PHYSICS

Overall grade boundaries

Standard Level

Grade:	1	2	3	4	5	6	7
Mark range:	0-15	16-25	26-35	36-48	49-58	59-70	71-100

Higher Level

Grade:	1	2	3	4	5	6	7
Mark range:	0-16	17-27	28-39	40-50	51-60	61-72	73-100

This report is based on an analysis of the examination papers and of student performance. Information is also provided by assistant examiners marking the papers and by 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 provided 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.

In a report such as this, more emphasis is placed on those areas where candidates had difficulties rather than where performance was good. The report should be read in this context.

Standard Level Paper 1

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-8	9-10	11-13	14-15	16-18	19-28

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	21-23	24-27	28-39

IB multiple choice physics papers are designed to have, in the main, questions testing conceptual ideas rather than the ability to carry out calculations. Calculations can be assessed more appropriately in questions on Papers 2 and 3. Calculators are thus neither needed nor allowed for Paper 1. A proportion of questions are common to the SL and HL papers, and the additional questions in HL provide further syllabus coverage.

The May 2002 papers were generally well received. Approximately 95% of the teachers who commented on the Papers felt that they contained questions of an appropriate level. A small number thought that the SL Paper was a little more difficult. With few exceptions, teachers thought that the Papers gave satisfactory or good coverage of the syllabus. However, coverage should be judged in conjunction with Papers 2 and 3. All teachers also felt that the presentation of the Papers was either satisfactory or good. However, it was felt that the wording of a small number of questions could have been improved. Further comment will be made on these questions later in this Report.

Statistical analysis

The overall performance of candidates and the performance on individual questions are illustrated in the statistical analysis of responses. These data are given in the grids below.

The numbers in the columns A-D and Blank are the numbers of candidates choosing the labelled option or leaving the answer blank. The question key (correct option) is indicated by an asterisk (*). The *difficulty index* (perhaps better called facility index) is the percentage of candidates that gave the correct response (the key). A high index thus indicates an easy question. The *discrimination index* is a measure of how well the question discriminated between the candidates of different abilities. A higher discrimination index indicates that a greater proportion of the more able candidates correctly identified the key compared with the weaker candidates.

SL Paper 1 Item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
5	144	357	3917*	132	4	86.01	.19
7	217	3541*	390	403	3	77.75	.38
27	406	3467*	192	460	29	76.13	.27
20	362	475	304	3402*	11	74.70	.29
28	365	307	3147*	719	16	69.10	.41
9	385	3146*	37	979	7	69.08	.43
10	3144*		1098	295	13	69.03	.13
3	3056*	467	827	183	21	67.10	.45
17	660	685	2967*	229	13	65.15	.41
1	300	2873*	764	614	3	63.08	.33
26	2795*	589	441	691	38	61.37	.42
29	299	393	1043	2755*	64	60.49	.38
25	2260*	1288	897	85	24	49.62	.27
6	500	2197*	1126	719	12	48.24	.40
4	516	2170*	328	1531	9	47.65	.41
8	2152*	2062	106	232	2	47.25	.53
16	229	1448	2086*	787	4	45.80	.49
19	372	2033*	1959	172	18	44.64	.39
2	1153	754	2010*	619	18	44.13	.43
12	111	1970*	2267	199	7	43.25	.34
30	1177	1952*	656	641	128	42.86	.26
22	1817*	864	721	1117	35	39.89	.42
13	862	1080	1720*	880	12	37.76	.31
24	1272	302	1626*	1342	12	35.70	.20
11	2122	1480*	906	40	6	32.49	.39
23	698	1903	1465*	459	29	32.16	.22
15	1251	648*	370	2263	22	14.22	.10
14	3563	239	614*	116	22	13.48	.21
18	386	516	1389	2239	24		.00
21	708	859	1792	1183	12		.00

In Q10 above A and B were both marked correct with 3144 correct answers.

HL Paper 1 Item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
35	214	2479*	104	218	15	81.81	.21
5	414	137	2380*	93	6	78.54	.10
10	208	2293*	17	509	3	75.67	.37
26	100	2274*	537	112	7	75.04	.39
40	119	219	384	2271*	37	74.95	.36
32	99	610	2227*	81	13	73.49	.45
25	259	2130*	45	586	10	70.29	.17
8	358	2089*	534	44	5	68.94	.50
15	156	85	2029*	753	7	66.96	.27
20	407	287	1990*	316	30	65.67	.40
17	441	327	1957*	289	16	64.58	.42
22	23	1922*	542	530	13	63.43	.40
1	550	314	1888*	272	6	62.31	.48
3	190	1854*	179	801	6	61.18	.45
6	368	248	554	1853*	7	61.15	.20
4	116	461	596	1852*	5	61.12	.60
39	460	192	1843*	487	48	60.82	.49
2	1837*	44	98	1040	11	60.62	.38
31	1836*	727	426	30	11	60.59	.36
38	449	476	1811*	252	42	59.76	.40
12	241	323	1777*	646	43	58.64	.35
34	553	1692*	561	187	37	55.84	.35
7	122	695	546	1659*	8	54.75	.02
24	306	1648*	960	100	16	54.38	.47
28	1605*	393	428	577	27	52.97	.51
33	467	216	749	1570*	28	51.81	.36
37	783	354	285	1550*	58	51.15	.49
11	1115	1493*	394	21	7	49.27	.56
14	240	1483*	917	361	29	48.94	.62
19	589	794	1414*	210	23	46.66	.35
9	55	78	1502	1392*	3	45.94	.40
30	795	230	1295*	699	11	42.73	.35
36	148	1252*	826	769	35	41.32	.53
21	235	335	1175*	1272	13	38.77	.37
29	419	1145	1131*	308	27	37.32	.32
13	1696	100	1110*	121	3	36.63	.40
16	1619	192	1051*	143	25	34.68	.46
23	64	1405	982*	563	16	32.40	.25
18	464	544*	345	1662	15	17.95	.16
27	490	327	983	1210	20		.00

Comments on the analysis

Difficulty. For both HL and SL the difficulty index varies from below 20% (relatively 'difficult' questions) to greater than 80% (relatively 'easy' questions).

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.

'Blank' response. In both Papers, the number of blank responses increases for the last few items. This may indicate that candidates did not have sufficient time to complete their responses. However, this does not provide an explanation for 'blanks' early in the Papers. 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.

Comments on selected questions

Candidate performance on the individual questions is provided in the statistical tables above, along with the values of the indices. For most questions, this alone will provide sufficient feedback information when looking at a specific question. Thus comment will only be given on selected questions, i.e. those that illustrate a particular issue or where a problem can be identified. Thanks are extended to those schools and teachers who have commented on particular questions.

