PHYSICS

Overall grade boundaries

Higher Level

Grade:	1	2	3	4	5	6	7
Mark range:	0-15	16-27	28-38	39-49	50-59	60-71	72-100

Standard Level

Grade:	1	2	3	4	5	6	7
Mark range:	0-14	15-26	27-38	39-48	49-59	60-70	71-100

This report is based on an analysis of the examination papers and of student performance, as well as input from assistant examiners marking the papers and comment from schools and teachers. We would like to thank all those who took the time to provide comments on the papers. All such feedback was considered during grade award deliberations. While it is not possible to respond individually to those who gave input, we would like to acknowledge the role that such contributions play in the grade award process and in helping to improve the examinations.

Overall performance on the physics examinations was satisfactory and the distribution of grades was comparable to previous years.

It is natural in a report such as this to give more attention to areas where candidates had difficulties than to those where they did well, and the report should be read with this in mind.

Standard Level Paper 1

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-10	11-14	15-16	17-19	20-21	22-29

IB multiple choice physics papers are designed to have conceptual rather than calculation questions. This approach, emphasizing the qualitative rather than the quantitative, is based on the view that the MCQ format is suited to testing conceptual understanding, while calculations can be better assessed in the problems in Papers 2 and 3. Calculators are thus neither needed nor allowed in Paper 1. The papers were designed to have a range of difficulty of questions and reasonable topic coverage. A proportion of questions are common to the SL and HL papers, and the additional questions in HL tend to be of a somewhat higher level of difficulty.

The November 2001 papers were very well received and the comments were overwhelmingly positive. 93 % of the teachers who commented on Paper 1 felt that it was of broadly similar standard to last year's while 6% thought it a little harder. All respondents felt the difficulty was appropriate and that it contained questions of the correct level. 93% felt that the paper gave a satisfactory or good coverage of the syllabus whilst 6% felt the coverage was poor. All felt that clarity and wording were satisfactory or good. The Form G2, available from the *Vade Mecum*, is used to comment on examination papers and teachers are encouraged to submit these forms as they are valuable feedback to the examining team and play an important role in setting grade boundaries. We thank schools and teachers who may have commented on particular questions on the G2 forms.

Statistical analysis

The overall performance of candidates and how they performed on the various questions can be usefully illustrated by the statistical analysis of responses. These results are given in the table below, SL Paper 1 Item Analysis. The numbers in the columns *A-D* and *Blank* are the numbers of candidates choosing the labelled option or leaving the answer blank. The question key (correct option) is indicated by an asterisk (*). The *Difficulty Index* (perhaps better called facility index) is the percentage of candidates who got the question right. A high index thus indicates an easy question, and the table has been presented in the order of difficulty from easiest to hardest question. The *Discrimination Index* is a measure of how well the question discriminated between better and weaker candidates. A higher value of discrimination index indicates that a greater proportion of the better candidates got the question right compared to the weaker candidates.

SL Paper 1 Item analysis

Question	**A**	**B**	**C**	**D**	**Blank**	**Difficulty Index**	**Discrimination Index**
2	20	22	369*	1		89.56	.18
16	14	351*	6	41		85.19	.21
12	45	22	335*	9	1	81.31	.32
18	20	332*	44	15		80.58	.24
17	22	4	318*	68		77.18	.21
19	27	29	63	293*		71.11	.33
26	289*	10	51	60	2	70.14	.22
27	284*	69	36	21	2	68.93	.39
8	270*	96	24	22		65.53	.37
14	7	44	266*	95		64.56	.37
5	127	6	251*	28		60.92	.48
20	243*	60	77	30	2	58.98	.45
23	31	220*	105	56		53.39	.52
1	122	217*	55	15	3	52.66	.51
22	16	205*	40	148	3	49.75	.51
25	202*	57	14	139		49.02	.50
3	165	23	200*	22	2	48.54	.24
29	91	63	53	197*	8	47.81	.16
6	192*	168	18	34		46.60	.54
13	84	189*	68	69	2	45.87	.49
7	9	178*	148	77		43.20	.23
15	31	63	152	163*	3	39.56	.36
4	36	147*	112	116	1	35.67	.40
10	133	122*	88	68	1	29.61	.17
24	60	110*	85	153	4	26.69	.06
21	72	115	113	109*	3	26.45	.41
11	206	55	102*	47	2	24.75	.18
30	99*	117	162	27	7	24.02	.41
9	142	80*	97	92	1	19.41	.16
28	97	77	100	133	5		.00

Comments on the analysis

Difficulty Range. It will be noted that the Difficulty Index has a very wide range. The index varies from about 19 (a hard question with only 19% of candidates getting it right) to about 89 (an easy question with 89% of candidates getting it right).

Discrimination. The Discrimination Index is satisfactorily high overall. The index reaches values up to 0.54, drops to less than 0.2 for only a few questions. This is a satisfactory outcome, indicating that on the whole the paper discriminated reasonably well.
It should be noted that no indices or key is given for question 28: the question was withdrawn for reasons discussed below.

Comments on selected questions

For the most part the questions were judged to be good, in that they were conceptual, well formulated and suited to the MCQ format. 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. Thus comment will only be given on selected questions, i.e. those that illustrate a particular issue or where a problem was identified. Note that questions on which students performed well are not in general discussed, but can be identified from the analysis above. Detailed discussion are reserved for questions that students found difficult or where misconceptions are identified by popularity of distracters. Thus most of the comments below identify conceptual difficulties that students have with certain physical situations, and hence should serve as feedback for teaching. Each of the comments below resulted from discussions in the Grade Award Meeting.

QUESTION 3 (HL Q 4)

This was a moderately difficult question with a low discrimination index. Whilst 49% got it right, 40% chose distracter A. There may have been confusion in *greater speed* and *shorter time* but it illustrates a useful teaching point about free-fall motion under initial velocity conditions.

QUESTION 4

Only 35% got this right. Time and time again in IB exams students show that they are unable to draw free body diagrams accurately, and the desire to draw arrows in pairs on any and every body (fear of Newton 3?) is overwhelming. Even though **force** was in **bold letters**, more than half of all candidates chose C or D.

QUESTION 7 (HL Q7)

This was a harder question which did not discriminate well. Nearly the same number of students who got it right elected distracter C, and the question will serve as a useful model of a classic conundrum in dynamics.

