PHYSICS TZ1 (IBNA / IBLA)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 26	27 - 36	37 - 46	47 - 57	58 - 67	68 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 25	26 - 36	37 - 45	46 - 55	56 - 64	65 - 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 graphs should be involved. However, there are exceptions. The moderator needs to determine whether or not the intention 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 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 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 - 12	13 - 15	16 - 19	20 - 23	24 - 27	28 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 9	10 - 12	13 - 14	15 - 16	17 - 18	19 - 30

General comments

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

Only a small percentage of the total number of teachers or the total number of Centres taking the examination returned G2's. For SL there were 52 responses from 380 Centres and for HL there were 30 responses from 215 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, with many of the G2's received containing favourable comments. The 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 more demanding and a small number of Centres thought that the papers were a little easier than last year's papers. 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 that returned G2's 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	*434	80	251	1367		20.36	0.19
2	405	*1566	91	69	1	73.45	0.44
3	1032	929	49	*122		5.72	0.09
4	398	*812	886	34	2	38.09	0.49
5	1852	8	20	*252		11.82	0.15

6	*1687	135	247	63		79.13	0.38
7	*747	801	294	286	4	35.04	0.58
8	*769	830	221	308	4	36.07	0.29
9	473	358	339	*957	5	44.89	0.62
10	528	*809	514	279	2	37.95	0.23
11	271	*978	489	392	2	45.87	0.50
12	178	*1517	131	303	3	71.15	0.41
13	*615	181	823	508	5	28.85	0.46
14	*1017	281	548	279	7	47.70	0.55
15	87	123	*1831	88	3	85.88	0.18
16	531	*1458	60	83		68.39	0.55
17	80	125	97	*1828	2	85.74	0.22
18	*670	952	209	297	4	31.43	0.25
19	410	*1123	501	94	4	52.67	0.45
20	599	*585	543	403	2	27.44	0.02
21	551	328	768	*481	4	22.56	0.12
22	117	321	*1383	309	2	64.87	0.39
23	82	*1159	483	403	5	54.36	0.43
24	316	134	*863	816	3	40.48	0.22
25	82	*1333	640	69	8	62.52	0.37
26	321	258	*1341	206	6	62.90	0.36
27	498	183	842	*600	9	28.14	0.28
28	75	156	611	*1289	1	60.46	0.55
29	16	119	*1913	82	2	89.73	0.18
30	130	383	*828	782	9	38.84	0.32
31	268	1245	*415	200	4	19.47	0.32
32	*1151	412	349	214	6	53.99	0.42
33	680	711	*675	63	3	31.66	0.32
34	643	194	305	*985	5	46.20	0.47
35	488	624	251	*764	5	35.83	0.28
36	*917	331	864	13	7	43.01	0.18
37	522	*876	501	226	7	41.09	0.27
38	76	225	*1658	167	6	77.77	0.42
39	201	302	592	*1028	9	48.22	0.52
40	76	797	*777	473	9	36.44	0.54

Number of candidates: 2132

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	575	383	1713	*2525	2	48.58	0.59
2	*936	288	736	3235	3	18.01	0.14
3	104	102	*2917	2073	2	56.12	0.39
4	1419	*2989	431	358	1	57.50	0.61
5	*1479	3002	396	315	6	28.45	0.32
6	*4091	506	550	51		78.70	0.26
7	2357	2562	107	*169	3	3.25	0.03
8	1180	*1328	2592	87	11	25.55	0.28
9	208	*4139	404	444	3	79.63	0.34
10	1288	1206	1202	*1485	17	28.57	0.46
11	1105	*1664	1691	721	17	32.01	0.21
12	*908	633	2404	1240	13	17.47	0.30
13	*2155	975	1345	702	21	41.46	0.44
14	858	735	*2639	954	12	50.77	0.50

15	1710	454	*2432	581	21	46.79	0.42
16	380	*2789	1120	889	20	53.66	0.38
17	1408	*1536	1103	1144	7	29.55	-0.03
18	1379	879	1827	*1098	15	21.12	0.11
19	*3607	840	323	409	19	69.39	0.41
20	427	1101	*2781	881	8	53.50	0.40
21	1238	1039	1167	*1745	9	33.57	0.45
22	468	*4090	355	280	5	78.68	0.37
23	55	486	*4279	368	10	82.32	0.33
24	683	1409	*1513	1553	40	29.11	0.17
25	1083	*1799	1618	674	24	34.61	0.36
26	2071	*2604	376	138	9	50.10	0.07
27	1786	453	797	*2137	25	41.11	0.45
28	23	2930	*1776	460	9	34.17	0.26
29	1302	1701	665	*1511	19	29.07	0.22
30	*2057	765	2311	46	19	39.57	0.15

Number of candidates: 5198

Comments on the analysis

Difficulty

The difficulty index varies from about 6% in HL and 3% in SL (relatively 'difficult' questions) to about 86% in HL and 82% 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, with one exception, had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. This was achieved in the 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.