SL Paper 1 Comments on selected questions

QUESTION 6

It may have been better to show the arrows on the diagram with different lengths. However, the difference was made clear in the text with bold type. The statistics for the question are quite satisfactory.

QUESTION 8

It would have been more satisfactory to have had a different length for the horizontal arrows and for the vertical arrows in the key (A). This did not affect the validity of the question in that the very popular wrong answer was B. This latter response indicated a serious misconception of the situation in that a resultant force was required for constant velocity.

QUESTION 10

The question and diagram did not make it clear whether the string is extensible or inextensible. Consequently, the key could be A or B. Both options were allowed.

QUESTION 13

Candidates were not informed that the metals have different specific heat capacities. The most common distractor was B. Since option B involved unequal changes in internal energy, then these candidates did not understand the underlying concept and were unlikely to have been disadvantaged by the omission.

QUESTION 18

A narrow interpretation of the syllabus on this topic could lead to candidates being disadvantaged in this question. Consequently, the question was withdrawn from the Paper.

QUESTION 21

The question was withdrawn from the Paper. The question is rather wordy and includes the possibly unfamiliar term ‘flat battery’. Furthermore, the extent of syllabus coverage on this topic is open to a certain degree of interpretation.

HL Paper 1 Comments on selected questions

QUESTION 2

As expected, the most popular incorrect response was the inverse of the key (A). There may have been some confusion with axes. In question papers based on the latest syllabus, candidates will be told ‘plot the variation with (quantity X) of (quantity Y)’. The first quantity mentioned should be plotted on the x-axis unless there is an instruction to the contrary.

QUESTION 13

Option A, although not the correct response, was the most popular. It may have been fairer to inform candidates that the mass M is greater than m. However, regardless of this, the only correct solution is C. The force on each mass due to the tension in the cord must be the same.

QUESTION 18

This question proved to be difficult. Candidates failed to realize that the mass affects not only the kinetic energy of the bullet but also, for a given energy, the temperature rise.

QUESTION 19

Although the statistics for this question are acceptable, it would have been better to refer to ‘potential energy’, rather than ‘potential’.

QUESTION 21

Although this question has a rather low difficulty index, its discrimination is high. The question discriminates well between the more able candidates.

QUESTION 23

A difficult question but one that discriminates quite well. Candidates should be able to deduce that the wind speed will not affect the frequency.

QUESTION 27

The question was withdrawn from the Paper. The question is rather wordy and includes the possibly unfamiliar term ‘flat battery’. Furthermore, the extent of syllabus coverage on this topic is open to a certain degree of interpretation.

QUESTION 29

The most popular response was B, although this was not the key. It appears that many candidates thought, quite wrongly, that power dissipation is directly proportional to resistance, without any consideration of current.

Examiner comment

In general, conceptual questions of the type used in these multiple choice papers demand good understanding of basic concepts and principles, often more so than quantitative formula-based problems. They require insight into 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 in textbooks. Thus it is not surprising that some candidates struggled with the conceptual nature of the questions. Nevertheless, it is encouraging that many candidates scored high marks and demonstrated good preparation for the examination.

Standard Level Paper 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-12	13-18	19-24	25-30	31-36	37-50

General comments

Judging from the very few critical comments on the teacher feedback forms, the examination would seem to have been well received by schools.

Feedback from schools can be summarized as follows:

- about 60% found the paper to be of a similar standard to last year, 5% a little easier and 35% a little more difficult
- about 90% found the level of difficulty appropriate and about 10% too difficult
- about 60% found the syllabus coverage satisfactory and 40% good
- about 40% found the clarity of wording satisfactory, 50% found it good and 10% poor
- about 40% found the presentation satisfactory and 60% found it good.

The examination would seem to have offered suitable challenges to strong candidates and also appropriate accessibility to weaker candidates.
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, did not pay heed to the space available for answering a particular sub-question or to the marks available and hence gave needlessly lengthy answers.

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

The majority of candidates showed the steps in calculations and so were able to take advantage of “error carried forward” marks. However, some candidates still continue not to show their working and so lose partial marks when the answer that they write down is incorrect.

The areas of the programme that proved difficult for the candidates

The manipulation of data (as opposed to substituting numbers into equations) caused problems for many candidates.
Often, the impression gained from scripts is that candidates are using the equations given in the Data Booklet without thought.
The interpretation of graphical data and explanations of physical phenomena are beyond some candidates.

In this examination, the following topics proved difficult for many candidates:

- analysis of electrical circuits
- establishing the equivalence between *BIL* and *Bqv*
- discussion of the principle of momentum conservation
- vector nature of momentum
- vector nature of velocity
- ionisation processes

In general, many candidates seemed to be well prepared in respect of the following topics:

- graph plotting and data analysis
- simple kinematics
- ideal gas calculations
- basic wave properties

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

Section A

QUESTION A1 Data Analysis

Although this question dealt with a topic outside the Standard Level syllabus, candidates did not appear to be disadvantaged by this and treated the question for what is was, namely a data analysis question.
Graph plotting was generally good but some candidates omitted units on the axes and/or chose tortuous scales. A few candidates drew dot-to-dot curves.
Most candidates found the correct values for steady current and resistance of the coil. Tangents were usually drawn clearly and with reasonable accuracy.
A significant number of candidates omitted the unit for the inductance of the coil.

QUESTION A2 Motion under gravity

This question was often well answered but weaker candidates floundered. A large number of candidates used positive numbers for both directions of velocity.
The sketch graph was usually well drawn, but quite a few candidates drew a velocity-time graph rather than the speed-time graph as required in the question.

QUESTION A3 Testing an electrical circuit

This question defeated a lot of candidates. Clearly many of them did not realize that resistors in series divide the supply voltage in proportion to the value of their resistances. In this respect, if there is 6 V across three equal resistors, then the voltage across each must be 2 V; if there are two equal resistors then the voltage across each is 3 V. This shows the ease of the question. However, most candidates thought that to answer the question, the current in each resistor has to be found. This gave them a lot of problems particularly when most tried to find the total resistance of the network.
Some candidates who could not answer the first part of the question were able to gain credit for recognizing how to test the circuit and for identifying the faults that would produce a reading of 6 V on the voltmeter.

