May 2013 subject reports

Physics TZ2 (IBAP & IBAEM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 16	17 - 31	32 - 43	44 - 53	54 - 64	65 - 74	75 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 15	16 - 28	29 - 39	40 - 50	51 - 60	61 - 70	71 - 100

Higher Level Internal assessment

Component grade boundaries

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 Internal assessment

Component grade boundaries

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 is well established. Centres know the required paperwork and they more often than not perform established IA investigations. There were no significant problems. There were a variety of 4/PSOW forms but many centres were using the PDF version found on the OCC. The majority of candidate reports were word-processed and graphs were drawn on graphing programs. There is increasing use of ICT, and this is highly encouraged.

The vast majority of centres are providing a comprehensive practical program. Although many candidates are only assessed on several items, candidates nonetheless have experienced a variety of hands on activities, including ICT and numerous topics. Most candidate lab reports are word processed, and most graphs are produced electronically. There is a well-established set of teacher prompts for the Design criterion, and most candidates are doing a good job at this. Occasionally, however, teachers still require a hypothesis for Design, but candidates are not penalized for this. Also, occasionally, a teacher's prompt may contain two variables. This makes it impossible for the candidate to select an appropriate independent variable. One centre used computer simulations for all their assessment, and this is unsuitable for the current IA criteria. Finally, a few centres are treating design as a research topic, allowing candidates to use textbooks and the Internet. This is totally inappropriate as it leads to established and standard investigations, including relevant equations.

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

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

The range and suitability of the work submitted

Most centres had a comprehensive practical program and teachers are assessing appropriate work. Although mechanics has traditionally been the main focus of practical work, there is a range of hand-on activity in all major physics topic areas. The difficulty of investigations is consistently at the correct level. Indeed, this exam session the quality of IA work was exceptional. The use of ICT is now commonplace. 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.

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

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

Candidate performance against each criterion

Design

The vast majority of centres used appropriate and well-established design prompts. In a few cases, however, the prompts were not appropriate, such as asking a candidate to design an investigation to measure the specific heat capacity of water, or when the teacher provided both independent and dependent variables. Good design prompts are ones that have candidates looking for a function between two variables, not a specific value. Candidates need to be reminded that for a complete under design that variables need to be defined (and vague statement like “I will measure the time” needs 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. No hypothesis is needed under design, and the better design investigations are one where the candidate does not know the theory or relevant equation. Design is not a research or textbook based activity.

Data Collection and Presentation (DCP)

Candidates earned the highest marks under the DCP criterion. The vast majority of candidates are making good use of ICT, and word processing their reports and using graphing software. This is to be encouraged. Raw data always has uncertainty, and the candidate should address this. Moderators are looking for a brief statement to why the candidate gives a particular value of uncertainty, and this holds for both raw and processed data. When assessing DCP candidates are expected to have produced graphs. 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. There was one centre where the teacher awarded full marks for D and DCP where only two data points were graphed and there were no uncertainties. In examples such as this, the marks awarded by the teacher would be adjusted by the moderator.

Conclusion and Evaluation (CE)

Under CE aspect 1, 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, 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’. If candidates perform a standard and well-established physics lab, and CE is assessed, then it is unlikely that they can really come up with weakness or improvements. CE is best assessed when candidates also have designed and performed the investigation themselves. Many candidates construct two parallel columns corresponding to CE aspects 2 and 3. This helps the candidate make their ideas clear.

Recommendations and guidance for the teaching of future candidates

- Many centres are allowing candidates only two opportunities to earn their best marks. It is recommended that after candidates become familiar with the expectations of IA, that they have a number of opportunities to be assessed, perhaps three or four from which the highest two of each criterion are used for their IA mark. It is also recommended that simulations not be used for assessment.

- 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. Also, research on the Internet or in the library is not appropriate.

- Lab reports should have descriptive titles, like “How The Length of a Pendulum Affects the Period” and not “Pendulum” or “Physics IA”.

- Teachers should included comments on the candidate report or on an attached sheet that state exactly what level of achievement and why they awarded the mark, as such detailed attention to assessment allows an appropriate level of marking and is usually justified by the teacher. This practice is encouraged. If the teacher’s marks seem reasonable then the moderator will accept them.

Further Comments

One issue that came up several times in the May 2013 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 in other areas, 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. There were many outstanding examples of lab work, and lots of use of ICT. However, teachers are reminded that design investigations are not meant to be research projects. Searching the Internet is not appropriate; using established textbook theory and known equations should be avoided.

Moderators normally accepted 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 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 variable is independent and which is controlled.

Moderators do not mark down when similar (but not word for word identical) procedures are given for a narrow task. The moderator will make a comment on the poor suitability of the task on the 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, assessment statement 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, that is, 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 aspects 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”.

Higher level paper one

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 - 15	16 - 21	22 - 25	26 - 29	30 - 33	34 - 40

Standard level paper one

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 9	10 - 11	12 - 14	15 - 17	18 - 20	21 - 30

General comments

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

Only a small percentage of the total number of teachers or the total number of centres taking the examination returned G2’s. For SL there were 153 responses from 772 centres and for HL there were 164 responses from 731 centres. Consequently, general opinions are difficult to assess since those sending G2’s may be only those who feel strongly in some way about the papers. The replies indicated that the May 2013 papers were generally well received, with many of the G2’s received containing favourable comments. The majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level and generally in line with last year’s papers, although 23% found the HL paper (and 38% the SL paper) more difficult than the May 2012 paper.

With few exceptions, teachers thought that the presentation of the Papers and the clarity of the wording were either satisfactory or good.

Statistical analysis

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

The question key (correct option) is indicated by a shaded cell.

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

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	3890	850	198	450	5	72.13	0.28
2	215	604	4396	170	8	81.51	0.21
3	1116	628	3538	85	26	65.6	0.48
4	2675	711	858	1125	24	49.6	0.46
5	425	294	2674	1979	21	36.7	0.52
6	1385	152	396	3436	24	63.71	0.51
7	4101	329	835	110	18	76.04	0.33
8	611	4341	214	219	8	80.49	0.30
9	1329	2272	580	1180	32	42.13	0.56
10	1166	3820	155	247	5	70.83	0.37
11	3186	407	291	1497	12	59.08	0.25
12	925	1390	1539	1518	21	28.15	0.43
13	638	320	963	3440	32	63.79	0.49
14	1345	272	269	3489	18	64.69	0.42
15	3576	503	968	312	34	66.31	0.36
16	1593	1441	1477	831	51	29.54	0.53
17	1814	873	1924	749	33	35.68	0.34
18	3550	788	652	379	24	65.83	0.44
19	670	3848	723	135	17	71.35	0.52
20	819	958	2850	736	30	52.85	0.62
21	772	4489	72	56	4	83.24	0.28
22	245	3467	969	698	14	64.29	0.62
23	1104	2049	2046	161	33	37.99	0.58
24	2727	1652	651	318	45	50.57	0.45
25	295	1685	457	2925	31	31.24	0.00
26	206	851	395	3924	17	72.76	0.52
27	343	1858	303	2877	12	53.35	0.39
28	569	873	291	3634	26	67.38	0.42
29	3848	269	789	471	16	71.35	0.43
30	3503	1064	371	421	34	64.95	0.53
31	274	536	4064	499	20	75.36	0.44
32	607	897	3617	238	34	67.07	0.32
33	1204	493	3430	237	29	63.6	0.42
34	862	3672	144	689	26	68.09	0.32
35	205	47	183	4935	23	91.51	0.18
36	329	1240	2768	982	74	51.33	0.47
37	222	1106	1150	2884	31	53.48	0.34
38	344	224	4248	536	41	78.77	0.32
39	3244	865	884	298	102	60.15	0.60
40	1041	535	1133	2616	68	48.51	0.38

