Chemistry Timezone 2

Overall grade boundaries

To protect the integrity of the examinations, increasing use is being made of timezone variants of examination papers. By using variants of the same examination paper candidates in one part of the world will not always be taking the same examination paper as candidates in other parts of the world. A rigorous process is applied to ensure that the papers are comparable in terms of difficulty and syllabus coverage, and measures are taken to guarantee that the same grading standards are applied to candidates' scripts for the different versions of the Examinations papers. For the May 2017 session, the IB has produced timezone variants of Chemistry SL/HL Papers 1, 2 and 3

Standard level Timezone 2

Grade:	1	2	3	4	5	6	7
Mark range:	0-14	15-27	28-39	40-50	51-60	61-71	72-100

Higher level Timezone 2

Grade:	1	2	3	4	5	6	7
Mark range:	0-16	17-29	30-42	43-54	55-64	65-75	76-100

Higher level and Standard level internal assessment

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-3	4-6	7-10	11-13	14-16	17-19	20-24

The range and suitability of the work submitted

The range of work in terms of suitability for the assessment by the new I.A. criteria was similar to May and November 2016 with a large number of candidates presenting work which was the outcome of independent enquiry and showed evidence of curiosity, engagement and a sense

of ownership of their Individual Investigations. Teachers and support staff in the many schools that encouraged such varied investigations should be commended greatly on their efforts since the facilitation of such opportunities for sizeable classes is a logistical and organizational challenge.

Overwhelmingly the work presented involved hands-on primary data collection. The most popular were rate of reaction studies, redox titrations and combustion calorimetry with very many of these investigations being related to food chemistry. The most successful of these investigations had identified an independent variable that was continuously measurable (such as concentration, mole fraction, temperature, etc.) and also a dependent variable that could be measured quite precisely using techniques commonly available in a school laboratory such as temperature measurements, acid-base or redox titrations, gas volume measurements, mass changes, etc. It was seen that some schools have increased the range of options available to students to good effect by acquiring a spectrophotometer or some extra data logger probes such as those determining carbon dioxide or oxygen concentrations in the atmosphere.

There were however many less successful investigations. A significant number of students did not identify a suitable independent variable and focused simply on comparative assays of brands of cleaning product, pharmaceuticals or strains of fruit and vegetables. Other students showed quite a bit of imagination but struggled to generate usable data when they had tried to develop their own measurement technique such as using digital photography to quantify colour or to somehow evaluate strength or quality of odour. We don't want to stifle creativity but teachers should monitor such projects closely to see if meaningful data is being generated and if necessary redirect the student while there is still opportunity to do so. It is a pity for an enthusiastic student to generate in the end no usable results which consequently does make achievement against some of the criteria, especially Analysis, more limited.

Similarly to the May and November 2016 sessions few students presented reports based on secondary data. Models and simulations yielded an extremely low number of investigations and the few database orientated investigations were generally weak with little data presented - which counters the purpose of using a database rather than generating primary data. Some moderators expressed that they felt that teachers would more readily promote such investigations if separate expectations of secondary data investigations were sent out to schools. Although this thinking is understandable it is important to state that the assessment criteria and associated expectations have to be the same for all types of investigation submitted for IA. Teachers are advised to look at the expanded Teacher Support Material for examples of what can be achieved in this area.

With regards to overall achievement the mean moderated mark per student was similar to last year with a shortfall of about half a point compared to the May 2016 mean. The magnitude of the mark readjustment through moderation again showed a significant reduction compared to the last session under the old framework in 2015 and once again teachers across the IB world should be commended.

There were variations in attainment across the two levels and also across the IB regions. The mean moderated mark for Time Zone 1 Higher Level students was 13.4 marks out of 24 whereas for Standard Level the mean was 12.3. This difference was even more apparent in Time Zone 2 schools with HL candidates being awarded a mean moderated mark of 15.6 while

for SL the mean was 13.7. These differences are not surprising considering the fact that SL students have to carry out the same internally assessed task and be evaluated by exactly the same criteria despite having significantly less prior scaffolding time in their Practical Scheme of Work and also having studied the topics in less depth with a more limited opportunity to have acquired and practiced crucial data processing skills. The reasons for the differences seen between Time Zones 1 and 2 can only be conjectured and those schools whose marks are significantly short of the mean should reflect on how they are scaffolding, facilitating and assessing the Individual Investigation. It must be stressed that examiners are allocated unidentifiable reports from both levels and time zones. Similarly, from the outcome of the Individual Investigations submitted in Spanish, where the mean moderated marks were also significantly behind Time Zone 2, it is clear some schools need to reflect on their current practices and seek help from the Online Curriculum Centre and IBO authorized training such as the Category 3 Focus on IA workshops.

Candidate performance against each criterion

Personal Engagement:

The candidates were awarded either one or two marks with fairly equal frequency with a zero award being very rare.

There were less cases than in the May 2016 session of the students' efforts to justify their choice of topic spilling over into overlong and contrived narratives relating to their early childhood experiences.

The commonest limitation to achievement was where students failed to show genuine curiosity by presenting a very undemanding research question where the outcome too self-evident, such as determining how the mass of alcohol combusted affects the heat energy evolved or whether time current passes affects the mass change of an electrode during electrolysis. Where students presented a research question that reflected a question that they genuinely appeared interested in answering and couldn't already be expected to know the answer then credit was easily given.

The second part of the descriptor regarding personal input and initiative is evidenced across the whole report and here the outcome was again variable. A good number of students did show plenty of personal input and initiative in the designing and implementation or presentation of the investigation but it was not uncommon for students to simply repeat a commonplace school investigation with a procedure that had not been adapted or extended in any way. Another indication that students were not fully engaged was when there were clear limitations in the initial methodology that could have been quickly and easily addressed during the process but the student made no attempt to do so.

Successful students evidenced input by applying a known technique to an interesting real world situation and then by fully using their time to carry out trials at plenty of values of independent variable as well as including repeats rather than confining themselves to the simple few trials specified in the old internal assessment framework.

Exploration

Of the six-point criteria (Exploration, Analysis and Evaluation) it was Exploration that proved the most successful for students with Higher Level candidates on average securing midway between 3 and 4 points while Standard Level students averaged 3 points.

In many cases a suitable topic was identified and a relevant research question was described to a better extent than in May 2016. Many research questions fell into the category of determining how a measurable independent variable effected an identified dependent variable and these generated reports that were easily assessable with the IA criteria. Weaker research questions were those simple brand analyses of food, cleaning or pharmaceutical products. Any trends identified would be explainable in terms of business principles (manufacturers decide the composition rather than being the outcome of solely scientific principles). There are possible fruitful avenues available by studying commercial products but these really only open up if a student can link some component of the product composition (which they can experimentally determine or read from the packaging) to a chemical or physical property of the product.

The quality of the background information was mixed and possibly weaker than in May 2016. Frequently it was of general character rather than addressing the specifics of the chosen research question or methodology. The top level descriptor requires the background information to be entirely appropriate and relevant so teachers should advise students to keep it focused. A common failing was that students failed to include balanced chemical equations for the key reactions associated with their investigation.

In terms of taking into consideration the significant factors that may influence the relevance, reliability and sufficiency of the collected data the responses of the candidates were similar to last year in that it was extremely varied. A good number of students clearly controlled relevant variables, selected a suitable number of values of independent variable and repeats in order to establish reliability and sufficiency. However an equal number of students didn't carry out repeats and most significantly failed to correctly identify or control key variables with the result that their data did not properly answer their research question. For example many investigations focusing on food tended to ignore relevant variables such as variety of food, moisture content and storage conditions. Another weakness was that quite a few candidates omitted reporting capacities for volume measuring instruments or used inappropriately imprecise glassware such as beakers and measuring cylinders instead of volumetric flasks and graduated pipettes. The correct choice affects uncertainty and should be carefully considered during design. Also while many students considered rightly the calibration of instruments such as pH-meters, others ignored this relevant step thereby decreasing the reliability of collected data.

Even more so than last year students showed at least some awareness of **safety**, ethical or environmental issues relevant to their methodology. In many cases this was confined to a quite basic measures such as gloves and safety glasses but an increased number of candidates did consider safe and environmentally appropriate disposal of reagents.

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Analysis

The overall achievement for Analysis was close to that for Exploration although the marks were distributed widely across the range.

Most students recorded sufficient data related to the independent and dependent variables so that they could subsequently carry out sufficiently meaningful process and interpretation. Qualitative observations were often recorded although it was not uncommon to find photographs replacing, rather than supporting, written qualitative data. The interpretation of these photographs was frequently not easy and this practice should not be encouraged. Fewer students though recorded the wider data that can provide valuable context for the evaluation of the procedure such as measurements of controlled variables, for example the temperature of the reaction mixture, as opposed to room temperature, in studies of reaction rates or the current in electrolysis investigations where all too often students simply assume current is directly proportional to the voltage setting on a power pack without actually measuring for themselves. In common with other sessions a significant number of candidates reported solely processed data such as added volume of a titrant or averages instead of raw data and thereby limited their achievement.

We saw that a common approach to processing was simply to average the dependent variable data and then plot a graph against the independent variable to see the nature of the relationship. Very often this was done well enough to award good credit.

Other common data processing approaches were quantitative determinations based on titrations (plenty of redox titrations featured which stretched the students) and calorimetry calculations. Last year it was noted that teachers needed to check calculations through carefully since moderators were uncovering serious processing errors that led to significant downward mark adjustments. This session the situation seemed much improved. Although students are still prone to processing errors these were more often identified by teachers.

Some common areas of weakness surfaced. Calculations in acid-base chemistry were often erroneous with the relationship between pH and pK_a poorly understood and some students assumed pH values were additive. In rate of reaction investigations a significant number of students didn't actually calculate a rate at all and contented themselves with comparative comments on reaction time and there were many reports where students presented inappropriate bar charts rather than properly constructed graphs. On other occasions graphs were presented but students opted for establishing average rate instead of using tangent at initial times which rather diminished the purpose of constructing the graph.

There was a variety of evidence presented towards the consideration of the impact of measurement uncertainty on the analysis. These included
- Sensible protocols on propagation of errors through numerical calculations such as outlined in Topic 11.1 of the Chemistry Guide or the TSM or standard deviations on a sufficiently large data set or square rooting sum of the squares, etc.
- Well-constructed best fit graph lines
- Error bars on graphs (this was much more common this year than in the past).
- Maximum or minimum slopes.
- Appropriate consideration of outlier data.

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- Consideration of equation of a graph line and the R^2 value
- Consistent significant figures and decimal places.
- Comparison of data from different data sources (secondary data examples) to evaluate reproducibility.
- Evidence of investigation of research into the uncertainties associated with database data.

No investigation needed to include all these features to achieve full credit and most students were able to reach at least the middle band descriptor in this regard.

Some weaknesses that arose were: a significant number of students who made no attempt to propagate uncertainties through calculations, a number of candidates presented lines of best fit on graphs involving discrete independent variables which is of course not valid, frequently error bars were inconsistent with the record uncertainties while there are still quite a number of students who present numerical results to an excessive number of significant figures. More pleasingly compared to last year there appeared to be a reduction in the number of inappropriate statistical treatments such as T-tests on a minimum of data and the use of Excel seemed improved with less polynomial graph lines appearing like water slides and roller coasters!

Most students were able to interpret their processed data so that subsequently a conclusion to the research question could be deduced although in a significant number of cases the interpretations were often merely prose descriptions of the data and in other cases there was no interpretation at all. When interpreting a graph a common mistake was to describe linear negative slopes as inversely proportional and any deviation from linearity in a positive slope was termed exponential. Less students this year simply presented a complicated Excel graph line equation without any appreciation of what it may be indicating as an underlying trend.

It is worth noting that some students achieved poorly across Analysis since their designed methodology was too limited and only a small amount of data was collected and the consequent processing and consideration of uncertainties was unchallenging. The IA framework places the responsibility on the student and part of the independent learning task is for students to be aware of the criteria up front and for us to challenge them at an early stage of the process as to whether they think their proposed investigation gives them chance to fully satisfy the criteria and counsel them accordingly.

Evaluation

Evaluation this continues to be the most challenging criterion and the students' attainment was significantly behind those for Exploration and Analysis by about half a point on average. This is probably not surprising since it is a demanding reflective criterion requiring higher order thinking skills while the writing of the relevant report section comes at the end of the process when possibly fatigue has set in and often the submission deadline is looming large.

The first part of the criterion was fulfilled fairly well with most students able to draw a conclusion that was consistent with the data to an extent that met the 3-4 band descriptor or above.

The second part of the criterion was not well fulfilled by a large number of candidates as students failed to correctly describe or justify their conclusion through relevant comparison to the accepted scientific context. For this part of the descriptor students could possibly be making the comparison of their experimentally determine quantities to readily available literature values and/or referring to whether any trends and relationships identified were in line with accepted theory possibly by referring back to their original background information. It was disappointing how few students achieved this successfully.

The descriptors regarding limitations and improvements also were not well fulfilled by many students. Strengths were rarely addressed and limitations were usually procedural and few. Very few investigations addressed systematic and random errors in details while many referred to them but failed to identify them in their specific investigation. Suggestions for improvements usually included more repetitions even at times when the number of trials had been acceptable. Specific improvements that were also related to previously identified limitations were less common. Moderators did see a bit more meaningful emphasis on extensions being given this year which addressed a weakness from the last May session.

Communication

As in the May 2016 session the Communication criterion was in most cases quite well fulfilled and averaged midway between 2 and 3 marks. Understandably this criterion, along with Personal Engagement, saw a minimal differential between Higher and Standard Level candidates.

Most reports were clearly presented with an appropriate structure and many students gained credit for coherently presenting the information on focus and outcomes. Common weaknesses were for insufficient detail to be included in the description of the methodology and for students to not present at least one worked example calculation so the reader could understand how the data was processed.

Many reports were mostly concise and nearly all of them did meet the 12 page limit which did prove sufficient for even the most sophisticated investigations. Less students than last year included lengthy appendices in order to circumvent the page limit ruling which was good since examiners do not have to read the appendices so vital marks could have been lost. Most of the reports were relevant although the one common area of weakness was the inclusion of general background information that wasn't focused on the Research Question.

With regard to the use of terminology and conventions many students proved inconsistent in their use of labelling graph axes, units, decimal places and significant figures although in most cases understanding was not greatly hampered. The using of citations and references was overall very good.