Section B

QUESTION B1 The bouncing ball

This was a popular question and often well answered.
Candidates did not appear to be thrown by the different slopes given in the original graph. (In fact, a few candidates actually pointed out that the slopes should be the same!) A wide range of alternative solutions was accepted so that no candidate was disadvantaged by this error.
Most candidates could correctly mark the times at which the ball strikes and leaves the surface and also find the acceleration and the maximum height. However, there were many errors caused by ignoring the vector nature of momentum in finding the momentum change of the ball. Quite a few candidates tried to find the average force that the ball exerts on the surface using the equation $F = ma$. This was quite acceptable, but not with the acceleration as g!
Discussions of the principle of momentum conservation were generally poor, with very few candidates appreciating that momentum is conserved within the ball-Earth system. Explanations of the equal forces exerted by ball and surface were also often weak.
Sketch graphs of the harder ball's motion were often well done by the better candidates.

QUESTION B2

Part 1 Ideal gas behaviour

The question was not popular. In general, candidates scored higher marks on Part 1 than on Part 2.

There were some confused descriptions of the difference between temperature and internal energy of a gas. A significant number of candidates thought that temperature is the kinetic energy of the molecules and/or confused a macroscopic description of internal energy with a microscopic description.
Candidates also found it difficult to explain why the temperature of a gas rises when it is compressed rapidly. Although not explicitly on the syllabus, candidates should have enough knowledge of mechanics to realize that molecules will rebound from the moving piston with greater speed i.e. energy will be transferred to the molecules by the collision with the moving piston.
Most candidates coped well with the calculations of temperature (except for the usual failures to convert to degrees Kelvin), thermal energy and pressure.

Part 2 Magnetic forces

This question really showed up the inability of some candidates to handle algebraic manipulations. There was a great deal of meaningless manipulation by many candidates both in trying to show that $I = \frac{Nvq}{L}$ and that *BIL* and *Bqv* are equivalent expressions.

Candidates often managed to gain credit for the correct force directions. However, the weaker candidates frequently struggled to gain any credit in any section of this part of question B2.

QUESTION B3

Part 1 Waves in a rubber cord

This was a very popular question with Part 1 being generally better answered than Part 2.
The only section of this part that gave significant problems to some candidates was the shape of the fundamental waveform in the cord.
In view of the confusion between the terms *first harmonic* and *fundamental*, 4 Hz and 2 Hz were both accepted as correct answers to the last part of the question. In hindsight, in order to avoid ambiguity, this question should have been better phrased as " what is the frequency of the next harmonic".

Part 2 Radioactive decay

This question was sometimes quite well answered.
A significant number of candidates gave strange explanations of *half-life* (e.g. "time for an atom to halve") and/or *isotope*. Many candidates seemed to think that an element could have only one isotope. Some candidates did not read part (b) carefully and so gave the atomic number and the neutron number for radon instead of polonium.
There were some very weak explanations of the term *ionisating radiation* in spite of the fact that the explanation is given in the following section!
There was some confusion in the question about ion production in respect of the terms *ions* and *ion pairs*. However, examiners were generous with the 2 factors but in the event, this made little difference to many candidates since they clearly did not understand the ionisation process.
Although the unit eV is not explicitly in the Standard Level syllabus, in the context of the question in which it is given, the unit is an irrelevant. Similarly, it was felt that although the term *activity* is not used explicitly in the syllabus, it's meaning was unequivocal in the context of the question in which the term was used.

Recommendations and guidance that teachers should provide for future candidates

Recommendations from the examination team include the following ideas.

- More practice is needed with the interpretation of data – particularly if the data is presented in graphical form.
- More practice with algebraic manipulation. Candidates can be encouraged to first attempt the manipulation using numerical values and then see how this can be generalised.
- To place more emphasis on the need for answers to be precise and detailed. The number of marks awarded for a question can always be taken as a guide to the amount of detail required.

In general, candidates should

- be given precise and unambiguous definitions of physical quantities.
- always be encouraged to read carefully all the questions in Section B before making any choice.
- gain experience in answering examination questions early on in the course, when a particular topic is completed. Relevant questions (or parts of questions) from past examinations should be used to reinforce the understanding of the topic.
- be encouraged to always show their working in the answers to numerical questions.
- use a ruler to draw straight lines in diagrams or for linear graphs.
- use pencil for diagrams and sketches.

Higher Level Paper 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-11	12-23	24-36	37-46	47-57	58-67	68-95

General comments

Judging from the very few critical comments on the teacher feedback forms, the examination would seem to have been well received by schools. and colleges
The feedback can be summarised as follows:

- about 60% found the paper to be of a similar standard to last year, 10% a little easier and 30% a little more difficult
- about 95% found the level of difficulty appropriate and about 5% too difficult
- about 60% found the syllabus coverage satisfactory and 40% good
- about 50% found the clarity of wording satisfactory and 50% found it good
- about 40% found the presentation satisfactory and 60% found it good.

The examination would seem to have offered suitable challenges to strong candidates and also appropriate accessibility to weaker candidates.
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 attention to the space available for answering a particular sub-question or to the marks available, resulting in needlessly lengthy answers.

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

The majority of candidates showed the steps in calculations and so were able to take advantage of "error carried forward" marks. However, some candidates still continue not to show their working and so lose partial marks when the answer that they write down is incorrect.

The areas of the programme that proved difficult for the candidates

The manipulation of data (as opposed to substituting numbers into equations) caused problems for many candidates.
Often, the impression gained from scripts is that candidates are using the equations given in the Data Booklet without thought.
The interpretation of graphical data and explanations of physical phenomena is beyond some candidates.

In this examination, the following topics proved difficult for many candidates:

- analysis of electrical circuits
- establishing the equivalence between BIL and Bqv
- discussion of the principle of momentum conservation
- the thermodynamics of the refrigerator.

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

In general, many candidates seemed to be well prepared in respect of the following topics:

- graph plotting and data analysis
- projectile motion
- photoelectric effect
- ideal gas behaviour
- basic wave properties
- radioactive decay

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

Section A

QUESTION A1 Data Analysis

Although this question dealt with a topic outside the Higher Level syllabus, candidates did not seem to be disadvantaged by this and treated the question for what is was, namely a data analysis question.
Graph plotting was generally good but some candidates omitted units on the axes and/or chose tortuous scales. A few candidates drew dot-to-dot curves.
The only part of this question that proved difficult to the majority of the candidates was deducing the expression for the time constant. If the candidates had been asked to determine the time it takes for an object to reach a certain speed knowing its acceleration, then they would have no difficulty with this. In effect, this was all that they were being asked to do. The majority of the candidates who attempted this part tried to fool the examiners with bizarre and meaningless algebraic manipulation.

