PHYSICS TZ2 (IBAP & IBAEM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 26	27 - 38	39 - 48	49 - 58	59 - 69	70 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 13	14 - 24	25 - 35	36 - 45	46 - 57	58 - 67	68 - 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

The transition to the revised IA structure went very well. The majority of schools understood the requirements. Teachers continue to demonstrate an improvement in selecting appropriate labs for each criterion. Problems occurred, however, when teachers assigned two clearly defined variables for design, or assessed design when determining a specific quantity, such as gravity. The rule of thumb is to look for a function or relationship between two variables. Students need to make decisions and different students should come up with slightly different investigations given the same teacher prompt. Although hypothesis is no longer required under the planning of an investigation, some teachers are asking students for this. It should be noted that assessment does not address hypothesis. However, some physical interpretation may occur in CE, and hypothesis might appear here, but it is not required.

Data collection and presentation was done well. Occasionally teachers awarded full marks when units and uncertainties were absent, and of course these are required. Occasionally teachers would mark DCP when no graph was drawn. Under DCP students are expected to process data by graphing. Teachers need to access investigations that are appropriate to the criteria.

The majority of schools offered a diverse practical program with investigations ranging from low tech to the use of sophisticated equipment. Most schools covered a wide range of topics, but more than a few schools failed to provide students with practical experience on both options studied. Teachers are reminded that investigations on physics topics not in the syllabus can be appropriate for learning experimental skills. The majority of schools completed the required hours. There were a few suspicious cases, however, where (for example) a school claimed 4 hours of IA time for a thought experiment on gravity, and another school claimed 5 hours investigating Hooke's law. Moderators often question such claims.

DCP and CE are usually inappropriate for assessment when students work with simulations, such as radioactive decay using dice or a computer model of Snell's law. These are learning exercises but they are not appropriate for assessment. Standard textbook labs with standard classroom equipment are not usually appropriate for assessment under CE.

Candidate performance against each criterion

Design

The majority of schools are assigning appropriate design topics. The key to success under the design criterion is the teacher's prompt. It needs to direct a student toward a research question without doing the student's thinking for them. Variables need operational definitions. If a student says she will measure the size of a crater, then she needs to explain what the size is. Is it the width measured from rim tops, the depth measured from the level surface or just what? The terms independent, dependent and controlled variables need to be clearly understood by students.

Controlling variables was properly addressed in most cases but there were occasion where students needed to be more specific. Just saying, "I will measure the period of a pendulum" is not sufficient. Attention to detail is expected for a complete. Similarly, sufficient data requires an appreciation of the scope and range of values, as well as repeated measurements. Most students are addressing these issues. Occasionally teachers over-mark this aspect. Teachers are reminded that moderators only know what is written out in the student's report.

Data Collection and Processing

This criterion tends to earn the highest marks for students. The expectations are clearly spelled out in the IA descriptors. Teachers are reminded that the expectations for the treatment of errors, uncertainties and graph gradients are detailed in the Physics Course Guide syllabus. There were only a few instances where students were told what to graph. Teachers are reminded to read the clarifications in the Physics Course Guide under DCP for what is expected from the student. A few students drew free-hand graphs. The IB expects students to use graph paper or preferably graphing software.

A complete in DCP aspect 3 requires students to present processed data appropriately (without mistakes or omissions). The clarifications in the course guide state that a relevant graph will have appropriate scales, axes with units, properly plotted data points, a best-fit line, and that error bars and minimum and maximum gradients will be used to determine the uncertainty in the gradient. Section 1.2 of the syllabus gives the details of what is expected. Students may use more sophisticated methods of error analysis, such as standard deviation and other statistical methods, but the course guide explains the minimum level of error and uncertainty appreciation.

It is expected when assessment is made under DCP that students construct graphs. However, there may be exceptions to this, where DCP is appropriate for assessment but a graph is not appropriate. For example, perhaps students are using time-lapse photographs of a moon orbiting Jupiter and gather data to determine the gravitational constant, G. There would be raw and processed data, and raw and processed uncertainties. The final value of G would have an uncertainty range (and it would be compared to the accepted value) and yet no graph would be relevant. Such an investigation could earn a complete under DCP aspect 3.

There may be other examples of assessed work under DCP without graphs. In such cases the moderator must assess the type of investigation and determine if a high school student could have and should have constructed a graph. If a graph would have been relevant but one was not used, then a complete cannot be awarded to DCP aspect 3.

For example, in a simple pendulum experiment to determine g, a student may have processed data and found an average for gravity. Without a graph a possible systematic error (perhaps of wrongly determined length of the pendulum) would not have been revealed. In an example of a Boyle’s law experiment, the dead space in the pressure gauge would not be revealed without graphing the data. Or, when measuring the speed of sound with an open-ended resonance tube, only appropriate graphing reveals the end-effect. In all these cases the moderator could not accept a complete for DCP aspect 3 without a graph.

Finally, there is a type of experiment that may or may not be appropriate for graphing. In an experiment to measure the specific heat capacity of water, a student may process data and uncertainties correctly and then calculate a numerical value of c. However, it may be relevant to construct a graph in this experiment because of an experimental error in the heating process. A graph of temperature against time (for constant electrical power source) would reveal a non-linear temperature increase with time, hence revealing an important experimental error. In this case a graph is relevant and hence required for the work to earn a complete under DCP aspect 3.

When a student’s investigation is assessed for Design as well as DCP then a graph is most certainly required. This is because, under Design, students should be looking for a function or relationship between two variables. These variables would then be appropriately graphed.

The conclusion from the above observations is that in the majority of investigations, a graph is expected. Teachers are advised that when assessing DCP t graphs should be involved. However, there are exceptions. The moderator needs to determine whether or not the intentions of the physics syllabus statements about error analysis have been achieved without a graph and whether or not the student’s investigation should have involved a graph.

