PHYSICS (IBAP & IBAEM)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-16	17-28	29-39	40-49	50-59	60-70	71-100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-15	16-26	27-37	38-48	49-56	57-68	69-100

Internal assessment

Component grade boundaries

Higher level

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

Standard level

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 the work submitted

Most schools are providing the IB physics student with a well balanced and challenging practical program. There is evidence of experimental work in most of the syllabus areas, including the options, and in areas outside the IB curriculum. Many group 4 projects are interesting and there is evidence that students are enjoying their work. There was almost no evidence of ‘fill-in-the-blank’ worksheets. Many standard textbook experiments were carried out, and in most cases these were fine for assessment under the criteria of data collection, data processing and presentation, and conclusion and evaluation, but they were not appropriate for planning (a) or planning (b) assessment. This needs to be appreciated by some teachers. A few schools allocate too much time for any one investigation. For instance, 4.5 hours to verify Hooke’s law is hard for a moderator to believe. Teachers need to remember that the time allocation is class-time only.

Candidate performance against each criterion

Although the majority of teachers clearly understand the five criteria, the two that caused the most problems were planning (a) and conclusion and evaluation. Teachers need to keep in mind that under planning (a) students must speculate about the relationship or function in an investigation. Measuring gravity or confirming the conservation of momentum are not open-ended prompts that allow students to address each aspect. Conclusions need to relate back to the original hypothesis, and analyse the data in a way that confirms or denies the original question. Details of the three aspects must be given to the students when they write their conclusions and evaluations. Most students are weak on expressing the limitations or weaknesses in their procedure. They need to think about the scope and range of the investigation as well as the underlying assumptions.

Most students do well under data collection assessment. Errors and uncertainties are usually included in data tables, and brief comments are made about the estimates of these errors and uncertainties. Attention is being given to significant figures.

Data processing and presentation is often well done but contains a few weak areas. Too often a student will make calculation, for example when determining the index of refraction by measuring appropriate angles. Then they would repeat this a number of times for various angles, and would average the numerous values of the index of refraction. A much better method of processing would be to graph the appropriate angles and use the gradient to determine the refractive index. This would eliminate any systematic shift in data, give a visual image of the data scatter and hence the quality of the data, and would allow for minimum and maximum gradient calculations. There are still a few students who connect the dots on a graph when a best straight line would have been appropriate. There are also graphs where the data suggests a curve and yet the student forces a best straight line. Students should be encouraged to extend their graphing skills. Finally, a number of higher level students are using the minimum and maximum gradient of a graph to find the uncertainty in the best straight-line gradient. This is encouraging.

Recommendations for the teaching of future candidates

- The open-ended nature of planning (a) investigations needs to be appreciated by both the teacher who sets the prompt for the investigation and by the student.
- Group 4 projects are often the result of a team effort and so these projects are normally not appropriate for assessment by any of the first five criteria. They may be assessed under the non-moderated criteria of Manipulative Skills and of Personal Skills (a)
- The IB encourages the use of ICT. A majority of students are producing investigation documents by word processing, and many students are using graphing programs. This is good news. A few schools are using data logging for some investigations, and a few schools are using spreadsheets to process data.
- Teachers and students need to be aware of the difference between the expectations (based on the syllabus) of standard and higher level students when it comes to the handling of errors and uncertainties.
- More teaching is needed in the area of graphing skills, including the treatment of errors and uncertainties in graphs.
- The continued used of the IB's Online Curriculum Centre is encouraged. It is evident that many teachers are making good use of the resources here, especially the planning investigations.

Further comments

The overall evidence is that internal assessment of the physics program is clearly understood by the majority of teachers and students, and that the application of the IA criteria is done in a satisfactory way. The vast majority of 4/PSOW and the new 4/IA cover sheet forms have been completed correctly.

Paper one

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-10	11-13	14-17	18-19	20-23	24-26	27-39

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-10	11-13	14-16	17-18	19-21	22-29

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.

