PHYSICS (IBNA/IBLA)

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-15	16-27	28-39	40-49	50-60	61-70	71-100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-15	16-28	29-37	38-48	49-58	59-69	70-100

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	11-15	16-21	22-24	25-28	29-31	32-40

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-10	11-13	14-16	17-20	21-23	24-30

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. 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. A small number of teachers considered that the clarity of wording was poor. It would be helpful to specify the wording that might have caused problems so that some remedial action may be taken, if necessary.

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.

HL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	1259*	514	136	41		64.56	.32
2	109	133	452	1254*	2	64.30	.52
3	192	1628*	93	37		83.48	.23
4	1692*	213	16	28	1	86.76	.22
5	153	197	1481*	118	1	75.94	.47
6	58	1413*	426	53		72.46	.42
7	1528*	183	136	92	11	78.35	.33
8	72	499	506*	866	7	25.94	.22
9	34	155	1364*	395	2	69.94	.36
10	984*	735	166	64	1	50.46	.43
11	905*	456	397	181	11	46.41	.18
12	1433*	70	172	275		73.48	.15
13	231	188	1297*	234		66.51	.30
14	33	907	965*	44	1	49.48	.16
15	360	333	151	1102*	4	56.51	.28
16	1343	431*	63	110	3	22.10	.31
17	238	83	138	1491*		76.46	.26
18	610*	105	665	566	4	31.28	.30
19	509	963*	212	266		49.38	.34
20	173	138	104	1534*	1	78.66	.34
21	64	289	254	1334*	9	68.41	.34
22	109	1687*	138	15	1	86.51	.25
23	131	248	1430*	138	3	73.33	.30
24	233	692	887*	134	4	45.48	.43
25	142	143	1403*	259	3	71.94	.41
26	710	44	102	1091*	3	55.94	.31
27	1382*	124	255	170	19	70.87	.39
28	232	1254*	315	147	2	64.30	.21
29	164	226	1381*	174	5	70.82	.47
30	964	306	425*	248	7	21.79	.17
31	249	517*	338	835	11	26.51	.12
32	180	1540*	103	111	16	78.97	.29
33	214	527	908*	288	13	46.56	.51
34	550	898*	302	173	27	46.05	.56
35	165	119	873*	781	12	44.76	.41
36	450	594	618*	244	44	31.69	.40
37	818	79	888*	147	18	45.53	.27
38	1622*	119	104	80	25	83.17	.31
39	238	624	965*	96	27	49.48	.37
40	277	761*	585	303	24	39.02	.45

Number of candidates: 1950

SL paper 1 item analysis

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
1	2705*	1038	277	112		65.46	.42
2	535	607	525	2443*	22	59.12	.51
3	495	3123*	376	137	1	75.58	.31
4	100	1608*	2296	124	4	38.91	.28
5	3146*	857	38	90	1	76.13	.36
6	1451	1561*	306	799	15	37.77	.42
7	173	2489*	1269	192	9	60.23	.51
8	1376*	988	1236	526	6	33.30	.46
9	2646*	708	495	236	47	64.03	.43
10	294	203	859	2767*	9	66.96	.23
11	194	1591	833*	1495	19	20.15	.14
12	1944*	333	157	1691	7	47.04	.02-
13	706	695	645	2076*	10	50.24	.30
14	551	385	1109	2065*	22	49.97	.54
15	2687	868*	243	325	9	21.00	.29
16	477	957	1390	1298*	10	31.41	.31
17	399	483	308	2929*	13	70.88	.46
18	244	749	2436*	696	7	58.95	.44
19	187	972	537	2408*	28	58.27	.35
20	1837*	1462	710	105	18	44.45	.45
21	1705	176	304	1940	7	46.95	.35
22	1009*	1842	757	508	16	24.41	.43
23	2185*	471	826	551	99	52.87	.41
24	246	661*	1565	1598	62	15.99	.18
25	561	845	2214*	468	44	53.58	.54
26	992	153	789*	2164	34	19.09	.26
27	1676	241	1743*	436	36	42.18	.15
28	177	343	2391*	1158	63	57.86	.58
29	3106*	358	395	212	61	75.16	.35
30	454	2231*	1341	50	56	53.99	.51

Number of candidates: 4132

Comments on the analysis

Difficulty. For both HL and SL the difficulty index varies from about 20% (relatively 'difficult' questions) to greater than 75% (relatively 'easy' questions).

Discrimination. Except for one question at SL, 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 Q11 and HL Q 8

A majority of students used the maximum force in this equation rather than the average force, thus missing the factor ½. The students who chose option B did not check the units attached to this answer.

SL Q21 and HL Q26

Option A was a popular distractor, suggesting that students knew about electrostatic forces between charges but had little understanding of electrostatic induction. In the stem of the question, the term "insulator" was used, as opposed to "conductor", in accordance with the definitions given in the syllabus.

