Physics TZ1 (IBAM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 15	16 - 29	30 - 40	41 - 50	51 - 61	62 - 71	72 - 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 14	15 - 27	28 - 40	41 - 49	50 - 60	61 - 69	70 - 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 and 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, and the majority of candidate reports are word-processed and graphs are presented using appropriate software. The required hours of practical work seem to not be a problem, and there is evidence of good syllabus coverage. Teachers are reminded that investigations can be on topics not found in the syllabus.

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

Data Collection and Processing

In a comprehensive data collection exercise possibly with several tables of data, the candidate has been inconsistent with significant digits for just one data point or missed units out of one column heading, then the moderator will not mark this minor error down. If the moderator feels the candidate has demonstrated that they were paying attention to these points and made one careless slip then the moderator can still support maximum marks under the "complete not meaning perfection" rule. This is an important principle since good candidates responding in full to an extended task are unfairly penalized more often than candidates addressing a simplistic exercise. The candidate is not marked down if they have not included any qualitative observation(s) and the moderator cannot think of any that would have been obviously relevant. The moderator does not mark down if there is no table title when it is obvious what the data in the table refers to. Often candidates do all the hard work for DCP and then lose a mark from the teacher because they did not title the table. Except for extended investigations it is normally self-evident what the table refers to.

The expectation for the treatment of errors and uncertainties in physics is described in the Subject Guide and the TSM. Both SL and HL candidates are assessed on the same syllabus content and the same standard of performance.

All raw data is expected to include units and uncertainties. The least count of any scale or the least significant digit in any measurement is an indication of the minimum uncertainty. Candidates may make statements about the manufacture's claim of accuracy, but this is not required. When raw data is processed, uncertainties need to be processed (see the Subject Guide, syllabus details 1.2.11).

Candidates can estimate uncertainties in compound measurements (± half the range), and they can make educated guesses about uncertainties in the method of measurement. If uncertainties are small enough to be ignored, the candidate should note this fact.

Minimum and maximum gradients should be drawn on linear graphs using uncertainty bars (using the first and last data points) for only one quantity. This simplified method becomes obscured when both graph quantities contain uncertainty bars. Other uncertainty analysis is expected when graphs are non-linear.

If the candidate has clearly attempted to consider or propagate uncertainties then moderators support the teacher's marking even if they may feel that the candidate could have made a more sophisticated effort. If propagation is demonstrated in part of the lab then full credit can be awarded even if error analysis is not carried through in every detail (as long as the candidate has demonstrated an appreciation of uncertainty then they can earn a complete).

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

Conclusion and Evaluation

Moderators often apply the principle of "complete not meaning perfection". For example, if the candidate has identified the most sensible sources of systematic error then the moderator can support a teacher's marking even if the moderator can identify one more. Moderators are a bit more critical in the third aspect that the modifications are actually relating to the cited sources of error. If the moderator feels a task was too simple to truly meet the spirit of the criteria, then they will comment on the 4/IAF as to the unsuitability of the task giving full justifications. This will be provided in feedback but the moderator will not necessarily downgrade the candidate. Yes, this does mean that candidates could get high DCP marks for quite brief work on limited data but, if they have fulfilled the 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 - 20	21 - 23	24 - 27	28 - 30	31 - 40

Standard level paper one

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 12	13 - 17	18 - 19	20 - 22	23 - 24	25 - 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 very small percentage of the total number of teachers or the total number of Centres taking the examination returned G2’s. For SL there were 35 responses from 479 Centres and for HL there were 64 responses from 266 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 there was a suggestion that the SL paper was considered a little easier than its predecessor.

With no 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	39	70	2903	83	0	93.8	0.13
2	308	294	1457	1033	3	47.08	0.40
3	306	2041	195	551	2	65.95	0.44
4	22	221	140	2712	0	87.63	0.24
5	1561	226	1076	231	1	34.77	0.23
6	89	96	683	2219	8	71.7	0.42
7	460	2147	45	442	1	69.37	0.41
8	2083	354	345	309	4	67.3	0.44
9	240	39	2407	406	3	77.77	0.37
10	93	2509	416	76	1	81.07	0.38
11	990	1949	82	73	1	62.97	0.17
12	2304	249	48	493	1	74.44	0.36
13	425	639	868	1160	3	37.48	0.49
14	503	652	1415	521	4	45.72	0.48
15	289	313	165	2327	1	75.19	0.38
16	1376	335	1255	125	4	44.46	0.38
17	116	776	834	1363	6	26.95	0.27
18	130	1192	523	1249	1	40.36	0.33
19	111	805	1496	683	0	26.01	0.35
20	124	858	1606	503	4	51.89	0.38
21	106	789	174	2025	1	65.43	0.41
22	50	2255	617	173	0	72.86	0.39
23	302	1851	840	98	4	27.14	0.34
24	693	1568	184	648	2	20.94	0.26
25	839	982	833	437	4	26.91	0.33
26	179	493	758	1655	10	53.47	0.41
27	355	118	1720	899	3	55.57	0.52
28	626	1034	1134	298	3	33.41	0.39
29	546	1159	250	1131	9	36.54	0.41
30	277	1836	100	875	7	59.32	0.07
31	555	287	2006	242	5	64.81	0.43
32	133	259	841	1848	14	59.71	0.30
33	3003	39	36	15	2	97.03	0.08
34	2284	387	296	118	10	73.8	0.45
35	201	185	1132	1572	5	50.79	0.30
36	750	609	1368	363	5	44.2	0.57
37	2749	214	25	104	3	88.82	0.21

38	1071	1564	199	257	4	34.6	0.19
39	122	346	350	2267	10	73.25	0.47
40	205	1591	855	436	8	51.41	0.10

