PHYSICS (IBNA/IBLA)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-16	17-29	30-41	42-51	52-61	62-71	72-100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-16	17-29	30-38	39-49	50-58	59-70	71-100

Thanks are extended to those schools and teachers who have commented on particular questions on the G2 feedback forms. Teachers are strongly encouraged to send in G2 comments on all components of the external examination, papers 1, 2 and 3, SL and/or HL. These may be sent either by hard copy, via IBNET or the OCC. These comments provide valuable information to the Grade Award team in respect of determining grade boundaries.

Internal assessment

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-9	10-15	16-21	22-27	28-31	32-37	38-48

The range and suitability of work submitted

The majority of schools are providing balanced and thorough practical programs in high school physics. Although mechanics is traditionally the most popular topic many other areas are being covered, including the options. Some difficulties arise in the suitability of investigations for assessment when schools teach two or more academic programs together. When an experiment is appropriate for one curriculum it may not be appropriate for the group 4 IA criteria. The teachers need to pay close attention to this issue. Standard investigations with worksheets need careful scrutiny before assessing these using the IA criteria. Many schools are correctly recognizing error analysis with uncertainty bars on graphs. This has improved over previous years. Overall, most school follow the administrative paper work requirements correctly. Many schools are following the examples of investigations given on the OCC.

Candidate performance against each criterion

The two planning criteria remain the most difficult for both students and teachers. The best planning (a) investigations are set before the students have covered the relevant theory. Planning (a) investigations need to be open ended, and the best examples are where students look for a function or relationship, not a specific value or measurement. Determining the acceleration due to gravity, or the specific heat capacity of an unknown liquid, or to confirm Newton's first law, are NOT appropriate planning (a) investigations. Using standard lab equipment for an investigation is often penalized under planning (b). There needs to be a variety of ways to investigating a topic. Often the Group 4 project is assessed under planning but it is difficult here for the moderator to know just what an individual student contributed. In general, it is best not to assess the group project because students are working in teams.

Data collection is often very well done. Students are more than ever aware of uncertainties. In physics, all raw data measurements have an uncertainty and this needs to be indicated with the recorded data. When assessing data collection teachers must be careful not to tell the students what data to collect or how to record the data. Students must figure this out when they are assessed under data collection. Sketching water wave patterns or the pattern of iron filing due to a magnet does not count as data collection.

Data processing and presentation is not done as well as it should be. Often students are told what to do with their data, and this is not appropriate for assessment under DPP. The use of graphing software is encouraged but students must also demonstrate good graphing technique. Although more schools are including uncertainty bars on graphs, students must also justify the amount of uncertainty they record and not let the graphing program do it automatically. The number of significant digits must be appreciated. Often a systematic shift in the best straight line is not accounted for.

The conclusion and evaluation assessment criterion is also difficult for students. Conclusions must be based on a reasonable interpretation of the processed data and the original research question. Appreciating the scope and limit of an investigation is often difficult for students. Suggestions for improvement are often vague or general. Simply stating that a digital video would improve the quality of data is superficial and usually wrong. More critical thought is needed in each aspect of the CE criterion.

Recommendations for the teaching of future candidates

- Teachers must choose appropriate investigations to assess each criterion. Students and teachers must have copies of the IA criteria. The use of worksheets or standard labs is often not appropriate for IA assessment.
- When teachers submit samples of IA for moderation, the verbal and written instructions for each moderated lab must be included.
- Group 4 projects are often the result of team effort and as such not appropriate for individual assessment under the IA criteria.
- The IB encourages the use of graphing software but students must be in control of it and produce meaningful graphs.
- The syllabus content distinction between SL and HL under the handling of errors and uncertainties is important when assessing DPP.
- Continued use of the Online Curriculum Centre is encouraged.

Further comments

The overall trend shows a noticeable improvement in the administration and in the assessment of practical work. The influence of the OCC is noticeable, and the treatment of errors and uncertainties has improved.

Paper 1

Component grade boundaries

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-11	12-14	15-17	18-19	20-22	23-29

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 - 10	11 -16	17-22	23-25	26-28	29-31	32-39

General comments

IB multiple choice physics papers are designed to have, in the main, questions testing knowledge of facts, concepts and terminology and the application of the aforementioned. These assessment Objectives are specified in the Guide. It should be noted that multiple choice items enable definitions and laws to be tested without full recall, but requiring understanding of the underlying concepts.

Although the questions may involve simple calculations, calculations can be assessed more appropriately in questions on Papers 2 and 3. Calculators are therefore neither needed nor allowed for Paper 1.

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

The number of G2's received was a small percentage of either the total number of teachers or the number of Centres taking the examination. Consequently, general opinions are difficult to assess since those sending G2's may be only those who feel strongly in some way about the Papers. The replies indicated that the May 2005 papers were generally well received. The majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level. A small number thought that both Papers were a little more difficult. With few exceptions, teachers thought that the Papers gave satisfactory or good coverage of the syllabus. However, it should be borne in mind that overall coverage must be judged in conjunction with Paper 2. All teachers also felt that the presentation of the Papers was either satisfactory or good.