Conclusion and Evaluation

CE aspect 1 achievement level 3 requires students to ‘justify’ their reasonable interpretation of the data. Going beyond a partial requires something more than summarizing the graph. Perhaps some physical theory, or at least some physical interpretation or meaning is required here. Students should ask themselves what the gradient of the graph means, what (if anything) a systematic shift in the graph might mean, and what the scatter of data points might mean. Aspect 1 is probability the most difficult of all IA to achieve a complete. Students often confuse the words “linear” with “proportional” when talking about a graph’s line.

Recommendations for the teaching of future candidates

- Teachers should make sure that all assessed work is appropriate for assessment by the relevant criterion. This may sound obvious but there are numerous cases where students were denied possible marks because the teacher assessed inappropriate tasks. Remember that only a fraction of all the hours attributed on the 4/PSOW form need to be assessed.
- Although only the two highest marks per criterion are used to establish a student's IA grade, students need a number of opportunities at assessed work in order to improve and do their best. Some schools are marking only two sets of work, and this is unfair to the student.
- Teacher's are reminded to use only the most recent version of the 4/PSOW form (the current one has spaces for the moderator's and senior moderator's marks), and to include the 4/IA cover form. The PS mark is established with the group 4 projects but no evidence of the project is required for moderation. Remember to send only the lab samples that are to be moderated. Some schools are sending entire portfolios. Finally, students and teachers must sign and date the 4/PSOW form.
- There is ample evidence of the use of ICT. The IB encourages this. The majority of students are word-processing their lab reports, and many schools are using graphing software. The other ICT requirements are being met.
- Teachers are reminded of the teacher support material (TSM) that is available on the Online Curriculum Centre (OCC) physics pages. See Assessment, Internal Assessment, and then TSM. The material here covers issues of design, errors and uncertainties, MS and it includes 10 student labs that are marked with moderator comments.
- Teachers are allowed to respond to student questions as they do their experimental work and as they write up their reports. However, teachers must not grade a draft of a lab report, and teachers should respond to questions only by directing students' routes of inquiry (and not answering questions directly). In assessing student work using IA criteria, teachers should only mark and annotate the final draft. See the section of the Physics Course Guide called “Guidance and authenticity” for more detail.
- It is essential when work is to be assessed that students work on their own. There cannot be a set of common data, or identical results if the work is to be assessed.

Further Comments

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 can 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 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 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. Student 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 the 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 - 18	19 - 22	23 - 25	26 - 29	30 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 10	11 - 13	14 - 16	17 - 20	21 - 23	24 - 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 81 responses from 380 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 May 2009 papers were generally well received. The large majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level. However, a significant minority 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 few exceptions, teachers thought that the Papers gave satisfactory or good coverage of 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, in the case of a large majority, good. It must be kept in mind that the physics May 2009 exam session was the first session involving the new physics syllabus.

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	291	1051	1120	*1447	10	36.92	0.21
2	273	1436	*1731	474	5	44.17	0.44
3	397	*1975	371	1170	6	50.40	0.45
4	*2157	516	1145	96	5	55.04	0.15
5	*1347	1449	892	229	2	34.37	0.46
6	110	321	*3326	157	5	84.87	0.24

7	1855	*1731	176	153	4	44.17	0.47
8	844	*1661	420	970	24	42.38	0.34
9	123	26	*3564	203	3	90.94	0.16
10	145	*1896	1529	343	6	48.38	0.30
11	197	1482	*1936	299	5	49.40	0.45
12	190	*2999	467	261	2	76.52	0.27
13	*2869	446	329	269	6	73.21	0.41
14	838	*1347	*1092	632	10	62.24	0.32
15	*2277	1005	137	499	1	58.10	0.38
16	1321	307	372	*1912	7	48.79	0.36
17	367	771	*1886	886	9	48.12	0.24
18	*2057	701	812	330	19	52.49	0.51
19	500	669	*2090	649	11	53.33	0.35
20	95	601	*2918	302	3	74.46	0.46
21	106	421	*2994	389	9	76.40	0.42
22	569	*2672	168	502	8	68.18	0.37
23	54	*1758	2006	95	6	44.86	0.39
24	1431	*983	99	1388	18	25.08	0.29
25	442	850	*1999	607	21	51.01	0.34
26	*2449	121	1082	261	6	62.49	0.34
27	246	499	541	*2627	6	67.03	0.50
28	947	772	476	*1701	23	43.40	0.44
29	1544	274	282	*1815	4	46.31	0.30
30	*1236	807	1004	852	20	31.54	0.34
31	*1132	546	*1554	677	10	68.54	0.25
32	1356	266	286	*2003	8	51.11	0.37
33	*1644	1887	240	146	2	41.95	0.35
34	270	709	844	*2074	22	52.92	0.36
35	379	548	384	*2580	28	65.83	0.55
36	77	52	*3653	133	4	93.21	0.10
37	639	*2846	316	110	8	72.62	0.38
38	303	*1340	990	1267	19	34.19	0.25
39	*2832	158	782	130	17	72.26	0.30
40	731	441	727	*2014	6	51.39	0.38

Number of candidates: 3919

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	295	1029	971	*1300	18	35.98	0.26
2	*2128	137	441	904	3	58.90	0.52
3	545	1711	*1047	306	4	28.98	0.37
4	399	*2011	473	725	5	55.66	0.35
5	78	294	*2661	576	4	73.65	0.42
6	410	*1390	474	1330	9	38.47	0.31
7	2213	675	*379	345	1	10.49	0.11
8	*1832	660	1012	101	8	50.71	0.18
9	499	178	1210	*1718	8	47.55	0.25
10	170	102	*2869	471	1	79.41	0.36
11	*2117	740	370	372	14	58.59	0.50
12	224	*2721	424	242	2	75.31	0.22
13	1541	*1276	564	219	13	35.32	0.48
14	920	*871	*1147	662	13	55.85	0.27
15	*1086	*1751	617	156	3	78.52	0.29
16	*1747	366	1314	179	7	48.35	0.40