Number of candidates: 3095

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	170	187	5370	237	5	89.96	0.20
2	26	445	5224	270	4	87.52	0.21
3	4730	39	268	928	4	79.24	0.38
4	597	623	2390	2353	6	40.04	0.42
5	681	3438	643	1199	8	57.6	0.47
6	117	862	1494	3487	9	58.42	0.48
7	1795	2598	560	1004	12	43.52	0.25
8	2976	510	1907	567	9	31.95	0.03
9	203	324	1693	3724	25	62.39	0.51
10	3616	1516	283	548	6	60.58	0.50
11	1346	3439	226	953	5	57.61	0.49
12	3382	534	777	1270	6	56.66	0.49
13	2647	728	221	2365	8	39.62	0.57
14	150	3958	1688	167	6	66.31	0.59
15	1407	4111	190	250	11	68.87	0.24
16	315	198	866	4571	19	76.58	0.23
17	344	2645	1102	1868	10	31.3	0.28
18	282	1299	2936	1444	8	21.76	0.17
19	3320	786	945	905	13	55.62	0.63
20	321	2055	2480	1094	19	41.55	0.41
21	426	1792	841	2896	14	48.52	0.48
22	918	175	2633	2225	18	44.11	0.48
23	191	5314	127	325	12	89.03	0.20
24	1770	1754	1850	581	14	29.39	0.37
25	5539	165	177	76	12	92.8	0.18
26	3711	937	957	338	26	62.17	0.50
27	503	2111	2120	1206	29	35.52	0.35
28	395	1741	598	3206	29	53.71	0.45
29	1782	1184	2220	762	21	37.19	0.49
30	5058	619	65	207	20	84.74	0.28

Number of candidates: 5969

Comments on the analysis

Difficulty

The difficulty index varies from about 21% in HL and 22% in SL (relatively ‘difficult’ questions) to about 97% in HL and 93% in SL (relatively ‘easy’ questions). The papers gave an adequate spread of marks while allowing all candidates to gain credit.

Discrimination

All questions had a positive value for the discrimination index. Ideally, the index should be greater than about 0.2. This was achieved in 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, there were a small number of blank responses which became slightly more frequent as the paper progressed. This may indicate that some candidates had insufficient time to complete their responses, but it may also indicate that they were more poorly prepared for items occurring later in the written syllabus. Candidates should be reminded that there is no penalty for an incorrect response. Therefore, if the correct response is not known, then an educated guess should be made. In general, some of the 'distractors' should be capable of elimination, thus reducing the element of guesswork.

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 Q5 and HL Q3

No work is done only if there are no forces on the object. So clearly the only possible answer is B.

SL Q8 and HL Q5

Most candidates opted for A, presumably knowing that a doubling of the radius halves the centripetal acceleration; yet they overlooked the resulting doubling of the speed of Q compared to P.

SL Q15 and HL Q11

Great care needs to be taken when teaching about the fundamentals of waves, and how their properties emerge from the simple oscillation of particles. Here it is clear that the three particles, one under each of the B-arrows tips and the other immediately under B are all in their rest position. Hence B must be the correct response. The discrimination index was low showing that even the more able candidates were distracted by A.

SL Q17 and HL Q18

A surprising number of candidates opted for B. Any candidate who has actually done this very basic experiment, however, will have no trouble in choosing the correct response.

SL Q18 and HL Q19

Candidates are usually good at performing simple circuit calculations, but tend to flounder when asked ‘dynamic’ questions commenting on how a change in one part of a circuit will affect the whole circuit. When teaching this topic it is important to explore the dynamics of a circuit, before applying Ohm’s Law.

SL Q24 and HL Q28

Many candidates thought this an example of nuclear fusion. However, bombarding a nitrogen nucleus with an alpha particle in order to create an isotope of oxygen is clearly not what is normally meant by fusion. It may be that those candidates who selected C were not acquainted with the phenomenon of artificial transmutation.

SL Q29 and HL Q36

Carbon dioxide does indeed absorb the Sun’s infrared light (option A), but this is not the reason why it is a greenhouse gas. Hence C is the best answer.

HL Questions

Q17

When unpolarized light passes through a polarising filter its intensity halves. Clearly all angles of the polarising filter are logically equivalent and therefore immaterial. However, when polarized light passes through a polarizing filter its intensity is reduced depending upon the angle of the filter to the plane of polarization. Hence C is the only logically possible answer. The most popular response, however, was D, presumably since the candidates referred to their formula booklets before thinking through the situation illustrated.

Q23

Each diagram gives just three adjacent equipotentials. There is therefore no attempt made at completeness as may be found in a text book. Candidates should know that the two equipotentials further from the mass should have a greater distance between them than the pair closer to the mass. Hence only C can be correct.

Q24

The most popular response was B, presumably since most candidates assumed it was a closed system, despite being told that the satellite ‘is moved’. A satellite cannot obtain a higher orbit without some energy input, which leaves D as the correct response. There should be no need for recourse to formulae and calculation if the candidate has secure conceptual understanding of satellite motion.

Q25

It would seem that most candidates intuitively chose between A and B, with only those who understood Lenz's Law selecting C or B. The essence of the solution is that as the square is entering the field the flux linkage is increasing, while as it is leaving the linkage is decreasing. Hence neither A nor B can be correct. And since the direction of the current is such as to try to reduce the change in flux linkage, it should set up a magnetic field out of the page as the loop enters the field. Hence C is the correct answer.

Candidates clearly need more practice in the application of Lenz's Law in a variety of different situations.

Q29

The responses showed that the majority of the candidates understood that the wavelength gets smaller with increasing speed of the electron (responses B and D). However they failed to realize that the energy given to the particle is proportional to the square of the velocity. Hence the factor of $\sqrt{2}$ is necessary when considering the momentum.

Q30

A number of candidates mistakenly assumed the electron energy levels were negative – as they are within an atom.

Q32

Teachers objected to this question as there was no exact answer; however the rubric for Paper 1 invites the candidates to choose the best answer. They should be able to estimate and make approximations. In this case the best answer is obvious from a quick sketch graph. It is not necessary to use a calculator.

Q38

The first digit in a binary number is the most significant bit, whether it is a 0 or 1. Not all text books are clear about this, however it is expected that teachers and candidates use a variety of sources when learning.

SL Questions

Q13

The drawing of M at an arbitrary point in its cycle may have confused the weaker candidates. Many opted for B or C, which would suggest that they thought the mass had kinetic energy at the extremities of its oscillation when the velocity is zero, clearly an impossibility.

Q27

Many candidates perhaps used the wrong equation when opting for their response. This was not a wind turbine! Other candidates may have had the correct equation, but not known the meaning of all the symbols. Contextualizing and explaining the dynamics of the equations in the data book is an excellent revision activity for Paper 1.

Q28

There were many G2 comments criticising the precision of the wording as well as the Physics behind this question. It was good, however, to see that the candidates had no such problems. The power received decreases as the distance to the Sun increases, hence only B and D could possibly be correct. And as the albedo increases so more power is reflected and less reaches the Earth's surface. So D must be the best response. Again, it must be emphasised that equations should be viewed dynamically, rather than as icons to be remembered.