Recommendations for the teaching of future candidates

- Students should develop investigations that seek to answer research questions whose answer is not self-evident to them known beforehand.
- Encourage students to include any relevant balanced chemical equations in their introductory material so it is clear as to the reactions and processes involved in their

investigation.
- Encourage students to reflect on data while collecting it so they have the chance to modify methodology if the data are proving insufficient, unreliable or erroneous.
- It is good practice for students to give a safety and environmental evaluation for any investigation involving hands on practical work even if it is to show that safety and eco-friendly disposal have been evaluated but no special precaution is then required.
- Encourage students to describe briefly in a paragraph the process of developing their methodology. This narrative will help explain the amount of data collected and give insight into the decision making of the student that in part evidences Personal Engagement.
- Ensure students record all relevant associated data and not just the independent and dependent variable data.
- When evaluating methodology encourage a consideration of underlying factors affecting the validity of the method such as range, sample size, use of an alternative reaction system to study the same phenomenon, etc.
- Encourage students to interpret results quantitatively wherever possible. This will also provide a sound foundation for high quality conclusions.
- Students should consider suggestions for improvements that are related to previously identified limitations and that should be realistic and specific to their investigation.
- Methodologies should be written in sufficient detail so that the reader could in principle repeat the investigation and also so that an idea of the associated uncertainties can be gained.
- Where relevant to the analysis students should present at least one worked example calculation so the reader could understand how the data was processed.
- Discourage the inclusion of appendices.

Further comments

When assessing the students work teachers should:
- Carefully check methodology for any missing key variables that would invalidate the conclusions being drawn.
- Carefully check calculations for errors that would affect the conclusions being drawn.
- Apply the model of best fit marking of the criteria evenly and not prioritizing some descriptors over others when awarding marks.

Standard Level Paper 1 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-7	8-11	12-15	16-18	19-20	21-23	24-30

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General comments

The number of candidates who answered the paper was 6983, a 6.38% increase on May 2016. The paper consisted of 30 multiple choice questions on the Subject Specific Core. The exam was done without calculator or data booklet. A small minority of candidates did not answer every question; there is no penalty for a wrong answer. I have suggested a strategy for tackling multiple choice papers at the end of the report.

133 teachers gave feedback from a total of 995 schools. Apart from those for whom the comparison was not applicable (2%) the approximate percent comparison with last year's paper is as follows:

Much easier	A little easier	Of similar standard	A little more difficult	Much more difficult
1	7	65	21	5

As to the percent level of difficulty, the following answers were given:

	Too easy	Appropriate	Too difficult
Level of difficulty / %	1	92	7

Suitability of question paper in terms of clarity and presentation (approximate %):

	V poor	Poor	Fair	Good	V good	excellent
Clarity of wording	0	1	14	31	36	19
Presentation of the paper	0	0	9	23	40	28

In general, the paper seems to have been well received with comments such as "appropriate and according to syllabus", "more straightforward than last year", and "very nice test!".

There was a comment suggesting there were few questions on organic chemistry. The paper is, however, set with regard to the time allocation for each topic and there were exactly the required number of marks on Topic 10.

Another comment said that "measurements" was not well covered. Much of this assessment is taken care of by Internal Assessment.

There were comments that some questions were difficult for SL students. Both SL and HL are examined on the Core to the same standard; hence many questions are common to both papers. HL is more material – which may or may not be harder. The SL paper needs questions that will discriminate between grade 6 and grade 7 candidates.

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The order of questions in paper one follows topic order so candidates who are troubled by the more mathematical questions that can occur early in the paper should be advised to leave them until later.

One respondent commented that "too many questions test ability to read carefully". All questions should be read carefully, as any well-prepared candidate will know.

The mean mark on the paper was 18.52 (M16: 17.45) with standard deviation 5.57 (M16: 5.0).

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

The difficulty index (percent of candidates giving the correct answer) ranged from 11.57% (M16: 13.77%) to 88.87% (M16: 90.56%). The discrimination index (indication of the extent to which questions discriminated between high and low-scoring candidates) ranged from 0.00 (M16: 0.17) to 0.61 (M16: 0.60).

The following comments are made on individual questions:

Question 1

This was the first of three more mathematical calculations which can be left to later in the time allotted by those who are not comfortable with this type of question. It was answered successfully by 81% of the candidates.

Question 3

We admit that we could have made the question easier by stating the reagent in excess. There do, however, need to be some more testing questions (for the grade 7 candidates) in the paper. 45% answered it correctly.

Question 6

One respondent commented that this question and Q 15 require knowledge of the relationship between wavelength and energy. That is true but the questions are testing quite different topics.

Question 8

The term "lanthanoides should be known" – see guidance. We admit the error in using the term "lanthanide". 60% of the candidates scored this mark.

Question 9

In the diagram, we could have given the full structural formula showing all the atoms and all the bonds or we could have presented urea as $(NH_2)_2CO$. In the event, we gave the candidates some help by pointing out the C=O bond and leaving them to think about the rest of the molecule. 61% answered this correctly (whilst 33% gave A).

Question 11

It is accepted that the term "giant molecule" may not be familiar to students and we should have used "giant covalent, network covalent or macromolecular". It did not make any difference to candidates as silicon dioxide is certainly not a small molecule although disappointingly 20% thought it to be so. The most common wrong answer, indeed the most common answer, was D. Many candidates do not understand that CO_2 and SiO_2 are different, only 37% giving the correct answer.

Question 13

One respondent had an issue with the term "reaction coordinate" which is a standard term used.

Question 15

It was suggested that this is testing for SL students. If so, it is any example of a grade 7 discriminator. Many thought C to be correct.

Questions 16 and 17

Questions with a common stem have been set in the past and there was a clear warning given: *Questions 16 and 17 refer to the following reaction.* It is not clear why one respondent thought these kinds of questions should be avoided. The suggestion for Q17 that "you could use colour change by adding an indicator to the mixture" is not acceptable.

Question 18

This was the easiest question on the paper with an 89% success rate.

Question 19

There was a suggestion that giving the activity series was too much information. At the paper authoring meeting, there was considerable discussion about whether or not it should be included. It depends on whether or not candidates are/should be familiar with the non-reaction of copper with dilute hydrochloric acid from their practical experience.

Question 26

This turned out to be the hardest question on the paper. The question refers to "conditions" so assumes that an oxidizing agent and ethanol will be present in the reaction mixture. Hence, answer D is the best answer.

Question 30

This was a question about graphical analysis, something that is tackled very poorly in internal assessment and is covered in 11.2. It required candidates to recognize that n is proportional to $1/T$. 44% answered this correctly. In retrospect, we should have asked the relationship between P and V.

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Recommendations and guidance for the teaching of future candidates

A possible approach to multiple choice exams:

- If you do not like topic one questions, start the paper at, say, question 4.
- If you find the more mathematical questions challenging, leave them for the moment and return to them after you have completed the questions with which you feel more comfortable.
- If you find it inconvenient to have the Periodic Table at the front of the paper, tear off the front page of the examination so that you can refer to it more easily.
- Allow yourself about one minute for each question. Remember to choose the best answer for each the question. Some of the "distractor statements" are correct – but do not answer the question.
- If the question is taking longer than a minute, make a note of any answers that you have discarded and move on to the next question.
- After completing and recording all the questions you can do, return to those with which you have had difficulty (including the first few questions if you did not begin at question 1).
- Keep an eye on the time and, in the last minute of the examination, choose and record an answer for *every* question not yet answered. There is no penalty for wrong answers, so do not leave any question unanswered.

Higher level Paper 1 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-10	11-16	17-22	23-26	27-29	30-33	34-40

General comments

The number of candidates who answered the paper was 10406, a nearly 10% increase on the previous year. The paper consisted of 40 multiple choice questions on the Subject Specific Core and the Additional Higher Level material. The exam was done without calculator or data booklet. A small minority of candidates did not answer every question; there is no penalty for a wrong answer. I have suggested a strategy for tackling multiple choice papers at the end of the report.

222 teachers gave feedback from a total of 1010 schools. Apart from those for whom the comparison was not applicable (3%) the approximate percent comparison with last year's paper is as follows:

Much easier	A little easier	Of similar standard	A little more difficult	Much more difficult
0	5	59	28	5

As to the percent level of difficulty, the following answers were given:

	Too easy	Appropriate	Too difficult
Level of difficulty / %	0	91	9

Suitability of question paper in terms of clarity and presentation (approximate %):

	V poor	Poor	Fair	Good	V good	excellent
Clarity of wording	0	1	18	35	31	15
Presentation of the paper	0	0	6	30	37	27

In general, the paper seems to have been well received with comments such as "fair", "challenging but not tricky", "an appropriate paper in terms of syllabus coverage and level of difficulty" being used. Several comments about lack of time were made.

One respondent suggested that there were too many questions designed to trick the candidates. No questions were written with that end in mind.

There was a comment about syllabus coverage. In this paper, the number of questions on each topic exactly mirrored the teaching hours.

The order of questions in paper one follows topic order so candidates who are troubled by the more mathematical questions that can occur early in the paper should be advised to leave them until later.

The mean mark on the paper was 27.79 (M16: 26.23) with standard deviation 6.56 (M16: 6.40).

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

The difficulty index (percent of candidates giving the correct answer) ranged from 33.24% (M16: 19.64%) to 91.99% (M16: 92.24%). The discrimination index (indication of the extent to which questions discriminated between high and low-scoring candidates) ranged from 0.16 (M16: 0.11) to 0.55 (M16: 0.55).

The following comments are made on individual questions:

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Question 1

If candidates might be discouraged by stoichiometric problems at the beginning of the paper (they are in topic 1 so they come at the beginning), then they should start elsewhere in the paper. In the event, 86% answered this correctly.

Question 2

We admit that we could have made the question easier by stating the reagent in excess. There do, however, need to be some more testing questions (for the grade 7 candidates) in the paper. 62% answered it correctly.

Question 5

This was found to be confusing to read with too many layers of complexity. 57% scored the mark.

Question 6

This was the "easiest" question on the paper with a 92% success rate.

Question 7

The term "lanthanoides should be known" – see guidance. We admit the error in using the term "lanthanide". 60% of the candidates scored this mark.

Question 8

It is difficult to see how ligand chemistry can be taught without the concept of ligand substitution even though it may not be mentioned specifically in the syllabus. 66% of the candidates scored the mark.

Question 9

In the diagram, we could have given the full structural formula showing all the atoms and all the bonds or we could have presented urea as $(NH_2)_2CO$. In the event, we gave the candidates some help by pointing out the C=O bond and leaving them to think about the rest of the molecule. 79% answered this correctly (whilst 19% gave A).

Question 10

4.3 states "deduction of resonance structures, examples include *but are not limited to* C_6H_6, CO_3^{2-} and O_3". Thus PO_4^{3-} is "fair game". It is possible to draw the phosphate ion with and without a double bond – so more than one Lewis structure means that it displays resonance. 59% correctly gave answer C.

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Question 11

We accept that the question might have been better worded: Which metal has the strongest metallic bond*ing*? 69% gave the correct answer.

Question 12

This question was answered well (81%). A and C could be eliminated immediately and then it was a question of deciding which of C–F and C–Cl bonds is the stronger.

Question 15

There is no mathematical proof required here and 69% scored the mark.

Question 16

There was some concern that the electron affinity had not been split into 1st and 2nd EAs. There was no intent to confuse, only to make the diagram and question simpler giving one less number to manipulate. 83% of the candidates answered this successfully.

Question 17

15.1 in the syllabus covers hydration energies. Only 37% gave the correct answer.

Questions 18 and 19

Questions with a common stem have been set in the past and there was a clear warning given: *Questions 18 and 19 refer to the following reaction.* It is not clear why one respondent thought these kinds of questions should be avoided. The suggestion for Q19 that "you could use colour change by adding an indicator to the mixture" is not acceptable.

Question 20

It may be a fair point that this question is too difficult without the Arrhenius equation. That having been said, 81% scored the mark.

Question 21

Candidates found this question more difficult (48%) and there were some comments about the wording. The question requires an understanding of reaction mechanisms. C is the correct answer.

Question 24

There was a suggestion that giving the activity series was too much information. At the paper authoring meeting, there was considerable discussion about whether or not it should be included. It depends on whether or not candidates are/should be familiar with the non-reaction of copper with dilute hydrochloric acid from their practical experience.

Question 26

Dative covalent and coordinate bonds are covalent; hence "covalent" was used for A. 72% scored the correct answer.

Question 27

We accept that we could have used the term "acid strength" in place of "acidity". There is no need to convert pK_a to K_a or vice versa. By inspection of K_a values, chloroethanoic acid is stronger than ethanoic acid. This gives answers B or D. By inspection of pK_a values, hydrogen fluoride is stronger than hydrogen cyanide, giving answers C or D. The only "common" answer is D which was achieved by 69% of the candidates.

Question 30

It was important to read this question carefully. It only required a change of "zero point" and 72% of candidates answered this successfully.

Question 31

There was much comment (and discussion) about the representation of the salt bridge. There is no salt bridge as the "curly wire" is a conductor connecting two electrolytic cells in series (and thus the current is the same in both cells). There was no need to have electrode potentials as the reaction can be considered the electrolysis of water. One commented that a power source would have been clearer but the labels "+" and "–" indicate that there is a power source. We apologize for the different shapes of the electrode casings!

Question 32

There seems to be some confusion about the nomenclature of functional groups. Perhaps *carboxyl* was confused with *carbonyl* and *amino* with *amide*. Only the hydroxyl group is present. 77% success rate.

Question 34

There is only one compound that has a secondary carbon atom, A.

Question 36

This turned out to be the hardest question with only 33% of the candidates scoring. Many (over 49%) failed to spot that alkenes can be reduced. (Reaction of alkene with hydrogen is covered in 10.2.)

Question 37

This question was thought by some to be extremely difficult. It is testing 20.1 and 20.2. Nevertheless, 54% scored.

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Question 38

We apologize for the "blob" at the bottom of the singlet which seems to have caused difficulties for some. It does not seem to have caused difficulties for the students, 86% of whom scored.

Question 39

This was a question about graphical analysis, something that is tackled very poorly in internal assessment and is covered in 11.2. It required candidates to recognize that n is proportional to $1/T$. 44% answered this correctly. In retrospect, we should have asked the relationship between P and V.