Number of candidates: 5393

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1057	1077	1037	1639	22	33.92	0.54
2	2991	948	328	552	13	61.9	0.34
3	1680	742	2264	115	31	46.85	0.56
4	2913	1421	244	246	8	29.41	0.27
5	1379	825	914	1685	29	28.54	0.35
6	1833	476	1955	549	19	40.46	0.37
7	614	459	2553	1150	56	23.8	0.34
8	855	294	445	3230	8	66.85	0.36
9	1013	3029	391	391	8	62.69	0.45
10	1422	1239	470	1663	38	25.64	0.36
11	487	2348	1762	202	33	48.59	0.62
12	511	370	2101	1836	14	10.58	0.19
13	605	599	1481	2101	46	43.48	0.47
14	1471	495	424	2386	56	49.38	0.44
15	178	3107	857	674	16	13.95	0.22
16	1255	812	1788	948	29	37	0.54
17	1283	2309	949	260	31	47.79	0.62
18	1191	1566	1395	600	80	28.87	0.17
19	556	2237	1028	974	37	46.3	0.62
20	164	3485	993	169	21	72.12	0.30
21	1489	1458	1222	613	50	30.17	0.13
22	442	1089	636	2637	28	54.57	0.61
23	398	387	4003	38	6	82.84	0.32
24	399	2125	378	1884	46	38.99	0.33
25	436	4229	105	46	16	87.52	0.12
26	1482	1285	1401	502	162	26.59	0.40
27	460	58	214	4071	29	84.25	0.29
28	501	1515	1875	870	71	38.8	0.43
29	542	560	3085	561	84	63.85	0.34
30	236	1120	1234	2177	65	45.05	0.39

Number of candidates: 4832

Comments on the analysis

Difficulty

The difficulty index varies from about 28% in HL and 11% in SL (relatively ‘difficult’ questions) to about 92% in HL and 88% in SL (relatively ‘easy’ questions). The papers gave an adequate spread of marks while allowing all candidates to gain credit.

Discrimination

All questions, except one, had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. This was achieved in the majority of questions. However, a low discrimination index may not result from an unreliable question. It could indicate a common misconception amongst candidates or a question with a high difficulty index.

‘Blank’ response

In both Papers, the number of blank responses was randomly distributed throughout the test. This may indicate that candidates had sufficient time to complete their responses, but simply left the questions they were unsure of. But there were an unusually high number of blank responses. Candidates should be reminded that there is no penalty for an incorrect response. Therefore, if the correct response is not known, then an educated guess should be made. In general, some of the 'distractors' should be capable of elimination, thus increasing the probability of selecting the correct response.

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

Candidate performance on the individual questions is provided in the statistical tables above, along with the values of the indices. For most questions, this alone will provide sufficient feedback information when looking at a specific question. Feedback will be given only on selected questions, i.e. those that illustrate a particular issue or drew comment on the G2's.

SL and HL common questions

SL Q2 and HL Q1

It should be noted that 'electric field strength' is a vector quantity.

SL Q5 and HL Q4

It would seem that a number of SL candidates misread the question and thought that the object was 'at rest'. This underlines the importance of reading the question carefully and not jumping to conclusions –candidates should have noticed the word 'frictionless' and concluded that the system must therefore have some acceleration.

SL Q7 and HL Q5

The statistics indicate that a good number of candidates overlooked the fact that velocity is a vector quantity. So its change, in this question is 8.0 ms^{-1}, not 2.0 ms^{-1}.

SL Q24 and HL Q27

Assessment statement 7.2.3 in the Physics Guide requires that the candidates are able to 'describe the ionizing properties of alpha, beta particles and gamma radiation'. It would seem that a number of candidates did not read the question, which asked for them in increasing order, carefully enough and opted for B, rather than the correct D.

HL Questions

Q7

On the surface of a planet the gravitational field strength can be taken as invariant. This did not confuse the candidates although there were a number of teachers who wondered how high the crater was and whether this would affect the acceleration.

Q10

The work done on a gas is the **total** area under a P-V graph. Many candidates incorrectly opted for response A.

Q11

There were a number of comments on this question from the teachers. In this situation the slight change in volume of the water/ice can be taken as negligible and it must be assumed that the water is not at 0^{o}C, otherwise no melting would occur. The statistics showed that the better candidates understood this, choosing A as the best response.

Q12

This question elicited a number of comments on the G2s and the statistics showed that the topic had been sufficiently understood by only the better candidates. These two systems were clearly not identical – otherwise they would have had the same y-intercept. Y had a blunter peak which was visibly to the right of X's peak, making D the best answer.

Q16

Around the same number of candidates opted for A, B and C. The better candidates clearly favored the correct response, A. A quick and simple sketch reveals the answer immediately – this should be the candidates' natural reaction given a resonance problem of this nature.

Q18

This was another question that elicited a number of critical comments from teachers, although the statistics showed two-thirds of the candidates choosing the response A. The amount of light reflected from a glass surface is negligible (and unquantifiable within the parameters of the question), so clearly A was the best response.

Q23

Candidates should first read the question and look through the possible responses, consulting the data booklet only if necessary. Clearly if a transformer is ideal then the power output will equal the input.

Q25

This question stem needed careful reading. The discrimination index of 0.00 showed that even the better candidates were jumping to conclusions. When work is done, it must be stated clearly what it is that is doing the work, and on what. So if a weight is being lifted, then the lifter is doing (positive) work against the field, which means that the field is doing negative work on the ball. This needs to be clearly spelt out to candidates. In this case there is a charge moving in an electrical field and the candidates are being invited to state the work done *by the field* on the charge.

SL Questions

Q1

The candidates found this question difficult with the statistics indicating that many may have been guessing. It is clear (also from paper 2) that many candidates are not comfortable with percentages. It may be a good idea for teachers to make sure their candidates can perform simple percentage calculations without recourse to a calculator.

Q4

The most popular response was A. It can only be guessed that perhaps the candidates were confusing the gravitational field strength with the acceleration of the body despite the clear reference to terminal speed in the stem.

Q6

The candidates were clear that the acceleration was decreasing – so had linked this conceptually with the decreasing force. Around half of candidates perhaps confused acceleration with velocity and decided the kinetic energy must also be decreasing.

This question is modelling what happens when an arrow is fired and as such it will be obvious that the speed is increasing while the arrow is in contact with the string.

Q8

This was well done by the candidates who correctly identified the origin of the force as the frictional force of the road on the tyres.

Q12

This question was very poorly answered. There are many graphs associated with simple harmonic motion (SHM) which are sinusoidal, but these are the graphs with *time* on the horizontal axis. Having *displacement* on the axis, though, will produce different graphs and candidates should be equally familiar with these. In this case it should have been clear that at the extremities of SHM velocity will be zero, while at the equilibrium point it will be maximum. So the only possible answer is A, showing half a cycle of SHM.

Q15

It was clear from paper 2 that candidates had no real grasp of the physical meaning of the different ways of representing a wave. They are comprised of oscillating particles, but can be represented either as ray, or as a series of wave fronts or graphically. It appears that this area of the syllabus is not being rigorously taught.

Q18

B was the most popular response, presumably as the candidates were thinking ‘twice the charge, twice the potential difference’. A moment’s back checking, however, would show that this would lead to an alpha particle with four times the energy of the proton; therefore the correct response must be C.

Q21

The candidates were not sure of how to tackle this. At some stage in their course, however, they should have seen wires carrying a current in the same direction, attracting each other; in which case this question is trivial.