HL Questions

Q9

Newton's universal law of gravitation cannot be applied to two spherical masses, unless their separation is much greater than their diameters. In the case of planet Earth, the Earth is not spherical and not of uniform density.

Q14

The answer does not depend on the choice of a scale. The line of action of all the forces acting on the object must pass through a single point.

Q16

A number of students did not know that a solid will melt at constant temperature.

Q30

A popular distractor was option A, revealing a total misconception of the nature of momentum and kinetic energy.

Q39

The more able students interpreted correctly "particular time interval" to mean "per unit of time"

SL questions

Q12

A large number of students assumed, wrongly, that the tangential velocity is constant across the disc, thus confusing tangential velocity and angular velocity. This is a popular misconception.

Q16

A majority of students chose either B or C, rather than D. This is possibly due to a misconception of the quantities ΔV and Δm. The best approach here was to concentrate first on the definition of density.

Q22

A significant number of students failed to square the distance *r*.

Q24

This question was essentially about the definition of an e.m.f. and it is clear that a very large majority of students do not understand this concept. They were distracted by other issues and considerations.

Q27

A significant number of students do not appreciate the role played by electric forces in the nucleus, regardless of the stability of the nucleus.

Q30

The verb "fuse" refers specifically to the event of fusion in nuclear physics. Induced endothermic reactions are not referred to as fusion events. The most popular (incorrect) distractor was C. Such a choice suggests that a large number of students did not appreciate an essential facet of nuclear energy.

Paper two

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-10	11-21	22-31	32-42	43-53	54-64	65-95

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-13	14-15	16-21	22-27	28-32	33-50

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 mean that one should be cautious about drawing any firm conclusions but at both levels the majority of teachers thought the paper to be of a similar standard than those in previous years. A small percentage thought the papers were slightly more difficult than last year's. More than 80% of the respondents felt the papers were of an appropriate level of difficulty 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 and examination that appeared difficult for the candidates

The examining team also identified the following areas: -

- Extracting data from graphs, especially when the units on the axes are not straightforward but include powers of ten
- Correct descriptions of the methods of thermal energy transfer
- Thermodynamics (cycles and thermal energy transfer)
- Moments of forces and the conditions for translational and rotational equilibrium
- An understanding of the concept of photons and their role in the explanation of the photoelectric effect
- The law of conservation of momentum, its applicability in various situations and the definition of an elastic collision
- Vector diagrams and vector subtraction
- The distinction between transverse and longitudinal waves in terms of energy propagation
- Electromagnetic induction

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

It was pleasing to see the following skills demonstrated: -

- Graphical analysis
- Mathematical substitution into a given equation
- Symbol manipulation to prove a given relation or formula
- Computational skills
- Radioactive decay

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*

(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 carelessly draw the line leaving too many points on one side of the line. The use of the symbol θ to denote temperature is perfectly normal and students must be aware of the many ways a particular physical quantity may be denoted.

(b) It was rather disappointing to see many candidates having difficulty with this question. Many just described in words that the height decreased with increasing temperature and few were able to correctly identify the intercept and slope of the line or make any reference to the fact that the given equation was of the standard form $y = mx + c$.

(c) The great majority of students managed to complete this part correctly.

(d) Few students managed to score full marks on this part. The labelling on the horizontal axis ($\frac{1}{r}/\times10^3\ \text{m}^{-1}$) clearly confused many even though it is completely standard. The paper contained an unfortunate typographical error (the exponent in m^{-1} was missing) but this did not seem to affect the candidates. Omitting the factor of 10^3 was the common mistake here even among those candidates who realized that they had to find the equation of the straight line in the form $h = \frac{c}{r}$ and then substitute $r = 25$. Very many of the comments to the result of the calculation were either irrelevant or plainly incorrect. (A 25 m tall tree with capillary diameter of the order a few thousand km did not elicit a comment.) Part of the training that should be provided in a physics course is the ability to evaluate the answer to a particular problem and to judge whether this answer is sensible. Many students took the question to mean that they had to describe in words what they did with mathematics in the first part of the question.

A2 [HL only] – *Rotational equilibrium*

It was surprising to see many candidates unable to write down the conditions for translational and rotational equilibrium. It was also disappointing to see many unorthodox methods for the solution of a problem involving moments of a force. This has also been observed in past examinations. Many students use a "ratio" type method that usually leads to wrong answers.

A3 [SL question A2] - *Electric circuit*

Circuits continue to cause problems to candidates. Most students correctly answered that the lamp would not light but could not provide an adequate reason why. The circuit diagram for measuring the *I-V* characteristics of the lamp was generally well done but many strange-looking circuits were also produced (many without a variable resistor or potential divider) that meant that no data could be taken from that experiment.