Recommendations and guidance for the teaching of future candidates

A possible approach to multiple choice exams:
- If you do not like topic one questions, start the paper at, say, question 4.
- If you find the more mathematical questions challenging, leave them for the moment and return to them after you have completed the questions with which you feel more comfortable.
- If you find it inconvenient to have the Periodic Table at the front of the paper, tear off the front page of the examination so that you can refer to it more easily.
- Allow yourself about one minute for each question. Remember to choose the best answer for each the question. Some of the "distractor statements" are correct – but do not answer the question.
- If the question is taking longer than a minute, make a note of any answers that you have discarded and move on to the next question.
- After completing and recording all the questions you can do, return to those with which you have had difficulty (including the first few questions if you did not begin at question 1).
- Keep an eye on the time and, in the last minute of the examination, choose and record an answer for *every* question not yet answered. There is no penalty for wrong answers, so do not leave any question unanswered.

Standard Level Paper 2 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-12	13-18	19-24	25-29	30-35	36-50

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General comments

This generally seemed a straightforward paper, structured in a fairly accessible manner with relatively few multi-mark questions with many of these being subdivided into a number of simple answers. It produced scripts over the whole mark range, though an encouraging proportion of students scored well on it. At the other end there were a distressing number students who had obviously been very poorly prepared for the paper and who found even the most basic concepts challenging, often leaving many questions unanswered and only achieving single digit scores.

In response to some comments, teachers should be aware that the setting of examination questions is only carried out in reference to the current subject guide and does not take into account how material is presented in the various IB Chemistry textbooks.

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

- Identifying problems in a practical procedure and suggesting solutions
- Relating chemical models to the critical observations underpinning them
- Combining redox half-equations
- Handling uncertainties
- Inferring chemical equations and deducing factors disturbing an equilibrium
- Clearly differentiating between intermolecular and intramolecular interactions
- Resonance structures
- Applying generalized concepts to particular situations.
- Equations for acid deposition from nitrogen oxides
- Deducing the monomer from the structure of an addition polymer
- Carrying out titration calculations
- Recognizing that fragments in a mass spectrometer have a positive charge

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

- Calculating an empirical formula from mass data
- Calculating percentages of isotopes in an element
- The product of sodium oxide reacting with water
- The effect of metal and non-metal oxides on the pH of water and hence their effect on indicators listed in the data booklet
- Calculating concentrations from the mass of solute and volume of solution formed
- Drawing Lewis structures, though often lone pairs on peripheral atoms were omitted
- Predicting the shape of simple molecules from the Lewis structure
- Calculating oxidation states of molecules and hence deducing the oxidizing agent
- Predicting the effect of a change in conditions on reaction rate
- Free radical halogenation reactions, especially photochemical initiation
- Applying concepts from Brønsted-Lowry theory
- Calculating amount from volume and concentration, and molar mass from amount and mass
- Carrying out calorimetric calculations

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

Question 1

- (a) (i) Most candidates deduced the correct empirical formula with little difficulty, the only common mistake being to use the relative molecular mass of O_2 rather than the relative atomic mass, but even then candidates usually obtained an ECF mark for their final answer.

- (a) (ii) Quite a challenging question, with only a minority of students suggesting that the decomposition (often incorrectly referred to as combustion) was incomplete. Just a handful of candidates appeared conversant with the technique of heating to constant mass. Quite a number gave explanations that would result in the mass being lower than expected, exemplifying a mistake running throughout the paper; a failure to read the question carefully. Quite a number of students stated the problem was heat loss, but struggled to justify this.

- (b) Most candidates gained this mark, with most opting to calculate the percentage of ^{107}Ag present rather than choosing a simpler proof.

- (c) (i) Most students realised the effect of the oxide on the pH of the solution and correctly used this, along with section 20 of the data booklet, to correctly predict the colours of the indicator. The formula of the product from Na_2O was well known and that from P_4O_{10}, though more challenging, was known by an encouraging number of students.

- (c) (ii) This again was a challenging question with only a minority of students recognizing that molten ionic solids conduct as a result of their ions becoming mobile. Many students, in spite of answering the previous part correctly, appeared to be unaware that P_4O_{10} is molecular and hence behaves differently to Na_2O.

- (d) Whilst many students could describe the emission spectrum, and mistakenly did this, it was more of a challenge interpreting it in terms of the quantization of electron energy levels, with the energy difference diminishing as the energy increased, though many students gained partial marks. Many also mentioned sub-shell structure which the simple H-atom spectrum does not support.

Question 2

- (a) (i) Many students correctly used section 24 of the data booklet to access the required half-equation, though a number quoted the oxidation of the metal to the divalent state.

- (a) (ii) Combining redox half-equations, adjusting stoichiometry to cancel out the electrons still proves to be a skill beyond many students.

- (b) (i) Even simple uncertainty calculations appear to present most students with a major challenge.

- (b) (ii) Not a simple calculation, but many students could correctly calculate the molar mass and use it to calculate the concentration of solution from the given mass of solid and volume of solution.

- (b) (iii) Having correctly calculated the concentration of solution above, using this, with the titration data given, to calculate the concentration of the second reagent was beyond most students, though a number who did not take account of the molar ratio, gained partial credit.

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Question 3

- (a) (i) Quite a few students seemed unable to formulate the equation for the decomposition of PCl_5 and use it to write a correct equilibrium expression. Many students thought the value of the equilibrium constant was required and attempted to use data from the graph to calculate this.
- (a) (ii) A challenging question in which students were expected to observe the changes that had occurred in equilibrium concentrations and then deduce that a reduction in temperature was the only way these could have occurred for an endothermic reaction. As expected only a handful of students were capable of this (a good discriminator for Grade 7 candidates).
- (b) Almost all students managed to draw the bonding electrons around the central atom of PCl_3, but a disappointing number then lost the mark by failing to mark the lone pairs around each chlorine. The shape of the molecule was well known.

Question 4

- (a) (i) This provided an unexpected challenge for many students. Firstly many discussed dinitrogen tetraoxide rather than molecular nitrogen and secondly many invoked intermolecular forces rather than the bonding within the molecules. Another common mistake was that hydrazine contains a double bond between the nitrogen atoms, though most students knew that molecular nitrogen contained a triple bond.
- (a) (ii) Again there was some confusion between intramolecular and intermolecular forces but most, encouragingly, recognized that hydrazine could form hydrogen bonds. A disappointing number of students however seemed to regard these as intramolecular bonds, rather than intermolecular forces, and thus lost the mark.
- (a) (iii) The majority of students correctly calculated the oxidation state of the nitrogen in the two compounds, though a number lost the mark by failing to follow conventions in expressing it, but it was encouraging to note these errors were less common than in the past.
- (a) (iv) An encouragingly number of students recognized hydrazine as the reducing agent and could support this with appropriate evidence.
- (b) The Lewis structure of ozone was not well known and few candidates noticed that both structures were required, indicating perhaps they were not familiar with the concept of resonance.

Question 5

- (a) (i) Most students wrote generalized statements about reactants getting used up and their concentrations falling. That of the sulfuric acid would indeed decrease, but the concentration of magnesium remains unchanged (as a solid), though its surface area decreases.
- (a) (ii) Almost all students managed to draw a curve with a greater initial gradient that produced the same volume of gas as the one given, though in some cases the carelessness of the drawing, such as passing through a maximum resulted in forfeiting the mark.
- (b) In spite of the diagram as a prompt, less than half the students realized that the activation energy of the reverse reaction is sum of the enthalpy change and that for the forward reaction.
- (c) A challenging piece of factual recall and there were many unbalanced equations

and unusual products, with only a handful of students remembering the equation resulting in the mixture of HNO_2 and HNO_3.

Question 6

- (a) Most students managed to write the correct initiation reaction, but the propagation stages were less commonly known.
- (b) Correct answers to this, in spite of two being accepted, were rare, though most students were aware that hexene would react readily with bromine. Many students seemed unaware of the nature of the delocalised bonding in benzene and mistakenly said that it would react because of the presence of double bonds
- (c) Deducing the structure of the monomer from the given polymer structure proved to be an unexpectedly difficult challenge. Some students gave the molecular rather than a structural formula, but the majority did not seem to have any idea how to approach the question.

Question 7

- (a) (i) The vast majority of students correctly recognised water as an amphiprotic species.
- (a) (ii) Most students could identify one of the conjugate acid-base pairs.
- (b) (i) Another very well answered question with most students correctly calculating the amount of alkali from its volume and concentration.
- (b) (ii) Again most students could combine the previous answer with the given mass to calculate the required molar mass.
- (b) (iii) This required students to deduce the pH of the alkali from its concentration and then use the result to determine the hydrogen ion concentration. Only a small minority could do this.

Question 8

- (a) (i) This Hess' law question required students to correctly combine the enthalpies of three related processes to calculate the required enthalpy change. An encouraging number, probably about half, succeeded and many of those who did not only made one error and hence benefitted from ECF.
- (a) (ii) Many students successfully used the energy evolved in the previous equation to calculate the final temperature of a sample of a sample of water absorbing it. This required adjusting the units of either the volume, or the energy, with consequent problems. Nevertheless students performed well on the question with most gaining at least partial credit.
- (b) (i) Whilst many correctly recognised the formula of the species giving rise to the line in the mass spectrum, the majority lost the mark by failing to put the positive charge.
- (b) (ii) Students who just read the m/z value from the mass spectrum (108) were at an advantage over those who used the data booklet to calculate a more precise molar mass (108.1) as the latter is incorrect because lines in mass spectra are isotope specific.

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Recommendations and guidance for the teaching of future candidates

- Training candidates to read the question carefully with regard to what exactly it is asking, the command term used (and the implications of this, taking into account the number of marks available) as well as any specification of the units or precision of the answer. When comparing things, reference should be made to both. If a question is about to a particular substance or reaction, then the answer should specifically refer to it.
- Practicing writing answers to questions frequently asked so as to avoid making mistakes, particularly with regard to the precise use of language, that have previously been problems.
- Note that the Nature of Science sections of the syllabus are examinable.
- Encourage students to write out the method of their calculation as this may enable the examiner to award partial credit for incorrect answers. Rounding should only be carried out at the end otherwise it can lead to significant errors.
- Carry out more exercises in which candidates are required to deal with experimental uncertainties or reflect on weaknesses in practical techniques.
- Ensure candidates know what kind of bonding is likely to be present in a given compound and, for molecular substances, that they clearly discriminate between intramolecular and intermolecular interactions, and when these are broken.

Higher level Paper 2 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-13	14-26	27-37	38-48	49-58	59-69	70-95

General comments

This was an accessible paper (although more difficult than in M16) with a wide range of marks, the best candidates were able to shine and the mean mark was in the region of 48 out of 95. There were strong scripts where candidates displayed an excellent knowledge of the subject. There was, however, a worrying minority where it seemed that students, even after two years of study, failed to grasp even the most basic chemical concepts. Just over 2% of candidates scored 10 or fewer marks and just under 1% scored 5 or fewer marks.

The number of students who answered the paper was 10,406. For the second time in the May session there was no choice in paper two which allowed a "mixed topic" approach to the questions. The lack of choice did not seem to bother the candidates, most of whom made it through to the end of the paper even though there were five more marks than in under the previous guide. Nearly 96% of the candidates attempted the last questions in 9(b).

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241 teachers gave feedback from a total of 1010 schools. Apart from those for whom the comparison was not applicable (4%), the approximate percent comparison with last year's paper is as follows:

Much easier	A little easier	Of similar standards	A little more difficult	Much more difficult
0	7	49	30	11

As to the level of difficulty, the following responses were given (approximate %):

	Too easy	Appropriate	Too difficult
Level of difficulty	0	83	17

Suitability of question paper in terms of clarity and presentation (approximate %):

	V poor	Poor	Fair	Good	V good	Excellent
Clarity of wording	0	4	16	31	35	13
Presentation of the paper	0	1	10	27	41	22

In general, the paper seems to have been well received and there were comments such as "paper is appropriate and according to syllabus", "the exam was well balanced" and "very nice test with well formulated and imaginative questions". There were some individual concerns about the length of the paper, it being challenging due to more numerical questions and issues with wording in some places such as 1(d) and 4(d)(i). In particular, several teachers commented on question 7 being too challenging, with incorrect statements such as the "NMR was incomplete" and "no possible structure can be represented by the NMR spectrum". 5(b)(iii) was also found too specific as students are not required to know the colour of NO_2. However other answers were acceptable such as IR or UV-Vis spectroscopy.

Others commented that there were too many parts for a couple of the questions or there was too much or two little of some particular area of the syllabus. When the papers are authored, there is a complex setting grid used to ensure that syllabus coverage and objective type are within acceptable parameters. We aim to examine the whole core and AHL syllabus over papers one, two and Section A of paper three and match the number of marks for each topic to the recommended time allocation in the Guide.

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It is important that candidates write within the box for each question; however, there was some tendency to write outside the box area, rather that on an additional page. It was noticeable that some candidates, whilst continuing on an extra page, did not refer the examiner to the additional page. It is really important that candidates write "see extra sheet" in the answer box in such cases.

Teachers should be aware that paper authors set question papers by reference to the current subject guide and do not consider how material is covered in Chemistry text books, whether bearing the IB logo or not.

References were given to the data booklet in many questions but candidates should not assume that because there is no reference, the data booklet is not needed. They would have found it helpful in Q 4 a (i). The data booklet should be a candidate's constant companion during the two-year course.

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

- Experimental work, suggesting design improvement
- Interpreting graphical information for equilibrium reactions
- Q and K_c values comparison in equilibrium problems
- Bonding in the resonance structures of ozone
- Explanation of decrease in reaction rate with time
- Activation energy and its dependence on T
- Equations for the reaction of NO_2 in the atmosphere to produce acid deposition
- NMR ratio of hydrogen environment and splitting patterns from structure
- Reactions of bromine with hydrocarbons under different conditions
- Reagents for nitration of benzene
- Calculating $[H^+]$ in a basic solution
- Techniques to detect the equivalence point of titration
- Writing balanced equations
- Arithmetic errors and incorrect signs in calculations

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

- Stoichiometric calculations to determine empirical formula
- Determining relative abundance of isotopes
- Period 3 oxides, reaction with water, some product formula
- Colour in 3-d block compounds
- Redox chemistry – oxidation states, reducing agents, redox equations
- Identification of organic functional group that can be oxidized
- Calculation of $E^\ominus$ value given half-equations
- Bond lengths and bond strengths
- Intermolecular hydrogen bonding
- Graphical representation of results for rates of reaction
- Deducing rates expression for a reaction
- Enthalpy change calculations using bond energy and thermodynamic data
- Identification of amphiprotic species

- Identification of conjugate acid-base pair in a reaction
- Calculation of amount, in mol, and molar mass from data
- Entropy change and Gibbs free energy change calculations

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

Question 1

- (a) (i) Generally done well. Some incorrectly used the mass of the oxide instead of Ag to calculate its amount in moles; some used $M_r(O_2)$ but then did not account for the factor of 2 in determining the empirical formula.
- (a) (ii) Poorly done; very few candidates scored M2 regarding improvement for the proposed suggestion.
- (b) Very well done; many preferred to calculate the percentages of the isotopes.
- (c) (i) Generally done well; however, the colour was at times listed the wrong way around and few candidates were able to deduce correctly the product H_3PO_4 resulting from the addition of P_4O_{10} to water.
- (c) (ii) Average performance; some thought that both molten Na_2O and P_4O_{10} conduct; others made reference to mobile electrons or to ions in solution.
- (d) About 15% did not answer this question, the performance was mediocre and few scored [2]. Answers were often in terms of 2, 8, 18 or sublevels or orbitals and absorption and emission spectra.