Q25

Teachers wished to debate the answer to this question, but the candidates had no problem with it. In paper 1 candidates are required to give the **best** answer, which here is clearly B.

Q26

This was a difficult question as shown by the statistics. It is perhaps best done by considering the units. As long as the candidates know that the volume expansion coefficient is in deg^{-1}, then B is the only possible answer. It should also be noted that as the effective width and breadth of the oceans stay constant, the coefficient of volume expansion is the same as the coefficient of depth expansion.

Recommendations and guidance for the teaching of future candidates

Multiple Choice items are an excellent, motivating and highly time-efficient way of testing and promoting learning as a course is being taught. They can be used as warmers to stimulate discussion as well as for quick tests and should never be regarded as add-ons to be practiced, a paper at a time, solely for the final examination session.

There is no single most successful strategy with MCQs, so flexibility of thinking is needed. The correct response may be found by elimination, by consideration of units, by use of simple proportion, or by 'exaggeration' – mentally allowing one of the quantities to get very much larger, or smaller. Occasionally simple factual recall is needed.

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. Frequently responses can be eliminated, either because they are transparently absurd, or because two responses are logically equivalent.

Graphs, force diagrams and other means of illustration are a fundamental way in which physicists seek to model and understand the world. Candidates should be encouraged to sketch their answers to problems before they plunge into calculations. There is evidence, also from the written papers, that this is not the case.

The stem should be read carefully. It appears that some candidates do not read the whole stem but rather, having ascertained the general meaning, they move on to the options.

Multiple choice items are kept as short as is possible. Consequently, all wording is significant and important. They should also bear in mind that they are asked to find the **best** response. Sometimes it may not be strictly 100% correct but Physics candidates should be used to identifying and ignoring quantities that have negligible impact.

Candidates should consult the current Physics Guide (March 2007) during preparation for the examination, in order to clarify the requirements for examination success. There was evidence in this year's exam that 'new' questions were especially problematical for the candidates; teachers should be aware, though, that questions are constructed from the requirements of the syllabus – not from previous papers!

This Guide does invite the candidates to recall certain simple facts, although most of Physics is process orientated. Such facts lend themselves to Multiple Choice questioning so the teachers should not be afraid to require their candidates to occasionally memorise information. Definitions (which are universally poorly given in written papers) are perhaps best tested and learned with simple multiple choice questions.

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

Higher level paper two

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 13	14 - 27	28 - 37	38 - 47	48 - 57	58 - 67	68 - 95

Standard level paper two

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 6	7 - 13	14 - 19	20 - 24	25 - 28	29 - 33	34 - 50

General comments

168 sets of HL G2 comments and 158 SL were received from centres. A high percentage of centres (over 90% for both papers) thought that the papers were appropriate in standard.

80% of teachers felt that the papers were of a similar standard (56% of responses HL) or a little more difficult than the previous session. The clarity and presentation of the papers were regarded as good or satisfactory.

In fact the papers at both levels were, judging by the statistics, much easier than the previous session. Means were up significantly compared to previous sessions and the standard deviations remained similar indicating the presence of some easier questions than immediately past years.

There was comment from a small number of centres on the exponential decay in A1 (a)(ii). Some felt that it was beyond the limits of the SL syllabus. (An SL candidate should be able to state that a half-life curve is exponential (Physics guide assessment statement 7.2.6) and to determine half-life (assessment statement 7.2.8). These two statements together validate the question as asked.) Other comments suggested that the question was asked too early in the examination. However, it is normal practice to for the first question in paper 2 to be a data analysis question and deviation from this would probably have disturbed candidates even more.

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

- Exponential tests
- Calculations involving transfer of thermal energy
- Explanations of calculations in the context of questions where the candidate is asked to show the answer, or determine the answer
- **[HL only]** meaning of potential
- **[HL only]** explanations of electromagnetic induction effects
- **[SL only]** distinction between energy and momentum

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

- Use of kinematic equations
- **[HL only]** charge-coupled device calculations
- **[HL only]** diffraction and Rayleigh criterion

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

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

Section A

A1 **[HL and SL] Data analysis question**

(a) (i) Few candidates scored full marks. Too often examiners saw poor quality draughtsmanship and ruler-straight lines through the first three points. Most candidates were able to ensure that their lines stayed within the bounds of the error bars. Candidates are encouraged to read through the whole question before attempting to answer – had this been done then they might have gained additional clues from what followed. It should be noted that the skill being tested here was the ability of the candidates to ignore the points and draw a smooth curve through the uncertainty bars.

(ii) Good tests of exponential change were beyond many. Examiners expect to see a systematic test carried through accurately. A suitable test might include identification of half-life behaviour, constant ratio behaviour, or fitting to an exponential function. Each of these approaches could have scored full marks. Often there were vague and meaningless statements about the asymptotic behaviour of the graph.

(b) (i) This was adequately done by about half of the candidates although there were few confident tangents seen by examiners. Errors were to omit the unit and to try to work out a gradient over the full 30s.

(ii) Examiners expected to see an evidenced solution. Candidates who wrote down the answer without explanation gained little credit.

(c) The answer here had to use the answer to (b)(ii) and most candidates were able to do this satisfactorily. A substantial number failed to take account of the prefix to the unit in the resistance and were a factor of 10^6 out in their answer.

A2 [HL and SL]

(a) (i) and (ii) These were high scoring questions with a substantial number of correct solutions. Even those who could not answer (i) were able to take their incorrect value and use it correctly in (ii).

(b) This part was not straightforward and demands some thought by candidates – ideally before they put pen to paper. A number of candidates achieved two marks. Common faults included: setting the final speed in the water at higher than the final speed in air; a significantly curved first section before t_1; incorrect curvature between t_1 and t_2 and lack of a final constant speed or a zero final speed.

(c) **[SL only]** This straightforward question was not well done. Many candidates did not draw two clear lines of appropriate length with a ruler – crude, free-hand sketches were very common. The question asks for labelling and this should be done with words, not symbols. Mention of up thrust was not required in the answer, although its inclusion was treated as neutral.

A3 [HL] & B1 part 2 [SL]

(a) There was a widespread failure to respond to the command term. “Distinguish” implies some type of comparison but often candidates simply gave definitions (which could in this mark scheme attract full credit). However, only a few received two marks. Explanations of the meaning for thermal energy were weak and usually failed to make clear the need for a temperature difference in the transfer of the energy.

(b) (i) Many were able to access both marks, but some lost credit by then inserting an extra final step and going part way to the solution to (ii). As these candidates did not fully understand what was meant by “change in internal energy” they could not achieve full marks for this part question.

(ii) This part question was more poorly done than (i). Incorrect solutions included: failures to subtract the 28 kJ arrived at in (b)(i), and incorrect arithmetic.

(c) **[SL only]** (i) This was poorly done with most candidates unable to calculate the mass of water that had been vaporized.

(ii) The part question invites the candidates to consider the energy of the molecules and to link this to the constant temperature of the boiling water. Responses were mostly unfocussed with few candidates able to put forward a logical or clearly articulated explanation.

A4 [HL] & B1 part 1 [SL]

(a) (i) Although many were able to give a correct statement of the meaning of the term isotope there were a disappointing number who could not. In general, candidates should attempt to give clearer, more succinct definitions.

(ii) Equally, definitions of radioactive half-life were often weak, incomplete and confused, referring to the amount or mass of the total (rarely initial) substance rather than its activity. These are straightforward definitions to memorize and candidates would be well advised to spend time on this routine task.

(b) (i) The proton number was almost invariably correct.