'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. Feedback will be given only on selected questions, i.e. those that illustrate a particular issue or drew comment on the G2's.

SL and HL common questions

SL Q2 and HL Q1

As the weights of different objects are plotted against the corresponding masses of those objects, it is expected that the data plotted would yield a best fitting straight line that passed through the origin. Given that the best fitting line for the data plotted is straight but does not pass through the origin and that the uncertainty bars are small, it is indicated that the measurements show a significant systematic error but a small random error.

SL Q7 and HL Q3

There is a popular misconception that a decrease in gravitational potential energy will always be associated with an increase in kinetic energy. As the lift (elevator) descends, the speed is constant and as a result, the kinetic energy of the lift (elevator) remains constant. This does, of course, lead to an interesting opportunity for discussion related to conservation of energy.

SL Q11 and HL Q10

The intermolecular potential energy of the molecules in an ideal gas is assumed to be zero at all times i.e. constant.

SL Q13 and HL Q14

The time period is unaffected by a change in amplitude but the energy is directly proportional to the square of the amplitude. A mass oscillating on a spring is not explicitly mentioned on the syllabus but like the simple pendulum, it is an integral component of Simple Harmonic Motion (SHM).

SL Q17 and HL Q20

The responses to this question indicated that many candidates were unfamiliar with circuit electricity, a topic which is suitable for teaching from a practical perspective. An ideal voltmeter would have a very high (infinite) resistance.

SL Q18 and HL Q21

A number of candidates seemed unfamiliar with the light dependent resistor (LDR), a device listed in the new Physics guide, with the circuit symbol given in the current Data Booklet.

SL Q24 and HL Q30

Many candidates appeared unfamiliar with the unit MeV c^{-2}, despite the fact that the Physics Guide states that students should be familiar with this unit.

SL Q25 and HL Q37

While the efficiency of a modern natural gas power station would vary from text to text, any reputable text would place the figure closer to 50% than any of the other options given on the examination paper.

SL Q29 and HL Q35

Greenhouse gases allow ultraviolet to pass through them (i.e. they transmit ultraviolet light) but absorb infrared radiation.

SL Q30 and HL Q36

Three of the four responses were incorrect and only one option was possible. Any confusion between carbon capture and carbon fixation was not relevant here as it was clear that the option referring to carbon fixation was not correct.

HL Questions

Q5

The Newton's third law pair of forces in this case is the gravitational force of the Earth acting on the boy and the gravitational force of the boy acting on the Earth.

Q24

This question was challenging, given that the diagram shown is two dimensional and some candidates struggled to envisage the situation in three dimensions.

Q31

This is a topic that was new to the Physics Guide and while the more able candidates selected the correct response, a large number were unfamiliar with the knowledge required to answer this question.

Q33

A number of candidates neglected the neutrino accompanying β^+ decay. Some candidates may have over-complicated the question by considering subsequent reactions (such as pair annihilation), following the β^+ decay.

SL Questions

Q3

The correct response was selected by the majority of candidates but a large proportion assumed that on deployment of the parachute, the parachutist would travel upwards. This was presumably as a result of having seen film of parachutists, where the parachutist being filmed appears to travel upwards relative to the camera, as their parachute is deployed.

Q5

The majority of candidates selected an incorrect option, as a result of a misunderstanding of equilibrium. Candidates should have realized that during equilibrium the sum of the vertical upwards forces acting on the suitcase will be equal in magnitude to the sum of the vertical downwards forces.

Q14

Candidates are expected to recall the orders of magnitude of the wavelengths of the principal radiations in the electromagnetic spectrum, as stipulated by the Guide.

Q21

This question was a good discriminator and was answered correctly by the more able candidates. A number of candidates confused an electric field with a magnetic field. Some candidates failed to realise that charges are subject to a force as a result of magnetic fields, only when moving.

Q28

To heat the amount of water used in a typical household, a large area of photovoltaic cells would be required and this is a disadvantage. Some candidates were distracted by the inclusion of the variation of weather conditions for one of the options, however candidates should have realized that the power radiated by the Sun is unaffected by the weather conditions on Earth.

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 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.

Candidates should consult the current Physics Guide during preparation for the examination, in order to clarify the requirements for examination success.

