PHYSICS TZ2 (IBAP & IBAEM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 15	16 - 27	28 - 38	39 - 48	49 - 59	60 - 69	70 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 13	14 - 24	25 - 35	36 - 44	45 - 54	55 - 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

General comments

The IA moderation for the May 2011 exam session went very well. The majority of teachers appreciated the IA expectations and the moderators knew their business. This does not mean that everything was perfect; one centre marked by the old criteria, Planning A and Planning B, and one moderator's work was re-moderated. Moreover, there is growing evidence that many centres are assessing just two examples of each criterion, leaving the candidate no room for improvement.

There now exists a body of established Design prompts for teachers that most centres use again and again. The OCC and teacher training workshops may be responsible for this positive step. Physics IA is becoming like an old pair of shoes, mostly comfortable but with some wear and tear.

More and more teachers are giving candidates an IA checklist, and this has positive consequences in the achievement levels of the candidates. This is good practice and is encouraged. The checklist is simply a restatement of the criteria expectations.

The range of practical programs is as wide as ever, while the average centre has an adequate and appropriate IA program. The practical side of IB physics is indeed being addressed.

The range and suitability of the work submitted

There was ample evidence that most centres are providing comprehensive practical programs, covering a wide range of investigations. The use of ICT is now commonplace, and the majority of candidate reports are word-processed and graphs are presented using appropriate software. The required hours of practical work seem to not be a problem, and there is evidence of good syllabus coverage. Teachers are reminded that investigations can be on topics not found in the syllabus.

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

Teachers must be careful when giving the dependent variable in the design prompt, as there were a few cases where candidates were also given the independent variable. There were a number of cases where the candidate actually had two independent variables, such as changing the mass by changing the size of a ball. The teachers should have caught this major mistake and guided the candidate to a more productive approach. General guidance is allowed.

The Group 4 Project seems to be well integrated into the practical programs. Once again, a few centres provided evidence of the project but evidence is not required (only an indication of the date and hours on the 4/PSOW form).

Candidate performance against each criterion

Design

Teachers have mastered the art of giving design prompts. However in a few cases, the prompts were not appropriate, such as asking candidates to design an investigation to measure gravity or to confirm Ohm's law. Good design prompts should have candidates looking for a function between two variables, not a specific value. Candidates need to be reminded that, for a complete in Design, variables need to be defined (and vague statements like "I will measure the time" need to be clarified as to just how this will be done). Operational definitions help in the design of a method as well. This comes under the ability to control variables.

Data Collection and Processing

Candidates tend to have the most success with DCP. Raw data always has uncertainties. Moderators are looking for a brief statement as to why the candidate has given a particular value of uncertainty, and this holds for both raw and processed data. Significant figures and the least count of measuring devices are relevant here. When assessing DCP candidates are expected to have produced a graph.

There were some cases where graphs would have been relevant but candidates just made calculations. These cases cannot earn complete for DCP aspect 3. Teachers need to be aware of this expectation. Also, it is important that the candidate (and not the teacher) decides what quantities to graph and how to process the data.

Conclusion and Evaluation

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

Recommendations for the teaching of future candidates

- Candidates need a clear understanding of the IA criteria. To help with this, the teacher could give candidates a copy of a really good IA, one that earned all completes.
- Candidates need to be trained in achieving the IA aspects. Group work, teacher guidance, even peer review can help but of course in such cases the teacher would not mark the IA for an IB grade on the 4/PSOW.
- It is important that when practical work is assessed that the candidate works alone. This does not mean, however, that another candidate cannot help, say, release a ball from a given height while the candidate measures the time. All measurements must come from the candidate being assessed. Occasionally moderators find identical data sets and then they are suspicious. Also, research on the Internet or in the library is not appropriate.

Further Comments

One issue that came up several times in the May 2011 session was the matter of assessing aspect 3 of Design and the issue of sufficient data. Although teachers expect explicit reference to this in the preliminary aspects of the candidate’s report, there are cases where evidence for this can be found in what is considered the data collection and processing part of the candidate’s report. Normally, candidates mentioned repeated measurements, but if they fail to mention this but clearly take repeated measures and use the average, then we will still give the candidate credit for this (similarly, for the range and number of data points). If the data table reveals a sufficient number and an adequate range, then the expectation under Design will still be met. The moderators are giving the candidate the benefit of doubt here, and are not punishing candidates for not doing exactly what the moderator would like to see. Instead, the moderator looks for evidence to give a candidate credit.

Most teachers assessed appropriate work and awarded appropriate marks. Moreover, most candidates were working hard and producing good physics lab reports. However, teachers are reminded that design investigations are not meant to be research projects. Searching the Internet is not appropriate.

Moderators normally kept the teachers' marks, but occasionally they raised or lowered marks. If there is a trend, teachers tend to over-mark the Conclusion and Evaluation criterion. If the teachers have applied the criteria appropriately then the moderation system should support them. Moderators are not there to apply their own pet theories and practices as teachers, but to ensure that the centres 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 next sections contain the advice that physics IA moderators follow.

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 candidate the dependent variable (as long as there are a variety of independent variables for the candidate to identify). Giving the candidate the general aim of the investigation is fine if the candidate has 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 candidate follows without any modification or **all** candidates 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 already complete, for candidates to fill in. If the candidate has not recorded uncertainties in any quantitative data then the maximum given by the moderator is "partial" for aspect 1. If the candidate has been *repeatedly inconsistent* in the use of significant digits when recording data then the most a moderator can award is "partial" for aspect 1. 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 labelled axes is provided (or candidates have been told which variables to plot) or candidates follow structured questions in order to carry out data processing. For assessment under DCP aspect 3, candidates 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.

