PHYSICS TZ2 (IBAP & IBAEM)

Overall grade boundaries

Higher Level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 16	17 - 30	31 - 42	43 - 52	53 - 63	64 - 72	73 - 100

Standard Level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 26	27 - 39	40 - 48	49 - 59	60 - 68	69 - 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

IB Procedures for the May 2012 exam session

Schools are clearly aligned with the IB expectations. The cover sheet and an appropriate 4/PSOW accompanied all the IA samples, as well as candidate instructions for each investigation. A few schools included evidence of their Group 4 Project, although this is not required. The overall moderation of the May 2012 exam session ran smoothly with only a few problems. The majority of schools assessed their candidate's work in an acceptable and consistent way. Little moderation was required.

Overall, teachers knew the IA requirements, they used the appropriate forms and the sampling procedures were followed. Homemade 4/PSOW forms were for the most part acceptable, but a few schools forgot to include the boxes for the moderator and principal moderator's marks. Deadlines were met and there were very few procedural difficulties. The May 2012 exam session IA moderation ran very smoothly.

Comments unique to the May 2012 exam session

According to the 4/PSOW forms, schools are providing their candidates with rich and diverse practical programs. There is evidence of an increasing use of ICT, and the majority of candidate lab reports are word processed with computer-generated graphs. The majority of schools are also demonstrating appropriate treatment of errors and uncertainties. Unfortunately, there are a few schools that are allowing candidates to hand draw graphs, without graph paper, connecting data point to data point. There is a well-established set of teacher prompts for the Design criterion, and most candidates are doing a good job at this. Occasionally, however, teachers still require a hypothesis for Design, but candidates are not penalized for this. Also, occasionally, a teacher's prompt may contain two variables. This makes it impossible for the candidate to select an appropriate independent variable. Finally, a few schools are treating Design as a research topic, allowing candidates to use textbooks and the Internet. This is totally inappropriate as it leads to established and standard investigations, including relevant equations.

Many schools are now assigning only two investigations, each assessed by all three criteria. This is unfair to the candidate, as they have no opportunity to improve their work. This is especially worrisome when a candidate earns low marks.

A number of schools are giving their candidates an IA checklist; this is most helpful to the candidate as it often spells out the details of the IA expectations. This is good practice and is encouraged. Finally, the majority of teachers are marking their candidate's work with brief comments and IA criteria achievement levels. This candidate feedback benefits them and helps the moderators justify the teacher's mark. This practice is encouraged.

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 do not seem to 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 candidates 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 (D)

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 to be awarded 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 (DCP)

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. To be awarded a complete in 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 be awarded a 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 (CE)

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 and, for example, release a ball from a given height while the first 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.
- Lab reports should have descriptive titles, like “How The Length of a Pendulum Affects the Period” and not “The Pendulum”.
- Teachers that included comments on the candidate report or on attached sheet that stated exactly what level of achievement and why they awarded the mark often were not moderated up or down, as such detailed attention to assessment allows an appropriate level of marking and is usually justified by the teacher. This practice is encouraged.

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.

When moderators mark down—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 labeled 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.

When moderators mark down—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 the 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.

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

When moderators do not mark down—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 variable is independent and which is 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.

When moderators do not mark down—Data Collection and Processing

In a comprehensive data collection exercise possibly with several tables of data, if 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 down this minor error. 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 manufacturer'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.

When moderators do not mark down—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.

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). To earn a complete in CE (aspect 1) 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 – 17	18 - 23	24 - 26	27 - 30	31 - 33	34 - 39

Standard Level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 11	12 - 16	17 - 18	19 - 21	22 - 23	24 - 29

General comments

A proportion of questions are common to the SL and HL papers, with the additional questions in HL providing further syllabus coverage. A pleasing number of centres taking the examination returned G2's. For SL there were 146 responses from 688 centres and for HL there were 144 responses from 729 centres. This is a welcome increase on previous years, yet there are still too many schools that do not provide feedback. The replies received indicated that the May 2012 papers were generally well regarded, with many of the G2's received containing favourable comments. There were, however, a few problematical questions and these will be dealt with below. The overwhelming majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level.

With very 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 the greyed 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	3149	904	631	411	3	61.77	0.28
2	195	557	3794	547	5	74.42	0.4
3	29	412	3013	1641	3	32.19	0.25
4	3047	509	931	607	4	59.77	0.33
5	113	4751	213	19	2	93.19	0.17
6	4584	370	88	54	2	89.92	0.18
7	556	2186	647	1687	22	42.88	0.32
8	809	590	785	2913	1	57.14	0.49
9	4448	343	128	176	3	87.25	0.21
10	4043	630	222	197	6	79.31	0.28
11	522	434	1881	2258	3	44.29	0.42
12	205	422	1996	2460	15	39.15	-0.02
13	674	431	315	3675	3	72.09	0.45
14	165	3826	523	578	6	75.05	0.46
15	124	619	3105	1233	17	24.19	0.19
16	4772	86	215	24	1	93.61	0.14
17	4196	173	540	184	5	82.31	0.31
18	957	851	2300	972	18	45.12	0.42
19	772	340	3399	578	9	66.67	0.32
20	334	947	2230	1568	19	30.76	0.35

21	3042	909	513	629	5	59.67	0.6
22	55	335	4644	57	7	91.09	0.18
23	71	4715	179	130	3	92.49	0.16
24	2688	525	1602	266	17	31.42	0.24
25	363	406	161	4152	16	81.44	0.34
26	708	55	4282	49	4	83.99	0.17
27	1343	578	180	2987	10	58.59	0.52
28	3926	607	437	119	9	77.01	0.31
29	1670	669	2025	721	13	39.72	0.43
30	228	380	3607	877	6	70.75	0.52
31	2583	284	1096	1120	15	50.67	0.42
32	1119	602	406	2953	18		
33	2236	442	1634	772	14	32.05	0.32
34	395	3876	457	365	5	76.03	0.3
35	655	3980	353	89	21	78.07	0.33
36	4484	131	207	259	17	87.96	0.22
37	152	431	4310	196	9	84.54	0.21
38	98	150	4443	397	10	87.15	0.23
39	3351	352	946	427	22	65.73	0.5
40	527	3885	390	285	11	76.21	0.48

