PHYSICS TZ2 (IBAP & IBAEM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 26	27 - 39	40 - 49	50 - 60	61 - 71	72 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 12	13 - 23	24 - 35	36 - 45	46 - 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 IB's expectations are being meet by the majority of schools. Teachers understand the IA criteria and are marking in a consistent and appropriate manner. Most schools required very little or no moderation. Many of the 4/PSOW reveal very good practical programs.

Often candidates were assessed by all three criteria in the same investigation. This allows for trial and error and the possible revision of the initial design ideas. This is good scientific practice. Assessing all three criteria in one investigation also allows candidates to better appreciate the IA expectations in the conclusion and evaluation.

There were several examples of the use of ICT in assessed work. This is good news and the IB encourages the use of ICT.

Some teachers are asking candidates for a hypothesis in their Design section, and although this is not penalized, a hypothesis is not required. Moreover, the lack of a hypothesis allows for a truly open-ended investigation. Perhaps a physical interpretation (along the lines of a hypothesis) could come into the first aspect of CE for the achievement level of complete.

On a more critical note, there are some trends that need correction. First, a noticeable number of schools are marking only two investigations or each criterion only twice. Sometimes, these are the first two labs listed on the 4/PSOW. This is unfair to the candidate who should have a number of chances at achieving their best two IA marks. Second and this is related to the first item, there are a number of candidates with noticeable low IA totals awarded by teachers. These have been checked and rechecked by moderators, and the low marks are truly justified. This is not encouraging. Teachers need to structure the teaching of IA in a way that allows candidates to improve, to learn from their mistakes, and do their best. In fact, the IB expects candidates do perform well on IA. For issues of guidance see the *Physics Course Guide* “Guidance and authority” pages 19-20.

Another critical point concerns graphs. Some teachers are accepting graphs that have hand drawn axes and estimated number lines as well as estimated data points. This is unacceptable at high school level. Candidates need to use printed graph paper for hand drawn graphs. Free graph paper software is readily available online. These candidates should be allowed a second chance at DCP. The majority of candidates, however, are successfully using graphing software.

A few teachers have little idea of what the Design criterion is about. For instance, there were examples of assessing Hooke’s law for Design, confirming Ohm’s Law, group work for assessment, and so on. The prompt “Investigate the relation between the current and the voltage for a metallic conductor, a filament lamp and an electrolyte” was given and then assessed on Design. The teacher also gave a handout with all the relevant theory and equations. This is a worthwhile investigation but it is not appropriate for assessment under the Design criterion.

Continuing this last critical point, there is the perennial problem of teachers assessing Design for an investigation that is already thoroughly understood by the candidate. In such cases, the candidate knows the relevant theory and equations. If teachers assess Design investigations where there is a standard textbook theory and relevant equations, such as the simple pendulum or the resistance of a wire, then it is essential that the labs be assigned before the relevant theory is covered in class. Too often candidates quote the relevant equation (and so there is no clear opportunity to select variables).

Under DCP, there were several cases of the teacher giving the candidate data tables with units, and the instructions of what to graph. This may be a good exercise but it is not appropriate for assessment.

Some teachers are giving ‘completes’ for DCP aspect 3 when graphs do not appreciate uncertainties; error bars and minimum and maximum gradients for linear graph lines are normally expected.

The range and suitability of the work submitted

The transition to the revised IA structure went very well. The majority of schools understood the requirements. Teachers continue to demonstrate an improvement in selecting appropriate labs for each criterion.

Problems occurred, however, when teachers assigned two clearly defined variables for design, or assessed design when determining a specific quantity, such as gravity.

The rule of thumb is to look for a function or relationship between two variables. Candidates need to make decisions and different candidates should come up with slightly different investigations given the same teacher prompt. Although hypothesis is no longer required under the planning of an investigation, some teachers are asking candidates for this. It should be noted that assessment does not address hypothesis. However, some physical interpretation may occur in CE, and hypothesis might appear here, but it is not required.

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

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

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

Candidate performance against each criterion

Design

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

Controlling variables was properly addressed in most cases but there were occasion where candidates needed to be more specific. Just saying, "I will measure the period of a pendulum" is not sufficient. Attention to detail is expected for a complete. Similarly, sufficient data requires an appreciation of the scope and range of values, as well as repeated measurements.

Most candidates are addressing these issues. Occasionally teachers over-mark this aspect. Teachers are reminded that moderators only know what is written out in the candidate's report.

Data Collection and Processing

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

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

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

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

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

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

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

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

Conclusion and Evaluation

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

Recommendations for the teaching of future candidates

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

In assessing candidate work using IA criteria, teachers should only mark and annotate the final draft. See the section of the Physics Course Guide called "Guidance and authenticity" for more detail.

- It is essential when work is to be assessed that candidates work on their own. There cannot be a set of common data or identical results if the work is to be assessed.

Further Comments

This last section contains the advice that is given to physics IA moderators. Overall, moderators normally keep the teacher's marks, but occasionally they raise or lower marks. If the teachers have applied the criteria to appropriate tasks in good faith then the moderation system should support them. Moderators are not here to apply their own pet theories and practices as teachers, but to ensure that the schools are using the criteria within acceptable bounds according to the official descriptors. In other words, moderators are **looking for the systematic error beyond the random error in the application of the aspects of the criteria**. The following advice is given to the moderators.

When moderators mark down

Design

The moderator will mark down when the teacher gives a clearly defined research question and/or the independent **and** controlled variables. The teacher may give the 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 candidates have significantly modified the teacher prompt or question (e.g. made it more precise, defined the variables). The moderator will mark down when a method sheet is given which the 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 that are just filled in by candidates. If the candidate has not recorded uncertainties in any quantitative data then the maximum given by the moderator is 'partial' for the first aspect. If the candidate has been *repeatedly inconsistent* in the use of significant digits when recording data then the most a moderator an award is 'partial' for the first aspect. In physics data is always quantitative. Drawing the field lines around a magnet does not constitute DCP.

The moderator will mark down when a graph with axes already labelled is provided (or 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. The method for this is often the minimum and maximum gradients using the first and last data points.

Conclusion and Evaluation

If the teacher provides structured questions to prompt candidates through the discussion, conclusion and criticism then, depending on how focused the teacher's questions are and on the quality of candidates' response the maximum award is *partial* for each aspect 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 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 procedures which is independent and which are controlled.