Conclusion and Evaluation

If the teacher provides structured questions to prompt candidates through the discussion, conclusion and criticism then, depending on how focused the teacher's questions are and on the quality of candidates' responses the maximum award is partial for each aspect that the candidate has been guided through. The moderator judges purely on the candidates 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 candidates.

Design

Moderators do not mark down when the independent and controlled variables have been clearly identified in the procedure but are not given as a separate list (we mark the whole report and there is no obligation to write up according to the aspect headings). Moderators do not mark down when there is a list of variables, and it is clearly apparent from the procedure which is independent and 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 on the poor suitability of the 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 candidate 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 candidate 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 candidates responding in full to an extended task are unfairly penalized more often than candidates addressing a simplistic exercise. The candidate 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 candidates do all the hard work for DCP and then lose a mark from the 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 Subject Guide and the TSM. Both SL and HL candidates 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. Candidates 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 Subject Guide, syllabus details 1.2.11).

Candidates 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 candidate has clearly attempted to consider or propagate uncertainties then moderators support the teacher's marking even if they may feel that the candidate 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 candidate has demonstrated an appreciation of uncertainty then they can earn a complete).

Moderators **do not** punish a teacher or candidate if the protocol is not the one that is taught i.e. top pan balance uncertainties have been given as ± 0.01g when teachers may feel that if the tare weighing is considered then it should be doubled. Moderation is not the time or place to establish a favoured IB protocol.

Conclusion and Evaluation

Moderators often apply the principle of "complete not meaning perfection". For example, if the candidate has identified the most sensible sources of systematic error then the moderator can support a teacher's marking 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 they will comment on the 4/IAF as to the unsuitability of the task giving full justifications. This will be provided in feedback but the moderator will not necessarily downgrade the candidate. Yes, this does mean that candidates could get high DCP marks for 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 of the limits of the data range, but it might also be an analysis that includes some physical meaning or theory, even a 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 reveals a linear and proportional relationship".

Paper one

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 14	15 - 19	20 - 23	24 - 26	27 - 30	31 - 39

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 - 28

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 for the centres taking the examination returned G2 forms. For SL there were 179 responses from 663 Centres and for HL there were 197 responses from 643 Centres. Consequently, general opinions are difficult to assess since those sending G2 forms may only be those who feel strongly in some way about the papers. The replies indicated that the May 2011 papers were generally well received, with many of the G2 forms received containing favourable comments. The vast majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level with less than 10% saying the level was too difficult.

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. Over 97% of the teachers that returned G2 forms felt that the presentation of the Papers and the clarity of wording were 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 a shaded cell.

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	524	3872*	138	200	5	81.71	0.30
2	424	4246*	17	51	1	89.60	0.20
3	3555*	247	650	274	13	75.02	0.28
4	3904*	159	537	135	4	82.38	0.21
5	648	1622	1898*	563	8	40.05	0.40
6	2470*	485	770	1003	11	52.12	0.26
7	1073	434	2694*	532	6	56.85	0.47
8	1782*	1108	1213	619	17	37.60	0.37
9	291	262	1278	2905*	3	61.30	0.39
10	535	3205	231	763	5	0	0.00
11	2190*	197	1667	671	14	46.21	0.43
12	764	357	526	3082*	10	65.03	0.47
13	858	1095	1976*	806	4	41.70	0.48
14	503	1197	2750*	260	29	59.03	0.36
15	304	360	737	3322*	16	70.10	0.40
16	495	972	1506*	1734	32	31.78	0.28
17	385	181	865	3299*	9	69.61	0.43
18	484	1964	1956*	310	25	41.27	0.22
19	1038	1016	248	2435	2	21.44	0.35
20	3335*	769	296	317	22	70.37	0.43
21	1005	203	397	3106*	28	65.54	0.39
22	193	104	602	3833*	7	80.88	0.30
23	1727	2482*	383	135	12	52.37	0.50
24	872	1107*	2493	235	32	23.36	0.33
25	310	602	3132*	675	20	66.09	0.35
26	740	591	1194	2200*	14	46.42	0.25
27	725	140	100	3766*	8	79.47	0.34
28	1038	2412*	840	428	21	50.90	0.43
29	262	2823*	1382	257	15	59.57	0.36
30	2187*	670	1541	305	36	46.15	0.45
31	407	671	1324*	2324	13	27.94	0.26
32	676	1437	2494*	112	20	52.63	0.53
33	3583*	175	797	172	12	75.61	0.24
34	83	260	925	3466*	5	73.14	0.33
35	2587*	903*	388	851	10	73.64	0.28
36	427	2869	1068*	343	32	22.54	0.14
37	219	3764*	362	372	22	79.43	0.29
38	425	225	3732*	330	27	78.75	0.31
39	2475	951*	416	868	29	20.07	0.19
40	2655*	1116	778	155	35	56.02	0.46

Number of candidates: 4739

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	487	220	164	3353*	3	79.32	0.23
2	829	2873*	157	359	9	67.69	0.39
3	542	1281	1000	1394	10	0	0.00
4	1644	1021	341	1214*	7	28.72	0.36
5	693	3404*	49	79	2	80.53	0.32
6	2751*	276	842	346	12	65.08	0.39
7	128	115	2911	1072*	1	25.36	0.31
8	645	2033	1060*	476	13	25.08	0.34
9	337	407	1557	1911*	15	45.21	0.34
10	1046*	561	1911	685	24	24.75	0.34
11	928	1913	395	977	14	0	0.00
12	1401	845	1121*	852	8	26.52	0.35
13	1975*	530	885	804	33	46.72	0.30
14	89	1325	2704*	105	4	63.97	0.45
15	695	1242	1971*	296	23	46.63	0.30
16	1036	637*	1342	1186	26	15.07	0.15
17	2849*	691	381	270	36	67.40	0.41
18	1020	469*	440	2291	7	11.10	0.14
19	1143	1408	1185*	423	68	28.03	0.23
20	1187	317	410	2284*	29	54.03	0.34
21	357	200	721	2937*	12	69.48	0.45
22	2344*	972	507	372	32	55.45	0.40
23	231	571	2592*	790	43	61.32	0.37
24	474	3162*	353	221	17	74.80	0.45
25	2819*	223	929	240	16	66.69	0.35
26	115	352	1036	2709*	15	64.09	0.37
27	1873*	776*	474	1078	26	62.67	0.33
28	510	2430	872*	382	33	20.63	0.04
29	1043*	1392	600	1116	76	24.67	0.36
30	862	1990*	367	962	46	47.08	0.40