Number of candidates: 5098

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	2860	651	719	271	4	63.49	0.35
2	1874	1062	1152	413	4	41.6	0.3
3	301	750	2766	685	3	61.4	0.52
4	71	397	2768	1267	2	28.12	0.12
5	676	685	254	2877	13	63.86	0.47
6	2080	727	855	838	5	46.17	0.29
7	597	2966	723	217	2	65.84	0.37
8	253	1249	1001	1990	12		
9	679	3293	118	411	4	73.1	0.41
10	3340	472	317	373	3	74.14	0.44
11	676	3162	189	473	5	70.19	0.5
12	235	3206	909	151	4	71.17	0.41
13	226	2635	719	913	12	58.49	0.58
14	254	539	2604	1096	12	24.33	0.11
15	27	36	3932	507	3	87.28	0.19
16	2004	1169	415	906	11	44.48	0.57
17	2137	574	1586	200	8	35.21	0.27
18	130	554	3699	114	8	82.11	0.34

19	850	1892	1420	330	13	31.52	0.33
20	837	138	202	3316	12	73.61	0.35
21	115	3610	519	248	13	80.13	0.32
22	362	3177	500	457	9	70.52	0.48
23	746	109	3536	107	7	78.49	0.22
24	1664	418	228	2187	8	48.55	0.54
25	1214	2049	624	599	19	45.48	0.54
26	598	3290	489	111	17	73.03	0.29
27	2541	806	454	686	18	56.4	0.36
28	3586	213	365	319	22	79.6	0.33
29	142	1779	1460	1111	13	64.14	0.35
30	119	676	3526	174	10	78.27	0.21

Number of candidates 4505

Comments on the analysis

Difficulty

The difficulty index varies from about 24% in HL and 22% in SL (relatively 'difficult' questions) to about 93% in HL and 87% in SL (relatively 'easy' questions). About half the items were in the range 50% to 80%. This indicates that the candidates found the papers relatively easier compared to previous years so the questions 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 Q4 and HL Q3

Most candidates selected the incorrect response of C. The only difference between C and D is the relative lengths of the vertical arrows and as a component of *F* contributes to the upward force the correct answer must be D. Candidates are urged to read **all** the options given as they are required to select the best option and clearly, in this case, D is better than C.

SL Q6 and HL Q4

A few teachers commented that this question was too wordy. Yet the statistics show that most candidates understood that no work is done on a body if the force acts upon it at 90° **to its motion**, as is the case with circular motion.

SL Q10 and HL Q9

There were a few comments from teachers saying that this fell outside the requirements of the syllabus. Under item 3.2.6, however, it would be expected that candidates understand evaporation as happening from the surface of the liquid and the question was deemed fair. The overwhelming majority of the candidates gave the correct response.

SL Q14 and HL Q15

This was indeed an unusual question, although perfectly fair as a test of 4.5.1. Most candidates did not realize that a wave, in reflecting off the boundary of a less dense medium, will not undergo any phase change. Hence the pulse will not be inverted – the opposite of what happens if the reflection is off a denser medium.

SL Q23 and HL Q26

The time scale necessary to lay down the resource (uranium) is immense compared to its current rate of its consumption. For that reason it is regarded as non-renewable.

SL Q24 and HL Q27

Many candidates clearly did not understand the role of the moderator in a nuclear power station.

SL Q30 and HL Q37

The burning of fossil fuels is the main contributor of greenhouse gases to the environment. The overwhelming majority of candidates understood this and were not confused by the distractor B (deforestation).

HL Questions

Q7

Many candidates chose D, despite the use of Vm^{-1} as the units of electric field strength.

Q12

There were many comments on this question from the teachers, ranging from it being unfair to it being impossible. The physics of the situation is clear, though. The process is adiabatic, as there is no thermal energy transfer involved. It is also reversible. Hence there is no change of entropy either in the gas or the surroundings (Entropy change = $\Delta Q/T$). Alternatively it can be argued that the total entropy cannot decrease, hence, by elimination, D must be the best answer. This question is covered by the syllabus item 10.3.3 and was deemed fair.

Q18

Young's double slit experiment is not explicitly on the syllabus. But candidates are expected to study the condition for constructive interference in terms of the path difference (4.5.6). This question was deemed fair and it was pleasing to see how many candidates chose the correct response.

Q20

It is reasonable to expect higher level physics candidates to know the value of cos30°, and if they do not, they can always sketch the relevant triangle. The evidence from the statistics, though, would suggest that the majority of candidates either omitted to factor in the effect of the light passing through the first polarizer, or that they thought the intensity was reduced by the factor cos60° (rather than $\cos^2 60°$) on passing through the second polarizer.

Q24

Too many candidates, here and elsewhere, are omitting to read the axes when interpreting a graph. In this case they missed the power of ten.

Q32

This was outside the requirements of the syllabus, as many teachers observed, and the question was discounted.

Q33

From their responses it seems as if there were many candidates who were unfamiliar with the basic structure and function of the mass spectrometer.

SL Questions

Q2

B and C were commonly chosen distractors. A simple teaching strategy for such situations is to invite the candidates to consider what happens if the angle is zero. Clearly the required component also becomes zero, in which case neither B nor C can be correct.

Q7

The mass of the spring is negligible; hence it cannot have any kinetic energy, thus automatically eliminating C and D.

Q8

As many teachers pointed out the question should have referred to the tension in the string rather than the centripetal force. This clearly also confused many of the candidates and the question was discounted.

Q16

The vast majority of candidates understood, correctly, that the radius had to be larger – but many chose B, incorrectly thinking that the radius, rather than the cross-sectional area, changes proportionately with the length for two wires of common resistance.