Moderators do not mark down when similar (but not word for word identical) procedures are given for a narrow task. The moderator will make a comment though on the poor suitability of task on 4/IAF form. Moderators do not only mark the equipment list, they give credit for equipment clearly identified in a stepwise procedure. Remember moderators look at the whole report. Moderators do not insist on +/- precision of apparatus to be given in the apparatus list. This has never been specified to teachers and the concept of recording uncertainties is dealt with in DCP. Moderators do not downgrade a teacher's mark if something as routine as safety glasses or lab coats are not listed. Some teachers consider it vital to list them each time and some teachers consider them such an integral part of all lab work that they go without saying. Moderators support the teacher's stance here.

Data Collection and Processing

In a comprehensive data collection exercise possibly with several tables of data the 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 unfairly get 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 class teacher because they did not give the table a title. Except for extended investigations it is normally self-evident what the table refers to.

The expectation for the treatment of errors and uncertainties in physics is described in the Course Guide and the TSM. Both standard level and higher-level 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. Candidate may make statements about the manufacture's claim of accuracy, but this is not required. When raw data is processed, uncertainties need to be processed (see the Course Guide, syllabus section 1.2.11)

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 award 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 you teach i.e. top pan balance uncertainties have been given as +/- 0.01g when you may feel that if we consider the tare weighing then it should be doubled. Moderation is not the time or place to establish the favoured IB protocol.

Conclusion and Evaluation

Moderators often apply the principle of 'complete' not meaning perfect. For example, if the candidate has identified the most sensible sources of systematic error then the moderator can support a teacher's award even if the moderator can identify one more. Moderators are a bit more critical in the third aspect that the modifications are actually relating to the cited sources of error. If the moderator feels a task was too simple to truly meet the spirit of the criteria, then comments on the 4IAF as to the unsuitability of the task giving full justifications will be provided in feedback but the moderator will not necessarily downgrade the candidate. This does mean that candidates could get high DCP marks for some quite brief work on limited data but, if they have fulfilled the aspect's requirements within this small range, then the moderator will support the teacher's marks.

The most challenging aspect of CE is the differentiation between a partial and a complete under aspect 1: "States a conclusion, with justification, based on a reasonable interpretation of the data." A justification may be a mathematical analysis of the results, one that includes an appreciation 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 reveal a linear and proportional relationship". See the last paragraph in the Conclusion and Evaluation comments in section B above.

Paper one

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 15	16 - 20	21 - 24	25 - 29	30 - 33	34 - 40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 10	11 - 14	15 - 16	17 - 19	20 - 21	22 - 30

General comments

A proportion of questions are common to the SL and HL papers. Additional questions at HL provide further syllabus coverage both of core material and AHL topics.

A very small proportion of Centres returned G2 forms or comments. For SL there were 18 responses from 437 Centres and at HL 18 responses from 236 Centres. It is therefore difficult to assess the opinion of candidates and teachers to the papers. The few replies that were received indicate that the papers were viewed as either the same as last year or slightly more difficult. The level of difficulty was regarded as appropriate by the vast majority. The majority agreed that the syllabus coverage was satisfactory to good, that the clarity of wording was satisfactory or good, and that the paper was well presented.

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	3444 *	89	665	49	1	81.07	0.22
2	20	114	215	3896 *	3	91.71	0.13
3	518	2736 *	769	192	33	64.41	0.47
4	530	3108 *	482	124	4	73.16	0.46
5	207	3366 *	311	343	21	79.24	0.36
6	2364 *	349	551	974	10	55.65	0.31
7	141	3600 *	414	87	6	84.75	0.23
8	69	845	315	3016 *	3	71	0.31
9	1724	285	2073 *	158	8	48.80	0.46
10	435	2429 *	396	983	5	57.18	0.54
11	196	447	1265	2336 *	4	54.99	0.39
12	752	820	330	2337 *	9	55.01	0.53
13	2221 *	680	981	332	34	52.28	0.37
14	535	63	3158 *	485	7	74.34	0.29
15	561	222	3015 *	430	20	70.97	0.38
16	2584 *	442	90	1130 *	2	60.83	0.10
17	432	1799 *	1474	532	11	42.35	0.42
18	675	630	1582	1343 *	18	31.61	0.18
19	2118 *	440	1621	60	9	49.86	0.58
20	791	402	1296	1744 *	15	41.05	0.37
21	381	3417 *	189	253	8	80.44	0.28
22	356	2977 *	495	411	9	70.08	0.46
23	662	2633 *	597	346	10	61.98	0.47
24	296	722	2911 *	304	15	68.53	0.46
25	2140 *	1326	480	281	21	50.38	0.42
26	103	1436	626	2068 *	15	48.68	0.25
27	526	1088	643	1981 *	10	46.63	0.61
28	474	1469	422	1851 *	32	43.57	0.32
29	2508 *	1080	404	248	8	59.04	0.62
30	571	530	354	2784 *	9	65.54	0.37
31	2029 *	577	1330	298	14	47.76	0.39
32	396	909	2330 *	593	20	54.85	0.43
33	18	1004	2960 *	257	9	69.68	0.28
34	409	234	659	2919 *	27	68.71	0.23
35	1015 *	125	1262	1832	14	23.89	0.18
36	1573 *	386	720	1538	31	37.03	0.42
37	481	902	1574 *	1255	36	37.05	0.38
38	162	3420 *	140	503	23	80.51	0.28
39	877	555	2466 *	300	50	58.05	0.27
40	894	620	2431 *	262	41	57.23	0.45

