (a) but many had problems with exponentials in (b) and so were not able to answer part (c) sensibly.

In (d) a variety of physical mechanisms, often correct, other than scattering were given for blurring of the image. However, the use of a lead collimation grid to remedy blurring was not well known. In (e) image enhancers were either well described or the question was not answered.

I3 Use of lasers

Candidates either knew about pulse oximetry or they did not.

I4 Dosimetry

In part (a) most candidates knew the difference between absorbed dose and dose equivalent. However, although there were some complete solutions to (b) (i) many candidates did not make a start. They had more success with parts (ii) and (iii).

Option J – Particle physics

This was not a popular option.

J1 (SL D2) Leptons and mesons

This was the best answered question in the option. However, it was clear that some candidates were attempting this option as a last resort and had not really studied the option in any depth.

Part (a) was often correct but the Feynman diagrams in (b) rarely showed the virtual particle. A significant number of candidates had a good understanding of quark structure, conservation laws and the Pauli Exclusion Principle.

In part (f) (**HL only**), the unit of MeV c^{-2} caused some candidates problems.

J2 Particle accelerators

In part (a) many candidates **sho**wed a good understanding of the cyclotron but answers to (b) showed that the synchrotron was less well understood. In the problem few candidates recognised that the rest mass of the proton needed to be considered. Part (d) on the use of the Boltzmann factor was either done well or left unanswered.

J3 the standard model

A significant number of candidates left the question unanswered. Of those candidates who did attempt the question very few knew anything about deep inelastic scattering.

Recommendations and guidance for the teaching of future candidates

- Candidates should be given precise and unequivocal definitions of physical quantities.
- Candidates should be provided with the list of command terms as set out in the Guide. The interpretation of the terms should be explained to them. It is clear, for example, that many candidates do not know the difference between “state” and “explain”.
- Candidates should realise that in their answers to questions that start with the command term “show”, they must set out the working clearly and logically and also explain the steps in their calculation.
- Candidates should be given plenty of opportunity during the course to practice examination questions from past papers. ,
- Candidates should be advised to pay attention to the number of marks for a sub-question and the number of lines made available for the answer as these are a good guide as to the depth of answer required.
- Enough time should be devoted to cover the chosen Options in depth. It is not recommended that candidates study an option on their own but if they do so then their progress should be frequently monitored by the teacher.