QUESTION 8 (HL Q8)

This was similar to question 7 (a similar concept was being tested) but 65% of all students got it right, showing that Newton’s Third Law force-pairs can at least be recognized. (See the comment to Q 4)

QUESTION 9 (HL Q9)

Perhaps unsurprisingly, the SL candidates did worse than the HL on this question (at HL 29% got it right and at SL 19% did so.) Essentially the criticism is the same as for Q4 above, and the inability of candidates to draw or interpret a free-body diagram is painfully clear. Add to this the confusion common at SL over the direction (and cause) of centripetal forces, and we have 34% of SL candidates wrongly saying A and 30% of HL candidates wrongly saying C.

QUESTION 11

Twice as many students elected A as did the correct answer C. A forgivable error but one that needs to be cleared up in the teaching of the topic.

QUESTION 15 (HL Q17)

A good discriminator but a hard question. Nearly as many chose C as D. Although the answer would not be exactly 4ΔT in reality, it is still close enough to a theoretical value that the student should recognize.

QUESTION 24 (HL Q30)

It was clear that many candidates had forgotten that an alpha particle has double the charge **and** four times the mass of a proton. The question ought to have added "ignoring gravitational effects" although these are extremely small compared to electric forces and can effectively be neglected in answering this question. At SL this was the worst discriminator (suggesting that as many good candidates got it wrong as poor candidates).

QUESTION 28 (HL Q35)

As many students chose A as C The most popular choice was D, showing confusion between Thomson's work and that of Robert Millikan. The question had intended to elicit the answer A as this is the experiment that is done in the laboratory to verify *e/m*. Detailed historical research indicates that Thomson never used crossed fields, and in fact B is closer to the historical method. Since the question is technically inaccurate, it was withdrawn.

Areas where students had difficulties and areas where they were well prepared

It is difficult to generalise in a broad-based paper such as Paper1 over areas of difficulty or where students were well prepared. Several appropriate comments can be inferred from the question-by-question analysis above. In general, conceptual questions of the type used in these multiple choice papers demand good understanding of basic concepts and principles, physical insight into new situations and the ability to apply qualitative reasoning to understand how various factors affect a system. These skills, an important component of 'thinking like a scientist', sometimes tend to be neglected in teaching and textbooks. Some candidates struggled with the conceptual nature of these multiple-choice questions but it is encouraging to note from the statistics that many candidates did remarkably well.

Recommendations for the teaching of future candidates

The nature of the questions highlights the need to emphasize conceptual understanding of the basics. Qualitative reasoning about physical systems should be taught in addition to formula-based problem-solving. As always, it is recommended that more effort be given to an understanding of *free body diagrams*, the meaning of vector arrows drawn on such diagrams (in terms of magnitude, direction and the resolution and addition of such vectors into components or resultants) and the treatment and understanding of "fictitious forces" (e.g. centripetal force acts **inwards** and has no equal and opposite partner to be drawn by obligation).

Higher Level Paper 1

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-10	11-13	14-16	17-20	21-24	25-28	29-39

IB multiple choice physics papers are designed to have conceptual rather than calculation questions. This approach, emphasizing the qualitative rather than the quantitative, is based on the view that the MCQ format is suited to testing conceptual understanding, while calculations can be better assessed in the problems in Papers 2 and 3. Calculators are thus neither needed nor allowed in Paper 1. The papers were designed to have a range of difficulty of questions and reasonable topic coverage. A proportion of questions are common to the SL and HL papers, and the additional questions in HL tend to be of a somewhat higher level of difficulty.

The November 2001 papers were very well received and the comments were overwhelmingly positive. 85 % of the teachers who commented on Paper 1 felt that it was of broadly similar standard to last year's while 15% thought it a little harder. All respondents felt the difficulty was appropriate and that it contained questions of the correct level. 85% felt that the paper gave a satisfactory or good coverage of the syllabus whilst 15% felt the coverage was poor. 92% felt that clarity and wording were satisfactory or good. The Form G2, available from the *Vade Mecum*, is used to comment on examination papers and teachers are encouraged to submit these forms as they are valuable feedback to the examining team and play an important role in setting grade boundaries. We thank schools and teachers who may have commented on particular questions on the G2 forms.

Statistical analysis

The overall performance of candidates and how they performed on the various questions can be usefully illustrated by the statistical analysis of responses. These results are given in the table below, HL Paper 1 Item Analysis. The numbers in the columns *A-D* and *Blank* are the numbers of candidates choosing the labelled option or leaving the answer blank. The question key (correct option) is indicated by an asterisk (*). The *Difficulty Index* (perhaps better called facility index) is the percentage of candidates who got the question right. A high index thus indicates an easy question, and the table has been presented in the order of difficulty from easiest to hardest question. The *Discrimination Index* is a measure of how well the question discriminated between better and weaker candidates. A higher value of discrimination index indicates that a greater proportion of the better candidates got the question right compared to the weaker candidates.

HL Paper 1 Item Analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
27	19	23	335*	14		85.67	.26
20	20	334*	30	7		85.42	.15
16	4	21	304*	62		77.74	.36
24	24	304*	12	51		77.74	.32
8	295*	74	8	14		75.44	.26
2	284*	42	41	20	4	72.63	.41
5	81	4	276*	30		70.58	.56
21	88	5	276*	21	1	70.58	.36
29	18	272*	68	33		69.56	.55
6	268*	98	11	14		68.54	.46
26	9	267*	22	93		68.28	.50
1	83	262*	43	3		67.00	.41
37	80	245*	48	17	1	62.65	.56
14	50	239*	82	19	1	61.12	.51
4	121	13	238*	19		60.86	.16
40	58	27	237*	67	2	60.61	.51
17	12	44	99	235*	1	60.10	.54
33	220*	12	109	49	1	56.26	.10
18	99	49	216*	27		55.24	.44
22	16	89	213*	73		54.47	.53
32	166	19	191*	14	1	48.84	.52
23	63	64	76	188*		48.08	.52
7	4	180*	147	60		46.03	.26
19	179*	103	38	68	3	45.78	.30
34	97	35	79	179*	1	45.78	.23
11	127	85	178*	1		45.52	.60
10	51	16	147	176*	1	45.01	.10
3	102	172*	23	94		43.98	.55
36	169*	22	131	64	5	43.22	.10
25	32	24	163*	170	2	41.68	.38
28	147	26	149*	69		38.10	.12
30	79	141*	81	88	2	36.06	.39
31	33	97	137*	122	2	35.03	.49
15	106	130*	133	22		33.24	.33
39	126*	170	85	8	2	32.22	.53
9	96	113*	114	68		28.90	.29
13	17	56	209	109*		27.87	.46
38	109*	115	130	34	3	27.87	.54
12	180	100*	61	50		25.57	.36
35	127	47	122	94	1		.00

Comments on the analyses

Difficulty Range. It will be noted that the Difficulty Index has a good range. The index varies from about 25 (a hard question with only 25% of candidates getting it right) to about 86 (an easy question with 86% of candidates getting it right).