Only a small percentage of the total number of teachers or the number of Centres taking the examination returned G2's. 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 2006 papers were generally well received. The majority of the teachers who commented on the Papers felt that they contained questions of an appropriate level. However, a significant minority thought that both Papers were more demanding. Such changes in demand can be accommodated when grade boundaries are set. With few exceptions, teachers thought that the Papers gave satisfactory or good coverage of the syllabus. When commenting on coverage, it should be borne in mind that this must be judged in conjunction with Paper 2. Most teachers 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. In general, a higher discrimination index indicates that a greater proportion of the more able candidates correctly identified the key compared with the weaker candidates. This may not, however, be the case where the difficulty index is either high or low.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	189	813	638	1180*	23	41.50	.43
2	321	83	2016*	421	2	70.91	.10
3	138	2462*		238	5	86.59	.07
4	1493*	374	643	326	7	52.51	.29
5	250	2258*	127	205	3	79.42	.37
6	1341*	838	341	309	14	47.16	.26
7	192	612	1673*	351	15	58.84	.38
8							
9	801	1421*	530	84	7	49.98	.55
10	493	85	1417*	834	14	49.84	.21
11	161	676	1345*	647	14	47.30	.43
12	69	456	1449	853*	16	30.00	.16
13	178	76	2416*	167	6	84.98	.22
14	1088	386	684*	671	14	24.05	.30
15	55	636	1883*	265	4	66.23	.35
16	16	308	594	1917*	8	67.42	.39
17	95	1320*	797	630	1	46.42	.54
18	269	1764*	355	430	25	62.04	.38
19	297	114	1112*	1318	2	39.11	.31
20	875	277	1474*	210	7	51.84	.15
21	263	721	118	1731*	10	60.88	.50
22	1996*	518	188	137	4	70.20	.31
23	176	426	835	1382*	24	48.61	.39
24	309	232	1797*	495	10	63.20	.45
25	177	279	2335*	48	4	82.13	.30
26	1791*	165	115	758	14	62.99	021
27	119	1365	617	732*	10	25.74	.14
28	291	376	1931*	242	3	67.92	.16
29	1172*	476	505	661	29	41.22	.13
30	361	693	523	1247*	19	43.86	.51
31	238	770*	1084	705	46	27.08	.19
32	403	242	1668*	514	16	58.67	.41
33	756	301	479	1267*	40	44.56	.56
34	601	1237*	88	902	15	43.51	.16
35	1202	184	187	1247*	23	43.86	.52
36	371	1622*	630	196	24	57.05	.34
37	203	301*	177	2128	34	10.58	.04-
38	290	640	444	1438*	31	50.58	.44
39	1338*	341	916	203	45	47.06	.35
40	701	498	501	1101*	42	38.72	.32

Number of candidates: 2843

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	233	996	473	715*	32	29.19	.38
2	36	39	2352*	21	1	96.03	.06
3	140	2074*		232	3	84.68	.08
4	2034*	49	247	117	2	83.05	.26
5	361	1653*	352	80	3	67.49	.39
6	1075*	655	476	232	11	43.89	.25
7							
8	85	619	1512*	229	4	61.73	.35
9	767	928*	598	152	4	37.89	.44
10	404	1304	344	390*	7	15.92	.17
11	1046	820*	202	364	17	33.48	.17
12	38	54	1600*	747	10	65.33	.31
13	204	763	833*	636	13	34.01	.29
14	209	716*	1057	464	3	29.23	.49
15	706	1520*	176	41	6	62.06	.23
16	290	1179*	440	514	26	48.14	.40
17	175	1788*	220	256	10	73.00	.36
18	255	732	150	1305*	7	53.28	.50
19	273	314	163	1690*	9	69.00	.44
20	782	458*	599	591	19	18.70	.18
21	1144*	302	808	184	11	46.71	.37
22	160	1245	483	550*	11	22.45	.09
23	241	264	1594*	342	8	65.08	.24
24	1059	269*	648	459	14	10.98	.02-
25	277	1324*	413	422	13	54.06	.43
26	963*	377	426	656	27	39.32	.15
27	491	717	489	714*	38	29.15	.37
28	2073*	154	173	33	16	84.64	.29
29	1241	249	220	707*	32	28.86	.41
30	292	1242*	665	210	40	51.71	.33

Number of candidates: 2449

Comments on the analysis

Difficulty. For both HL and SL, the difficulty index varies from about 10% (relatively 'difficult' questions) to about 85% in HL and 96% in SL (relatively 'easy' questions). The majority of items were in the range 30% to 70%. Thus, the Papers provided ample opportunity for all candidates to gain some credit and, at the same time, gave an adequate spread of marks.

Discrimination. All questions, with one exception, 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. This may indicate that candidates did not have sufficient time to complete their responses,

despite a lack of comments from teachers to this effect. Even so, 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 Q3

Candidates should appreciate that a best-fit line may be straight or curved unless they are told specifically that the line is either a straight line or a curved line. In this question, option B is clearly the best-fit line for the data points. However, the line in option C would just pass through the regions of uncertainty for all of the points. Therefore, options B and C were both accepted.