Statistical analysis

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

The numbers in the columns A-D and Blank are the numbers of candidates choosing the labelled option or leaving the answer blank. The question key (correct option) is indicated by 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
1	108	708	2713*	310	6	70.55	.27
2	1409	454	1338*	639	5	34.79	.28
3	342	2275*	1110	114	4	59.16	.34
4	2390*	230	946	267	12	62.15	.45
5	535	1022	1663*	624	1	43.25	.28
6	15	31	3340*	458	1	86.86	.17
7	593	1402	1580*	255	15	41.09	.39
8	974	389	2120*	355	7	55.13	.39
9	2623*	678	108	413	23	68.21	.37
10	1711	1753*	77	302	2	45.59	.26
11	119	503	3103*	118	2	80.70	.26
12	63	2928*	656	194	4	76.15	.19
13							.00
14	691	328	2355*	461	10	61.24	.46
15	302	3226*	213	99	5	83.90	.22
16	2452*	715	283	391	4	63.77	.31
17	122	263	116	3342*	2	86.91	.23
18	228	2267	933*	414	3	24.26	.17
19	1277	2096*	196	265	11	54.51	.43
20	560	818	1275*	1176	16	33.15	.37
21	245	207	98	3289*	6	85.53	.26
22	1225	2161*	252	197	10	56.20	.30
23	279	751	303	2504*	8	65.12	.20
24	390	783	471	2195	6	57.08	.43
25	855	699	1612*	658	21	41.92	.26
26	717	337	1970*	799	22	51.23	.09
27	339	729*	453	2308	16	18.95	.28
28	172	196	491	2979*	7	77.47	.40
29	337	1129	307	2057*	15	53.49	.37
30	475*	1766	1151	412	41	12.35	.05

Q13 was not included in the test.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	33	297	1222*	113	3	73.26	.23
2	155	1069*	403	41		64.08	.33
3	90	1018*	282	268	10	61.03	.44
4	799	301*	162	401	5	18.04	.21
5	209	457	748*	254		44.84	.30
6	153	173	91	1250*	1	74.94	.40
7	248	581	766*	70	3	45.92	.44
8	683*	551	166	267	1	40.94	.24
9	24	179	1426*	38	1	85.49	.19
10	1152*	57	48	410	1	69.06	.46

11							.00
12	122	51	1439*	56		86.27	.23
13	264	113	1083*	202	6	64.92	.48
14	129	1194*	70	275		71.58	.30
15	806*	151	240	470	1	48.32	.34
16	197	128	1190*	153		71.34	.41
17	173	1392*	59	42	2	83.45	.30
18	39	105	27	1496*	1	89.68	.20
19	137	1138*	194	199		68.22	.34
20	50	107	164	1346*	1	80.69	.36
21	28	42	1180*	413	5	70.74	.33
22	516	1041*	50	58	3	62.41	.38
23	240	992*	225	198	13	59.47	.36
24	1376*	102	123	66	1	82.49	.28
25	898*	151	506	110	3	53.83	.29
26	173	575	811*	102	7	48.62	.34
27	96	78	33	1459*	2	74.47	.26
28	402	1029*	98	137	2	61.69	.29
29	113	424	73	1057*	1	63.36	.07
30	312	210	797*	345	4	47.78	.28
31	145	186	694	628*	15	37.64	.20
32	341	1047*	97	172	11	62.76	.38
33	479	420	121	636*	12	38.12	.35
34	139	61	46	1414*	8	84.77	.24
35	125	429	84	1022*	8	61.27	.39
36	176*	817	544	116	15	10.55	.04
37	263	776*	325	286	18	46.52	.37
38	542	312*	651	142	21	18.70	.32
39	441*	62	865	281	19	26.43	.21
40	597	885*	94	70	22	53.05	.32

Q11 was not included in the test.

Comments on the analysis

Difficulty. For both HL and SL the difficulty index varies from below 20% (relatively ‘difficult’ questions) to greater than 70% (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 or a question with a high difficulty index..

‘Blank’ response. In both Papers, the number of blank responses tends to increase towards the end of the test but there are notable exceptions. 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. Therefore comment will only be given on selected questions, i.e. those that illustrate a particular issue or where a problem can be identified.

SL and HL common questions

SL and HL Q5
This should have been an item with a high difficulty index. However, this was not the case. Many candidates think, quite wrongly, of displacement as a 'distance moved' or as a scalar quantity. These misunderstandings frequently lead to poor performance in Paper 2 questions.

SL Q13 and HL Q11
Two of the options, namely C and D, have poorly drawn diagrams in that one of the vectors v has an incorrect length. Option C was intended to be the Key but the error means that the change in velocity Δv must be incorrect. Consequently, the item was withdrawn from the test. The diagrams will be corrected for the final published version of the question papers.

SL Q19 and HL Q22
Several comments were received as to the values marked on the *displacement* axis. Values of displacement of less than zero must be negative and would normally be shown as negative when shown on a graph. There should be no confusion here.
The principle of superposition states that, where two waves meet, the resultant displacement is the sum of the individual displacements at that point. Thus, from this statement, resultant = $x_1 + (-x_2)$. Candidates have been confused into thinking that, where one displacement is above the axis and the other below, the displacements should be subtracted. Displacement is a vector quantity and the vectors should, when considering superposition, always be summed.

SL Q22 and HL Q28
The wording 'may be' in the stem of the item was chosen carefully. There are two distinct and correct definitions of electric field strength – the fundamental definition and the 'working' definition. Consequently, it would have been incorrect to state 'is defined' because what was required here was the fundamental definition only.
Option A is clearly wrong for two reasons. First, no ratio is included and thus electric field is defined as being a force. Second, a unit positive charge is a huge charge and would distort the field under examination. Thus, for these two reasons, Option A is incorrect and Option B is the key.