(ii) All the basics of this question were understood, the calculation was not well completed by many. Candidates need to understand that to gain full credit in response to “show that” they must convince the examiner that all steps are shown. This is best done by taking the calculation through to at least one more significant figure than is quoted in the question and explaining each line of calculation in words. Even strong candidates are not as careful as they could be about this.

(c) **[SL only]** This was another question where the candidates needed to articulate a logical argument. It was extremely poorly done. It would seem that candidates are muddled between the concepts of energy and momentum. There were attempts to gain a mark but candidates did not consider in the first instance why the neutron energy has to be greater than 2.5 MeV. This should not have been beyond the more able SL candidate.

(c) [HL] & (d) [SL] Failure to recognize that the antineutrino not the neutrino is produced marred this normally well-answered question.

[SL only] (i) The graph was well done with most candidates able to draw a smooth straight line and read from their graph.

(ii) This part question was done confidently by the majority of candidates.

A5 [HL only]

(a) The question was worth three marks and candidates should look to provide three points: meaning of potential, nature of the test charge, and direction and position of the start and end points in the definition. Many gave two of these but not the third. Only a handful of candidates gave worthless accounts. Again, it should be stressed that candidates need to memorize definitions.

(b) (i) Candidates often fail to convince examiners in show that questions such as this. A complete quotation of the equation in use and a full substitution are required as a minimum.

(ii) This was generally well done. Candidates knew which equation to use and manipulated the data well.

(iii) This followed directly from the previous value. This was only recognized by about half the candidates; a good test of candidates' physics.

A6 [HL only]

(a) The explanation of the reason for the constant force required in moving the rod at constant speed was poorly done. There is an electromagnetic element to the answer and also a mechanics element. Only a very small number of candidates were able to come to terms with both in the answer. Indeed, a significant number were attracted down a route involving Lenz's law (required in (b)) and failing to provide any response about the constancy of the force. Others were clearly at a loss and were talking in terms of the motor effect, presumably thinking that the rod was driven by an imposed current.

(b) Lenz's law statements (first mark) were poor and unfocussed – again, this is standard bookwork that a candidate should be able to reproduce almost without thought. Most could not give any sort of connection between the law and the effect without a repeat of the previous answer which may or may not have been worthy of credit.

(c) About half of the candidature was able to arrive at a correct answer. Many candidates stopped having found only the total force on the rod.

Section B

B1 Part 1 [HL] & B2 Part 1 [SL]

(a) Many were able to state Coulomb's law or to give the equation with explanations of the symbols. Some candidates however failed to define their symbols and lost marks.

(b) (i) The electric force was calculated well by many.

(ii) The answer to (i) was well used to determine the magnitude of *E*. However, many candidates did not read the question and failed to state the direction of the field or gave it in an ambiguous way.

(iii) Calculations to show the order of magnitude of *H/E* were generally well done. The last step was often missing with the answer simply given as a fraction.

(iv) Many obtained this simple mark.

(c) (i) Many candidates gave confused or incorrect definitions of the emf of a cell. Previous comments in this report on the memorizing of definitions apply. Too many had recourse to the next part and used this idea in their answer.

(ii) This was well done.

(iii) A large number of candidates completed this calculation stylishly, generally explaining steps (or at least writing down the algebra) in a logical way. There were many correct and original solutions that gained full marks.

B1 Part 2 [HL only]

(a) Too often (in the vast majority of scripts) answers focussed on differences in the *microscopic* properties of idea and real gases. These were not judged worthy of credit. G2 comments that this was not on the syllabus were incorrect (assessment statements 3.2.12 & 10.1.2).

(b) (i) and (ii) Candidates were allowed the use of symbols for the thermodynamic quantities and consequently these were higher scoring questions than usual. However, some candidates only dealt with the nature of the change rather than going on to discuss the work done in the two cases.

(c) This was poorly done. Most failed to even select the correct part of the cycle before failing to provide a self-consistent account of the non-mechanical energy transfer.

B2 Part 1 [HL] & A3, B3 part 2 [SL]

(a) Many were able to obtain the minimum mass of coal with only a small penalty for a power of ten error. Solutions were usually logically presented and complete. A common mistake was the inability to process the percentage efficiency correctly.

(b) This is another case where candidates must be guided by the allocated marks. Four were assigned and it is reasonable that this is broken down into two marks plus two marks. Usually only one response worthy of credit was seen per advantage and disadvantage. Candidates must (as in previous examinations) be wary of giving trivial and vague responses: “radioactive waste is dangerous” “coal produces a greenhouse effect”, etc.

(c) **[(a) SL]** This was another calculation in which candidates are becoming well versed. There are a number of steps and many were able to negotiate them with ease. Failures included omitting the efficiency or getting it the wrong way up in the equation. Although full marks were given for the correct answer candidates would be well advised in such questions, to fully explain each step in their argument so that part-credit can be obtained. A jumble of arithmetic with the wrong answer will score zero.

(d) **[(b) SL]** A sizeable majority talked about the infrared radiation being trapped in the atmosphere. This did not attract full credit as it fails to grasp the nettle of the interaction between the earth’s surface and the atmosphere. A generous number of points were available on the scheme but most gained two out of three marks. This question was poorly answered by Spanish-speaking candidates.

(e) **[(c)(i) SL]** This was well done and explained by most.

(e)(ii) **[SL only]** This was another “show that” question. Candidates need to display reasoning - more able candidates could satisfy examiners on this point.

B2 Part 2 [HL only]

(a) Examiners saw a good standard of sketch graph with many accurate diffraction patters. The alignment between the two patterns for the purpose of the Rayleigh criterion was not so well done. It was sometimes difficult for examiners to decide whether there was alignment between the central maxima and a first minimum or otherwise. Examiners will not give the benefit of the doubt to untidy or ill-considered work.

(b) In the calculation of the Moon-Earth distance, explanations were often missing or negligent. Candidates did not consider whether to use 1.22 or not (either was accepted). Only clear reasoning was rewarded in the mark scheme.

(c) (i) Statements of the nature of polarized light were exceptionally poor and usually failed to give any description of what was acting in one plane. Examiners were looking for an attribution to the electric field vector or similar.

(ii) The usual error of forgetting to subtract the answer from 90° was committed by most candidates.

B3 Part 1 [HL & SL]

(a) Candidates were asked to define SHM as applied to the situation in the question. Many failed to do this and wrote in general terms about SHM.

(b) (i) This was well done.

(ii) Almost all candidates were able to identify a correct point for the maximum acceleration.

(iii) and (iv) Solutions for these were confused. Some attempted to use kinematic equations. Others mixed metres and centimetres in their answers. Other algebraic errors were present too (e.g. confusing $12^2 – 4^2$ for $(12 - 4)^2$). This is an area that candidates could practice more.

(c) (i) There were three marks for this question: for distinctions between longitudinal and transverse and for a clear description of the point of comparison. The latter was the mark most frequently lost. Many candidates have the vague idea that something about transverse is perpendicular and that the same parameter is parallel for longitudinal, but what “that something” is was frequently confused.

(ii) Candidates are now taking more care over the clear declaration of the frequency leading to the wavelength.

B3 Part 2 [HL only]

(a) (i) Capacitance was generally well defined.

(ii) Many gained a mark for suggesting that the process was related to the photoelectric effect. Too many went on to repeat the question in terms of “build up of charge”. Few took the hint from (i) that a response in terms of capacitance was required.

(iii) It was common to see one of the two required responses present (usually potential difference) but rare to see both quoted.

(b) The multi-step calculation was generally well done. Calculations appeared to be reasonably laid out, but examiners would still wish to see more explanation of the steps in order to award partial credit. Some candidates obtained ludicrous values for their answer. They should be aware that impossibly large or small answers are unlikely to be required.