QUESTION A2 Projectile motion

This question was often well answered but weaker candidates floundered. Some candidates did not resolve the velocity into components and in finding the speed with which the stone hit the sea, some candidates determined only the vertical component of velocity. Some candidates who used an energy argument (which is the more elegant approach) for this part forgot that the stone still has a horizontal speed at its highest point.
Some candidates drew a trajectory for the stone and marked on this the components of velocity. This did not gain any credit. In fact, they were asked to sketch graphs showing how the components vary with time.

QUESTION A3 Testing an electrical circuit

This question defeated many candidates. Clearly many of them did not realise that resistors in series divide the supply voltage in proportion to the value of their resistance. In this respect, if there is 6 V across three equal resistors, then the voltage across each must be 2 V; if there are two equal resistors then the voltage across each is 3 V. This shows the ease of the question. However, most candidates thought that, in order to answer the question, the current in each resistor had to be found. This gave rise to problems particularly when most tried to find the total resistance of the network.
Some candidates who could not answer the first part of the question were able to gain credit for recognizing how to test the circuit and for identifying the faults that would produce a reading of 6 V on the voltmeter.

QUESTION A4 Planck's constant and the LED

Frequently, this question was done well. However, some candidates could not make the correct conversion from electron-volts to joules and some tried to find Planck's constant from the de Broglie relation - a classical example of misuse of the Data Booklet!

Section B

QUESTION B1 Energy and momenta changes in α-particle scattering

This was not a particularly popular question but there were some excellent answers with some candidates gaining full credit. Generally, the marks were on the high side indicating that the question was, more often than not, attempted by the stronger candidates.
A few candidates thought that the force on the α-particle in position 1 would be zero because of its distance from the nucleus. Weaker candidates who attempted this question could not handle the vector diagram.
Calculation of the recoil kinetic energy of the gold nucleus was often done well but many candidates made hard work of it by not using the equation $E = \frac{p^2}{2m}$. Candidates who attempted the justification of the Geiger-Marsden assumption, argued either from momentum or from their answer to the recoil energy. Both approaches, if correct, were given full credit.
Some candidates failed to mention the Coulomb repulsive force when explaining what happens to the kinetic energy of the α-particle as it approaches the gold nucleus.
Determining the closest distance of approach of the α-particle to the gold nucleus would seem to be a technique well known and understood, or not known at all. A popular misconception was to attempt a calculation in terms of the force between the nucleus and α-particle, an approach that led nowhere.

QUESTION B2

Part 1 Ideal gas behavior

This was quite a popular question with Part 1 scoring higher marks than Part 2.
There were some confused descriptions of the difference between temperature and internal energy of a gas. A significant number of candidates thought that temperature is the kinetic energy of the molecules and/or confused a macroscopic description of internal energy with a microscopic description.
Most candidates coped well with the change in molecular distribution, calculations of temperature (except for the usual failures to convert to degrees Kelvin), internal energy and pressure. However, a significant number of candidates did not realise that there is no change in internal energy when temperature remains constant. Consequently, the gas must loose an amount of energy equivalent to the work done when compressed.

Part 2 Magnetic forces

This question really showed up the inability of some candidates to handle algebraic manipulations. There were a great number of meaningless manipulations by many candidates, both in trying to show that $I = \frac{Nvq}{L}$ and that *BIL* and *Bqv* are equivalent expressions.
Candidates often managed to gain some credit for correct force directions, calculation of the force on each wire and in the description of the subsequent motion of wire Y. However, the weaker candidates often struggled to gain any credit in any section of this part of question B2.

QUESTION B3

Part 1 Waves in a rubber cord

This was a very popular question with Part 1 being generally better answered than Part 2.
The only section of this part that gave significant problems to some candidates was calculating the fundamental frequency of vibration of the stretched cord. Some candidates just did not realise that they had to use the formula $v = \sqrt{\frac{T}{\mu}}$ in order to find the frequency.
In view of the confusion between the terms *first harmonic* and *fundamental*, 4Hz and
2 Hz were both accepted as correct answers to the last part of the question. In hindsight, in order to avoid ambiguity, this question would have been better phrased as " what is the frequency of the next harmonic".

Part 2 Radioactive decay

This Part was often well answered.
A significant number of candidates gave strange definitions of *half-life* and/or did not read part (b) carefully and so gave the atomic number and the neutron number for radon instead of polonium.
There were a significant number of candidates trying to "fiddle" the relation between half-life and decay constant and there were some very weak explanations of the term *ionisating radiation*.
Most candidates drew a good best-fit line and also recognized that the decay constant is found from the slope of this line. However, some candidates tried to find its value by substituting into the exponential equation. The determination of the half-life was usually done well, with a considerable number of candidates gaining error-carried-forward marks.

QUESTION B4

Part 1 The bouncing ball

This question was not as popular as B2 or B3. Part 1 was often well answered but most candidates found Part 2 very troublesome. Most candidates could correctly mark the times at which the ball strikes and leaves the surface but there were frequent errors in ignoring the vector nature of momentum in finding the momentum change of the ball. In some scripts, candidates tried to find the average force that the ball exerts on the surface using the formula $F = m\,a$. This is acceptable, but not with the acceleration as g!
Discussions of the principle of momentum conservation were generally poor, with very few candidates appreciating that momentum is conserved within the ball-Earth system.
Sketch graphs of the harder ball's motion were often well done and candidates did not appear to be disadvantaged by the different slopes given in the original. In fact, a few candidates actually pointed out that the slopes should be the same!

Part 2 The refrigerator

This part was rarely answered with any confidence.
Some candidates were able to correctly identify the stages during the cycle when energy is ejected and absorbed by the refrigerant even though they might not have been familiar with the idea of isobaric isotherms. (Isobaric as a result of the vaporisation and the condensation of the refrigerant.) However, explanations of the energy absorption and ejection were often vague. Very few candidates appreciated the concept of coefficient of performance in order to show that for every unit of energy used by the motor, six would be ejected to the surroundings. Neither could they relate this fact to why a heat pump is likely to be a cheaper method of heating a house than using a conventional heater.
Many candidates thought that the cold reservoir of a heat pump would be the inside of the refrigerator!

Recommendations and guidance that teachers should provide for future candidates

Recommendations from the examination team include the following ideas.

- More practice is needed with the interpretation of data – particularly if the data is presented in graphical form.
- More practice with algebraic manipulation. Candidates should be encouraged to first attempt the manipulation using numerical values and then see how this can be generalised.
- To place more emphasis on the need for answers to be precise and detailed. The number of marks awarded for a question can always be taken as a guide to the amount of detail required.