17	579	530	348	*2151	5	59.54	0.51
18	186	591	*2336	491	9	64.66	0.51
19	463	287	*2638	216	9	73.01	0.39
20	647	*2100	278	582	6	58.12	0.37
21	*1556	891	469	687	10	43.07	0.41
22	592	514	*1775	721	11	49.13	0.54
23	1405	495	326	*1378	9	38.14	0.36
24	448	561	499	*2097	8	58.04	0.55
25	156	659	*2491	294	13	68.95	0.38
26	307	*2099	954	242	11	58.10	0.38
27	322	464	411	*2407	9	66.62	0.22
28	347	931	730	*1580	25	43.73	0.40
29	725	741	436	*1692	19	46.83	0.63
30	682	*2278	511	123	19	63.05	0.40

Number of candidates: 3613

Comments on the analysis

Difficulty

The difficulty index varies from about 25% in HL and 11% in SL (relatively ‘difficult’ questions) to about 93% in HL and 79% 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, 40% of the coefficients of discrimination were in the 0.40 bracket.

‘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 an educated guess should be made. In general, some of the ‘distractors’ should be capable of elimination, 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.

SL and HL common questions

SL Q1 and HL Q1

A number of teachers indicated their reservation toward this question involving purely memorization. The syllabus indicates that such a question can be expected. The correct response proposes a number for the mass of the universe clearly different from the other distractors and representative of the lower limit of the values presently accepted.

SL Q6 and HL Q3

A highly discriminatory question. The diagram was helpful in understanding the physical situation even though the use of the conjunction “after” would be preferable to the use of the conjunction “when”.

SL Q14 and HL Q14

The interpretation of the expression” The refractive index of refraction of medium 2 **relative** to medium 1 is” might have represented some difficulties for students for whom English is not the mother tongue. Consequently, answers B and C were accepted.

SL Q23 and HL Q32

It is good to remember that the process of fusion is characterized by the presence of neutrons and nuclei of comparative masses as products of the reaction.

HL Questions

Q7

A highly discriminatory question. Answer A was the most popular answer with many students not knowing a key characteristic of an electric field that is the work done in an electric field is independent of the path followed in the field. This was the focus of the question.

Q10

When the expression “proportional to” is used, it is understood to be “directly proportional to”. Otherwise, it would be specified in the question.

Q17

The topic is covered in the section 11.4.3 of the syllabus.

Q31

The intended answer A is accepted. However, due to the diversity in the design of nuclear reactors, the answer C was also accepted.

Q33

This question is about a traditionally challenging concept. A majority of students choose answer B rather than the right answer A. The question is formulated in such a way that it is the physics that is important here not the algebra (sign). A good discrimination coefficient.

SL questions

Q7

A very high coefficient of difficulty with, as a consequence, a low coefficient of discrimination. This question requires a strict application of Newton's third law. A very large number of students were distracted by other parameters especially the tension in the wire. The tension in the wire is not, strictly speaking, the reaction of the lamp to the action of the Earth W on the lamp. W is the action of the Earth on the lamp, so the reaction of the lamp (-W) must be acting on the Earth itself.

Q15

This (challenging) question was about the nature of a wave (here a pulse) as explained via SHM. It has a slightly negative coefficient of discrimination and high coefficient of difficulty. Because of the ambiguity in the position of point P (the answer A requires that point P be lower to the left on the pulse segment), answers A and B were accepted. The published version of this question will show velocity rather than acceleration in the stem of the question with the relevant answer being B.

Q27

The photoelectric effect is not strictly in the SL syllabus (7.1.4). However, the description of the basic mechanism of the *photo*voltaic cell should include the name of the process.

Recommendations and guidance for the teaching of future candidates

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.

Considering that the May 2009 physics exams covered a new syllabus, , the results obtained for Paper 1 are very encouraging.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 20	21 - 31	32 - 41	42 - 50	51 - 60	61 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 14	15 - 19	20 - 25	26 - 30	31 - 50

In this first presentation of a new syllabus a careful scrutiny of G2 forms was of especial importance. As usual, only a small percentage of centres returned a form, but at HL more than half of all centres felt that the standards were similar to the previous year, this rose to 75% for SL. About 30% felt that HL papers were a little more difficult (16% for SL), about 10 % at both levels felt that papers were easier than hitherto. The statistics do not bear this out however as at SL the mean mark rose by 0.5 compared to May 2008 and at HL the mean mark rose by 5 marks returning to the levels of May 2007. The vast majority felt that the syllabus coverage, clarity of wording and presentation of both papers were either satisfactory or good.

General comments

Many candidates found it hard to perform well on these Papers even though it was felt that there were plenty of marks accessible to those who may struggle with the more conceptual aspects of the course. As identified last year, candidates often lost marks as a result of definitions that lack precision or were expressed in non-scientific language. In fact, precision was an issue throughout the Papers. For example, as for last year, a significant number of candidates lost some relatively easy marks as a result of unacceptable lines of best fit in the data analysis questions (A1). It should be emphasised to students that “line of best fit” does not necessarily mean a straight line. There are many other types of line. Candidates do not always appear to take account of the mark structure

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

The examining team identified the following areas: -

- The reasons why relationships can be described as directly proportional
- The understanding of the term pixel
- The definition of resistance
- The need to explain the steps in a calculation clearly
- Stating the assumptions of the kinetic theory of an ideal gas
- Explaining the conditions required for simple harmonic motion
- A clear understanding of the meaning of resolution in diffraction theory (HL)
- The physics of climate change
- An understanding of the term ‘estimate’

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

It was pleasing to see the following skills demonstrated: -

- Symbol manipulation to prove a given relation or formula
- Use of Sankey diagrams
- Gas law calculations and *pV* diagrams for a gas

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

General comment

Some G2's suggested that the requirement in the HL test for candidates to take logs of a power expression and to indicate the graphical treatment needed to deduce the value of the exponent was beyond the syllabus.