Candidates can expect the proportion of questions covering a particular topic to be the same as the proportion of time allocated for teaching that topic, as specified in the Guide. Ample time should be apportioned to the teaching of such topics as Global Warming and the Greenhouse Effect. The common knowledge that most people have about these areas of the Guide is not always sufficient to answer questions on these topics, which are not trivial.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 21	22 - 31	32 - 41	42 - 52	53 - 62	63 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 5	6 - 11	12 - 17	18 - 21	22 - 26	27 - 30	31 - 50

42 G2's were received from SL teachers and 28 from HL teachers. This is, unfortunately a small number, but their comments indicated that about half thought that the papers were of a similar standard to the previous year. In both levels, though, a significant number of teachers (39%) found that the exam was more difficult than in 2008.

The vast majority of teachers found the papers were of an appropriate level of difficulty, and were satisfied with the syllabus coverage, clarity of wording and presentation of the paper.

10% of SL teachers thought the syllabus coverage was poor. Their comments indicated that they were surprised by the prominence given to the Greenhouse Effect in question B1.

The following comments were made regarding the background information expected of the students:

- Some students may not know that mercury is a liquid at room temperature.
- Some students were thrown by the use of the word ‘dynamo’ instead of the more familiar ‘generator’.
- Students did not know what a ‘nuclear level energy diagram’ was.
- Students did not know what a ‘binary star’ was.

There were a number of comments suggesting that teachers were rushed teaching the new syllabus and could not, therefore, cover all topics in sufficient depth.

General comments

This was the first exam testing the new syllabus and it was clear that certain topics had not been given due weight. Of particular concern was the lack of physics focus on environmental issues. It is not sufficient for students to simply use their common sense combined with a bit of background reading. The topic needs to be taught and given its allotted time.

It should also be noted that students can achieve a useful score on the paper through learning the definitions. It was clear that most students were not aware of the importance of rigorous and concise definitions. Students should learn them as part of their exam preparation.

In this 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.

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

- The greenhouse effect.
- Simple harmonic motion
- Atomic and nuclear spectra
- Simple circuit diagrams
- Explaining concepts and processes clearly.
- Describing physical phenomena in a rigorous fashion.
- Giving definitions.
- Presenting calculations in an understandable manner.

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

- Performing simple mechanistic calculations.
- Gaining relevant information from graphs.

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

A1 Data analysis

This question invited the students to make simple common sense deductions from a rather unusual graph. In such cases the students need to spend time understanding the situation. This involves careful reading. Most students overlooked the statement that the uncertainties were ‘too small to be shown on the graph’. Hence they tried to stitch together the two parts of the graph with one smooth line instead of going through each and every point shown.

A (a) displayed many misconceptions and inaccurate use of language. It should be noted that the word *proportional* **only** refers to a straight line passing through the origin. Other ways of describing a relationship are: ‘linear’, ‘*non-linear’ (*giving a *curve)* and *‘exponential’.* These words have very specific meanings and students need to know how to use them accurately.

The students who had accurately understood the situation being graphed were able to answer (b) – (c) well.

A2 Impulse

a) Most students were able to define *impulse*, but there were a number who tried to do so with undefined symbols (“Impulse is Ft”), or who used inaccurate language. It is worth noting that the word “over” should not be used in definitions (“Force over time” for impulse; or “velocity over time” for acceleration!). Instead students should use ‘multiplied by’ or ‘divided by’.

b) and c) The best students carefully explained what they were doing, using words and formulae before plunging into mathematics. A significant number of students tried to fiddle the answers to (b); examiners were not fooled – unless it was clear where the numbers came from, credit was not awarded. In (c) there is a varying force, so it was expected that the students would distinguish in their algebra between F_{av} and F_{max}.

B3 Part 1 SL and A3 HL Internal Energy

a) Note that the question asked the students for a reply *in the context* of heating a piece of copper. It is important that students are able to relate their knowledge to concrete situations. The answers should therefore contain a reference to copper.

Most students were not able to clearly say what they understood by *internal energy*. Those who did rarely referred to copper atoms. Again *heating* was well understood as the transfer of thermal energy, but to what?

(b) and (c) HL (b) was well done by the stronger students, but only the best were able to show conceptual understanding of *thermal capacity of a gas* to be able to answer (c) accurately.

(b) SL. Very few students were able to relate macroscopic quantities to what was happening at a molecular level. They had the general idea, but were not rigorous in linking the frequency of collisions of the molecules with the piston with the increase in volume.

A3 SL; A5 HL Energy degradation

This was another example where the students were being invited to apply their knowledge to a very specific situation. It is a pity that a number of students misunderstood *dynamo* for *dynamite* and had the power station exploding! The students should be familiar with the stages of electrical power generation and be able to comment accurately and specifically on energy transformations. (a) required relating the concept of *energy degradation* to the *context* of power generation. (b) needed some reference to 'coal' rather than a bland 'energy input'; and (c) invited the students to *identify the process*. This meant considering *what* is happening and *where.* So for example in A, "Energy is lost in heat" would not get credit; but "Heat rises through the chimneys by convection" would.