SL Q7 and HL Q8

It would have been preferable to have stated, in the stem, that the rocket 'accelerates forwards', rather than 'moves forwards'. With the present wording of the question. option A could be correct if appropriate start- and end-points are chosen. Thus, the question has not been included.

SL and HL Q9

This question had a high discrimination index with average or below average difficulty index. The question appeared to be a good test of understanding of the topic.

SL Q14 and HL Q17

The results would indicate that, amongst weaker candidates, it needs to be stressed that the degree Celsius and the degree kelvin have the same magnitude.

SL Q22 and HL Q27

This question proved to be difficult for candidates. The majority thought that option B would be the key. Clearly, they considered only the magnitudes of the charges and ignored the inverse-square nature of the distances.

SL Q30 and HL Q36

There was some comment from a small number of teachers that the diagrams were poor. The statistics at both SL and HL would indicate that those who understood the phenomenon had little or no difficulty in understanding the options.

HL Questions

Q10

The difficulty index for this item was approximately 50% and with an acceptable discrimination index. It would have been better to state categorically that it is the work done against the given forces. However, the distractors rule out any other possibility and are clearly incorrect.

Q12

The question asks for the speed of the stone as it hits the sea. Many candidates gave the response corresponding to the vertical velocity.

Q14

Candidates should realise that, when a body moves vertically upwards and there is significant air resistance, then the acceleration will have a magnitude greater than g. Thus, there is only one possible correct option.

Q32

The polarity of an individual peak cannot be determined. What is known is that the two peaks will have opposite polarities.

Q33

The wording of the stem is correct. The question refers to a constant r.m.s. current. This means that the root-mean-square current is constant and, by implication, the peak current is also constant. The stem does not state that the alternating current is constant.

Q34

Where candidates are asked to draw such diagrams, the quality is usually well below that which is expected. In this item, candidates could be tested on their understanding, without involving any drawing skills. Options A and C are clearly incorrect because the majority of the deviation occurs either before or after reaching the nucleus. Option D is incorrect because it involves an almost instantaneous change in direction i.e. the force of repulsion acts over a very limited range of distance.

Q37

This negative discrimination index indicates a very popular misconception. Namely, that at constant intensity, the photoelectric current is constant. Intensity is a measure of light power per unit area. If the frequency is increased, then photon energy increases. For constant power per unit area, the photon flux must decrease, giving rise to a change in photoelectric current.

Q38

In option D, it may have been preferable to state 'a given nucleus'. However, the item has a very high discrimination index that would indicate that candidates were not disadvantaged.

SL questions

Q10

The stem of the question refers to a steel ball but the options make reference to a sphere. However, this does not appear to have been a factor as far as the candidates are concerned. The low difficulty index was due to candidates failing to realise that the system comprises the ball/sphere and the plate. This phenomenon can be illustrated well using a Newton cradle – the executive toy!

Q11

The popularity of option A would suggest that weaker candidates considered only the loading of the wire. The stem clearly states that the force returns to zero.

Q20

From comments received, it would appear that there is some confusion here. The stem does not mention the speed of a standing wave. In fact, this would be incorrect. A standing wave is the result of interference when two travelling waves move in opposite directions in the same region of space. The speed is the speed of either of these two travelling waves that give rise to the standing wave.

Q24

This item had a very low difficulty index and a negative discrimination. The reason for this is a popular misconception on the part of candidates. Resistance is not defined as the gradient of a V/I graph. Resistance is, however, defined as the ratio of potential difference across the component and the current in the component. Therefore, when using a graph, the current I for a specific value of potential difference *V* must be ascertained and then the ratio *V/I* gives the resistance at that particular value of *V* and *I*.

Q29

The majority of candidates gave the answer for the number that remained, rather than the number that had decayed. The use of emboldened text in questions in physics is quite intentionally kept to a minimum so that, when it is used, candidates should realise that it has real significance.

Recommendations and guidance for the teaching of future candidates

Candidates should make an attempt at every item. Where they cannot provide the correct response, then they should always choose that option which, to them, appears to be most likely. It should be emphasised that an incorrect response does not give rise to a mark deduction.

The stem should be read carefully. It appears that some candidates do not read the whole stem but rather, having ascertained the general meaning, they move on to the options. Multiple choice items are kept as short as is possible. Consequently, all wording is significant and important.

Having decided on the correct response, candidates should check that all other options are not feasible.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-12	13-24	25-34	35-45	46-56	57-67	68-95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-9	10-14	15-20	21-25	26-31	32-50

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 means that one should be cautious about drawing any firm conclusions. However, at both levels the majority of teachers thought the paper to be a similar standard to those in previous years. More than 85% of the respondents thought that the papers were of an appropriate level of difficulty. The vast majority felt that the syllabus coverage, clarity of wording and presentation of both papers was either satisfactory or good.