A3 [SL only] *Circular motion*

It was satisfying to see many correct answers to all parts of this question. The vectors in (a) were correctly drawn and the calculation in (c) was complete. A few students lost a mark for significant digits in (c).

A4 [HL only] - *Thermodynamic processes*

This question was not done well. Many students could draw correctly the arrows representing thermal energy transfer in the heat pump but very few could explain correctly why the processes in (b) were isothermal. The question alerted candidates to the presence of a phase transition and that should have guided students to the right explanation. Most candidates could not identify the parts of the cycle where thermal energy was absorbed or rejected from the heat pump. The working substance of the heat pump was obviously not an ideal gas. The majority automatically assumed that all heat engines operate with ideal gases.

Section B

Question B2 was the most popular question among SL students. HL students chose mainly two from B1, B3 and B4. Question B2 was the least popular choice.

B1

B1 Part 1 [HL only] – *Kepler's third law*

(a) This part was answered well by most, including the derivation in part (iv).

(b) This was also answered well, but frequently a mark was deducted for a significant digit error. It is rewarding to see correct calculations in gravitation after many not so successful attempts in the past. Many students used the data given to *first* find the mass of Jupiter and *then* to use $g = \frac{GM}{r^2}$ to find the magnitude of the gravitational field strength. This alternative approach, followed by many, was awarded full marks. In (i), an approximate value of the gravitational field strength on the surface of Ganymede was required. Thus it is perfectly correct to use the orbital radius of Ganymede for r in the formula for g although, strictly speaking, what is required is the difference between the orbital radius and Ganymede's radius.

B1 Part 2 [SL question B1] – *Heating water electrically*

(a) **[SL part (d) (i)]** Many students could not answer this part. At best, a few mentioned the words "conduction" and "convection" and even fewer mentioned "radiation". Very few could describe how one or more of these mechanisms actually transferred thermal energy from the heating element to the water. Students must learn that, with three marks available and five lines provided for an answer, a two-word reply simply will not give them full marks.

(b) **[SL part (d) (ii)]** Very many candidates answered this part well. It is satisfying to see a (numerically) moderately involved question being answered correctly.

(c) **[SL part (d) (iii)]** "Heat loss" was the frequent answer to this question but students must learn to be precise and identify the place/body where the thermal energy is lost. It was rare to see *two* correct reasons why the previous calculation is only an estimate.

(d) **[SL part (d) (iv)]** This was well done by most. A few had the correct formula but failed to convert the kW to W.

(e) **[SL part (d) (v)]** Very few candidates realized that, initially, the heating element was cold and so its low resistance implied that there would be a large current in it.

(f) **[SL part (e)]** The first part to this question was completed correctly by the majority of candidates (some did use the power of 7.2 kW, but the majority answered the question without reference to a particular numerical value of the power). The second part caused many difficulties. A common answer was that the 110 V supply would take less time to heat the water or that it would cost more money.

B2 Part 1 [SL question B3 part 1] – *Electric motor*

(a) **[HL only]** Many students omitted the brushes in (i) but could correctly identify the forces on the loop in (ii). The answers to (iii) were confused. Many seemed not to know that the purpose of the split ring commutator is to reverse the current in the coil in order to ensure continuous rotation. Very few students realized that inertia would make the coil move past the point where the net torque on the coil is zero.

(b) **[SL part (a)]** This was generally well done. A common mistake was to incorrectly calculate the weight using the mass of 15 g by failing to convert the grams into kilograms in (ii). In (i), many students did not label the arrows representing the forces.

(c) **[SL part (b)]** This part had a mixed response. In part (i) many suggested measuring the speed of the weight as it moved upwards, without any detail as to how this was to be done. In part (ii) many assumed that the weight was still accelerating and so had difficulties finding the force. In part (iii) many students had difficulty with the concept of efficiency.

(d) **[HL only]** It was a small minority of candidates who could fully answer this question. Many mentioned that n could be found from the slope but very few wrote down $\ln E = \ln k + n \ln I$. Many also said that $\ln E$ should be plotted against $\ln kI$. It is clear that logarithms still cause major problems for students.

(e) **[HL only]** This part was not well done. Very few candidates mentioned Faraday's law or even a changing magnetic flux. In parts (ii) and (iii), very many candidates used the data booklet and found the formula $V = Blv$. They then attempted to answer the question in terms of this formula. Electromagnetic induction was very poorly answered this year.

(f) **[HL only]** In this part, the majority answered part (ii) correctly but very few could identify the position where the coil is parallel to the magnetic field in (i).