Recommendations and guidance for the teaching of future candidates

Multiple Choice items are an excellent 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 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.

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

– indeed 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 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 - 11	12 - 22	23 - 32	33 - 42	43 - 52	53 - 62	63 - 95

Standard level paper two

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 8	9 - 15	16 - 20	21 - 25	26 - 30	31 - 50

General comments

35 sets of HL G2 comments and 65 SL were received from centres. A high percentage of centres at both levels thought that the papers were appropriate in standard. 77% of SL teachers felt that the papers were of a similar standard (71% 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 by the majority though 10.6% of SL (11.1% of responses HL) regarded the clarity of wording as poor. In fact the papers at both levels were, judging by the statistics, more difficult than the previous session.

Examiners felt that the majority of candidates made a fair attempt at the full range of questions and had done general preparation well. Many were able to make a good attempt at novel situations (such as the impact of a golf club head on impact with a golf ball).

Examiners commented that many candidates fail to interpret the command terms in questions, using these terms almost always interchangeably. In many cases examination technique was not finely honed meaning that some straightforward marks were missed. For example in "explain whether" questions there must be some explanation and in "show that" questions equations should be stated, numbers and values of constants substituted in and answers fully calculated to more than one significant figure. Generally many candidates disregarded units and sensible use of significant figures. Units and precision are an integral part of physics and, by paying little heed to these aspects, candidates are wasting an opportunity to impress.

The examiners reported a lack-lustre knowledge of definitions shown by many candidates. Such questions should present straightforward marks but many candidates appeared content with a superficial general knowledge of definitions which fail to gain marks – examples in this paper were superposition, binding energy and rms values.

As in many examinations examiners felt that calculations were done rather better than explanations.

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

- drawing a smooth curve through a non-linear series of points with error bars
- drawing free body diagrams
- using Pythagoras's theorem when calculating a path difference
- calculating the acceleration at a non-zero or non-maximum value in shm
- application of Faraday's and Lenz's laws
- using the method of stopping potential to calculate electron energies
- calculation of emfs in parallel circuits
- gravitational potential energy (when not close to the Earth's surface)
- estimating area in an enclosed curve

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

- application of the conservation of energy and momentum
- showing the variation of kinetic energy with time for a simple harmonic oscillator
- calculating forces in a uniform electric field
- calculating the power available from a wind generator
- determining the equivalent resistance for a combination of series and parallel resistors

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

Section A

A1 [HL & SL] Data analysis question

(a) Many candidates failed to recognise that the number of decimal places is a reflection of the precision of a piece of equipment – it this case the millivoltmeter. Using different number of significant figures simply indicates that the reading is larger or smaller but it will be to the same precision. A sizeable proportion of candidates believed the number of decimal places was something that they could choose in an arbitrary manner.

(b) [HL] and (c) [SL]

(i) Most candidates were able to correctly plot the data point despite there being a relatively difficult scale division.

(ii) The majority of candidates drew an appropriate error bar.

(iii) Many failed to take sufficient care when sketching the line of best fit. Lines of best fit are not always straight and it is important that candidates practise drawing curves in preparation for examinations. It was common to see multiple lines, some of which did not pass through the horizontal part of the error bar (the vertical edges being irrelevant and of arbitrary length).

(c) **[HL]** and (d) **[SL]** Most candidates were able to find the percentage uncertainty in the *d* value or correctly added the two percentage values; many were unable to do both.

(d) **[HL only]**

(i) There were good attempts at finding the unit of *k* but many candidates failed to recognise that the power in an exponential is dimensionless, giving *k* the units of d^{1} (i.e. m^{-1} or cm^{-1}).

(ii) Although most candidates appeared to be able to perform the appropriate logarithm function to the equation many failed to take the next step and actually state what values needed to be plotted on the graph (that is, $\log_e \varepsilon$ vs. *d*).

(iii) Again, showing that the gradient was equal to $-k$, most ignored the minus sign and incorrectly stated that the gradient was *k*.

(b) **[SL only]**

(i) Most candidates failed to realise that the result of multiplying a series of corresponding values of ε and d only needed to show different values for the equation to be disproved but that all possible values would need to be taken prove it (clearly an impossibility).

(ii) By performing the task in (i) most candidates showed that there was too large a discrepancy between the three sets of products to suggest that the equation was viable.

A2

(a) Most candidates failed to state that acceleration is the rate of change of velocity and that as velocity is a vector it has both magnitude and direction. With there being a change in direction the car accelerates. Many erroneously talked about there being a change of direction of the acceleration – the direction is always centripetal.

(b) Few marked in reaction acting at each wheel and the weight acting from the centre of gravity. The weight needed to be larger than the combined reaction to give a resultant centripetal force (this is shown by the relative length of the lines). Most candidates were unconcerned about the point of application of the forces and often added spurious horizontal and/or centripetal forces. Centripetal forces, being the resultant of the other force, should not be marked in on free body diagrams like this.

(c) The majority of candidates made a good attempt at calculating the maximum speed by equating the weight to the centripetal force (that is, in the limit there is no reaction force).

A3

(a) Few candidates stated the principle of superposition clearly enough to gain a mark – most talked about the sum of the amplitudes rather than of the displacements.

(b) (i) With hindsight having a distance of 4.0m as well as the $4A^2$ was unfortunate and weaker candidates felt obliged to include the distance in their explanation. Of course this did make it clear to examiners that such candidates had very insecure knowledge of this topic. Most answers were unconvincing and highlighted the lack of understanding of this principle.

(ii) A minority of candidates used Pythagoras's theorem to show that the path difference was half a wavelength leading to destructive interference. Weaker candidates tried to argue the case without performing any calculation.

A4 [HL] & B1 Part 1 [SL]

(a) (i) Nearly all candidates gained a mark for recognising the change from kinetic to potential energy in this part. Fewer recognised that the club head would not transfer all of its energy to the ball and therefore retained a significant amount of energy.

(ii) This part was well done by many.

(b) A minority of candidates became bogged down by the deformation of the ball and club head idea and ventured into elastic potential energy ideas. This had a successful outcome in many cases when there was discussion of the compression providing further kinetic energy to the ball on recovering its shape. The most straightforward solution was to use to principle of impulse being equal to the change in momentum (as shown in the question heading) and simply to recognise that an increased contact time would be expected to give a greater change of momentum for a constant force.

(c) (i) This was well done with the only real problem being deciding which was the speed change of the ball.

(ii) Less candidates than anticipated recognised that the force on the club head was equal and opposite to that acting on the ball (applying Newton's third law of motion).