Question 2

- (a) (i) Very well done well, although some incorrectly added the two electrons on the reactant rather than the product side.
- (a) (ii) Overall good performance, but with some listing Sn going to Sn^{2+} or including electrons in the overall redox equation.
- (a) (iii) Very well done but with some arithmetic errors in calculation or in determining the molar mass of $K_2Cr_2O_7$.
- (a) (iv) About 11% did not answer this question. The performance was satisfactory; some did not include the mole ratio from the redox equation, or forgot to convert the volume to dm^3 or made arithmetic errors in calculations.
- (a) (v) Very well done.
- (b) (i) Very good performance but with typical errors of not using the correct sign and coming up with incorrect $E^\ominus$ value. Some arithmetic errors were extremely disappointing (such as 0.95V instead of 0.85V).
- (b) (ii) Only satisfactory performance due to two key errors, namely using n = 1, rather than 2 and not converting the units to kJ.
- (b) (iii) Good performance with many listing the splitting of d-orbitals without reference to colour depending on the energy difference between the split 3-d orbitals. Few made reference to dependence of colour on different ligands and almost no one identified as different number of ligands affecting colour.
- (c) Good performance. Some did not recognize that zinc is a stronger reducing agent than iron and is oxidized instead of iron.

Question 3

- (a) (i) Good performance. Deciphering the diagram was a challenge for some while other candidates considered the reverse equation. Some calculated the value of K_c, rather than giving the expression.
- (a) (ii) Mediocre performance; not many gained [2]. Some missed the "sealed flask" and gave answers based on pressure or concentration changes, but this would not have caused the change shown in the graph.
- (b) Very good performance; incorrect answers involved missing lone pairs on P or Cl atoms or both. Unfortunately some included a dot and a cross to represent one pair of electron – this does no score the mark.

Question 4

- (a) (i) Good performance; hydrazine was a challenge as some thought it has a double bond; others did not read the question carefully and compared N_2H_4 with N_2O_4, rather than with N_2.
- (a) (ii) Well done, although it was difficult, on occasion, to figure out if the bonds were supposed to be *inter or intra*-molecular in nature.
- (a) (iii) Well done, with typical errors in calculation or listing as 2+, instead of +2.
- (a) (iv) Well done with answers often related to change in oxidation numbers.
- (b) (i) Mediocre performance. Some answers were in terms of hybridization; very few scored M1 without reference to pi electrons. Almost no one mentioned that lone pair on p orbital (of O atom) delocalizing with pi electrons (from double bond). Few listed both O-O bonds having equal bond energy.
- (b) (ii) Satisfactory performance; some students listed an extra pair of electrons on central O atom or drew structure with half bonds and many calculated formal charges incorrectly.
- (c) Very good performance. Some listed a different shell rather than a lower or inner shell; others listed "closer to nucleus" and "electron more tightly held" but these are similar ideas and represent only one marking point, not two.
- (d) (i) Satisfactorily done. Many omitted the calculation for Q or considered it the K_c value. Almost half the candidates who calculated the Q value correctly then reached the incorrect conclusion that the forward reaction is favoured.
- (d) (ii) Satisfactorily done; many candidates used the equation, $\Delta G^{\ominus} = -nFE^{\ominus}$ to try and calculate a value for ΔG, rather than realizing that the reaction is at equilibrium and thus $\Delta G = 0$.

Question 5

- (a) (i) Poorly done; few were able to relate to concentration of acid or surface area of Mg. Most had an understanding but lacked accuracy in the answer. Many incorrectly referred to concentration of Mg decreasing. Mg is a solid with constant concentration but its surface area decreases with time.
- (a) (ii) Well done but with some poor sketches either not going through the origin or going above or below the maximum volume.
  (b) (i) Very well done; some left out the rate constant, k, in the rate expression, others wrote the equilibrium constant expression instead.
- (b) (ii) Good performance but some had no clue or listed incorrect the second step as the rate determining step.

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- (b) (iii) Poorly answered but it was not the intention of the author to require knowing the colour of NO_2. IR or UV-Vis spectroscopy were possible answers.
- (b) (iv) Although the performance was good, it was surprising how many incorrectly listed the activation energy of the forward reaction given in the graph or subtracted the value from enthalpy of reaction given.
- (b) (v) Satisfactory performance with a variety of incorrect graphs including straight lines with increasing or decreasing slopes.
- (c) Mediocre performance. Some answered in terms of effect of temperature on energy of molecules ($E \geq E_a$); others manipulated the Arrhenius equation to try and come up with a relationship between T and E_a.
- (d) Poorly done; it was disappointing to see many equations that were not balanced or incorrect products listed such as the CO, NaOH and O_3.

Question 6

- (a) Good performance on an often asked question where many scored the mark for the initiation step but with typical errors in propagation steps. This included forming H• and not recognizing that the Cl• reacts with methane to produce the •CH_3, which then reacts with Cl_2 to produce CH_3Cl and Cl•.
- (b) Very well done but with some mathematical errors and signs changed in other cases.
- (b) Good performance; however, some drew the structure of the repeating unit or listed the formula of the section of the polymer given.

Question 7

- (a) (i) Satisfactory performance. It seems candidates did not pay attention to the molecular formula, as this would have helped them arrive at the ratio of the hydrogen environments. M1 scored often; M2 and M3 not as regularly.
- (a) (ii) Well done but with some incorrect answers including aldehyde and carboxyl, instead of carbonyl.
- (a) (iii) Satisfactory performance; the question was generously marked with [1] awarded for any aldehyde or ketone with the correct molecular formula. Few presented the correct structural formula.
- (b) (i) Poorly done.
- (b) (ii) Satisfactorily done; answers included not only 1-bromobutane structural formula but also structures with incorrect numbers of C and H atoms or with the name of the product.
- (c) (i) Mediocre performance; many had no idea of the reagents involved.
- (c) (ii) Poorly done with general lack of reference to π bonds in benzene. Incorrect answers included reference to double bonds or alternate single and double bonds.
- (d) Satisfactory performance; accuracy of the curly arrows was an issue with curly arrow not originating from the lone pair or negative charge on O of OH^- to C. Some drew curly arrow showing Br leaving incorrectly starting from C rather than C-Br bond; others were unable to draw the transition state.

Question 8

- (a) (i) Very well done; some, however, were not sure of the definition of "amphiprotic" and listed HOCl as the answer.

- (a) (ii) Again very well done, but some mismatched the species.
- (a) (iii) Again very well done, but some mismatched the species.
- (b) (i) Extremely well done.
- (b) (ii) Again, extremely well done.
- (b) (iii) Satisfactory performance; about 15% did not answer the question. Others either listed the concentration of hydrogen ion, or included calculations that made little sense.
- (b) (iv) Again, satisfactory performance. Almost all students used the argument of the starting point but many did not identify the buffer region or that the pH at equivalence point is greater than 7.
- (b) (v) Good performance since "indicator" was accepted as an answer. Appropriate answers included calorimetry/heat exchange, listed under 5.1 (enthalpy change of neutralization reactions/simple reactions in aqueous solution) and reference to conductivity probes under 8.4 in the Guide.
- (b) (vi) Good performance by those who knew what they were doing; others had no idea.
- (c) Good performance where many managed the calculation correctly. Difficulties included not being able to convert pK_a value to K_a. Some used the (Henderson–Hasselbalch) equation given in the data booklet, section 1, B.7 but were unable to carry out the correct substitutions.

Question 9

- (a) (i) Well done; answers included usual errors of not dividing by "2" and not managing the signs correctly.
- (a) (ii) Again well done; Many used "200kJ" and there were quite a number of correct answers. If only one mark was to be picked up, it was M2 with ECF.
- (b) (i) Very well done; main error was in not managing the sign correctly.
- (b) (ii) Good performance with typical error being not using consistent units; there were some examples of negative T values.

Recommendations and guidance for the teaching of future candidates

In addition to the usual advice about reading the questions carefully and paying attention to mark allocations and command terms candidates are advised to bear in mind the following points.

- Only write in the box. Examiners cannot see much of what is written outside the box so there is a chance that it will not be marked. If you need more space, write on a continuation sheet and write "see continuation sheet" in the answer box.
- Write legibly. If an examiner cannot read your (correct) answer it will gain no marks. Draw diagrams carefully. If you make a mess of the first attempt, draw a new one on an extra page. Amended diagrams do not always scan very well.
- Do not write out the question. It wastes space in the answer box (and it wastes time!).
- Make sure you leave enough time for later marks. Remember that the questions (1, 2, 3 etc.) may not be of uniform length.
- Read the question carefully to make sure that you answer it – and not what you would like the question to be.

- Make sure you are familiar with the data booklet well in advance of the examination. You will always be asked to use it and time saved there can be used to write answers.
- Draw Lewis structures very carefully and don't leave extraneous dots/marks on the paper which can be mistaken for electrons. Don't forget to include all non-bonding (lone) pairs.
- Look at the number of marks available and try to make the same number of points in your answer.
- Write out calculations neatly and in a logical manner. If marks for working are to be awarded, the examiner needs to be able to read and understand what you are doing.
- "Keep going" with calculations as errors are carried forward so that a correct method in a later part of the question is rewarded. Show all steps in a calculation and avoid arithmetic errors.
- Take notice of units and significant figures.
- If you are asked to make a comparison or predict a difference, then you need to mention both compounds.
- You should be aware of the "list principle". If you are, for instance, asked for one reason and you give two, one of which is correct and the other incorrect, you will score no marks.
- Practice writing and balancing equations.

Standard Level Paper 3 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-4	5-8	9-11	12-14	15-18	19-21	22-35

General comments

We received feedback on from 147 teachers on the G2 comment forms. 79% of the teachers found the paper of appropriate difficulty. When comparing it to last year's paper, 48% found it to be of a similar standard, while 32% found it to be a little more difficult and 5% found it to be a little easier. 82% of teachers thought the clarity of wording was good to excellent, and 86% thought the presentation of the paper was good to excellent. Teachers agreed that the paper was suitable for all students regardless of religion, belief systems, gender, and ethnicity. There were only a few minor concerns for those candidates with learning disabilities. Please note that IB coordinators should contact the IB for help prior to the examinations when necessary.

Portions of Section A appeared to be a bit challenging for some candidates although some students performed well on this section during this session. Option A was the least selected option with only approximately 5% of the students from this session. The questions appeared more challenging than in other options but with so few students selecting this option it was more difficult to compare the statistics for individual questions. Option B was completed by

approximately 28% of the students during this session. Most students appeared well prepared for this option especially if they were also taking biology. Overall there were issues with details of drawing organic structures and the calculation related to iodine number. Option C was selected by 33% of the candidates with students doing relatively well. Option D was the most popular with 35% of the students completing these questions. Students also responded relatively well to the Option D questions.

There were many positive comments from teachers about the Options. In general, teachers felt each of the options had a reasonable range of questions. There were also several comments about the paper being a reasonable length for the time given. The biggest concern was the inclusion of a buffer calculation question in Option D. Buffer calculations are included in the Option D core (section D.4) and papers may include questions involving related core material.

Most concerns expressed by teachers focused on Section A of the exam. Comments included concerns about the amount of data based vs experiment based questions, the fact that the questions appeared to be focused on geography, and the idea that the topics and units were unfamiliar to students. While these comments will be considered for future examinations please note that data based questions related to environmental topics may continue to be a focus for Section A (Aim 8 of the programme). The programme guide provides many links to environmental issues relating to the core and options concepts. Students should be able to interpret data from a variety of sources and apply their knowledge in both familiar and new circumstances.

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

- Data based and environmental questions in Section A
- Experimental work in Section A
- Explanation of the plasma state and its production in ICP- MS/OES
- Properties needed for liquid crystals
- Iodine number calculations
- Discussion questions related to equilibrium
- Conventions for drawing organic structures
- Solving buffer problems using the Henderson–Hasselbalch equation
- Electrophoresis
- Interpreting molecular dipoles
- Explanation of the increased potency of diamorphine compared to morphine based on their chemical structure and solubility
- Explanation of how compounds such as ranitidine (Zantac) can be used to inhibit stomach acid production

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

- In the Options, candidates performed better when questions were based on factual information than when an interpretation was required.

- Many candidates showed satisfactory skills at analysing the data in Section A and answering questions concisely
- Identification of features of the molecules that allow them to absorb visible light
- Relating IR absorbance ranges and functional groups
- Nuclear reactions

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

Section A

Question 1

- (a) In general this was a well answered question. Examiners recognized the issue with reading the graph and accepted a wide range of answers.
- (b) A vast majority of students scored at least one point by completing the first calculation and/or providing the correct number of significant figure for tonnes of carbon dioxide.
- (c) (i) There were many comments about the graph related to question c. The y-axis should have been ΔAPO, not APO. While many students correctly provided one of the several possible answers it was disappointing to see many losing the mark due to just stating the variable (temperature or pressure) or using unclear/incorrect wording (not stating concentration).
- (c) (ii) Many answered the idea of different seasons or stations at different latitudes correctly but often the text was way too similar to that in the stem or too vague. Very few students considered or correctly answered the idea of oxygen dissolving better in cold water and in some cases students stated more oxygen dissolved in higher temperatures of water.
- (c) (iii) In general a well answered question. Some students missed the mark due to missing the negative sign or rounding errors. No specific number of significant figure were required but students should be instructed to use the correct number of significant figures and round correctly at the end of each mathematical operation, not at the end of each step.
- (c) (iv) Many students achieved the mark but a significant number of candidates gave vague arguments, described the trend or restated the question.