B3

B3 Part 1 [SL question B3 part 2] - *Waves*

(a) The meaning of the terms "transverse" and "longitudinal" 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 question, few candidates referred to the propagation of energy at any time at all in their answers. Answers typically involved the phrases "up" and "down" and "right" and "left".

(b) Part (i) was generally well answered with the majority of the candidates realizing that the wave is longitudinal. However, candidates were seldom successful in providing a reasonable argument to support their answers. In part (ii), marks were awarded to those candidates who realized that the distance travelled is 3.0 m. Those who assumed 6.00×10^{-4} s to be the period of the wave and $\lambda = 3.0$ m for the wavelength and then used $v = \frac{\lambda}{T}$ scored no marks despite the answer being numerically correct. Part (iii) was concerned with an explanation of the production of sound when the hammer hits the rod. As with other questions requiring an "explanation", this part was not well answered. Most answers revolved around the concept of the energy of the hammer being transferred to sound without any details of the mechanism as to how that might come about. Part (iv) was generally answered well except that many students failed to justify why the rod vibrating in its fundamental mode would have a wavelength equal to 3.0 m.

(c) **[HL only]** This was disappointing. Candidates attempted to explain the varying intensity of sound in terms of beats or the Doppler effect. Those who did mention interference rarely made reference to the conditions for interference in terms of path difference and wavelength. This is another example where students need to realize that a three-mark question with five lines of answer space cannot be answered with a single phrase such as "because of interference". Generally, parts (ii) and (iii) were answered well.

B3 Part 2 [SL question B2 part 2]- *Radioactive decay*

(a) **[SL part (a) (iii)]** Most candidates could identify particle X as being hydrogen but in many cases, the answer did not specify a hydrogen nucleus as opposed to a hydrogen atom.

(b) Part (i) was answered fully only by a few candidates. The crucial step that activity is proportional to the number of radioactive atoms present was missed by many. For HL part (ii), answers were either fully correct or contained garbled formulae leading nowhere.

B4

B4 Part 1 [SL question B2 part 1] - ***Momentum***

The answers to this question were disappointing at both HL and SL. The fact that it involved very basic physics makes it even more disappointing.

(a) Very few candidates seemed to be aware that the total momentum of a system stays the same only when no external force acts on the system. Many repeated the question by including the word "conserved" in their answers, without any further amplification.

(b) Very few candidates seemed to know what was meant by an elastic collision. Many said that a collision is elastic if the bodies do not stick together during the collision. Part (ii) is where only a minority of candidates scored marks. The great majority could not relate the law of conservation of momentum to the case of the puck hitting the wall. Candidates were unable to identify the system under consideration and then determine whether external forces were acting on the chosen system. Many of the answers provided were contradictory.

(c) This part required a simple subtraction of vectors but very few were able to do this successfully. Instead, the vast majority calculated the sum of the initial and final momenta of the puck. Since the angles involved gave the magnitude of the sum as being the same as that of the difference, many candidates must have left the examination room thinking that they had scored all four marks allocated to this part.

(d) Many candidates were able to derive the force through $F = \frac{\Delta p}{\Delta t}$ but then failed to realize that this expression gives the magnitude of the *average* force acting on the body during the time interval Δt. A few obtained the correct numerical answer by writing $F_{\text{max}} = \frac{\Delta p}{\Delta t}$ with $\Delta t = 6\text{ ms}$. This is, of course, incorrect and no marks were awarded to these candidates.

B4 Part 2 [HL only] - ***The quantum nature of radiation***

(a) Many candidates attempted to account for the threshold frequency without mentioning photons. Many of those who did use photons and the photon energy formula $E = hf$ appeared unable to take the next step and argue that if the photon energy hf was less than the work function, no electrons would be emitted.

(b) Most obtained correctly the threshold frequency from the graph in (i). In part (ii) many seemed to remember that the Planck constant was somehow related to a slope but could not justify why the slope was indeed *h*. Many therefore obtained the slope in units of eV s and presented that as *h* without further justification. (iii) Many achieved the correct answer, a few with the help of error carried forward (ECF).

(c) Many candidates were able to calculate the speed of the electron correctly in (i). In part (ii), many used the de Broglie formula $\lambda = \frac{h}{p}$ in order to find the wavelength of the photon. The numerical answer for the de Broglie wavelength is different from that of the minimum photon wavelength but that did not stop candidates from claiming that it was approximately equal to the given wavelength.

(d) This was, perhaps, the best-answered part of B4 part 2. Most candidates could draw a reasonable X-ray spectrum even though a few diagrams were incorrect in that they did not show a minimum wavelength, characteristic lines and a reasonable 'tail'.

SL additional questions: -

[SL question B1 (a)-(c)] – *Heat capacity*

(a) The definitions given for heat capacity were rarely correct and lacked the necessary detail and precision.

