International Baccalaureate
Baccalauréat International
Bachillerato Internacional

PHYSICS TZ1 (IBNA / IBLA)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 15	16 - 27	28 - 38	39 - 49	50 - 59	60 - 70	71 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 25	26 - 36	37 - 46	47 - 56	57 - 65	66 - 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 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.

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 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 11	12 - 15	16 - 17	18 - 20	21 - 22	23 - 30

General comments

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

An increased percentage of the total number of teachers or the total number of centres taking the examination returned G2 forms compared with May 2010. For SL there were 101 responses from 448 centres and for HL there were 48 responses from 258 centres. Even given this increase, general opinions are difficult to assess since those sending G2 forms may only be those who feel strongly about the Papers. The replies indicated that the May 2011 papers were generally well received, with many of the G2 forms containing favourable comments. The great majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level. Most respondents thought that both Papers were of a similar demand to last year's papers, while a significant minority of Centres thought that the papers were a little easier than last year's papers.

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. Virtually all teachers that returned G2 forms felt that the presentation of the Papers was either satisfactory or good.

Statistical analysis

The overall performance of candidates and the performance on individual questions are illustrated in the statistical analysis of responses. These data are given in the grids below. The numbers in the columns A-D and Blank are the numbers of candidates choosing the labelled option or leaving the answer blank.

The question key (correct option) is indicated by an asterisk (*). The *difficulty index* (perhaps better called facility index) is the percentage of candidates that gave the correct response (the key).

A high index thus indicates an easy question. The *discrimination index* is a measure of how well the question discriminated between the candidates of different abilities. In general, a higher discrimination index indicates that a greater proportion of the more able candidates correctly identified the key compared with the weaker candidates. This may not, however, be the case where the difficulty index is either high or low.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	747	743	324	893*	2	32.96	0.45
2	29	74	2288*	317	1	84.46	0.29
3	473	225	1755*	254	2	64.78	0.50
4	1504*	247	159	794	5	55.52	0.43
5	180	1719*	443	363	4	63.46	0.46
6	1213*	376	216	901	3	44.78	0.42
7	1845*	368	444	41	11	68.11	0.44
8	359	1619*	304	426	1	59.76	0.36
9	139	480	1491*	597	2	55.04	0.46
10	274	471	414	1550*		57.22	0.45
11	932	739	987*	48	3	36.43	0.48
12	453	396	1353*	506	1	49.94	0.44
13	250	481	1135*	839*	4	72.87	0.25
14	207	98	2206*	196	2	81.43	0.25
15	1503*	549	467	187	3	55.48	0.56
16	509	681	1238*	277	4	45.70	0.45
17	518	1688*	434	69		62.31	0.56
18	200	246	1184	1078*	1	39.79	0.22
19	706*	1452	133	416	2	26.06	0.30
20	1105*	307	890	406	1	40.79	0.53
21	856	1179*	427	247		43.52	0.33
22	1040*	769	361	537	2	38.39	0.19
23	57	154	181	2317*		85.53	0.29
24	192	2056*	169	291	1	75.90	0.32
25	1181	518	902*	104	4	33.30	0.50
26	148	2344*	128	86	3	86.53	0.31
27	1074*	273	1184	175	3	39.65	0.37
28	1316*	518	157	709	9	48.58	0.47
29	488	310	855*	1048	8	31.56	0.34
30	215	1422	1003*	66	3	37.02	0.07
31	887	1067*	521	213	21	39.39	0.23
32	354	681*	1121	548	5	25.14	0.27
33	113	2389*	132	71	4	88.19	0.21
34	117	75	1053	1458*	6	53.82	0.35
35	716	421	54	1514*	4	55.89	0.65
36	1260*	331	824	286	8	46.51	0.53
37	232	83	136	2254*	4	83.20	0.22
38	106	1967*	441	188	7	72.61	0.28
39	735	183	552	1232*	7	45.48	0.58
40	235	247	1914*	306	7	70.65	0.17

Number of candidates: 2491

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1331	1952*	1107	1139	3	35.29	0.25
2	2314	1225	789	1191*	13	21.53	0.37
3	1317	636	2647*	932		47.85	0.50
4	99	270	4182*	978	3	75.60	0.40
5	2951	1495*	267	818	1	27.02	0.24
6	1139*	1726	1816	845	6	20.59	0.22
7	80	160	519	4770*	3	86.23	0.26
8	314	316	4680*	217	5	84.60	0.32
9	709	2907*	1124	777	15	52.55	0.40
10	2002*	890	527	2105	8	36.19	0.37
11	2788*	599	1195	934	16	50.40	0.45
12	2981*	1160	1135	232	24	53.89	0.47
13	1967	1744	1711*	105	5	30.93	0.43
14	677	928	1221	2702*	4	48.84	0.36
15	653	229	525	4122*	3	74.51	0.40
16	3888*	337	410	892	5	70.28	0.34
17	1588	2492*	1158	286	8	45.05	0.51
18	459	672	4152*	238	11	75.05	0.32
19	1171	2393*	425	1529	14	43.26	0.08
20	575	376	3015*	1555	11	54.50	0.64
21	1436	2010*	1343	727	16	36.33	0.26
22	370	4432*	451	275	4	80.12	0.42
23	4616*	690	106	110	10	83.44	0.32
24	1841*	780	2551	341	19	33.28	0.24
25	2022*	888	1770	843	9	36.55	0.41
26	572	279	1007	3661*	13	66.18	0.42
27	2299	962	128	2125*	18	38.41	0.67
28	402	316	4433*	345	36	80.13	0.11
29	400	180	2057	2878*	17	52.02	0.39
30	1956	563	2794*	187	32	50.51	0.48