In general, candidates should

- be given precise and unambiguous definitions of physical quantities.
- always be encouraged to read the all questions in Section B carefully before making any choice.
- gain experience in answering examination questions early on in the course. When a particular topic is completed, then relevant questions (or parts of questions) from past examinations should be used to reinforce the understanding of the topic.
- be encouraged to always show their working in the answers to numerical questions.
- use a ruler to draw straight lines on diagrams or on linear graphs
- use pencil for diagrams and sketches.

Standard Level Paper 3

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-8	9-12	13-17	18-22	23-27	28-40

General comments

The G2 feedback forms submitted after the examination contained both praise and constructive criticism and the critical comments were taken into careful consideration during the grade award process in making judgments about the overall level of difficulty and the likely effect of particular questions on candidates. The process of setting grade boundaries is responsive to teacher feedback and teachers are urged to submit their comments (if they have any) on the form G2. The feedback can be summarized as follows:

- about 60% found the paper to be of a similar standard to last year, 6% a little easier and 30% a little more difficult
- about 62% found the syllabus coverage satisfactory and 30% good
- about 50% found the clarity of wording satisfactory and 50% found it good
- about 43% found the presentation satisfactory and 54% found it good.

Whilst there were some challenging questions this year, the majority of candidates seemed to find the paper accessible and there were plenty of examples of excellent understanding of the material.

The most popular options were A (Mechanics) and H (Optics). The least popular were D (Medical) and E (Historical).

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, did not pay attention to the space available for answering particular sections of questions or to the marks available. Consequently, they gave needlessly lengthy answers or used continuation sheets unnecessarily.

Candidates should to be encouraged to ensure that they have turned the page and answered every part of a particular Option question. Several candidates missed C3.

Candidates in this session made fewer significant digit errors than in some recent sessions. This is a welcome trend in the pursuit of precision.

The majority of candidates showed the steps in calculations and so were able to take advantage of “error-carried-forward” marks and also for marks awarded for partially correct responses. However, a worrying number of candidates, sometimes all from one or two centres, simply wrote down an answer to numerical calculations without any working being shown (often with multi-part calculation steps). Whilst such an answer would always gain full marks (if fully correct) it is a practice that will always be to the candidates’ disadvantage.

The areas of the programme that proved difficult for the candidates

- The manipulation of data (as opposed to substituting numbers into equations) caused many problems for candidates.
- Candidates are often using the equations given in the Data Booklet without thought.
- The interpretation of graphical data and explanations of physical phenomena is beyond some candidates.
- Gravitation, particularly in its mathematical aspects.
- The Bohr model.
- The concept of energy degradation and entropy.
- Scaling.

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

Some candidates demonstrated a good understanding of the option questions that they attempted and had obviously been well prepared for the examination. In particular, the Options B (Atomic and Nuclear), F (Astrophysics), and G (Special and General relativity) allowed the best candidates the opportunity to show a deep understanding of the principles involved.

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

Option A – Mechanics

QUESTION A1 Vector components of parabolic motion

The drawing of vectors seems not well taught in many Centres – candidates pay attention to direction in all cases but not to length. There should have been a clear difference between the lengths of the arrow at M and at K. Weaker candidates drew in a vertical arrow at L as well. The calculations in (b) and (c) were generally satisfactory, though the most common error was to use the equations of motion with the modulus of the velocity (20 ms^{-1}) instead of its vertical or horizontal components. Whilst (b) asks for the *time* to reach maximum height, some candidates calculated *the maximum height* and left it at that.

QUESTION A2 Gravitation

This gravitation question probably caused more difficulty than any other. The phrase *to escape the gravitational attraction* invited a wealth of loose and vague ideas such as “to just escape the pull of the planet” and “to overcome the gravity force” with this word “overcome” being the most commonly used across all English-speakers. The key idea that reducing the force to zero implies increasing the distance to infinity was lost on large numbers of candidates. The proof of the expression $v_{escape} = \sqrt{\frac{2GM}{r}}$ depended critically on an understanding of work done per unit mass (i.e. gravitational potential). This point was missed by many candidates. Part (b) was relatively easy in that values were placed into a given equation. Even so, many weaker candidates forgot to convert the radius of 5 km into metres. Part (c) was quite difficult. Most candidates correctly equated centripetal and gravitational acceleration to obtain the low orbit speed, but many had difficulty in predicting an “orbit” with ¾ of this speed. In fact a wide range of responses was allowed for the one mark awarded.

Option B - Atomic and Nuclear Physics extension

QUESTION B1 Hydrogen Emission Spectrum

The Bohr model proved very difficult for many candidates and the various formulae available to them appeared to confuse rather than to help them. The explanation required in (a) for 4 marks was for *how* the series arise and *why* the lines are crowded at one end. Many candidates had only a superficial understanding and their answers reflected this. Some concentrated on only one aspect of the question instead of both. The transition arrow extended from the line **above** $n = 4$ (i.e. $n = 5$) to the line $n = 2$. Students may have either remembered that the Balmer Series (which was discovered first, from visible radiation) dealt with transitions to $n = 2$, or have inferred this from the data in the question and the wavelengths in Diagram 2. The wavelength calculation from the indicated transition (part (c)) was generally satisfactory although many used eV instead of joules giving a ridiculously small wavelength.

QUESTION B2 Duality

Whilst (a) was generally well done, (b) was often misread as "a phenomenon that supports wave-like behaviour" instead of "a phenomenon that supports wave-like behaviour *of matter*". The wave nature of large particles was generally understood (part (c)) but rarely explained in terms of *momentum* (e.g. $\lambda = \frac{h}{p}$) or the impossibly small diffraction effects.

QUESTION B3 Nuclear Fusion

This question was generally rather well answered.

Option C - Energy extension

This was one of the least popular of the Options. In general, it was answered well except for the concepts of energy degradation and entropy which were poorly understood.

QUESTION C1 Heat engine efficiency

Part (a) was straightforward and a wide range of possible temperatures T_{cold} were allowed for, given winter and summer temperatures in the candidates' own countries. (Some thought 0 K should be T_{cold}!) The reasons for maximum efficiency not being obtained in practice were too often put down to a vague "energy losses", instead of looking for thermodynamic reasons. The calculation in (c) was straightforward. However, both (d) and (e) caused difficulties to candidates who understood the idea of degradation of energy, but were at a loss to explain it in terms of order or its ability to be transformed again into useful work.

QUESTION C2 Solar Energy transformation

One might have expected an easy 4 marks here, with two advantages and two disadvantages. Many students were hard-pushed to give more than one of each which were significantly different from one another.

QUESTION C3 Efficiency of conversion

Some candidates did not attempt C3 and it may be they did not turn the page as instructed and thus missed 4 marks. Of those who did attempt it, many did not find the question as intimidating as it looked. The calculation of overall efficiency in (b) was a challenge to many who had clearly never done this before (multiplying successive efficiencies of conversion).

