May 2018 subject reports

Chemistry TZ1

Time zone variants of examination papers *To protect the integrity of the examinations, increasing use is being made of time zone 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 examination papers. For the May 2018 examination session the IB has produced time zone variants of Chemistry.*

Overall grade boundaries

Higher level

Grade:	1	2	3	4	5	6	7
Mark range:	0 16	17 29	30 42	43 53	54 64	65 75	76 100

Standard level

Grade:	1	2	3	4	5	6	7
Mark range:	0 15	16 28	29 40	41 52	53 62	63 75	76 100

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 IA criteria was as usual varied although anecdotally it does seem that we are seeing fewer schools submitting completely unsuitable directed work which did not give the students a suitable opportunity for independent inquiry.

Overwhelmingly the work presented involved hands -on primary data collection. A survey of several hundred investigations that were seen by the standardization team showed that less than 2% were based on secondary data from databases.

Overwhelmingly the work presented involved hands -on primary data collection. A survey of several hundred investigations that were seen by the standardization team showed that the two most common topic areas by far were food chemistry and kinetics with both areas representing almost 25 % of the submitted investigations each. Within food chemistry a full half of those were vitamin C analysis followed by significant numbers of caffeine determinations, vinegar titrations and a number of iron and calcium determinations. What was far less common this year were studies of wine oxidation. The other topic areas that were the basis of a significant number of Individual Investigations (about 5% each) were: acid/base chemistry including a number of weak investigations where simply a pH probe was put in a weak acid solution and the temperature raised; enthalpy determinations most often of fuel combustion; a variety of studies on soaps and shampoos; studies on factors affecting electrolytic and electrochemical cells and finally the usual range of overly narrow brand analyses such as iron content in diet supplements or antacid tablet comparisons.

The same survey showed that less than 2% were based on secondary data from databases or simulations. Although each session since 2016 we have seen only a very small number of such types of investigation those we have seen have often been very good and attained very well against the criteria. The fear expressed by teachers has been that such investigations have limited capacity to take into consideration measurement uncertainty. This is often a valid consideration and certainly such investigations work best when there is more than one source of data available so that the variance between sources can be evaluated.

One concern raised by a few examiners was where school submitted samples where all students had studied the same topic e.g. in one school all students had looked at a different aspect of vitamin C contents while in another case all students had constructed a voltaic cell with only superficial changes in system. This is poor practice and is discouraged.

Pleasingly there was less material than last session that failed to show primary correction by the teacher. This is encouraging since the teacher’s marking comments do help the examiners understand the reasoning behind the mark awards and makes the support of the marks more likely.

Candidate performance against each criterion

Personal Engagement:

The overwhelming majority of students managed to achieve at least one point for Personal Engagement. A continuing weakness is that the student’s justification of their choice of research question and topic spilling over into overlong and contrived personal narratives. Also, some teachers seem to consider Personal Engagement to be a section of the report and require students to write it up before beginning their research. It is actually a holistic criterion assessed using evidence across the whole report.

The commonest limitation to achievement was where students failed to show genuine curiosity by presenting a very undemanding research question where the outcome was too self-evident, such as determining how the mass of alcohol combusted affects the heat energy evolved, whether the time current passes affects the mass change of an electrode during electrolysis or a trivial brand analysis such as comparing different antacids. 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 as in previous sessions the outcome was again variable. 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. Less highly achieving candidates should themselves not to be 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.

It is worth encouraging students to describe briefly in a paragraph the process of developing their methodology. This will help explain the amount of data collected and give insight into the decision making of the student.

It was reported from the examining team that some teachers' annotations indicated that the expectation for PE was linked to whether the student was SL or HL. It has to be remembered that the assessment framework and associated expectations is identical for both levels and that the external moderator will not know whether the report in front of them is from a HL or SL candidate.

Exploration

The achievement in Exploration was variable although most students were able to achieve at least middle band fulfillment of the assessment criterion.

In many cases a suitable topic was identified and a relevant research question was described with the research question often falling into the category of determining how a measurable independent variable effected an identified dependent variable. These research questions achieved well against the assessment descriptor and also frequently facilitated a successful fulfillment of Analysis and Evaluation criteria.

In the English written reports, it was less common than in previous sessions to find investigations more than one research question was proposed. Such investigations often lose focus and it is better for students to concentrate on answering a single clear research question in depth. Also, less prevalent this year was the use of not properly defined terms such as "efficiency" and "suitable". Within the Spanish reports however it was reported that well-focused research questions were in a minority although the teachers' marking did not often reflect this.