B4 Part 1 [HL] & B2 Part 2 [SL]

(a) Most could define linear momentum correctly using the terms mass and velocity.

(b) A common error re-emerged in this examination. If asked to state a law of conservation a candidate must *not* simply say that the “quantity is conserved”. This tells the examiner nothing (other than that the candidate has read the question) and will never attract marks. This is a simple examination skill that many candidates continue to fail to learn.

(c) Few were able to give adequate discussions of the how momentum conservation applies to one of the most common cases discussed in teaching at this level, that of a rocket in free space. There was no clear recognition that the system is closed or even what the system is or that the important factor is the *change* in momentum of the fuel and therefore the rocket. These are difficult ideas for candidates to grasp but examiners expected better attempts from the most able.

(d) (i) This was well done.

(ii) About one-third of candidates failed to recognise that the mass of Joe needs to have the mass of the ball added to it for a correct solution of the problem.

(e) Most candidates adopted an approach via repeated applications of kinematic equations, although an energetic approach would have involved less repetition for them. Inaccuracies in manipulating Joe’s mass were not penalized twice.

B4 Part 2 [HL only]

(a) This frequently asked question was well answered.

(b) This was poorly done with many candidates attempting an approach that involved the direct use of $c = f\lambda$ with a spurious speed substituted in the equation. The approach via use of the momentum of the particle was rare.

(c) (i) This was also poorly done. Candidates failed to identify the argon nucleus as the relevant one to talk about, and even if they did, they were prone to ascribing the origin as due to electron transitions in the atomic shells.

(ii) The calculation of the age of the Earth was well done by many using a variety of approaches. Approaches that failed included an erroneous attempt via a proportional half-life.

Recommendations and guidance for the teaching of future candidates

- Require candidates to memorize definitions
- Insist that calculations are presented in a logical and well-explained way
- Developing logical written arguments

- Ability to make a quick and accurate sketch graph of the relationship between two variables
- Simple algebraic transformations and ability to handle powers in equations
- Learn to use reading time wisely and to read questions carefully and accurately

Higher level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 15	16 - 23	24 - 29	30 - 34	35 - 40	41 - 60

General comments

The paper discriminated well. The vast majority of candidates appeared to have sufficient time to complete their answers.

154 of 167 of HL centres responding found the level of difficulty appropriate. 11 centres thought it too difficult. 2 thought it too easy. 116 of 159 HL centres thought the paper was of the same standard as last year. 32 centres thought it more difficult. 11 centres thought it easier than last year.

The majority of HL centres thought that the presentation of the paper and clarity of wording was either good or satisfactory. 19 centres thought that the presentation of the paper was poor. There were comments from teachers on the presence of a blank page in Option I. This is not the first occasion that a Paper 3 has been in this format. Candidates are reminded to be mindful of the internal instructions in the examination paper and to check that they have answered all questions in an option.

Option E (Astrophysics) is the most popular option, closely followed by G (Electromagnetic waves), I (Medical Physics), H (Relativity). Relatively few centres attempted option F (Communications) or J (Particle physics).

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

General difficulties (HL and SL)

- Highlighting key phrases or data in a question.
- Checking that questions have not been missed. Candidates are reminded to turn the page.

- Crossing out work that is correct and not replacing it with an alternative answer.
- Knowing what the symbols represent in a data book formula or equation.
- Powers of 10 and unit prefixes.
- Use of the inverse square law and the formula for the surface area of a sphere.
- Careless arithmetic and algebraic errors. Calculator mistakes are far too common.
- Showing working in 'show that' questions. Always show more significant digits than are given.
- General layout of working in numerical questions - needs to be planned and methodical.
- Sequencing the presentation of facts to support an explanation or description.
- Use of a ruler in drawing diagrams. Even for sketches it can be very useful.
- Paying attention to specific command terms - determine, explain, estimate etc...
- Paying attention to the number of marks awarded for each part question. Often candidates provide fewer key facts than required.

Higher level difficulties

- Apparent and absolute magnitudes of stars - particularly the reverse scale.
- Correctly referring to peak wavelength in a black-body graph - not maximum wavelength.
- The values, in terms of solar mass, of the Chandrasekhar and OV limits for neutron stars.
- Distinguishing red and blue-shifts and realizing that the latter is for approaching galaxies.
- The conventional units for and approximate value of Hubble's constant.
- The relationship between sampling rate and bit-rate.
- Operational amplifier circuits, virtual earth, current flow and the condition for saturation.
- Sequencing events in explaining mobile phone communications.
- Knowing the function of a cellular exchange. Many believe that it is a process.
- Differences between and sketches of diffraction/interference intensity patterns.

- X-ray production and the explanation for the minimum wavelength.
- Knowledge of the phase change for 'hard' reflections.
- The mechanism for colour production for white light incident on thin films.
- Relativistic kinematics, especially simultaneity and time dilation.
- Relativistic mechanics, especially the use of the units MeV, $MeVc^{-1}$ and $MeVc^{-2}$
- Definition of attenuation coefficient and the use of units such as cm^{-1}.
- Dosimetry calculations, including changing eV to J and using time in seconds.
- Symbol knowledge and use of the available energy equation for particle collisions.
- The operation of a wire chamber - but modest improvement is evident.
- Feynman diagrams, especially the direction of the time axis for anti-particles.
- Deep inelastic scattering and asymptotic freedom.

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

The best candidates have fully covered the syllabus, show good understanding, can manipulate equations, show all working in a methodical way and explain concepts with clarity. The weakest candidates often fail to read the whole question, have poor knowledge of concepts, lack conciseness and clarity in answers, don't show all working or use the wrong equation. Clearly many candidates have studied past papers and are able to demonstrate good knowledge of the commonly tested parts of the syllabus. Candidates often perform far better with calculation questions than with questions requiring recall of laws, definitions, experiments and concepts. Weaker candidates may score all of their marks on calculations, which possibly indicate that this is often all that they have been prepared for. Options A, B, E, and G at SL and E, H, G and I at HL are very popular and most candidates make a good effort to tackle these questions.

Noted improvements at HL

- Very few candidates answering fewer or more than two Options.
- Keeping responses within the answer box provided.
- Referring to the use of an extension sheet within the answer box.

Some improvements in knowledge or understanding were seen in the following syllabus areas:

- Interpretation of HR diagrams

- Hubble's law definition
- Interpretation of AM waveforms
- Calculations involving decibels
- Use of the Bragg formula
- Length contraction
- Calculations involving the Lorentz factor, gamma
- Statement of the equivalence principle
- NMR imaging (a very noticeable improvement)
- Hadron structure
- Quantum numbers and their conservation rules

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

Higher Level (questions marked * were also on the SL paper)

The * comments for Options E to J also apply to SL candidates although there are few additional comments that apply only to SL. SL unique questions are covered in the SL P3 section of this report.

Option E - Astrophysics

The most popular Option.

***E1. Stars** (a) was well answered, although <u>apparent</u> magnitude at 10pc was often missed. In (b)(i) and (b)(ii) the explanation for choosing star X was often missing and powers in the table were often misunderstood. Candidates are often unsure whether to describe star Y as having higher or lower absolute magnitude than star X. It is less ambiguous to refer to star Y as having greater luminosity. (c)(i) was done very well with just a few making arithmetic errors, such as forgetting the square root. In (c)(ii), most candidates chose a suitable red star temperature and could calculate the radius. Too many chose an incorrect surface area formula. Almost everyone identified star X as a red giant/supergiant in (c)(iii) due to its radius (~ 1 AU), and 'low' temperature. A common mistake in (d) was to refer to the 'blackbody' spectrum, but most HL (and some SL) candidates were able to obtain 1 mark for reference to the dark absorption lines of a star's spectrum. Some candidates even referred to Doppler-shift corrections being necessary to match these lines with laboratory emission spectra.