It is the clear view of the examiners that this analytic skill is one that can be expected of candidates at HL and centres can expect to see questions that require the use of a logarithmic analysis from time to time in the future.

The context for this question was straightforward.

a) This was well done with almost all candidates drawing appropriate curves that sat within the error limits.

b) This was not well done. The non-linear nature of the data was recognised as the reason for non-proportionality at large times. Few were able to state that up to 120s, although the data lay on a straight line, this line did not go through the origin and so the relationship was not *directly* proportional.

c) Although many candidates understood the basis of the method, often one mark was lost because the line drawing was sufficiently poor to push the answer outside the error limits imposed by the examiners

d) Examiners were hoping to see slopes determined from extrapolated lines from early times. In fact the majority of candidates used triangles for the first 100 s only and lost marks for this inaccurate approach.

e) This was done well.

f) [HL only]

(i) Despite the G2 comments, many candidates from all levels of ability were able to take logarithms of both sides of the equation and use this to state the appropriate graph to draw.

(ii) Again, many were able to relate the gradient of their log-log graph to the exponent in the power law.

g) HL and (f) SL: The graph sketches were mostly poor although creditworthy. Few bothered to relate the graph clearly to the earlier printed graph and initial gradient and final values were at best approximate.

A2 [HL and SL] Electrical resistance

a) (i) There were few really clear definitions of electrical resistance. Many resorted to slang expressions: 'voltage over current' was particularly common. Candidates should be encouraged to define symbols if used and to display equations clearly.

(ii) Only the weakest candidates were unable to determine the resistance of the heating coil.

(iii) This was a 'show that' question and full explanations were expected including the re-arrangement of the equation from the data booklet. Candidates cannot expect full credit for negligent or careless re-arrangements.

Many candidates obtained full credit here.

A3 [HL and SL] Force fields

a) Many were able to relate the idea of a field of force to a region in space, but few indicated the result of the field, i.e. a force on a mass or a charge, etc placed in the region.

b) The types of field were well identified with candidates at HL generally getting 2 out of 3 correct and candidates at SL getting 3 out of 5.

A4 [HL] and B3 part 1 [SL] Wave power

a) Most gained one mark out of two here. Candidates either wrote about the conversion of kinetic energy in the wave into kinetic in the duck or other moving part of the convertor, or they focused on the conversion from kinetic to electrical. They need to be encouraged to look in a holistic way at questions such as this.

b) Both questions here: a 'show that' and 'deduce' were poorly done. It was clear that many candidates were groping towards an answer with very little idea of what was going on. The level of presentation of answer was exceptionally poor. Candidates cannot expect full credit unless each step of their argument is present.

(i) It was unusual to find a clear statement that the change in the centre of mass of the wave was A not $2A$. The factor of ½ involving λ was also fudged.

(ii) The relationship between wave arrival time and the number of waves arriving per second was poorly described by most.

c) This question required an estimate of the wave speed. A question involving the term 'estimate' will often require one or more of the variables to be estimated by the candidates. Many candidates simply ignored this and left the wave speed as a symbol; credit but not full credit could be obtained for this approach.

d) Many candidates recognized that the crude square-wave model in the question means that there is too large an estimate of the wave volume. A large number went on to suggest that this is an under-estimate of the wave power and lost one of the two marks available.

A5 [HL only] CCD devices

a) Statements of the meaning of the term pixel were far too loose and did not refer to the CCD as instructed in the question.

b) Although most candidates had a reasonable idea of the mechanisms at work in the pixel when photons strike it, explanations were incomplete and usually omitted one or more steps in the process.

c) Many were able to state that the location of the pixel was required; other correct responses were also possible.

d) There are many advantages of a CCD in comparison with a photographic film and the candidates were well able to state these.

Section B

B1

Part 1 [HL and SL] Bullet from a gun

a) Less than half the candidates were able to connect the variable force with a variable acceleration, but many more stated that the kinematic equations only applied under conditions of constant acceleration.

b) (i) Once candidates had the idea that a mean force was required for the final 2 ms of the graph, they had few problems. Approaches from other directions were much less successful.

(ii) Fewer than half the candidates recognised that the area under the graph was equal to the change in momentum and this question was very poorly done.

c) (i) A knowledge of the momentum change should lead directly to a change in speed of the bullet, but it rarely did so with candidates going around in circles and usually failing to gain any credit for confused and inaccurate calculations.

(ii) As in the previous part, most candidates could not cope with the comparatively simple physics here and very many attempted to use a *force* × *speed* approach but became confused by the need to account for both an average force and an average speed.

d) There were many standard statements of Newton's third law but most explanations only attracted half of the remaining marks. It was rare to see the action-reaction pair clearly identified and remaining explanations were generally weak and meandering.

B1 Part 2 [HL only] Motion of a charged particle

a) Many understood the basis of the calculation, but too often calculations were marred by omissions of factors of 2 and 4 in the charge and mass of the particle.

b) (i) The magnitude of the electric field was often well calculated apart from power of ten errors, the expressed units were often incorrect.

(ii) Again, the acceleration was well handled apart from the 2 and 4 factor omissions also observed in part (a). Candidates were not penalised twice for these errors.

c) (i) This very simple calculation was completed successfully by many.

(ii) Many had a clear idea of what they needed to do and about half the candidates carried the calculation and deduction through without error. Some, having correctly evaluated the distance concerned, deduced the opposite result through not having thought the problem through correctly.

B1 Part 2 [SL only] Fossil fuels

a) (i) Most could state the meaning of the term ‘fuel’.

a(ii) to (d) are the same as B2 Part 2 [HL]

B2

B2 Part 1 [HL only] Ideal gases

a) (i) The assumptions were not clearly expressed. Many candidates quoted the assumed elasticity of the collisions, forgetting that these are already mentioned in the question. The question asked for ‘further assumptions’ and this should have been a clue.