Number of candidates: 5532

Comments on the analysis

Difficulty

The difficulty index varies from about 25% in HL and 21% in SL (relatively 'difficult' questions) to about 88% in HL and 86% in SL (relatively 'easy' questions). The majority of items were in the range 30% to 70%. Thus, the Papers provided ample opportunity for all candidates to gain some credit and, at the same time, gave an adequate spread of marks.

Discrimination

All questions had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. This was achieved in all but one question on each paper. 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 each Paper, the number of blank responses was relatively consistent throughout the whole paper. There was no evidence that candidates did not have sufficient time to complete their responses, aligning with comments from teachers to this effect. At HL only questions 7 and 31 produced more than single figures of blank responses. At SL 15 questions yielded between 10 and 36 'blanks' with the majority being in the low teens. 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 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 Q2 and HL Q1

Although it may not be clear what the precision of the ammeter is the greatest precision would be 0.01 A so the % uncertainty in I would be 10% therefore the % uncertainty in I^2 would be 20%. Any other ammeter precision will give an I^2 value of greater than 20%. Thus D is the only answer possible.

SL Q4 and HL Q2

Although statistically it seems that the candidates interpreted this question as intended, it is a fair comment (from the G2 forms) that it makes little sense to talk about the average speed at 25 seconds – brevity dominated here and it would have been more appropriate to compare the instantaneous speed after 25 seconds with the average speed over the first 25 seconds.

SL Q9 and HL Q5

The use of the word 'normal' to direction of motion was questioned here but the examiners felt that this was totally appropriate in the context of this circular motion question. Normal to the direction of motion means centripetal and there clearly needs to be a centripetal force to allow circular motion but there will be no increase in the direction of motion, giving B as the key (and most common response).

SL Q13 and HL Q11

The direction of vibration is perpendicular to the direction of propagation restricting A and C as possible contenders. With the wave travelling from left to right P must lead the particle at the crest (which can only move downwards at a later instant) thus P moves in direction C.

SL Q19 and HL Q18

The LDR is one of the named sensors to be used in a potential divider circuit so candidates were expected to recognize its symbol (in Data Booklet) and know that increasing light intensity reduces the LDR resistance. Thus with an increase in light intensity the potential difference across the fixed resistor will increase (as shown on the voltmeter).

SL Q21 and HL Q21

A variety of rules could be used here but the key things to remember are that the electron is negatively charged and that the magnetic field lines go away from the north magnetic pole.

SL Q24 and HL Q27

The high mass of the alpha particle means that it interacts strongly with matter and ionizes gases very effectively, thus giving the alpha a short range. Gamma-rays have such a large range because their photons interact very little with matter. Gamma-rays and X-rays of the same energy will, of course, be identical except for the manner in which they are produced.

SL Q27 and HL Q35

The most popular response at SL suggested that many SL candidates thought that the power produced by a wind turbine is proportional to the wind speed; at HL most candidates recognized that the power is proportional to the cube of the speed.

SL Q29 and HL Q34

The question is about the energy change in the generator, nothing else; thus the input to the generator is its (rotational) kinetic energy and the output is electrical energy.

HL Questions

Q12

Although the angles of incidence and refraction were not marked, it was a simple process to calculate them and then use the usual Snell's law relation.

Q13

The examiners accepted comments that pipes closed at one end conventionally produce odd harmonics and in this context the term 'second harmonic' could be confusing. Having any harmonic with a frequency of less than fundamental makes no sense so options A and B should have been discounted. Thus candidates answering either option C or D were credited with gaining a mark here. The word 'second' should have been replaced by 'next highest' to avoid any confusion.

Q19

Equating the induced emf to the rate of change of flux linkage comes directly from the usual statement of Faraday's law. This would only be true for the rate of change of magnetic flux for a coil of one turn – not a coil with a 'large number of turns'. N in the equation is very important.

Q22

For an electron to move in a circular path in an electric field the lines of electric flux must be perpendicular to the direction of motion at all times and can only be A.

Q31

Candidates are expected to know the order of magnitude of the nucleus and then use Heisenberg's position/momentum relationship to estimate the uncertainty in the momentum. The key was the most common answer given.

SL Questions

Q1

It is apparent from the very even spread of answers that many candidates are unsure of the difference between fundamental units and derived units.

Q5

This straightforward calculation using $F=ma$ gave candidates more trouble than anticipated. Many appeared to be confused between the driving force and the net (resultant) force.

Q6

The distinction between speed and velocity was not recognized by many candidates opting for B and C rather than the key A.