Question 2

- (a) Very poorly answered in terms of full marks. Many students received marks for mass of lighter before and after the experiment and volume of gas or volume of displaced water but often pressure and temperature were left out. Frequently terms were not used properly such as amount being used for volume or mass. Weight was accepted for mass.
- (b) (i) Not well answered. Quite a few answers illustrated students didn't understand the process. While this actual lab is not necessarily done by all students, stating there was a combustion under water or that butane is soluble in this solvent strongly suggests poor lab skills and/or shallow knowledge of core concepts. Students also did not consider how their suggestion would change the value of the molar mass. Many

students gave an answer that would cause a result leading to a larger molar mass (for example – butane gas escaping) not a smaller molar mass as requested (for example – lighter massed while wet). This experiment is based on a required lab so students should be familiar with methods required to determine the molar mass of a gas by experimental methods.

- (b) (ii) Quite a few students scored here as ECF from 2bi. Those who didn't often suggested unclear or unrealistic instruments/apparatuses. The terms 'precise' and 'accurate' were often used incorrectly. Students with strong lab skills provided reasonable and solid suggestions underlining the need of integrating the practical programme with rest of course.

Section B

Option A

Question 3

- (a) Not well answered and often blank.
- (b) Many students scored at least one point by achieving 2 or 3 of the 4 answers but in general not well answered.
- (c) Only stronger students obtained this point usually resulting from 'increased surface area'. Many students only received 1 or 2 of the possible 3 marks.

Question 4

Those that scored usually did through identifying the two plastics that cannot be distinguished as HDPE and LDPE. Stronger candidates also provided sufficient detail to explain why to receive the second mark.

Question 5

- (a) Very disappointing. Adsorption and desorption seem to elude most candidates and many left this blank or attempted answers through redox arguments.
- (b)(i) Stronger candidates scored here while others obviously guessed and did not receive any marks.
- (b)(ii) As no ECF was allowed from 5(b)(i) and there were very few correct answers.
  In one script in Spanish a student wrote the compounds incorrectly throughout, Cl_2Ni instead of $NiCl_2$. This is tricky since in Spanish naming is inverted, however teachers should work on this problem as this convention is well known and documented.
- (c) Again, very disappointing as many candidates left it blank, but others managed to score the mark for calculating the amount in moles. Too many answers illustrated very shallow knowledge of this concept.

Question 6

- (a) Another question that proved too challenging. Candidates tried to describe what they knew about the topic rather than addressing the question. Some scored for the description of the polar molecule.
- (b) Yet another challenging question with students often not attempting it or providing answers related to the topic but not the actual question.

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Option B

Question 7

- (a) Quite well answered with many fully scoring and others at least obtaining one mark for either a correct amide bond or the correct order of the amino acids. Teachers need to stress details when drawing structures for appropriate bond linkages and if students are going to use condensed formulas they need to use the correct formula (CO-NH not CO-HN for an amide link). Many candidates lost marks for these issues. Students were only penalized once for incorrect bond linkages in the paper.
- (b) Well answered and disulphide bridge was often seen. The most common incorrect answer seen here was peptide bond.
- (c) Many correct answers. Weaker students presented the zwitterion, missed the charge, or had other incorrect formula issues. Incorrect bond linkages were also frequently seen in this structure.
- (d) Rather disappointing results. Representations were ignored and this helped many scoring at least one even through inverse order. While it was clear students were familiar with theory behind the experiment, representation showed a shallow understanding of real outputs or poor attention to the prompt. The question specifically asked for lines to be shown on the diagram. While spots were not penalized it is important that candidates read questions carefully. Some students also used incorrect abbreviations for the amino acids (Glu instead of Gln for glutamine).

Question 8

- (a) The first mark identifying stearic acid and a structural reason which will cause it to have a higher boiling point was usually achieved by even weak candidates. Many students missed explaining how the higher boiling point and structure related to stronger London forces and did not receive the second mark.
- (b) Many students scored the first mark solving for the amount in moles but only the stronger candidates were able to obtain the other 2 marks. Many answers clearly showed students had not developed necessary knowledge or skills to solve this type of problem.

Question 9

- (a) Candidates performance on this question was quite disappointing. The sodium linoleate compound (structure or name) was only occasionally answered correctly and choline hydroxide (structure or name) was rarely seen.
- (b) In general a well answered question with hydrolysis being the most popular responses.

Question 10

- (a) Most students obtained at least one mark with many scoring both marks. Quite a few candidates lost the second mark due to using incorrect abbreviations for ether or not identifying the second functional group correctly. Some candidates confused aldehydes with ketones or carboxyl groups.
- (b) Many good answers were seen for this question. Weaker candidates didn't show the 1,4 beta link or provided unreasonable links. Some candidates had 5 bonds to the carbons in the 1,4 beta link, adding the link without removing the atoms that form water

during the condensation reaction for the formation of a disaccharide.
- (c) This question was well answered. Renewable and toxic products were quite popular. Students who did not receive marks often gave vague or incomplete answers.
- (d) A bit disappointing with students providing rather vague, non-scientific arguments, or popular media answers.

Question 11

Many students could identify the presence of the hydroxyl group and the fact that the compound was mostly non-polar. In general a well answered question.

Option C

Question 12
- (a)(i) Very well answered question.
- (a)(ii) Most students obtained at least one mark by identifying the products as having higher binding energy. Release of energy often associated not associated with mass defect resulting in an incomplete argument for the second mark.
- (a)(iii) Candidate's performance on this question was disappointing. Some students clearly didn't understand the question or failed to properly address it. Students who did not receive marks often used spectra or spectrum for spectrometry.
- (b) Better answered than in previous sessions with many students obtaining the mark usually through 'several alternating double and single bonds' or 'conjugated'.

Question 13
- (a) Most students obtained at least two marks with many receiving all four marks. Those that failed to obtain more often provided an argument and its converse which was not permitted or a vague explanation. Teachers should remind students to provide unique and specific answers for each prompt when considering advantage vs disadvantage type responses.
- (b)(i) Many good answers with a significant number of students obtaining at least one mark from the use of correct units or the correct value. Students need to be careful with proper rounding and significant figures even if significant figures are not part of the markscheme.
- (b)(ii) While many students obtained one mark here, the answers were often disappointing and suggested the option had not been covered in depth. Answers were often vague or non-scientific. The mark for 'large volumes of hydrogen required' or 'hydrogen has lower density' was the least common mark to be received.

Question 14
- (a) In general a very well answered question.
- (b)(i) Answers were better than in previous sessions and students were required to use correct state symbols and include an equilibrium arrow in the equation for the mark as indicated in the question.
- (b)(ii) Many students achieved one mark for the correct balanced equation. The mark related to discussion of the equilibrium was frequently poorly addressed or not addressed at all.

- (c)(i) A well answered question with several possible responses.   The balanced equation using C(s) was the most popular choice.
- (c)(ii) This was answered better than in previous sessions and while state symbols weren't considered for the mark, many students entered them correctly. Some students had problems balancing this equation.
- (c)(iii) A rather disappointing result with many vague answers and not many scoring here.

Option D

Question 15

- (a)(i) While many students answered this question well, some skipped this and the follow up question, 15aii.
- (a)(ii) While candidates seem skilled in finding of the amount in moles many approached this question rather poorly or didn't even attempt it. Some students ended up with an incorrect answer due to having an incorrect molar mass for aspirin.
- (a)(iii) Most students obtained at least one mark, usually by identifying melting point as a method. Those that didn't often failed to realize the question asked for a technique. Some students missed a mark here for stating spectra or spectrum instead of spectroscopy. While melting point would be an acceptable technique for some organic solids (including aspirin), boiling point does not work for all organic compounds as some will decompose. Students should understand the difference between these two methods.
- (b)(i) While many still struggle with this topic, this question was better answered than in past sessions.
- (b)(ii) This question proved to be a real challenge for candidates where they were required to compare, giving a reason, the bioavailability of soluble aspirin with aspirin. Only approximately 10% of candidates scored the one mark. This question was discussed widely during standardization and it was agreed that the question was open to interpretation. The question itself did not trigger any G2 comments but there was some discussion on the OCC, so the question deserves some comment here in this report for this reason. The term soluble aspirin is a term that is sometimes used to describe dispersible aspirin tablets but in the context of this question, it may be taken to mean the sodium salt of the carboxyl functional group. However, it would not be unreasonable that some candidates may have assumed that dispersible aspirin was being discussed in the question. Dispersible aspirin would most likely be absorbed more quickly from the GI tract due to the increased rate of disintegration of the dosage form compared to a non-dispersible dosage form such as a conventional tablet. In a tablet dosage form, the rate limiting step of drug absorption can often be the rate of disintegration. Therefore, the dispersible tablet could have a more rapid absorption. In this context, bioavailability refers to the total % of the administered dose that is available to act at the site of action. The bioavailability of either dispersible or non-dispersible aspirin would be expected to be very similar even if the rate of absorption is marginally different due to differences in the rate of disintegration/dissolution. There might be a slight increase in the bioavailability of the dispersible aspirin as it may be absorbed ever so more quickly from the stomach potentially reducing the rate of hydrolysis of the aspirin compared to standard aspirin. However, depending on the dosage form design,

an enteric coating formulation of standard aspirin could potentially have a higher bioavailability than the dispersible aspirin as it would be protected from degradation in the low pH environment of the stomach and be more completely absorbed from the small intestines. If we assume that the soluble aspirin mentioned in the question refers to the sodium salt of the aspirin, similar arguments to the above could be made. The salt might enter solution more readily than the associated carboxylic acid equivalent due to enhanced solubility.   However, this is unlikely to dramatically affect the bioavailability. There could be a small increase in bioavailability of the soluble aspirin due to a more rapid absorption due to the more rapid dissolution which could potentially reduce the amount of aspirin degraded in the stomach acid due to the decreased residence time. Other factors could also affect the bioavailability such as formulation type *etc.* It is for this reason that two answers were accepted for this question – if a candidate stated that the bioavailability of soluble aspirin is marginally higher due to the increase in the rate of dispersion or the increase in the absorption in the mouth/stomach mucosa or if a candidate equally stated that the bioavailability of soluble aspirin is approximately the same as that of aspirin since the ionic salt reacts with hydrochloric acid in the stomach to produce aspirin again; either type statement would have scored the mark. What was not accepted however (and which was a commonly seen response) was candidates stating that the bioavailability of soluble aspirin is higher than that of standard aspirin due to greater solubility in blood. To pass the lipid membrane and get into the blood plasma in the stomach, aspirin must first become a neutral, non-ionized molecule, or otherwise it will not pass the gastric mucosa. So, it does not matter which form is ingested. Once in the blood, the degree of ionization of aspirin will be controlled by the plasma pH, not by the form in which it was ingested. Interestingly according to various data, the bioavailability of standard aspirin is between 70 and 100%, depending on how it is ingested (*e.g.,* fine powder with water will give over 95% bioavailability). Some older textbooks give values ranging from 40 to 80%, probably because of non-optimal formulations of older tablets. Therefore, soluble aspirin can appear to have marginally higher bioavailability than normal aspirin, and that will primarily be as a result of fine dispersion of aspirin in the stomach. However, the question was deemed to be open to possible interpretation and that is why two possible answers were allowed in the marking of this question.

Question 16

- (a) Most of the candidates obtained one mark usually by addressing the solubility in lipids. Those that didn't obtain marks through by identifying the functional groups present or the polarity of the compound usually presented incomplete arguments.
- (b) Many students were able to identify one of the listed correct reagents for this process and it was answered better than in the past.
- (c) Candidates had a rather disappointing response to this question, with many vague answers that often included narratives based on addictive behaviours rather than the therapeutic window or activity of the compounds.

Question 17

- (a) Reasonably well answered although there are still many students who responded to this question as if it was based on direct acid neutralization which is incorrect. Other frequent mistakes involved incomplete answers to the medicinal action of the products.

- (b) Poorly answered and difficult for many examiners to read. Some candidates managed to score the first mark for calculating the molarity of the solution but calculation of pH seemed to challenge a significant number of students. Looking at core topics that are related to the options is an important part of the curriculum.

Question 18

- (a)(i) Many candidates scored one mark for this question but addressing the command terms 'compare' and 'contrast' still elude many students resulting in incomplete arguments. Students need to be aware that the 'difference' requires reference to both compounds.
- (a)(ii) In general a well answered question. The wavenumbers for the IR absorption range for any functional group in either compound were accepted.
- (b) Many obtained one mark through 'animal testing' but weaker students had answers that were often journalistic and addressing questions related to ethics continue to be challenging for many students. Quite a few candidates mentioned testing on humans without reference to consent or 'criminals'.

Question 19

- (a) Not well answered. Many students presented vague journalistic answers related to damage to the environment or water contamination.
- (b) Very poorly answered and once again weaker students gave vague journalistic answers.

Recommendations and guidance for the teaching of future candidates

- NOS is at the heart of the programme. Candidates need to approach the subject from this stance rather than considering NOS as a stand-alone component. Failure to do so will result in students struggling with questions that focus on NOS.
- The experimental laboratory programme should be integrated with the rest of the course and students should be familiar with the application of lab techniques for all topics and the options taught. Be sure to provide students with personal hands-on experience for all of the required labs as indicated by the programme. When traditional hands-on experiments are not possible virtual ones should be implemented to help students understand this integral part of the course.
- Core topics that are related and relevant should be considered when teaching the option. Ideally these should be integrated with the rest of the course.
- Candidates continue to struggle with questions that require explanations, interpretations or multiple steps. Very often they addressed only one part of the question while neglecting the others.
- The interpretation of command terms continues to be an issue. Students should be provided with a list of the command terms and their definitions so they are familiar with expectations for each individual term and how they are applied in a variety of questions and responses.
- Candidates should always look at the associated marks allocations in questions. Together with the command terms the marks provide guidance on the depth expected by examiners for each answer.