(ii) The 3 mark allowance should have indicated to the candidates that something more than a discussion of internal versus potential energy was required. Discussions of the requirement to use the average kinetic energy were very rare.

b) The calculations in parts (i) – (iii) were well done by a high proportion of the candidates.

c) (i) The *p*-*V* graph was well drawn by many after what was clearly a careful analysis and understanding of the changes to the gas. Some candidates omitted to give any clue as to the direction around which the cycle was carried out and were penalised.

(ii) The labelling of changes during which the gas does work on the external surroundings was not so good, with multiple or ambiguous responses.

(iii) Many understood that the area under the curve relates to the work done in a particular change, but often it was very unclear which area the candidate thought was important in this particular case. Such ambiguity led to the withholding of one mark.

B2 Part 2 [HL] B1 Part 2 [SL] Fossil fuels

(a) Only non-derived fuels were accepted. So diesel is not regarded by examiners as a fossil fuel.

(b) Statements of why fossil fuels are said to be non-renewable were weak. The essential point is that the rate of consumption of these fuels is (wildly) greater than the rate of formation. Thus the fuels will run out. Statements that ‘they cannot be used again’ are self evident and not worthy of credit.

(c) The Sankey diagram work could have been better even though many gained full credit. Candidates were reluctant to reveal exactly how they had determined the efficiency and examiners had to resort to examinations of the printed diagram to look for evidence that candidates had used it. Candidates, once again, need to make their working methods more obvious.

(d) Many found three reasons for the widespread continuing use of fossil fuels hard to find. Two with a repeated reason was the norm. Some candidates gave so little detail in their answers that credit could not be given. ‘Transport costs’ is difficult to credit unless more detail is given.

B2 Part 2 [SL only] Nuclear processes

a) and (b) are the same as B4 Part 1 [HL] (a) and (c)

c) Too many candidates showed the alpha particle touching the gold nucleus before recoil.

d) (i) Most knew the name of the process.

(ii) Many candidates were able to manipulate the powers of ten and the required equation to arrive at a correct answer.

(iii) This was poorly done with many having no clear idea about the method or the conversions required in this calculation.

B3

B3 Part 1 [HL] and B2 Part 1 [SL] Simple harmonic motion

a) Candidates were often able to indicate the direct proportionality between acceleration and displacement and the direction difference between the two as requirements for simple harmonic motion. However, only about half were able to relate these requirements to the graph.

b) About half were able to convince the examiners (it was a ‘show that’ again) that they were able to derive the answers. Presentation was universally poor with steps in the argument not arranged logically.

c) (i) Candidates often identified the relationship between direction of energy propagation and direction of medium motion. It was rare to see a statement of what the wave actually is in terms of oscillation of the medium.

(ii) The calculation was often correct.

B3 Part 2 [HL only] Diffraction of light

a) (i) Descriptions were incomplete. The spreading out of the light was referred to, the appropriateness of the diffracting aperture dimension was not.

(ii) The aperture in the question was very wide. A consistent width of the central maximum was not required by the examiners who were marking the secondary maxima in terms of the relative height and the position of minima.

(iii) Many candidates had success with the calculation especially in the first part where they needed to calculate the angle for the first minimum. After this factors of 2 error crept in leading many to obtain only partial credit.

b) (i) The usage of the term ‘resolved’ was described correctly by about half the candidates.

(ii) The outlines of the reason for non-resolution of two lights a large distance away were poorly done. Many candidates even failed to make clear that the dominant effect in this process is diffraction. This was clearly not understood by many.

B4

B4 Part 1 [HL] B2 Part 2 [SL]Nuclear processes

a) The nuclear reaction was often completed correctly.

b) **[HL only]**

(i) Many could cope with the half-life calculation but there were occasional power of ten errors.

(ii) On the other hand, many candidates began the emission calculation but then could not carry it through so that examiners found themselves awarding marks only for the opening parts of the whole calculation.

c) **SL (b)**

(i) The straightforward indication of the deviation angle was well done by only about one-third of candidates. There was a widespread failure to construct the final direction fo the alpha particle back to the extrapolated original direction. Too often candidates resorted to marking an angle between the original and the path at a point where the particle had further deviation to come.

(ii) About half the candidates recognised that the changed gold isotope has the same charge and that therefore there will be no change in the deviation.

d) **[HL only]**

This calculation was poorly done with little understanding of how to begin.

B4 Part 2 [HL] / B3 Part 2 [SL] Albedo

a) The physics of infra-red absorption was poorly described. The underlying processes of resonance and vibrational energy states of the gas molecules were not widely appreciated.

b) There was lack of clarity about the exact atmospheric processes.

c) Generally well-answered.

d) (i) Candidates were vague as to the directions in which the energy is reflected and absorbed

(ii) Statements of the meaning of albedo as a ratio were rare. Too often candidates jumped to a statement that ‘albedo decreases’ without a clear explanation of how the changes in reflected energy lead to this.

e) Many candidates were able to cope well with this simple calculation.

f) Reasons quoted were weak and usually focussed on the nature of the numerical estimates in part (e).

Recommendations and guidance for the teaching of future candidates

Once again a common theme has been the lack of precision in written answers, especially in those requiring an explanation. Arguments that logically follow through relevant stages were few. Candidates should be encouraged to be able to define the terms that they are using and to define symbols if they are using them. Candidates are still not sensitive to the significance of the action verb that starts a question; an “explain” requires a more detailed answer than a “state”. Candidates need to be ready to provide one or more variables in a calculation when the word ‘estimate’ appears as an action verb.

The examination team recommends working through past papers (and the associated mark schemes) as a good preparation for the examination. Not only will this give candidates a familiarity with the format of the examination but also many should be able to gain 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 - 5	6 - 11	12 - 19	20 - 25	26 - 31	32 - 37	38 - 60

Standard level

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

General comments

The majority of candidates appeared to find the Paper accessible with several examples of good understanding of the material. There was no evidence that candidates were short of time to complete their work.