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 try to eliminate those responses which seem most unlikely and thus increase their probability of guessing the right answer. It should be emphasized that marks are not deducted for an incorrect response.
- There is some evidence that candidates complete this paper too quickly and fail to take in the whole stem. They should be encouraged to read the whole question through carefully to make sure that they have not overlooked any key information.
- The Data Booklet is a very useful resource that can be used to give units as well as numerical values of constants. It is essential that candidates are aware of what the symbols in the equations actually represent.
- The relative number of questions set in this paper mirrors the time that is expected to be devoted to teaching each topic. Candidates cannot expect to be able to leave whole topics out during revision – there will be questions on each of the topics.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 8	9 - 17	18 - 27	28 - 38	39 - 48	49 - 59	60 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 8	9 - 12	13 - 17	18 - 22	23 - 27	28 - 50

The number of G2 forms received from SL teachers was 101 and 48 from HL teachers. At SL, 71% of the forms indicated that the level of difficulty was appropriate and the rest thought the paper was too difficult. At HL, 73% thought the level of difficulty was appropriate and the rest thought it was too difficult.

Compared with last year's paper, 44% of the teachers who responded found the SL paper to be of a similar standard, 33% found it a little more difficult and 6% thought the paper was much more difficult. 5% thought it was a bit easier. The clarity of wording was found to be satisfactory by 53% of the teachers and good by 42%. The presentation was found to be satisfactory by 46% and good by 53%. At HL, of the teachers who responded, 44% found the paper to be of the same level of difficulty as last year, 27% a little more difficult and 3% much more difficult. The clarity of wording was found to be satisfactory by 60% of the teachers and good by 35%. The presentation was found to be satisfactory by 50% and good by 44%.

Overall, both papers were deemed to be of good quality with regard to clarity of wording and presentation but perhaps a bit on the difficult side. On the other hand some teachers commented positively on the conceptual nature of some of the questions.

General comments

A general comment by SL teachers was that there was too much emphasis on circular motion.

Of particular concern was the lack of physics focused on environmental issues. It is not sufficient for candidates to simply use their common sense combined with a bit of background reading. The topic needs to be taught and given its allotted time.

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

In this paper there was a balance between calculation and explanation but also an emphasis on understanding basic Physics concepts (work done, equilibrium, polarization, interference, photons, longitudinal waves, binding energy calculations).

It was evident from wordy responses that the candidates did not know how to express themselves clearly and as a result marks were dropped unnecessarily.

At HL, B1 and B2 were the most popular questions by far. At SL, B2 was the most popular choice.

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

- The concept of proportionality
- Calculation of uncertainties
- The concept of work in gravitation
- Polarization and interference
- Free body force diagrams
- Longitudinal waves
- Emf
- The concept of binding energy
- Simple circuit diagrams
- Explaining concepts and processes clearly
- Describing physical phenomena in a rigorous fashion
- Giving definitions
- Presenting calculations in a logical and understandable manner

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

- Performing simple calculations
- Gaining relevant information from graphs

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

A1 (SL&HL) Data analysis

a) This question displayed many misconceptions and inaccurate use of language. It should be noted that the word *proportional* **only** refers to a straight line passing through the origin. Thus to graphically justify that two variables, y and x, are proportional to each other it is necessary to justify that a graph of y versus x gives a straight line through the origin. To justify that they are *not* proportional to each other then, it is sufficient to point out that either the graph is not straight or that it is does not pass through the origin.

b) It must again be stressed that a “line of best fit” does not *necessarily* indicate a straight line. It was disappointing to see so many graphs with straight lines that did not pass through the error bars.

c) (HL only) The relationship $D = cn^{p}$ is "linearized" by taking logs: $\log D = \log c + p \log n$ and so a graph of $\log D$ versus $\log n$ is required, with *p* as the gradient. Although mathematically correct, the expression $p = \frac{\log(D/c)}{\log n}$ cannot be used since *c* is unknown.

d) (d) (HL) (c) (SL) In part (i) it was clear that many candidates were unsure about how to calculate the uncertainty in D^2 given the uncertainty in *D*. To begin with, the uncertainty ΔD in *D* is obtained from the error bar shown on the graph. Candidates were unsure as to whether ΔD was equal to the length of the error bar or half of it. Very few could write $\Delta D^2 = 2D\Delta D$ or that the percentage uncertainty in D^2 is twice the percentage uncertainty in *D*. This raises serious questions about work done during Internal Assessment. In part (ii) the same issues about proportionality discussed earlier surfaced here as well. In part (iii) it was expected that the value of *k* would be obtained from the gradient of the graph and not by choosing a specific data point. Calculation of the uncertainty in *k* involved lines of maximum and minimum gradient.

A2 (HL) Gravitation

a) Most candidates gave the argument that since the displacement is zero, the work done must also be zero. This is true only for conservative forces, such as gravity, for which the work done does not depend on the path taken but only on the initial and final positions. A very small number of candidates mentioned this. The majority answered, incorrectly, that work is the product of force and displacement and displacement here was zero. Many did obtain full marks, however, by pointing out that the work involves the cosine of the angle between the force and the displacement which in this case is a right angle and so the work done is zero.

b) The majority of candidates could do these standard textbook examples.

c) The majority of candidates thought that the work done would be positive but very few could actually compare the total energy of the satellite in the two positions and deduce that further away from the planet the total energy of the satellite had to be larger. Candidates must be reminded that when a part of a question states an answer, that answer will most likely be useful in answering the next part of the question.