Discrimination. The Discrimination Index is satisfactorily high overall. The index reaches values up to 0.56 and drops to 0.1 for only a few questions. This is a satisfactory outcome, indicating that on the whole the paper discriminated reasonably well. Those questions with a very low index are in general easy ones, but not exclusively so, indicating that it is not always the case that hard questions discriminate best between good and poor students.

It should be noted that no indices or key is given for question 35: the question was withdrawn for reasons discussed below.

Comments on selected questions

For the most part the questions were judged both by the examining team and by the schools to be good in that they were conceptual, well formulated and suited to the MCQ format. 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 when looking at a specific question. Thus comment will only be given on selected questions, i.e. those that illustrate a particular issue or where a problem was identified. Note that questions on which students performed well or which discriminated well will generally not be discussed, but can be identified from the analysis above. Detailed discussion are reserved for questions that students found difficult or where misconceptions are identified by popularity of distracters. Thus most of the comments below identify conceptual difficulties that students have with certain physical situations, and hence should serve as feedback for teaching. Each of the comments below resulted from discussions in the Grade Award Meeting.

QUESTION 4

This was an easy question but with a low discrimination index. Whilst 60% got it right, 31% chose distracter A. There may have been confusion in *greater speed* and *shorter time* but it illustrates a useful teaching point about free-fall motion under initial velocity conditions.

QUESTION 7

This was a harder question which discriminated quite well. Nearly the same number of students who got it right elected distracter C, and the question will serve as a useful model of a classic conundrum in dynamics.

QUESTION 8

This was similar to question 7 (a similar concept was being tested) but 75% of all students got it right, showing that Newton's Third Law force-pairs are being properly taught.

QUESTION 10

This question was moderately difficult (the most popular choice was the correct one) though far more candidates got it wrong than right and it had the lowest discrimination index. Virtually all "wrong" answers said both momentum and kinetic energy are conserved. There is probably a degree of "conditioning" of students into believing that in *all* systems momentum and KE are conserved. It would be helpful to concentrate in the teaching of this topic on the definition of a *system.*

QUESTION 13

This question should have been easy with a rapid mental or on-paper application of $\frac{pV}{T}$ is constant. The problem, as ever, is the failure to use the thermodynamic temperature scale.

QUESTION 19

This question was moderately difficult and discriminated moderately well. It can be considered a "standard text-book" question and often appears in physics books. It could be argued, as one teacher did, that the process *in the short-term* does not violate the Second Law, in much the same way that in certain thermodynamic processes heat can, over a cycle, be completely turned into work. However such short-scale operations were not the intention behind the question.

QUESTION 25

Almost as many candidates chose D as chose C. This may have arisen from the difficulty of *describing* the phenomenon of beats, rather than from not knowing what is happening at all.

QUESTION 30

It was clear that many candidates had forgotten that an alpha particle has double the charge **and** four times the mass of a proton. The question ought to have added "ignoring gravitational effects" although these are extremely small compared to electric forces and can effectively be neglected in answering this question.

QUESTION 33

This was an easy question (judged by the difficulty index) but a poor discriminator. Many "good" candidates were seduced into thinking only a magnetic force acts on the electron. The key phrase was *while the rod moves steadily.*

QUESTION 35

As many students chose A as C. The question had intended to elicit the answer A as this is the experiment that is done in the laboratory to verify *e/m*. Detailed historical research indicates that Thomson never used crossed fields, and in fact B is closer to the historical method. Since the question is technically inaccurate, it was withdrawn.

Areas where students had difficulties and areas where they were well prepared

It is difficult to generalise in a broad-based paper such as Paper 1 over areas of difficulty or where students were well prepared. Several appropriate comments can be inferred from the question-by-question analysis above. In general, conceptual questions of the type used in these multiple choice papers demand good understanding of basic concepts and principles, physical insight into new situations and the ability to apply qualitative reasoning to understand how various factors affect a system. These skills, an important component of 'thinking like a scientist', sometimes tend to be neglected in teaching and textbooks. Some candidates struggled with the conceptual nature of these multiple-choice questions but it is encouraging to note from the statistics that many candidates did remarkably well.

Recommendations for the teaching of future candidates

The nature of the questions highlights the need to emphasize conceptual understanding of the basics. Qualitative reasoning about physical systems should be taught in addition to formula-based problem-solving.

Standard Level Paper 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-5	6-11	12-16	17-22	23-28	29-34	35-50

General comments

The feedback from teachers was generally very positive. Ninety percent of the replies received thought that the paper was of the appropriate level of difficulty. An even higher percentage rated the paper to have a satisfactory or good syllabus coverage. All replies rated the clarity of wording and the presentation of the paper to be satisfactory or good. A clear majority rated the paper to be good in all aspects.

In general candidates appeared to allocate their time appropriately and there was no evidence that candidates were disadvantaged by lack of time. However, some candidates, as in previous years, do not pay heed to the space available for answering a particular sub-question or to the marks available and give needlessly lengthy answers.

Most candidates made significant digit errors (even though the leeway for this is generous) and unit errors and so lost a mark.

The majority of candidates showed the steps in calculations, if at times somewhat messily, and so were able to take advantage of “error carried forward” marks.

Section A was compulsory while candidates had a choice of questions in Section B.
The vast majority of candidates correctly followed the rubric and answered the required number of questions. However, a few answered more than one question in Section B and did not indicate on the front of the question paper which question they wanted marked. Under the circumstances the examiner marks the first question answered and ignores the other question
Overall in Section B no particular preference of question choice was shown.

Areas of the program and examination which proved difficult for candidates

Many candidates had difficulty with half-life calculation difficult and not many showed a very good understanding of the principle of superposition.
Quite a few candidates have difficulties with power calculations and in particular combing power and time to get energy. The two concepts, power and energy, are often confused by many candidates.
The role played by uncertainty in measurement is also an area which confuses many candidates.
Some candidates have difficulty with the manipulation of numerical and algebraic data and a large number often find it difficult to explain clearly observations in terms of physical concepts.