Q17

Most candidates chose A – an intuitive guess, but an incorrect one. When X breaks then the resistance in the circuit *increases* hence Z will be dimmer. Hence only C or D could be correct. And since Y has half the battery voltage across it, rather than a third previously, it has increased in brightness.

Q19

B was the most popular choice despite it clearly representing a *force,* rather than field strength. The field strength at a point is the acceleration of a mass placed at the point, so clearly C is the correct response.

Q27

In order for fusion to occur in a reactor the temperature of the plasma needs to be in the region of 25 million degrees – almost twice as hot as the core of the Sun. Sustaining such temperatures is the main obstacle to the viable production of fusion energy. The correct response here is clearly A.

Q29

Most candidates chose the correct response, B. Many teachers commented that various sources support response D as correct. Both B and D were therefore accepted as correct.

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 emphasized 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.

Some of the responses will be debatable, but the candidate is required to select the *best* response so should read all the options before deciding. Having decided, candidates should check that all other options are less feasible or patently incorrect.

Multiple choice questions should be an integrated part of the Physics course. They are an excellent way to quickly assess the candidates' understanding and progress and provide motivating material for group discussion. For homework they have the potential to stimulate thinking without consuming too much time.

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 - 11	12 - 22	23 - 31	32 - 41	42 - 52	53 - 62	63 - 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

G2 reports were received from 161 SL teachers and from 159 HL teachers. This represents roughly one quarter of schools. Comments in the reports indicate that roughly 90% thought the levels of difficulty HL and SL papers to be appropriate. No-one found the SL paper to be too easy but about 2% thought that this applied to the HL paper.

For SL, 64% found that the level of difficulty was comparable to that of May 2011 with 12% and 15% finding the examination respectively a little easier or a little more difficult. Reports for HL are broadly similar with 56% finding the examination standard comparable to 2011 with figures for those finding the test a little easier or a little more difficult standing at 11% and 21%. Only a handful found the tests much easier or much more difficult.

There was general satisfaction with the clarity of wording and presentation of the paper with HL being regarded as either satisfactory or good by 98% of schools. The figure for SL clarity and presentation was 97%.

There was a suggestion in the written comments that the expectation that candidates should recall the surface area of a sphere and other standard volumes and areas is beyond the syllabus. However, this knowledge is clearly expected from the mathematical requirements (*Physics Guide, p. 130)*.

General comments

Examiners commented on the very poor presentation demonstrated by some candidates. Examples of very poor practice can be seen in both weak and high scoring scripts alike.

Some explanations continue to be written illegibly. If material cannot be read, it is judged incorrect. It is the responsibility of the candidate to write clearly, not that of the examiner to decipher a carelessly written script. This applies equally to words, numbers and units.

Definitions always feature in questions (they are an example of assessment objective level 1 tasks). Many candidates could not recall or suggest adequate definitions for standard terms this year; they had not learnt either the definition or the idea behind it so that they were unable to construct the appropriate form of words on the day. This is a vital skill for examinations. Candidates should learn to produce rigorous and concise definitions.

Candidates continue to present explanations that lack clarity and substance and that are evidently written in an ill-considered way. This is an area that candidates can address during their preparation work with past papers.

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

- definitions of field and field strength in electric gravitational and magnetic contexts
- tests of inverse proportionality
- the kinetic model for an ideal gas
- reasons for the stability or otherwise of an atomic nucleus
- energy levels in hydrogen atoms

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

- the mathematics of simple harmonic motion
- explanations of the Doppler effect
- kinematics

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

A1 HL & SL Data analysis

(a) Candidates were required to draw a smooth curve through a series of points. Few could do this adequately and it was rare to see a good construction. Lines were usually point-to-point, kinked in some way, or "hairy" (meaning that the candidate had a number of separate attempts to draw the line). This is evidently not a skill that all candidates possess.

There is still a widespread misconception that when the question asks for the candidate to "draw a best-fit line" this implies that the line is straight. This error is seen in work representing all the IB languages and is a simple point that traps candidates year after year.

(b) The question required a test of inverse proportionality. Examiners were expecting candidates to show that *fh* was *not* a constant for two well separated points. Only about 75% the cohort could manage this. Many tried to show that *f/h* was constant and gained little credit other than for choosing two well separated data points.

(c)(i) This part required a straight line *going through all the error bars.* Here candidates made good attempts. A common error was to fail to draw the line through the origin.

(c)(ii) It should have been a simple matter to determine the gradient of this graph with its intercept at the origin. Many candidates missed the 10^{-3} in the axis scaling and went on to omit the unit from their answer. A widespread failure to add units to a gradient calculation has been a feature of several recent paper 2 examinations.

(d) Candidates understood the dangers of extrapolation but could not express them well.

A2 HL & SL Kinematics

(a) As in the previous question, candidates appeared to understand the distinction between average and instantaneous speeds but could not express a concise or (sometimes) meaningful account. Some good answers were seen that used calculus ideas but this was not required by the examiners.

(b)(i) Candidates were required to recognize that the area under an acceleration–time graph yields the speed change of a particle. They were also expected to give a realistic number of significant figures in their answer. This trapped very many.

(b)(ii) A very large majority of candidates were able to give a good sketch of a parabola for their answer. Failing answers included a straight line through the origin and a straight line parallel to the *x*-axis.

A3 HL & SL Nuclear reactions

(a)(i) A good statement of the meaning of *nuclide* was rare. *Isotope* was much better understood and explained.

(a)(ii) The majority identified the alpha particle as the other particle in the reaction. Common errors included the neutron, various forms of neutrino, and the previously unknown alpha photon.

(b) Candidates found it difficult to explain why U-235 is more unstable than a stable isotope of lead. It was rare to see clear statements of repulsive nature of the coulomb force and that it acts between protons whereas the strong nuclear force is attractive so that the balance of proton: neutron is changed in the more stable lead. Explanations in terms of binding energy per nucleon were also accepted. Explanations couched in terms of binding energy alone were usually incorrect.