Number of candidates: 4227

Comments on the analysis

Difficulty

The difficulty index varies from about 20% in HL and 10% in SL (relatively ‘difficult’ questions) to about 80% in both SL and HL (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 38 of the 40 HL questions and 27 of the 30 SL 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, or that the candidates were less confidant of material that is usually taught later in the course, 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 and hunches followed. In general, some of the 'distractors' should be eliminated, 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 forms.

SL and HL common questions

SL Q8 and HL Q5

Response B was a common choice in both HL and SL. One can only assume that the candidates were taking half of the total work done from 0 cm to 6.0 cm, rather than looking at the relevant area under the graph.

SL Q9 and HL Q9

Many candidates opted for C. It should be stressed that the molecules of an ideal gas are regarded as having zero potential energy. This caught out many candidates in paper two as well and clearly needs to be reiterated to the candidates.

SL Q11 and HL Q10

As many teachers noted there was no correct answer to this question as the word 'average' was omitted from the stem leading a significant number of candidates to opt for D. This question was, therefore, discounted from both SL and HL.

SL Q12 and HL Q13

Many candidates thought that kinetic energy can be negative and opted for A or B. This question clearly caused much confusion suggesting that the candidates had not previously seen graphs of kinetic energy for SHM.

SL Q18 and HL Q19

At both levels candidates opted for D with great enthusiasm! This is a case of candidates failing to distinguish between their working understanding of a concept and the way physicists define a unit. Definitions must be learnt.

SL Q25 and HL Q33

Sankey diagrams are quantitative and candidates should understand that the greatest proportion of the output from a fossil-fuelled power station is in the form of thermal energy.

SL Q27 and HL Q35

The favourite response was the correct one, A. Many teachers, however, pointed out that both A and B could be construed as correct depending upon ones understanding of ‘leads to’ in the stem. Both responses were therefore accepted as correct.

SL Q28 and HL Q36

This appeared to be an easy question with an obvious (yet wrong) response. The evidence from the discrimination index would suggest that those who gave the correct response were, perhaps, guessing. But the potential energy, *mgh,* of the water depends upon both *h* and upon its *mass*, which is itself proportional to *h*. Hence the correct answer is C.

HL Questions

Q4

Many teachers argued that, as the direction of F was not specified, both A and D could be construed as correct. However the statistics indicated that the candidates correctly identified the forces as operating in different directions.

Q8

There seemed to be some confusion amongst the candidates here with both B and C being popular options. Note that *total energy* refers to the sum of potential and kinetic energy when referring to an orbiting satellite.

Q16

This is an unusual question but certainly not beyond the syllabus specifications (11.2.2 and 11.2.4). Candidates should know that the change in frequency from a moving reflecting surface is twice that from a moving source.

Q18

Many candidates opted incorrectly for B. A simple sketch showing a critical situation for violet light alongside red light (with the maxima in the same position) will show that the red light will not be resolved. Hence C.

Q24

Many candidates chose C. Perhaps they were ‘on automatic’ and did not read the question carefully. Or perhaps they just had not learnt their definitions.

Q26

The vast majority of candidates understood that the mass decreases in a fission reaction and hence avoided options A and B. But a considerable number opted for C indicating that they had not correctly understood that if binding energy is defined as being positive then it will *increase* in a fission reaction as the mass *decreases*.

Q31

Many candidates opted for D. Perhaps they had not read the question carefully, but it should be clear the emission spectrum relates to electron energy levels and has nothing to do with *nuclear* energy levels.

Q39

Most candidates opted for A indicating that they were not distinguishing between linear and area scaling factors.

SL Questions

Q3

Many teachers stated, quite correctly, that magnetic flux was not on the SL syllabus. This question was therefore discounted.

Q4

This question had a good discrimination index despite A being the most popular response. The weaker candidates clearly took the graph at ‘face value’ and assumed the velocity was decreasing; the skill of being able to think from a graph to the physical reality is one that needs to be taught. In this case the acceleration is positive throughout the journey indicating that the velocity must be increasing.

Q7

It should be clear to the candidates that the change in velocity, i.e. the acceleration, acts towards the centre of a circle. Most candidates opted for C though, perhaps as a result of simply adding the two vectors shown in the diagram.

Q10

Candidates need to be able to distinguish between thermal capacity and *specific* heat capacity. However neither depends upon the temperature, so the candidates’ most common response of C was clearly incorrect.

Q13

The candidates clearly understood that the resonant frequency did not shift (as in C) and that the amplitude of oscillation fell very rapidly as f diverged from f_0. Hence A was correct. Many teachers, however, argued that A, B and D were all equivalent, yet differently scaled, graphs. This is not the case as the zero has been marked in on the y-axis only. Where the intersection of the axes is the true origin then both axes will be marked with a zero (as in Q12).

Q16

The least popular response was correct. The question states that the electrodes are maintained at a constant potential difference. Since the kinetic energy is gained at the expense of the potential energy, and since potential energy is given by $q\Delta V$ it should be clear that B is the correct response.