(b) Students appeared to be guessing as to which substance would have its temperature raised by a larger amount, as evidenced by the incorrect arguments that justified their answers.

(c) Students were generally confused by having to write “word equations”. Most resorted to “heat lost = heat gained’.

[SL question B2 Part 2]

(a) (i) This was generally well answered.

(a) (ii) Generally well answered.

(b) (ii) This was answered rather well. This is an encouraging sign when considering past problems with calculations involving the Avogadro constant.

(c) This was generally well done but with some notable exceptions related to carelessness in the plotting of points or graphs with a completely wrong shape.

(d) (i) and (ii) This was generally well answered.

Recommendations and guidance for the teaching of future candidates

Whereas candidates in this year’s examination appeared to do well in calculations, a common theme has been the lack of precision in written answers, especially in those requiring an explanation. Arguments that logically follow from each other were few. Candidates should be encouraged to be able to define the terms that they are using. 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 recommends working through past papers (and the associated mark schemes) as a good preparation for the examination. 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. Some candidates answered all the questions on separate sheets of paper and wrote nothing on the examination paper itself. This included copying graphs that must have been very time consuming for those candidates. Situations such as this would have been avoided if those candidates had practised with past papers. Candidates must also be encouraged to write clearly and legibly, to avoid the use of a pencil and always to have a ruler with them during the examination.

Paper three

Component grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-13	14-18	19-24	25-30	31-36	37-60

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-9	10-13	14-17	18-20	21-24	25-40

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. Some candidates appeared not to appreciate 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, others 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. friction in Option A and ray diagrams in Option H).

Significant digit errors 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 significant number of candidates simply wrote down an answer to numerical calculations without any working being shown (often in multi-part calculations). If candidates are asked to deduce that a particular value is correct, then clearly no marks can be awarded when no working is shown. The action word 'deduce' will always imply that explanation and working of intermediate stages are required.

The feedback from teachers on the G2 forms for SL and HL can be summarized as follows. However it should be remembered that a relatively small number of forms were received and that these may not be a representative sample.

Standard Level

74% found the paper to be of a similar standard to last year and 26% a little more difficult. However, overall, 91% found the paper to be of an appropriate standard and 9% thought it to be too difficult.
About 63% found the syllabus coverage satisfactory and 35% found it to be good.
55% found the clarity of wording satisfactory, 10% thought it was poor and 35% found it good.
About 49% found the presentation satisfactory and 51% found it good.
As in previous years, the option B (Quantum Physics and Nuclear Physics), option C (Energy Extension), option D (Biomedical Physics) and option E (The History and Development of Physics) were not popular.

Higher Level

Approximately 52% found the paper to be of a similar standard to last year, 10% a little easier and 33% a little more difficult. However, overall, 92% found the level of difficulty appropriate and 8% thought it was too difficult.
About 67% found the syllabus coverage satisfactory and 33% good.
About 58% found the clarity of wording satisfactory and 29% found it to be good.
Approximately 58% found the presentation satisfactory, 38% thought it was good and 4% found it to be poor.

As in previous years, the option B (Quantum Physics and Nuclear Physics), option C (Energy Extension), option D (Biomedical Physics) and option E (The History and Development of Physics) were not popular.

The areas of the programme and examination that appeared 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 where statements concerning physical quantities are required. Such statements were either poorly expressed, incomplete, imprecise or just plain incorrect. Examples include

- factors that affect the magnitude of a frictional force
- the purpose of a mass spectrometer
- advantages and disadvantages of wind power
- the logarithmic scale for loudness
- real/virtual images
- use of lasers

In Option A, gravitation proved beyond the capabilities of the great majority of SL candidates. In Option B, candidates showed weaknesses in the photoelectric effect and the mass spectrometer. Option D revealed large gaps in the knowledge of candidates at both SL and HL on basic items on the syllabus such as loudness and the use of ultrasound/X-rays. As in past examinations candidates displayed a striking weakness when drawing ray diagrams in Option H. Thin film interference proved to be beyond the capabilities of most 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 digits.

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

SL only

Option A – Mechanics

Question 1 Projectile Motion

(a) It was pleasing to note that very few candidates used the approximate value of 10 m s^{-2} for the acceleration of free fall. However, when finding the total kinetic energy, many considered only the change in gravitational potential energy.

(b) A common error was to consider 34% of the energy when calculating the speed. Surprisingly, a significant number of candidates who failed to consider the initial kinetic energy in (a) now included this energy in the calculation.

Question 2 Gravitation

(a) Most answers included either 'gravitation' or 'gravity'. Candidates should be encouraged to use scientific language, rather than common parlance.

(b) Answers here were disappointing. All too frequently, expressions for gravitational force and centripetal force were equated without any explanation. Furthermore, subscripts, essential for this deduction, were frequently omitted. Candidates should appreciate that, where a deduction is involved, then the work should be explained.