(iii) Most made a good attempt at calculating the speed of the club head.

A5 [HL] & B2 Part 1 [SL]

(a) (i) Nearly all candidates correctly stated the amplitude as being 32 mm.

(ii) Most were able to measure the period and many then went on to calculate the frequency with the occasional hiccup with conversion of ms into kHz etc.

(b) (i) A large proportion of candidates correctly determined the maximum speed of the object by correctly calculating the angular speed and multiplying it by the amplitude. Full marks were awarded to those calculating the gradient of the tangent to the displacement-time graph at zero displacement.

(ii) In the simplest route to the answer candidates were usually successful in measuring the displacement at 140 ms and then using the defining equation for SHM to calculate the acceleration. Other routes were allowed as alternatives but success was infrequent.

(c) Given the relative difficulty of transposing the displacement into a velocity and then squaring it to find the shape of the kinetic energy function, this part was done very well. Most candidates recognised that the energy was always positive, of twice the frequency of the displacement graph and took a cosine squared shape. Sketches were of variable quality but often better than others on the paper.

B1 Part 1 [HL only]

(a) (i) This was generally poorly answered, with candidates often failing to refer to Faraday's and Lenz's laws or the specifics of the graph.

(ii) Many candidates used the correct value for the potential difference but were unsure of the meaning of rate of change of magnetic flux; it was commonly believed that this was simply Φ which left candidates searching for a time value.

(b) (i) The definition of the rms current in terms of the equivalent direct current was very poorly known and many simply said that it was the peak value divided by root 2.

(ii) Few managed to do this well with the most common (incorrect) answer being 0.42V.

(iii) Although many hinted at damping, few candidates overtly mentioned it or related it to the dissipation of energy in the coil.

B1 Part 2 [HL and SL]

(a) (i) The definition of either mass defect or nuclear binding energy was badly understood and there were many confused answers to this part. As in previous years the most common misunderstanding amounts to candidates believing that the nuclear binding energy is the energy that holds the nucleons together in the nucleus.

(ii) The majority of candidates labelled the most stable region within tolerance. A minority appear to have missed this part of the question and not answered it at all – candidates should be reminded to read the paper carefully and not to throw away marks by speed reading.

(iii) For a straightforward nuclear energy question this part was poorly answered. It was quite common to see candidates ignoring the fact that two deuterons were fusing to produce helium. As a ‘show that’ question, it is important that candidate do produce a final answer that is to more than the one digit approximation – many were satisfied by setting out the calculation and then immediately approximating to 4pJ without showing that this was the case. This will always lose a mark in such questions.

(b) (i) This part was quite well done by many candidates with the proton (in the first equation) and the electron or antineutrino (in the second equation) being the most common omissions or having mistakes in the proton or nucleon numbers.

(ii) Few candidates completed this well. Most did no more than to make a statement and it was uncommon for candidates to state that the beta decay is temperature independent. The best answers explained that the deuterium nuclei needed high kinetic energies to be able to approach each other and overcome the Coulombic repulsion and allow the strong nuclear force to come into play.

B2 Part 1 [HL only]

(a) Most candidates choosing this option were able to answer this well although a minority forgot to mention that this was the **minimum** energy needed for a photon to eject an electron from a metal surface.

(b) (i) The technique for measuring the maximum kinetic energy of the emitted electrons was poorly known. Centres would be well advised to use a simulation if they do not have the opportunity to actually perform this experiment with a photocell.

(ii) Given that is such a simple circuit this was very badly answered with many ‘circuits’ not being circuits at all – in essence, ignoring the polarity needed for the cell, this is a simple resistance measuring circuit. Few realised that the detector must have a negative voltage to prevent the electrons from reaching it.

(c) (i) In recognising that the gradient gives a value for the Planck constant, most candidates answered this correctly.

(ii) Again, this was well answered although few candidates mentioned that the work function was the negative of the value of the maximum kinetic energy intercept.

(iii) This was more involved and less well answered. Although many realised that the threshold frequency was the intercept on the frequency axis, few went on to say that the threshold wavelength was the speed of light divided by this value.

(d) Only those candidates approaching this by relating the intensity of light to the number of incident photons per second tended to be successful here. By stating this it was a simple matter or recognising that there is a one to one correspondence between photons and electrons so more intense light inevitably meant more electrons emitted per second. Many wasted time in explaining why emission of electrons meant that the incident light had a frequency higher than the threshold frequency.

B2 Part 2 [HL and SL]

(a) (i) As this is worth two marks, candidates should see the signal that force per unit charge is unlikely to gain full marks; and so it proved. Although a mark was available for saying this there needed to be a reference to the charge being a positive test charge.

(b) (i) G2 comments that the term ‘polarity’ was confusing to candidates proved to be unfounded and nearly all candidates marked in a positive and negative terminal – although the actual polarity was often incorrect.

(ii) With error carried forwards, the direction of the field was often correct but the drawing often was below an acceptable standard with line of force not bridging the plates, being very unevenly spaced and having no edge effect.

(iii) This calculation was almost invariably very well done.

(c) (i) In another ‘show that’ question it was expected that candidates would use Coulombs law and the data value for the electronic charge to give a value of more than one digit; often this was not the case but otherwise this was generally well done

(ii) Most candidates used their value for the force (or 9×10^{-24} N) and the mass of the electron on the data sheet to calculate a correct value for the acceleration.

(iii) This was an unusual opportunity for candidates to use Newton’s laws and many did say that the acceleration would decrease with distance. Too often they incorrectly believed that this meant that the electron would slow down – it continues to accelerate but at an ever decreasing rate.

(iv) Clearly, this part represented a simplification of a complex situation but as set up was not beyond the skills of most of the candidates. The electron represents an instant in which a conventional current would leave the page and the field at this instant would be that of concentric circles with an anti-clockwise (counter-clockwise) direction. Many candidates did draw this but diagrams were too frequently hurriedly drawn and of a poor standard.

B3 [HL and SL]

(a) (i) Many did not mention the kinetic energy of the wind (often referring to ‘wind energy’). All types of kinetic energy were referred to as ‘mechanical’ energy by many candidates. The general structure of this type of wind generator was generally well-known.

(ii) This part was generally well answered with those candidates completing the area calculation usually going on to gain both marks.

(iii) Again, this was well answered with nearly all candidates recognising that is not possible to have fractional generators and, therefore, rounding up their answers to 2 from the 1.7 calculation.