Option D - Medical Physics

This Option also had a limited number of attempts from candidates. As last year, the question on scaling proved difficult.

QUESTION D1 Cardiovascular system

This question was fairly straightforward and candidates had little difficulty here.

QUESTION D2 Scaling

This question caused immense difficulties, despite the fact that there is almost always a scaling question in Option D. Part (b) produced more guesses than calculations. A wide tolerance was given over the estimates.

QUESTION D3 Hearing

This question had a good balance between factual recall, drawing, calculation and descriptive writing. Each part was, in general, answered well although the role of the cochlea was not well-described. Many candidates omitted major features or focused on its role in balance and equilibrium.

Option E - Historical physics

This was not a popular option. It covers a wide range of material and many candidates were not well prepared for it. Too many answers lacked the required detail and were anecdotal rather than relying on principles of physics.

QUESTION E1 Models of Solar System

The Option had limited popularity. Even so, those that undertook it were often unclear about astronomical models. Part (a)(ii) was misread by many candidates who either offered an explanation of the Copernican model or gave a description of what Copernicus believed. What was asked for was *an explanation of the Sun's and stars' motion* according to Copernicus (i.e. that the rotation of the Earth made the Sun and stars appear to move). In (b) there were many answers that were accepted for valid and relevant observations that Galileo made, but the consequent rationalisation according to the Ptolemy model was difficult for many candidates. Part (c) caused little or no problems and most understood, in (d), the nature of an empirical relationship. Many, however, had no concept of empiricism.

QUESTION E2 Energy Concept

Many students do have difficulty with *explanations* – either through problems of language or through lack of practice. Parts (a), (b) and (c) taxed some students in this respect. The cannon-boring experiment was remembered well, although often the essential point of *continuously generating an unlimited amount of heat* whilst boring continued was lost.

QUESTION E3 Photon Model

A few students scored well here and nearly all appeared to understand the main idea but used loose terminology.

Option F – Astrophysics

This was very popular and often answered well. The relation between the Doppler effect and the binary star spectra escaped many candidates.

QUESTION F1 Aspects of Antares A and Deneb

This question involved making inferences from the data in the table. Students did not have noticeable difficulties here. However, many suggested that Deneb's distance could be deduced from its parallax angle being too small to measure, rather than being fainter whilst having a greater luminosity than Antares A. The parallax angle was not given, rather than being stated as too small to measure. Nevertheless, partial marks were awarded for this answer. Both parts (b) and (c) were answered well although the calculation of distance from parallax angle was sometimes inferred from first principles without considering the angle in *seconds* of arc.

QUESTION F2 Spectroscopic Binary

Whilst the rubric to part (a) of this question referred clearly to a spectroscopic binary system, many students treated it (and referred to it) as an eclipsing binary. Nevertheless, it was generally answered well, although very few candidates worked out the period in part (b). The usual answers were 5 or 10 days instead of 20.

QUESTION F3 Olber's Paradox

This was generally well answered by all students who attempted Option F, with many interesting and imaginative analogies described to explain Olber's view (looking into a forest and seeing trees, eventually, in every direction).

Option G - Special and General Relativity

This was quite popular but many candidates found the term "paradox" difficult to explain.

QUESTION G1 Michelson-Morley Experiment

Some variation was allowed in the response to the questions about the Michelson-Morley experiment. Few candidates were able to make explicit reference to the speed of the Earth through the ether wind. Similarly, details as to why the experiment was repeated (part (c)) were not always clear. Vague responses were common.

QUESTION G2 Time Dilation

Virtually all candidates made correct calculations using the time dilation formulae for the relativistic effects in parts (a) and (b). The most common error was to interchange the frames of reference (the Earth's and the astronauts'). In part (c), the inherent difficulty that many candidates show in explaining phenomena adequately appeared again, with the required explanation of the (twin) paradox. It was not acceptable merely to *name* this as "The Twin Paradox", as if that explained what was paradoxical. The symmetry and equivalency of the two descriptions needed to be stressed.

QUESTION G3 Gravitational Redshift

This was one of the lowest scoring questions. Few students could do more than generalise, and many merely referred to gravitational red-shift without mentioning photon energy and hence reduction in frequency.

Option H – Optics

Optics is always popular but many candidates do not score well since they are unable to draw ray diagrams and often do not understand applications of optical devices.

QUESTION H1 Plane Mirrors

Candidates who have studied ray optics still fail to produce accurate ray diagrams. An image produced in a plane mirror is about as straightforward as it could be yet rays, image position and orientation were often quite wrong. The geometry and argument behind the double reflection in (b)(i) was expressed well by most candidates but very few candidates were able to put the device to any use in part (ii).

QUESTION H2 Focal Length of thin lens

This question caused considerable difficulties for many candidates who attempted it. The set-up is a standard arrangement. It placed before the candidate the opportunity to make inferences based on knowledge of optics and the ability to draw ray-diagrams. This latter requirement, rather than the unfamiliar combination of mirror and lens, caused so many students to stumble over this part. As discussed in previous reports, students who study ray optics need to be able to draw ray diagrams! Parts (b), (c) and (d) were clearly guesses in many cases. In (c) even 0 was allowed (if it clearly meant "there is no magnification").

QUESTION H3 Interference

The determination of slit separation d caused little difficulty, except in that some candidates used $\theta = 0.25°$ rather than $\theta = 0.50°$. The sketch of the intensity pattern (part (b)) for multiple slits with the same separation was as varied as it could be, and hardly any candidates were able to draw this correctly.

Recommendations and guidance that teachers should provide for future candidates

Recommendations from the examination team included the following ideas:

- Candidates should read the question paper through before starting, not only to gauge the variety of questions but also the number of sections in each question and the difficulty before choosing and starting. (See comment to C3 above.)
- Candidates should read each question carefully and focus their answers accordingly. (See comment to E1 (a) (ii) above.)
- Some candidates are needlessly losing marks as a result of not showing their working to numerical problems. It is **essential** to show working if they are not to be disadvantaged in the marking process.
- More practice is needed with the interpretation of data – particularly when the data is presented in graphical or tabular form.

- It is important that Options are not left until the end of the course. This can lead to their study being rushed or incomplete. The time available for the study of the Options should be allowed for and carefully integrated into the programme as a whole. Candidates should not attempt to answer an Option that they have not studied.
- If candidates study an Option on their own, then teachers should ensure that their progress is carefully monitored and that adequate support is given. Students from a school that answered questions in the same option generally performed better than those that answered questions from different options.