Number of candidates: 4248

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	2610 *	168	928	83	7	68.76	0.32
2	291	1004	926	1565 *	10	41.23	0.32
3	63	178	344	3202 *	9	84.35	0.24
4	961	2764 *	46	24	1	72.81	0.24
5	1315 *	388	730	1350	13	34.64	0.47
6	755	2224 *	682	127	8	58.59	0.52
7	334	287	988	2176 *	11	57.32	0.30
8	402	2551 *	400	416	27	67.20	0.41
9	1652 *	546	603	974	21	43.52	0.39
10	296	2890 *	503	95	12	76.13	0.23
11	658	223	267	2642 *	6	69.60	0.33
12	302	549	1396	1539 *	10	40.54	0.41
13	566	1706 *	450	1063	11	44.94	0.51
14	304	601	2560 *	314	17	67.44	0.45
15	2476 *	985	182	148	5	65.23	0.35
16	475	391	1851	1042 *	37	27.45	0.29
17	659	353	445	2322 *	17	61.17	0.50
18	415	1071	2033 *	262	15	53.56	0.14
19	1560	508	836	870 *	22	22.92	0.33
20	141	269	2990 *	374	22	78.77	0.25
21	1094	413	203	2051 *	35	54.03	0.37
22	430	889	2419 *	306	22	56.61	0.46
23	1363 *	1337	670	372	54	35.91	0.33
24	3100 *	198	327	165	6	81.66	0.25
25	54	970	2444 *	316	12	64.38	0.36
26	667 *	250	942	1918	19	17.57	0.13
27	582	1406 *	1161	628	19	37.04	0.21
28	1112 *	387	680	1582	35	29.29	0.24
29	404	1783 *	532	1027	50	46.97	0.29
30	441	748	1133 *	1419	55	29.85	0.20

Number of candidates: 3796

Comments on the analysis

Difficulty

The difficulty index varies from about 23% in HL and 18% in SL (relatively 'difficult' questions) to about 92% in HL and 84% 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 3 questions across both papers. 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, there is an increase in the number of blank responses for the last few questions. Teachers did not indicate a lack of time. The advice of the examiners is still that candidates should make an educated guess for any item about which they are not certain. No penalty is awarded for an incorrect response. The element of guesswork can be reduced by the elimination of some of the distracters.

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 Q1 and HL Q1

Many found this straightforward but a sizeable minority at both levels failed to multiply by 100 to convert to a percentage.

SL Q3 and HL Q2

It is clear that many candidates are not familiar with the vector nature of displacement and its dependence only on the starting and end points of the motion.

SL Q6 and HL Q4

G2 comments referred to the use of the term "plan view". This is a standard phrase used in these examinations in previous years that candidates ought to know. It means that the view of the situation is taken from (vertically) above. However, the difficulty index indicates that there was no such uncertainty in the minds of very many candidates.

SL Q9 and HL Q6

There were references to friction acting on the box in the G2 reports. There was no mention of friction in the question and neither candidates nor teachers should infer difficulties where none are meant to exist. Although, there may be small energy perturbations during the initial acceleration of the box, when the motion has settled down to a constant velocity the gas conditions will be unchanged.

SL Q10 and HL Q7

This gave few difficulties except to those who inverted the equation.

SL Q12 and HL Q11

Again, SL candidates performed worse than HL and many thought that a car suspension system needs to be moderately damped.

SL Q13 and HL Q10

Although this gave few problems to HL candidates, SL candidates were much more uncertain with distracter D (effectively x against t).

SL Q19 and HL Q20

Few SL candidates scored correctly on this question. It was clear that many did not consider the variation of electric field strength inside the sphere to be different from that outside; many chose A. HL candidates scored better and even those who were incorrect usually recognised that there is a change at the sphere surface, but assumed that the electric field continues inside the sphere at its surface value.

SL Q22 and HL Q24

This was answered well, but a significant distracter was response B. Candidates choosing this are probably confusing proton and nucleon number.

SL Q23 and HL Q25

At both levels distracter B was popular indicating that these candidates are confused about the distinction between the units MeV and MeV c^{-2}.

SL Q25 and HL Q33

Candidates now seem much more comfortable about the distinctions between renewable and non-renewable fuels.

SL Q26 and HL Q35

The question statistics show that only a minority understand with clarity the meaning of critical mass.

SL Q28 and HL Q36

This was a difficult question and one that needed clear thinking. The key is in the phrase "*maximum theoretical electric power available".* This depends on the rate at which energy can be extracted by the turbine and this depends on both the value of H_0 and the graph slope (related to the rate at which water can flow).

SL Q30 and HL Q37

Candidates were uncomfortable in applying their knowledge of the Stefan-Boltzmann Law to a simple climate model. It is important for them to remember that material from Topic 8 is firmly rooted in physical principles and laws, not simply descriptive material.

HL Questions

Q9

Too many failed to think carefully about the question and gave the standard answer for the area that they will have evaluated many times in class. However, this was not the standard question!

Q17

Candidates failed to appreciate that the resistors were simply in parallel. The frequency of distracters indicates that many candidates were at a loss. They would have been well advised to re-draw the network in a more familiar format.

Q18

Many failed to remember that a constant rate of change of magnetic field strength leads to a constant value of induced emf. Others forgot that the direction of induced emf is such as to oppose the change causing it.

Q19

A change in the frequency of rotation causes two changes in the output of a generator: an emf change and a frequency change. Many candidates suggested one but not the other.

Q31

This question is a topic mentioned specifically and directly in the syllabus. Many found it difficult with a significant number confusing atomic and nuclear energy levels.

SL Questions

Q2

Candidates needed to take care here – and many did not. Three, one or no vector quantities are all possible and incorrect. Candidates were probably careless in their reading.

Q5

A large number of candidates quoted the force *F* applied to the box, forgetting that the statement that the velocity is constant (hence no acceleration) is the key that the net force is zero.

Q16

Many failed to take care with the units and gave the correct magnitude but the wrong unit.

Q27

Many candidates think that changes in Earth's albedo and the Earth-Sun distance are significant enough to cause the annual variations in solar power incident on the Earth's surface.

Recommendations and guidance for the teaching of future candidates

Candidates should make an attempt at every item. Where they cannot provide the correct response, then they should always choose that option which, to them, appears to be most likely. It should be emphasised that an incorrect response does not give rise to a mark deduction.

Candidates probably read questions quickly and less than thoroughly. Questions are set as concisely as possible, and this means that all words are of importance.

Too often candidates are confronted by straightforward topics from the Guide and then reveal themselves as unprepared for these. Paper 1 tests assessment statements at objective levels 1 and 2. This will involve some straight recall as well as more difficult deductions within questions.

As noted in specific questions above, the physics involved in Topic 8 is not trivial and candidates are preparing themselves in too facile a manner for this area of study. The intention is that examinations of the Topic will cover real physics at an appropriate level and many candidates have not recognised the requirement to develop a full understanding at the required standard.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 9	10 - 18	19 - 30	31 - 40	41 - 50	51 - 60	61 - 95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 13	14 - 18	19 - 23	24 - 28	29 - 50

General comments

It should be noted that both the general and the specific comments refer to common errors and/or areas of misunderstanding and that the examiners saw some excellent scripts in which candidates showed a very good grasp of the underlying concepts of physics.