(b) (i) Most candidates were able to suggest why the winds above the sea are higher than those above the land for the same height. A minority incorrectly answered this in terms of convection currents and sea versus land temperatures.

(ii) Nearly all candidates were able to correctly read the two values from the graph and a slight majority of these went on to correctly cube the ratio.

(c) Most candidates knew the difference between photovoltaic cells and solar heating panels. A minority believed that both would normally produce electricity.

(d) (i) This was not well known and many candidates simply added the emfs to give a value of 9.0 V rather than the correct 3.0 V.

(ii) Nearly all candidates correctly calculated the resistance of the series portions of the modules but there were frequent errors in combining these to find the total resistance – with the parallel formula often being incorrectly written in shorthand

(iii) Although many candidates recognised how they should use the power formula, very few were able to used the correct resistance and the correct voltage.

(iv) Many candidates knew that a failing cell would still allow current in other parallel branches, but few explained that the series combination increased the emf and the parallel combination increased the current in a module.

(e) (i) A significant minority of candidates insisted that the reduction in the Sun's intensity was due to radiation reflected from atmosphere. Few went on to do the calculation to support their answer but there were a small number of very good answers to this part.

(ii) Here again, many mentioned radiation reflected by atmosphere rather than variations in solar emissions or the non-circularity of Earth's orbit.

(iii) This part was generally poorly done. The '24-hour period' confused many candidates and few were able to follow the argument through to a logical conclusion.

B4 Part 1 [HL only]

(a) Many candidates stated that the Newton's law force is proportional to the masses of the objects in question, rather than the product of the masses.

(b) This part was generally well done with most candidates coming to the correct outcome; too often steps were missed out in the derivations and this cost candidates mark. It is essential that they realise that a derivation must include every step. The presentation of this part left much to be desired in quite a large minority with mathematically incorrect statements being given.

(c) (i) Most candidates were able to substitute values into the equation and rearrange it to find a value for *R*. Many then fail to subtract the radius of the Earth.

(ii) Very few candidates completed this part correctly. Confusion between potential and potential energy was common as were adding the height in kilometres to the radius of the Earth in metres. A sizeable minority of candidates attempted to use the *mgh* equation.

(iii) This part was quite well answered with most candidates realising that the increase in height meant an increase in potential energy. Several argued that the magnitude decreased but being a negative quantity this meant an increase.

B4 Part 2 [HL]

(a) Few candidates were able to explain thermal energy was the energy transfer between two objects at different temperatures. Many knew the definition of internal energy but a high percentage omitted to mention the potential energy (probably assuming that the gas was ideal).

(b) (i) Many candidates appeared to attempt to calculate area without actually saying what they were doing; although this was obvious when they referred to the area of a square, in many case it was not obvious and marks were lost when the candidates technique produced an answer out of tolerance. In examples like this there will be a reasonable tolerance for the area and it is not expected that candidates will waste considerable time in counting the small squares.

(ii) Although some candidates were aware that a clockwise cycle applies to net work done by the gas, this does not explain the choice. Simply saying that the area under the expansion was greater than the area under the compression was all that was needed.

(iii) This part was mostly well done by candidates. It is accepted, in line with SL A1, that showing constancy of two *PV* values does not prove that the change is isothermal; however in terms of deducing that the change is isothermal this technique is fine – that is, the candidates are told that it is isothermal and they are simply illustrating that this is the case. Often examiners will expect three values to be taken in questions such as this.

(iv) This part was well done by those many candidates who used any appropriate variant of the ideal gas equation to calculate the temperature.

(v) The large majority of candidates did well here although a minority were deducted marks when they used contradictory statements such as isochoric and compression or expansion.

Recommendations and guidance for the teaching of future candidates

- Encourage candidates to set out calculations in a logical and presentable fashion
- Encourage candidates to write legibly and draw diagrams neatly with due care and attention in circuit diagrams, showing field lines and vector diagrams of all types
- Encourage candidates to learn definitions as an aid to the understanding of concepts
- Encourage candidates to go the extra step of calculating a final value to at least one more significant digit than the approximate on given in ‘show that’ calculations
- When apparatus may not be readily available teachers should use computer-based alternatives of standard experiments – many of these will be found on a web search using the key word ‘applet’.

Higher level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 7	8 - 15	16 - 22	23 - 28	29 - 34	35 - 40	41 - 60

Standard level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 4	5 - 9	10 - 13	14 - 17	18 - 21	22 - 25	26 - 40

General comments

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

The number of G2 forms received from SL teachers was 66, and the number received from HL teachers was 37. The feedback from teachers on the G2 forms is summarised as follows.

Standard Level

- 94% thought the level of difficulty appropriate, while 6% thought it too difficult.
- 58% found the paper of a similar standard to last year. 8% found it a little easier and 2% much easier, while 19% found it a little more difficult and 3% much more difficult. 11% answered “not applicable”.
- 45% thought the clarity of wording satisfactory and 54% thought it good, whereas 2% thought it poor.
- 41% found the presentation of the paper satisfactory and 59% found it good.
- The most popular option was A (Sight and wave phenomena), followed by B (Quantum physics and nuclear physics), D (Relativity and particle physics), E (Astrophysics) and G (Electromagnetic waves) in roughly equal numbers. Very few candidates answered options C (Digital technology) or F (Communications).

Higher Level

- 92% thought the level of difficulty appropriate, while 8% thought it too difficult.
- 49% found the paper of a similar standard to last year. 14% found it a little easier but no centre found it a lot easier. 22% found it a little more difficult, while 3% found it much more difficult. 14% answered “not applicable”.
- 56% thought the clarity of wording satisfactory, 36% thought it good and 8% thought it poor.
- 43% found the presentation of the paper satisfactory, 54% found it good and 3% found it poor.
- The most popular options were E (Astrophysics), G (Electromagnetic waves), H (Relativity) and I (Medical physics). Very few candidates answered option F (Communications) or J (Particle physics).

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

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

- Option C – Digital technology
- Cepheid variables and their use as standard candles
- Option F – Communications

- The diffraction grating
- Use of X-rays to determine atomic spacing in a crystal
- Thin-film interference
- Simultaneity
- Relativistic dynamics
- Gravitational red-shift
- Amplification of sound in the middle ear
- Neutral current
- Giving clear definitions (e.g. standard candle, virtual image, coherent, frame of reference, loudness, absorbed dose, effective half-life, neutral current)
- Calculations involving logarithms, exponential functions and ratios (especially with quantities raised to powers higher than 2.