SL Q23 and HL Q29
Although the difficulty index was quite high, there are still large numbers of candidates who associate, in some way, resistance with the gradient of the *I/V* characteristic.

SL Q30 and HL Q36
This item had one of the lowest difficulty indices. Confusion frequently arises where a negative quantity increases in magnitude. Some texts represent graphically the binding energy per nucleon as being negative. Thus an increase in the magnitude of the binding energy per nucleon is indicated by a more-negative value on the graph. Hence the confusion.
In this item, care was taken to state increased/decreased *in magnitude*.

SL questions

Q2
It is a very widely, but wrongly, held view that the unit of charge is a fundamental unit.

Q18
Distractor B was the most common answer and is indicative of imprecise thinking and learning. The distance between any two crests implies any number of wavelengths. Wavelength should be defined as in Option C (the key) or as the distance between two neighbouring/successive wavefronts.

Q26
Candidates should understand that a freely suspended compass needle is not confined to rotation about a vertical axis and that it will indicate angle of dip. They should appreciate that the Earth's field is only parallel to the Earth's surface at the Equator.

HL Questions

Q4
The difficulty index for this item was low. Candidates need to be aware of the fact that, where the fractional uncertainty in the power of a quantity is required, then the fractional uncertainty in the quantity itself is multiplied by the numerical value of the power.

Q18
There was some comment in G2's as to whether n is a constant.
The equation $pV= nRT$ applies to a *fixed mass* of an ideal gas. Thus if the mass is fixed, or constant, then n must be constant. If the mass of gas is changed, then the initial and final states of the gases cannot be related directly using $pV= nRT$.

Q25
It should be understood by candidates that two waves may not be coherent if they have the same frequency. Constant phase difference implies constant frequency and also that the beams are coherent.

Q31
This item was made easier by having only one graph where the potential inside the sphere has a constant non-zero value.
Candidates should realise, where static charge is situated on an isolated conductor, the potential must be constant and, since work would have to be done to bring further charge to the sphere, the potential cannot be zero.

Q38
It is interesting to note that a very clear majority of candidates associated an emission line spectrum with *excitation* of electrons, rather than a de-excitation.

Paper 2

Component grade boundaries

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-12	13-15	16-21	22-26	27-32	33-50

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-11	12-23	24-32	33-42	43-53	54-63	64-95

The G2 comments that were received were very helpful when reviewing the perceived difficulties of this year's paper. The small number of forms received for both papers mean that one should be cautious about drawing any firm conclusions but at both levels the majority of teachers thought the paper to be either of a similar standard than those in previous years. More than 75% of the respondents felt the papers were of an appropriate level of difficult at either level. The vast majority felt that the syllabus coverage, clarity of wording and presentation of both papers was either satisfactory or good.

General comments

Many candidates found it hard to perform well on these papers even though it was felt that there were plenty of marks accessible to those who may struggle with the more conceptual aspects of the course. As identified last year, candidates often lost marks as a result of definitions that lack precision or were expressed in non-scientific language. In fact, precision was an issue throughout the papers. For example a significant number of candidates lost some relatively easy marks as a result of unacceptable lines of best fit in the data analysis questions (A1).

The areas of the programme that proved difficult for the candidates

The examining team also identified the following areas: -

- Working with powers of ten continues to cause problems, as does symbolic manipulation
- The ability to treat a body as a single particle and analyse the forces acting
- Working with Heat capacity
- An understanding of the theoretical explanation of the photoelectric effect
- Sketching acceptable magnetic fields
- Working with Newton's second law in any form other than $F = m\,a$
- Working with acceleration - time graphs
- Understanding wave motion and vibration (other than wavelength, amplitude and $v = f \times \lambda$) particularly resonance
- Electrical quantities including electromagnetic induction.

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

It was pleasing to see the following skills demonstrated: -

- Understanding of the practical problems encountered in experiments involving temperature measurement
- Mathematical substitution into a given equation
- Identification of the wavelength of a wave on a string
- Understanding 'isotope', 'half-life' and β decay
- Understanding what is meant by an isochoric or an isobaric process
- Understanding that velocity is tangential and acceleration is normal to the path of an object undergoing circular motion

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

There were many common questions between SL and HL. The comments below are arranged in the order that the questions appeared in the HL. The cross-references to the SL paper appear in **[brackets]**.

Section A

A1 [HL and SL] - *Data analysis question*
(a) A significant number of candidates were unable to draw an appropriate straight line of best fit for the points provided, though this did not cause any difficulty to the majority. The most common mistakes were to attempt to draw the line without the aid of a ruler or to join the 1^{st} , 3^{rd} and 5^{th} points.

(b) Surprisingly, many candidates failed to use the intercept and/or the gradient of the graph in order to calculate required constants but instead they took data from two of the given points and attempted to solve a pair of simultaneous equations. Whatever technique used, many candidates made mistakes with the powers of ten and with units.

(c) Very few candidates correctly suggested that the constant B should be zero; the most common error was to suggest the value 8.3 having confused this with the universal molar gas constant.

(d) Many candidates managed to pick up marks by showing that they were correctly working with the numbers that they had identified in parts (b) and (c). It was, however, common to see candidates make errors involving powers of ten.

[HL only]
(e) Only a handful of candidates attempted to approach this problem in an appropriate way. It was disappointing to note that only a small minority were able to calculate the total percentage error in any given reading of PV. These candidates were then often unable to progress any further with the determination of absolute error in the calculated value of the intercept.