A3 (HL) Polarization

a) There were few correct answers given to this definition question. Most referred to light propagating in the "same direction" or the "same plane" but few could point out anything about the electric field.

b) In part (i) there were mixed answers. Many realized that the angle of 50° was the polarizing angle for the plastic and so got full marks for both parts of this question but many had vague references to total internal reflection and Malus' law with $I \propto \cos^2 50^\circ = 0$. Part (ii) was answered by many candidates.

c) In parts (i) and (ii), teachers commented that this was a difficult conceptual question. Interestingly many candidates gave correct answers to both parts which was very encouraging. In part (i) there could be no light since the two components had parallel electric fields with a half wavelength path difference and so destructive interference would take place. In part (ii) the electric fields were at right angles to each other and so light would be observed since no destructive interference would take place. The weaker candidates were fooled into saying that there would be no light observed in part (ii) because the polarizers were at right angles to each other, obviously remembering the situation of two parallel polarizers at right angles to each other and a single beam of light going through.

A4 (HL) Thermodynamics

a) Most candidates calculated that the temperature at B would be 400 K but many just stated it without justification. The question explicitly asked to "calculate" the new temperature.

b) Most realized that the work done in part (i) is the area under the curve and did the calculation correctly. In part (ii), similarly, there were many correct answers with candidates applying the first law of thermodynamics correctly.

c) There were surprisingly many incorrect answers in drawing the isothermal curve joining B to A in part (i) and usually the answer given to part (ii) was inconsistent with the curve drawn in part (i).

A5 (HL) and A3 (SL) Circular motion

a) It was very surprising that in this basic mechanics force diagram question so many candidates could not properly identify the forces on the ball. Many answers had arrows in every which way and the great majority had an arrow towards the centre labelled "the centripetal force" (and quite a few had an arrow away from the centre labelled the "the centrifugal force" – this raises the question: are teachers mentioning/discussing this term in class?). Labels for the weight often included "gravity", a vague term, instead of "gravitational force" or "weight" or even "force due to gravity". Equally surprising, many candidates thought the ball was in equilibrium, and many of those who thought that it was not could not provide any correct reason for their answer.

b) The calculation of the speed of the ball was not done very successfully. Candidates tried playing with the second law of mechanics but often got lost in arithmetic and trigonometric ratios.

B1 part 1 (SL) Nuclear reactor

It was commented that the SL paper was heavy on nuclear physics. However, this question was on Topic 8.

a) Surprisingly few candidates could recall the term "enrichment".

b) There was a lot of confusion with large numbers and a lack of clear thinking in navigating through the calculations.

c) The very popular answer to this part was that a meltdown would follow.

d) This was well answered.

B1 part 1 (HL) CCD and photons

a) (a) and (b) These parts were generally well answered by most candidates.

c) (i), (ii), (iii) The problems for the candidates started here, where it was common to see arithmetic operations with the given data in an attempt to get the required answer.

This is typical in questions where the numerical answer is given. Candidates must be reminded that examiners are not fooled by this trick! At the same time, many candidates gave perfect answers to these parts. In parts (iv), (v) many candidates attempted to use the formula $p = mv$ for the momentum of the photon using the mass of the electron or proton instead of using $p = h/\lambda$ .The calculation of the pressure on the pixel was beyond most candidates but again a fair number answered both parts (iv) and (v) correctly.

B1 part 2 (HL) and B1 part 2 (SL) Simple harmonic oscillations and waves

a) This standard part of the course required application of the basic formulae of simple harmonic motion and it was obvious that these formulae are not well understood by many candidates. It was common to see application of the formulae of rectilinear motion to this problem.

b) This was the most well answered part of the question.

c) Graph 2 was reproduced here in order to help candidates but perhaps it was not necessary – it just made the question spread out over many pages and this may have made it appear more difficult than it was. However it was rare to see completely correct answers here. It was mentioned twice in the question that we were dealing with a longitudinal wave. Teachers, in their G2 comments, expressed the belief that this should have been repeated here as well. It was obvious that candidates were answering the question for a transverse wave. But one wonders whether we are stressing enough in the classroom that the displacement–distance graph is the same for both transverse and longitudinal waves.

B2 part 1 (HL) and B2 part 1 (SL) Mechanics and thermal physics

a) Most answered this part correctly.

b) In part (i) answers suffered from the same problem as that in A5 (HL), namely very sloppy force diagrams. Surprisingly, in part (ii) many candidates could not obtain the answer to this question by finding the slope of the graph. Instead, many found the average acceleration in the first 2 s, $14/2 = 7\ \text{m s}^{-2}$! In parts (iii) and (iv) there were many correct answers.

c) This part was well answered, including the last part on the assumptions made in the estimate of the temperature increase.

B2 part 2 (HL) and B2 part 2 (SL) Nuclear physics

a) (i) The definitions of binding energy provided were not accurate. A typical answer was “the energy needed to hold a nucleus together”. In part (ii), there were many good answers to the calculation of the binding energy but also many blank responses.

b) Part (i) was well done but part (ii) was poorly done. Few candidates seemed to know that the energy released may be calculated from the difference in the binding energies of the products and the reactants.

c) This tough question separated the very best of the candidates from the rest. The weaker candidates were totally lost and there were frequent references to forces between protons and electrons.