(c) There was much muddled thinking here with M_2 being wrongly identified as the larger mass since it is further from the point P. Candidates were advised to use the answer in (b) and yet this advice was frequently ignored. Clearly, candidates were expected to analyse the expression given in (b).

Question 3 Frictional Forces

(a) Frequently, the quoted factors were not independent of one another. For example, weight of object on the surface and reaction force. Many quoted 'speed' without making it clear that the crucial factor is whether the object on the surface is at rest or moving, not the speed at which it is moving.

(b) Generally, the forces were shown correctly although a significant number of answers indicated a non-normal reaction force or friction acting down the slope.

(c) In (i), deductions were, in general, disappointing. Many did not realize that they should resolve forces along and at right-angles to the slope. In (ii), very few candidates realized that the maximum value of μ would be 1.0. Teachers should advise students that, where it appears that the value of μ is greater than 1.0, then effects other than friction are involved.

Option B - Atomic and nuclear physics extension

Question 1 Photoelectric effect

(a) Frequently left unanswered. Candidates are expected to realize that V_S gives a measure of the (maximum) kinetic energy of the photoelectrons and that light intensity determines the rate of emission of photoelectrons, not their kinetic energy.

(b) Again, answers were disappointing. Very few candidates wrote down a word equation and/or an algebraic expression to represent the photoelectric effect. Consequently, they were unable to appreciate how the graph was to be used. Candidates were told to explain their working. This instruction was intended to encourage them to quote an appropriate equation or expression.

Question 2 Mass Spectrometer

(a) Frequently, inappropriate wording such as 'weigh atoms' was used.

(b) Any type of mass spectrometer was acceptable. A schematic diagram was required so that detail was not necessary. For example, in a Bainbridge type spectrometer, it was sufficient to show a block labelled 'velocity selector' rather than give detail of the crossed electric and magnetic fields.

(c) Some candidates were unaware of the method by which the problem could be approached. A common error was to determine the fraction of one of the isotopes in the whole sample, rather than the ratio of the two isotopes.

Question 3 Radioactive Decay

(a) Clearly, some candidates had learned their work carefully. It was apparent that others had either not studied the topic or had not committed the work to memory. These should have been easy marks for candidates. Any relevant property was accepted (e.g. charge) whether or not it is actually included in the Guide.

Option C - Energy extension

It is disappointing to find that, even in an 'Energy' Option, candidates do not appear to be able to distinguish clearly between the terms 'energy', 'power' and 'force'.

Question 1 Ideal Gas

(a) In (i), candidates were equally divided between constant volume, constant pressure and constant temperature. In (ii) and (iii), it was pleasing to note that, where the calculation was attempted, thermodynamic temperature, rather than Celsius temperature, was used.

(b) In a significant number of answers, it was not realized that external work was involved. It was common to find that the calculated external work was added to the thermal energy supplied.

(c) There were some correct answers but the majority of candidates were unable to decide whether to calculate the sum or difference of the various energies. Again, written explanation was, in general, either lacking or less than adequate.

Question 2 Power Generation

(a) It appeared as if many candidates were not able to express their ideas using appropriate wording. The words 'bodies' and 'rotting' were not uncommon. The concept of partial decomposition of organic matter under conditions of 'high' temperature and pressure was rarely apparent.

(b) The majority of candidates could give at least one advantage. However, 'pollution free' was not accepted. Whereas it was expected that the advantages would be stated, in (ii) some explanation of the stated disadvantages was required in order for marks to be awarded.

SL and HL combined

Option D - Biomedical physics

Question 1 Scaling

(a) With few exceptions, this was answered well.

(b) Many candidates did not seem to realize that, for the same volume, a long cylinder has a larger surface area than a sphere. Inappropriate and inaccurate statements such as 'a cylinder means more energy is absorbed' were common.

Question 2 Hearing

(a) In general, candidates described one type of loss, not both.

(b) Answers to (i) and (ii) were disappointing although the calculation in (iii) was completed successfully by those who could manipulate the lg function. It would appear that a large proportion of candidates were aware of intensity level without understanding the concepts associated with this term.

Question 3 X-rays

(a) Most candidates could identify at least one process.

(b) In (i), the meaning was widely understood. However, in (ii), few candidates realized that the ratio would be equal to 0.5^8.

(c) Many thought that X-rays would 'show up the bone'. It was not appreciated that ultrasound would not penetrate significantly into the bone.

AHL

Question 4 Lever Systems

A significant number of candidates stated that the force in the muscle would be much greater than the load. They did, therefore lose credit for failing to give an explanation. In complete answers, there was some discussion of the relative distances of the relevant forces from the pivot.