A4 HL (a) was done well by most students, but only the very best students realised that the peak voltage would be doubled in (b).

B1 Part 1 SL; B2 part 1 HL Greenhouse Effect

This question was very poorly done. Quite a few students even wrote comments that they had never been taught it! This is a new topic and carries considerable weight in the new syllabus, so it needs to be given adequate time and attention. Questions cannot be answered using students' common knowledge. Most students were unable to describe what was meant by a 'greenhouse gas' in (a), gave only a vague definition of 'Emissivity' and 'Albedo' and were totally thrown by the calculations that followed in c, d and e.

B1 Part 2 SL Motion of a ball falling in oil

A surprising number of students were unable to accurately define average and instantaneous speed. Only the best students were able to identify the area under the graph in (b) as the distance travelled; and whereas students were able to gain one or two marks in (c) and (d), they failed on the whole to *deduce*, *explain* or *state* with any rigour.

B2 Part 2 HL Digital storage devices

(a) and (b) were done well by the vast majority of the students; But very few were able to define *magnification* and few were able to gain full credit for (d). In such questions it would really help examiners giving ECF and part-credit if the students could be persuaded to explain their reasoning rather than just presenting a mass of numbers and calculations.

B2 Part 1 SL; B3 Part 1 HL Simple Harmonic Motion and waves

There were very few correct definitions of *SHM*. Again, this was a new topic and there was evidence that it had not been adequately covered by the students. (bi), however, presented few problems, although there was a certain amount of sloppiness in the exact positioning of the graph. (bii) invites the students to use data from the graph in a calculation. In such cases it would be usual for the students to state what data they are using. Simply stating that the energy was 0.6 J when the distance was 0.05 m would gain the student 2 marks out of the 4. But there were a fair number of fully correct answers amongst the stronger students.

(ci) was a universal disaster, despite the fact that such a question has been frequently asked before. 90% of students seem unable to analyse a wave in terms of the motion of the particles comprising the medium and relating this to the direction of travel of the wave. (cii) was, on the contrary, extremely well done suggesting that students are spending far too much time 'calculating' and far too little time 'describing and explaining'.

A similar disparity was observed in (d). Drawing the wavefronts in (ii) required a fundamental understanding of waves and was generally poorly done; Calculating the angle in (i) was, however, well done.

B2 Part 2 SL; B4 Part 1 HL Decay of Radium-226

Most SL students were able to define ‘Isotope’, but the definition of half-life was generally sloppily done. Note that it is the *nucleus* that decays, not the *sample* or *amount*. But the best definition of half-life is operational in terms of the activity of the sample. (b) SL was well done.

It was surprising to find how many students were unable to calculate the proton and neutron numbers in (c) SL and (a) HL. And very few were able to relate the spontaneous decay of Radium to its lack of stability and hence smaller binding energy.

Most students were able to gain full credit for (d) SL / (b) HL.

(c) HL was well done by the majority of students, although there were many careless mistakes in (iv) borne of untidy and muddled presentation.

B3 Part 2 SL; B1 Part 1 HL Electric fields and electric circuits

(a) was well done with students losing marks mostly through careless drawing. (b) and (c) were calculations that allowed the better students to confidently gain full credit.

(d) was a simple series circuit that confused many students. Needless to say the SL students (in (i)) were unable to define either ‘emf’ or ‘internal resistance’. Many of the students then were confused as to which formula for *Power* to use, and what values of V/I/R to substitute. This question provided clear evidence that students were uncomfortable with simple circuits.

B1 Part 2 HL Atomic and nuclear spectra

A surprising number of students were confused about the direction of the arrows, suggesting, perhaps, a conceptual misunderstanding about the origin of the atomic spectrum. Only the better students were able to complete (b) successfully.

(c) was mostly left blank, showing that the students did not know what was required of them. The question was designed to test the idea that a nucleus can exist in an excited state and in falling to its ground state emits a gamma photon. (d) was poorly done despite it being a straightforward calculation.

B3 Part 2 HL Gravitational fields and potential

In keeping with other definitions in this exam (a) was very poorly done. (bi) and (bii) were both well done, but most students did not know where to start in (biii).

B4 Part 2 HL Diffraction and resolution

(a) was partially done with most students understanding the conditions for a minimum. But they failed to identify that the destructive interference was occurring between the central ray from X with light from the top edge of the slit.

(b) was mostly accurately done, but very few students were able to gain any credit on (c) and (d).

Recommendations and guidance for the teaching of future candidates

- Require the students to learn their definitions.
- Spend equal time setting *and marking* explanatory questions as calculations.
- Insist on calculations being set out in a logical and communicative fashion.
- Give adequate time to the teaching of environmental issues.
- Read the question carefully.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 5	6 - 11	12 - 18	19 - 23	24 - 29	30 - 34	35 - 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 many 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. However, it should be realised that fewer than 25% of Centres submitted G2 forms.