B3 part 1 (HL) Quantum aspects of the electron

a) (a) and (b) were generally well done by the few candidates who attempted this question.

c) The calculation of momentum proved difficult, with few candidates realizing that they had to first find the wavelength of the electron from the graph and then use $p = h/\lambda$. Many used $p = mv$ and then struggled, in many cases creatively, to find a value for the speed.

d) There were many correct answers to this question.

e) The first part was mostly done well but a few candidates were struggling with attempts to calculate an uncertainty using Topic 1 ideas. Part (ii) was difficult with hardly any correct answers. The idea was that since the energy difference is subject to an uncertainty, the wavelength that is given by $\lambda = hc/\Delta E$ would also be subject to a (very small) uncertainty as well.

f) This was a textbook example where candidates had to show that they understood that in part (i) the energy levels are positive and in part (ii) the separation of the levels increases with increasing *n*.

B3 part 2 (HL) and B3 part 1 (SL) Electric circuits

a) There were serious problems with the definitions in parts (i) and (ii). Admittedly, emf is a hard concept for most candidates but even the definition of resistance caused problems.

b) There was some confusion and comments on G2 forms about this part. The relation to be proven was Kirchoff's law, yes, but it had to be proven by applying the law of energy conservation to the circuit, not simply stated.

c) The graphs of resistance versus voltage were unusual but a fair number of candidates managed to score full marks here.

d) The simple calculations of the emf and the power in the circuit were surprisingly not done well by the majority of the candidates.

B4 part 1 (HL) and B3 part 2 (SL) Energy balance of the earth

a) This question intended to have candidates reproduce the argument of why the average intensity (averaged over the entire Earth's surface) is ¼ of the total incident intensity. This question was probably misunderstood by candidates who argued about reflected intensity instead. It is clear that this new topic is not well understood by candidates and that teaching does not concentrate on the physics of the situation.

b) The misunderstandings alluded to in (a) continued in (b)(i) where many candidates seemed to have no idea what emissivity is. On the other hand the calculation in part (ii) was generally well done and the calculation in part (iii) was less well done. ECF was applied here for an incorrect intensity in the formula to determine the Earth's surface temperature.

c) In part (i) there were vague references to "resonance" here. It is preferable to concentrate on molecular energy levels instead, in explaining why infrared photons are absorbed by greenhouse gases.

B4 part 2 (HL) and A2 (SL) Motion in a magnetic field and electromagnetic induction

a) The three parts to this question were standard textbook examples of motion in a magnetic field; it was the expectation of the examining team that candidates would have done better here. As commented before, the fact the numerical answers to each part were given (so that the next part could be done) made many candidates produce all kinds of arithmetical operations out of which the answers miraculously appeared.

b) In part (i) it was surprising to see so many incorrect answers for this basic question on vector subtraction. In part (ii) it was expected to see an application of Pythagoras' theorem to calculate the magnitude of the change in the momentum. In part (iii) it was required to find the magnitude of the *average* force on the electron and that is *not* given by $F = qvB$ (a few candidates made this mistake) since the direction of the force is not constant. Rather it was expected to use $F_{ave} = \Delta p / \Delta t$. Many candidates got this part correct.

c) Electromagnetic induction is always problematic in examinations and this question was not an exception. In this question, one had to clearly explain that the induced emf in the loop would produce a current in such a direction that the currents would repel, thus requiring the loop to be pushed, i.e. work had to be done. In part (ii) quite a few candidates realized that eventually the work done in pushing the loop is dissipated as thermal energy in the loop.

Recommendations and guidance for the teaching of future candidates

- Ensure the candidates learn the definitions of basic physical quantities.
- In those cases where an answer is given in part of the question, then that answer should be used for the next part of the question if needed.
- Candidates must be reminded that when a question asks for the derivation of a certain algebraic explanation, the confused and garbled display of formulas and symbols with the given answer magically appearing in the end does not fool examiners.
- Insist on calculations being set out in a logical and communicative fashion.
- Give adequate time to teaching the *physics* of environmental physics.
- Practice questions on electromagnetic induction
- Candidates should read the questions carefully, and not repeat the statement of the question in the answer.
- Practice past examination questions and show candidates the markschemes so that they can understand how their answers will be marked by the examiner.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 8	9 - 17	18 - 23	24 - 29	30 - 34	35 - 40	41 - 60

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 8	9 - 13	14 - 17	18 - 20	21 - 24	25 - 40

General comments

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

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

Standard Level

- 96% thought the level of difficulty appropriate, while 2% thought it too easy and 2% too difficult.
- 70% found the paper of a similar standard to last year. 21% found it a little easier and 5% much easier, while 5% found it a little more difficult. No one found it much more difficult.
- 52% thought the clarity of wording satisfactory and 48% thought it good, with no one thinking it poor.
- 41% found the presentation of the paper satisfactory and 55% found it good, whereas 4% found it poor.
- The most popular option was A (Sight and wave phenomena), followed by B (Quantum physics and nuclear physics), D (Relativity and particle physics), E (Astrophysics) and G (Electromagnetic waves) in roughly equal numbers. Very few candidates answered options C (Digital technology) or F (Communications).