General comments

There were some excellent scripts at both levels. However, many candidates, particularly at SL, found it hard to perform well on these papers even though there were plenty of marks accessible to those candidates who struggle with the more conceptual aspects of the course. As identified last year, candidates often lost marks as a result of definitions that either lack precision or are expressed in non-scientific language. 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). It should be emphasised to candidates that a best-fit line is not necessarily a straight line.
Candidates often lacked algebraic manipulation skills and also the ability to give coherent, scientific explanations for particular phenomena.

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

The examining team also identified the following areas with which many candidates had difficulty:

- Working with powers-of-ten continues to cause problems, as does symbolic manipulation
- Converting between absolute and percentage uncertainties
- Gravitational potential and gravitational energy
- Distinguishing between wavefronts and the direction of travel of a wave
- Drawing sensible magnetic field patterns
- Derivation of the ideal gas equation
- Vector diagrams
- Solving circuit problems
- Sketching acceptable magnetic fields
- Working with Newton's second law in any form other than $F = m\,a$
- Explaining the formation of stationary waves
- Electromagnetic induction

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

Generally, candidates seemed well prepared in the following areas:

- Solving problems involving power
- Solving heat engine problems
- Mathematical substitution into a given equation
- Differences between travelling and stationary waves
- Understanding 'isotope', 'half-life' and β-decay
- Understanding what is meant by an isobaric process

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

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

Section A

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

Many candidates drew a straight line of "best fit". (See above).

(b) **[HL only]**

Many candidates were successful here. A common error however, was to suggest a plot of lg(*F/k*) against *n*lg*x*.

(c) **[(b) SL]**

This was often done well but some candidates failed to state a conclusion based on a calculation of the breaking stress of the thread.

(d) **[HL only]**

Many candidates failed to double the percentage error.

(e) **[SL (c)]**

It was unfortunate that proof reading did not detect the unit error given in the question (2.4×10^{-2} cm rather than 2.4×10^{-2} m). Many candidates, in fact, read the unit as metres and those that did not and correctly used the area under the graph, obtained an answer very close to the answer given in (i). Those candidates who used average force correctly did, of course, have no problem. Unfortunately a significant number of candidates did not know either method of solution. A common error was to multiply the breaking force by the breaking extension. Part (ii) was often done well.

A2 [HL only] – *Gravitational potential*

(a) Few candidates managed to score all three marks for the definition, with many omitting 'per unit mass' or reference to a point/small mass.

(b) Weaker candidates used the data book expression for the gravitational potential and a combination of r, R and R_0 to mean the same thing.

(c) The determination of the gravitational field strength was often done well.

(d) A large number of candidates used V instead of ΔV. Many candidates either could not start the work or attempted to use *mgh*.

A3 [SL question B3 – part 1] - *Ideal gas*

This was essentially a teaching question.

Many candidates did well but weaker candidates struggled with part (b) **[SL(c)]** and (c) **[SL(d)]**, with many not attempting part (c).

(e) **[SL only]** Most candidates were able to calculate a correct value for the mass of the gas.

Section B

B1 [SL question B1 part 2] – *Mechanical power (SL and HL) and heat engines (HL)*

This was a very popular choice at SL and quite popular at HL.

(a) and (b) These were done well by the majority of the candidates.

(c) It was unfortunate that the term "friction force" was used in the stem whereas the more correct term "resistive force" had been used elsewhere in the question. However, this did not disadvantage candidates. The calculation of the time and work done was done well by most candidates. However, in calculating the power, many candidates only considered the gravitational force.

Part (iv) **[SL only]** This was often done well.

(d) and (e) **[HL only]** Weaker candidates struggled with the calculation of the acceleration and often did not know how to start. The better candidates frequently scored high marks and most candidates did well on the calculation of the speed at the bottom of the incline. However, few candidates recognised that, if the car is moving at constant speed, then the frictional force is equal to the component of weight down the incline.

(f) Few candidates noted that the action verb is "explain" and did not mention what change is to be considered i.e. a compression or expansion. However, most candidates knew that the change is isobaric.

(g) Arrows were often correctly drawn and most candidates correctly related the area to the difference in energy transfers. However, many answers to part (iii) were often wrong or incomplete. A significant number of candidates thought that a Carnot engine is 100% efficient.

(h) This calculation was often done well.

B2 [HL (a), (d) (e) (f) and (g), SL B1 Part 1] ***Waves***

[HL (b), (c), SL A2]

(a) **[HL and SL]** Most candidates managed one correct difference between stationary and travelling waves but weaker candidates struggled to find a second.