Question 5 Ionising Radiation

There were some candidates who did not answer the question but, instead, described the illnesses or the symptoms. Many candidates found difficulty in relating short- and long-term effects to either cell death or non-lethal DNA damage.

Option E – The history and development of physics

Question 1 Planetary Motion

(a) Most answers included a reference to the positions of planets but far fewer included the times at which the positions were determined.

(b) A mention of elliptical, rather than circular orbits, was found in most scripts. Only a minority made a reference to the Sun at one focus of the ellipse.

(c) A common response was to state that Newton 'proved Kepler's laws'. Rarely was it mentioned that Newton developed the laws of gravitation which enabled Kepler's laws to be derived.

Question 2

(a) Some candidates paraphrased the question by stating that 'an electric current produces a magnetic field'. A brief outline of Oersted's experiment was required and this was provided by more-able candidates.

(b) Only a minority of candidates were able to answer this part of the question.

Question 3

(a) Generally, the fluid nature of caloric was stated. However, few mentioned that caloric was expected to flow between bodies when they are at different temperatures or gave any further detail in order that the second mark could be awarded.

(b) Most described, to a greater or lesser extent, the production of thermal energy as a result of friction. An alternative approach would be a discussion of energy transfer as a result of a change of phase.

Question 4 Discovery of the Neutron

In general, this question was poorly answered. It appeared as if candidates were unaware of any detail as to how the protons were identified.

(a) Few candidates mentioned how the radiation emerging from the wax blocks was investigated (e.g. using a cloud chamber).

(b) With few exceptions, candidates did not appreciate how the mass of the neutron was determined.

A HL

Question 5 Bohr Model of the Atom

(a) With few exceptions, the symbol was identified correctly.

(b) In (i), most candidates did state that momentum is quantized but the magnitude of a quantum was rarely stated, either in (i) or (ii). Consequently, in (ii), very few made any progress towards deducing the given equation.

(c) The calculation presented very few problems, apart from errors when using a calculator. However, there were very few sensible comments. Where a candidate had completed the calculation successfully, then a comment to the effect that the value is close to that found experimentally would have been suitable.

(d) Most candidates quite correctly made a reference to additional electrons.

Option F – Astrophysics

Question 1 Stars

(a) Well answered by most candidates.

(b) Perhaps because the answer was given, this simple calculation was completed successfully by nearly all candidates.

(c) Very few answers included a reference to any effect of the atmosphere. Many thought the increase was due to a longer base line. Many of those who did realize that the atmosphere was of significance merely stated that the satellite would be outside the atmosphere.

(d) In (i), the majority of answers were acceptable. However, it was apparent that a minority of candidates had very little understanding of the concept. In (ii), most did state, in one way or another, that Betelgeuse would appear brighter. The calculation in (iii) presented few problems, apart from the unit for the answer. In (iv), opinion was approximately equally divided as to which star would be more distant. There were some very good answers where luminosity and brightness were compared, leading to the correct conclusion. Unfortunately, there was also much muddled thinking.

Question 2 Olbers' Paradox

(a) With few exceptions, candidates referred to an infinite Universe.

(b) A minority of candidates still refer to any line of sight ending on a star. In many answers, summing of shells was not made clear and the conclusion reached was not that the night sky should be as bright as during the day but rather, the sky should be infinitely bright.

AHL

Question 3

Most answers included a reference to 'high' temperatures, but frequently, no reasoning was given. Fewer candidates mentioned high density or pressure and very rarely was any reason given for this condition.

Question 4

Most could give at least one characteristic. The most common were 'very distant' and 'high luminosity'. Candidates should ensure that, in questions of this form, they do not give the same answer in two different ways. For example, 'moving away at high speeds' and 'large Doppler shift' would not be considered as separate characteristics.

Question 5 Hubble Constant

(a) In view of the fact that symbols were defined in the question, the equation was given correctly in the vast majority of scripts.

(b) Most candidates appeared to understand that they needed to compare a quantity, calculated using the Hubble constant, with the equivalent measured quantity. Frequently, there were arithmetical errors. Having completed the calculation, candidates were expected to make an appropriate comment. In many answers, a comment was omitted. Some did comment on the uncertainty in the value of H_0, others made reference to the closeness when the number of significant digits was considered whilst others pointed out that a 30% difference could not really be explained on this basis. Any sensible comment was accepted.

Option G - Relativity

Question 1 Time and Length

(a) Surprisingly, it became apparent that many candidates use the term 'frame of reference' without an understanding of the concept.

(b) In (i), there was some doubt as to whether the instant at which A and B were struck was in the frame of reference of O or of C. Consequently, either solution was acceptable, provided sufficient explanation was provided. The majority of answers in (ii) were correct.