(c) **SL only** Calculations of the kinetic energy of the fission products in a nuclear reaction were carried through competently by many. Some however failed to show clearly the conversion from atomic mass units to electronvolts and lost some credit for this.

A4 HL; B1 Part 1 SL Ideal gases and specific heat capacity

(a) Many could only give one sensible assumption of the ideal gas kinetic model. It was very common to see the bald statement that there are no interatomic forces between the molecules. Candidates failed to give the proviso that this is not true during the collisions between molecules and with the walls of the container. Some candidates tried unsuccessfully to convince examiners that the empirical gas laws are in themselves assumptions.

(b)(i) Many could either define the mole of argon in terms of 12 g of carbon-12 or in terms of a correctly stated Avogadro number. Either was acceptable if clear.

(b)(ii) Although almost all were able to identify the starting point for the calculation of the specific heat capacity of argon, a very common error was to forget that the molar mass is quoted in grams not kilograms. It was therefore common to see answers that were 1000 times too small.

(c) **SL only** Explanations for the decrease in temperature of the gas on expansion were weak. The key to the explanation is that, at the molecular level, temperature is a measure of the average kinetic energy of the particles. This was often missing from the answers.

A5 HL Electric potential

(a) There were three marks for this question and most scored 1 or 2. The full definition of electric potential at a point was simply not well enough remembered. Many forgot that it is (i) the work done per unit charge on a (ii) positive (test) charge (iii) as the charge is moved from infinity to the point in question.

(b)(i) Most failed to read the question and did not realize that the question required the direction with respect to an equipotential surface. Most gave the direction relative to the diagram.

(b)(ii) This was well done by a great many, however examiners did expect to see a full substitution, it was not acceptable to leave the permittivity of free space as a symbol in this “show that” question.

(b)(iii) Even where candidates could negotiate a path through this testing question, solutions were seldom clear.

A6 HL Induced emf

It continues to be apparent that candidates find this a difficult area of the syllabus in which a clear and unshakeable understanding of the concepts is required.

(a)(i) A good number did not consider the forces acting on the electrons as instructed and therefore gained few, if any, marks. Of the remainder, some were able to discuss the forced motion of the electrons in the field and how this leads to the direction of the forces on the electrons along the rod. It was rare to see a consideration of the connection between the work done on the electrons and the emf itself.

(a) (ii) Only a few candidates could adequately explain what is meant by a rate of change of flux. The “rate of change” aspect was usually missing.

(b)(i) The calculation of magnetic field strength followed directly from a substitution into a Data Booklet equation and so was often well done apart from the inevitable power of ten errors by those who forgot the “m” in “mV”.

(b)(ii) This was very poor indeed. Many could not even state Lenz’s law adequately and could get no further. It was rare to see a good link made between the law itself and the induced current in the circuit.

B1 Part 1 HL; B2 Part 2 SL Fields and potential difference

(a) **HL only** In this part candidates were completely at a loss and could not state the meanings of the symbols in the definitions of gravitational or electric field strengths. This was a disappointing failure in what was meant to be an easy opener to the whole question.

(b) **HL** Following (a) candidates failed widely on this part too. They often had little idea which data to use (mass and charge were frequently confused) and sometimes the meaning of the constants in the equations failed them too. This was compounded by arithmetic errors to make a straightforward calculation very hard for many.

(c) **HL**; (a) **SL** However, this part was done well.

(d)(i) **HL**; (b)(i) **SL** Many have now learnt the definition of resistance that this syllabus requires. Some still continue however to provide (spurious) explanations of how resistance arises.

(b)(ii) **SL only** This was a description and many candidates were able to gain one point. But the second point for an analysis of the internal power dissipation of a cell was universally absent.

(d)(ii) **HL** It was gratifying to see a good number of consistent and successful attempts to evaluate the value of the resistance in the circuit. Those who failed could usually show that the terminal pd across the cell was 3 V but sometimes could get no further.

(d)(iii) **HL** Almost all provided an equation that can in principle lead to a calculation of power supplied, the main failure was to use incorrect data (there are three possible pd or emf values to choose) for the evaluation.

B1 Part 2 HL Thermodynamics

(a)(i) Some candidates simply repeated the information they had already supplied in A4(a) without thinking the problem through afresh. The correct ideas of low pressure and high temperature were commonly seen in scripts.

(a)(ii) Many recognized that adiabatic changes involve no energy interchange. Those who talked about no exchange of heat were penalized. The bald term "heat" is not awarded credit in this examination.

(b) This was often well done with perhaps a third of the candidates gaining full or near-full marks for recognition of the work done and a deduction from this of the sign of ΔU and W.

(c) Although about half were able to arrive at a close estimate of the work done in the cycle, sometimes explanations were brief and obscure. A string of numbers without explanation does not endear itself to the examiners who can only rarely give credit to partial solutions if it is not clear what ideas are in use or where the data is coming from.

B2 Part 1 HL; B3 Part 1 SL Solar power

(a) In an easy opener, candidates were asked for the energy changes in solar heating panels and photovoltaic cells. Sometimes the word "energy" did not appear in the answer. It is important for candidates to give a clear statement of the initial and the final energy forms expressed in scientific language.

(b) (i) and (ii) There was a wide variety of correct responses here. However some are clearly confused about the uses of solar heating panels and photovoltaics.

(c) This was done well with many correctly showing the intensity arriving from the Sun and incorporating the effect of albedo appropriately.

(d) This was not so impressive (as (c)) with many inclusions of the factor of 4 with no explanation of its origin. This was not acceptable.

(e) This was straightforward but a clear manipulation of Stefan's Law was required, ideally with a calculation with significant figures quoted to better than the quoted answer. Many failed in this respect by giving an initial substitution and nothing else. Examiners needed to see correct handling of the fourth root to award full credit.

B2 Part 2 HL Digital storage

(a) This question was, as so often, characterized by candidates saying the same thing twice. It is important in this type of question to identify two separate examples or issues in order to be sure of avoiding repetition.

(b)(i) Many candidates could not recall the capacitive or charge storing feature of a pixel and talked in general terms about response to colour or in a vague way about the photoelectric effect.