The levels of knowledge, understanding and skills demonstrated

Many candidates coped well with standard definitions, with substituting numerical values into standard formula and with graph plotting. The level of knowledge and understanding varied, just as one would expect across the entry with some candidates showing an excellent grasp of the concepts tested in this examination. At the other end of the scale some candidates exhibited little or no understanding of the concepts addressed by the questions.
The levels of knowledge and understanding are treated in more detail in the following section.

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

Section A

QUESTION A1 *Internal resistance of a battery (data analysis question)*

Most candidates were able to calculate the power correctly but the error analysis defeated many of them. Some candidates gained partial credit for working out the error in the resistance but few managed a complete solution. The term “absolute error” would seem not to be understood by a large number of the entry.
Many candidates drew good graphs but some candidates continue to choose poor scales and to join the data points with straight lines.
The maximum values of the resistance was usually read correctly from the graph but many candidates did not recognize the reason (the uncertainty in locating the maximum value from the graph) for their value lying within manufacturers’ tolerance. Candidates often though that their values was not consistent with the tolerance and gave irrelevant reasons for this such as heat lost in the battery and wires.

QUESTION A2 *Bouncing ball and contact time*

Several candidates assumed zero acceleration in determining the velocities of the ball and few recognized the vector nature of momentum and invariably calculated the momentum change of the ball from scalar subtraction.
Although many candidates knew that the area under the graph represented the momentum change few actually used it determine the contact time and invariably assumed a constant contact force thereby missing the whole point of the question.

QUESTION A3 *Radioactive decay- the age of a campsite.*

A disappointing number of candidates could not complete the equation or give a sensible answer as to why the amount of C-14 decreases with time.
Many of the candidates failed to recognize that two half-life's had passed and tried to determine the age by a ratio method.

Section B

QUESTION B1

Part 1 *Change of Phase, thermal energy transfer and specific heat capacity*

Some candidates calculated the energy from the specific heat rather than from the latent heat and so had problems in showing the power supplied was about 1000 W.
Most candidates recognized that energy would be lost to the surroundings but quite a few did not realize that the thermal conduction equation was needed to determine the temperature drop across the base of the saucepan.
Explaining why the temperature of the base is not at the temperature of the flame proved very difficult for most candidates The examiner was looking for any reasonable relevant explanation here but most candidates who attempted this just mentioned energy lost to the surroundings.
The determination of the specific heat capacity was often well done but defeated some candidates because they did no know how to combine power and time to get the energy. To this end some candidates equated the energy needed to heat the water to the energy needed to

heat the saucepan. Working was too often set down haphazardly making it sometimes difficult for the examiners to award error carried forward marks.

Part 2 *Motion of charged particles in electric and magnetic fields.*

It is possible that some candidates failed to show the directions of the electric and magnetic force on the diagram because there was no answer space. However, of those that did answer this some got the directions reversed whilst some though that the magnetic force was circular.
Candidates who wrote down the correct expressions for the forces usually went on to get the proof correct but many found it challenging to explain why the ion moves on a circular path, failing to recognize that the magnetic force is always at right angles to the direction of motion.

QUESTION B2 *Wave properties*

Many candidates correctly marked the wavelength although the wave front diagram confused some of the candidates. Wavelength calculations were generally correct but the sketch of the graph half a period later defeated a lot of the candidates.
Drawing wave fronts proved difficult for a lot of the candidates and not many even got the simple case of reflection correct.
It was most unfortunate that the wrong angle was given in the diagram for the situation of internal reflection. However, this did not seem to affect any of the candidates and most did the calculation assuming that the incident angle was in fact 35^0 and were given full credit. The very few candidates who recognize that in fact with the angle given there would be no transmission across the boundary was also given full credit. Many candidates recognized that with an angle of 45º internal reflection would take place.
Many candidates found the interference part of this question difficult. Intensity graphs were often weak and explanations of the shape of the graphs in terms of the principle of superposition were often confused and wrong.

QUESTION B3 Braking *distance*

Some candidates had a great deal of difficulty with the first part of the question and were not sure what actually was being asked of them and so were unable to actually make a start on showing that the minimum breaking distance depends on the square of the speed. Quite a few candidates used a correct energy or kineamatic argument to support this dependency but too often candidates resorted to irrelevant anecdote.
Calculations of the time to come to rest and the average breaking force were often well done but some candidates did not know how to start.
Quite a few candidates recognized that the reaction time would play a part in computing the stopping distance but this part of the question did seem to confuse some candidates who misinterpreted this as being caused by skidding. The subsequent graph and its interpretation were obviously determined by the previous answers given to the explanation of stopping distance. However, even if the explanation was wrong quite a few candidates drew a correct graph.
Many candidates answered correctly that the braking distance would be greater on an incline but few gave a valid or complete explanation.
There was much confusion between power and energy in determining the power output of the car and quite a few candidates did not seem to know the relationship between force and power.

Recommendations and guidance for the teaching of future candidates

The above comments on specific questions show the areas of the syllabus examined with which candidates often have difficulty.

In general when preparing candidates for the examination they should be encouraged to:

- learn clear and unequivocal definitions of physical quantities.
- understand the logical connection between concepts.
- be able to recall and comprehend material covered in lessons. (This can be achieved by frequent testing.
- understand recently acquired knowledge where possible before moving on to the next topic.
- gain experience in examination technique by answering questions from previous examinations.

Candidates should always read questions and graphs very carefully so that they take full advantage of the information given. This means in respect of graphical information that they should carefully identify variables and units on the scales of graphs.

Answers should be complete; arguments should be build up step-by-step and working in numerical problems should be clearly and logically set out. In this examination many candidates in particular lost marks in calculating the value of the specific heat capacity of aluminium. (SL B1 part 1 (c)). In quite a few scripts wrong answers might well have been due to an arithmetic slip but in scripts in which working was not set out clearly examiners were unable to reward error carried forward marks.

When answering the examination candidates should give careful consideration to the selection of a Section B question. They should be encouraged to read the questions carefully before making a selection. When answering the different sub-sections of the questions it is important that they take the mark allocation into account for the section since this is a good guide to the length and/or complexity of the answer expected.

The use of past examination questions should be adopted early on in the course. Where possible whole questions or parts of questions should be used to reinforce learning and understanding when each syllabus topic or sub-topic is completed.

Higher Level Paper 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-11	12-23	24-32	33-43	44-54	55-65	66-95

General comments

The feedback from teachers was generally very positive. Ninety percent of the replies received thought that the paper was of the appropriate level of difficulty. An even higher percentage rated the paper to have a satisfactory or good syllabus coverage. All replies rated the clarity of wording and the presentation of the paper to be satisfactory or good. A clear majority rated the paper to be good in all aspects.