- Students are not required to answer questions in complete sentences. They may focus their responses as bullet points.
- Handwriting continues to be a problem with some responses being illegible. The IB Coordinators should be made aware of specific situations with enough time so that special accommodations may be arranged. Students should consider they type of pen used as well since some can smear or bleed through the paper making marking more challenging when scripts are scanned.
- Bond connections should be emphasized throughout the course as well as correct organic nomenclature and different representation systems such as abbreviations, condensed format, and organic line structures. While not all of these methods are required, if students are going to use a particular representation it must be used correctly.
- Please encourage candidates to use A_r values in section 6 of the data booklet, round numbers correctly, and state their answers to calculations to an appropriate number of significant figures including logarithmic values. Discourage rounding after each step or prior to reporting their final value.
- Train students to be specific in their answers using scientific terms, and to read questions carefully to ensure that they answer every part of the question.
- Throughout the course, draw your students' attention to the implications of concepts as they are related to the environment. Suggestions are provided in the right-hand column in the programme guide. This should dissuade students from producing journalistic or vague answers.
- Relating acidity to pH change was a difficult concept for a number of candidates, which was surprising for a core concept. Please provide opportunities for using pH values and pH measurements in the lab.

Higher level Paper 3 Timezone 2

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0-6	7-12	13-17	18-22	23-26	27-31	32-45

General comments

Based on the 241 G2 comments received, the majority of teachers found the examination paper to be of an appropriate standard (84%) in terms of level of difficulty, though 16% were of the opinion that the paper was too difficult. This mirrored N16 statistics. Only 3% considered the paper slightly easier than in M16; 52% considered the paper of a similar standard but 32% found it marginally more difficult (the remainder, found it considerably more difficult). Hence,

close to 40% of teachers who responded to the survey deemed the M17 HLP3TZ2 paper to be more difficult than M16.

Drilling further into the G2s, although the majority of teachers found few issues with the more popular Options B, C and D, there was some criticism in particular of the data-based question, Question 1, in Section A. The experimental question, Question 2, also generated a number of G2 comments.

Based on feedback received from examiners, although many stated that the examination paper was acceptable, the majority did state that overall performance was noticeably weaker than in M16, especially in Section A, where there was some concern voiced of the standard of response given by candidates particularly on Question 2, the laboratory based question. Taking the paper as a whole, many candidates did not appear to be fully prepared for experimental-based questions, had difficulty handling NOS type questions and often struggled on questions that involved integration of core chemical concepts with the more applied topics across the options (*e.g.* interpretation of ^{1}H NMR spectroscopy). In summary, Section A in M17 appears to have resulted in a slightly more challenging paper, though overall performance, certainly at the upper end, appears to have been considerably weaker this session.

As regards the clarity of wording on the paper, the following were the statistics: excellent – 14%, very good - 32%, good - 34%, fair – 14%, poor - 6%; very poor - remainder. The corresponding statistical data for the overall presentation of the paper was as follows: excellent – 17%, very good - 40%, good - 30%, fair – 10%, poor - 3%.

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

- Section A again appeared to highlight the weakness of many candidates in dealing with an unfamiliar data-based type problem, namely Question 1. Many candidates continue to struggle somewhat with the nature of the data-based question posed in Question 1.
- Many candidates also appeared highly challenged with experimental-based questions which was somewhat of a surprise at HL. This was particularly evident in the standard of responses seen in Question 2 in Section A. A comprehensive, experimental programme is an essential tenet of the new IB Diploma Chemistry curriculum.
- Many of the weaker candidates (and even some of the better candidates) also struggled with NOS-based questions, again a key characteristic of the new curriculum.
- Questions that were not similar to questions asked on previous examinations proved to be often the most challenging for candidates. Scientific analysis, critical thinking, higher order deductive reasoning and application to novel situations continues to be a major weakness for candidates taking the new syllabus. This was borne out predominantly in this session in Section A.
- One of the features of the new P3 is the integration of core chemical concepts with applied material. Some candidates struggled with fundamental chemical concepts on this paper – in particular functional groups, polydentate ligands, significance of entropy, intermolecular forces, equilibria, theoretical yield, interpretation of ^{1}H NMR spectroscopy and structural formulas.
- Candidates often had difficulty understanding the various command terms in questions.

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- In Option A – Materials, the following topics were not well understood: methods of assembling nanocomposites, role of EDTA as a polydentate ligand, process of converting carbon monoxide to carbon dioxide in a catalytic converter, calculation of molar solubility, detection limit in ICP-MS/ICP-OES.
- In Option B – Biochemistry, calculating the iodine number, the chemical reaction between a phospholipid and excess sodium hydroxide, differentiating between a functional group and the class to which an organic compound belongs, deducing the structural formula of a disaccharide from two monosaccharides and explaining the shape of a haemoglobin-oxygen saturation curve were the most problematic.
- In Option C – Energy, the following sub-topics were found to be challenging – the idea of mass defect, binding energy calculations, disadvantages of using hydrogen as a primary fuel source in cars and DSSCs.
- In Option D – Medicinal chemistry, calculation of theoretical yield, bioavailability of soluble aspirin compared to standard aspirin, interpretation of ^{1}H NMR spectroscopy, idea of a splitting pattern and functional groups proved to be the most difficult sub-topics.

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

- Candidates performed very well on questions that appeared on recent examination papers *e.g.* calculations involving the Henderson-Hasselbalch equation, explaining why diamorphine passes more readily than morphine through the blood-brain barrier, role of a chiral auxiliary and the problem on half-life.
- Candidates performed satisfactorily on questions which leant themselves to recall of specific factual information *e.g.* change that occurs in the retinal residue during the absorption of visible light.
- Candidates managed to solve, with a reasonable degree of proficiency, the majority of the simple, routine, mathematical based questions throughout the paper which involved using an equation from the data booklet.
- In Option A, the following areas were well answered – distinct phase of a composite, atom economy and IR spectroscopy.
- In Option B, candidates had a good understanding of amino acids, gel electrophoresis and competitive inhibitors. Most candidates also did reasonably well on the buffer question.
- In Option C, the following topics were reasonably well applied to the questions posed – nuclear equations, half-cell equations for the methanol fuel cell and the EMS.
- In Option D, candidates appeared to be well prepared for topics such as calculation of the amount of substance, IR spectroscopy, conversion of aspirin to water-soluble aspirin, explanation why diamorphine passes more readily than morphine through the blood-brain barrier, function of a chiral auxiliary and half-life.

Overall candidates performed better on questions related to factual information and simple numerical calculations but had greater difficulty with questions where an application or interpretation was required or where NOS was involved, as well as most questions based on experimental work or unknown situations associated with the data-based question. In many

cases candidates also failed to score full marks in questions by only giving partial answers, sometimes ignoring the allocation of marks for a given question.

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

Section A

Very few candidates scored high marks in Question 1, the data-based question. In addition, candidates had great difficulty with the experimental-based question, Question 2. A high percentage had no idea of what the experiment really involved nor had knowledge of the equation underpinning the deduction of the molar mass, M, of butane.

Question 1

There were numerous G2 comments on Question 1. The central concerns of teachers were the following: poorly presented graphical representations with axes not clearly labelled and poor shading; incorrect y-axis in (c) (should be ΔAPO, not APO); complex syntax throughout – very difficult for ESL candidates to unpack many of the questions; very difficult first question, deemed much more difficult than the data-based question on the specimen paper and those which appeared in the M16 and N16 papers; question was more focused on geographical concepts than assessing chemical understanding; unfamiliar unit type (per meg) for IB Diploma Chemistry students *etc*. Many of these points are valid and have been noted for future examination paper authoring meetings. The main focus of the data-based question is to assess a learners' ability to apply their knowledge to an unfamiliar scientific situation, analyze and critique data, all within the broad spectrum of an applied chemistry context. In this particular example, the question focused on energy and climate-induced changes in the ocean. Although candidates who would have studied Option C on Energy would be familiar with Energy as a central chemical topic, the question itself, with its environmental emphasis should be accessible to all learners taking the current IB Chemistry syllabus, where Environmental chemistry is integrated throughout the entire syllabus, both in the core and across all four Options. Although Environmental chemistry was a distinct, stand-alone option in the previous syllabus, in the new programme, due to its inherent importance across multiple sub-disciplines of chemistry, Environmental chemistry is deemed a key connecting strand across the entire chemistry curriculum and hence should be highlighted in the delivery of the programme. It should be noted that data-based questions related to environmental topics may continue to be a focus for Section A questions based on Aim 8 of the programme. The programme guide provides many links to environmental issues relating to the core and options concepts.

Part (a) involved candidates having to estimate the percentage of energy consumption which did not produce carbon dioxide in a given year (2013) from the associated graph. Many candidates were able to arrive at a correct answer in the permitted range, 11-16%, although not all recognized that renewables, hydroelectricity and nuclear energy should be included in calculating the percentage. Many teachers commented correctly that the question stem should have indicated what the term renewables covers by way of energy sources, as some renewables such as biofuels also directly produce carbon dioxide. This is a fair point and this was taken into account in the wide range of acceptable percentages during the marking. Few

scored both marks in part (b). The majority scored M1, for 37037 million tonnes of carbon dioxide using the best-fit equation, but only the better candidates then were able to calculate the mass of oxygen gas, namely 2.7×10^4 million tonnes. This became a discriminating mark at the upper end for potential Grade 7 candidates. Others did not adhere to the instruction in the question, namely that the answer had to be written correct to two significant figures. (c) (i) was reasonably well answered, though often partial answers were written, such as just temperature, pressure and an increase in oxygen. None of these responses scored. In (c) (ii), almost no candidate scored both marks. M1 was usually scored but few mentioned the fact that oxygen dissolves better in cold water.   Some teachers also commented that this understanding of solubility was on the edge of the interpretation of the syllabus (which is also a fair point) though the question itself was designed as a NOS based question, crafted using the "suggest" command term. Only the really top-end candidates managed to score full marks. (c) (iii) proved to be problematic for almost half the candidature. The commonest error was to omit nitrogen in the numerator, but then to include it in the denominator! In (c) (iv), the better candidates gained the mark, but partial answers tripped up a number of candidates *e.g.* by stating a decrease in oxygen. This was not sufficient to score the mark (concentration had to be mentioned for example in this context!).

One final point on Question 1 (c): this graph was based on the original scientific paper, Keeling R.F., Kortzinger A. and Gruber N. (2010) Ocean deoxygenation in a warming world. *Annu. Rev. Mar .Sci.* (2), pp. 199-229. In this paper, Figure 10 had a typographical error where the *y*-axis should have been labelled as ∆APO, instead of APO (per meg). The original paper legend for this Figure had this clarified by reference to the equation and the authors of the paper confirmed when contacted that the *y*-axis label in the publication in fact contained this typographical error.

Question 2

There was also a plethora of G2 comments on this question. Many teachers thought that the diagram was poorly presented (unclamped cylinder, tilted cylinder, different sized bubbles of gas *etc.*) and the fact that some students may not have carried out this experiment in the laboratory, thereby giving an advantage to those that did. The first point is a fair criticism. As regards the second point, it should be noted that this question is based on the experimental experience and involved a laboratory-based question centred around the determination of the molar mass of butane in a disposable plastic lighter. It was very obvious from the responses given that a very high proportion of candidates had no idea of the equation ($M = mRT/pV$) which underpins this experiment. A surprising number of candidates assumed that the lighter combusts in water and therefore discussed the experimental results in terms of incomplete combustion, volume of carbon dioxide produced, solubility of carbon dioxide in water *etc.* Such answers may demonstrate a lack of hands-on experimental work and lack of a scientific approach to problems (and even general common sense!).

In part (a), candidates were required to list the data that would need to be collected in the experiment. In many cases, "the kitchen sink" type parameters were cited – time, amounts, masses *etc.* Many candidates did manage to scavenge one or two marks, but this was usually achieved most likely by guesswork. Too often the term "amount" was used. The most common omission was pressure, followed by temperature.   Some mentioned "temperature change" which was incorrect. Many stated that the mass of gas would be collected (a difficult parameter to measure directly), instead of stating that the mass of the lighter before and after the

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experiment needs to be measured. In (b) (i), few scored even one mark. As most did not understand the relationship between the molar mass and pressure and volume from the equation, few were able to give valid explanations that would have yielded a low result for the molar mass of butane. The most common incorrect answer was candidates stating that there is an escape of gas from the cylinder. In (b) (ii), rarely was any sensible answer given, though some candidates did manage to mention use of a gas syringe or collecting the gas through a tube.

In summary, this question highlighted a lack of understanding of basic experimental concepts and possibly a dearth of experimental work (either in the laboratory where resources and facilities are available or via simulated experiments) undertaken perhaps in some centres (though certainly not all). This continues to be an area of concern in the assessment of the new chemistry programme.

Section B

Option A – Materials

Over 5% of candidates chose this Option in M17. Although most candidates found the majority of questions accessible, there were very few candidates who scored really high marks on this Option during this session. One teacher in a G2 however commented that the questions in Option A were interesting and challenging and many major topics were touched on. There appeared to be a solid improvement in general performance and understanding of concepts in this Option compared to both M16 and N16.

Question 3

In part (a) candidates had to state the two distinct phases of a composite *i.e.* the reinforcing phase and the matrix phase. This proved to be of no difficulty for candidates. In part (b), few scored full marks, but less than 50% scored at least one mark. One suspects that in many cases, guesswork was also invoked here. There were some G2 comments in relation to this question. One teacher stated "The guide doesn't give specific nanotechnology methods for students to study. It seems unreasonable to ask specifically for lithography and metal coordination with no additional information about these techniques. A short description of these and asking students to make a judgement would have been appropriate. However, as it stands, if students didn't happen to find these in their studies they could only guess. I wasn't able to find information about "metal coordination" techniques. I believe that this is "surface coordination" but can't verify without more information. Especially in an emerging field, we can't count on strict vocabulary to be established". In the Applications and Skills section of A.6 on Nanotechnology in the guide, the curriculum states that candidates should be able to distinguish between physical and chemical techniques in manipulating atoms to form molecules. Taking the overall HL syllabus, it would be expected that candidates should have a good appreciation of the bottom up, chemical nature of metal coordination, though mention of surface coordination might have been a better descriptor for candidates. It is fair to state that lithography is just one example of a physical, top down approach, and is not explicitly mentioned per se in the guide, but one would assume that many teachers would choose this as a good example of a method of assembling nanocomposites, especially in view of the design of integrated circuits. 20% of candidates did in fact score full marks on this question.   Perhaps the stem could have been

more explicit in this regard in setting the context with respect to the terminology of lithographic etching. In (c) (i), most recognized that an addition polymerization occurs and hence the atom economy of the first step is 100%. In (ii), many candidates suggested that an addition polymerization is involved as there is no loss of small molecules. In (iii), candidates had to identify one functional group in the repeating unit. Most stated correctly that an amido or an amino group is present. It should be noted that although carbamoyl was accepted for amido, this is not strictly correct for this repeating unit as the carbamoyl group is actually H_2NCO-, which is not present here as there is no $-NH_2$ group attached to CO.