Weaker candidates could not decide which angle to use and did not make the connection that the answer could have been reached by measurement of the wavelengths.

(b) **[HL and SL(A2 a)]** This was generally not done well with many candidates giving 'the waves are bent' as their reason

(c) **[HL and SL (A2 b)]** Weaker candidates could not decide which angle to use and did not make the connection that the answer could have been reached by measurement of the wavelengths.

(d) **[SL (b)]** This was generally poorly done. Candidates failed to note that the action verb is "explain". Many answers were anecdotal and rarely resorted to physical principles.

(e) **[SL (c)]** Very few candidates actually answered the question and assumed that the experiment had measured the speed v and so stated a graph plot in terms of v and T , not referring to the frequency f.

(f) **[HL only]** Diagrams were often vague and imprecise, and rarely was the position of the source correctly shown with respect to the wavefronts. However, explanations of the difference in frequency heard by the two observers were usually correct.

(g) **[HL only]** Explanations of the term *beat frequency* were often incomplete. In the calculation, many candidates used an approximate version of the correct Doppler equation but clearly did not realise what they had done. Furthermore, very few appreciated that the incident wave is also Doppler shifted.

B3 [SL B3 Part 2] ***Electric current [SL and HL] and the effect of electric currents***

(a/b)Apart from the incorrect positioning of the point P on the potentiometer, the only other part of the sub-question that was poorly answered was describing and explaining the shape of the characteristic of the conductor Y. Many candidates just said it is non-ohmic or that it could be a filament lamp. Non-ohmic does not explain the shape. A 240 V filament lamp would not produce this shape in this voltage range and does not, therefore, provide an adequate explanation.

(c) **[HL only]** This was generally well answered**.**

(c) **[SL only]** Generally well answered**.**

(d) **[SL A3 (c)]** (i) This was not done well. Few candidates considered the vector nature of the two fields.

(ii) A number of weaker candidates failed either to place arrows on the vectors or gave an incorrect direction. Many drew B_w as the hypotenuse.

(iii) Many candidates answered this well but some failed to convert centimetres to metres.

(e) and (f)**[HL only]** Answers were very disappointing. Electromagnetism is clearly an area of the syllabus that candidates find difficult.

B4 [SL B2] ***Nuclear energy and radioactive decay***

(a) **[SL (c) (ii)]** This calculation was, in general, done well.

(b) **[SL (f)] Statements of the law of conservation of momentum were often incomplete.** References to external forces, momentum remaining constant and a closed system were rare.

(c) **[SL (g)]** This was usually done well.

(d) **[SL (h)]** There was much confusion here between conservation of energy and conservation of momentum. However, the better candidates often scored high marks.

(e) **[HL only]** The calculation of the de Broglie wavelength was done well by the better candidates but weaker candidates often made no attempt.

(f) **[HL only]** This was often done well by a significant number of candidates.

(g) **[HL only]** Few candidates realised that, to determine the half-life of barium, they had to use that portion of the graph where little caesium was left in the sample.

SL additional questions: -

A3 (a) and (b)] ***Magnetic fields***

(a) There were a lot of carelessly drawn patterns with field lines crossing each other.

(b) Many candidates missed out the word “bar”.

B2 (a), (b) and (c)(i) ***Nuclear energy***

(a) Many candidates thought that binding energy is the energy that holds the nucleus together.

(b) No problems here.

(c) Mass of a C-12 nucleus was a common misconception.

Recommendations and guidance for the teaching of future candidates

A common theme this year, as in previous years, was the lack of precision in written answers and associated definitions. For instance, candidates should be given precise and unambiguous definitions of physical quantities and statements of physical laws.
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.
It is important that candidates are made familiar with the action verbs. For example, where the action verb is “explain”, the number of marks and the number of lines available for the answer should alert candidates to the fact that more than factual recall is required to score high marks.
As has been suggested in the past, the examination team recommend working through past papers (and the associated mark schemes) as good preparation. Not only will these give candidates

familiarity with the format of the examination but also many should be able to gain a good understanding of the level of detail required and of the skills that are being assessed.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-14	15-20	21-26	27-32	33-38	39-60

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-5	6-10	11-14	15-18	19-21	22-25	26-40

General comments

The majority of candidates seemed to find the paper accessible and there were many 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.