Higher Level

- 96% thought the level of difficulty appropriate, while 4% thought it too difficult. No one thought it too easy.
- 76% found the paper of a similar standard to last year. 21% found it a little easier, while 3% found it a little more difficult. No one found it much easier or much more difficult.
- 50% thought the clarity of wording satisfactory and 50% thought it good, with no one thinking it poor.

- 45% found the presentation of the paper satisfactory and 55% found it good. No one found it poor.
- The most popular options were, in the following order, H (Relativity), E (Astrophysics) and G (Electromagnetic waves). Options I (Medical physics) and J (Particle physics) were answered by fewer candidates in roughly equal numbers. Very few candidates answered option F (Communications).

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

Most questions seemed to be quite accessible to candidates who were well prepared for the exam. However, the areas identified by the examination team as being particularly difficult were as follows:

- Lines in the emission spectrum of hydrogen
- Charge-coupled devices (CCDs)
- Schmitt triggers
- Thin film interference
- The Michelson-Morley experiment
- Producing precise answers that address directly the requirements of the command term in the question, in particular “describe”, “outline”, “explain” and “discuss”
- Producing answers of sufficient detail for 3 or 4 mark questions
- Providing clear working in mathematical calculations with each step clearly laid out
- Giving correct and precise definitions e.g. Hubble’s law, *focal point*, *proper length*, the equivalence principle, exchange particle, *acoustic impedance*

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. There were many candidates who were well prepared for this exam and produced answers that showed good understanding of physical concepts.

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

SL only

Option A – Sight and wave phenomena

A1 Standing (stationary) waves

Candidates seemed to be well prepared for questions on this topic. Some comments on G2 forms expressed concern that in (b)(ii), the word “node” could refer to a displacement node or a pressure node. By far the most common usage is to mean displacement node. If the examining team wished to refer to pressure nodes, this would be specifically stated. There was no evidence that any candidate was disadvantaged by referring to a pressure node.

A2 The Doppler effect

In (a), while there were many correct answers, many candidates referred to the case of the moving source, where waves are compressed together and the observed wavelength changes. Some answers referred to loudness changing with distance, as opposed to frequency changing with speed. The calculation in (b) was very well done in general, although many candidates lost a mark for too many significant digits.

A3 Resolution and accommodation

In (a), many otherwise correct answers omitted the factor of 1.22 from the Rayleigh criterion. Some candidates were able to state the Rayleigh criterion correctly, but were unable to relate this mathematically to the distance to the birds and the distance between the birds. Part (b) was well done in general, although some answers did not specify how the lens changes shape to cope with near and far objects.

Option B – Quantum physics and nuclear physics

B1 The photoelectric effect

This was a classic and fundamental question that appeared to discriminate well among candidates, who scored the full range from 0 to 4 marks. Candidates who did not score well did not make any specific mention of energy, and it was therefore difficult to gain any marks. Some candidates did have some idea about the photoelectric effect, but failed to put together a clear, precise answer. This is an example of candidates finding it difficult to give enough detail for a 4 mark "explain" question.

B2 Atomic spectra

The deduction in (a) was generally done well, although some answers contained very messy working with the answer simply stated at the end. Some candidates found the conversion from joule to eV difficult. Part (b) was generally done well also, so candidates clearly had some understanding that photons of specific wavelengths are emitted due to transitions of electrons between energy levels with specific energy differences. Very few candidates, however, were able to deduce from the diagrams given why the spectral lines get closer together with decreasing wavelength.

B3 Radioactive decay

This question was generally done reasonably well by most candidates. A significant number showed confusion in part (a), however, with many giving the reaction for beta minus decay. The calculation in part (b)(ii) was done well, although with working that was often very difficult to follow. A common error was to multiply the initial activity by the decay constant. The graphs in parts (b)(iii) and (iv) were done particularly well, showing good conceptual understanding of half-life.

Option C – Digital technology

These comments are based on a very small number of candidates who answered this option.

C1 Analogue and digital storage

This question was done reasonably well on the whole. In (b), few candidates gained the second mark for outlining how the analogue process of retrieval affects future quality, an example of not giving two points in a 2 mark question. Some candidates found the calculation in (c) difficult, many making mistakes with powers of ten.

C2 Charge-coupled devices (CCDs)

Many candidates struggled with the mathematics of (a) and (b). In (a), many neglected to take the square root of the areas to get linear magnification, while many struggled to convert cm^2 and/or km^2. In (b), again many neglected to take the square root to find the number of pixels along a side, or made power of ten errors. In (c), almost every candidate thought that improving the quantum efficiency would improve resolution, which shows a lack of understanding of the concepts involved.

C3 Schmitt trigger

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

C4 Mobile phone network

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

Option D – Relativity and particle physics

D1 Length contraction and simultaneity

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

D2 Mesons

This question was identical 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 Planets in the solar system

This question tested simple recall of basic knowledge. Most candidates scored very well. A surprising number made mistakes in ordering the planets correctly. While this syllabus statement (E.1.1) is not examined very often, the requirements are clearly stated in the teacher's notes and should therefore be taught. Some candidates inserted planets that did not appear in the stem – this can only be due to not reading the question properly.