There were very few G2 responses at either level (15 at HL and 19 at SL) and it is therefore difficult to draw any meaningful conclusions. However, the majority of the responses noted that the papers were of a similar standard to last year and that the level of difficulty was appropriate. Nearly all responses indicated that the syllabus coverage was either satisfactory or good and likewise the clarity of wording and presentation of the papers.

General comments from teachers would seem to indicate that on balance, the SL and HL papers were both well received.

As last year, of particular concern was the lack of physics content in answering questions on the greenhouse effect and the enhanced greenhouse effect. It is not sufficient for candidates to simply use common sense combined with a bit of background reading. The topic needs to be taught with rigour and not anecdotally. Answers such as “the gases absorb radiation and so heat up the atmosphere” show no understanding of the topics at all.

It should also be noted that candidates can achieve marks through learning correct definitions. It was clear that most candidates were not aware of the importance of rigorous and concise definitions. Candidates should learn these as part of their exam preparation.

In this paper there was the usual balance between calculation and explanation and these involve different skills. The former were often done well, but it was evident that many candidates did not know how to express themselves clearly in explanations and/or discussions and as a result they lost a significant number of marks.

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

- The role of maximum and minimum gradient
- The enhanced greenhouse effect.
- emf
- electromagnetism
- Simple harmonic motion
- nuclear spectra
- Explaining concepts and processes clearly.
- Describing and explaining physical phenomena in a rigorous and logical way.
- Stating definitions precisely and unambiguously
- Presenting calculations in a manner easy for examiners to follow

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

- Performing simple calculations.
- Use of correct units and/or significant digits
- Reading data from graphs.

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

A1 Data analysis

HL and SL

Few candidates had difficulty with adding error bars but many seemed to miss the data point at the origin when drawing the line of best fit. Too often, as in the past, “line of best fit” is interpreted as meaning a straight line.

Explanations of why the data does not support a direct proportion were often incomplete with reference to the role of the error bars often missed. Also many candidates did not read the question carefully in that it asked for energy and not height.

HL

The few teachers who commented on the use of log graphs are referred to the mathematical requirements in the Guide. Not many candidates appreciated why lines of maximum and minimum gradient where given even though they often found the gradients of these lines. A recognition that a gradient of 0.25 does not lie within the range of the maximum and minimum gradients was rarely seen.

SL

The drawings of the two lines were often done well but again, explanations as to which theory is best supported lacked precision.

A2 SL only Circular motion and global warming

Many candidates stated that the car was accelerating because of the change in direction without specifying that it is the velocity that is changing direction. This is another example of candidates not being precise in their answers.

The problem was often well done and most candidates correctly identified carbon dioxide.

Rather than describe a mechanism for the enhanced greenhouse effect (see AS 8.6.5 in the Guide), many candidates described the greenhouse effect. A good description of this was credited with 2 marks.

A2 HL and B1 Part 2 SL Radioactive decay and binding energy

Descriptions of radioactive decay often lacked precision with no reference being made to a spontaneous or random process.

The senior examination team regret that even with all the checks and balances, beta + decay was asked for in the SL question. To make sure that candidates were not disadvantaged by this, all combinations of Z = 18 or 20 and neutrino/antineutrino were allowed for full credit.

In the calculation many answers just divided 37216 by 40 and there were some very esoteric answers as to why the binding energy of argon is greater than potassium.

A3 HL and SL Change of phase and latent heat of vaporization

The differences between evaporation and boiling with respect to temperature and surface area were generally well known and the calculation was also often done correctly.

Whereas many candidates realised that energy is lost to the surroundings they insisted, in spite of the question stating otherwise, that this would lead to a smaller value for the LHV. They did not appreciate that the value used in calculating the LHV is, because of energy loss, greater than the actual amount of energy used for the phase change.

A4 HL only Induced emf and transformers

The role played by Faraday's and Lenz's laws in establishing a current in a coil was not well understood. As in previous years, candidates generally find the topic of electromagnetism difficult.

Too many candidates thought that the rms value of a time-varying current is the average value of the current. The idea that it is a measure of the equivalent dc power dissipation is a concept that seems to be alien to many candidates even though this is clearly mentioned in the Guide.

Many candidates also failed to recognise that power loss in a transformer reduces as the square of the voltage.

A5 HL only Standing waves

Many candidates answered all parts of this question well and most managed to gain at least some credit. The most common error was in the calculation in failing to recognise that the wavelength is four times the length of the pipe.

A6. HL only Polarization

The distinction between polarized and unpolarized light often lacked precision; e.g. “the light vibrates in all directions.......”

Sketches were often correct but often not labelled.

B1 Part 1 HL (a), (b) and (c) and SL B3 Part 2 (a) (b) and (c) Electric fields and electrical resistance

Many candidates were able to correctly distinguish between a conductor and an insulator in terms of electrons but few seemed to realise that if an electric current is due to the net motion of electrons then a force is required to move them and that force is provided by an electric field. A hint to this was actually provided in the calculation that followed, a calculation that a surprisingly number of candidates got wrong.

B1 Part 1 HL (d), (e), (f) and (g) and SL B2 Part 2 (a), (b), (c) and (d)

Definitions of resistance often lacked a context. SL candidates were also asked to state Ohm's law and few appreciated the connection between the resistance of a conductor and constant temperature.

The resistivity calculation was often done well as were the power calculations. However, the examiners rarely saw a correct definition of emf. If candidates are unable to define this quantity then it is not clear how they can understand the concept. A simple definition as the power supplied per unit current would give candidates a clear insight into the nature of the concept as a property of a current supplying device e.g. battery.

SL only B3 Part 2 (d) and (e) Electric and gravitational fields

Many candidates did not know the differences and similarities between the two fields but the calculations were often done correctly.

B1 Part 2 HL only Radioactive decay

Descriptions of how the alpha decay spectrum provides evidence of nuclear energy levels were poor or completely wrong. Very few candidates understood that the different alpha energies represent decay to different energy states of the daughter nucleus.