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

Many candidates were well prepared for options A, B, D, E, G, H and I. The best candidates have clearly seen the syllabus and show good understanding, can manipulate equations, show all working in a methodical way and explain concepts with clarity. The weakest candidates fail to read the question, have poor knowledge of concepts, lack conciseness in answers, don't show all working or use the wrong equation. Clearly many candidates have studied past papers and are able to show good knowledge of the commonly tested parts of the syllabus.

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

Standard Level

Option A – Sight and wave phenomena

A1 The eye and sight (a) Almost no candidate mentioned a screen or object onto which light is shone so that mixing can be observed. Some candidates described colour mixing by subtraction using paints, while some discussed colour perception in the brain. (b)(i) and (ii) were well done in general.

A2 Radio telescopes (a) was well done by some, although many used the equation appropriate for sound not the approximation for light where $c >> v$. In (b) (i) candidates often got the first mark by implication when gaining second mark. There was a lot of confused algebra in (b)(ii).

A3 Standing waves in a vibrating string (a) and (b) were well done in general, though many forgot to multiply the length by 2 to obtain the wavelength in (b).

A4 Polarization This was poorly done in general – this topic is rarely well understood. Many candidates referred to different concentrations of solution and a significant minority referred to the analysis and reduction of mental stress in humans.

Option B – Quantum physics and nuclear physics

B1 Atomic energy levels (a) Candidates struggled with this question. Although they demonstrated some familiarity with the idea, they could not clearly describe the connection between atomic structure and the emission spectra, usually discussing electrons without photons. The arguments leading from atomic spectra to energy levels were not logically organised. There were very few correct answers to (b). (c) (i) was reasonably well done by many, although many did not refer to the de Broglie hypothesis explicitly and thus relate wavelength to momentum and so to energy. (c)(ii) was poorly answered. Not many candidates understood the relation between amplitude and probability of locating the particle. (c)(iii) was well done by most.

B2 Radioactive decay This question was well done in general. In (b) many candidates referred to mass halving rather than activity.

Option C – Digital technology

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

C1 The operational amplifier (op-amp) As has been stated in just about every subject report for this syllabus, operational amplifiers are clearly not well understood by candidates. Teachers who choose to teach this option need to spend considerable time practising this type of problem with their candidates. (a) was poorly answered, with many answers referring to uses rather than properties of op-amps. A small number of candidates approached (b)(i) well. Most failed to begin. (b)(ii) was poorly answered. (b)(iii) was very poorly answered. Answers usually indicated no understanding of why the buzzer turns on.

C2 The use of mobile phones Most candidates were able to come up with at least one reasonable issue, usually to do with pollution or landfill. Some candidates referred to the dangers of radiation to the human body.

C3 A charge-coupled device (CCD) in a digital camera (a) was very poorly answered on the whole. Some candidates did attempt a calculation, but it was rarely clear why particular values were being multiplied or divided. There were some good answers to (b) but most candidates were unable to begin. (c) was rarely done well.

Option D – Relativity and particle physics

D1 Relativistic kinematics There were some good, clear answers to (a) but there were many vague statements about "point of view". There were also some good answers to (b) but most candidates struggled. It was rarely stated that light travels at the same speed for all observers. (c) (i) was well done and (c)(ii) was very well done.

D2 Elementary particles This question was well answered.

D3 The Ω^- particle (a) Many candidates knew about the idea of strangeness, but did not assign a numerical value. (b) was reasonably well answered. There were some good answers to (c) but many vague responses. Some candidates discussed the concept of colour but did not mention that this is an additional quantum property required to distinguish otherwise indistinguishable quarks.

Option E – Astrophysics

E1 Asteroids There were many vague answers to (a) that only just scraped the mark by saying rocky/icy. (b) was well answered in general.

E2 The properties of a star (a) was very well done in general. Many answered (b) well, but a large minority made mistakes with powers or tried to evaluate both luminosities then find the ratio and failed in the process. A lot of poor algebra and messy working was evident. (c) was well done in general.

E3 Variable stars and supernovae (a)(i) was very poorly done. Some candidates described a standard candle as a star that changes brightness, i.e. a Cepheid variable. In (a)(ii) most candidates knew that Cepheid variables change luminosity in a periodic way, but few mentioned that their luminosity is high and so they are visible from great distances. Often the general concept seemed known to the candidate in (a)(iii) but the actual practical procedure was not specified. (b) was well answered but a few candidates confused 5lg for 51*g* (acceleration due to gravity on earth).

E4 Newton's model of the universe Many candidates had knowledge of the currently understood nature of the universe, but did not mention ***evidence*** as to how we know.

Option F – Communications

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

F1 Amplitude modulation Almost no candidate answered (a)(i) correctly, the most common answer being 150 MHz. Candidates were confused between the carrier wave and information signal. A few candidates answered (a)(ii) correctly. Some candidates gained the first two marking points in (b) with a discussion of the effect of noise on amplitude, but no candidate gained the third marking point by mentioning the role of the receiver. In (c) most candidates knew that FM has shorter range than AM, but very few gained any of the other marking points.

F2 Analogue-to-digital conversion (a) and (b)(i) were very poorly answered. In (b)(i) many candidates took the next two values to be 4.0ms and 5.0ms. This could have been due to not absorbing the information about sampling rate given in the stem of the question. There were some correct answers to (b)(ii).

F3 An optic fibre There were very few correct answers to (a) although this is fairly basic geometrical optics. Some attempted to use the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ for refraction at the core/cladding boundary. In (b) very few answers showed refraction on entry, but many showed total internal reflection correctly. (c) was very poorly done with almost no correct answers.

Option G – Electromagnetic waves

G1 Light and optical instruments (a)(i) Rays were generally well done, but the image was sometimes not drawn at the intersection of the rays, and frequently the image was not labelled. There were very few correct answers to (a)(ii), although this is a standard definition. Many candidates stated that the image is virtual because it is on the same side of the lens as the object. While this is true, it is not an explanation of why the image is virtual rather than real. (b)(i) and (b)(ii) were very well done although some candidates omitted the negative sign in (b)(ii). (c)(i) and (c)(ii) were reasonably well done. (d) was very well done, with only a few candidates put the focal point nearer the lens.