Question 2

(a) There were very few problems in (i). In (ii), the majority did show that the speed would be c. However, it was apparent that many of the less-able candidates have difficulty with the interpretation of the signs in the equation.

(b) Many answers merely stated that 'c is constant'. Further detail was required as regards a reference to which the speed is constant. Some candidates, to their credit, made reference to the permittivity and the permeability of free space.

Question 3

(a) It was not uncommon to find that an equation, with no explanation of symbols was given or, when defining rest mass, some vague statement such as 'energy of the mass at rest' was given. Total energy was explained satisfactorily by a greater number of candidates.

(b) This was done well by most candidates and they realized why the answer is an estimate.

(c) A significant number of candidates lost marks through carelessness. Candidates should realize that, when sketching a graph, the important features should be clear. Indeed, the command 'sketch' was avoided and was replaced by 'draw' in order to discourage sloppy work. For example, the line drawn should be asymptotic at $v = c$. It should not be parallel to the line $v = c$ or cross it. It was not uncommon to find the drawn line approaching the line $v = c$ and then moving away from it!

AHL

Question 4 Evidence to support General Relativity

(a) Most answers were satisfactory.

(b) The same comment applies here as in G3(c) for (i). Many lines were wavy or did not show bending of straight lines near to the Sun. Frequently, all the bending occurred in a region distant from the Sun. In (ii), descriptions were seldom adequate in that no mention was made as to how it was known that the light had deviated. That is, the star appeared to have moved relative to the background stars.

Question 5 Black Holes

(a) It was realized that severe warping of space-time would occur. There is, however, a misconception that 'nothing can escape from a black hole'. Whether an object can escape does, of course, depend on the degree of warping etc at the position of the object.

(b) This calculation presented very few problems apart from a failure to take the square of *c*.

Option H Optics

Question 1 Image formation

(a) In (i), most candidates did show the position to within ±5 mm. Although most candidates did draw two appropriate construction rays in (ii), the quality of the work sometimes left much to be desired. The mark for the image position was not awarded where the construction was poorly executed.

(b) Although most answers were satisfactory, a significant minority gave no explanation or were unsure as to why the image would be virtual.

(c) Generally answered correctly although it was not uncommon for the microscope to be confused with a magnifying glass.

(d) In (i), very few realized that L_1 must not be moved so that the object distance is unchanged. More-able candidates explained correctly how to adjust the position of L_2. Many did, however, think that the first image should be coincident with L_2. In (ii), very few answers made a reference to angles subtended by the final image and by the object at the eye. Indeed, it appeared as if the concept of angular magnification was unknown in the vast majority of answers.

Question 2 Refraction and total internal reflection

(a) This simple question was poorly answered by most candidates. All that was required was a statement that the ray must be incident on the surface in the more dense medium and that the angle of incidence must be greater than the critical angle. Frequently, neither of these two points was made.

(b) In (i), the majority of solutions were correct. However, less-able candidates frequently failed to realize that the angle of incidence was not 68°. In (ii), sketches were, once again, frequently poor. It was expected that the emergent ray would cross the normal and would be deviated away from the normal.

(c) With few exceptions, candidates made reference to the scratching of the fibre. However, frequently it was not made clear that it is the core that is protected. The reason for providing such protection was made clear by only the most able candidates.

(d) Many answers involved 'coherence'. The most common correct response, together with an explanation, involved the monochromatic nature of the light. Other factors could include speed of switching and ability to direct the emitted light.

AHL

Question 3 Two-source Interference

(a) Many thought that wider slits would give rise to more fringes. Where the description was correct, the majority could not give a satisfactory explanation.

(b) It should be realized that the pattern consists of a series of light and dark fringes. A mere statement that 'the fringes are lighter' is unsatisfactory not only as a statement but it also lacks explanation.

Question 4 Thin Film Interference

(a) Most candidates did arrive at the conclusion that the thickness should be ¼ λ. However, in reaching this conclusion, very few considered possible phase changes at the reflecting surfaces.

(b) With very few exceptions, candidates thought that magenta light would interfere constructively and all other colours would undergo complete destructive interference. They did not appreciate that, in such thin film interference, destructive interference would occur for wavelengths in the middle region of the visible spectrum, leaving extreme wavelengths to give rise to the purple colour.

Recommendations and guidance for the teaching of future candidates

Recommendations from the examination team included the following:

- 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 within 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 where the same two options were answered by all generally performed better than those where several different options were attempted.
- 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 number of marks allocated 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 diagrams that are fully labelled.
- Candidates should be familiar with the contents of the Data Booklet.
- Answers should be written in the appropriate space on the examination paper itself.
- Students should be given more practice at the manipulation of ratios in both numeric and in symbolic form.
- Students should be given as much practice as possible with past exam questions.
- Where students study option H, they need far more practice with the drawing of ray diagrams.