A2 [HL only] - *Projectile motion*
Most candidates were able to demonstrate an understanding of the independence of horizontal and vertical motion for projectile motion but were then unable to use the graphical data provided either to estimate the range of the object or to calculate the acceleration of free fall. Some candidates confused horizontal motion and vertical motion from the start.

A3 [SL question B1 – part 2] - *An experiment to measure the temperature of a flame*
Disappointingly it was extremely rare to see an appropriate and precise definition of *heat capacity*. Some were able to make a reasonable, if inappropriate, attempt at defining the *specific heat capacity* but even these candidates tended to lack precision in their answers. Many were able to correctly explain some of the experimental procedures described in the questions, but the mathematical section at the end of the question was often done very poorly indeed. Typically candidates substituted the values given for heat capacity in equations that they had developed which involved specific heat capacity and then ignored (or cancelled out) the masses because the values were not given in the question. Those that were able to get started often forgot to include the calorimeter in the calculation.

A4 [HL only] - *The photoelectric effect*
This question was generally not done well. Candidates were asked to discuss the weaknesses of the wave model of light with respect to two observations about the photoelectric effect. Many candidates were unable to make any sensible observations but those that were able to make some comments often wrongly discussed how the particle model for light correctly explained the observations.

Section B

B1

This was the most popular question in section B and some candidates were able to produce near perfect answers to both parts of the question.

B1 Part 1 **[SL question B2 part 1]** - *Momentum and the kinematics of a proposed journey to Jupiter*
(a) Many candidates knew that conservation of momentum meant that momentum did not change, but very few indeed were able to include the appropriate precision or indeed make any reference to a closed system or to the lack of an external force. It should be noted that a significant number gained no credit at all because their answer did no more than rephrase the question. For example, the answer "The law of conservation of momentum states that momentum is conserved" would gain no marks at all as no extra information or detail has been supplied by the candidate.

(b) and (c) Most candidates answered these questions well. Those candidates that lost marks often failed to show their working clearly enough. This was particularly required in these questions as the mathematical answer was given in the question. The weaker candidates left these questions blank.

(d) Many candidates gave confused answers to this question though it was pleasing to see some excellent answers. A significant number of candidates approached the problem by finding the momentum change of the Xenon atoms after one second and used this to calculate the acceleration of the rocket assuming a negligible mass change for the rocket. While this approach is appropriate for the question, many failed to identify the assumption in their working and thus lost marks. A significant number did not add the mass of the fuel to the mass of the rocket to get the total mass being accelerated.

(e) A surprisingly small number of candidates were able to identify the loss of mass as the reason for increasing acceleration. Too many were happy to state that the acceleration was increasing because the ship was going faster. Many others wrongly suggested that the acceleration was increasing with time because the rocket was moving away from the Earth and the pull of gravity was decreasing.

(f) Many candidates were able to make a vague link between the area under the graph and speed but it was rare for candidates to be precise and identify the area with the change in speed. Only a few candidates were able to cope with variable acceleration. In general, those finding the average acceleration fared better than those finding the area. A common mistake was for candidates to attempt to calculate the area *on the diagram,* rather than the area between the line and the x-axis.

(g) The common error here was to forget that the total time was the sum of two parts but many were able to gain credit as "error carried forward".

B1 Part 2 **[SL question B2 part 2]** - *Radioactive decay*
(a) Typically candidates knew something about the term isotopes but it was rare to see a precise or unambiguous definition.

(b) Many mistakes were made completing the nuclear reaction equation. Most candidates thought that the atomic number decreased after β^--decay. As SL candidates do not need to know about the existence of neutrinos or anti-neutrinos, answers as vague as "energy" or "gamma" were accepted for the other item involved in the decay. HL candidates needed to correctly identify the anti-neutrino.

(c) and (d) Many were able to make a reasonable attempt at plotting the exponential graph. Typically HL candidates did not draw the graph with sufficient precision to predict the activity at the later times. SL candidates were provided with some data and many were able to use it correctly to estimate the half-life. Some candidates, however, attempted to plot a straight-line graph.

[HL only]
(d) and (e) Many candidates were able to attempt the HL calculations but typically marks were lost because units were omitted. The candidates tended to find the final calculation slightly more difficult.

B2

B2 Part 1 **[SL question B3 part 1]** - *Waves and wave motion*
(a) The meaning of 'transverse' did not seem to be understood by the vast majority of the candidates. Typically the phrases 'direction of the wave' and 'direction of energy propagation' were thought of as distinct directions. Although it was a specific requirement given in the questions, few candidates referred to the propagation of energy at any time at all in their answer.

(c) and (d) The terms amplitude, wavelength, period and the wave equation were generally well understood though a significant number thought the amplitude was the distance from crest to trough.

(e) Although many were unable to provide all the correct information in their diagram, a pleasing majority correctly shifted the wave profile by $\lambda/4$.

(f) and (g) The idea of resonance as a system being driven at its natural frequency was generally unknown and even the better candidates often failed to gain any credit for these questions. There was a great deal of confusion between resonance and standing waves.

(h) The frequency of the first harmonic caused many problems. The few that knew $\lambda = 2L$ often still had $\lambda = 30$cm.

B2 Part 2 **[HL only]** - *The possibility of generating electrical power using an orbiting satellite.*
Many candidates found this question hard.

(a) The answers to this question often typified the lack of precision that has already been identified as a problem throughout the paper. It was extremely rare for a candidate to know that gravitational field strength was defined in terms of force per unit mass. Even many of the good candidates scored zero marks for this question.