The feedback from teachers on the G2 forms for SL and HL is summarized as follows based on a greater number of G2 forms with respect to last year.

Standard Level

- A great majority of centres (90%) found the paper to be of a similar standard to last year, with a balanced 7% who found it much more difficult (no one found it a little more difficult) and a 3% who found it much easier (no one found it a little easier). Even though the judgement is certainly more difficult as this is the first session examining the new syllabus, comparisons may have been significantly done as some of the most popular options remained similar.
- An overwhelming 96% found the level of difficulty appropriate with only a 4% judging the paper to be too difficult.
- Positive numbers reflected the reception of the paper in terms of syllabus coverage (64% judged it good and 34% satisfactory, only 2% poor). Everybody agreed about the clarity of wording being appropriate (73% good, 27% satisfactory) and approved the presentation of the paper (82% good, 18% satisfactory).
- There was a clearly uneven choice of options, with options A (Sight and wave phenomena), E (Astrophysics) and G (Electromagnetic waves) being the most popular ones. Fewer centres opted by B (Quantum physics and nuclear physics) or D (Relativity and particle physics), and very few included in their choices either options C (Digital technology) or F (communication).

Higher Level

- 63% of the centres found the HL Paper to be of similar standard to last year. However, a significant 35% found the paper a little more difficult, with a small 2% finding it much more difficult. Despite this comparison, the level of difficulty was judged to be appropriate by a great majority (87%) with a 13% who found it too difficult.

- In terms of syllabus coverage, clarify of wording and presentations no one judged the paper to be poor. 70% found the coverage to be good, with the rest judging it satisfactory. 67% found the clarity of wording good, with the remaining 33% finding it satisfactory, and 87% judged the presentation good, with the remaining 13% satisfactory.
- There was a clear cut difference among the choice of options. 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), I (Medical physics) and J (Particle physics) being clearly disfavoured by the centres, 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:

- Explaining concepts in Physics in a way that demonstrates understanding (e.g. polarization, the de Broglie hypothesis, capacitance, the postulates of Special Relativity, gravitational red-shift, interference patterns, attenuation coefficient.)
- Standing waves and modes of vibration
- Drawing consistent conclusions from a given set of evidences mentioned, as in models of the Universe.
- Applying Hubble's law to estimate the age of the Universe.
- The mechanism of amplitude modulation.
- The use of block diagrams to describe transmission of signals.
- Solving problems involving circuits incorporating operational amplifiers.
- A simple explanation to account for the sky to be blue.
- The application of key concepts in relativity to specific situations.
- 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

Repeatedly through the paper candidates showed a good technique to solve problems. Even when this was not necessarily accompanied by a consequent understanding, the mathematical skills to apply formulas and reach correct answers is to be recognized.

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

SL only

Option A – Sight and wave phenomena

A1 The eye and sight

This question showed mixed results, from candidates who very easily scored full marks to others who missed the point with irrelevant arguments in (b), even trying to justify Jim's reasoning. It was surprising to see a high percentage of answers that just missed to answer yellow for (a), even though the syllabus specifically asks for colour mixing of light.

A2 Standing waves

Better results were seen for (b) and (c), requesting numerical answers, than for (a). A large proportion of candidates were not able to draw the displacement of the string correctly and consequently also faced problems in (c) to relate the wavelength to the length as being 4L. Even though it would have been more accurate to specifically mention that the string at t=0 was at its maximum displacement, this did not seem to have been the reason for the problems faced by candidates, as the wrong drawings were very often related to other harmonics than the fundamental (first) one.

A3 Doppler effect

Even when some candidates had problems to understand the set up, this was the best answered of the questions in this option. There were many correct to the point answers and those who understood the situation were also successful mathematically. A few typically misinterpreted the Doppler equation.

A4 Polarization

Candidates experienced problems in stating clearly the meaning of unpolarized light. They usually seemed to know but were unsuccessful at using proper scientific language. Many were correct in (b) about the transmitted intensity but were less successful explaining the reason. Very few showed familiarity with the use of polarization in the determination of the concentration of certain (sugar) solutions.

Option B – Quantum physics and nuclear physics

B1 Photoelectric effect

This was a classic and fundamental question that seemed to discriminate well, with some candidates not scoring at all and some candidates scoring full marks. A number of students did not read the question attentively enough and reproduced the classic graph of maximum kinetic energy vs. frequency. In (b) there were good numbers of well done calculations, in eV, with some students choosing to take a longer route transforming into J values.

B2 Wave nature and quantum energy states

Candidates were usually much more successful in the numerical questions in (b) and (c) than in describing with precise language the de Broglie hypothesis. Many vague statements were read here. This analysis should draw teachers´ attention as it seems to indicate what kind of skills are more elaborated and exercised through the courses. Students in general need to face more frequently the need of defining, stating and describing and to do so with proper language.

B3 Nuclear physics and radioactive decay

As it seems to be the pattern for many of these questions, most candidates addressed correctly the numerical questions but not the definitions. Even those who were far from defining the decay constant correctly attempted and usually succeeded in parts (b) and (c). In (c) (i) though, there were many different versions in which candidates applied the formula given in the stem, in that some were not familiar with the calculation of the energy of an electron transition. Even those who did not reach the expected value of $= 4.3\times10^{-19}\,\mathrm{J}$, managed to get marks through error carried forward (e.c.f) in (c) (ii).

Option C – Digital technology

C1 Data storage

This questions was usually very well answered in parts (a) and (b) (i), with some erroneous answers or no answers in (b) (ii), with some candidates who seemed not to be familiar to how digital information is stored on a compact disc. For Part (c), most candidates gave a correct suggestion, usually failing to assert that it is the production of vast numbers of CDs (and/or DVDs) the reason to connect with environmental issues.