Question 4

In this question in part (a) candidates had to identify the other product formed when ethane-1,2-diamine reacts with chloroethanoic acid. Many stated HCl, thereby scoring the mark. Few scored all three marks in part (b), though many did score at least one mark, usually for stating that EDTA is a polydentate ligand. Virtually no candidate stated that there is an increase in entropy by the release of smaller monodentate ligands previously complexed or the fact that heavy metal ions are trapped inside the ligand. A point of note for future candidates: according to IUPAC, the term "dative covalent bonding" is now obsolete and "coordination bonding (or coordinate bonding)" is the preferred term.

Question 5

The wording of the question in part (a) appeared to really challenge candidates and few scored any marks at all in this question, where an outline of the process of the conversion of carbon monoxide to carbon dioxide was required. Three distinct marking points were required here. M1 required candidates to state that carbon monoxide adsorbs onto palladium. M2 required candidates to state that new bonds formed (or an equivalent type statement). M3 necessitated candidates to state that carbon dioxide then desorbs from the surface of the catalyst. There were two G2 comments on this question. One teacher stated that it would be difficult to come up with three separate points in the response to this question; another stated that the reactions in a catalytic converter are not specified in the syllabus. This in fact is based on Topic A.3 of the syllabus; the question was framed around the process for the conversion and not a specific reaction. In contrast, parts (b) (i) and (ii) were really well answered. Part (iii) focused on a solubility product question, which was more challenging than in previous sessions as candidates had to calculate the molar solubility of nickel(II) hydroxide at pH = 10.5. Many candidates did not entirely know what is meant by the term "molar solubility" (the solubility of a compound in mol dm^{-3}), and in particular how to deduce this. For M1, some incorrectly wrote Ni^+, instead of Ni^{2+}, in the K_{sp} expression. In (c) (i), most candidates could differentiate between paramagnetic and diamagnetic materials *i.e.* the fact that paramagnetic materials have unpaired electrons, whereas diamagnetic materials have all their electrons paired up. Scoring M2 proved more difficult, and many went on to simply repeat the stem of the question *i.e.* the fact that paramagnetic materials are attracted to a magnetic field, without stating that the unpaired electrons align with an external magnetic field. In paramagnetism, the spin and motion around the nucleus (namely the orbital angular momentum) of the unpaired electrons generates minute magnetic fields. As such, when a paramagnetic material is placed in an external magnetic field, the magnetic fields of each atom align with this external field, causing the attraction to the magnetic field. In the case of diamagnetic materials, the magnetic fields caused by electron spin and orbital angular momentum tend to cancel each other out (so a diamagnetic

material is slightly repelled by the magnetic field). In 5 (c) (ii), approximately 50% of candidates scored full marks on the sketches of the graphs of resistance *versus* temperature for a conductor and a superconductor. In 5 (c) (iii), only the better candidates scored all three marks when contrasting type 1 and type 2 superconductors.

Question 6

Liquid crystals were an integral of the previous chemistry curriculum and hence it was surprising that very few candidates scored full marks in part (a) in relation to explaining why being a polar molecule and having a long alkyl chain are essential components of a liquid crystal molecule. Most had some idea of the fact that the orientation of the molecule is influenced by the electric field for a polar molecule. Few mentioned the fact that due to the long alkyl chain, molecular alignment can occur. Part (b) turned out to be a discriminating question for Grade 7 candidates. Virtually no candidate was able to suggest one factor which might influence a detection limit in ICP-MS/ICP-OES. Like the bioavailability question on soluble aspirin *versus* standard aspirin in Option D, this transpired to be one of the most challenging questions on the paper. One teacher commented in a G2 that the detection limit of ICP-OES is not specified in syllabus. It should be noted that this question is based on Topic A.2, and is a NOS type question, which is an integral part of the new curriculum. A wide spectrum of answers was accepted here *e.g.* variation in methodology, different detection limits for MS and OES *etc.* Such answers are well within the realms of feasible answers that a candidate having taken the HL Chemistry programme with NOS at its fulcrum should be able to suggest.

Question 7

This question concentrated on the IR spectra of a number of different plastics. Most candidates were able to state that HDPE and LDPE have similar IR spectra, but surprisingly few could relate this to molecular structure *i.e.* the fact that both are polyethylene based.

Option B – Biochemistry

Option B on Biochemistry and Option D on Medicinal chemistry, were the two most popular options, with approximately 36% of candidates choosing each Option. Overall candidates conveyed a good, solid knowledge of biochemical concepts. In several of the questions, performance was strong.

Question 8

In part (a) candidates had to deduce the structural formula of the dipeptide, Cys-Lys. This was generally well done, with most candidates getting the correct order. However, the amido link was not always correctly shown, and a significant percentage of candidates gave incorrect bond linkages. In (b), many candidates scored the two marks on the electrophoresis question. Some gave the reverse order for the relative positions of the three amino acids however. It should be noted that the question asked specifically for lines to be shown on the diagram. Spots were not penalized but it is important than candidates always read a question carefully. Many also incorrectly wrote Glu instead of Gln for the symbol of glutamine. Glu is in fact glutamic acid. In (c) (i), the most common error for the drawing of the zwitterion of alanine involved writing H_2N- instead of H_3N^+-. It was somewhat surprising and disappointing to see this type of error at HL.

It should also be noted that candidates were asked to draw the zwitterion of alanine. As such, ideally all bonds should be shown (as opposed to writing a structural formula). This is a point of note for future candidates. Some candidates also placed the + charge on the hydrogen instead of the nitrogen even when they showed all the bonds in the structural representation. In part (c) (ii), candidates had to calculate the pH of a buffer solution. This was reasonably well answered, and many scored the one mark for calculating the pH to be 9.72. In the data booklet, the Henderson-Hasselbalch equation is given in section 1, and this was the simplest way to answer this question. Some candidates incorrectly inverted [conjugate base] and [acid] in the Henderson-Hasselbalch equation. Some chose to use an alternative method involving K_a to deduce the pH and although slightly longer, the method chosen was equally perfectly valid.

Question 9

It was surprising that very few candidates scored both marks in this question in part (a). Although many stated that stearic acid is the fatty acid that has the highest boiling point due to being saturated, few stated that this is due to stronger London forces of attraction, which is a key point of the explanation. It should also be noted that according to IUPAC, "van der Waals forces" are the attractive or repulsive forces between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or of ionic groups with one another or with neutral molecules. The term *includes*: dipole–dipole, dipole-induced dipole and London (instantaneous induced dipole-induced dipole) forces. This point of note is emphasized in the new Chemistry curriculum. Some candidates stated just double bonds instead of stating the exact type of bonds *i.e.* stearic acid has the highest boiling point since it has no carbon to carbon double bonds. The reason being that stearic acid does actually contain a double bond, namely a carbonyl group as part of its carboxyl functionality. Part (b) focused on the calculation of the iodine number of sunflower oil. The better candidates scored all three marks here for calculating the number to be 156. Most candidates were able to deduce 0.0615 mol for the amount of iodine, but many used the molar mass of atomic iodine instead of diatomic iodine in the calculation, ending up with an iodine number of 78, which scored only two marks. The question also asked candidates to deduce the iodine number to the nearest whole number; hence 156 was required as the answer.

Question 10

Hardly any correct answers were seen where candidates scored both marks. This turned out to be the hardest question on the entire P3, with just 2.5% of candidates scoring both marks. It was not generally recognized that the sodium salt of the acid would be produced (many gave fatty acids). Some candidates cited water and phosphate, even though the question specifically asked for organic products! Although a few of the better candidates were able to write the correct chemical formula for sodium linoleate virtually no candidate could identify choline hydroxide. In contrast, part (b) was well answered and most scored the mark for stating hydrolysis or saponification. The most common incorrect answer was condensation. The most common incomplete answer was displacement.

Question 11

In part (a), functional groups certainly posed a problem for a number of candidates, with only 30% of candidates scoring full marks. In the straight chain form, many incorrectly stated

hydroxyl. Few could identify the hemiacetal group in the ring structure (or at least have stated the ether group which was accepted).   An ether and an ester were mixed up by several candidates.   A high percentage of candidates did not understand the inherent difference between the class to which a compound belongs to and the idea of a functional group. This difference is stressed in the new syllabus and should be highlighted by teachers. Part (b) was poorly done. In many cases an incorrect 1,4 beta link was represented. The connecting oxygen was often omitted and representations of structures showing carbons surrounded by five bonds was often evident!   Only 30% of candidates scored the mark for the structural formula of sucrose. Part (c), a NOS based question, was poorly answered. Many candidates tried to present answers based on the problem of synthesizing a new compound instead of addressing the challenge of scaling up a given synthesis. A very broad range of acceptable answers were possible here *e.g.*   minimizing the impact to the environment, consideration of the atom economy, cost of production *etc.* so one would have expected that this would have been a very easy mark to score for candidates, based on a NOS centred chemistry syllabus. Only 30% of candidates scored the mark.

Question 12

Candidates did reasonably well on this question. In (a), the extensive system of conjugation was typically identified as the structural feature which enables rhodopsin to absorb visible light. In (b), the majority of candidates stated that *cis*-retinal converts to *trans*-retinal during the absorption of visible light.

Question 13

Both (a) and (b) proved no problem for candidates. In (c), an outline of the significance of the value of K_m was requested. Many candidates failed to read the question and did not convey the inverse relationship *e.g.* a low value of K_m means the reaction is fast at low substrate concentration *etc.*

Question 14

Part (a) focused on a hemoglobin-oxygen saturation curve. This was not well answered. The idea of cooperative binding was rarely mentioned, though the idea that the affinity of partially oxygenated hemoglobin for oxygen increases was often referred to by the better candidates. In (b), candidates had to explain why carbon monoxide is toxic to humans. This was well understood and the competitive inhibitor nature of carbon monoxide was usually mentioned and hence less oxygen is transported.

Question 15

This question on DNA proved to be tricky for candidates in part (a). The question asked specifically to outline how the structure of DNA allows it to be negatively charged in the body. Many (though certainly not all!) mentioned phosphate, but did not give an explicit answer to the question posed, namely the fact that the phosphate groups in the nucleotide fragments are almost completely ionized. The nucleotide sequence of -CTGCCTAGT- was deduced by a significant proportion of candidates in part (a).

Option C – Energy

This was a popular option in M17, with 27% of candidates opting for the Energy Option. It was encouraging to see a high proportion of candidates continue to choose this new option. Performance was very satisfactory overall, and the Option did not generate many G2 comments from teachers, who deemed that the questions were pitched at the correct standard. As in previous sessions of the new syllabus, DSSCs continue to be poorly understood with respect to the redox reactions taking place.

Question 16

In (a) (i), the correct nuclear equation was usually given, though some candidates wrote N (which is the symbol for nitrogen) instead of n for neutron. In (ii), M1 was usually scored for stating that helium has a higher binding energy per nucleon. However, many lost M2 and did not refer to mass defect being converted to energy. In (iii), only the better candidates scored full marks. Many only scored one mark for answers in the range 3.0 to 3.4 MeV for the energy released. In (b), candidates were asked to state the technique used to show that the sun is mainly composed of hydrogen and helium. The better candidates stated spectrometry; some candidates stated simply spectrum which did not score as a technique was asked for. Although "spectroscopy" was accepted it should be noted that in the context of this question "spectrometry" is technically the more correct answer. As described in the IUPAC Gold Book of Terminology, "spectroscopy" is the study of physical systems by the electromagnetic radiation with which they interact or that they produce. "Spectrometry" however is the actual measurement of such radiations as a means of obtaining information about the systems and their components. A minor point of note for best practice with respect to terminology.

Question 17

In (a), few scored all four marks. Candidates often confused specific energy with energy density. Energy density is the energy released from a fuel per unit volume of fuel whereas specific energy is the energy released from a fuel per unit mass of fuel consumed. The energy density is useful when identifying the volume or space requirements for the storage of a liquid fuel. Hence in this question fossil fuels would have a higher specific energy than biofuels. In (b) (i), only the better candidates scored both marks. Incorrect numerical answers were often cited (such as 286 kJ g^{-1}), and sometimes incorrect units for specific energy were given (such as kJ, kJ mol^{-1} *etc.*). In (b) (ii), few scored both marks. The idea that hydrogen has a lower energy density was rarely cited. Part (c) focused on the methanol fuel cell. This was reasonably well understood and it was encouraging to see the correct half-cell equations being deduced at the two electrodes during discharge. In (c) (ii), many candidates knew that H^+ ions pass from the anode to the cathode but few gave a more detailed explanation in part (ii), which required them to convey the idea that the H^+ ions are then used to reduce oxygen at the cathode.

Question 18

Parts (a) (i) and (ii) were well answered. In (b) (i), the most common errors involved candidates failing to include an equilibrium sign or giving incorrect state symbols *e.g.* writing (aq) instead of (l) for water. In (b) (ii), many candidates ignored the rubrique which specified that an equation had to be included. This eliminated the awarding of M1 for many candidates. In addition, a

minority also did not refer to the fact that the equilibrium shifts to the right causing an increase in [H_3O^+], thereby decreasing the pH.

Question 19

In (a), for the silicon based solar cell few mentioned the fact that the absorption of the photons occurs in the semiconducting material. For the DSSC, most knew that the dye in fact absorbs the photon. Charge separation was poorly outlined for both, though many had at least some idea of holes and electrons for the silicon based photovoltaic cell. The redox processes involved in the DSSC as in recent sessions were poorly understood. In one G2 a teacher commented that the wording in part (a) could have been clearer *e.g.* 'where' absorption of photons and charge separation occur. This is a fair point and one which will be noted for future papers. In (b), the most common answer given was the fact that DSSC cells are cheaper than silicon based photovoltaic cells.