***E2. Cosmology** In (a) far too many candidates did not refer to characteristics such as CMB is blackbody EM radiation peaking at 2.7K, has no specific source, is isotropic etc. In (b)(i) most graphs showed a blackbody wavelength peak, but not always the necessary asymmetry.

Reference to 'maximum wavelength' is not correct in (b)(ii) - peak wavelength or wavelength at maximum intensity are better terms. The fact that CMB was a specific prediction of the Big Bang model, long before its discovery, was generally not mentioned in (b)(iii).

E3. **Stellar evolution [HL only]** (a) (stellar mass ratio) was well answered, although sometimes the working was poorly presented. Hydrogen depletion was usually not specifically mentioned, in (b)(i) as the cause for a star to leave the main sequence. Many gave unnecessary information about the subsequent path to a neutron star. For (b)(ii) the upper or lower limits for the mass of a neutron star were known, but rarely both. The range 1.4Ms to 2.5Ms or 3Ms was allowed. Often the names of the limits were given, but not the values.

E4. **Hubble's Law [HL only]** The statement of Hubble's law is a frequent question and was generally well answered. However too many candidates still mention planets or stars rather than galaxies or omit to mention recessional velocity. In (b)(i) the value of the velocity of M31 was almost always correct, but 'towards Earth' was usually missing. Hubble's constant calculations were done well in (b)(ii), with a variety of units used. It was expected that candidates would refer to the fact that M31 is not very distant and does not recede as a reason for the value in (b)(ii) being invalid. Few did. Instead reference was often made to the reason for the general uncertainty in the value of H - probably because the latter has been a more usual question in recent past papers. In teaching this topic it is obvious that a range of values for H can be found in textbooks. These can easily become out of date, but the value obtained in (b)(ii) was about 5 times that currently accepted. Candidates are obviously expected to have some idea of this value.

Option F - Communications

This option was chosen by few candidates.

***F1**. **Modulation** (a) was done well, with just a few errors in reading the modulation graph. The most common error was in knowing which features of the graph to use for calculating the amplitude of the signal wave. The power spectrum in (b) was also usually correct, having sidebands shown with lower power.

SL candidates showed little knowledge of this topic and appeared to be simply making guesses from the graph provided.

***F2**. **Digital Transmission** In (a) very few candidates knew that the minimum sampling frequency, for faithful reproduction of a waveform, is twice the signal frequency. Hence the maximum signal frequency is 22 kHz. The Shannon - Nyquist theory, mentioned in most IB Physics textbooks, was occasionally referred to. There were many wrong values for bit-rate; many divided when they should have multiplied.

***F3. Attenuation** (a) The meaning of the term attenuation is well known by most, but references to energy loss in cables due to resistive heating or EM radiation were fairly rare. In (b) (i) candidates often overlooked the 13dB signal loss that was allowed. Nevertheless many used simple calculations to determine the need for 35 amplifiers. (b)(ii) was generally well answered in terms of less attenuation (per km) in optical fibers than copper cables, although many stated that the optical signal speed was greater. They are comparable.

At SL, the calculation was attempted by most but received very few marks. The advantages of optical fibers were not that well appreciated although candidates were able to gain some marks by guessing or using their own general knowledge.

***F4**. **Operational amplifier** In (a)(i) candidates often repeated the question by referring to an amplified, inverted signal , rather than to opposite polarity/sign. (a)(ii) and (iii) were not well done and many were unable to state that the currents in the two resistors are almost equal. (b) was easier, but often the negative sign for gain was missed or saturation overlooked in (b)(ii).

At SL, the responses to these questions were generally hit or miss and it appeared that candidates were either well prepared or not prepared at all for them).

***F5**. **Mobile phone systems**: Candidates often failed to sequence their answers in a logical way. Many thought that a cellular exchange was a process rather than a physical computer system and so thought that the question was only asking about the handover that occurs when a mobile phone is moving between cells. This question was a good discriminator and was only well answered by candidates who had presumably been taught the skills of sequencing the delivery of information. Encouraging the use of bullet points is recommended and perfectly acceptable in examinations. Even the weakest candidates will have some success with calculations; the strongest candidates will also be able to handle descriptive questions like F5.

Option G - Electromagnetic waves

This was the second most popular Option.

***G1. EM wave properties** Both parts were well answered by the majority. A small number of candidates did not realize that the wave diagram needed to be labeled or only showed one point on the wave to represent the wavelength. Careless candidates often referred to the fact that all EM waves travel at the same speed, but omitted to say in a vacuum/free space.

***G2**. **Astronomical Telescope** (a)(i) was a 'show that' question, but many simply stated the definition of focal length in long-winded written answers. More perceptive candidates used the lens equation to show that $d=f$ since $u=\infty$. Answers varied from perfect to imperfect for parts (i), (ii) and (iii), although most candidates gained marks. The use of a construction line from the tip of I to the centre of the eyepiece enabled many candidates to produce an accurate diagram easily. Not all candidates used rulers. (b) was answered correctly by the majority.

***G3**. **Interference** (a)(i) was surprisingly poorly answered. Very few mentioned zero path difference for the central fringe. In (a)(ii) a common mistake was to ignore the factor of two resulting from the distance given being between M and the first minimum. In (b) the regular intensity distribution, for double slits, was drawn well by many. Quite often a single slit diffraction pattern was shown and this scored zero. Many had seen previous past papers and knew what to write for (c) - brighter, narrower maxima, same spacing.

G4. X-rays (a)(i) A 'show that' question signifies that detailed working must be shown as the final answer was given. Not all candidates are aware of this fact. Nevertheless the vast majority gained the first mark for substituting the correct values into the minimum wavelength equation. To show that a calculation was actually performed it was necessary to show at least one more correct significant figure than is given in the question. (a) (ii) was poorly answered. Candidates often restated the question by writing that this was the most energetic X-ray possible, rather than referring to the maximum electron energy (of 28keV) producing a single photon. In (b) crystal spacing was usually correct, but inevitably some candidates omitted the factor of two in the Bragg formula or used the wrong angle.

G5. Thin film interference (a) There is considerable uncertainty amongst candidates about the surface at which a phase change occurs on reflection. (b)(i) was an easy two marks for most. However (b)(ii) was poorly answered. More often than not only refraction, diffraction or dispersion were mentioned - even though the G5 question was clearly indicated as being about thin film interference. It is very good practice for candidates to read the stem of the question carefully before starting, and to highlight key phrases or data.

Option H- Relativity

***H1. Relativistic kinematics** In (a) the key words <u>at</u> <u>rest</u> (relative to an observer) were sometimes missing in the definition of proper length. The whole of (b) was done well by nearly all candidates (But not so well by SL candidates). Length contraction seems well understood. In (c) an estimated 1% of candidates knew that the question had nothing to do with light that Albert sees. Almost all of the remaining percentage of candidates explained that light 'reached Albert' at different times. This is irrelevant. The question is not about Albert seeing the light arrive, but is about the moment the light leaves a particular lamp. Since many centres have submitted G2 comments doubting the correctness of this question, here is an explanation. The reasoning is as follows: Each light wave has to travel from one event (emission) to the next event (reception by <u>Mileva</u>). While the two light waves are both traveling at speed c, Albert sees Mileva move left, towards the light <u>waves</u> emitted by the entrance lamp. Thus he can deduce that the light from the entrance lamp has a shorter distance to travel to Mileva than light from the exit lamp in <u>his</u> frame. To reach Mileva at the same time as light from the exit lamp, the entrance lamp must have switched on second. (Which light he actually <u>sees</u> first depends on which side of Mileva he is, but is not part of the question). Simple spacetime diagrams, although not mentioned in the Subject Guide, will help candidates visualize such events. Happily the constancy of the speed of light often came to the rescue to allow one mark to be gained. In (d) there were many completely correct answers, but some were confused about the exact nature of the two events, which had nothing to do with the length of the tunnel. Far too many candidates were unsure about who measured the proper time and who measured the dilated time. See comments for H2 below.