Standard Level

- 32% found the paper to be of a similar standard to last year, 3% easier, 41% a little more difficult and 24% much more difficult. Overall, 76% found the paper to be of an appropriate standard and 28% thought it too difficult.
- about 43% found the syllabus coverage satisfactory, 17% thought it was poor and 40% found it good.
- about 51% found the clarity of wording satisfactory and 45% found it good with 4% finding it satisfactory.
- about 30% found the presentation satisfactory and 62% found it good whereas 8% found it poor.
- This was the first examination based on the new syllabus. The most popular options were A (Eye, sight and wave phenomena), G (Electromagnetic waves), B (Atomic,

nuclear and quantum physics) and E (Astrophysics). Students chose these four options in roughly equal numbers.

Higher Level

- about 24% found the paper to be of a similar standard to last year, 40% a little more difficult and 36% too difficult. Overall, 69% found the level of difficulty appropriate and 31% thinking it too difficult.
- about 45% found the syllabus coverage satisfactory and 48% good while 7% thought it was poor.
- about 41% found the clarity of wording satisfactory, 52% found it good and 7% found it poor.
- about 34% found the presentation satisfactory and 66% thought it was good.
- The most popular options were G (Electromagnetic waves), E (Astrophysics) and H (Relativity) in roughly equal numbers. There was a marked absence of scripts in the new options F (Communications) and J (Particle physics). Medical physics (Option I) was also underrepresented.

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

This was the first time the new syllabus was examined and it is natural that teachers stayed, mainly, with the old option topics. Option B, at SL only, while essentially being the same as the old material now includes additional material on wavefunctions and the uncertainty principle. The decision to include these new topics on this examination proved very difficult (almost disastrous) for most candidates. The idea of a wavefunction and a simple calculation based on the Heisenberg principle for momentum and position proved beyond the capabilities of the candidates. For the remaining options the areas identified by the examination team as being difficult were as follows:

- Understanding and use of the Doppler effect.
- Resolution
- Aspects of the photoelectric effect.
- As mentioned above, the meaning of a wavefunction and the application of the uncertainty principle. It was disappointing to see candidates struggling to bring in what they knew from experimental uncertainties in Topic 1 into this option. It was obvious that the majority of candidates had not practiced similar questions in the classroom.
- Nuclear energy levels and the argument for the existence of the neutrino.
- Simultaneity in relativity.
- The logarithmic nature of the absolute magnitude in astrophysics.
- Lack of mathematical ability in handling ratio problems.
- The Oppenheimer-Volkoff limit and neutron stars.
- The terms attenuation and dispersion as they apply to optical fibres.
- All aspects of the operational amplifier.

- Explanations of why the sky is blue during the day and red during a sunset.
- Once again, ray diagrams even for the simplest of all possible such diagrams as that found in this examination paper.
- Explanation of X-ray spectra and the conditions for X-ray scattering.
- Applications of relativistic mechanics to decays and collisions.
- Particle physics in general and Feynman diagrams and detectors in particular.
- 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", "discuss" and "describe".

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

Simple mathematical calculations were often done well by the majority of candidates. In fact, it was good to see that candidates were able to choose the correct formula and substitute in it correctly. Many candidates appeared well prepared and able to produce some excellent answers that showed a good understanding of the concepts, particularly in options A, E, F and G.

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

SL only

Option A – Eye, Sight and Wave phenomena

A1 Vision and resolution

Very many candidates were able to score many points on this question. Most were clear about the differences of photopic and scotopic vision and most could identify the correct colour that would be visible with varying degrees of success in their argument. For the part on resolution most could correctly calculate the diffraction angle but few could then put this together with the given data to determine the distance. Resolution remains a difficult concept for students.

A2 Polarization

Most candidates had an idea of what polarized light means but few could give precise definitions in terms of the electric field oscillating on just one plane. Many candidates knew that when the angle of incidence is the Brewster angle the refracted ray makes a right angle with the reflected ray. This allowed them to apply Snell's law to the situation to derive $n = \tan\phi$. Those who could not derive this were able to use the formula in the data booklet and obtain the correct answer.

A3 The Doppler effect

Many candidates took *c* in the question to mean the speed of light and so obtained a very large speed for the blood cells. The markscheme allowed for these answers. With hindsight it would have been preferable to use a different symbol for the speed of ultrasound in blood. There were reasonable answers as to why a range of frequency shifts would be observed.