Apart from gaining one mark for stating that the beta spectrum is continuous, few candidates gained any further marks in outlining how the beta decay energy spectrum suggests the existence of the neutrino. The idea of an energy difference between the maximum energy of the betas and energies of the other betas was one that escaped most candidates.

The calculation of the decay constant was a “show that” and although often done correctly, many candidates set out their working in such a disorganised and haphazard manner, that the examiners often had difficulty in assessing whether candidates actually knew what they were doing. The importance of setting out working in a clear and logic manner cannot be emphasised strongly enough.

The other two calculations were often done correctly.

B2 Part 1 HL and SL Oscillations and waves

Quite a number of candidates drew the wrong direction for the acceleration and explanations as to why the equation shows that the wood is executing SHM were not always clear.

There was much confusion in trying to show that the length of the wood is 0.70 m. Even though many candidates were able to determine a correct value of the angular frequency they were not able to make the next step.

Diagrams and labelling were often correct as was the calculation of the acceleration.

The wave speed was often calculated correctly but a common error was to mis-read the time axis as length and determine a value for the wavelength from this even though the wavelength is given in the question stem. This clearly demonstrates the need to read questions carefully.

Many candidates did not appreciate that the energy depends on the square of the amplitude.

B2 Part 2 HL only. Gases and thermodynamic processes

Answers as to stating a way in which real gases differ from ideal gases often lacked precision-e.g. “they do not obey the gas laws” or “there are no forces between the molecules of an ideal gas”. In the former answer, the examiners would be looking for “for all values of p, V and T” and in the latter “except on contact”.

Many candidates were able to state correctly what is meant by an adiabatic change and also to successfully complete the calculations.

Although a significant number of candidates recognised that degraded energy was no longer available to do useful work, they often failed to explain why in terms of the energy being dissipated. The 2 marks for the question and the command term “explain” should have alerted candidates to the fact that more than just a statement was required as an answer.

Whereas many candidates were able to score a mark for recognising that the second law of thermodynamics states that the entropy of the universe is increasing, they were often unable to take their answers any further. The examiners were looking for a recognition that entropy is a measure of disorder and that dissipated energy leads to a temperature rise of the surroundings and hence an increase in disorder.

B3 HL Part 1 and B1 Part 1 SL Fossil fuels and greenhouse effect

Many candidates were able to correctly state two reasons as to why world energy consumption is provided by fossil fuels but a common error was to give one of the reasons as cheapness; on its own this is meaningless.

The concept of energy density was generally well known and the calculation on rate of consumption was often done correctly.

Descriptions of the enhanced greenhouse effect were generally poor, lacking in precision and relevant detail. Many answers were anecdotal. Few candidates mentioned the random direction of the re-radiation by the greenhouse gases.

Many candidates thought that albedo depends on degree of latitude and there were few correct answers to show that the reflected intensity from Earth is about 100 W m^{-2}. The examiners were looking for an understanding that the radiation from the Sun is spread over the cross-sectional area of Earth. However, a large number of candidates gained one mark for calculating the percentage of the total radiation reflected due to the average albedo.

There was much confusion in converting between km and m in the calculation on sea level rise.

B3 Part 2 HL only Electric potential

Whereas a substantial number of candidates where able to give a complete definition of electric potential, not many could explain why the potential inside a charged sphere is constant; the examiners where looking for a recognition that the electric field is the gradient of the potential.

Answers to deducing an expression for the total energy of the electron in the Bohr model were poor but quite a few candidates gained error carried forward marks in estimating the orbital radius of the electron.

B4 Part 1 HL and B3 Part1 SL Momentum, energy and power

A significant number of candidates knew what Newton meant by action and reaction. However, there were few good discussions on the conservation of momentum as applied to the Earth-book system. Few candidates appreciated that the net force on the system is always zero and as such, the total momentum of the system is always zero.

In finding the energy dissipated as a result of the collision many candidates did not calculate the speed of the ball and spike after collision and so only gained partial credit.

Calculations of the frictional force and the time for the machine to raise the ball to a height of 1.6 m were often correct. Nonetheless, weaker candidates often did not know how to start and left the answer spaces blank.

B4 Part 2 HL only CCD's and digital data storage

Most candidates knew that the photoelectric effect was responsible for the emission of electrons from a pixel. However, outlines of how an image is formed were often confused and showed little understanding of the process.

It would seem that candidates either knew how to tackle the problem on the potential difference or did not and left the answer space blank.

Many candidates did not read the question about the retrieval of stored data carefully and instead of talking about retrieval of data centred their answers on the storage of data in general.

Recommendations and guidance for the teaching of future candidates

- Pay attention to the command terms and number of marks for a sub-question
- Use time to read through the question paper before starting to answer
- Read all questions carefully

- Candidates should be given precise and unambiguous definitions of physical quantities and they should learn these.
- Practice answering past examination questions
- Practice setting out calculations in a logical way
- Candidates when answering “show” or “determination” .questions should always make their ideas clear to examiners
- Give adequate time to the teaching of environmental issues.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 5	6 - 11	12 - 20	21 - 26	27 - 31	32 - 37	38 - 60

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 2	3 - 5	6 - 11	12 - 15	16 - 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. However, it should be realised that fewer than 25% of Centres submitted G2 forms.

Standard Level

- 50% found the paper to be of a similar standard to last year, 10% easier, 20% a little more difficult and another 20% much more difficult. Overall, 75% found the paper to be of an appropriate standard and 25% thought it too difficult.
- about 25% found the syllabus coverage satisfactory, with 75% considering the coverage good.
- 50% found the clarity of wording satisfactory with about 41% finding it good and 9% poor.
- about 73% found the presentation good and 23% found it satisfactory with none judging it as poor.

- The overwhelmingly most popular options were, in this mentioned order, A (Eye, sight and wave phenomena), G (Electromagnetic waves), E (Astrophysics) and B (Atomic, nuclear and quantum physics). The other options were underrepresented, chosen by very few centres.

Higher Level

- about 40% found the paper to be of a similar standard to last year, 40% a little more difficult and 20% too difficult. Overall, 65% found the level of difficulty appropriate and 35% thought it too difficult.
- about 47% found the syllabus coverage satisfactory and 30% good while 23% thought it was poor.
- about 47% found the clarity of wording satisfactory, another 47% found it good and 6% found it poor.
- about 41% found the presentation satisfactory while a larger 59% thought it was good.
- The overwhelmingly most popular options were E (Astrophysics), G (Electromagnetic waves) and H (Relativity) in roughly equal numbers. There was a very marked absence of scripts in option F (Communications) and few centres opting for Options I (Medical physics) and J (Particle physics).