(b) Many were able to correctly deduce the relationship but some were obviously just quoting equations from the data booklet without evidence of any real understanding or explanation.

(c) There were some successful answers identifying the direction of the magnetic force on the electron but many candidates were clearly guessing.

(d) Most candidates just quoted the formula from the data booklet rather than applying this formula to the situation described and thus failed to gain credit. If they got this formula wrong there were able to gain credit in subsequent questions as "error carried forward".

(e) Some candidates were able to use their answer to part (d) to calculate the electric field in the wire but it was very rare for a candidate to be able to use this to calculate the e.m.f. Many candidates were clearly using the symbol E to represent e.m.f. and electric field interchangeably.

(f) Few candidates equated the gravitational force to the required centripetal force but those that did were often able to see the calculation through to the end without fault.

(g) A significant number of candidates were able to gain credit on this question by appropriate substitution of values into their answer to part (c).

B3

B3 Part 1 **[SL question B1 part 1]** - e.*m.f and internal resistance*
This was the least popular B question.

(a) and (b) Those who understood the terms usually scored quite well but many were clearly guessing.

(c) It was extremely rare for a candidate to include a variable resistor when attempting to draw the appropriate circuit and thus almost nobody scored full marks for this question. Disappointingly, the vast majority of the candidates were even unable to correctly complete the circuit with voltmeters and ammeters.

(d) Of the candidates that were able to engage with these questions, many were able to identify the e.m.f. as the potential difference across an open circuit but too many had the short circuit current as 0.9 A, presumably as the line provided stopped at this point. It was rare for candidates to extrapolate the line correctly. Most correctly identified the gradient as the internal resistance of the cell, but few were able to justify this statement.

(e) This question tended to be done absolutely correctly or candidates were unable to make any progress. Surprisingly few candidates were able to correctly calculate the total resistance of the circuit under the conditions described.

B3 Part 2 **[HL only]**- *wave properties of light and electrons*
(a) Few candidates made any reference to the lack of coherence in regard to the light from a tungsten filament lamp. It was more common for candidates to refer to the range of frequencies emitted.

(b) Many were able to sketch some form of fringe pattern, but some were clearly guessing and many diagrams lacked precision.

(c), (d) and (e) The calculations and substitutions were done well by a limited number of candidates. The majority, however, appeared to be taking equations from the data booklet at random and substituting some values into these equations without any real thought about the physics involved.

B4

B4 Part 1 **[SL question A2]** - *Driving a metal bar into the ground and the engine used in the process*
(a) A significant number of candidates tried to use the conservation of (kinetic) energy to solve this problem. A pleasing number of candidates did correctly see this as conservation of momentum and many managed to get the correct answer. The most common error was to transfer *all* the momentum to the bar.

(b) The most common approach here was to use $a = \frac{v^2}{2s}$ rather than the work-energy theorem but using either approach some candidates were able to get the right answer. Only a few candidates correctly included the weight or the loss of potential energy after the collisions in their calculations and thus it was reasonably rare to see a correct final answer.

[HL only]
(c) This question seemed to prove problematic for many candidates even though the underlying physics was reasonably straightforward. In general candidates were able to calculate the height to which the object needed to be raised but often they were unable to complete the question by making the link between the total energy of the falling object and the useful power output of the diesel engine.

(d) and (e) Many candidates gave confused explanations for an adiabatic process, but the isochoric and isobaric processes were identified correctly and well understood.

(f) Lack of precision was once again a problem in the question. Most candidates knew that the area in question was related to work but the majority failed to make it clear that this was the work done by the engine *in one cycle*.

(g) and (h) These calculations were often done well though some candidates' answers were confused.

B4 Part 2 **[SL question A3]** - *The force between current-carrying wires*
(a) The SL candidates were asked to identify the direction of the force on each wire and a significant number were able to do this though many were clearly guessing as the force was

often shown circling the wire or parallel to the wire. The standard of the diagram for the magnetic field, however, was poor. A significant number were able to identify the correct field direction, but the overall pattern and the approximate spacing between the field lines were rarely done with precision.

[HL only]
(b) Very few candidates were able to relate the situation given in the question to the formal definition of the ampere. Once again lack of precision was often an important factor.

(c) **[SL part (b)]** A correct description of the motion was rare. The increasing force with decreasing separation was missed by many candidates. Some were able to state that the acceleration was increasing but few were able to explain why this was the case. It was common for candidates to imply that an increasing velocity implied an increasing acceleration

SL additional questions: -

[SL question B3 part 2] – *Atomic models*
(a) Almost all labelled the acceleration of the electron and its velocity correctly.

(b) Only a relatively small number of candidates could do more than quote the general equation given in the data booklet for the electrostatic force.

(c) This calculation question was done very poorly. Very few candidates attempted to equate the electrostatic force and the centripetal force.

(d) Many candidates took this question as opportunity to display their general knowledge of orbital electrons. Only a tiny minority outlined *evidence* that supported the existence of discrete energy level as required by the question.

Recommendations and guidance that teachers should provide for future candidates

A common theme this year was the lack of precision in written answers and associated definitions. Candidates should be encouraged to be able to define the terms that they are using at all times. A significant number of candidates (particularly at standard level) appeared to be under prepared for this examination. For these candidates, the experience cannot have been rewarding or encouraging.
As has been suggested in the past, the examination team recommend working through past papers (and the associated mark schemes) as a good preparation. Not only will this give candidates a familiarity with the format of the examination but also many should be able to gain a good understanding of the level of detail required as well as the skills that are being assessed.