The feedback from teachers on the G2 forms for SL and HL can be summarized as follows:

Standard Level

- 70% found the paper to be of a similar standard to last year, 24% easier and 6% more difficult. Overall, 94% found the paper to be of an appropriate standard and 4% thought it too difficult.
- about 51% found the syllabus coverage satisfactory, 3% thought it was poor and 46% found it good.
- about 50% found the clarity of wording satisfactory and 50% found it good.
- about 36% found the presentation satisfactory and 64% found it good.
- as in previous years, the most popular options were A (Mechanics) and H (Optics).

Higher Level

- about 67% found the paper to be of a similar standard to last year, 21% easier and 12% a little more difficult. Overall, 94% found the level of difficulty appropriate and 4% thought it was too difficult.
- about 35% found the syllabus coverage satisfactory and 62% good
- about 40% found the clarity of wording satisfactory and 57% found it good
- about 27% found the presentation satisfactory, 73% thought it was good
- As in previous years, the most popular options were H (Optics), F (Astrophysics) and G (Relativity).

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

The areas identified by the examination team as being difficult were as follows.

- Resolution of forces in 2-D situations.
- Explaining concepts in Physics in a way that demonstrates understanding (e.g. making arguments based on the exponential law for the attenuation of the transmitted intensity in X-rays, explaining why the time measured by a given clock is the proper time, Galilean transformations)
- The concept of stress and its scaling properties.
- The use of barium meals.
- The application of the principle of moments to a biomechanical situation.
- Similarities and differences between cathode rays, rays of light and waves.
- The Schrödinger model.
- The concept of Olbers' paradox.
- The order of magnitude of the frequency of visible light.
- Newton's rings and interference.
- Providing sufficient depth and detail in questions with a mark allocation of more than one mark.. This was particularly true in those questions involving the action verbs "explain", "discuss" and "describe".

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

Simple mathematical calculations were often done well by the majority of candidates. Many candidates appeared well prepared and able to produce some excellent answers that showed a good understanding of the concepts, particularly in the Astrophysics and Optics options.

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

SL only

Option A – Mechanics

Question 1 Trajectory of a golf ball

The majority of candidates seemed capable of making a reasonable attempt at analysing this straightforward application though a significant number muddled the horizontal and the vertical motions. Some used vector addition to calculate the initial velocity and then used this value in the equations for constant linear acceleration. A significant number correctly attempted to substitute the vertical components of the motion into the constant acceleration equations, but failed to remember that the direction of the acceleration is opposite to the initial vertical component of velocity. Even when mistakes were made in the first section, many were correctly able to calculate the range of the golf ball.

Question 2 A spacecraft

A surprisingly small number of candidates clearly stated that the speed of the spacecraft was changing as a result of the gravitational force due to the Earth. Many implied that it was the change in gravitational 'pull' that resulted in a change of speed. Typically candidates correctly achieved the calculation of average acceleration though a significant number failed to identify the correct direction. Part (a)(iii) was poorly done with very few candidates able to equate average acceleration with average gravitational field strength. Typically candidates attempted to substitute into $F = \frac{GM_1M_2}{r^2}$.

The final sketch of the variation with distance from the surface of the Earth of the gravitational potential energy of the spacecraft was often poorly executed. Common mistakes were to assume a constant gravitational field and/or to assume the gravitational potential energy was zero at the surface of the Earth.

Question 3 Equilibrium of a beam

Although straightforward, this question proved to be challenging for many candidates and implies that few had sufficient exposure to similar problems during their studies. Only a handful of candidates realised that the force acting on the beam at the hinge would have both horizontal and vertical components. A significant number were clearly guessing. Few of those that did have the correct general idea represented the direction with any precision. It was rare for candidates to realise that the direction of the force would be towards the mid point of the supporting wire.

Option B – Quantum Physics and Nuclear Physics

Question 1 The photoelectric effect

The first section required candidates to explain the features of a graph showing the variation of the maximum current with the intensity of the monochromatic light. Typically candidates only described the graph and thus scored no marks. In the second section, many candidates seemed to know, in general, that increasing the frequency of light increased the electron energy but it was very rare to see good graphs to show the variation with potential difference of the current.

Question 2 Atomic spectra

The calculation of the wavelength of an emitted photon as a result of the transition between two given energy levels tended to be either done well or not at all. Some candidates muddled or forgot the units of their answer.

Question 3 Radioactivity

This question required candidates to calculate the decay constant and the half-life from an initial activity given the initial number of atoms. Many candidates clearly did not understand the meaning of activity and were unable to start the calculations, but those who did often scored highly. Some marks were lost as a result of incorrect units. Many candidates did not seem to understand what was being asked of them in the final question

Question 4 Alpha-particle scattering

Surprisingly, few candidates were able to score any marks in this question. When sketching paths of α-particles moving towards gold nuclei, candidates often failed to take into account the initial directions given in the diagram. Often paths were sketched without any precision. Only vague explanations were offered as to how knowledge of the initial KE of the α-particles enabled an upper limit for the diameter of a nucleus to be estimated.