C2 Capacitance and charge-coupled devices (CCD)

Many candidates seemed to know what capacitance is, even when some did not necessarily score the mark as they tended to offer descriptive answers. They were familiar with the mechanism for light to produce a potential difference across the pixels although the wording was usually unclear. Most candidates were able to handle calculations in (c) reaching the expected answer of 0.065mV.

C3 Operational amplifiers

Very few candidates really demonstrated a familiarity with this section of the syllabus. Even when some candidates were able to score full marks in part (a), showing basic knowledge about operational amplifiers, very few if any were able to score in (b), usually showing no skills to solve problems involving circuits incorporating operational amplifiers.

Option D – Relativity and particle physics

D1 Simultaneity and length measurement

In part (a), it was common to see incomplete answers, with the reference to the speed of light in free space usually missing. Part (b) was unnecessarily complicated by the unfortunate inclusion of the term “appear”. This seemed to confuse students who tended to focus on the distance from lights to Barbara, many times with inconsistent arguments. The edited version of the paper will read differently, to focus on the simultaneity issue, asking “why the lamps with not light simultaneously, according to Barbara”.

Part (c) was consistently answered correctly, with no signs of disadvantage in (c) (iii) for the unusual choice of axes, as candidates either scored full marks or clearly interpreted a different graph, drawing curves asymptotically approaching c. In (d) students seemed to be aware of the idea of symmetry being key to identify this classic paradox, and many candidates managed to score full marks.

D2 Fundamental interactions and elementary particles

This question was usually well answered, with candidates scoring many marks showing solid knowledge. Most candidates forgot to quote the photon as an exchange particle for the electro-weak interaction, probably due to a quick reading of the question. Even though candidates had trouble and only a few reached successfully the expected answer $\approx 4\times10^{-27}$ s in (c), many candidates were aware and gave correct arguments for the reason for exchange particles to be known as elementary particles and referred to Pauli exclusion principle when explaining why the quarks have a colour associated with them.

SL and HL combined

Option E – Astrophysics

E1 Stars

Most candidates were aware of characteristics of a red supergiant, even when lack of precise language obscured in occasions the number of marks, e.g. when referring to large or big stars, without quoting a specific physical quantity. Most scored about constellations giving the key characteristic of forming a (recognizable) pattern on the sky.

Even when "show that..." type of questions seem to encourage incorrect trials, a large proportion of candidates showed correctly the distance from Antares after having shown correct understanding of both apparent and absolute magnitude concepts. In (b) (iii) both spectroscopic and stellar parallaxes were accepted, but a few candidates failed to specify any. Part (c) was also successfully solved with many candidates scoring full marks, working confidently with the luminosity relationship.

E1 [HL only]

Unfortunately, this part of the question focused on a star that, not being a main sequence one, does not allow for the mass-luminosity relationship in the data booklet to be used. Encouraged by the range given in the stem, obtained from that relationship, candidates used it consistently to deduce it, and that path was obviously accepted. As Antares is not a main sequence star, it will be replaced for the final edited version of the paper. Both neutron star and black hole were then accepted possibilities for its probable final evolutionary state.

E2 Models of the universe

Many candidates were familiar with the models and were quite confident in answering the question. Some candidates did structure their answers in a logical way to score full marks. In certain cases lack of a cohesive argument led to fewer marks being awarded e.g. after an initial statement mentioning "infinite and uniform", these qualities were not included in the argument in a logical manner,

E3 [HL only] Hubble's law

Again, candidates were more successful when estimating than when suggesting. In (a) many failed to clarify that the difficulties are for galaxies at great distances or when their recession speed is large. In (b), a few missed to recognize the need to use the minimum value of the range provided.

Option F – Communications

F1 Radio communication

A small number of candidates took this option. Those who did were proficiently able to explain the differences between carrier and signal waves and also about amplitude and frequency modulation. However, there were very few who estimated correctly the frequency ratio to be from 12 to 13 or that sketched the form of the signal wave as expected, with some incorrect trials of just drawing a wave from the positive to the negative values, showing misunderstandings with respect to modulation.

Advantages or disadvantages of amplitude over frequency modulations were more confidently answered.

F2 Transmission of signals

Very weak answers were read here about transmission of signals. Many candidates thought components X and Y to be ADC (analogue-to-digital converters) instead of parallel to serial / serial to parallel converters, and therefore missed the point of the question, with very few showing familiarity in (b) with the concept of time-division multiplexing. However, as it seems to be the pattern throughout the paper, candidates were more successful when it came to solve mathematical problems, perhaps helped by the fact that most were familiar with the concept of attenuation, usually well explained in the answers.

F3 [HL only] [SL C3] Operational amplifiers

Candidates who took this option had clearly not been sufficiently exposed to solving problems involving circuits incorporating operational amplifiers. Even though most knew what it is and successfully answered (a), including the correct calculation of an inverting amplifier (however very often stating incorrectly the answer in Ω), almost no candidates managed to solve the circuit about the use of an op-amp as a non-inverting Schmitt trigger.

F4 [HL only] Mobile phone systems

Candidates were usually very familiar with this section and the clear impact of this topic among teenagers was seen by the range of very imaginative answers for (c) that were usually accepted (as, e.g. a candidate bringing up the issue of using cell phones to cheat in international exams in physics or another discussing very explicitly parental control).

Option G – Electromagnetic waves

G1 Nature of electromagnetic waves

Surprisingly, about half the candidates had serious problems to produce a simple explanation (as specifically requested by the syllabus) for the sky to be blue. The same half usually produced very wrong answers for the daytime sky of the Moon to be black, even though the other half correctly stated it in terms of the lack of atmosphere.

G2 Interference and lasers

Candidates were in general familiar with the concept of interference, though some failed to follow the action verb of the question, and did not completely explain it, i.e. did not give a detailed account of the causes, reasons or mechanisms. However, a significant proportion of the candidates correctly referred to stimulated emission and population inversion and correctly identified coherence in (b) (ii). The degree of sophistication of question (c) was thought not to be significant and the candidates' answers usually verified that with their answers, as many successfully focused on the reflection of light. Point (d) was answered correctly as it was the case through the paper with problem solving, even when in some cases candidates only obtained partial marks through e.c.f. when failing to recognize correctly the distance between maxima to be 500m.