Paper 3

Component grade boundaries

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-5	6-10	11-13	14-17	18-22	23-26	27-40

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-13	14-20	21-26	27-32	33-38	39-60

General comments

The majority of candidates seemed to find the paper accessible and there were examples of good understanding of the material. In general, candidates appeared to allocate their time appropriately and there was no evidence that candidates were disadvantaged by lack of time. Many candidates appeared not to know that their answers should be given in the spaces provided in the examination paper and, instead, used continuation sheets unnecessarily. A few candidates answered more than two Options and a few answered only one. It was clear that some candidates answered Options for which they had not been prepared. It was also clear that parts of the options were not studied as completely as others (e.g. gravitation in Option A, sound in Option D, relativistic mechanics in Option G and diffraction in Option H).

Candidates should to be encouraged to ensure that they have turned the page and answered every part of a particular Option question. Significant digit error and unit errors continue to decrease. 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 simply wrote down an answer to numerical calculations without any working being shown (often with multi-part calculation steps). Also, if candidates are asked to deduce that a particular value is correct, then clearly no marks can be awarded if no working is shown.
The feedback from teachers on the G2 forms for SL and HL can be summarized as follows:

Standard Level

- 62% found the paper to be of a similar standard to last year, 22% a little easier and 16% a little more difficult. However, overall, 94% found the paper to be of an appropriate standard and 6% thought it too difficult.
- about 54% found the syllabus coverage satisfactory, 4% thought it was poor and 42% found it good.
- 51% found the clarity of wording satisfactory, 6% thought it was poor and 39% found it good.
- about 44% found the presentation satisfactory and 56% found it good.
- as in previous years, the most popular options were A (Mechanics) and H (Optics).

Higher Level

- about 58% found the paper to be of a similar standard to last year, 21% a little easier and 21% a little more difficult. However, overall, 85% found the level of difficulty appropriate and 15% thought it was too difficult.
- about 65% found the syllabus coverage satisfactory and 35% good
- about 65% found the clarity of wording satisfactory and 35% found it good
- about 40% found the presentation satisfactory, 55% thought it was good and 5% found it poor.
- As in previous years, the most popular options were H (Optics), F (Astrophysics) and G (Relativity).

The areas of the programme that proved difficult for the candidates

A very prominent feature of this examination at both Standard and Higher Levels has been the lack of precision and detail in the definition of various physical quantities. The definitions were either poorly expressed, incomplete, imprecise or just plain wrong. Examples include

- gravitational potential
- biological half-life
- dark matter
- cosmic background radiation
- postulates of relativity
- focal point of a lens

Gravitation proved beyond the capabilities of the great majority of SL candidates in Option A. In Option B, candidates showed weaknesses in the Bohr model and X-rays. Option D revealed large gaps in the knowledge of candidates at both SL and HL on basic items on the syllabus such as frequency discrimination and the sound intensity level scale. As in past examinations candidates displayed a striking weakness in ray diagrams in Option H and single slit diffraction proved very difficult for the HL candidates.

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

Candidates produced some excellent answers that showed a good understanding of the concepts and showed skill in problem solving, with good equation manipulation and attention to units and significant figures.

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

SL only

Option A – Mechanics

Question 1 Parabolic motion

It was pleasing to see a very significant number of candidates performing very well on this question with many answering correctly the more challenging part (c). However, a few gave $9.8\ \mathrm{m\,s^{-2}}$ as the acceleration of free fall on the surface of the planet in (a) (ii) without any justification.

Question 2 Gravitation

This question was answered well by only a handful of candidates. The definition of gravitational potential proved too difficult. Very few candidates could use the fact that the gravitational field strength is zero at $r = 0.8$ to deduce the ratio of the masses. A few candidates attempted to use the graph to deduce the masses separately without realising that first the scale of distance was arbitrary and worse still that the potential was the combined potential of the two masses. Candidates did not do much better in (b) (ii) where they had to calculate the energy needed to get to the moon. There were attempts using the escape velocity but very few could use the graph. Overall the performance on this question was very disappointing.

Option B - Atomic and nuclear physics extension

Question 1 The Bohr model and the hydrogen atom

There were mixed answers to this question with many candidates realising that absorption of light or collisions had something to do with the question. The answers however were not precise enough.

The calculation in (b) (i) was generally well done. Many candidates could answer this quickly by using the value of Planck's constant in units of eV. Most candidates had trouble explaining (b) (ii) despite their correct answers in the previous question. As in past exams, the discussion of Schrodinger's theory proved beyond most candidates.

Question 2 X - rays

It was surprising to see that many candidates were unaware of the fact that charges radiate when decelerated rapidly. These candidates were therefore lost in answering this question. In parts (b) and (c) however, many could calculate the minimum wavelength and most knew that the minimum wavelength would shift to the left.

Question 3 Particle physics

This was not well answered. Most could deduce (or recall) the charge of an antineutrino. A few candidates may have found the term *electron antineutrino* instead of plain *antineutrino* confusing. The name of the interaction was beyond the majority of the candidates.