In general candidates appeared to allocate their time appropriately and there was no evidence that candidates were disadvantaged by lack of time. However, some candidates, as in previous years, do not pay heed to the space available for answering a particular sub-question or to the marks available and give needlessly lengthy answers.

Most candidates made significant digit errors (even though the leeway for this is generous) and unit errors and so lost a mark.

The majority of candidates showed the steps in calculations, if at times somewhat messily, and so were able to take advantage of “error carried forward” marks.

Section A was compulsory while candidates had a choice of questions in Section B.
The vast majority of candidates correctly followed the rubric and answered the required number of questions. However, a few answered more than two questions in Section B and did not indicate on the front of the question paper which questions they wanted marked. Under the circumstances the examiner marks the first two questions answered and ignores the third question
Overall in Section B no particular preference of question choice was shown.

Areas of the program and examination which proved difficult for candidates

As in previous years many candidates find the concept of gravitational potential and its application to non-uniform fields difficult and also thermodynamic energy changes.
In this examination Huygen’s principal was examined in depth and this too proved difficult for the candidates.
The role played by uncertainty in measurement is also an area which confuses many candidates.
Some candidates have difficulty with the manipulation of numerical and algebraic data and a large number often find it difficult to explain clearly observations in terms of physical concepts.

The levels of knowledge, understanding and skills demonstrated

Many candidates coped well with standard definitions, with substituting numerical values into standard formula and with graph plotting. The level of knowledge and understanding varied, just as one would expect across the entry with some candidates showing an excellent grasp of the concepts testing in this examination. At the other end of the scale some candidates exhibited little or no understanding of the concepts addressed by the questions.
The levels of knowledge and understanding are treated in more detail in the following section.

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

Section A

QUESTION A1 *Internal resistance of a battery (data analysis question)*

Most candidates were able to calculate the power correctly but the error analysis defeated many of them. Some candidates gained partial credit for working out the error in the resistance but few managed a complete solution. The term “absolute error” would seem not to be understood by a large number of the entry.
Many candidates drew good graphs but some candidates continue to choose poor scales and to join the data points with straight lines.
The maximum values of the resistance was usually read correctly from the graph but many candidates did not recognize the reason (the uncertainty in locating the maximum value from

the graph) for their value lying within manufacturers' tolerance. Candidates often though that their values was not consistent with the tolerance and gave irrelevant reasons for this such as heat lost in the battery and wires.

QUESTION A2 *Bouncing ball and contact time*

Several candidates assumed zero acceleration in determining the velocities of the ball and few recognized the vector nature of momentum and invariably calculated the momentum change of the ball from scalar subtraction.
Although many candidates knew that the area under the graph represented the momentum change few actually used it to determine the contact time and invariably assumed a constant contact force thereby missing the whole point of the question.

QUESTION A3 *Gravitational potential energy.*

This question was rarely tackled with any real confidence. The proof at the start of the question was often fudged with only a few candidates realizing that the gravitational force at the surface of the Earth needs to be equated to the mass x acceleration.
Quite a few candidates determined a correct value for g_0 from the graph but very few knew how to use the graph to determine a change in potential; most candidates assumed a uniform field and used *mgh*.

QUESTION A4 *Radioactive decay- the age of a campsite.*

A disappointing number of candidates could not complete the equation or give a sensible answer as to why the amount of C-14 decreases with time.
There were some excellent answers to the calculation using the decay law but quite a few candidates just did not know how to start.
Not many candidates recognized that the age of coal means that hardly any activity will be left.
Only a few candidates recognised that coal is very much older than the burnt wood from an ancient campsite and so very little C–14 activity would be left. Wrong answers were usually on the lines that the wood that forms coal is radioactive.

Section B

QUESTION B1

Part 1 *Change of Phase, thermal energy transfer and specific heat capacity*

Some candidates calculated the energy from the specific heat rather than from the latent heat and so had problems in showing the power supplied was about 1000 W.
Most candidates recognized that energy would be lost to the surroundings but quite a few did not realize that the thermal conduction equation was needed to determine the temperature drop across the base of the saucepan.
Explaining why the temperature of the base is not at the temperature of the flame proved very difficult for most candidates The examiner was looking for any reasonable relevant explanation here but most candidates who attempted this just mentioned energy lost to the surroundings.
The determination of the specific heat capacity was often well done but defeated some candidates because they did no know how to combine power and time to get the energy. To this end some candidates equated the energy needed to heat the water to the energy needed to heat the saucepan. Working was too often set down haphazardly making it sometimes difficult for the examiners to award error carried forward marks.

Part 2 *Thermodynamic cycle*

Some candidates gave excellent answers to this question but of these not many managed to determine the efficiency and usually used an incorrect value for the total energy absorbed during the cycle.
Other candidates struggled and clearly did not understand what was happening during the cycle but of these quite a few were still able to determine the work done during the process Y -Z.
It was pointed out in the feedback forms by one teacher that this could not be an isothermal process from X-Y since for it to be so the pressure at X must be 4 atmospheres. This is indeed true but in the sense that this could be a cycle for any thermodynamic substance, the calculations are not affected in any way. However, the examiner agrees that it would have been better to have given a correct isotherm.

QUESTION B2

Part 1 *Coefficient of dynamic sliding friction*

Surprisingly few candidates were able to add arrows and names to represent the forces that act on a block sliding down an inclined plane. Many were, however, able to pick up reasonable scores for the whole question as a result of their attempts at the resolution of these forces. Encouragingly, working in symbols seems not to present problems for the majority candidates. There were some very good answers to the questions, but only a small number were able to estimate the coefficient of static friction from the angle of incline of the plane

Part 2 *Motion of charged particles in electric and magnetic fields.*

It is possible that some candidates failed to show the directions of the electric and magnetic force on the diagram because there was no answer space. However, of those that did answer this some got the directions reversed whilst some though that the magnetic force was circular.
Candidates who wrote down the correct expressions for the forces usually went on to get the proof correct but many found it challenging to explain why the ion moves on a circular path, failing to recognize that the magnetic force is always at right angles to the direction of motion.
It was pleasing to see the number of candidates who were able to deduce an expression for the radius of the circular path of the ion. The final question asked candidates to outline the principles of a mass spectrometer. Many were able to give good and complete answers, but some lost marks by failing to include sufficient detail. Some candidates were clearly guessing.