(b)(ii) It was quite common to see a discussion of the pd generation across the pixel but descriptions of the digitization were sketchy at best and often non-existent.

(c) As in other parts of the paper, the calculation and decision regarding resolution or otherwise were rarely well explained. Candidates did not use the space available to them well and it was sometimes difficult to decipher the meaning of the jumble of numbers and symbols with which the examiners were confronted. Candidates have only themselves to blame if they lose marks because their working cannot be determined.

B3 part 1 HL; B2 Part 1 SL Kinematics

(a) Linear momentum was defined accurately. Only a handful used speed rather than velocity in the definition.

(b) Newton's second law of motion appeared to be well understood but some failed to quote it in the context of momentum and gave the simpler statement in terms of *F=ma*.

(c) Many were able to show that impulse is equal to the change in momentum.

(d)(i) This was another question where candidates let themselves down very badly with their quality of explanation and presentation. Although many obtained the correct answer it was often not clear that they had fully appreciated the assumptions they were making. Examiners (for full credit) were looking for explanations typically in terms of the area under the *F-t graph* – it was rare to see this – with a full consideration of the evaluation of the isosceles triangle. Many candidates will have scored only one mark for an evaluation of the momentum change (usually by inference rather than by direct candidate statement) and one mark for the answer.

(d)(ii) This straightforward application of the kinematic equations was often well done, but some candidates failed to read the question carefully and could not identify the correct values for the speed of the truck.

(d)(iii) A common error was to evaluate $(4.8-2.3)^2$ rather than the correct $(4.2^2-2.8^2)$ in the route towards the change in kinetic energy. However, whether evaluating the correct change in kinetic energy or not, most were able to divide a value for the change by the time calculated in (ii) to determine an average rate of energy dissipation.

(d)(iv) Candidates were required to indicate the basis for the calculation (conservation of momentum) and to identify the algebraic or numerical method they were using. Although many gained full marks, once again candidates did not make it easy for examiners to establish the basis for the method. Clear statements of momentum conservation were rare and examiners were frequently expected to infer the method from an undefined set of symbols sometimes unrelated to this particular problem.

(d)(v) Most candidates gained one mark from this question by outlining the transfer in kinetic energy from first to second truck. Few recognized the role of the trucks' coupling mechanism preferring to emphasize the relatively minor and generalized roles of heat and sound dissipation in the collision. This is a frequent response in energy transfer questions such as this; candidates should consider specific examples in the question rather than making recourse to more general issues of energy transfer.

B3 Part 2 HL Resolution

(a)(i) Many recognized that the phenomenon at work is diffraction. Common incorrect responses included "Rayleigh criterion" and "interference".

(a)(ii) Candidates often failed to make clear that their answer referred to the diffraction patterns of G_1 and G_2, it was common to see candidates writing about the "first maximum of G_1" etc.

(a)(iii) Many were able to negotiate this two-step calculation with ease.

(b)(i) Descriptions of red shift in terms of the Doppler effect were well done with many high marks seen.

(b)(ii) Candidates frequently became confused in this calculation as to the meaning of the symbols quoted in the Data Booklet. Examiners often saw answers of about 3 x 10^8 m s^{-1} (or greater) with no realization by the candidate that an answer of this magnitude is implausible.

B3 Part 2 SL Fields

(a) In this part candidates were completely at a loss and could not state the meanings of the symbols in the definitions of gravitational or electric field strengths. This was a disappointing failure in what was meant to be an easy opener to the whole question.

(b)(i) The diagrams presented to examiners frequently gave a clear indication of the direction and shape of the field pattern. This was well done.

(b)(ii) Following (a) candidates failed widely on this part too. They often had little idea which data to use (mass and charge were frequently confused) and sometimes the meaning of the constants in the equations failed them too. This was compounded by arithmetic errors to make a straightforward calculation very hard for many.

B4 Part 1HL; B1 Part 2 SL Simple harmonic motion

There were a few G2 comments suggesting that this question was off-syllabus as it involved (the G2s claimed) the use of Hooke's law. In fact, *k* was defined as force per unit extension rather than as the spring constant and the whole question was accessible through knowledge based purely on SHM theory.

(a)(i) Many realized that for two marks they were required to state the relationship between acceleration and displacement and give the direction of acceleration.

(a)(ii) and (iii) The determination of the maximum acceleration and the period of oscillation were well done by many at HL. A number of routes were possible for part (iii) and all gained equal credit. Answers were patchier from SL candidates who struggled more than the HL with these tasks.

(a)(iv) **SL only** Performance was again patchy. Some of the candidates at SL do not seem at ease with the ideas and equations that lie behind SHM theory.

(b) Despite the mark allocation of 2, candidates gave one of two ideas about critical damping, either that there was no oscillation, or that the system returns to rest in the quickest possible time. It was rare to see both statements.

(c)(i) Examiners were disappointed to see that candidates could only rarely give a complete description of a longitudinal travelling wave. Descriptions were vague and rarely made the relative directions of energy propagation and particle displacement clear in an unambiguous way.

(c)(ii) Although many obtained the correct answer, the method used was often unexplained with no obvious link to the graph via a statement of frequency or period. Such non-clarity was penalized.

(c)(iii) Most candidates were unable to make progress with this question and it was frequently left blank. The problem required a recognition that a distance of 1.8 cm corresponded to a ¾ λ shift and hence a corresponding shift on the graph.

B4 Part 2 HL Energy levels in atoms

(a)(i) Although a good chain of argument was seen from many, some candidates struggled to relate the diagram to the existence of energy levels. Sometimes this resulted in a description of photon release that was accurate but irrelevant.

(a)(ii) Simple algebraic misconceptions prevented many from obtaining a correct solution. It was common to see a subtraction of the values of the two wavelengths rather than a subtraction of the reciprocals. Candidates who carried both energies through separately scored more highly than those who attempted early subtractions.

(b)(i) This question is frequently asked and, as usual, was poorly answered by those who forgot to define the meanings of the symbols they used in their answer.