Option C - Energy extension

Question 1 Nuclear energy and thermodynamics

Part (a) was generally well done but many candidates did mention "heat" and "thermal energy" as the forms of energy released in the fission reaction. Those who had not studied this option carefully gave amusing definitions of where the neutrons are slowed down. Despite getting bogged down in unit conversions it was pleasing to see a good number of candidates getting the answer right in (a) (iv) for the amount of mass undergoing fission in a year. Question (b) was very well answered with a few exceptions such as (b) (iv) where many candidates referred to every possible law of Physics (and a few others) but not the second law of thermodynamics.

Question 2 Wind power

This was not done as well as question 1 but there were many candidates who realised that the power would increase by a factor of 8 and not 2 as the majority had answered. There were varied and usually imprecise answers to (ii). Many could identify correct answers to (b). A frequent answer to (b) was that windmills do not adversely affect the environment – however pollution is caused in the manufacture of windmills and there is some evidence that low frequency waves emitted during their operation have ill effects on people and animals.

SL and HL combined

Option D - Biomedical physics

Question 1 Scaling

As in past years this was an all or nothing question with those who had practised similar questions getting full points and those who had not getting nothing. In (b) few candidates could explain why the child (having a larger rate of energy loss *per mass*, i.e. a higher Q value) was at greater risk.

Question 2 Sound and hearing

This was very disappointing. Only a handful of candidates had any idea of how the cochlea distinguishes frequencies or why the response of the ear (physiologically being logarithmic) is measured in terms of a change of sound intensity level rather than intensity of sound. In fact it was clear from the answers that candidates interpreted the terms *sound intensity* and *sound intensity level* to mean the same thing in which case they could obviously not answer the question.

Question 3 Diagnostic methods

In (a) most candidates could give the standard examples of where each of the three methods could be used. The question however asked to *explain* why that particular method was used. As a result most candidates could score no more than a single point in (a).

In (b) many candidates missed the point and referred to, for example, applications of X –rays in safety/security contexts and not medical diagnosis. Others simply repeated their answers to (a).

AHL

Question 4 A person bending

Very few candidates saw that the force at the pelvis and the components of P and W are pushing the spine in opposite directions thereby compressing it. Even though many candidates had an idea of what to say, frequently their answers were imprecise. In any case most missed half the answer which was the force at the pelvis pushing along the spine. Part (c) was disappointing in that only a handful of candidates thought to use an argument based on equilibrium to answer the question. In fairness, the question could have been made more accessible by making it more explicit.

Question 5 Radioactive isotopes

This was generally done well with exceptions in (a) that required a definition of biological half-life.

Option E – The history and development of physics

Question 1 Models of the universe

This question again showed the lack of precision in the candidates' answers. Whereas most knew what the Ptolemaic and Copernican models were about, in (a) few could precisely use these models to explain the motion of the stars. Very many candidates missed the statement that in the Ptolemaic model the stars are fixed on the celestial sphere that rotates around the earth.

In (b) a fair number of candidates correctly identified distance as the key variable in answering the question.

Question 2 Force and motion

This was generally well done with many candidates realising that according to Aristotle a net force must be present for motion to be possible and that the larger the speed the larger the force. However, a disappointing number of candidates thought that a net force must also be present according to Galileo. This is clear evidence that a sizable number of students today still think along Aristotelian lines when discussing force and motion!

In (b) most could identify the larger mass of the stone as responsible for falling first but few could link that with a greater force as well.

Question 3 Theories of heat

In part (a) there were generally muddled answers few of which mentioned the term *fluid of heat* or *fluid of combustion*. Part (b) made reference to the work of Lavoisier in rejecting the phlogiston theory. Lavoisier's name does not appear on the syllabus explicitly and his inclusion in the question probably caused some anxiety among candidates. The context of the question was phlogiston though and any candidate who mentioned any experimental piece of evidence against phlogiston received marks. In part (c) relating to Rumford's work, the overwhelming majority of candidates could connect Rumford to the boring of cannons and stopped there. They could not provide any explanation as to why Rumford's observations (which were poorly described) led to the demise of the fluid theory of heat.

AHL

Question 4 The Bohr model and ionised helium

Most candidates found this question a difficult one. Only a handful could correctly describe Bohr's condition in (a) and in (b) few could explain how an emission spectrum is formed. The calculation of the ionisation energy in (c) and the discussion of discrete energy levels in Schrodinger's theory proved beyond the abilities of the great majority of candidates.

Option F – Astrophysics

Question 1 Eclipsing binary stars

It was pleasing to see many candidates realising that the distance of the two stars from Earth is essentially the same and hence that the star with the largest apparent brightness would also be the star with largest luminosity. The calculation in (a) (ii) was done with varying degree of success.

In (b) (i) a disappointingly large number of candidates had the stars in positions that were not diametrically opposite or even eclipsing each other. The intensity-time graph has no scale on the vertical axis. The biggest drop in intensity occurs at 5 years when A blocks the much smaller and less bright B.

Question 2 Cosmology

It was pleasing to see a large number of candidates familiar with the terms flat and open universe. Parts (a) and (b) were generally well done. Most answered part (c) well but some candidates confused dark matter with black holes. For the most part, candidates gave the standard examples of dark matter in (c) (ii). This question was well done.

Question 3 Cosmic background radiation

This was generally well done but most answers lacked sufficient detail to get both marks. Many candidates thought that this is radiation coming from stars. In (b) many candidates realized that the new curve has its peak shifted to the right and is under the old curve. The markscheme was lenient and accepted a curve with a similar shape and the peak shifted to the right as correct.