QUESTION B3

Part 1 *Braking distance*

Some candidates had a great deal of difficulty with the first part of the question and were not sure what actually was being asked of them and so were unable to actually make a start on showing that the minimum breaking distance depends on the square of the speed. Quite a few candidates used a correct energy or kinematic argument to support this dependency but too often candidates resorted to irrelevant anecdote.
Calculations of the time to come to rest and the average breaking force were often well done but some candidates did not know how to start.
Quite a few candidates recognized that the reaction time would play a part in computing the stopping distance but this part of the question did seem to confuse some candidates who misinterpreted this as being caused by skidding. The subsequent graph and its interpretation were obviously determined by the previous answers given to the explanation of stopping

distance. However, even if the explanation was wrong quite a few candidates drew a correct graph.

Part 2 *Photoelectric effect*

This question on the photoelectric theory tended to be done well or not at all. The calculations from the graph of stopping potential versus frequency were done reasonably thought it was very rare to find a candidate that related the work function to the y-axis intercept. Most simply substituted values into the equation.

QUESTION B4 *Wave properties*

Many candidates correctly marked the wavelength although the wave front diagram confused some of the candidates. Wavelength calculations were generally correct but the sketch of the graph half a period later defeated a lot of the candidates.
It was most unfortunate that the wrong angle was given in the diagram for the situation of internal reflection. However, this did not seem to affect any of the candidates and most did the calculation assuming that the incident angle was in fact 35º and were given full credit. The very few candidates who recognize that in fact with the angle given there would be no transmission across the boundary was also given full credit. Many candidates recognized that with an angle of 45º internal reflection would take place.

The derivation of the law of reflection from Huygen’s principle was done very badly indeed. Most candidates did not make a meaningful attempt at this section.

The final section on interference was done well but almost nobody put enough detail into their answers for the very last question on beats.

Recommendations and guidance for the teaching of future candidates

The above comments on specific questions show the areas of the syllabus examined with which candidates often have difficulty.

In general when preparing candidates for the examination they should be encouraged to:

- learn clear and unequivocal definitions of physical quantities.
- understand the logical connection between concepts.
- be able to recall and comprehend material covered in lessons. (This can be achieved by frequent testing).
- understand recently acquired knowledge where possible before moving on to the next topic.
- gain experience in examination technique by answering questions from previous examinations.

Candidates should always read questions and graphs very carefully so that they take full advantage of the information given. This means in respect of graphical information that they should carefully identify variables and units on the scales of graphs.

Answers should be complete; arguments should build up step-by-step and working in numerical problems should be clearly and logically set out. In this examination many candidates in particular lost marks in calculating the value of the specific heat capacity of aluminium. (HL B1 part 1 (d)). In quite a few scripts wrong answers might well have been due to an arithmetic slip but in scripts in which working was not set out clearly examiners were unable to award error carried forward marks.

When answering the examination candidates should give careful consideration to the selection of a Section B question. They should be encouraged to read the questions carefully before making a selection. When answering the different sub-sections of the questions it is important that they take the mark allocation into account for the section since this is a good guide to the length and/or complexity of the answer expected.

The use of past examination questions should be adopted early on in the course. Where possible whole questions or parts of questions should be used to reinforce learning and understanding when each syllabus topic or sub-topic is completed.

Standard Level Paper 3

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-8	9-13	14-17	18-22	23-26	27-40

General comments

Option A was attempted by more than three quarters of the candidates, although performance was generally quite poor. Option H was also very popular, whereas options B, C, and D were not chosen often. Option E was rarely chosen although the questions were quite straightforward. Option G was chosen less often than in previous sessions.

The areas of the programme which proved difficult for candidates

There were few attempts at Option B (Nuclear Physics), Option G and especially Option E (Historical Physics). This may suggest that these Options are perceived as difficult to teach or that the questions were not very accessible. In a November session where the number of candidates globally is relatively small, it is difficult to generalise about why certain Options are not tackled. Other areas of difficulty identified by the examining team include:
Collisions in two dimensions. (A2)
De Broglie wavelength (B1)
X-ray spectrum and mechanism of production (surprisingly) (B3)
Thermodynamic cycle and processes. (C2)
Addition of force vectors (D2)
Reflection and refraction of rays and polarisation (H2)

The levels of knowledge, understanding and skill demonstrated

A large majority of candidates chose Option A (Mechanics Extension) though the success rate for A2 wasn’t high. About half of all candidates chose Option H although there were often key areas of this topic which were not well demonstrated (such as the ability to draw ray diagrams, and the understanding of the wave and particle theories of light). Most candidates had seen or experimented with Young’s Slits and could describe this as evidence for the wave nature of light. The astrophysics option (F) was in general well answered, with some students performing outstandingly in this topic.

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

A Mechanics Extension

QUESTION A1 *Earth and Moon*

Performance varied, with the best candidates scoring well and the worst doing very poorly. It seemed as if Newton's Law of Universal Gravitation had not been well taught – in part (a) some candidates either stated Newton's Third Law of Motion or made some reference to force between bodies without quantifying it. Few even gave the equation. Some wrote the algebraic equation without defining the symbols used. Part (b) proved conceptually challenging: many candidates showed pairs of equal and opposite force arrows acting on the moon. The scale of the force arrows was rarely in relation to the magnitude of the forces. The calculation of the ratio in (c) was straightforward, and only mathematical errors prevented candidates from scoring fully. Many errors were careless, such as forgetting to square the separating distance. The data in the Spanish version was erroneous in that the Sun's and Moon's masses were reversed. No candidate appeared to notice this and the "plug & chug" approach meant that whatever values were given were put into the formula and the answer calculated. Most obtained the right answer for the ratio calculation in (c), although a number did not write down the ratio of equations first, but calculated each individual force numerically - a cumbersome procedure. This may reflect a shortcoming in teaching. Few candidates scored well in (d) where they were asked to hypothesise about the Earth no longer exerting a force on the Moon. A few gave some ideas based on Newton's First Law and supposed straight-line motion into space.

QUESTION A2 *Collision in two dimensions*

Although momentum conservation in two dimensions is on the syllabus, it was clear that this had rarely been taught. It requires treatment in terms of vectors and components. Most candidates treated the billiard ball collision as a one-dimensional rectilinear problem, using the straight-line conservation equation they were familiar with, in order to calculate the speed of the black ball after collision. Interestingly, many nevertheless then proceeded to calculate a direction for the black ball. Many marks were lost out of the six available for (b) and few candidates calculated both the magnitude and direction of the velocity of the black ball, despite the question specifying that both were required. Surprisingly, part (c) was not well done. Some candidates simply said no energy was lost since energy is always conserved. Others calculated the final kinetic energy using $KE = ½ m (v_1 + v_2)^2$.