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

- The careful and precise reading of values off graphs.
- Production of precise answers addressing the requirements based on the command verb present in the question.
- Providing sufficient depth and detail in questions with a mark allocation of more than one mark. This was particularly true in those questions involving the action verbs "explain", "discuss" and "describe".
- Lack of mathematical ability in handling ratio problems.
- Standing waves and the explanation of their variation in amplitude.
- Resolution applied to specific situations
- .Kinetic energy of electrons in the box model
- CCD's and quantum efficiency calculations
- Circuits involving operational amplifiers
- Black body spectrum.
- Refraction applied to optic fibres.
- Modulation and information signal.
- X-ray diffraction applied to specific measurements
- The Oppenheimer-Volkoff limit.
- Dose equivalent and dose quality factor
- Bubble chambers.

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

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

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

SL only

Option A – Eye, Sight and Wave phenomena

A1 Vision and the eye

Many candidates were able to score full or significant points on this question. Most stated clearly a function of cone and rod cells (even when many answers were as short as just mentioning photopic or scotopic vision), and most could describe correctly their distribution on the retina, eventually linking this distribution to explain in (c) why an object can be most clearly seen sideways in very dim light. Some candidates confused insensitivity to colour with black and white vision.

A2 Standing waves

Candidates seemed to be familiar with the topic but fewer than expected succeeded in identifying ω as 500π and therefore getting the frequency of 250Hz. The mathematical approach to show that the length of the string was 2.0 m was not usually explained consistently. A "show that" type of question requires reasoning displayed in a logical way as to identify the candidate understanding, and this was not always the case.

A3 Diffraction and resolution

Most candidates displayed the knowledge required to gain the marks from questions (a) and (b), reading correctly the graph (a graph that allowed for a precise reading of 0.0014 rad), calculating the λ as $5.6x10^{-7}$m or reproducing the pattern to the right (or left) of the shown one with the maximum at that mentioned angle. However, most showed problems to put that knowledge in context and apply it to a typical situation as the one presented through the analysis of the Very Large Array (VLA). Very few answers reached the correct value of $1.1x10^{17}$m.

A4 Polarization

This question showed a range of work from excellent answers to careless drawing of diagrams. Candidates who understood the situation easily gained full marks, with others losing marks particularly for a lack of or unclear labelling to unambiguously identify the expected horizontal graph at half the incident intensity as U and a curve starting at I_0 with minimum at 90 degrees and a second maximum at 180 as P.

Option B – Atomic, Quantum Physics and Nuclear Physics

B1 The photoelectric effect

This question was done reasonably well with many candidates gaining full marks. Even when the markscheme acknowledged and allowed for those candidates who calculated the maximum speed of the emitted electrons from the equation (as they could have been misled by the disagreement between the gradient and the theoretical value of the Planck's constant), leading to a value of 2.6×10^{6} ms^{-1}, the graph is supposed to represent results obtained experimentally and therefore does not necessarily have to reflect the theoretical ones.

Candidates were intended to use only the graph, as indicated by the stem "use the graph to", in the case of (b) (ii), and that should have and indeed produced in many cases the expected value of 6.1×10^{5} ms^{-1}.

B2 Quantum aspects of the electron

This question showed a very variable range of marks, from full to one, as candidates who attempted it usually scored in (a), showing familiarity with the concept of quantization. Some candidates muddled their answers in (b) (i) failing to show clearly the stated value of difference in energy by identifying the appropriate values for n=1 and n=2. The fact that the quoted formula incorrectly included π did not seem to disadvantage anyone, even though the markscheme had allowed for the correct answer of $\Delta E_{min} = 1.8 \times 10^{-17}$J for those working from the data booklet. Those who succeeded in (b) (i) usually obtained 3.4×10^{-8}m as the wavelength, with the markscheme also accepting 1.1×10^{-8} for those who might have checked the data booklet in (b) (i). The expected reason in (c) about spectral lines crowding in the infrared rather than in the ultraviolet as in the real H spectrum was mentioned by the most prepared candidates.

B3 Radioactive decay

The probability of decay per unit time (of a particular nucleus) or the constant of proportionality between activity and number of nuclei were the standard definitions accepted. Most candidates who scored quoted the first one approximately well. However, there still are candidates who quote mathematical equation for definitions without a proper identification of the symbols used. For (a) (ii), both 9.4×10^{10} and 9.6×10^{10} was accepted, as the discrepancy between the answers becomes negligible as the decay constant becomes smaller. Working from the definition of the decay constant ($\Delta N = \lambda N$) or through the equation ($\Delta N = N\ (1 - e^{-\lambda t})$) were then the paths accepted. Many explained reasonably well why the sample was shown to contain more than one isotope, but fewer succeeded then in estimating the second half-life as within the accepted range of 0.65 / 0.75 seconds, by using the extreme right part of the curve mainly produced by the decay of that second isotope.

Option C – Digital technology

C1 Charge-coupled devices (CCDs)

Within an option not chosen by a significant number of candidates, those who attempted it showed familiarity with CCDs. Despite answering correctly about the basics of its functioning, few were able to go through the basic mathematics even when both (b) (ii) and (b) (iii) were standard questions of this topic; more succeeded in expressing the equivalent voltage in binary notation though, identifying correctly the basic nature of the question.

C2 The mobile phone system

In a classic question about this topic, candidates were able to score from within the alternatives accepted for a base station (receiving/transmitting radio signals from/to mobile phones, communication with cellular exchange, selecting from the frequencies allotted to it by the cellular exchange for a particular call) and for cellular exchange (allowing entry in to the network, allocation of different frequencies to base stations, avoiding interferences, rerouting calls to different base stations).

C3 The operational amplifier

Even for the few candidates who were familiar with the typical graph showing the variation of the output voltage of a non-inverting op-amp and with the idea of saturation, solving/interpreting basic circuits proved to be a difficult and unsuccessful task.