(b)(ii) Most candidates who attempted this part convinced examiners that the proof was complete and accurate.

(c) This one-mark conclusion to the paper simply required appropriate substitutions into the equation of (b)(ii). Most could not carry it through correctly.

Recommendations and guidance for the teaching of future candidates

- Encourage candidates to set out calculations in a logical and presentable fashion
- Encourage candidates to write legibly and express their ideas clearly
- Encourage candidates to learn definitions as an aid to the understanding of concepts
- Advise candidates to read questions carefully and thoroughly before beginning an answer

Paper three

Component grade boundaries

Higher Level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 14	15 - 22	23 - 28	29 - 33	34 - 39	40 - 60

Standard Level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 3	4 - 7	8 - 13	14 - 17	18 - 21	22 - 25	26 - 40

General comments

These papers discriminated well. There were many very good scripts but equally many scripts showing far less complete understanding of the candidates' chosen options. There was no evidence to suggest that candidates had any problems in completing the papers in the time allowed.

At both SL and HL, question E1 (a)(iii) incorrectly gave a luminosity value in units of W m^{-2} instead of the correct unit (W). There was no evidence that this mistake unsettled candidates, however those candidates defining luminosity as power per unit area in (a)(ii) were given full credit for their answers.

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

There is considerable difference between the popularity of the different options: at SL Options A (Sight and Wave Phenomena), E (Astrophysics) and G (Electromagnetic Waves) were most commonly answered; at HL the spread of popular options was wider with E (Astrophysics), G (Electromagnetic Waves) and H (Relativity) often being chosen but I (Medical Physics) and J (Particle Physics) also being popular choices. These options frequently produced the higher marks but many candidates found serious challenges in aspects of these topics as well as in the less commonly answered topics. Topics in which candidates often found difficulties were:

- Understanding the term ‘depth of vision’
- Using the terms colour subtraction and addition accurately
- Use of geometry and the diffraction equations in the resolution problem
- Explaining why the wave theory fails to explain the photoelectric effect
- Outlining why alpha and gamma spectra give evidence for the existence of nuclear energy levels
- Use of the radioactive decay equation
- Explaining the virtual earth concept in the non-inverting operational amplifier
- Outlining the use of a cellular exchange in a mobile phone network
- Understanding why the Hubble constant has such a wide tolerance
- Explaining time-division multiplexing
- Suggesting why dark and bright fringes do not contravene energy conservation
- Deriving the thin film interference formula
- Explaining relativistic observation in terms of simultaneity
- Applying the equivalence principle
- Explaining the roles of the magnetic fields in NMR imaging
- Interpreting the Feynman diagram
- Outlining the existence of the gluon from deep inelastic scattering of electrons

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

In general questions requiring mathematics were better answered than the descriptive questions. The majority of candidates had a good understanding of the most appropriate equation to use and performed accurate substitution and subsequent calculation(s). The clear majority of candidates showed understanding of the use of sensible significant figures and appropriate units.

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

SL only

Option A –Sight and wave phenomena

A1 Vision

Few candidates were able to differentiate between depth of vision and accommodation. The best answers were given in terms of the range of forming a clear image between the near point and the far point. Most candidates understood how a secondary colour filter transmits light by addition and subtraction of the component primary colours.

A2 Standing waves

Most candidates were able to state a sensible difference between standing and progressive waves and were able to draw the quarter wavelength fundamental wave in the pipe and perform the speed of sound calculation. Many found moving on to the subsequent parts more difficult and often confused the wavelength with the length of the pipe and using a value for the wavelength of ¾ the pipe length value.

A3 Resolution

Most candidates knew the meaning of the term 'resolved' in this context but rarely recognized that, with principal maximum of one image lying on the first minimum of the other image, the angle for θ was 0.008 rad. Many candidates were able to calculate the diameter of the aperture with error carried forwards.

A4 Polarization

Mentioning that the vibrations of the **electric field** were restricted to one plane were relatively uncommon. Although many candidates showed the horizontal polarized light with a peak at 90^o and zero at 0 and 180^o, the shapes frequently did not approximate to a $\cos^2$ graph. The unpolarized graph was generally well known.

Option B – Quantum physics and nuclear physics

B1 The photoelectric effect

Nearly all candidates could write something relevant regarding photons, however few were able to outline the failings of the wave theory of light in accounting for the threshold frequency. Most answers were too vague and failed to explain that the energy of a wave is related to the amplitude and therefore given sufficient time the wave theory suggests that light of any frequency should be expected to cause electron emission from any metal surface. The photon explanation was much better appreciated. In (c)(i) many candidates tried to calculate the threshold frequency using the photoelectric equation and in (c)(ii) there was much confusion relating to the use of electron volts.

B2 Nuclear energy levels and nuclear decay

Few candidates recognized that alpha and gamma spectra are both discrete and result from nuclear processes therefore suggesting that the nucleus has discrete energy levels. Many appeared to know that the beta spectrum is continuous but too often argued for neutrinos in terms of conservation of momentum rather than the necessary difference between the maximum positron energy and that of all other positrons emitted. Those candidates prepared to use the exponential decay equation usually did well in (b) but many simply had no idea of how to use the equation with substitution of the elementary charge for '*e*' being quite common.

Option C – Digital technology

C1 Digital Devices

The differences between the CD and the LP were well understood although the purpose of the groove on the LP was rarely clearly explained. Most candidates realized that the depth of a pit is a quarter of a wavelength but for many that was the end of their argument; failing to explain how the half wavelength path difference causes destructive interference. Formal definitions of capacitance were unusual with 'ability to store charge' being most common. Few candidates were able to complete the full calculation with the reciprocal of the quantum efficiency often being used and general confusion when using picofarads and millivolts, resulting in common power of ten errors.

C2 The operational amplifier

This question was identical to question F3 in option F and the reader is referred to the comments in that question.

C3 Cellular Exchange

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 identical to question H1 in option H and the reader is referred to the comments in that question.