Option B – Atomic, Quantum Physics and Nuclear Physics

B1 The photoelectric effect

The first part of the question was done reasonably well with many students making references to photons and work function and the relation of the photon energy to wavelength. This is a typical question where students must be careful to give complete answers to gain full marks. It was clear that some students had a good general idea of what was going on but were unable to put together a complete and precise answer. The calculation parts of the question were done with mixed success. The current was mostly correct and the work function less so. The third part, the quantum efficiency of the photosurface i.e. the ratio of the number of emitted electrons to the number of incident photons was poorly done.

Admittedly, it was a tough question. Many students were tricked by the last part in which the intensity of light is increased but the wavelength is also made larger than the threshold wavelength. Very few realized that the current in that case would be zero.

B2 Quantum aspects of the electron

This was a very poorly done question with clear signs that similar questions had not been attempted before. The question asked for a definition of the wavefunction and then a calculation of the momentum of the electron represented by that wavefunction. Most students had no clue about this question but those who realized that the formula $p = h/\lambda$ might be useful then had serious problems identifying the wavelength from the graph. The last part of the question that required a calculation of the uncertainty in the momentum was really badly done. Few could say anything about the uncertainty of the position as could be determined from the graph and all kinds of statements relating to Topic 1 were brought in. Teaching ideas for these new topics include: estimate of the energy of a particle confined in a linear region by using the uncertainty principle, deducing why an electron cannot be confined with a region that has the size of a typical nucleus whereas protons and neutrons can, comparing the energy levels in a hydrogen atom with those of the electron in the box, explaining why the electron in the box can never be at rest, explaining why the energy-time uncertainty relation implies that spectral lines cannot be infinitely sharp etc. Students should also see diagrams of wavefunctions and use these to determine in which cases the momentum or the position is least well defined etc.

B3 Nuclear energy levels and radioactive decay

Most were able to calculate the photon wavelength and the energy in the first two parts of the question (with some numerical mistakes in the wavelength calculation). A fair number of students knew that the existence of other particles in the decay implied that the energy would be shared and so the electron would not always have the same energy. This was an all or nothing question.

Option C – Digital technology

C1 The compact disc (CD)

This question was generally well done with the exception of the part (a) in which candidates had trouble providing correct arguments for deriving the relation between wavelength and pit depth. The calculations in part (c) caused problems for some, mainly arithmetical errors with powers of 10.

C2 The operational amplifier

This question was identical to question F4 in option F and the reader is referred to the comments in that question.

Option D – Relativity and particle physics

D1 Simultaneity

This question was similar to question H2 in option H and the reader is referred to the comments in that question. The difference is that the SL question did not ask for a definition of proper time.

D2 Relativistic kinematics

This question was identical to question H3 in option H and the reader is referred to the comments in that question.

D3 Fundamental interactions

This question was similar to question J1 in option J and the reader is advised to read the comments for that question with regard to Feynman diagrams. The SL question contained a calculation of the mass of the Z boson from knowledge of the range of the weak interaction. This was a straightforward application of a data booklet formula and was generally well done except for those cases where unit conversion created unnecessary trouble.

D4 Quarks

This question was identical to question J3 in option J. Please see comments for that question.

SL and HL combined

Option E – Astrophysics

E1 Stellar physics

This was a question examining the basic stellar quantities and the HR diagram (without explicitly providing one) and it was generally well done except for part (b) (ii) where it was required to know that the ratio of luminosities could be determined from a knowledge of the absolute magnitudes of the stars. Since two stars that *differ* by one unit of absolute magnitude have a *ratio* of luminosities of $\sqrt[5]{100}$, it follows that $\frac{L_1}{L_2} = \sqrt[5]{100}^{\,M_2 - M_1}$. In part (c) it was expected that students would realize that since the stars Achernar and Mira have the same absolute magnitude, then they must also have the same luminosity.

E2 Background radiation

Many candidates did very well on this standard question but there were sometimes vague references to Hubble's law in (c) without *explaining* the answer given. Stating that galaxies show redshift and nothing further is not enough.

E3 [HL only] Stellar evolution

Despite being a new item on the syllabus and therefore one that should have been well studied, many candidates had no idea about the Oppenheimer-Volkoff limit. It was frequently confused with the Chandrasekhar limit. Part (c) was surprisingly very well done by most candidates who correctly calculated the energy lost per unit mass and then realized that this implies that heavier stars spend less time on the main sequence. One of the great uses of the mass-luminosity relation is to predict lifetimes on the main sequence. Students must practice such estimates in the classroom.

E4 [HL only] Hubble's law

This was also well done by most candidates with few giving nonsensical answers as to why nearby galaxies may not obey Hubble's law. On the other hand there were also vague answers describing Hubble's law as "objects move with a speed proportional to distance" without bothering to specify what objects they were referring to and which distance.

Option F – Communications

F1 Amplitude modulation

This was an extremely straightforward question on the basics of AM modulation and it was very well answered by the majority that attempted it.