Option D – Relativity and particle physics

D1 Relativistic kinematics

Usually well done, candidates showed knowledge of basic definitions about proper length and proper time, despite certain lack of precision in the wording. Length of an object in the object's rest frame or the length as measured by an observer at rest relative to it, were the alternatives given credit. The time interval between two events taking place at the same point in space or the shortest time interval between events were the alternatives credited for proper time. The calculations involving time dilation or length contraction were either correctly done by many or just inverted by a few, leading to either 4 easily gained or easily lost marks for (b). The markscheme prevented a possible unfair loss of the significant digit mark by allowing the answer 4 m for (b) (ii) instead of the technically correct 4.00. The correct identification of laser B was a pleasing confirmation of understanding in (c) (i). Calculation of the difference in time between the firings proved more difficult but some candidates gained at least one mark due to error carried forward by showing a subtraction (usually 6.25 – 5 instead of the correct version (6.25 – 4) if they continued to determine a time interval dividing that difference by the speed of the spaceship.

D2 Quarks

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 Stars and galaxies

The question aimed to assess E.1.4 of the syllabus ("Compare the relative distances between stars within a galaxy and between galaxies, in terms of order of magnitude", Physics guide, page 102), together with the need of basic mathematical requirements, as stated in the syllabus, within the geometry and trigonometry section ("Recall the formulae for, and calculate areas of, right-angled and isosceles triangles, circumferences and areas of circles, volumes of rectangular blocks, cylinders and spheres, and surface areas of rectangular blocks, cylinders and spheres", Physics guide p. 130). However, partial credit (1/2) was given in (a) to candidates who used the cube of the radius instead, failing to recall the formula for the volume of a sphere.

Those who did not score also failed to show understanding of the concept of density, dividing by a linear dimension. Most candidates were able to score in (b), either by getting the right value of (3.8x) 10^{16}, or by error carried forward, getting the ratio of their values in (a).

E2 Luminosity, size and distance of stars

This question was high scoring in all its points. All the skills involved and the concepts assessed in the question (reading values with different scales from a graph, analyzing luminosity, calculating ratios for radii, connecting absolute and apparent magnitude to determine distances and suggesting possibilities for the effect of dust clouds, and the balance between gravitational and radiative pressure in the case of point (c), only for SL) were all very pleasingly answered correctly by a majority of candidates. The markscheme allowed for a range of answers in the case of the values to be read off for luminosity and absolute magnitude.

E3 Cosmic microwave background radiation (CMB) and the density of the universe

The question was very specific and the majority of candidates seemed to ignore or misinterpret the graph presented or to regurgitate ideas about the Big Bang without answering the question. Very few related the graph to the black-body curve to move then to justify with calculations the 3K mentioned by many. The problems associated with determining the density of the universe scored higher, with the existence of dark matter being by far the most (but only) popular mention. For HL most candidates were aware and referred correctly to the expansion/cooling of universe as a reason to allow for nuclei formation.

E4 [HL only] Mass-luminosity relation and the evolution of stars

Compared to last year there was a clear improvement in the number of candidates with a solid idea about the Oppenheimer-Volkoff limit. However, about half still confused it with the Chandrasekhar limit and therefore lost marks in (b). Despite this, most candidates who attempted this option were successful in the algebraic analysis to confirm that star X was a main sequence star.

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

Completing a high scoring option, this question was in general well answered. Despite the fact that some candidates had problems calculating the velocity of recession, accepted as $3.81 \times 10^{6} ms^{-1}$ or $1.27 \times 10^{-2}c$, about half the candidates were aware and correctly chose either Cepheids or Supernovae as methods to determine the distances shown on the graph presented. A great majority though, was able to show the age of the universe as 10^{17}s by explicitly determining the inverse of the slope of the graph.

Option F – Communications

F1 Modulation

In the least chosen of the options, very few of the candidates attempting it could actually draw the information signal as expected, where the right frequency (with three oscillations within the diagram presented) was the marking feature. An advantage of FM over AM modulation was more successful, with the first two of the alternatives accepted more often stated by at least a few (better signal-to-noise ratio, greater bandwidth or most of the power in the sidebands. However, question (b) was often awarded one mark as candidates did not put emphasis in the "state and explain" nature of the question.

F2 Sampling

Surprisingly very few of the candidates who attempted the option could handle a basic calculation, which required them to determine the time between samples as the inverse of the frequency (0.125 or 0.13 ms were both accepted not to disadvantage through SD deduction), determining the duration of the sample as 4x4.0 μs and then subtract both, to obtain 0.109 (also accepted 0.11) ms.

F3 SL / F4 HL Transmission of signals along an optic fibre

Coincident with F2, this question seemed to indicate that candidates choosing this option were not fond of basic calculations. Very few answers applied Snell's law consistently to determine the critical angle as of 62.2°, and even fewer realized than the angle of refraction for (a) (ii) should be 90°-62.2° leading to the largest angle of incidence to be 46.7°. There were some good answers for (b), but about half the candidates could not realize (not really necessarily connected to the option) that the area under a power-time graph represents energy (in this case, the energy of the signal).The shape of the signal after travelling a large distance had a few candidates drawing it correctly (lower and wider, with a curved shape) but again, very few if any succeeded in determining the power of the output signal after travelling a given distance in the fibre.

F3 [HL only] The mobile phone system

This question was identical to question C2 in option C and the reader is referred to the comments in that question

F5 [HL only] The operational amplifier

This question was identical to question C3 in option C and the reader is referred to the comments in that question.

Option G – Electromagnetic waves

G1 Laser light

The question showed good knowledge from the candidates who were usually able to score 2 marks, with their references with some details to population inversion and stimulated emission. More details, particularly mention to the metastable state where electrons stay for longer times than in normal excited states was required for full marks. Almost all candidates scored both marks in (b), with their mention to coherence, monochromatic or unidirectional.

G2 SL G3 HL Interference

Even when a diverse range of strange diagrams were observed, a good proportion of the candidates managed to draw either the typical central interference pattern or the interference pattern moderated by diffraction, with both possibilities accepted. However, many candidates lost easy marks by drawing untidy diagrams where the minima did not clearly touch the horizontal axis or the spacing of maxima was not uniform. Calculation for the separation of the bright fringes was done correctly by many. However, many candidates who were then able to state correctly the effect of the glass on the pattern were not able to explain it successfully, usually scoring 1 both in (b) (i) and (ii).