Q19

There is evidence that the candidates were guessing between responses A, B and C, knowing that the gravitational field strength must be less than 10 Nkg^{-1}. Some were perhaps confused by the change of units from km to m. But the knowledge that the gravitational field strength is the acceleration of free fall should lead directly to the correct response.

Recommendations and guidance for the teaching of future candidates

Candidates should make an attempt at every question. 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 emphasized that marks are not deducted for an incorrect response.

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.

Equal care should be taken in reading and interpreting graphs. Graphs describe the behaviour of a physical system and candidates should beware of opting immediately for the ‘obvious’ response based upon memory or appearances.

Candidates should expect questions that assess their knowledge of definitions. These should be learnt.

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 - 30	31 - 40	41 - 51	52 - 61	62 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 5	6 - 10	11 - 14	15 - 19	20 - 24	25 - 29	30 - 50

Just under 200 centres returned G2 forms for each of the HL and SL papers. The awarders urge centres to complete and return this information; it is of considerable importance for the Grade Award.

At both HL and SL an overwhelming number of respondents found the papers to be at an appropriate level of difficulty, only 10% felt that they were too difficult. This balance was also reflected in the comparison with last year's paper where about 20% of replies described this year's tests as “a little more” or “much more” difficult than in 2010 with the same percentage finding them to be “a little easier” or “much easier”.

Clarity of wording was only found to be poor by a very small minority (3 respondents at HL; 1 at SL) and the presentation of the paper was only seen as poor by 3% (HL and SL).

The statistics of the examination also agree with these perceptions by teachers. The mean mark on the components rose slightly compared to May 2010 (with similar standard deviations) and is thus moving towards the level of May 2009.

General comments

Candidates fail to give good accounts of definitions or standard bookwork and proofs. These are often poorly remembered and negligently presented.

A failure to present work carefully is generally observed by examiners across a wide range of candidate abilities. Candidates ought to work harder at communicating their physics in an examination context, and they should appreciate the need to produce clear pieces of writing and well-presented mathematical work.

Of particular concern is the continuing failure by candidates to recognize that scripts for Paper 2 are now marked on-screen. Examiners take great care to view all parts of an answer. However, only the answer box and a small area around it are presented to the examiner in the first instance. Candidates should provide clear indications that there is work written outside the boxes or on additional sheets so that examiners know to refer to it.

Candidates continue to ignore the distinctions between the allowed command terms. The demands of a “state that” and “explain” differ and candidates do not always perceive this. In mathematical questions, a “show that” or “determine” question must show a clear progression to the final answer with clear explanation throughout.

Some candidates continue to make large numbers of unit errors and significant figure errors throughout the paper. They are failing in one of the important technical areas of the subject.

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

The examining team identified the following areas:

- Data analysis issues (e.g. HL A1 (c)(iv))
- Free-body diagrams
- Movement of charge in conductors and insulators
- Equipotential surfaces
- Photoelectric effect
- Charge-coupled device calculations
- Orbital motion
- Polarization of electromagnetic waves

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

It was pleasing to see the following skills demonstrated:

- Kinematic calculations
- Ideal gas calculations

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

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

Section A

A1 [HL and SL] Data analysis question

The context for this question was straightforward.

a) **[HL only]** Very many candidates drew careful curves that incorporated all error bars. Some forced the line through the origin, but this was not penalized. A minority drew a straight line (which meant that error bars had to be ignored). A similar number drew curves that were badly presented, or that simply joined the points; such work did not receive credit.

b) **[SL part (a)]**

(i) Most were able to identify one (of several reasons) why the proportionality did not apply.

(ii) Almost all could state the value at the required point to a sensible accuracy.

c) **[SL part (b)]**

(i) Many fully understood the simple treatment of combination of errors and arrived at a correct and well-explained solution.

(ii) The error bars were usually correctly drawn, however in a small number of cases, candidates drew the same length bar for both points (usually using the value for the upper data point).

(iii) Unlike in (b) the reasons for proportionality were usually incomplete on this occasion and few candidates scored the mark. The fact that the line goes through the origin was often ignored.

(iv) This question was done poorly; the work of many candidates was very disappointing here. Only about half the candidates attempted to draw a straight line on the graph (they were told to “Use the graph”) and simply used two points on the graph without reference to a line. This gained little credit as the candidate gave no evidence at all that the chosen pair of points both lay on the line. Candidates then often compounded this by quoting a^2 as the answer to the question, failing to recognize that a square root was required.

(v) Most candidates were able to take their derived *a* (correct or not) and evaluate *k* however the unit of *k* was usually ignored.

A2 [HL and SL] Kinematics

a) The kinematic solutions seen were very pleasing with clear explanations and correct answers. However some candidates added an extra 80 m to the answer having failed to appreciate that the answer should have been “from the point where it [the stone] was thrown”, i.e. the top of the cliff.

b) Two routes to the answer were seen: a straightforward approach in which both sections of the motion are considered and totalled, and a method using a single determination of a quadratic equation from $s = ut + ½at^2$. Only about half the candidates using the second route were able to arrive at the answer without error. The first approach was well done by the majority attempting this route.

A3 [HL and SL] Internal and thermal energy

a) Few could repeat the Subject Guide definition of internal energy and relate it to that of the molecules or atoms of the substance under discussion. Understanding of thermal energy was very limited with a widespread failure to describe it in terms of transferred energy. Candidates evidently struggle with this concept.

b) **[SL only]** The distinction between internal energy of a solid and an ideal gas is not well understood by candidates. The emphasis is on the word “ideal” where no potential energy issues arise. Candidates were poor in their descriptions and explanations.

c) (b) **[HL]** and (c) **[SL]** The three sub-sections of this question led towards a determination of the final energy when iron at high temperature is added to cold water in a container. There was confusion over both units and ideas. In (i) both K and °C appeared, in (ii) many answers of 29°C were presented for the increase in the internal energy of the water, and in (iii) there were further errors in temperature units and significant errors. Only about half the candidates were able to work towards a full answer in (iii).