D2 Relativistic kinematics

This question was similar to question H2 in option H and the reader is referred to the comments in that question.

D3 the Decay of a kaon

This question was similar to question J1 in option J and the reader is referred to the comments in that question.

SL and HL combined

Option E – Astrophysics

E1 Properties of Aldebaran and galactic distances

Most candidates were able to give coherent answers regarding the differences between a constellation and a stellar cluster and could define luminosity correctly. Although virtually all candidates 'showed' that Aldebaran is 19 pc from Earth, few answers gained full marks with many examples of intermediate steps being omitted from the calculation. Few candidates stated that apparent magnitude is a **measure** of how bright a star appears **from Earth**. Failure to convert, giving d in parsec, was a common mistake in determining the absolute magnitude of Aldebaran. Although most candidates understood that Cepheid variables undergo period variation in luminosity few went on to explain how this could be used to measure distance. It was common for candidates to incorrectly state that there is a proportional relationship between the frequency or period of Cepheid variables and their luminosity. [HL only] Most candidates stated that Aldebaran's fate is that of a white dwarf and that of Betelgeuse is a neutron star, black hole or pulsar; few mentioned the intermediate phase of planetary nebular and supernova respectively. Most candidates appeared confused by how Betelgeuse could suffer the same fate as Aldebaran, failing to recognize that in the supernova stage it could lose sufficient mass to bring it under the Chandrasekhar limit.

E2 Development of the universe

Few candidates stated that a critical density universe would be one that stopped expanding but this would take infinite time. Most candidates gained some of the 3 marks for labelling and adding to the diagram. Although no penalty was applied in this instance, few candidates started their lines from a time earlier than the present time.

E3 [HL only] Hubble's law

Statements of Hubble's law were often imprecise with no reference to galaxies or an unclear meaning given for *d* in the equation. Few recognized that the wide variation of values given for the Hubble constant is due to the large uncertainties in estimation of intergalactic distances. The calculation of the distance of the galaxy from Earth was often well done.

Option F – Communications

F1 Radio transmission

Few candidates were able to unambiguously explain how the amplitude of the signal is used to change the frequency of the carrier wave. Although many candidates recognized that the side bands would have frequencies of 185 and 195 kHz, most forgot to include the carrier frequency. Most divided the allotted frequency range by the bandwidth and then correctly rounded their answers down to 13. The block diagram of the radio receiver appeared to be well-known but aerial/antenna was a common mistake for the tuning circuit; few appeared to recognize that the receiver would pick up a range of frequencies and therefore needs to be tuned to correct frequency for a station. Most candidates recognized C as a demodulator but explanations to the effect that it separates the signal from the carrier wave were often unclear.

F2 Transmission of digital signals along an optic fibre

Few answers were clear in stating that in sampling a signal there are usually (comparatively) long time intervals between signals which can be used for sending other samples sequentially. The calculation of the maximum distance between amplifiers was often well done but there was more confusion seen in answers attempting to determine the number of separate channels that could be transmitted.

F3 [HL only] Operational amplifier

Most candidates correctly calculated the gain to be 9; a minority used the inverting amplifier formula. Almost no candidate was able to explain why the very high gain of the operational amplifier means that the potential difference between the inverting and non-inverting inputs must be essentially zero for the amplifier to function correctly. The lack of significant current into the inverting input due to high gain was better understood.

F4 [HL only] Cellular exchange

This question was poorly answered with most answers amounting to no more than saying that cell phones are connected together through cellular exchange. Although candidates were asked to state one environmental issue arising from using cellular exchanges, many insisted on mentioning potential health issues.

Option G – Electromagnetic waves

G1 Nature of electromagnetic waves

Many candidates took the opportunity to draw a diagram to help their explanation but several gave no labels and drew poor diagrams. Without reference to electric and magnetic fields it is difficult to outline what is meant by electromagnetic waves. Examples of situations in which electrons may produce electromagnetic waves were often rather vague, for example 'in a laser' – which is true but needs further clarification.

G2 Astronomical telescope

Few candidates recognized that a telescope in normal adjustment forms a final image at infinity; thus the principal foci were often marked at positions other than P and point equidistant but on the other side of the eyepiece. It is impossible to award marks for freehand diagrams as was too often the case. In determining the diameter of the image of the Moon formed by the objective lens many candidates did not spot the simple geometry of the situation and θ as an opposite angle which made $\tan\theta = d/f_0$. Despite failing to determine d, many candidates went on to find the correct value for θ_E.

G3 Two-source interference

The vast majority of candidates recognized that diffraction plays a vital role in two slit interference. There was considerable confusion when sketching the variation with angle of the intensity; many incorrectly drew the variation for a single slit rather than the expected constant amplitude graph. Full marks were given to those candidates correctly showing the intensity being modulated by the single slit profile. Most candidates correctly applied the double slit formula to the calculation but forgetting to half the fringe separation as the distance between the central bright fringe and first dark fringe was common. Few candidates were convincing in their assertion that the energy lost in the dark fringes has gone into the bright fringes by superposition.

G4 [HL only] X-ray diffraction

Very few candidates scored more than a mark in attempting to explain why there is an intense beam for certain values of θ. Omission of the 2 in the X-ray diffraction equation was quite common but otherwise the calculation of *d* was generally well done

G5 [HL only] Thin-film interference

Often it seemed that candidates were going through the motion of showing the form of the thin film equation. Few explained the phase change occurred at both surfaces and therefore effectively cancelled. It was frequently unclear that candidates understood that the wavelength of the light passing into the magnesium fluoride was decreased even though most played with the numbers to make sure that they divided 640 by 1.38. Many candidates were able to do the final calculation by recognizing that for destructive interference the thickness of the film was a quarter of the wavelength in magnesium fluoride; a minority substituted m=0 into the equation.