Option D – Medicinal chemistry

Option D on Medicinal chemistry and Option B on Biochemistry, were the two most popular options, with approximately 36% of candidates choosing each Option. Overall performance was satisfactory though there were a few challenging questions *e.g.* the bioavailability of soluble *versus* standard aspirin in Question 20 (b) (ii). The NMR question on the structure of methadone, in Question 21, part (c) also proved to be a very good discriminating question for candidates at the upper end. There were few G2 comments on this Option. Some of the G2 comments included "Question 21 (b): about why codeine is not regulated in some countries is not part of the curriculum, so how are candidates supposed to know this?" and "Question 21 (c) (i): I think this question on the number of hydrogen environments is too difficult for this complex molecule (methadone). I feel that organic chemistry especially involving MR, IR, *etc.* should be made an option. There is too much to learn in one chapter and this area is very complex.". In relation to the latter G2 comment, it should be noted that one of the criticisms of the previous syllabus (based on feedback from various stakeholders) was that the previous Option D syllabus highly favoured candidates with a biology background, was too predictable in nature in terms of the range of examination questions asked, had a narrow series of sub-topics within the syllabus and lacked proper integration with core chemical concepts, as opposed to biological concepts. Many of these concerns have been addressed in the new curriculum for Option D and it is important that candidates are fully prepared in particular for the more chemistry-based focus of the sub-topics of this Option, which links core chemistry with a number of the applied areas of Medicinal chemistry. This approach of the new syllabus for this Option was very much captured in the questions posed to candidates in M17. As regards Question 21 (b), in relation to the regulation of codeine, this NOS based question stems from a general understanding of Topic D.3. from the guide.

Question 20

The integration of spectroscopy into this question on aspirin was welcomed by teachers. The majority of candidates did reasonably well on this question, but few scored full marks. In parts (a) (i) and (ii), a high proportion of candidates were able to calculate the amounts of each reactant though surprisingly many did not attempt the calculation for the theoretical yield in part (ii). In addition, a number of candidates did not deduce the correct molar mass for aspirin,

namely 180.17 g mol^{-1} and although not penalized, it was disappointing to see so many candidates ignoring significant figures in the calculation of the amounts in part (i). The limiting reagent was typically used in the calculation in part (ii) when attempted. In part (iii), two absorbances other than the absorbances due to the ring structure and C-H bonds, that would be present in the IR spectrum of aspirin had to be suggested. For the better candidates, this proved no problem, but many of the weaker candidates tripped up on this question, by giving an incorrect wavenumber range, 3200-3600 cm^{-1}, for the O-H bond, failing to recognize that the O-H in aspirin is that of a carboxyl group, and therefore is in the range 2500-3000 cm^{-1}, using section 26 of the data booklet. Using wavenumber ranges from section 26 of the data booklet was the simplest way to answer this question, but some candidates chose to answer the question by citing bonds, but unfortunately did not always correlate the bond type to the correct functional group, which was penalized *e.g.* many stated that there was an absorbance due to the C-O bond in the ether group in aspirin which was incorrect. In part (iv), the majority of candidates had little difficulty stating two techniques, other than IR spectroscopy, which could be used to confirm the identity of aspirin. A common mistake included stating "boiling point" instead of "melting point". (b) (i) was very well answered and the reaction with sodium hydroxide was typically the answer cited for the conversion of aspirin to water-soluble aspirin. (b) (ii) proved to be a real challenge for candidates where they were required to compare, giving a reason, the bioavailability of soluble aspirin with aspirin. Only approximately 10% of candidates scored the one mark. This question was discussed widely during standardization and it was agreed that the question was open to interpretation. The question itself did not trigger any G2 comments but there was some discussion on the OCC, so the question deserves some comment here in this report for this reason. The term "soluble aspirin" is a term that is sometimes used to describe "dispersible aspirin tablets" but in the context of this question, it may be taken to mean the sodium salt of the carboxyl functional group. However, it would not be unreasonable that some candidates may have assumed that dispersible aspirin was being discussed in the question. Dispersible aspirin would most likely be absorbed more quickly from the GI tract due to the increased rate of disintegration of the dosage form compared to a non-dispersible dosage form such as a conventional tablet. In a tablet dosage form, the rate limiting step of drug absorption can often be the rate of disintegration. Therefore, the dispersible tablet could have a more rapid absorption. In this context, bioavailability refers to the total % of the administered dose that is available to act at the site of action. The bioavailability of either dispersible or non-dispersible aspirin would be expected to be very similar even if the rate of absorption is marginally different due to differences in the rate of disintegration/dissolution. There might be a slight increase in the bioavailability of the dispersible aspirin as it may be absorbed ever so more quickly from the stomach potentially reducing the rate of hydrolysis of the aspirin compared to standard aspirin. However, depending on the dosage form design, an enteric coating formulation of standard aspirin could potentially have a higher bioavailability than the dispersible aspirin as it would be protected from degradation in the low pH environment of the stomach and be more completely absorbed from the small intestines. If we assume that the soluble aspirin mentioned in the question refers to the sodium salt of the aspirin, similar arguments to the above could be made. The salt might enter solution more readily than the associated carboxylic acid equivalent due to enhanced solubility. However, this is unlikely to dramatically affect the bioavailability. There could be a small increase in bioavailability of the soluble aspirin due to a more rapid absorption due to the more rapid dissolution which could potentially reduce the amount of aspirin degraded in the stomach acid due to the decreased residence time. Other factors could also affect the bioavailability such as formulation type, *etc.*

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It is for this reason that two answers were accepted for this question – if a candidate stated that the bioavailability of soluble aspirin is marginally higher due to the increase in the rate of dispersion or the increase in the absorption in the mouth/stomach mucosa or if a candidate equally stated that the bioavailability of soluble aspirin is approximately the same as that of aspirin since the ionic salt reacts with hydrochloric acid in the stomach to produce aspirin again; either type statement would have scored the mark. What was not accepted however (and which was a commonly seen response) was candidates stating that the bioavailability of soluble aspirin is higher than that of standard aspirin due to greater solubility in blood. To pass the lipid membrane and get into the blood plasma in the stomach, aspirin must first become a neutral, non-ionized molecule, or otherwise it will not pass the gastric mucosa. So, it does not matter which form is ingested. Once in the blood, the degree of ionization of aspirin will be controlled by the plasma pH, not by the form in which it was ingested. Interestingly according to various data, the bioavailability of standard aspirin is between 70 and 100%, depending on how it is ingested (*e.g.,* fine powder with water will give over 95% bioavailability). Some older textbooks give values ranging from 40 to 80%, probably because of non-optimal formulations of older tablets. Therefore, soluble aspirin can appear to have marginally higher bioavailability than normal aspirin, and that will primarily be as a result of fine dispersion of aspirin in the stomach. However, the question was deemed to be open to possible interpretation and that is why two possible answers were allowed in the marking of this question.

Question 21

The explanation given to part (a) where candidates had to explain why diamorphine passes more readily than morphine through the blood-brain barrier was well rehearsed and the majority scored both marks. A few candidates incorrectly stated that morphine contains the hydroxide functional group instead of stating that it contains the hydroxyl functional group. In part (b), candidates had to suggest one reason why codeine is available without prescription in some countries whilst morphine is administered under strict supervision. This was surprisingly difficult for many candidates and lots of general responses were cited, such as "codeine being less addictive", which is not strictly correct. The better candidates gave a more precise answer stating the morphine has a smaller therapeutic window. Many stated simply that codeine is less potent, which was accepted. Part (c) of this question focused on the use of proton nuclear magnetic resonance spectroscopy in the structural elucidation of methadone. This proved to be extremely difficult for many candidates, showing poor understanding of this fundamental analytical technique. The better candidates were able to predict that there are six different hydrogen environments in methadone, if the benzene rings are ignored. The most common incorrect answer given was three. In part (ii), many were able to cite the 2.2-2.7 ppm chemical shift, using section 27 of the data booklet, but surprisingly few gave the splitting pattern as a quartet. Many candidates appeared to confuse splitting pattern with integration trace. This was highly disappointing to see on a Higher Level paper.

Question 22

Part (a) was very well answered and most candidates stated that ranitidine (Zantac) functions to reduce stomach acidity by binding to the H2-histamine receptors in the cells of the lining of the stomach. Some candidates did not mention receptors at all and gave either a vague or an incomplete response. In part (b), candidates had to calculate the pH of a buffer solution. This was reasonably well answered, and many scored full marks for calculating the pH to be 10.15.

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In the data booklet, the Henderson-Hasselbalch equation is given in section 1, and this was the simplest way to answer this question. M1 was typically scored for $[Na_2CO_3] = 0.0629$ mol dm^{-3} but some candidates incorrectly interchanged [conjugate base] and [acid] in the equation. Some chose to use an alternative method involving K_a to deduce the pH and although slightly longer, the method chosen was also perfectly valid.

Question 23

In part (a) candidates had to compare and contrast the structures of oseltamivir and zanamivir, stating the names of functional groups. In general, this question was very well answered, and much better done than in previous sessions. Some candidates gave abbreviations instead of giving names of functional groups which did not score (*e.g.* C=O instead of carbonyl). Others gave classes of compounds instead of functional groups (*e.g.* alcohol instead of hydroxyl). Although not penalized, this practice should not be encouraged. For the similarity between the two structures, the best answer was the amido group. Other answers were accepted, though some not strictly correct. For example, some candidates stated that both structures contain the alkenyl functional group. The alkenyl group is technically a monovalent substituent (such as –CH=CH$_2$, –CH$_2$CH=CH$_2$, *etc.*) *i.e.* the fragment, containing an open point of attachment on a carbon atom, that would form if a hydrogen atom bonded to a doubly bonded carbon is removed from the molecule of an alkene. Others stated that both contain the amino functional group. In the context of these two structures this also is not strictly correct, as although oseltamivir contains an amino group, zanamivir actually contains the guanidine group. For the one difference, some candidates failed to note the action verb command terms of the question (compare and contrast) and simply mentioned one drug. This was not sufficient to score M2. In part (b), candidates had to suggest one ethical consideration faced by medical researchers when developing medications. The most common correct answer given was animal testing. This question was reasonably well answered.

Question 24

It would have been expected that candidates would have done better on this question where they had to suggest one problem associated with chlorinated organic solvents as chemical waste. Some candidates mentioned the carcinogenic nature of such solvents or the fact that they can be ozone-depleting. Surprisingly, few mentioned that some of these chlorinated solvents (*e.g.* CFCs) can be greenhouse gases, which one would have expected most to have known. In general, a lot of non-specific answers were seen such as references to doing harm to the environment or their ability to pollute water.

Question 25

Description of how a chiral auxiliary functions to produce the desired product, was very well executed by the majority and a high proportion of candidates gained all three marks here. This question was answered much better than in previous sessions and this was encouraging to see as the lack of understanding of a chiral auxiliary was flagged in previous subject reports. Some candidates thought that this was simply a two mark question in this session, and thereby only scored two out of the three allocated marks.

Question 26

Most candidates had at least some idea as to why alpha-radiation is particularly suitable for the treatment of leukemia and other dispersed cancers using TAT, and one was the mean score. Some candidates did not score M1 as their answers lacked fine detail in relation to the radiation type *e.g.* failing to state that alpha radiation is more damaging compared to other types of radiation. In (ii), candidates were required to outline how alpha radiation in TAT is directed to cancer cells. Approximately 50% of candidates gave a precise answer *e.g.* the fact that the radioactive isotope is administered using carrier antibodies. Part (b) was very well answered, though some failed to identify beta as the correct radiation type in part (i). In (ii), the most common error involved candidates inverting the mass number, *A*, and the atomic number, *Z*, for the nuclear symbol, $^{A}_{Z}X$. The half-life question in part (iii) was very well answered and nearly all candidates got the correct answer, namely 6.25%.

Recommendations and guidance for the teaching of future candidates

- Legible handwriting should be encouraged – there was strong evidence again of a noticeable number of scripts this session where examiners struggled greatly in trying to decipher what was written in several responses.
- It is critical that core chemical principles are brought to the fore in the Options, especially those which have often a twin biological focus e.g. Biochemistry and Medicinal chemistry. Core chemistry should always underpin applied topics. This is a major feature of the new curriculum.
- Candidates should always look at the associated mark allocations in questions. Candidates should not have to use extra continuation sheets if they tailor their answers to the space provided. This session once more far too many candidates wrote lengthy answers and used extra continuation sheets which were simply not required.
- Candidates often struggle with questions that require explanations or multiple steps. Candidates need to fully understand the various command terms and teachers should take time to review with candidates command terms throughout the two years of the programme to make sure they understand how these terms are applied in questions and responses. This was certainly a feature of this session.
- Candidates should prepare for the examination by working through past examination questions of the new syllabus (as they come on stream) and carefully study the markschemes provided. In addition, it is critical that candidates are continuously challenged throughout the delivery of the programme on NOS-based type questions. Candidates need exposure to data-based scientific problems involving unfamiliar situations, and should be able to interpret graphical representations, critique and interpret data and draw logical conclusions involving scientific methodologies.
- It is imperative that laboratory work lies at the heart of the IB chemistry programme. Ideally candidates should be exposed to a rich experimental experience in the laboratory where suitable facilities are available. Where this is not the case other resources such as simulated experiments should be sourced. If an analytical technique is required by an option and students are required to know the steps, then ideally the technique should be performed in class or by simulation.
- Environmental chemistry should be integrated in linked topics throughout the delivery

of the programme. This strand is also present in all four options and is of prime importance in the syllabus. Consideration of Aim 8 of the programme is worth emphasizing in this regard.

- Candidates should get ample practice at writing balanced equations and nuclear equations.

- Many candidates still use the class names of organic compounds instead of functional group names. Distinction between the two is a feature of the new syllabus. The inherent difference between an ester and an ether should also be stressed.

- Bond connectivities should be emphasized.

- Note that according to IUPAC, "van der Waals forces" are the attractive or repulsive forces between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or of ionic groups with one another or with neutral molecules. The term includes: dipole–dipole, dipole-induced dipole and London (instantaneous induced dipole-induced dipole) forces.

- Candidates should always use the precise values of the atomic masses in section 6 of the data booklet (typically given correct to two decimal places), round numbers correctly, and state answers to calculations to an appropriate number of significant figures including addressing the issue of significant figures when dealing with logarithmic entities. Rounding should be discouraged after each step or prior to reporting a final value in a problem. Significant figures associated with logarithms need to be handled carefully. For example, it is the number of digits in the mantissa part of a logarithm (i.e. the decimal part) that conveys the number of significant figures for a logarithmic entity (e.g. for a solution with $[H_3O]^+ = 1.0 \times 10^{-3}$ mol dm-3, the pH should be correctly reported as the $-\log_{10}(1.0 \times 10^{-3}) = 3.00$, since the concentration contains two significant figures, so 3.00 as the logarithmic entity has two significant figures in the decimal, mantissa part; the integer, characteristic part of the logarithm is not considered here. This is best practice mathematically for logarithms which are commonplace across the syllabus in questions related to pH and buffer solutions in particular.