A4 [HL] and B1 part 2 [SL] Atomic and nuclear

a) Most knew the definition of atomic mass unit, however some simply quoted the conversion to eV c^{-2} or forgot to specify that the definition refers to an *atom* of carbon-12.

b) This was well done. Common errors noted include failures in powers of ten.

c) (i) Although the majority recognized that a proton was produced, some lost marks by suggesting that this was a hydrogen atom. Other common wrong answers included the neutron and the neutrino.

(ii) This calculation proved difficult for many. It was common to see the magnitude of the deficit mass added to the initial kinetic energy of the α-particle rather than subtracted.

d) **[SL only]**

(i) Many could correctly state what an isotope was.

(ii) Definitions of radioactive half-life were negligent with vital parts of the definition omitted; again, candidates have simply not learnt this. “Mass” of the isotope is a common answer, neglecting to consider the presence of the daughter material after the decay.

e) **[SL only]**

The graph was generally accurate but poorly drawn. Most candidates arrived at a suitable scale which was notated appropriately. The meaning of the half-life is evidently well understood even if the classic definition cannot be recalled correctly.

A5 [HL] Change of gas state

a) (i) Very many candidates were able to arrive at a value for *R* from the data given. Some however fudged their answer to arrive at the accepted value of 8.31! It was common to see a unit of Pa m^3 K^{-1} mol^{-1} which, while it is acceptable, shows that the candidate quoting it has little sense of the true meaning of *R*.

(ii) Most recognized that the gas has to be ideal for the calculation in (i) to be carried through.

b) Many were able to say that the temperature must not change (isothermal). Too many simply repeated the word “isothermal” from the stem, this gained no credit. However, only a few stated with clarity that the system needs time to allow the energy to leak out *to the surroundings*.

c) This part was done well, unlike similar questions in recent examinations. Candidates can explain the direction of energy flow and its consequences for the system in terms of the first law of thermodynamics. However, too many failed to use the first law and wrote in general terms about pressure and volume changes.

A6 [HL] Induced emf

a) Definitions of magnetic flux were mixed, ranging from complete and secure statements of the appropriate equation (with clear definition of the angle between the normal to the area and the magnetic field strength) to vague attempts that mentioned flux without a consideration of the direction between area and field direction.

b) (i) Many candidates wrongly identified either 0 ms, 10 ms or 20 ms as the point at which the flux linkage was a maximum.

(ii) Those that had a clear understanding of the relationship between emf and rate of change of flux moved quickly and unambiguously to the correct answer. Those who did not understand the physics evaluated the gradient at 4.0 ms and failed to gain credit.

(iii) The calculation of rms induced emf was well done by the vast majority of candidates.

Section B

B1 part 1 [HL] and B2 part 2 [SL] Electric charge and resistance

a) There were many misapprehensions evident in this question. A large number of candidates described copper as an insulator and the plastic and rod as conductors. Only a limited number of scripts focussed on the role of the observer’s hand in allowing electrons to flow to or from Earth.

b) (i) The drawn shapes of the lines were adequate, but directions were often missing.

(ii) The shapes of possible equipotential surfaces were very poorly constructed. Candidates in their diagrams showed a poor understanding of the relationship.

c) Many candidates were able to give a clear and accurate determination of the length of the resistor.

d) (i) There was a widespread failure to consider the temperature increase in the metal resistor with increased power dissipation and therefore the recognition that the resistance of the metal rises as a result was usually absent. Even correct explanations for this part were poorly expressed.

(ii) Most were able to show that the current was 0.82 A in this straightforward question.

(iii) Very many candidates were able to estimate the resistance accurately and with appropriate detail.

B1 part 2 [HL only] Orbital motion

a) The deduction that the kinetic energy of a satellite is equal to half the magnitude of its potential energy was poorly shown by about half the candidates. The proof can begin with the equating of centripetal and gravitational forces for the satellite with a subsequent substitution into the kinetic energy equation, but many failed to remember this. Some got most of the way but failed to show the examiner the final step with the factor ½.

b) (i) (ii) and (iii) This sequence of calculations of the total energy, the orbital speed and the energy change for the satellite was poor. This is standard work and candidates made little of it. The understanding of energy topics in gravitational fields was poorly demonstrated by the candidates throughout this question.

B2 part 1 [HL] and B2 part 1 [SL] Power production

a) Many described degraded energy either as no longer useful energy or as lost to the surroundings, but rarely both. There were two marks offered for these.

b) (i) Outlines of the processes and energy changes in a nuclear power station were very poor. Examiners had to give the benefit of the doubt on many occasions. Some candidates thought that the U-235 is burnt (in the same way as a fossil fuel) to convert the energy for the process. Only rarely were there an attempt to describe the processes consistently and many answers focussed only on the operation of the turbines.

(ii) Equally, the heat exchanger and the turbine roles were poorly described and often simply repeated material from (b)(i).

c) Many were able to give a process during which energy is degraded, but weak answers were usually vague and meaningless.

d) There were a large number of correct solutions, in that the candidates obtained the correct answer, but the method by which they arrived at these was usually poorly expressed. This setting out of a calculation is an area in which candidates continue to be weak.

e) As in part (d) it was rare to find a well-expressed solution and in the case of incorrect evaluations, examiners found it difficult to understand what the candidate was attempting to do.