HL only

Option H – Relativity

H1 Simultaneity

Less candidates than might be expected gained the mark for stating the postulate of special relativity related to the speed of light; missing out the crucial words 'in a vacuum' or for 'inertial' observers was commonplace. Many explanations of the observations were marred by confusion regarding who was making the observation: since the ground observer and the trees are in the same reference frame the ground observer measures the proper time interval of the strikes to be zero (as we are told) hence the arrivals must be also simultaneous for the rocket observer and all inertial observers. Additionally since, to the rocket observer, the ground observer is moving towards the light from the strike at tree L and away from the light coming from the strike at tree R but they speed of light is constant and the signals arrive simultaneously, then the strike at tree R must have occurred before that at L.

H2 Relativistic kinematics

This question was generally well answered. Most candidates correctly calculated the time for the pulse to travel distance S to D from the standpoint of the two observers (occasionally the gamma factor was inverted). Most also calculated the distance between S and D according to observer Q. A minority of candidates failed to calculate the speed of the electron. Yet again it was the description which let candidates down in resolving why both observers would agree on the number of nuclei having decayed: Q is in the same frame as reference and therefore measures the proper time interval but the laboratory observer measured the journey of the pulse to be longer than that of Q thus time dilation is required to avoid the laboratory observer from observing more than half the number of nuclei having decayed.

H3 [HL only] Mass and energy

There were many good answers to this question but some confusion with units in part (b). Most candidates correctly read off *v* as being 0.96*c*, calculated the gamma factor and the mass. Most candidates correctly found the change in kinetic energy to be 320 MeV but then failed to recognize that a particle with charge +*e* would require a potential difference of 320 V in order to achieve this energy.

H4 [HL only] Relativistic mechanics

Most candidates attempted to manipulate the equations $p = \gamma mv$ and $E = \gamma mc^2$ to produce the desired equation; not all answers were clear enough to be awarded both marks however. Many simply stated that for zero mass the speed would need to be c. This was insufficient and it was expected that $E=pc$ should be substituted into the equation for v.

H5 [HL only] Equivalence principle

Good answers to the statement of the equivalence principle were fairly common and many successfully applied this principle to freefalling box. Few were good at explaining the box accelerating outside a gravitational field as being equivalent to a stationary reference frame in a gravitational field which would therefore red-shift the light giving an observed frequency lower than f_0. Most candidates gave acceptable answers to arrival times of the signals from the pair of satellites.

Option I – Medical physics

I1 Sound intensity levels

The majority of candidates were able to define sound intensity level and to give a suitable unit. A significant minority were confused by having to work out an intensity but the calculation was generally well done. Most understood both the short-term and long-term effects of loud sound.

I2 Nuclear magnetic resonance

Few candidates showed that they really understood the purpose of the strong constant magnetic field and the gradient field. Many talked about protons radiating without the stimulus of the applied rf signal.

I3 X-ray absorption

Most candidates drew an appropriate curve which passed through the key points and calculated the correct value for the attenuation coefficient. Arguments relating to comparing the attenuation coefficients were of variable quality but many followed a logical argument by recognizing that a curve falling off faster had a larger (negative) exponent therefore, for a given value of x, μ would be larger too.

I4 Radioisotopes used in medicine

Although it seemed that the term effective half-life was understood most candidates failed to mention the meaning of half-life and therefore limited themselves to only one of the two marks available here. Many candidates went on to gain most of the marks for the calculation. Most candidates made sensible comments regarding the reduced risk of using the nuclide with the shorter physical half-life. The majority of candidates recognized that lead shielding was a good form of protection for medical workers; few also mentioned that safety could also be achieved by physical distance.

Option J – Particle physics

J1 Decay of a kaon

Many recognized that a boson is a particle with spin of an integral value; few explain that it could be 0 or 1 because it comprises of a two quarks with spins of ±½. Significant numbers of candidates failed to identify X and Y (the arrow giving the charge direction and thus with the anti-strange quark being positive it moves in the opposite direction to time and is therefore X; the anti-muon also being positive again moves against the direction of time and is thus Y). Most recognized that the conservation of strangeness is being violated and this can only happen with a weak interaction (or else that neutrinos are only involved in weak interactions). Most candidates recognized that the exchange particle must be a W or Z boson but it was fairly random which was chosen (with several citing both) and there was only a slight majority in favour of positive charge. Most candidates correctly calculated the range but few were precise enough to say that **muon** lepton number needs to be conserved.

J2 Linear accelerators

Most candidates failed to make it clear that the protons are accelerated by the electric field in between the drift tubes and travel with constant velocities within them. Most recognized that as the protons have accelerated in between the drift tubes they will be travelling faster inside each consecutive tube thus maintaining a constant frequency and period, each successive tube needs to be longer than the previous one; however phrasing this clearly was uncommon. The proton-pion collision was generally quite well done; most recognized the appropriate conservation rules and made a good attempt at using the available energy equation (confusion between the target particle and accelerated particle was fairly common, however). In (c) the de Broglie wavelength was usually correctly calculated (although power of 10 errors were fairly common) and many recognized that this was the determining factor in resolution and that with the nucleus being larger than this wavelength the nucleons could be resolved but the quarks, being smaller, could not. Few candidates were able to outline that the momenta of quarks measured in deep inelastic scattering was greater than expected, implying other (massless) particles being present.

J3 Early universe and Higgs boson

This was relatively well done by those candidates recognizing that the energy = $\frac{3}{2}kT$ gave a temperature of 1.4 x 10^{12} K; most correctly took the logarithm to obtain log*t* and *t*. Although most recognized that the Higgs boson may be responsible for giving mass to particles, few said that this was the only undiscovered particle of the standard model or that failure to discover it would necessitate a change in this model.

Recommendations and guidance for the teaching of future candidates:

- Candidates would be well advised to consider the command terms in examinations – in particular ‘determine’ will usually require a more detailed answer than ‘calculate’

- Labelling diagrams will often help gain marks as it helps to make clear what the candidate is trying to show or explain
- Presenting the stages in calculations rather than just a final answer will gain marks if there is an error carried through in a correct method
- Simultaneity in Relativity is, still, not at all understood
- NMR is not well understood
- The evidence for gluons is not well understood