The quality of background information was variable. Some candidates clearly described the system under investigation, most probably including relevant chemical equations, and then provided very relevant theoretical context that was directly related to the research question in hand. In many other cases though the background was only focused on the wider topic so was subsequently too broad or actually unrelated to the research question under investigation. For example, quite routine analyses were pre-faced with extensive discussion of health and nutrition data from sources such as WHO but wouldn't include any of the actually background chemistry of the actual research question investigated.

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 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. As in previous sessions students often identified variables in list but then didn't address them in the method nor showed values in data collection. There is a common failing that when the students consider temperature as a control variable (maybe in a kinetics experiment) they only consider the ambient room temperature and not the temperature of the system. And even when relevant room temperature was often considered as 'constant' when investigations ran to days or weeks. In investigation systems where pressure is relevant it is routinely ignored. In a number of experiments the methodology described would not have yielded such results and in these cases teachers should be vigilant the student is reporting their data with integrity. For example, we saw spectrophotometry and the Beer-Lambert Law being wrongly applied to systems in suspension not solution and yet perfect data was collected.

Other frequently seen weaknesses included poor attention to drying in experiments where massing products was crucial, not calibrating instrumentation such as pH meters and most commonly imprecise volumetric work to make up solutions using measuring cylinders and beakers rather than graduated pipettes and volumetric flasks.

Since the current assessment framework was first assessed in May 2016 there has been a significant increase in the number of reports featuring meaningful awareness of safety, ethical or environmental issues relating to the use and disposal of equipment and materials. There are still exceptions such as the student using chloroform with no safety consideration and no comment from the teacher but these are becoming fewer. A few moderators noted that there have been a number of biochemistry related crossover investigations where animal products such as blood or liver have been used. These have to have been ethically sourced and safely stored and handled.

Analysis

The overall achievement for Analysis was similar to last May with overwhelmingly the majority of students securing some credit for recording data however the subsequent processing was understandably varied.

Many students recorded qualitative observations (although some only included photographs that did not focus the reader's attention on the relevant observations) and sufficient data related to the independent and dependent variables so that they could subsequently carry out sufficiently meaningful processing and interpretation.

Fewer students though recorded the data regarding the control variables such as reaction temperatures or reactant amounts. It is this wider data that can provide valuable context for the evaluation of the procedure. Other students included the expected qualitative data in the method, but such anticipated results do not always match those obtained during the collection of actual data, therefore this practice shouldn't be encouraged. Also note that while including uncertainties in the list of materials may be a good strategy, recorded data should include them as well so always encourage the recording of uncertainties in the raw data. As ever the most frequent omission was not recording the initial and final volumes in titrations but only the total volume used.

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 and calorimetry calculations. In some cases, the numerical calculations were demanding and it is important to note here that teachers must check through calculations when assessing Analysis. Yet again on a significant number of occasions calculations had been awarded the highest level by the teacher but when spot checked by the examiners revealed themselves to contain major errors that significantly affected the conclusions drawn. These oversights did then lead to the downward adjustment of the Analysis mark.

Other common areas of weakness were in rate of reaction investigations where students didn't actually calculate a rate at all and contented themselves with comparative comments on reaction time and many occasions where students presented inappropriate bar charts rather than a properly constructed scatter graph with line of best fit. Related to this type of investigation was the inappropriate selection of pH as the dependent variable in a rate experiment. Students did not recognize that the logarithmic nature of pH means that calculating the rate of change of pH does not simply relate to the change in concentration of reactants or products.

Students are expected to identify outlying data and to critically decide how to deal with them in the processing of data. Eliminating values by default so that relationship is the one expected is not in tune with our Nature of Science objectives. One common weakness is that some students failed to realize the collected data were within the uncertainty range and could hence not support the later interpretation.

Graphs obtained through the use of sensors which show no processing are actually raw data. Relevant uncertainties should still be included. It wasn't uncommon to find poorly chosen scales or graphs where important ranges included no data. Under these conditions the lines of best fit have questionable value.

Only with mixed success did students show evidence of consideration of the impact of measurement uncertainty on the analysis. This is disappointing since expectations regarding the treatment of uncertainties, how to use consistently significant figures and decimal places and the construction of graphs with lines of best fit are clearly described in topics 11.1 and 11.2 of the Chemistry Guide and the Teacher Support Material in the Programme Resource Centre within My IB.