B2 part 2 [HL] Charge-coupled device

a) Advantages and disadvantages of digital/analogue systems continue to be vague and unfocussed in terms of the exact nature of the question. Candidates should take greater care to focus on the area of the question. At the moment they give vague answers relating to the general area of digital communication.

b) Very few candidates described the emission of an electron-hole pair in the answer; this is an important part of the operation of the CCD. Most were only able to discuss the storage of charge as a result of the electron or hole movement in the pixel. This was a disappointing set of answers.

c) (i) and (ii) Both calculations (a deduction of the number of incident photons and the quantum efficiency) were poorly done, often with no written attempt at all. All the data for both parts were provided in the stem of the question and this may have been a factor in the weaknesses observed. Candidates cannot always be expected to be presented with the data and only the data required for a part question. The correct selection of data from a set of disparate quantities is an essential skill at this level.

B3 part 1 [HL] and B3 part 1 [SL] Power and efficiency

a) (i) Diagrams were poorly presented and ill-thought. 4 marks were assigned to this and candidates should have given much more care to it. Marks were given for appropriate descriptions, directions and lengths of the vectors. In particular, candidates should recognize that the term "acceleration" will not do for a driving *force*, and that "normal" simply implies "at 90°". The essential point about the upwards force from the surface is that it is a reaction force.

(ii) About half the candidates realized that the momentum change was zero as the velocity was constant.

b) The efficiency calculation was well done by many.

c) This question produced a mixed response varying from excellent fully-explained solutions to incoherent attempts with an incompetent inclusion of components or attempts that focussed on the change in the kinetic energy.

d) Many recognized that the way to estimate the forces was to access the net rate of change of energy and divide this by the speed, but there were two hurdles here: a determination of the correct net power and the correct speed. Very many failed at one or both of these and thus failed to provide a correct answer.

B3 part 2 [HL] Photoelectric effect

a) Marks were very poor here. It was a rare candidate who explained the answer "with reference to the Einstein model" as requested. There was only a spasmodic mention of the role of the photon or its energy. Many candidates demonstrated misunderstandings about the effect itself. Some thought that electrons arrive and photons are emitted; this was a disturbingly common misapprehension. Consequently it was difficult to award marks.

b) (i) This was commonly correct but often expressed in joule rather than eV as demanded by the question.

(ii) Again, units were often inappropriate but credit was given if the earlier unit in (b)(i) was incorrect. Many were able to manipulate Einstein's equation with ease.

c) Almost all candidates suggested that, in the photoelectric effect, when the frequency of incident light increases but the intensity remains constant, then the maximum emitted current increases. They neglected the dependence of the energy of the photon on its frequency. This is further evidence of the lack of understanding by candidates with this area of the syllabus.

d) Candidates often described what the de Broglie wavelength is, or gave an equation for it, but rarely both (as the markscheme and the mark allocation required).

B4 [HL] B1 part 1 [SL] Simple harmonic motion and wave phenomena

a) The description of amplitude was well done.

b) (i) Damping was either described in terms of energy/amplitude loss with time, or in terms of opposing forces, but rarely both.

(ii) Candidates had some uncertainty in discussing the negative sign in the SHM equation for the U-tube example. They were unclear about the terms in the equation and the relative direction of the vector quantities concerned.

(iii) About one-third of candidates were able to take the quoted equation and use it to determine the value of the time period. Many solutions petered out after a correct calculation of ω showing that the candidate could not recognize the subsequent conversion to T.

c) (i) Most candidates thought that the particle P is moving downwards or that it moves along the curve (downwards to the right).

(ii) Only strong candidates could negotiate their way through the required read-offs from the graph, the appropriate equations, and the use of ω to arrive at a correct answer.

(iii) This was a "show that" and most did not appreciate this point giving abbreviated solutions that gained little credit. Solutions that begin with the statement that "speed = distance ÷ time" need very careful treatment and explanation by the candidate if they are to be worthy of credit. The examiner expected a $v = f\lambda$ treatment and required the link between the two to be clearly shown.

(iv) Most candidates omitted this part. Of those who attempted it, about half were correct, the remainder tended to mark X at $y = 0$.

d) (i) Although there were many suggestions that the wave is reflected at one end of the string and that this interferes in some way with the incident wave to produce the standing wave these were generally weak and incomplete. Some candidates focussed entirely on the shape of the standing wave (not really the question). It was rare to see 3 marks awarded; 2 was more common.

(ii) Candidates were vague as to the nature of polarized light (a clear description in terms of the field vectors was required), as to the description of the travelling wave on the string, and as to the way in which it could be used. Many will have seen the demonstration in the laboratory but could not describe it with clarity.

(e) The vast majority of candidates calculated $90°-\theta$ (which is what emerges from the Data Booklet equation) and failed to take the final step to yield θ.

Recommendations and guidance for the teaching of future candidates

Candidates should be encouraged to commit definitions to memory and to be aware of standard pieces of mathematical theory.

The examination team continues to recommend the working through of past papers (and the associated markschemes) as a good preparation for the examination. Judging by this examination paper, there appears to be a need for candidates to have practice in selecting required and appropriate data when there are significant amounts of data provided in a question. Candidates also need practice in producing succinct solutions that fit into the boxes provided or, if this is impossible, giving clear directions as to the location of extra work.

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 - 2	3 - 5	6 - 10	11 - 14	15 - 18	19 - 22	23 - 40

General comments

The majority of candidates appeared to find the Paper accessible and there are many examples of good understanding of the material. There was no evidence that candidates were short of time to complete the examination.

The feedback from teachers on the G2 forms for SL and HL is summarized as follows. However, it should be realized that only 27% of centres submitted G2 forms.

Standard Level

- 59% found the paper to be of a similar standard to last year, 10% easier, 27% a little more difficult and 4% much more difficult. Overall, 85% found the paper to be of an appropriate standard and 15% thought it too difficult.
- Most found the syllabus coverage satisfactory or good.
- About 45% found the clarity of wording satisfactory and 55% found it good
- About 32% found the presentation satisfactory and 68% found it good.
- The most popular options were A (Sight and wave phenomena), G (Electromagnetic waves), B (Quantum physics and nuclear physics) and E (Astrophysics). Candidates chose these four options in roughly equal numbers.