B Atomic and nuclear physics extension

Rather few candidates chose this option and in general responses were surprisingly poor, considering the questions were reasonably straightforward.

QUESTION B1 *Electron beam in an electron microscope*

The question was straightforward, but many candidates had difficulties, perhaps because the concept of de Broglie wavelength seems not to be well understood. Many did not know that $KE = p^2/2m$ was useful to calculate KE.

QUESTION B2 Nuclear *transformation*

This was a straightforward question involving a standard calculation of mass change and energy release. Performance was reasonable.

QUESTION B3 *X-ray spectrum*

This was a ‘factual’ question assessing understanding of the mechanism of X-ray production, without a problem aspect. Performance was good for those who had studied the section, while it was clear that others had not.

C Energy extension

QUESTION C1 *Wind generator*

Candidates managed the qualitative parts (a) and (b) quite well, but the calculations in (c) and (d) proved difficult for some. Part (d) (ii) discriminated well between good and weak candidates.

QUESTION C2 *Thermodynamic cycle*

Thermodynamics often proves a difficult subject for students at this level, and it was true here also. In many cases there was a complete lack of understanding of processes in a thermodynamic cycle. Thermodynamics is conceptually difficult, but it is clear that much teaching has not provided an understanding of what is going on. Some candidates who tackled Option C skipped C2 entirely. In (c), many candidates did not use thermodynamic temperatures in the efficiency calculation.

Medical Physics

Option D was quite popular but not well done.

QUESTION D1 *Hearing and hearing loss*

Interpretation of information presented graphically often causes problems particularly with logarithmic scales and this graph was no exception. Although some candidates understood the basic procedures involved in a hearing test, few managed to give sufficient details to be awarded full marks. Parts (d) and (e) involved a simpler graph and the interpretation of this proved easier.

QUESTION D2 *Forces on spine during lifting*

The force diagram looked rather complicated and very few candidates were able to identify even an approximate direction for the missing force R and draw it in. Conditions for equilibrium and a correct mathematical treatment of force vectors in static balance do not seem to be well taught.

Historical Physics

So few candidates at Standard Level attempted this Option that no meaningful comments can be made about performance. It was generally well done in those cases where it was chosen.

Astrophysics

QUESTION F1 *Star Magnitude*

Surprisingly few candidates were able to predict which of two stars would appear brighter and there was confusion over apparent and absolute magnitude. (Some candidates wrote “*absolute magnitude means real magnitude*”). There was a tendency to use (wrongly) the equation

$b = \dfrac{L}{4\pi d^2}$. Generally the explanations and calculations on parallax were well done although some did not know $p=1/d$ nor the unit *parsec* (pc).

QUESTION F2 *Hertzsprung-Russell Diagram*

This part proved easier and most students were able to interpret the Hertzsprung-Russell Diagram correctly. The calculation of surface temperature using Wein's Law was also well done, although many candidates simply misread the x-axis units and entered metres instead of nanometres into the formula and then did not spot that their answers for temperature were ridiculous. In part *d (ii)* many candidates were unable to explain redshift and the Doppler effect. There were some very confused responses (some involving Hubble's Law) and getting a concise answer in four lines was rare.

Special and General Relativity

At Higher Level this is always a popular choice, but at Standard Level it rarely is. This session very few candidates chose it.

QUESTION G1 *Time dilation*

Many candidates misunderstood the term *proper time* and were unable to explain it. With hindsight it might be suggested that the wording of part (a) of this question was not as clear as it could have been, though there was no evidence either from school feedback or from candidates' work that they had been disadvantaged by this.

QUESTION G2 *The muon*

This part required both explanations and calculations. Where it was attempted it was satisfactory.

QUESTION G3 *Gravitational Redshift*

This part was particularly badly done by those who had attempted Option G. It was a pity as 5 marks were to be awarded here. The question asked for an explanation **AND** an outline of an experiment that demonstrated it. Most ignored the "and".

Optics

This was the second most popular Option on the paper.

QUESTION H1 *Magnifying glass*
As is often seen at this level, candidates are unable to draw accurate ray diagrams, either through lack of practise or through not knowing how. There were a large number of good diagrams, though, but many had features missing that were specifically asked for in the question (e.g. the position of the eye). Virtually all candidates used the lens formula rather than a scale diagram to calculate the object position, but in doing so nearly all forgot (or didn't understand) the sign convention appropriate to virtual images.

QUESTION H2 *Caroline looks at the pond*

A large number of candidates could not draw a pair of reflected and refracted rays. Typical errors included rays coming **from** Caroline's eyes and rays coming directly from the tree to Caroline. Many candidates could not explain the action of Polaroid sunglasses and the majority that attempted it suggested that it is the glasses themselves that polarise the light, thus missing the point of the question.

QUESTION H3 *Wave and Particle Theories*

Most candidates gave Young's Slits experiment as evidence for the wave theory, and that was quite well done. Few could offer anything by way of explanation of the particle theory although something like the photoelectric effect or Compton scattering was being sought.

The type of assistance and guidance that teachers should provide for future candidates

It should be stressed again to students in all schools that they should read carefully the questions before answering them, in order to avoid getting half-way through an Option and then deciding to abandon it for a different one. Students **must** write legibly. It seems self evident, yet there were some scripts in both Spanish and English so badly written that they were unreadable and therefore unmarkable. They should not use red pen or indeed pencil for writing answers on their scripts. Candidates could be encouraged to summarize experiments identifying the key or essential elements in a logical and organised manner. Candidates should be afforded as much opportunity as possible to practice producing exam answers, and IB past papers and past markschemes are excellent tools for this. The writing of numerical answers to superfluous number of significant digits should be avoided. Not only is it mathematically inept, but it is penalised in the IB exams. The general rule is that answers should be given to the same degree of accuracy as the data from which they are derived. Units belong on most numerical answers in physics and if these are missing a mark is lost. Care on these details also needs to be stressed in preparing future candidates.

Higher Level Paper 3

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-13	14-22	23-29	30-35	36-42	43-60

General comments

The number of comments received from teachers was limited but greatly appreciated by the examining team. The vast majority of those that did comment felt that the paper was of an similar standard in comparison to last year's paper. All felt that the paper was of an appropriate level of difficult, and rated the clarity of wording and the presentation of the paper either 'satisfactory' or 'good'. The vast majority was also pleased with the syllabus coverage.