E2 Hertzsprung–Russell (HR) diagram and properties of stars

This question was answered very well in general. In (a)(i), many answers included both stars A and B as red giants. In (b), many candidates gained the first 2 marks, but struggled to explain why star B must therefore have a bigger surface area and hence diameter. Some forgot that in a HR diagram, temperature decreases from left to right. In (c), many correct answers were messily laid out and difficult to decipher. For this type of multi-step calculation, candidates need to be taught how to lay out working neatly, showing each step clearly.

E3 Cosmology

Parts (a) and (c) were done well, although the significant digit penalty was lost by many candidates in (c). Part (b) was answered very poorly – while many candidates had some idea about the radiation being the same in all directions, or wavelength increasing with time, few candidates used these points to explain why the CMB radiation is consistent with an initially small, hot universe that has cooled due to expansion.

E4 [HL only] The star Khad (Phi Orionis)

This question was answered extremely well by the majority of candidates, who realized that Khad is a very large star and would therefore end up as a black hole or possibly a neutron star. There was some confusion about a red supergiant – some candidates believed that this is just a very large red giant, as opposed to a different type of star.

E5 [HL only] Hubble's law and the age of the universe

This question was answered well by a significant number of candidates, but many struggled to give enough detail in their answers. In part (a)(i), many answers vaguely talked about objects moving with speed proportional to distance, without specifying galaxies, recessional speed or distance from Earth. This is a standard definition that should be thoroughly learned. In part (a)(ii), many candidates stated that Andromeda is too close and so its red-shift is too small to measure. In part (b)(i), virtually no candidate gained the first mark by specifying what *d* and *v* referred to specifically. Part (b)(ii) was well done, though again some candidates lost a mark for too many significant digits.

Option F – Communications

These comments are based on a very small number of candidates who answered this option.

F1 Modulation

This question was reasonably well done by those who attempted it, although in part (b)(i) some candidates did not actually specify how information is encoded differently in AM and FM.

F2 Data transmission systems

This question was done well on the whole. Calculations on attenuation were particularly well done by several candidates.

F3 Satellites

This question was done well in general, although a surprising number of candidates were unable to come up with an ethical issue regarding a broadcast via satellite, focussing instead on military applications or espionage. Perhaps this was a case of not reading the question properly.

F4 [HL only] Schmitt trigger

Virtually no candidates gained more than 1 or 2 marks in this question. A few candidates gained 1 or 2 marks in (c). As has been stated in previous subject reports for this syllabus, operational amplifiers are clearly not well understood by candidates. Teachers who choose to teach this option need to spend considerable time practising this type of problem with candidates.

F5 [HL only] Mobile phone network

This straightforward question was answered well on the whole.

Option G – Electromagnetic waves

G1 Dispersion

This question was generally done well by the majority of candidates. In part (b), however, some answers referred to “scattering”, rather than “refraction/bending/splitting”. Diagrams in (c) were often good, but sometimes the red and blue rays were swapped around. Some candidates showed total internal reflection at the second surface.

G2 Convex lens

This straightforward question on one of the simplest types of ray diagram was generally done well. In part (a)(i), many candidates made no reference to the principal axis when defining *focal point*. Again this is a standard definition that should be learned. In part (a)(iii), many candidates stated that the image is virtual because it is on the same side of the lens as the object. While this is true, it is not an explanation of why the image is virtual rather than real. In (b), many candidates failed to realize that since the image is virtual, a negative sign must be placed before 25 cm in the lens equation. Some candidates swapped the values for object and image, leading to the same error. Error carried forward (ECF) was applied in this circumstance.

G3 Using a diffraction grating to view the emission spectrum of sodium

This relatively novel question was done well by a pleasing number of candidates, showing good conceptual understanding of viewing spectra with a diffraction grating. Many candidates failed to appreciate that when two numbers of similar magnitude are subtracted (or added), the precision should be to the same decimal place rather than the number of significant digits (i.e. 70.7 – 70.5 = 0.2 not 0.200). However, some latitude was given on this, as it was not really the point of the question.

G4 [HL only] X-rays

The calculation in (a) was done very well. Part (b) was an excellent discriminator, with the full range of marks from 0 to 3 gained.

G5 [HL only] Wedge film interference

This question was very challenging, although some excellent answers were seen. The idea that a phase change of π occurs upon reflection at one surface but not the other, leading to destructive interference for a path difference of half a wavelength, seems to be very difficult for many candidates. Many made a stab at the calculation in (b), although only a few knew what they were doing. This type of question has appeared in several past papers and needs to be practised by centres choosing this option.

HL only

Option H Relativity

H1 Length contraction and simultaneity

Definitions of proper length in (a) were often quite poor, with vague answers about the length measured in a stationary frame, without the idea that the observer and object need to be at rest relative to each other. Calculations in (b) were well done, although with the significant digit mark lost by many. Almost all candidates answered part (b)(iv) correctly, or at least gave an answer consistent with their answers to parts (i)-(iii). Candidates clearly had no trouble with the idea that the spaceship could be longer than the tunnel in the spaceship frame and vice versa. Part (c) on simultaneity was answered relatively well, although many candidates omitted the constancy of the speed of light from their argument and therefore could not score full marks.