F2 Transmission and sampling

This other straightforward question asked for simple descriptions of the various blocks in a transmission system but answers unfortunately were vague and imprecise. In part (b) most could correctly deduce the binary number corresponding to the given sample but then failed to correctly calculate the bit rate of the transmission. It seemed that most candidates were totally unaware of such a calculation. The answers to (c) were mixed.

F3 Optical fibres

There were no clear answers as to the causes of attenuation and dispersion in optical fibres and few could handle the logarithmic calculations of power loss. Very few candidates could state (by calculation or otherwise) that since an amplifier amplifies both signal and noise the signal to noise ratio is unaffected by the amplifier.

F4 [HL only] The operational amplifier

This was a very poorly done question with students unable to score many points other than the point in (d) (i) which was really a core question on potential dividers. There was clear evidence that the students had not practiced questions with the operational amplifier and were guessing at the answers. The importance of the gain = 1 amplifier was lost by most. On the other hand, there was a handful of candidates who did very well on this question.

Option G – Electromagnetic waves

G1 The colour of the sky

The majority of candidates failed to correctly answer this basic question. Most made references to refraction, diffraction and every other wave phenomenon except the role of scattering and its dependence on wavelength.

G2 The simple magnifier

It was extremely disappointing to see so many incorrect ray diagrams of what surely must be one of the simplest ray diagrams to draw! For the calculation part of the question the majority of candidates failed to realize that since the image is virtual the distance must be entered in the formula with a negative sign. Those candidates earned points by ECF for the next bit however. In (d) most candidates were unaware of the effects of lens aberrations.

G3 Interference

Surprisingly few candidates could argue that at the central point there is no path difference from the two slits and so constructive interference takes place, leading to a maximum in the light intensity. The graph of intensity versus angle was generally well done. The markscheme allowed for those candidates who took slit diffraction into account leading to a diffraction envelope. The rest of the question (diffraction with many slits) was actually well done by very many candidates.

G4[HL only] X-rays

Candidates had enormous difficulties with this question. The first part asked for a deduction from the fact that no characteristic lines were present in the spectrum and very few had any idea as to why this was the case. The next part about the existence of a minimum wavelength was also very poorly answered. It was clear that candidates were trying to put together an answer from what they remembered from various parts of the course without much success. The calculation of the minimum wavelength was well done – again a sign that plugging into formulas works for most candidates but questions requiring a deeper understanding of what goes on does not. Part (b) was about X-ray diffraction and this had mixed results. With hindsight, the inclusion of the formula for the path difference from neighbouring atoms in the same atomic plane might have been confusing for some candidates. A few tried to use this formula in place of the Bragg formula in (ii). And perhaps the angle θ in (ii) should have been defined rather than just stated. But it must be understood that there are two separate conditions for a strong reflected/scattered beam from a crystal.

HL only

Option H Relativity

H1 The Michelson – Morley experiment

This question was well done by most candidates who knew that Michelson and Morley were trying to measure the speed of the Earth through the "ether". This famous experiment was done before Einstein introduced relativity (and so the experiment was not to verify relativity as some students said). The idea was to essentially verify the existence of an absolute frame of reference in which the laws of electromagnetism as Maxwell had stated them would be valid. In fact the idea for the experiment apparently is due to Maxwell himself who, however, did not live long enough to see its results. The only negative thing about answers to this question was the wrong speed of light according to Galilean relativity asked for in (a) (ii). Most said $c+v$ rather than $c-v$.

H2 Simultaneity

It was thought that this would be an easy question but it turned out not to be. The very many questions on simultaneity recently have obviously had students memorize answers but unfortunately none of those fitted this question. It was simply required to notice that since time interval = γ x proper time interval and here proper time interval = 0 then time interval = 0 as well. Or, since *both* observers measure a proper time interval this can happen only if the interval of time is in fact zero. It was meant to be a simple deduction of a well known fact but practically no student got full marks for this question. In the first part about the definition of proper time the majority could give the correct definition but a few still insist on the nonsensical “time for events that are at rest with respect to the clock”. An event is a point in spacetime, it cannot move or be at rest with respect to anything.

H3 Relativistic kinematics

There were good answers to this question but not to part (b). Even though the question appeared before, it was, obviously, not studied by the overwhelming majority of candidates. This is a shame because it serves well as an example of relative motion, the heart of the relativity and is a great exercise in identifying proper time intervals.