The choice of options was as in previous year, the most popular options being Options F, G and H (Astrophysics, Special and General Relativity and Optics). There were very few attempts at Options D and E (Biomedical Physics and Historical Physics).

Areas of the programme and examination which proved difficult for candidates

There were very few attempts at options D and E (Biomedical and Historical Physics) which suggests that these options are perceived to be difficult. Other areas of difficulty identified by the examining team included the following:

- Working with logarithmic functions
- The resolution of forces
- The detail of some basic definitions and concepts
- Image formation with parallel rays
- The mathematics of diffraction at a circular aperture

The levels of knowledge, understanding and skills demonstrated

Perhaps it is not surprising to note that the basic routine definitions and calculations were often done well. It was pleasing to see that many candidates were able to take things further and apply their ideas to the situations with which they were presented. In particular the majority of candidates had success with:

- Precautions involving the use of radioisotopes
- The calculation of parallax angle
- The use of Wien's law
- The mathematics of special relativity
- Polarisation
- The Rayleigh Criterion

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

QUESTION D3 *Radioisotopes*

Surprisingly few candidates were able to explain the difference between biological and physical half-life let alone attempt a calculation involving both quantities. The definitions of absorbed dose and dose equivalent were often guessed. Many candidates could suggest appropriate precautions when introducing radioisotopes into the body.

QUESTION E4 *Second law of thermodynamics*

The name entropy and a statement of the second law involving it was known by most candidates, but the details of the contribution made by Boltzmann was beyond the majority.

QUESTION E5 *Gell-Mann's 'eight fold way'*

Some candidates left this question blank, but those that did attempt it tended to be able to deal with the questions concerning quarks. The associated exchange particle was less well known.

QUESTION F1

The second part of the question asked candidates to analyse data involving Cepheid variables. Many candidates found this hard, though some were obviously able to cope with the given logarithmic equation without difficulty. A popular error was to confuse the period of the Cepheid variable with its maximum absolute magnitude.

QUESTION F2

The evolution of a main sequence star and the nuclear processes inside the star were not as well known. A popular misconception was that all fusion finished with the red giant phase and that all stars ended up as white dwarf stars.

QUESTION G2 *Momentum and energy in a collision*

About half the candidates who attempted this question realised that the total momentum of the two identical particles travelling at equal speeds towards one another would be zero. About the same number could correctly calculate their total energy. The move into one of the particles' frames of reference confused many and only a small percentage of the candidates even attempted to use the relative velocity formula. Having said this, a significant number made their way to the end of the calculations without any error at all. Most understood that the different frames of reference would agree on the number of particles and photons formed as a result of the collision.

QUESTION H4 *Optical resolution*

This question dealt with diffraction effects, but unfortunately many candidates' answers did not address this phenomena. It was very rare to see a complete solution and unfortunately many candidates thought this was another ray diagram question. Many attempted to use the equation of Young's slits or the grating formula to calculate the minimum of the diffraction pattern. Those that did use the right formula often substituted in the length of the telescope when they should have used the size of the aperture. Many were, however, able to explain the Rayleigh criteria well.

Recommendations and guidance for the teaching of future candidates

Suggestions identified by the examining team include:

- Practice at the manipulation and interpretation of unfamiliar data – particularly if presented in graphical form.
- Students could gain confidence and fluency by going through the syllabus in detail to check their understanding – all too often a good paper contains a poorly answered section.
- More practice at descriptive answers. Calculations are often done well as compared with descriptions that tend to be muddled or confused.

Internal assessment (IA)

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-7	8-10	11-13	14-15	16-18	19-24

It was clear that most schools are teaching good high school physics in their practical programs. Many experiments were standard types of experiments, and most were relevant to the IB syllabus.

Administrative

Some schools sent entire portfolios, some schools marked more than two examples of each criteria to be moderated, some schools sent in work but did not clearly flag the material to be moderated, some schools forgot to submit the group 4 project evidence, some teachers forgot to sign the 4/PSOW form, etc. In one case, every lab was assessed by all the criteria and the summative mark was a total of all the marks under each criteria. The final mark included fractions. Teachers should refer to Section 4 of the Vade Mecum regarding these points.

Suitability of work

Many schools have investigations on a variety of topics but few schools were able to have a thorough coverage of the entire syllabus, all major sections and two options. It seems that many schools do not spend the 25% of class time that is expected. Planning exercises, as always, prove difficult to appreciate. One teacher assessed planning (a) and (b) when students used a computer simulation of the Milikan Oil Drop experiment. The aspects of the planning (a) criteria cannot be assessed in such an experiment. One school submitted investigations written up as fill in the blank type labs. This is clearly not appropriate. Many group 4 projects were interesting and well done.

Candidate performance

The IA criteria that were most successful were Data Collection, and Data Analysis. Many schools expressed uncertainties with recorded raw data. Very few were able to transfer this to graphs or through calculations in the conclusion. It was not uncommon for students to connect the dots on a graph instead of drawing a best straight line. Using a graphing program that does this for the student leads to poor physics.

The criteria of Evaluation, and Planning (b) were more or less satisfactory, although students often had trouble appreciating errors and uncertainties in their evaluations. Also, many conclusions were trite, simply stating that the experiment worked.

The most difficult criterion remains Planning (a). It is important that both teachers and students are familiar with the descriptors. Well established standard physics labs were often assessed by the planning (a) criterion. These are not appropriate for assessing planning (a).

Recommendations

Many schools are comfortable with the IA criteria and the mechanism for judging lab work. But there remains a number of schools that are not sufficiently familiar with what is required.

- It is recommended that both teachers and students have copies of the IA criteria, and that they study them. Teachers must design labs that are appropriate to the criteria.
- Planning (a) needs carefully set investigations, open-ended topics or themes and not well-defined questions provided by the teacher. There must be more than one response to the situation.
- It is recommended that teachers pay more attention to the handling of errors and uncertainties. All measurements are limited in their precision and accuracy. This should be recognized in lab work.

Although not all graphs need uncertainty bars, very few schools seemed to know about minimum and maximum slopes based on uncertainties. Careful attention must be given when assessing IA for standard and higher students. The criteria are the same for both, but the syllabus content of uncertainty analysis is different. Only labs that reflect the syllabus skills in SL should be set by the teacher and then assessed. An SL student cannot be penalized for not doing what is HL analysis.