Higher Level

- About 58% found the paper to be of a similar standard to last year, 28% a little more difficult and 14% much more difficult. Overall, 91% found the level of difficulty appropriate and 9% thinking it too difficult.
- Most found the syllabus coverage satisfactory or good.
- About 48% found the clarity of wording satisfactory, 49% found it good and 3% found it poor.
- About 33% found the presentation satisfactory and 67% 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 options F (Communications) and J (Particle physics).

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

As a rule candidates appear to be more comfortable with calculations involving straightforward substitution into a formula. But even here, some candidates have problems with powers of ten. Manipulation of ratios, as in previous years, continues to cause problems.

Candidates also continue to have difficulty with extended responses where they have to use their understanding of physics concepts to explain a particular phenomenon. This relates in particular to questions that start with the command terms “Explain”, “Discuss” and “Suggest”.

Apart from these general weaknesses the Senior Examining team identified the following areas with which many candidates had difficulty.

- “Speed” of a standing wave
- Resolution
- Measurement of half-life
- Nuclear energy levels and the argument for the existence of the neutrino
- Angular magnification
- Oppenheimer–Volkoff limit
- Scattering
- Operational amplifiers
- Mobile phone network
- Proper length
- Equivalence principle and Doppler shift
- Relativistic mechanics
- Michelson–Morley experiment
- Computed tomography
- Synchrotron
- Strangeness
- Deep inelastic scattering

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 correctly. A good number of candidates appeared well prepared and were able to produce some excellent answers that showed a good understanding of the concepts, particularly in options A, E, and G.

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

SL only

Option A – Sight and wave phenomena

A1 Standing waves

Most candidates were able to correctly state the relationship between λ and L for the standing wave shown and also correctly indentify two antinodes of the wave. However, very few candidates knew that the product $f\lambda$ for a standing wave relates to the speed of the two waves, the interference between which produces the standing wave.

A2 The eye and resolution

Few candidates knew how to relate intensity to power and hence made little progress with part (a) of this question. Similarly, knowledge of the Rayleigh criterion was often very sketchy or just not known. Hence the question to compare the ability of the eye to resolve images in moonlight and sunlight was usually very poorly answered.

The function of the rod and cone cells was well understood and many candidates gained full marks here.

Option B – Quantum physics and nuclear physics

B1 The photoelectric effect

This question was often well answered but candidates do need to be encouraged to set out their working clearly and unequivocally when asked to deduce a given value of a quantity.

B2 The de Broglie hypothesis.

Again, there were often good answers to this question. It was pleasing to note that many candidates were able to appreciate the role of the de Broglie wavelength in the Heisenberg uncertainty principle.

B3 Radioactive decay

The first part of the question was often done well but outlines of the measurement of the half-life of nitrogen-13 were often poor or incorrect.

Few candidates knew that the continuous nature of beta spectra and the discrete nature of gamma spectra lead to the idea of the existence of the neutrino.

Option C – Digital technology

Very few candidates attempted this Option and of these few, a number would appear to have chosen it without having any prior knowledge of the topics covered by the Option.

C1 Digital sampling

The two calculations in this question defeated most candidates.

C2 Digital camera

Descriptions of the structure of a CCD were often confused and attempts at the two calculations were often poor.

C3 The operational amplifier

This question is identical to question F5 in option F and the reader is referred to the comments in that question.

C4 Mobile phone network

This question is identical to question F2 in option F and the reader is referred to the comments in that question.

Option D – Relativity and particle physics

D1 Relativity

This question was similar to question H1 in option H and the reader is referred to the comments in that question. The difference is that the SL question did not ask about accelerating systems.

D2 The light clock

The principle of the light clock was poorly understood.

D3 Quarks

This question is identical to question J1 in option J and the reader is advised to read the comments for that question.

D4 Strangeness

This question is identical to question J3 in option J and the reader is advised to read the comments for that question.

SL and HL combined

Option E – Astrophysics

E1 Properties of a star

In (a) a common error was to state that a cluster was a collection of galaxies.

In (b) (i) the working of many candidates was difficult to follow. Candidates should be aware that a “Show that...” requires all steps in a calculation to be clearly shown.

The calculations in (b) (ii) and (iii) presented the usual problems of working with ratios, which many candidates find very hard. Some took the long way round, finding the radius of the Sun and then substituting into the Stefan Boltzmann law.

In (c) (i) the possibility of ECF in plotting the position of Betelgeuse on the HR diagram meant that many candidates got the marks for plotting wrongly calculated values from (b). However, some wrongly calculated values could not be plotted on the given scale of the diagram.

Several candidates' answers to (d) confused spectroscopic binaries with eclipsing binaries.

E2 Density of the universe

This was well answered by many candidates.

E3 [HL only] Stellar evolution

Many candidates had confused ideas about the Oppenheimer–Volkoff limit and the Chandrasekhar limit. Answers often referred to black holes and relatively few candidates distinguished between the main sequence mass and the core remnant mass.

E4 [HL only] The Hubble constant

Although often well answered a common error was to refer to stars rather than galaxies and also to omit a named method for determining galactic distances.

There were many correct answers to the calculation but there were the usual problems with handling the units of the Hubble constant.

Option F - Communications

F1 Modulation

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

F2 [HL only] Mobile phone network

This was rarely well answered. Many candidates stated that the role of the cellular exchange was to assign a range of frequencies to the base stations which is irrelevant to the question.

F3 Transmission of signals

Many candidates in answering (a) scored 2 marks but few mentioned the drop in the DC level.

Part (b) was surprisingly hard for candidates with only a minority understanding the concept of parallel/simultaneous transmission of data bits.

In (c) very few candidates calculated the correct minimum number of output bits. However the sampling frequency was often correctly found.