This question was done less well by SL candidates.

H2. Muon decay [HL only] (a) provided an easy two marks for the majority, as did (b)(i) for the muon half-life in the Earth rest-frame. In (b)(ii) not all candidates referred to their previous answers, as directed, in explaining the evidence for time dilation. There is uncertainty about the meaning of the words 'dilated time' and who perceives it. Candidates need to know that **dilated** means larger/longer and refers to the longer elapsed time on two <u>different</u> clocks in the observers frame compared to the shorter elapsed 'proper time' on a single, relatively moving clock. In other words, the relatively moving clock's elapsed time (between two events at which this clock is present) is always less than that between the observer's two clocks separated in space. This is a very difficult concept and candidates really need to try to get to grips with it. Without reference to clocks it is almost impossible to understand time dilation or simultaneity. Spacetime diagrams are helpful again here. Due to this misunderstanding there were many references to 'time running slow **for** the muons'. This is incorrect. Muon's time runs slow **for** the Earth observers. The difference is subtle but important.

H3. **Relativistic Mechanics [HL only]** In any question with units expressed in terms of c there is potential for confusion. However many candidates are now able use the relativistic energy - momentum equation correctly. (a) was well answered by many and in (b) gamma was often obtained correctly to find *V* - but many more got lost. Surprisingly no useful 'Pythagorean triangles' were seen which make understanding this topic much easier.

H4. **General Relativity [HL only]** (a) The equivalence principle was usually stated, but not always in unambiguous terms. In (b) very few candidates could work out what would happen. Many identified that this was equivalent to a gravitational field, but did not state that the direction was to the left. Few mentioned that helium was less dense than air and so would move right, in the same direction as the acceleration of the spaceship. Admittedly it is counter-intuitive. (c)(i) and (ii) were an easy two marks. But in (c)(iii) far too many candidates just stated that the position of the star should also be measured at night, without realizing that at night the star would be still be 'close' to the sun and so not in the night sky. It was expected that they would mention measuring the star’s position (at night!) when it is not 'close' to the sun - such as in six months time. More usually they referred, incorrectly, to measuring the distance to the star or measuring the mass of the sun. (c)(iv) was done well.

Option I - Medical Physics

I1. Hearing (a) The Intensity level formula was correctly stated by the majority, but sometimes symbols were not defined for the mark. (b)(i) was a 'show that' question which gained nearly everyone two marks. Most candidates seem confident in working with dB. However, calculating the distance at which the intensity level falls to 90dB was too difficult for most candidates as they could not identify which values to use or seemed unaware of the inverse square law.

I2. X-rays (a) Very few could define attenuation coefficient. Far too many candidates tried to define it in terms of half value thickness. If a defining equation is stated marks are only awarded if the meaning of every symbol is given. (b)(i) proved difficult for a candidate who did not realize that almost all of the low energy X-rays would be attenuated inside the body and so would never even reach the sensor. Even so they could answer (b)(ii) well in terms of less exposure to harmful X-rays. Arithmetic errors in (b)(iii) were common unless they were fortunate enough to work in cm. There were very few who did. An attenuation coefficient of 3 cm^{-1} was often mistakenly converted to 30 mm^{-1} .

I3. **NMR imaging** Both parts of this question were answered very well. It is clear that previous questions on NMR imaging have reaped benefits as now the majority can list most of the main physical principles involved.

I4. Radiation and Dosimetry (a) proved difficult if a candidate ignored the words 'diagnostic purposes'. Some candidates knew that gamma rays penetrate body tissues so that the isotope's location can be monitored; but many only referred to the low ionizing ability of the radiation or thought that the radiation was being used for therapy. In (b) most candidates realized that there was minimal damage to healthy tissue in method 1. (c)(i) and (ii), concerning physical and biological half-life, provided three easy marks for most. Weaker candidates simply reworded the question. There were few completely correct answers in (c)(iii). Some overlooked the 5.5h - or failed to work in seconds. Some failed to convert keV to J. Some made power of ten errors. Some did all of these.

Option J - Particle Physics

Relatively few candidates chose this option.

*J1. **[SL D2] Quarks and interactions (**a) was an easy mark, but it was expected that the meson structure would be very specifically stated. **In** (b) The magnitude of h/4π was rarely calculated. Pauli's exclusion principle was usually well stated in (c), but in (c)(ii) the fact that color is a quantum state was rarely mentioned. (d)(i) was very easy as was (d)(ii), although many did not mention the zero mass of the photon. (e) was almost always answered correctly.

J2. **Particle production** (a)(i) a strangeness = -3 was usually correctly given, as was the identification of X as a baryon. In (b) the calculation of the mass of X was rarely completely correct. Sometimes the wrong target mass was used, sometimes c was used in the calculations. (Many candidates struggle with these awkward units). Sometimes the Kaon masses were not subtracted from the energy available. Knowledge of the operation of the wire chamber is improving, but too many candidates confuse it with a spark counter, geiger counter or bubble chamber.

J3. **The standard model** (a) and (b) The explanations of asymptotic freedom and deep inelastic scattering are improving, but are often still far from clear. This is worth setting as a homework exercise as it is frequently asked. The Feynman diagram for the decay of the Higgs' boson in (c) was often only partially correct. A common mistake was to show antiparticles (positrons, antineutrinos) literally travelling backwards in time. Of course only the arrows point backwards. To gain marks it was necessary to show the Higgs decay to two W bosons, followed by at least one of the decays of a W boson to two leptons.

J4. **The early universe** (a) was either done using particle masses in $MeVc^{-1}$ or in kg. However often only one electron/positron mass was used. Boltzmann's constant was sometimes confused with Coulomb's constant. Many correct answers were seen. (b) was very poorly answered as there was no evidence that candidates realized that there would be a (blackbody) distribution of photon energies for any given T.

Standard level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 15	16 - 19	20 - 23	24 - 27	28 - 40

General comments

The papers discriminated well. The vast majority of candidates appeared to have sufficient time to complete their answers.

Almost all (157 of 163) centres found the level of difficulty appropriate. 6 centres thought it too difficult. None thought it too easy.

115 of 152 centres thought the paper was of the same standard as last year. 24 centres thought it more difficult. 13 thought it easier than last year.

Almost all centres thought that the clarity of wording and presentation of the paper was good or satisfactory. Three centres thought that the clarity of wording or presentation of the paper was poor.

Options A (Sight and wave phenomena), E (Astrophysics), B (Quantum Physics) and G (Electromagnetic waves) continue to be the most popular, whilst options C (Digital technology), D (Relativity and particle physics) and F (Communications) are chosen by far fewer candidates.

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

- Depth of vision is a poorly understood concept.
- Resolution – drawing neat diagrams to show the case of the patterns being just resolved.
- Resolution – calculations to find maximum distance and the effect of changing wavelength.
- Wave and particle theory in relation to the photoelectric effect.
- Calculations related to the photoelectric effect.
- Nuclear energy levels – many candidates referred to electron transitions.