G3 SL G2 HL The compound microscope

Most candidates were able to score both marks in (a) (i) by correctly determining the distance as 120 mm. Even when all candidates showed correct knowledge of real images, a few lost the mark in (a) (ii) by stating that it is real because is formed on the other side of the lens, which in its own does not explain why, as the command verb on the question required. A few problems with signs led to some candidates losing marks in (iii) but even then candidates tended to gain marks for the overall magnification at least through error carried forward.

G4 [HL only] X-rays

This question showed correct knowledge and understanding, with the usual problems in drawing careful diagrams putting attention to key details. Most candidates scored at least one mark in (a), losing the second due to non-vertical peaks or just peaks too wide. The remaining points were pleasingly high scoring, about a topic that has been clearly well covered by teachers. The identification of both mechanisms of the X-ray spectrum and the calculation to determine the Planck's constant were addressed correctly by a substantial number of candidates. Many though ended up scoring one or no marks in (d) either not realizing of the need of including the factor 2 to obtain the separation of the atomic planes as 2.39×10^{-10} m or just misinterpreting the formula to be applied.

Option H Relativity

H1 Frames of reference

The description of an inertial frame usually scored only one mark, as candidates tended to explain correctly the inertial aspect without doing so for the concept of frame of reference, where the mention to a coordinate system or a set of rulers and clocks was expected (i.e. a reference to the idea of frame of reference as a way to record events). Both (b) (i) and (ii) were usually done correctly, with a trend not to highlight the answer about the time being the same of the event in S'. Many candidates were familiar with the experiment mentioned by the syllabus in H.5.5. about the decay of a fast-moving pion into two photons.

H2 Relativistic kinematics

This question was identical to question D1 in option D and the reader is referred to the comments in that question.

H3 Relativistic mechanics

Very few candidates showed familiarity with this part of the syllabus or with the skills needed to determine the rest mass of upsilon (Y^0) to obtain the accepted answers of 9.49 or 9.50 $GeVc^{-2}$.

H4 General relativity

Candidates were familiar with Einstein's principle of equivalence, but many lost the mark with incomplete statements, where the accepted answers needed either the mention of a frame of reference accelerating in outer space (at *a*) being equivalent to a frame at rest in a gravitational field of g=a or an inertial frame in outer space being equivalent to a freely falling frame in a gravitational field. The suggestions for the frequency of the light beam measured at C to be less than at F were usually accepted either by focusing on the relative motion between the observer at C and the beam or by the equivalence principle focusing on the photon expending energy.

The path of light drawn as emitted from X was usually scoring the first two marks with many candidates drawing correctly a curved path hitting below Y both for the accelerating frame and due to the gravitational field, but failing to draw a straight line for the freely falling frame. The final question showed candidates identifying the experiment but drawing unclear and not labelled diagrams or not identifying correctly the two measurements needed to identify the bending of light.

Option I – Medical physics

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

I1 The ear and hearing

The few candidates who attempted this option showed an uneven knowledge about the ear and hearing. A few of them had problems to identify the basic feature of amplitude as the physical property related to the intensity of sound. More than a few had problems with the calculation and with the drawing of the variation with frequency of the threshold of hearing, doing it below instead of above the given curve.

I2 Ultrasound

The question was usually well answered with a good knowledge of both the definition of acoustic impedance and the explanation to match the impedances by the use of gel in order to avoid reflections and favour transmission.

I3 X-rays

Usually well done, with a correct definition of half-value thickness and correct calculations to obtain 2200m in (b) (i). Even those who failed to calculate the ratio correctly in (b) (ii) were aware of the protection provided by the atmosphere, even though sometimes the incorrectly calculated ratio was showing otherwise and therefore candidates needed to explain the contradiction to score. However, the topic of dose equivalent seemed not to have been correctly addressed as very few could handle question (d) (i), eventually scoring in (d) (ii) focusing on the protection provided by the plane or the clothing.

I4 Radio-isotopes

Usually well done despite some imprecise definitions of effective half-life.

Option J – Particle physics

Few candidates attempted this option. Those who did though, in general achieved pleasing results.

J1 Quarks

Most candidates who answered this option were familiar with quarks and were able to use the table to determine correctly the quark content of both the meson and baryon implied and the possible spin values for the meson (0 or ±1). Almost all candidates knew the Pauli exclusion principle even though some candidates did not score for their lack of precision referring generically to particles instead of identifying their application to fermions. Candidates were also familiar with the colour feature of quarks and deduced correctly quark flavour and colour quantum numbers in (d). Feynman diagrams (here and on other questions) were usually drawn and/or labelled much better than in previous examinations, although the number of candidates attempting the option comprised a limited sample.

J2 The bubble chamber

Both (a) and (b) were high scoring questions, with the standard answers expected identified correctly. However, (c) and (d) were not, with many candidates failing to outline why the pion was moving (because the photon paths are not opposite to each other) or suggesting the presence of magnets instead of the collision with molecules in the chamber as the reason for the shape of the path.

J3 Feynman diagrams

As mentioned above, and highlighting the limited nature of the sample, candidates attempting the option were familiar and seemed to have studied appropriately Feynman diagrams, as opposed to what had been mentioned in the past subject report about this specific topic. A common misconception was that quarks would join together to form hadrons instead of realizing that more quarks would be made

J4 The universe

There were fair explanations by candidates who usually scored at least two marks.

Recommendations and guidance for the teaching of future candidates

Recommendations from the examination team included the following ideas:

- Candidates should be given as many as possible opportunities during the course to practice examination style problems, look at past papers and analyze in detail the markschemes. They should be guided also in order to appreciate similarities and differences regarding the syllabus content with those papers from or before 2008 examination sessions.
- Candidates should be provided with, and given assistance to interpret correctly the list of action verbs as specified in the syllabus. It is clear that many candidates do not recognise the difference between, for example, the stating, the outlining or the explaining of an answer.
- Candidates should know in detail and be familiar with the formulae involved in the mathematical requirements stated in the syllabus guide, as those formulae are not provided in the data booklet.
- When using a diagram to help answer a question, candidates should be encouraged to pay attention to the precision of the diagram. This is particularly true when reading values off them, and when they are to draw specific characteristic features on them.
- Enough time should be devoted to cover in depth the Options chosen. There seems to be evidence to argue that some candidates are studying at least one option on their own, without enough deep meaningful discussion during class time.