Where students did score credit was most often in numerical calculations related to stoichiometry or energetics when the followed a sensible protocol to propagate the uncertainty. Within graphical analysis the fulfilment of this aspect was less strong. Lines of best fit using Excel are often poor (there are other freely downloadable graphing programmes which can be more effective) and error bars where included often didn't match the uncertainty or the student failed to appreciate the significance on the trend being identified. The calculation of standard deviations grows in frequency although students often didn't appreciate why they were doing this or were calculating the standard deviation of far too small a data set – in the most extreme case this statistical treatment was carried out on just two data points. Generally speaking we do not expect standard deviation calculations in most chemistry analyses.

Many, but far from all, 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 slope was termed exponential. Also many students 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 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 teachers 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. Teachers shouldn't be drawn in to awarding high marks for limited analyses just because the methodology yielded insufficient appropriate data to carry out processing in line with our expectations.

Evaluation

Evaluation is the most challenging criterion to be fulfilled since an appreciation of the significance of their findings and the limitations of the methodology requires deep reflective thinking skills.

Most students were able to make a statement that drew a conclusion consistent with their processed data although frequently this was an overstatement of a trend observed but actually not clearly supported beyond the bounds of the measurement uncertainty

Many students failed to correctly describe or justify their conclusion through relevant comparison to the accepted scientific context. For this part of the descriptor students should either be making the comparison of their experimentally determined quantities to readily available literature values or referring to whether any trends and relationships identified were in line with accepted theory, ideally by referring back to their original background information.

Most students did succeed in identifying weaknesses and limitations although these were usually procedural (why the planned method was not properly implemented) and few were methodological (why the designed method itself was flawed or limited). In comparison to last year a few more investigations identified and evaluated systematic and random errors although candidates doing this were in a minority which once again is disappointing since these are distinctions outlined in Topic 11.1 of the Chemistry Guide.

The aspect of the criterion concerning suggestions for improvements and extensions were a general weakness. Often the weaknesses were superficial (more repeats, use a digital probe, have a second student help) and few addressed meaningfully methodological issues such as calibration, range or adapting the method to reduce systematic error. The extensions suggested were often limited such as to try a different fruit in a vitamin C titration

Communication

The Communication criterion was in most cases quite well fulfilled with the many students 3 marks.

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. Also, raw data was not always clearly presented. Often, we saw tables where uncertainties (of same value) and units were entered in each box rather than just once in the column heading weren't uncommon. Also, many students unnecessarily broke up their data into multiple tables that didn't easily facilitate comparison.

Reports were mostly concise and most of them did meet the 12 page limit. Less students this year includes lengthy appendices in order to circumvent the page limit ruling which was pleasing since this is not an acceptable strategy. Other reports included unnecessary cover sheets or indexes/contents pages.

Most of the reports were relevant although the one common area of weakness was the inclusion of too much general background information that wasn't focused on the Research Question as discussed in the section on Exploration earlier. A significant number of reports included pictures of chemicals, equipment and layouts that were totally unnecessary, e.g. a photograph of a common titration set up.

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. Also, there was frequent ambiguity in the use of the word amount and reference to weight not mass.

The using of citations and references was usually seen although it was common for it not to be clear where and if a cited source had actually been used. Note that proper referencing is necessary to establish the academic honesty of the work. It is not though a part of the Communication criterion so does not impinge on the mark.

Recommendations for the teaching of future candidates

- Students should develop investigations that seek to answer research questions related to chemical principles and to avoid research questions whose answer is known beforehand.

- Encourage students to only use background information that is specific to their research question.
- Encourage students to reflect on data while collecting it so they have the chance to adapt or extend their procedural phase if the data are proving insufficient or erroneous.
- It is good practice for students to give a safety and environmental evaluation in 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 procedures to use lower quantities of chemicals to preserve the environment.
- Ensure students record all relevant associated data and not just the independent and dependent variable data.
- Address topics 11.1 and 11.2 of Measurement and Data Processing before students embark on their Individual Investigations.
- 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.
- 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.
- 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.
- Title pages, indexes, content pages and appendices are unnecessary and should be discouraged.

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.
- Leave evidence of their assessment decisions for the moderator to understand the thinking behind the marks. Hand written annotations on the report scripts are fine for this purpose.