Option C - Energy extension

Question 1 Thermodynamics Processes

Candidates tended either to answer this question reasonably well or seemed to be guessing throughout. Those who were guessing tended to answer questions by substituting into inappropriate formulae.

Question 2 Wind power

The initial calculation proved too difficult for many candidates and few candidates were able to suggest a reason as to why it is impossible to extract all the power from the air. Typically, candidates explained why energy would necessarily be lost during the conversion process, rather than answering the question as posed. Many candidates could only suggest that wind turbines are not placed close to one another for fear of the blades colliding. Candidates were often able to suggest reasonable advantages and disadvantages of a wind turbine as opposed to nuclear power station, but often candidates were not able to express these ideas with any clarity and thus tended to lose marks.

SL and HL combined

Option D - Biomedical physics

Question 1 Stress in bones

This question was expected to be answered well but a surprisingly small number of candidates were able to make any real progress with the problem. Few related the maximum weight to the stress in the bone and many assumed that the weight being supported was only the weight of the bone itself.

Question 2 Sound intensity

Most candidates did not define sound intensity level with any mathematical precision. Those who did, often forgot to identify the variables given in the equation. In part (b), most candidates were unable to calculate the sound intensity level at the eardrum. Some were able to calculate the power per unit area at the eardrum but then did not complete the calculation. Few identified possible problems that could be caused by the high intensity.

Question 3 X-ray absorption

The mathematical sections of this question tended to be answered to a higher standard than the descriptive answers though even good candidates often lost marks through missing or incorrect units. The descriptive answers often lacked precision and rarely referred to the attenuation coefficient even when this was specifically requested in the question.

AHL

Question 4 Biomechanics

Once again, this descriptive question tended to be answered superficially with, for example, very few candidates referring to the principle of moments when attempting to explain why the mechanical advantage of the forearm is less than one.

Question 5 Effects of ionizing radiation on the body

The question started by asking candidates to state three factors that affect the absorbed dose and clearly some candidates did not understand the term. The answers to the subsequent question on possible precautions often included correct ideas but did not give sufficient information. It was typical for candidates to be able to state two precautions but, unfortunately, many omitted the explanation required by the question.

Option E – The history and development of physics

Question 1 Orbital motion

Many candidates knew that the Copernican model of the Solar System involves circular orbits of the planets around the Sun whereas Kepler's model involves elliptical orbits. They often struggled to find a second difference. Many thought that one model was geocentric and candidates often referred to epicycles.

Question 2 Aristotelian view of motion

Many candidates were able to name and to distinguish between forced and natural motion, but then failed to relate the specific path shown in the question to these ideas in anything other than a superficial way.

Question 3 Joule's experiment

This question asked for an outline of the experimental procedure and the measurements taken in Joule's experiment to determine the mechanical equivalence of thermal energy. Some candidates were unsure about how the experiment was conducted, but many lost marks by failing to include all the relevant details.

Question 4 Cathode rays

Many candidates scored reasonably well on this descriptive question concerning one of Crookes' experiments but a large number did not refer to the actual observations. In the final section, candidates were asked to comment on the suggestion that the cathode rays are a form of light. Many candidates were able to explain why this observation was wrong, but few included any discussion as to why some physicists had initially made this suggestion.

AHL

Question 5 The Rydberg formula and atomic models

A surprisingly large number of candidates were unable to represent the transition between named energy levels on the electron energy level diagram given in the question. Many were reasonably successful in the calculation that followed for the Rydberg constant. However, it was common to find that n and m were confused, resulting in a negative number. Candidates tended to be able to list some limitations of the Bohr model and some assumptions of the Schrödinger model but often marks were lost as answers were unclear or ambiguous.

Option F – Astrophysics

Question 1 Stars

This question was essentially factual recall but candidates often lost marks and a surprisingly large number of candidates had not learned this information. Typically, candidates knew that there must be some 'force' to prevent gravitational collapse but the descriptions were often not clear. Many candidates implied that visual binary stars could be seen as separate stars without the aid of a telescope or binoculars. Some candidates may have known the facts but failed to gain credit as their answers were too brief or ambiguous.

Question 2 The star Antares

Many candidates were able to complete all the calculations in this question without difficulty. Marks tended to be lost, however, for missing units or incorrect significant figures. The final question, asking candidates to deduce the ratio of the radius of Antares to the radius of the Sun, proved too difficult for a significant number.