G2 Laser light (a)(i) was very well done. Many candidates got one mark for "in phase" in (a)(ii), but few got two marks for "constant phase difference" even though this is the standard definition for coherence. This is a standard question that has been in several papers over the last few years. Teachers and candidates should take note of the following clarification - there can be two sources which are in phase (that is, have exactly the same phase) and so are coherent. There can also be two sources which have different phases at any one instant but have a constant phase difference/relationship and so are coherent. Thus "constant phase difference" is a better answer than "in phase" because "in phase" is a special case of "constant phase difference" (that is, the constant phase difference is zero). In (b) most candidates used the equation for double-slit interference rather than the equation for diffraction grating. Candidates appear to be far more comfortable with the double-slit case than the diffraction grating case. There were almost no correct answers to (c). Candidates clearly need a lot of practice answering questions on the diffraction grating.

Higher Level

Option E – Astrophysics

E1 Asteroids There were many vague answers to (a) that only just scraped the mark by saying rocky/icy. (b) was well answered in general.

E2 The properties of a star (a) was very well done in general. Many answered (b)(i) well, but a large minority made mistakes with powers or tried to evaluate both luminosities then find the ratio and failed in the process. A lot of poor algebra and messy working was evident. In (b)(ii) there was a lot of poor algebra and messy working. There was a much poorer understanding of ratio in this question, in particular dealing with the inverse power of 3.5. (c)(i) and (c)(ii) were both well done in general. (d) was well done in general, but many candidates thought that the Chandrasekhar limit was 4 M_S. The question was slightly confusing because the mass worked out in (b)(ii) is for a main sequence star, not a remnant after a supernova. The markscheme was flexible enough to allow for candidates who took the calculated mass to be the mass of a remnant, or those who said that the star would form a white dwarf if the remnant mass was less than the Chandrasekhar limit.

E3 Variable stars (a)(i) was very poorly done. Some candidates described a standard candle as a star that changes brightness, i.e. a Cepheid variable. In (a)(ii) most candidates knew that Cepheid variables change luminosity in a periodic way, but few mentioned that their luminosity is high and so they are visible from great distances. In (b) often the general concept seemed known to the candidate but the actual practical procedure was not specified.

E4 Newton's model of the universe Many candidates had knowledge of the currently understood nature of the universe, but did not mention ***evidence*** as to how we know.

E5 Red-shift (a) was very well done. (b) was well answered but a few candidates confused 5lg for 51*g* (acceleration due to gravity on Earth). Many candidates jumped to the final given answer without showing all steps or the answer to several significant figures. In questions which ask candidates to "show" that a given answer is correct, full working must be shown. (c) was well done in general but many mistakes were made with powers of ten. Some candidates calculated the answer in seconds, then unnecessarily converted to years. Unless specifically requested, it is not necessary to give answers using a particular unit – any valid unit will do.

Option F – Communications

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

F1 Amplitude modulation Almost no candidate answered (a)(i) correctly, the most common answer being 150 MHz. Candidates were confused between the carrier wave and information signal. A few candidates answered (a)(ii) correctly. Some candidates gained the first two marking points in (b) with a discussion of the effect of noise on amplitude, but no candidate gained the third marking point by mentioning the role of the receiver. In (c) most candidates knew that FM has shorter range than AM, but very few gained any of the other marking points.

F2 Analogue-to-digital conversion (a) was very poorly answered. (b)(i) was poorly answered - many candidates took the next two values to be 4.0 ms and 5.0 ms. This could have been due to not absorbing the information about sampling rate given in the stem of the question. There were some correct answers to (b)(ii).

F3 An optic fibre There were very few correct answers to (a) although this is fairly basic geometrical optics. Some attempted to use the equation $n_1 \sin\theta_1 = n_2 \sin\theta_2$ for refraction at the core/cladding boundary. In (b) very few answers showed refraction on entry, but many showed total internal reflection correctly. (c) was very poorly done with almost no correct answers. (d) was reasonably well done in general.

F4 The operational amplifier (op-amp) As has been stated in just about every subject report for this syllabus, operational amplifiers are clearly not well understood by candidates. Teachers who choose to teach this option need to spend considerable time practising this type of problem with their candidates. (a) was poorly answered in general. Many answers referred to uses rather than properties of op-amps. (b)(i) A small number of candidates approached (b)(i) well but most failed to begin. (b)(ii) was poorly answered. (b)(iii) was very poorly answered. Answers usually indicated no understanding of why the buzzer turns on.

Option G – Electromagnetic waves

G1 Light and optical instruments (a)(i) Rays were generally well done, but the image was sometimes not drawn at the intersection of the rays, and frequently the image was not labelled. There were very few correct answers to (a)(ii), although this is a standard definition. Many candidates stated that the image is virtual because it is on the same side of the lens as the object. While this is true, it is not an explanation of why the image is virtual rather than real. (b)(i) and (b)(ii) were very well done although some candidates omitted the negative sign in (b)(ii). (c)(i) and (c)(ii) were reasonably well done. (d) was very well done, with only a few candidates put the focal point nearer the lens.

G2 Laser light (a)(i) was very well done. In (a)(ii) many candidates got one mark for "in phase", but few got two marks for "constant phase difference" even though this is the standard definition for coherence. This is a standard question that has been in several papers over the last few years. Teachers and candidates should take note of the following clarification-there can be two sources which are in phase (i.e. have exactly the same phase) and so are coherent. There can also be two sources which have different phases at any one instant but have a constant phase difference/relationship and so are coherent. Thus "constant phase difference" is a better answer than "in phase" because "in phase" is a special case of "constant phase difference" (i.e. the constant phase difference is zero). In (b) most candidates used the equation for double-slit interference rather than the equation for diffraction grating. Candidates appear to be far more comfortable with the double-slit case than the diffraction grating case. Candidates clearly need a lot of practice answering questions on the diffraction grating.

G3 X-ray production and diffraction (a) Almost all candidates gained the first marking point in (a). Very few gained any of the other marking points. Many candidates referred to refraction not scattering. Some discussed the production of X-ray spectra. Many candidates had some idea that interference/diffraction of some sort takes place, but could not give details of how this leads to a determination of atomic spacing. (b) was very well done in general, but some candidates dropped *e* from the equation. (c) was well done in general, although the factor of 2 in the Bragg equation was often omitted and candidates often did not put $\sin\theta = 1$ to get the maximum wavelength.

G4 Thin-film interference (a) was well done in general. (b) was poorly understood. There were some good answers but many candidates omitted *n* or put $n = 1$ as in a diffraction grating.