Further comments

Higher level paper one

Component grade boundaries

Grade:	1	2	3	4	5	6	7

Mark range:	0 10	11 14	15 19	20 24	25 28	30 33	35 40

General comments

The number of candidates who sat this paper was over 5900 and the average mark scored was 22.29 out of 40 which was lower than the average mark in May 2017 (23.46 out of 40). New schools seem to have been a factor with new schools scoring lower than new schools the previous year.

There were 427 schools which took the exam, 63 of which were new schools. There were 61 responses on completed teachers' comment forms. Teachers are encouraged to complete these feedback forms every examination session. Teachers who sent feedback generally found the paper appropriate with some teachers suggesting it was slightly more difficult. Several teachers commented that the clarity of questions was improved from last year. A few teachers thought that some questions were quite tricky and required careful reading. A couple of teachers also commented that there were some challenging questions which took students a while to complete.

These overall impressions are supported by the statistics. Approximately 64% felt that the paper was of similar difficulty to last year with 11% viewing it as slightly easier and 18% a little more difficult. 7% answered NA.

Approximately 80% of respondents said the suitability of the paper in terms of clarity and presentation was good to excellent with 18% viewing it as fair and 2% as poor. Specific concerns will be addressed in individual question analysis.

The table below lists the questions from least to most difficult. It shows the numbers of candidates who selected each of the options A-D and the discrimination index for each question (how well the question discriminated between high-scoring and low-scoring candidates).

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
9	645	337	**4725**	213	4	79.76	0.32
32	316	575	**4715**	306	12	79.59	0.35
7	355	**4539**	602	423	5	76.62	0.44
1	183	989	**4491**	246	15	75.81	0.30
25	**4342**	196	1216	161	9	73.30	0.40
27	464	566	555	**4329**	10	73.08	0.51
20	**4278**	1233	349	63	1	72.21	0.57
34	414	**4269**	747	482	12	72.06	0.54
6	377	477	873	**4189**	8	70.71	0.51
18	316	394	1022	**4188**	4	70.70	0.41
4	463	**3899**	570	988	4	65.82	0.33
30	1486	**3660**	596	173	9	61.78	0.34
23	741	**3656**	680	826	21	61.72	0.45
15	736	818	720	**3647**	3	61.56	0.55
5	**3620**	1362	408	522	12	61.11	0.45
36	387	**3592**	1692	236	17	60.63	0.58
12	889	910	558	**3552**	15	59.96	0.46
13	**3525**	630	680	1083	6	59.50	0.53
40	1629	607	166	**3507**	15	59.20	0.27
33	**3484**	596	472	1354	18	58.81	0.53
26	683	1026	898	**3311**	6	55.89	0.46
16	**3281**	514	424	1694	11	55.38	0.29
38	290	1543	**3185**	886	20	53.76	0.33
39	**3114**	709	1021	1049	31	52.57	0.43
31	1063	439	**3110**	1288	24	52.50	0.56
17	647	304	**2902**	2064	7	48.99	0.55
10	411	**2900**	1878	729	6	48.95	0.37
2	**2847**	2239	212	625	1	48.06	0.31
11	1639	646	**2736**	895	8	46.19	0.23
3	1352	1493	373	**2689**	17	45.39	0.62
22	1184	**2608**	270	1856	6	44.02	0.61
35	1810	**2570**	806	721	17	43.38	0.42
37	1071	902	1364	**2549**	38	43.03	0.46
24	1622	1388	**2534**	373	7	42.78	0.34
19	1797	725	899	**2496**	7	42.13	0.60
28	1990	461	**2433**	1034	6	41.07	0.42
21	1131	218	**2046**	2514	15	34.54	0.28
8	520	**1982**	1089	2315	18	33.46	0.24
29	**1566**	970	2904	476	8	26.43	0.22
14	**697**	185	4840	193	9	11.77	0.04

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

- Lewis structures
- Organic synthesis reactions
- *E-Z* nomenclature
- Identifying when oxygen is reduced in a redox reaction.
- Mathematical calculations without a calculator.
- Ranking d-orbital splitting in a complex ion according to its colour.
- Understanding how number of valence electrons influences strength of metallic bonding.
- Being able to calculate $kJ \cdot mol^{-1}$ when the reaction is not balanced to 1 mol of reactant.
- Understanding how rate constant varies with temperature
- Being able to distinguish between amphiprotic and amphoteric.