H2 Relativistic velocity and energy

Parts (a) and (b) were done well, with most candidates realizing that the Galilean transformation is not valid for high speeds and gives an answer not consistent with special relativity. Part (c) was a good discriminator with a wide range of answers. A common error was to use the equation for total energy $E = \gamma m_0 c^2$, rather than kinetic energy $E_K = (\gamma - 1) m_0 c^2$.

H3 Michelson-Morley experiment

Part (a) was very poorly done. Many candidates discussed the relative speed of light and hence a time difference for the two different paths (gaining 1 mark for the idea of path difference), but not many referred to an interference pattern, changing or otherwise. Very few gained the last mark for using the magnitude of the change to measure the speed of light (relative to the aether). Interestingly, quite a few candidates gained 1 or 2 marks in (b), even if they had not done well in (a). Clearly, candidates know the basic fact that the experiment was to find the speed of light relative to the aether and that a null result was obtained, but do not know the details of how the experiment was conducted.

H4 Gravitational red-shift

This was another relatively novel question that was quite well done. Candidates obviously have a good basic idea of gravitational red-shift, although the details are not so well understood. Part (a) was answered well, except for part (iii), where many candidates just stated that g = 9.81 ms^{-2}, without adding that this value is assumed to be constant over the height interval. In (b), there were few clear statements of the equivalence principle (again a definition that needs to be learned), but most candidates realized implicitly that the situations in (a) and (b) were equivalent.

Option I – Medical physics

I1 Sound intensity levels

This question was generally well done by those candidates who attempted it, although many made power of ten errors in part (b)(i), and few candidates mentioned the threshold of pain in part (b)(ii). A common error in part (b)(iii) was to describe tinnitus as a decreased ability to hear particular frequencies.

I2 Medical imaging

This was a lengthy question that examined a range of medical imaging techniques. It was generally answered well, although the following errors were common. In part (a)(ii), many candidates thought that a barium meal was an enhancement technique, rather than a method to improve contrast. In part (b)(iii), few candidates knew that it is the difference in acoustic impedance between air and skin/tissue that causes the problem, though many knew that gel solves the problem as it has a similar impedance to tissue/skin.

I3 Radiation in medicine

This question was also quite well answered. However, many confused calculations were seen in (a). There seemed to be confusion about the difference between dose equivalent H and absorbed dose D. Since in this case the quality factor was 1 and so D and H were equal, many candidates muddled through. In part (c)(ii), a significant number of candidates believed that a film badge actually absorbs or reflects the radiation, as opposed to being an indicator of how much radiation is being absorbed by the wearer.

Option J – Particle physics

J1 Mesons

This question was generally well done by those who attempted it. A common error in (a) was to define a virtual particle rather than an exchange particle. This could have been due to not reading the question closely enough. In (d), many candidates gave the possible spin numbers as -1, 0 or 1, thus losing the first mark. It was still possible for them to gain the other 2 marks, however. Other parts of the question were well done.

J2 Accelerating particles

This question was well answered in general, but many candidates had trouble with (a) and (e). In (a), many candidates said something about attracting and repelling, without the idea that the direction of the force needs to change every half revolution. This is an example of candidates not producing precise enough answers to an “outline” question. In (e), many candidates did not produce answers directed towards a 3 mark question. Many candidates made a connection between momentum and wavelength, but did not explain clearly that alpha particles have greater mass and so greater momentum at the same speed, and did not make a connection between wavelength and resolution.

J3 Energy and conservation laws

Many candidates answered this question very well, showing good basic understanding of conservation of energy and baryon number in particle production.

J4 Cosmology and strings

Some candidates found the conversion from MeV to joule difficult, but otherwise this question was answered well in general.

Recommendations and guidance for the teaching of future candidates

Recommendations from the examination team include the following:

- Candidates should be given many opportunities during the course to practise past papers, and should be given access to markschemes. Many questions appear again and again in similar form and can be practised. Some questions, of course, are novel and test the ability to apply knowledge to unfamiliar situations.
- Command terms should be specifically taught to candidates, and they should be trained to respond appropriately to the command term when writing answers. The number of marks available should serve as an indication of the number of points that need to be made.
- Enough time should be devoted to cover in depth the options chosen. While it is natural to teach many of these options at the end of the course when all core material has been covered, enough time must be devoted to their study.
- Candidates must be discouraged to study options on their own. Whenever a candidate answers a different option to all other candidates in a centre, the results are almost always disastrous for that candidate. It is much better for candidates to answer options that have been properly taught in lessons.
- Definitions are often so vague that marks cannot be awarded. This type of question is very common and hard work is rewarded. Candidates who compile a glossary of definitions and spend time and energy learning them inevitably do better in this type of question.
- Working, especially for derivations or "show" questions, is often so messy as to be indecipherable. Candidates must be strongly encouraged to lay out working in a logical way that shows clearly each step they are taking. Candidates often squeeze answers into the available space, especially if they cross out some work. They should not be afraid to use an extra sheet and use the space to lay out working neatly.
- Teachers need to emphasize to candidates that many marks are lost due to incorrect or inadequate descriptions and explanations of physical phenomena. Candidates need to practise this kind of question a lot more than calculations and derivations.
- Many candidates lost the significant digit mark, often putting up to eight decimal places. If candidates are unsure about how many significant digits to use (the lowest level of precision of the data given), then good advice is to put two or three.