Most candidates correctly identified a disadvantage and advantage of using coaxial cable as opposed to a fibre optic cable.

F4 Signal power and attenuation

The calculation in (a) was frequently done correctly but (b) proved much more difficult for candidates; they found difficulty in substituting correct values for the powers in the logarithmic formula.

F5 [HL only] The operational amplifier

Part (a) was not well answered. Although a few candidates added the two connections correctly to the circuit diagram they often went on to make other connections that invalidated the circuit. The calculations were often done correctly.

Option G - Electromagnetic waves

G1 Properties of electromagnetic waves

In (a) many candidates gave properties that are common to all waves.

A common error in (b) was to confuse "edges" of the image with edges of the lens. Very few answers gained the full 3 marks.

In attempting to outline why the sky is blue a common error was to refer to absorption rather than scattering.

G2 Converging lens

The key word "ratio" was not often used in defining angular magnification. The second mark, for stating that the angles are subtended at the eye, was rarely achieved.

In (b) (i) many candidates did not recognize the negative image.

In (b) (ii) few candidates distinguished between linear and angular magnification, or appreciate that the image is at the near point rather than infinity.

In (c), almost all candidates answered that more magnification can be achieved using two lenses, not realizing that a single lens with arbitrary short focal length can achieve arbitrarily large magnification. It was rare to see the full 2 marks scored for this question.

G3 Interference of light

Most candidates knew what was meant by coherence but few answers in (b) referred to path difference. Part (c) was often well answered but one suspected that weaker candidates gained the mark for (i) by a lucky guess.

G4 [HL only] X-ray diffraction

Surprisingly, quite a few candidates failed to make any reference to energy levels in explaining why the characteristic wavelength is dependent on the target material. Of those who did, many did not distinguish between energy levels and gaps between energy levels.

The calculations were often done correctly but there were few correct answers to (c) with most candidates referring to increased precision.

HL only

Option H - Relativity

H1 Relativity

In (a) (i) a common misconception was that Carrie measured the proper length because the spaceship was in her frame of reference; the spaceship is in fact in all frames of reference. The point is that Carrie is at rest with respect to the spaceship.

Many candidates answered (b) correctly but often converted time and distances to seconds and metres respectively thereby introducing an unnecessary complication.

Part (c) was rarely answered correctly even though the question is just elementary kinematics simply a signal moving at c chasing Peter moving at 0.4c.

H1 (d) [HL only]

Full marks were usually gained by those candidates who invoked the equivalence principle and explained the frequency shift in terms of motion in a gravitational field. Explanations in terms of Doppler shift were often incomplete or incorrect.

H2 Relativistic mechanics

Quite often candidates who answered (a) incorrectly went on to answer (b) correctly. However, many candidates found the usual difficulty with units and invariably started (a) by writing down $KE = \frac{1}{2} mv^2$ and then got hopelessly lost.

H3 The Michelson-Morley experiment

The true purpose of the experiment did not seem to be well known. A common misconception was that it set out to verify special relativity rather than to measure the motion of the Earth through the aether. The reason for rotating the apparatus was also rarely understood. Hence the result, and the significance of the result, escaped many candidates.

H4 [HL only] Spacetime

This question was often well-answered. However in (c) quite a few candidates invoked the stretched rubber sheet.

Option I – Medical physics

I1 Hearing

The only part of this question that caused problems was (b)(ii). Quite a few candidates did not know how to go about calculating the number of pneumatic drills even though some of them had calculated the intensity level correctly in (b)(i).

I2 Ultrasound

Many candidates answered this question well. However, a common error in (c) was to refer to a difference in densities rather than impedances.

I3 Computed tomography

Most candidates had little understanding of the principles involved in CT.

I4. Radiation exposure

Many candidates did not really understand the difference between exposure and absorbed dose.

Although there were some complete solutions to the calculations in (b) a lot of candidates just did not know how to start.

Option J – Particle physics

Candidates from a few centres had clearly been well-prepared in this option. Generally though, the option was not popular and more often than not, answers to the questions were weak or non-existent.

J1 Quarks

Probably the best answered question in the option with many candidates gaining full credit.

J2 Synchrotron

Answers to (a) generally revealed only a superficial study of the topic. Most candidates had no idea of how a synchrotron works.

The few candidates who used a relativistic mechanics approach to (b)(i) often answered correctly; other candidates rarely made the assumption that the protons move with speeds close to that of light *in vacuo*.

In (b) (ii) many candidates recognized that the energy required to completely separate quarks increases with the separation of the quarks.

Part (c) was answered well by even the weakest candidates.

J3 Strangeness

Part (a) proved problematic but many candidates answered (b) correctly.

J4 Deep inelastic scattering

The concept of asymptotic freedom would appear to defeat most candidates. A simple description in terms of the decrease in the force between quarks as they are forced closer together is all that is required.

J5 The early universe

Both (a) and (b) were often answered correctly.

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 questions from past papers and should also be given access to markschemes.
- Candidates should be given clear and unambiguous definitions of physical quantities.
- Candidates should be provided with the list of command terms as specified in the syllabus and help with their interpretation should be given. It is clear that many candidates do not recognize the difference between, for example, “state” and “explain”.
- Candidates should be encouraged to set out their working, in a calculation, in a clear and logical manner.
- It should be emphasized to candidates that the mark allocation and space for the answer are good indications as to the length and depth of the answer required,

- Enough time should be devoted to teach the chosen Options in depth. The teaching of the Options should not be left until the end of the course.
- It should be noted that there are excellent resources for Particle physics listed on the OCC.
- Candidates must be discouraged from studying Options on their own. There was evidence that this was done in this examination with Options C, D and J. Reading popular books on relativity, particles and strings is to be encouraged but such reading should not form the basis of preparation for a physics examination.