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

- Conductivity of various carbon allotropes.
- pH at equivalence point
- Acid-base reactions
- Determining overall order of a reaction from rate data.
- Convergence of lines in the hydrogen emission spectrum.
- Identifying electrodes and electrolytes in an electrolytic cell.
- Understanding how surface area of a solid influences the rate of a reaction.
- Periodic trends.

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

- (1) Some teachers raised concern that a little more mental math was required for this calculation than usual. However, 76% answered this correctly and it did not appear to be an issue.
- (2) 48% correct with the most common misconception being that an inverse relationship is linear.
- (3) 45 % answered correctly. One teacher comment suggested that many students would know how to do the calculation but not in the format of this question. The most often chosen wrong answer does not support this as it incorrectly converts grams to mol and that it has the highest discriminatory index of any question on the test shows it was handled better by higher scoring students.
- (4) A well answered question with 2/3 of the candidates getting it correct. There was no common misconception as all distractors answered approximately the same number of times. One teacher said frequency can also mean (number of blue lines) in addition to frequency (1/s). While this is correct and could have been made clearer it is also fairly obvious the question is referring to the hydrogen spectrum.
- (5) Answered correctly by 61% of the candidates with the most common wrong answer using a drop in electron energy for ionization.
- (6) 71% answered correctly and it had a relatively high discriminatory index. Most of the incorrect responses correctly picked ionic bonding but had confusion on the properties.
- (7) One of the best answered questions in the paper. There was no one incorrect distractor which really stood out. Topic 3 appeared to have one of the highest marks per topic for the exam.
- (8) A poorly answered question with only 33% correct. The most common misconception being that violet colour displayed highest d-level splitting. Some teachers commented that the colour wheel or EM spectrum should have been given. However, it seemed clear that candidates had an idea of the visible light spectrum with the main misconception being the colour absorbed is what is seen and not its complement.
- (9) The question on the exam with the most correct answers at 80%. The main misconception being graphite is a lower conductor of electricity than diamond.
- (10) Almost 50% answered correctly with the common misconception being that NO_3^- has a lone pair rather than a double bond, yielding a trigonal pyramidal geometry.
- (11) Surprisingly only 46% picked aluminium, with 3 valence electrons as having the strongest metallic bond of the choices given.
- (12) Well done with a good majority correctly identifying all three compounds as having at least one sp^2 hybridized atom.
- (13) Lewis structure questions demonstrated a fairly high discriminatory index with better scoring candidates more capable of identifying that CH_2O has only one possible structure.
- (14) With only 12% correct answers this was by far the poorest answered question on the test. The misconception being the question asks for the answer in kJ mol^{-1} and the equation is for 2 mol of butane. This seemed confusing to all candidates.
- (15) 62% correctly chose how activation energy relates to exothermic/endothermic

reactions. All three distractors were chosen nearly equally by candidates who chose the wrong answer.

- (16) The majority of candidates were capable of answering this energy cycle question, with some being confused as to the sign of lattice enthalpy to use when the ionic substance is being dissolved.
- (17) This question appeared to be a guess as to if a negative entropy change would make the reaction spontaneous at high or low temperature with very few candidates selecting enthalpy change as a factor.
- (18) Answered correctly by 71% of candidates. Some candidates believed that the volume increase of equal concentration of HCl would increase rate being the most frequently chosen wrong answer.
- (19) The better scoring candidates were more capable of identifying the axis of a Maxwell-Boltzmann diagram. One teacher suggested the question was strictly a memory recall however the most common wrong answer showed the x-axis labelled as reaction progress. This seems to indicate some confusion between Maxwell-Boltzmann diagrams and energy profile diagrams.
- (20) 72% of candidates could determine overall order of a reaction from rate data.
- (21) While most candidates knew that temperature influences a rate constant, more candidates thought that the rate constant increased proportionally with temperature rather than exponentially.
- (22) This question on equilibrium had one of the highest discriminatory indices on the exam, being answered much better by candidates who scored higher. Teaching students some multiple-choice testing strategies would be helpful as 3 of the choices suggest that the equilibrium shift to the right with only one alternative showing a shift to the left.
- (23) The 2nd equilibrium question was handled quite well with 62% of candidates earning the mark. There was no clear choice of distractor amongst the wrong answers.
- (24) 42% of candidates could distinguish amphiprotic and amphoteric. One comment suggested “Questions 24 and 35 are certainly in the curriculum, but these questions are likely not good discriminators of student ability. They seem more likely to be discriminators of the teacher's coverage of the syllabus.”
- (25) 73% of candidates could find pH from a hydroxide concentration with no clear distinction between higher and lower scoring candidates.
- (26) The majority of candidates understood the relationship between Lewis acid/base and electrophile/nucleophile.
- (27) A well answered question, particularly among better scoring candidates which demonstrated knowledge of pH at equivalence between a strong base and weak acid.
- (28) A very poorly answered question with the many candidates picking O in OF_2 has having been reduced, rather than oxidized by the fluorine. A few teachers also commented that the oxygen is reduced in $2F_2 + O_2 \rightarrow 2F_2O$ and believed there to be two correct answers to this question.
- (29) A poorly answered question with the majority of candidates believing calcium and bromine are the products of electrolysis of an aqueous solution of calcium bromide. A few comments suggested that this question belonged on Paper Two when candidates have access to a table of standard electrode potentials. We however expect candidates to have some ideas of the reactivity series and potentials.
- (30) The vast majority of candidates could correctly identify electrodes and electrolytes