Higher Level Paper 3

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-14	15-22	23-29	30-36	37-43	44-60

General comments

Judging from the very few critical comments on the teacher feedback forms, the Paper would seem to have been well received by schools. If anything the Paper was felt to be a little hard and a little long. Feedback from schools can be summarized as follows:

- About 50% found the paper to be of a similar standard to last year, and 50% found it to be more difficult although over 80% thought it was of an appropriate level of difficulty.
- About 50% found the syllabus coverage satisfactory and 45% good.
- About 45% found the clarity of wording satisfactory and 50% found it good.
- About 35% found the presentation satisfactory and 65% found it good.

A significant number of students seemed to score the majority of their marks on very few sections of an Option, as if the other sections had not been covered. Furthermore, there is some evidence that candidates are attempting options for which they have not been prepared. However the majority of candidates seemed to find this Paper accessible and there were numerous examples of excellent understanding of the material examined.

The most popular options were F (Astrophysics), G (Relativity) and H (Optics). The least popular were option D (Medical) and option E (Historical).

In general, candidates appeared to allocate their time appropriately and there was no evidence that candidates were disadvantaged by lack of time. There was evidence of organizing ideas and planning answers. Most candidates made significant digit errors (even though the leeway for this is generous) and unit errors and consequently lost some credit.

The majority of candidates showed the steps in calculations and so were able to take advantage of “error-carried-forward” marks.

The areas of the programme that proved difficult for the candidates

As in previous years, there were far fewer attempts at options D and E (Biomedical and Historical Physics) compared with the other options. This suggests that these options are perceived to be difficult. Other areas of difficulty identified by the examining team included the following.

- Working with symbols rather than numbers
- The concept of energy degradation
- The inclusion of sufficient detail when required to do so
- The details of the Michelson-Morley experiment
- Space-time diagrams
- Accurate ray diagrams

Areas of the programme and examination in which candidates appeared well prepared

As in the past, answers based on routine definitions and calculations were often done well. Many candidates were able to attempt to extend their answers. The majority were making sensible and complete attempts at the questions. In particular the majority of candidates had success with:

- knowledge of the different models of the solar system.
- an understanding of the photoelectric effect.
- regions in the Hertzsprung-Russell diagram.
- a basic understanding of relativistic effects.
- the image formed in a plane mirror

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

In Options D, E, F, G and H many comments appertaining to HL candidates also apply to SL candidates.

Option D - Medical Physics

Not many candidates attempted this Option, but those that did seemed to find it difficult to achieve a reasonable standard.

QUESTION D1 Fluid flow in the human cardiovascular system

Most were able to make a reasonable start, but candidates found it hard to determine the units of viscosity. The ratio calculations involving fluid flow tended either to be done well or very poorly indeed. Candidates were rewarded for any sensible discussion in the final section of this question.

QUESTION D2 Scaling

Again, candidates tended either to answer this questions completely and with apparent ease or they failed to grasp the concepts of scaling and their answers tended to be very muddled or just guess-work.

QUESTION D3 Ultrasound and imaging

Surprisingly few candidates were able to explain the process of ultrasound imaging in enough detail to gain full credit although many clearly understood the basic principles. A large number did not understand the resolution implications of the choice of wavelength and the use of gel was very poorly explained. Many were able to write sensibly on the advantages of ultrasound over X-rays.

Option E - Historical physics

This was another option that proved to be unpopular. Most candidates were able to engage with all of the questions but a lack of detail in the answers was common.

QUESTION E1 The development of heliocentric models of the solar system

Almost everybody did know that heliocentric models involved motion of the planets around the Sun, but often the type of orbit (circular or elliptical) needed to be inferred from poorly sketched diagrams without labels. Many thought that an empirical relationship was simply a mathematical relationship. Few realised that Newton's ability to account for Kepler's laws involved his laws of motion as well as his law of universal Gravity.

QUESTION E2 Steam engines and energy degradation

Candidates seemed to find it hard to achieve high marks on this question and many clearly did not understand the operation of a heat engine. Candidates mixed up concepts or suggested wrong or vague answers e.g. 'degraded energy' or 'energy loss'. Not many candidates related degraded energy to *work*". Nevertheless, there were some excellent answers.

QUESTION E3 The photoelectric effect

The general principles of the photoelectric effect seemed to be understood by many candidates but, once again, they tended to lose marks through lack of detail. In particular, this question asked for two observations to be explained. It was typical for candidates to address only one of the observations in their answers.

QUESTION E4 Conservation laws and fundamental particles

Many could identify conservation of mass-energy and baryon number as the reasons why the given particle reactions could not take place. However, few were able to identify the lack of conservation of momentum in the final reaction. Often, if a process was proposed, the answer was correct.

Option F - Astrophysics

This was a very popular option.

QUESTION F1 Deducing properties of stars from observational and calculated data

Many were able to show an understanding of the effect of temperature on colour, but few could provide sufficient detail to explain their statements. It was typical to assume that any "cool" star must be a red giant. About half the candidates were able to correctly use the given apparent magnitudes to state which star appeared brighter. However, it was very common for candidates to assume that the stars had the some luminosity and to try to base an argument on a perceived difference in distance. Similarly many were able to state correctly which star was further away, though many assumed the lack of a provided parallax angle implied that it was too small to be measured. Some wrongly attempted to talk about the *ratio* of apparent magnitude to absolute magnitude. Others attempted to use irrelevant equations or unnecessary complex relevant equations instead of reasoning around the values of absolute and relative magnitude. The calculations were often successfully achieved, though a surprising large number wrongly transferred data from earlier in the question. Typically, marks were lost through incorrect use of units. Many substituted the area of a circle in the Stefan-Boltzmann equation.

QUESTION F2 A spectroscopic binary system

A large number of candidates thought that the changes in the spectral lines of the binary star system were caused when one star eclipsed the other. Those that did make mention of the Doppler effect often suggested impossible orbits around the centre of mass. Frequently, the diagram was not used efficiently. Not surprisingly, many thought the time period of the binary system was half its real value. Many were able to correctly substitute into the Doppler equation to calculate a velocity suggesting that they were doing so without understanding the physics of the situation.

QUESTION F3 The Hertzsprung-Russell diagram and stellar evolution

The general regions of the Hertzsprung-Russell diagram tended to be well know but it was common to see a lack of precision in candidates’ labeling of the diagram. Many correctly predicted the changes that took place in temperature, luminosity and size in going to a Red giant star although their explanations were often very superficial. It appeared as if candidates were aware of the relevant facts but were unable to organize their ideas and to express themselves on paper.