AHL

Question 4 Evolution of stars

Most students answered part (a) correctly. In (b) the answers again lacked the necessary precision and detail. Most seemed familiar with the 1.4 solar mass limit for white dwarfs but few could clearly explain that when this limit is exceeded the electron degeneracy pressure is not enough to stop gravitational collapse. In (ii) it was good to see many students arguing that if enough mass is ejected in the supernova so that the core is left with a mass less than the Chandrasekhar limit a white dwarf could form. Many did argue (incorrectly) that the mass would decrease due to fusion reactions that would be abundant because of the large mass of the star.

Question 5 Hubble's law

Most got part (a) of this question right. In part (b) it was disappointing to see many unclear answers. Many stated that speed was proportional to distance without identifying whose speed they were talking about and distance from where. In part (c) many could derive that $\frac{1}{H}$ is a measure of the age of the universe but in most cases a clear path of the argument and the assumptions made were lacking.

Option G - Special and general relativity

Question 1 Postulates of special relativity

The postulates of special relativity have appeared on IB exams many times but candidates still cannot state the correct answers.. In (a) the speed of light must be in vacuum and the observers involved are inertial.

A fair number of candidates realised that in (b) there is no violation of special relativity as the superluminal speed of 1.6 c does not refer to the speed of any inertial observer or signal. Many could do the calculation in (b) (ii) correctly but a few did come up with speeds greater than that of light.

Question 2 Relativistic kinematics

This question referred to time dilation and length contraction in the context of muon decay. This was a structured question leading to an explanation by two observers in relative motion of why muons are observed on the surface of the Earth. Most candidates did very well in parts (i) – (iii) of (a) but then had difficulty in using their correct results to answer the questions in (iv). Part (b) required the potential difference through which a muon must be accelerated and was not done well.

AHL

Question 3 Bending of light

Answers were generally correct in (a) and (b) but a number of candidates had no idea as to why an eclipse was needed. Many (obviously also taking the astrophysics option) thought that the measurement of the position of the star six months later had to do with a parallax distance measurement. In (c) generally correct paths were drawn. In explaining the path according to Einstein's theory most mentioned that the sun bends light (which was generously rewarded with one mark – generously because the sun bends light also according to Newton's standard theory of gravitation). A fair number of candidates stated, correctly, that light follows a geodesic in the curved space-time around the massive sun and it was good to see correct use of these technical terms.

Question 4 Relativistic mechanics

Part (a) should have been very straightforward so it was a bit surprising to see many incorrect answers here. In (b) it was obvious that candidates were not very familiar with the equation $E^2 = p^2c^2 + m_0^2c^4$. Those who attempted to find the momentum through $p = \gamma m_0 v$ were generally less successful. There were all sorts of problems with units. Only a small proportion of candidates managed to get this question right.

Option H Optics

Question 1 Light and the electromagnetic spectrum

Only a handful of candidates appeared to know that light consists of a pair of electric and magnetic fields at right angles to each other and to the direction of energy transfer. On the other hand most could correctly identify the positions of infrared, microwaves and gamma rays on the spectrum.

Question 2 Converging lens

Most students have an intuitive idea of what the focal point of a lens is but very few can correctly and precisely define it. The majority of candidates failed to mention that the focal point is on the principal axis and it is the point rays parallel to the principal axis pass through after refracting in the lens. Many candidates could do the ray diagram to show the formation of the image but, as in past years, a disappointingly large number cannot. The lens in the question was drawn as a single line in order to help the candidates draw accurate diagrams and avoid the confusion of what happens to the ray while inside the lens. There is evidence of confusion between lenses and mirrors, which suggests that in those classes where the IB is taught along with other programmes not enough time is spent on this topic leaving many students confused. In (b) the lens equation was generally well done and the height of the image correctly calculated.

Question 3 Compound microscope

Parts (a) and (b) were well done. In (c) the magnifications of the individual lenses were correctly calculated but were then added rather than multiplied.

AHL

Question 4 Single slit diffraction

This question proved very difficult for the majority of candidates despite the importance of single slit diffraction in Physics and in the syllabus. Many could identify the half angular width on the diagram in (a) and correctly identify the path difference as a half wavelength in (b) but few could correctly explain their answer. The derivations of $\theta = \frac{\lambda}{b}$ in (c) were muddled with many candidates attempting to use, incorrectly, the diffraction grating formula. Those who did make some progress had trouble justifying why $\theta \approx \phi$ in the end. In (d), many forgot to multiply by 2 and many did not include units. In (e) many candidates did not realise that the missing maximum corresponded to $n = 4$. This question was a poorly done

Recommendations and guidance that teachers should provide for future candidates

Recommendations from the examination team included the following ideas:

- 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 two options generally performed better than those that answered questions from several different options.
- 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.
- Candidates should read each question carefully. Answers must be focused – there is no need to write unnecessarily long sentences. Students must learn to answer precisely what the question asks.
- Candidates must ensure that they are familiar with the definitions of physical quantities. The definitions must be precise, accurate and detailed.
- Candidates should use the amount of marks allotted to a given part of a question as a rough guide to the amount of detail required in their answers.
- Candidates should be encouraged to produce clear and labeled diagrams.
- Candidates should be familiar with the contents of the Data Booklet.
- Answers must be written in the appropriate space on the examination paper itself.
- Students should need more practice the manipulation of ratios in both numeric and in symbolic form.
- Students must have much more practice with past exam questions on gravitation for the SL Option A, Mechanics.
- Students must have more practice with the equations of relativistic mechanics in option G, Relativity.
- Students must have much more practice with ray diagrams in option H, Optics.