Question 3 Olbers' paradox

Many gave outline answers to this question and lost marks by failing to include all relevant details. Very few candidates attempted to include quantitative arguments. In the second section, candidates often presented good suggestions to refute Olbers' arguments but these ideas could not gain credit if they were not related to the Big Bang model of the Universe, as required by the question.

AHL

Question 4 Star evolution

This was answered reasonably well. Typically, candidates lost marks on the two final sections. Surprisingly few candidates were able to state that after the fusion of hydrogen, helium fusion would commence in the star under consideration. Many incorrectly thought that the final fusion product of the star would be iron, even though the initial mass was only four times the mass of the Sun.

Question 5 Hubble's law

Marks were often lost through lack of precision when asked to define the symbol v in Hubble's law. Some candidates referred to the speed of objects, planets or the Universe as opposed to galaxies. Many clearly implied that the Earth must be at the centre of the Universe, in that v was defined in terms of the speed of objects moving away from the Earth. Few were able to demonstrate an understanding of how to use the Hubble constant (which was given in km s^{-1} Mpc^{-1}) to calculate a value for the age of the Universe in seconds or years.

Option G - Relativity

Question 1 Proper time

Many candidates' answers to the question on proper time suggested that they had some notion of the concept but their ideas were not stated with sufficient clarity to gain full marks. Most candidates were able to correctly calculate the γ-factor, but some incorrectly multiplied the given time by this factor.

Question 2 Simultaneity

Most candidates could correctly state that the two identified events would not be observed to be simultaneous by the observer outside the train but typically, candidates failed to refer to the constancy of the speed of light in order to explain why this would be the case.

Question 3 Relative velocities

Many candidates could only offer imprecise descriptions of Galilean transformations but were often able to correctly calculate the relative speed using both the Galilean and the relativistic transformation equations. Marks were often lost for the inappropriate treatment of significant figures. Almost all of the candidates knew that a relative speed that was greater than the speed of light is an impossibility.

Question 4 Mass-energy

Once again, few candidates were able to offer unambiguous descriptions of the difference between the rest mass-energy and the total energy of a particle. Few candidates were able to successfully complete the calculation and many felt the need to substitute, incorrectly, a numerical value for the speed of light.

AHL

Question 5 Space-time, gravitational lensing and black holes

Many candidates seemed to have a reasonable understanding of the concept of space-time but tended to have difficulties when expressing themselves. The answers to the extended questions on gravitational lensing often lacked precision and typically diagrams showed impossible and/or highly unrealistic paths for light rays.

Option H Optics

Question 1 The nature of light

Surprisingly, this question tended to be very poorly answered with few candidates able to refer to the electromagnetic propagation of energy or to recall the order of magnitude of the frequency of visible light.

Question 2 Refraction

A significant number of very muddled diagrams were submitted. Those that did have some merit often demonstrate a good understanding of refraction but lost marks through an incorrect identification of the image position. Many were able to state that the image is virtual but failed to gain credit as the question asked candidates to explain their answers. The final mathematical calculations were often done well.

Question 3 Magnification

Many were able to gain credit for their ray diagrams but then lost marks as a result of poor precision. A pleasingly large number of candidates were able to continue successfully with the mathematical calculation of the overall magnification produced by a microscope. Some lost marks in the final stages because they were unable to correctly combine the magnification produced by the eyepiece with the magnification produced by the objective lens.

AHL

Question 4 A wedge film

Good answers to this question were very rare indeed. Few could even correctly identify the surfaces involved in the production of the bright fringes. The details of how and why the waves involved resulted in a bright fringe were often confused or missing.

Question 5 The Rayleigh criterion

Some candidates clearly understood the Rayleigh criterion and were able to produce good sketches of the intensity distributions. The majority of answers lacked precision and some candidates were clearly guessing. The calculation proved too difficult for the majority of the candidates. Those who did make some progress often halved the separation between the headlights without also halving the angle.

Recommendations and guidance for the teaching of future candidates

Recommendations from the examination team included the following ideas:

- Candidates should be given more opportunities during the course to practice examination style problems.
- Candidates should be provided with, and given assistance with, the list of action verbs as specified in the syllabus. It is clear that many candidates do not recognise the difference between, for example, stating an answer and explaining an answer.

- When using a diagram to help answer a question, candidates should be encouraged to pay attention to the precision of the diagram. This is particularly true of ray diagrams, as many candidates failed to use even a sharp pencil and / or a ruler.
- Enough time should be devoted to cover in depth the topics chosen.