G3 Optical instruments

This was the highest scoring question of the option. Candidates consistently knew about linear magnification even though a few failed to refer to a specific quantity when stating the ratio (only mentioning image over object). Point (b) was answered correctly with a few not reading the inclusion of the term "magnitude" in (b) (ii). With different wording candidates managed to state what spherical aberration is and suggest how to reduce it.

G4 [HL only] Thin-film interference

Candidates were familiar with this topic but many either forgot to account for the phase change, therefore concluding that colour would be red instead of blue or account for the path difference to show that only one wavelength of the different possibilities for m produced a value within the visible spectrum, thus scoring partial marks.

G5 [HL only] X-rays

Candidates were familiar with the apparatus to produce X-rays even when labelling does not seem to be a habit consistently acquired. They were less precise to explain the origins of the characteristic spectrum to score all 3 marks, coming from the removal of electrons from inner shells, electrons of higher energy occupying the space left and the consequent emission of a photon of energy equal to the difference.

HL only

Option H – Relativity

H1 [SL D1] Simultaneity and length measurement

In part (a), it was common to see incomplete answers, with the reference to the speed of light in free space usually missing. Part (b) was unnecessarily complicated by the inclusion of the term "appear". This seemed to confuse students who tended to focus on the distance from lights to Barbara, many times with inconsistent arguments. The edited version of the paper will read differently, to focus on the simultaneity issue, asking "why the lamps will not light simultaneously, according to Barbara". Part (c) was consistently answered correctly, with no signs of disadvantage in (c) (iii) for the unusual choice of axes, as candidates either scored full marks or clearly interpreted a different graph, drawing curves asymptotically approaching c, as eventually asked in H2. In (d) students seemed to be aware of the idea of symmetry being key to identify this classic paradox, and many candidates managed to score full marks.

H2 Consequences of special relativity

Even though the axes should have been reversed to be consistent with the wording, candidates did not seem to be disadvantaged and were able to score full marks with a non-zero start, a reasonably linear graph at start then asymptotic to c. Some candidates missed the first mark as the start was either too close to notice or just from the origin. In (c) a few good derivations/applications were seen. Many did not really know the signification of the velocity transformation equation and just played around with symbols and numerical values hoping for the best. A few worked backwards from the quoted relative speed of approach assuming the velocity of the antiproton to be equal to reach the original velocity of the proton and were obviously given full marks.

H3 Gravitational red-shift and black holes

Very few candidates were accurate when describing the concept of gravitational red-shift. They were usually more successful with reference to spacetime or black holes. Unfortunately, an incorrect value of 14s was quoted in the original paper and therefore both the correct answer of 12s or the incorrect approach of using 2R as the distance from the black hole leading to 14s were accepted.

Option I – Medical physics

I1 Hearing

The mechanism of hearing was well known by the few candidates who undertook this option. Even when they were unsuccessful in (b) regarding the ability to explain with accurate wording, they usually scored marks when referring to impedance matching in (c) or when calculating the power created at the eardrum by sound.

I2 X-rays and ultrasound imaging techniques

Poor definitions were read for the attenuation coefficient, with many qualitative/descriptive rather than operational definitions given. Point (b) showed mixed results, with some candidates unable to work with exponential functions. Point (c) showed good results. In (d) the missing factor of 10^3 for the density of soft human tissue did not discourage the candidates who were able to calculate the acoustic impedance and compare the difference.

I3 Radio isotopes

Many difficulties were encountered by candidates here, with much better results in (b), not always complete. This section required a clear understanding of definitions of terms apparently similar (half-life involved in both cases).

Option J – Particle physics

J1 Fundamental interactions and elementary particles

This question was usually well answered, with candidates scoring many marks showing solid knowledge. Most forgot to quote the photon as an exchange particle for the electro-weak interaction, probably due to a quick reading of the question. Even though candidates had trouble and only a few reached successfully the expected answer $\approx 4\times10^{-27}$ s in (c), many candidates were aware and gave correct arguments for the reason for exchange particles to be known as elementary particles and referred to Pauli exclusion principle when explaining why the quarks have a colour associated with them.

J2 Particle accelerators

Candidates who attempted this option seemed to be aware of the subtleties of a cyclotron and scored highly in this question. They succeeded in locating correctly the magnets and their polarity but had more trouble to show that across the gap of the “D´s” is where the alternating electric potential difference is applied. In (d) the marking scheme allowed for answers based on an ordinary cyclotron, thus frequency being the same, or for a synchrocyclotron, therefore frequency decreasing.

J3 Electrons and positrons

Candidates were familiar with the standard model and often scored high, even when very few answers were seen in (c) reaching the expected value of 10^{10} K.

Recommendations and guidance for the teaching of future candidates

Recommendations from the examination team included the following ideas:

- Candidates should be given more opportunities during the course to practice examination style problems, and be alerted about the importance of frequently wording definitions in a way that shows understanding.
- Candidates should be provided with, and given assistance with, the list of action verbs as specified in the syllabus. It is clear that many candidates do not recognise the difference between, for example, the stating and the explaining of an answer. "Show that" type of questions should also merit a strategy in order to successfully show what is being asked.
- When using a diagram to help answer a question, candidates should be encouraged to pay attention to the precision of the diagram. This is particularly true when the diagram is the requested answer and therefore its labelling becomes key to show the understanding.
- Enough time should be devoted to cover in depth the Options chosen. In some cases candidates ignored a complete question of a given option as if the topic had not been studied in detail.
- The importance in reading questions very, very attentively before starting to write should be underlined at all times.
- More emphasis should be devoted to simple but key exam techniques, as in labelling, in using keys or otherwise to identify variables stated, in attempting to structure answers according to the question given and if possible to the mark allocation.