Option G - Special and general relativity

As in previous years, this option was the most popular choice on the Paper.

QUESTION G1 The Michelson-Morley experiment

Although the general aims and conclusions of the Michelson-Morley experiment were often well understood, few candidates gave answers that referred to the expected shift in interference pattern as a result of the rotation of the apparatus. Often the explanations were little more that just statements of the postulates of special relativity.

QUESTION G2 Time dilation and the twin paradox

Some candidates clearly understood the space-time diagram that was provided in this question but others resorted to guessing. Unfortunately the wording of the question was not as precise as it could have been, but candidates who demonstrated an understanding without going into the required detail were able to gain credit. Many completed the calculation successfully, although some made the obvious mistakes. The final section of the question was not done well. Many felt the paradox was that time should run at different rates for different observers. Some did recall an explanation in terms of accelerations.

QUESTION G3 A question about relative velocities

There were a surprisingly large number of errors in the first sections of this question that asked candidates to calculate Galilean velocity transformations. Furthermore, many failed to realise that the speed of a laser pulse must be recorded as c, irrespective of the observer.

Having made these fundamental mistakes, many were then able to gain credit by substituting correctly into the relative velocity formula. Not surprisingly, it was rare to see a good answer

QUESTION G4 Gravitational red and blue shift

Many candidates did well with the mathematical calculation of gravitational blue shift but in general they found the descriptive parts of the question harder. Of particular difficulty to some seemed to be the concept that the equation assumed a constant gravitational field, when this was clearly not the case in the situation presented.

Option H - Optics

Another popular option although many candidates seemed under-prepared in some aspects of the syllabus.

QUESTION H1 Reflection in plane mirrors

Many knew the location and size of the image in a plane mirror but were unable to draw coherent and accurate ray diagrams to locate it properly. Some stood by their inaccurately drawn rays and predicted huge variations in magnification. A pleasing number were able to show and verify the direction reversal of a ray in the corner reflector, though a common mistake was to assume that all angles were equal to 45°. A possible use for the system was less well answered.

QUESTION H2 Focal length of a thin lens

Very few candidates were able to draw a correct ray diagram of the situation and many were clearly guessing. Diagrams at total variance to the laws of reflection and refraction were not uncommon. On the other hand, some candidates clearly found this question very straight-forward.

QUESTION H3 Interference due to two and more slits

Again candidates tended to either answer this question correctly or they missed the point entirely. The majority could do the mathematical calculation of slit separation, but the effect of increasing the number of slits on the double slit pattern was not well known. It was common to imply that the separation of the fringes would be affected.

QUESTION H4 Myopia and the resolution of the human eye

Once again, many candidates were able to cope with the mathematical aspects of this question although it was very rare to see an answer that correctly identified the (virtual) image distance as being negative.

Recommendations and guidance that teachers should provide for future candidates

Many of the suggestions identified by the examining team have been mentioned in the past. This year's suggestions include:

- practice at the manipulation and interpretation of unfamiliar data – particularly the manipulation of ratios in symbolic 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.
- read each question very carefully so that the answer is well focused and complete.
- answers to qualitative questions require clear knowledge, precise definitions and completeness.
- the use of a compass and ruler makes it easier to construct diagrams and graphs that can be clearly annotated.
- despite the examination instructions, candidates are still using correction fluid and then failing to write in an alternative answer after the fluid has dried.

Internal assessment

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

General comments

As in previous years, an entire spectrum of practical work was moderated. It is clear the IA system is working well in the majority of schools and teachers and students are doing exceptional work in many cases. Often the teacher uses a grid where the aspects of each criterion are spelled out and so the "n/p/c" achievement levels are clearly indicated. This helps the teacher and the student, as well as the moderator. Many Group 4 Projects looked good, too.

The range and suitability of work submitted

The majority of schools are assigning and assessing very good high school level physics practical work. We are impressed overall by the solid physics that is being taught. Some schools offer a limited range of experiments, often missing out one or both options, or an entire topic. There are a few schools that still follow 'fill in the blank' worksheets.

Candidate performance against each criterion

Planning (a)

This is still the most trouble for schools. Often research questions were assigned to the student, and hence one aspect was moderated down to "not-at-all". Occasionally teachers assigned investigation such as "find the value of gravity" and this too did not lend itself to planning (a). On the plus side, a number of schools were using established examples of planning (a), examples that are used in workshops or mentioned in on-line discussion groups. The open-ended nature of this criterion needs to be emphasized. Defining a hypothesis and explaining it are often very difficult for students. Finally, teacher's instructions must be given in order to properly moderate this criterion.

Planning (b)

This was reasonably done in many cases. There are still schools giving out standard equipment, setting up standard methods, etc. and so these samples were moderated down. The success of planning (b) often depends on the topic assigned under planning (a). Students should be encouraged to sketch diagrams of the equipment and set-up. Often the teacher sets up the student so there is only one-way to proceed in an investigation. Both Pl(a) and Pl(b) should evoke different responses from different students within the same class.

Data Collection

This is often well done, with the exception of appreciating uncertainties. Very few schools acknowledge errors and report estimated uncertainties in their raw data. Teachers often award full achievement levels here and these cases were moderated down. Many schools are not teaching this topic, and many schools don't emphasis the correct use of significant figures.

Data Analysis

Standard processing and presentation occurs in most schools. There are still those who connect the dots on their graphs, and the vast majority of students ignore uncertainties in analysis. Allowing a computer to generate uncertainty bars without an argument or explanation of the value of the uncertainty is unacceptable. Students must do the work to get credit. Appreciation of significant digits is also often missing. Eg students quote an angle of 37.843567 degrees. Sometimes it seems as if the teacher has told the students how to process the data, so once again the teacher's instructions are important for moderation.

Evaluation

This could be one of the easiest areas to earn full points, but more often than not students do not seem to follow the aspects of the evaluation criteria. With just a little guidance here students could greatly improve their work. Often minor points are made, while overall relevance (the scope and limit of the investigation) is not addressed.

Recommendations for the teaching of future candidates

- Many schools are evaluating investigations using a grid of criteria/aspect with n, p and c indicated clearly. This helps the teacher and the student, as well as the moderator. The use of such a grid indicating the assessment details is highly recommended.
- Teachers and students should always have a copy of the IA criteria. Teachers need to keep these in mind when assigning and assessing investigations.
- Errors and uncertainties need to be taught and emphasized. All raw data collection should include an estimate of uncertainty. There are no absolute measurements.
- There are still cases of mistakes in paperwork and in the preparation of the sample material. Teachers should familiarize themselves with Section F and Section 4 of the Vade Mecum for the examination session in question.