Option H Relativity

H1 Relativistic kinematics There were some good, clear answers to (a) but there were many vague statements about "point of view". Most candidates answered (b)(i) correctly. Many candidates refused to put an answer greater than *c* because that is impossible, missing the point of the question (that the Galilean transformation gives a wrong answer so the relativistic transformation is required). In (b)(ii) most candidates got the signs wrong and so scored two marks out of three. There were some good answers to (c) but most candidates struggled. It was rarely stated that light travels at the same speed for all observers. (d)(i) was well done and (d)(ii) was very well done.

H2 Relativistic dynamics This was poorly done although there were some very good answers. A significant minority of candidates used the non-relativistic equation for kinetic energy.

H3 Gravitational red-shift (a) was very poorly done. Candidates had an understanding of photons gaining/losing energy and so changing frequency when travelling through a gravitational field, but had great difficulty understanding the same phenomenon by thinking in terms of acceleration and the Doppler effect. Many candidates tried to do a calculation even though no numerical information was given. It should be noted that the command term *deduce* means "Reach a conclusion from the information given" and so a calculation is not usually required. In (b) There were many good statements of the equivalence principle, but most candidates had difficulty relating it to the situation in (a).

H4 Spacetime A few candidates gave very good answers. Most candidates gained the first marking point by referring to mass distorting/warping spacetime, but then there were many vague descriptions of the Earth "falling into the well" of the Sun rather than the Earth following a geodesic through spacetime.

H5 The Michelson-Morley experiment Almost all candidates understood the implication of the experiment. However, very few candidates outlined the nature of the experiment.

H6 Black holes Many candidates correctly calculated the Schwarzschild radius but an amazing number failed to calculate the density given the mass and radius. Many candidates did not know how to calculate the volume of a sphere.

Option I – Medical physics

I1 The human ear (a)(i) was not well answered. Many candidates referred to the inner/outer ear rather than what was represented by the pistons in the model. Not many candidates gained full marks in (a)(ii). Many omitted the idea of levers amplifying force and the equation for pressure. (b) and (c) were answered quite well. However (d) was not well answered – many candidates drew what appeared to be random lines.

I2 The use of X-rays and ultrasound in medical imaging (a)(i) Many candidates had the idea of the difference between muscle and bone, but not all mentioned density or exposure on the plate. There were many mistakes in algebra in (a)(ii), especially with the exponent. Many candidates got confused with units, changing the thickness to m but not changing the attenuation coefficient to m^{-1}. (a)(iii) was well answered by most candidates. (b)(i) and (b)(ii) were well answered though answers to (b)(ii) were not always precise. (b)(iii) was very poorly answered. This was surprising as it was basically reading a value from a graph and applying the equation speed = distance / time. Many candidates misread the graph value and many forgot to divide by two to take into account travel and return time.

I3 The effects of radiation on living organisms (a) was reasonably well answered, although often the idea of per unit mass was missing. There were many convoluted calculations and power of ten errors in (b). The difference between *absorbed dose* and *dose equivalent* was not well understood. Very few candidates gained the first mark in (c)(i) as most said it was the time taken for amount of material to halve. More gained the second mark, realising that both a physical and biological process are in play. (c)(ii) was quite well done, even by those who did not get (c)(i) correct. (d) was well answered, though some just said “ability to destroy cells” or similar.

Option J – Particle physics

J1 Elementary particles (a)(i) and (a)(ii) were well answered although many answers just said “lepton” in (a)(ii) without naming it. (b)(i) and (b)(ii) were well answered.

J2 The Ω^- particle (a) Many candidates knew about the idea of strangeness, but did not assign a numerical value. (b)(i) was reasonably well answered. (b)(ii) was not well answered. There were some good answers to (c) but many vague responses. Some candidates discussed the concept of colour but did not mention that this is an additional quantum property required to distinguish otherwise indistinguishable quarks. (d)(i) was reasonably well answered. There were only a few good answers to (d)(ii).

J3 Hadrons There were only a few good answers to (a). Very few mentioned even the vague idea of quark confinement. (b) and (c)(i) were reasonably well answered. (c)(ii) was not well answered - most candidates had no idea about this question.

J4 The early universe This was reasonably well answered.

J5 String theory This was reasonably well answered.

Recommendations and guidance for the teaching of future candidates

- All candidates must be given the full Physics subject guide and Data Booklet. Both are essential learning tools.

- Candidates should be given many opportunities during the course to practise past papers, and should be given access to markschemes. Many questions appear in a similar form and can be practised. Some questions, of course, are novel and test the ability to apply knowledge to unfamiliar situations.

- Command terms should be specifically taught to candidates, and they should be trained to respond appropriately to the command term when writing answers. The number of marks available should serve as an indication of the number of points that need to be made.

- Enough time should be devoted to cover in depth the options chosen. While it is natural to teach many of these options at the end of the course when all core material has been covered, enough time must be devoted to their study.

- Candidates must be discouraged to study options on their own. Whenever a candidate answers an option different to all other candidates in a centre, the results are almost always disastrous for that candidate. It is much better for candidates to answer options that have been properly taught in lessons.

- Definitions are often so vague that marks cannot be awarded. This type of question is very common and hard work is rewarded. Candidates who compile a glossary of definitions and spend time and energy learning them inevitably do better in this type of question.

- Working, especially for derivations, or “show” questions, is often so messy as to be indecipherable. Candidates must be strongly encouraged to lay out working in a logical way that shows clearly each step they are taking. Candidates often squeeze answers into the available space, especially if they cross out some work. They should not be afraid to use an extra sheet and use the space to lay out working neatly.

- Although calculations were often done correctly, working was sometimes messy and difficult to follow. Sometimes it takes considerable effort to decipher an answer, even though it may be correct. Candidates should be given clear guidance on how to set out calculations neatly, with a checklist such as:

    - Write down quantities known and unknown

    - Select and write equation

    - Rearrange for unknown

    - Insert known quantities

- Calculate answer
- State answer with appropriate significant digits and unit
- Underline answer or highlight in some way

This would help candidates to clarify their thought processes, and help them to gain marks.

- Teachers need to emphasise to candidates that many marks are lost due to incorrect or inadequate descriptions and explanations of physical phenomena. Candidates need to practise this kind of question a lot more than calculations and derivations.
- Questions that ask for a description or explanation “with reference to” a specific phenomenon do in fact require a reference to that phenomenon in the answer.
- Candidates must be reminded that papers are scanned and so they must write clearly in blue or black ink and stay within the box, or use an additional sheet if necessary.