H4 [HL only] Relativistic mechanics

This proved difficult, even the first two parts that required nothing more than reading information from the graph and using (this has appeared on practically every paper in the last 10 years) $qV = \Delta E_{\mathrm{K}} = (\gamma - 1)mc^2$. But part (c) was disappointing. This is a course in physics at some depth and it cannot be expected that a question on relativistic mechanics will only involve substitution of numbers in one of the (many) relativistic mechanics formulas. The question required application of the laws of conservation of energy and momentum in order to deduce that momentum of the muon in the decay $\mathrm{K}^- \to \mu^- + \bar{\nu}$ at rest. The majority of the points, [3], went to the next part which was to find the kinetic energy of the muon given the momentum in the previous part. This substitution into the formula was not done successfully by most. Students still insist on not using relativistic units for mass, energy and momentum with disastrous results.

H5 [HL only] Black holes

This was a slightly unusual question and most parts of it were well done, definition of Schwarzschild radius and naming of gravitational redshift or time dilation. Students had trouble translating the information on frequencies into a time dilation factor. The calculation of the distance of the probe from the centre of the hole proved difficult as students were confused by the square root sign and the position of *r* in the formula.

Option I – Medical physics

This was a less popular choice among candidates compared with recent years.

I1 The ear and hearing

Parts (a) and (b) involved reading data from the graph and performing simple calculations that most candidates were able to do correctly. Most were also able to describe the role of the ossicles in hearing.

I2 Ultrasound imaging

This standard question was well answered by the majority of candidates. In part (d) many missed the factor of 2 in the time and few could give convincing descriptions of the differences of A and B scans.

I3 Radiation therapy

This was also a reasonably well answered question with gaps however in the answers to the differences in the response of normal and cancerous cells to radiation. Students seemed unaware of the difficulty of repair by cancerous cells as well as their increased vulnerability when they divide. The difference between biological and physical half-lives was not well understood but most could calculate the effective half-life from the given data.

Option J – Particle physics

Very few candidates attempted this option, which was generally not well studied. Most candidates who answered this option studied it only very superficially.

J1 Fundamental interactions

Few students could relate the law of conservation of charge to the fact that the exchange bosons in the diagrams were neutral. The Feynman diagrams were poorly done. Once a time direction is established (ignoring arguments about the relativity of time measurements by different observers), the convention is that particles move forwards in time (arrowhead in direction of increasing time) and antiparticles move backwards in time (arrowhead against direction of increasing time). The arrowhead is thus not the direction of motion but the direction of flow of negative electric charge. The syllabus clearly says that once a fundamental interaction vertex is given, the students should be able to use the vertex in order to construct a diagram for a given process. In (c) students were asked to state a reason for the less likely appearance of the process via the weak interaction. Many arguments could be given such as the smaller interaction strength of the weak interaction vertex or the appearance of a massive particle in an intermediate state. Students clearly had no idea how to answer this question. It must be stressed in teaching that a Feynman diagram is not just a picture by a mathematical expression used to calculate the probability of a process occurring and students should know what affects the value of that mathematical expression. Part (d) was a straightforward substitution in a data booklet formula but the lack of success with it indicates that students had not solved similar problems before.

J2 Particle detectors

Again, answers to this question revealed only a superficial study of this topic. Most students had no idea of how a bubble chamber works or what it measures and most could mention the irrelevant factor of cost as the advantage of proportional wire spark chambers over bubble chambers rather than the elimination of dead time in between photographs and, especially, the digital images obtained. This means that the laborious and time - consuming examination of photographs, that used to be done by humans, is now done by computer.

J3 Quarks

The “eightfold” diagram was criticized as too advanced. Perhaps, but there is hardly a resource on quarks that does not have this diagram as an example of the underlying symmetry of the light spin ½ baryons. In any case, all that was asked of the diagram was to identify the neutron, a truly elementary question that did not require any deep knowledge of the diagram itself. Few students seemed to be aware of the non-conservation of strangeness in weak interactions, such as the decay of the Ξ^-.

J4 Cosmology and strings

There were some reasonable answers to the question of why quarks were free particles in the very early universe but the calculation of the temperature caused problems with unit conversions. Recalling the standard argument for why we see matter rather than antimatter today, escaped most. There were also reasonable answers to the elementary questions on strings in (d). A common answer as to why we are not aware of the extra dimensions required by string theories was that we are 3-dimensional beings.

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, look at past papers and markschemes. At the same time it must be emphasized that not all new questions will be similar to past ones!
- 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.
- 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 of ray diagrams, as many candidates failed to use even a sharp pencil and / or a ruler.
- Enough time should be devoted to cover in depth the Options chosen. This is especially true of the new options in particular option J (Particle physics) and the new topics in Option B (Atomic, quantum and nuclear physics). There are excellent resources for Particle physics listed on the OCC.
- Students must be discouraged to study options on their own. There was evidence that this was done in this examination with options D and J. Reading popular books on relativity, particles and strings is great and is to be encouraged whenever possible but perhaps that is not enough preparation for a physics examination.