- Nuclear energy levels - evidenced by discrete alpha and gamma spectra.
- Formation of images on a CCD.
- Calculations related to magnification and resolution of images.
- Simultaneity – many took the wrong approach in answering this question.
- Nuclear Spin related to NMR.
- Mass and range of exchange particles.
- Using numerical information about stars to compare distances.
- Nature and significance of the CMB/CBR is poorly understood.
- The interpretation of the limitation imposed on output signal power was not well understood.

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

The best candidates have fully covered the syllabus and show good understanding, can manipulate equations, show all working in a methodical way and explain concepts with clarity. The weakest candidates often fail to read the whole question, have poor knowledge of concepts, lack conciseness and clarity in answers, don't show all working or use the wrong equation. Clearly many candidates have studied past papers and are able to demonstrate good knowledge of the commonly tested parts of the syllabus. Candidates often perform far better with calculation questions than with questions requiring recall of laws, definitions, experiments and concepts. Weaker candidates may score all of their marks on calculations. Options A, B, E, and G at SL and E, H, G and I at HL are very popular and most candidates make a good effort to tackle these questions.

Noted improvements at SL

- Simple numerical questions involving one equation.
- Standing wave descriptions and diagrams.
- Doppler effect.
- Radioactive decay.
- Advantages of digital recordings over analogue recordings.
- Calculations of lengths, distances and times of object moving relativistically.
- Compact disc / digital storage.

- Option D (Overlap with Option H) – Relativistic kinematics calculations.
- Hadrons and the Pauli exclusion principle.
- Calculations of star distance and radius.
- Amplitude modulated wave interpretation.
- Ray diagrams.
- Angular magnification.

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

Option A - Sight and wave phenomena

This was the second most popular option at SL.

A1. Depth of vision (a) was poorly answered and most had little idea of the context, with many referring to 3D vision or the ability to resolve points. (b) was also poorly answered although a few did appreciate it had something to do with changes in the iris / pupil size and were able to score one mark. A small number were able to score one mark by also stating that depth of vision increased without showing an understanding of the question.

A2. **Standing Waves** (a) and (b) were generally well done. Marks were lost by candidates leaving part of the answer blank or not calculating the period of oscillation correctly to apply it to drawing the line at a time of 2.0 ms. (c) was poorly answered with only a few responses referring to forced resonance or displacement at point M. Many described the formation of standing waves by the superposition of an incident and reflected wave as this is the question often asked. (d) was well answered although a few candidates left answers in terms of wavelength. 500Hz was all that was needed for the mark.

A3. **Doppler Effect** (a) was well done as this is a common question. However, there were still some responses which didn't clearly refer to the relative motion and some benefit of the doubt was given. (b) was mostly well done although some candidates were using the formula for electromagnetic waves or using the formula incorrectly. A common mistake is to confuse the moving source and moving observer formulae. 'Observer on top' is the rule. Some candidates missed stating a range after calculating the upper and lower bound of frequency**.**

A4. **Resolution** (a) was poorly done with few excellent responses. A few candidates included both distributions, but often displaced, with one being centred on the axis. Candidates need to ensure they that read the question carefully to ensure their diagrams are relevant to what is being asked. Responses to (b)(i) were rather mixed with many candidates scoring two marks. Errors included forgetting the factor of 1.22, confusing the pupil diameter and separation of the dots, or in combining all the numbers together. (b)(i) was similarly poorly done with only a few candidates appreciating that the reply was linked to the wavelength of light, but not always showing how this affected the ability to be resolved. No marks were awarded for simply saying that the dots were not resolved. This was a 'determine' question, so the answer had to be justified.

Option B - Quantum physics and nuclear physics

B1. Photoelectric effect Most candidates struggled to obtain many points in (a)(i) and (a)(ii) as they clearly didn't understand what the question was asking and just described the photoelectric effect in terms of particles and waves. Although candidates were better equipped to explain why the photon model was an improvement this was still relatively poorly answered. (b)(i) was poorly done with many candidates not appreciating that they were to use the gradient of the graph to determine Planck's constant. Some candidates “knew” the answer and seemed to have worked backwards. (b)(ii) was more straightforward with many candidates scoring the mark here for the y intercept. (b)(iii) was quite mixed with a whole range of approaches. A number of candidates attempted to use the wave equation, inserting the speed of light. It is a common mistake to think that de Broglie waves are EM radiation. Many equated electron energy with photon energy as they had forgotten that the question started with the words 'Use the graph to calculate'. This is one place where an organized approach can really help a candidate gain some credit.

B2. **Nuclear energy levels and radioactive decay** Candidates responded to (a) with mixed success. Those who appreciated that the question was referring to nuclear physics and not atomic physics were generally able to make some reference to the discrete nature of alpha and gamma spectra. (b)(i) was found to be easy for the vast majority of candidates. A large number of candidates made reference to neutrinos in (b)(ii) but weren't able to relate this to the continuous nature of a beta spectrum. (b)(iii) was poorly answered although some benefit of the doubt was given for reference to a transition from a higher to lower level. Many candidates referred to electrons / atomic transitions. (c) was well answered by the majority of candidates but a number still making an “estimated guess” by interpolating between half-lives. The use of logs didn't appear to cause many difficulties to those candidates who started with the correct approach.

Option C - Digital technology

This option was chosen by few candidates.

C1. Compact discs and charge-coupled devices (a) was well done with most candidates scoring both marks by referring to lands and pits, 1s and 0s. (b) is a standard question, again with most candidates scoring both marks, although responses such as “easier to access” are debatable. (c) was poorly done with most answers lacking a focus on the essential information. Starting the explanation with the incoming photons was expected. Many candidates made an attempt at answering (d) but, again, they got mixed up within the different steps of the process. There were a lot of Power of 10 errors and only a few correct answers.

Questions C2 onwards were also on the HL paper 3. They are marked with * in that section.

Recommendations and guidance for the teaching of future candidates

The option topics allow candidates to experience some of the more challenging and interesting areas of Physics. However the importance of the fundamental principles of the subject should not be underestimated. Definitions and statements of laws are sometimes poorly expressed or largely guesswork. In general candidates tend to perform less well on the descriptive parts of questions; these are often the cause of the difference between a mediocre and good grade. In setting private study exercises it is helpful for candidates to be given not only numerical questions but also plenty of extended response questions which are marked rigorously. Past papers provide the opportunity for essential practice with the style of questions candidates will face. Giving candidates model answers (as well as past markshemes) allows them to understand the level of response that is expected. These are often provided in IB Physics textbooks. The marking of key phrases in a question should be encouraged as so often an instruction or piece of information is missed. The mark for a question, given in the margin of the paper, is a useful indicator of the detail required in a response.

All candidates should be given the full IB Physics Subject Guide and Data Booklet. Both are essential learning tools and very useful as revision checklists. The subject guide and data booklet can be provided in teacher-annotated form, with textbook page references, web-site addresses and past paper question references. Although time consuming, it is so easy to do since both documents are in digital format. If they cannot be provided in this form at the beginning of the course, then the annotations can be added by candidates as the course progresses. Teachers are advised to have sessions, during revision, to explain the use of every equation and all items of data in the Data Booklet.

Centre G2 comments often complain that questions test information that is not in the guide. For example, that class M stars have surface a temperature of approximately 3000K, or the meaning of depth of vision. It is important to remember that the Subject Guide provides a framework, a list of aims and objectives, it is not meant to be a definitive list of facts. There are several excellent textbooks that interpret the various objectives. Physics department's schemes of work will usually make use of many additional online sources of information. The online curriculum centre, Wikipedia, Hyperphysics, CERN, NASA, Physics.org, outreach.atnf.csiro.au, phys.unsw.edu.au, etc, etc. provide a wealth of relevant and inspirational material. These can be organized by teachers into a very valuable learning resource, to supplement textbooks, in the teaching of each of the options (and the Core).