in an electrolytic cell.

- (31) Higher scoring candidates appeared to score better on identifying that the mass of the cathode had no effect on the mass of products formed in electrolysis.
- (32) Well answered question with 80% correctly identifying products of the reaction between steam and hex-3-ene.
- (33) Higher scoring candidates also seemed more capable of identifying the monomer from a drawn polymer.
- (34) The majority of candidates had no difficulty identifying a secondary alcohol.
- (35) Only 42% were capable of applying E-Z nomenclature.
- (36) The vast majority of candidates, particularly higher scoring candidates, could identify a molecule which contains a chiral carbon.
- (37) Organic synthesis questions were poorly answered both on Paper One and Paper Two.
- (38) Identifying index of hydrogen deficiency was well done with no clear distractor chosen as a wrong answer.
- (39) The majority of the candidates could correctly predict the ratio of signals in the ^{1}H NMR spectrum of pentan-3-ol.
- (40) Nearly 60% of candidates correctly stated that ^{1}HNMR spectroscopy can distinguish between primary and secondary alcohols with the most common misconception being they would react differently with acidified potassium dichromate.

Recommendations and guidance for the teaching of future candidates

- Candidates need to be reminded that they should choose the best answer to each question and to leave no questions unanswered.
- Ensure the whole syllabus is taught as every topic is examined in this paper.
- Questions in Paper One follow the order of the guide so candidates can begin at a topic they are confident in if Stoichiometric Relationships (Topic 1) is not their strongest choice.
- Candidates should read questions carefully and pay special attention to anything which is in bold. Question 14 was the most missed question on the exam probably due to not answering specifically what was asked.

Standard level paper one

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 7	8 10	11 13	14 17	18 20	21 24	25 30

General comments

The number of candidates who sat this paper was over 7500 and the average mark scored was 15.43 out of 30 which was lower than the average mark in May 2017 (17.03 out of 30).

There were 598 schools which took the exam, however there were at most 67 responses on completed teachers' comment forms. Teachers are encouraged to complete these feedback forms every examination session. Teachers who sent feedback generally found the paper appropriate with a good coverage of topics. Several teachers commented that the clarity of questions was improved from last year and that the paper had a range of difficulties. Some commented that the paper had many good questions although some took a fair length of time to solve.

These overall impressions are supported by the statistics. Approximately 67% felt that the paper was of similar difficulty to last year with 9% viewing it as slightly easier and 15% a little more difficult. 9% answered NA. Approximately 80% of respondents said the suitability of the paper in terms of clarity and presentation was good to excellent with 18% viewing it as fair and 2% as poor. Specific concerns will be addressed in individual question analysis.

The table below lists the questions from least to most difficult. It shows the numbers of candidates who selected each of the options A-D and the discrimination index for each question (how well the question discriminated between high-scoring and low-scoring candidates).

Question	A	B	C	D	Blank	Difficulty Index	Discrimination Index
5	**6739**	398	212	194	3	89.31	0.25
10	1273	562	**5282**	418	11	70.00	0.38
13	453	**5219**	628	1240	6	69.16	0.32
25	683	1187	**5131**	515	30	68.00	0.46
20	1584	273	**4904**	768	17	64.99	0.47
2	354	1748	**4898**	511	35	64.91	0.37
16	545	547	1678	**4767**	9	63.17	0.45
8	704	**4710**	1242	877	13	62.42	0.52
1	633	452	**4709**	1747	5	62.40	0.33
7	657	882	1454	**4538**	15	60.14	0.59
6	674	**4482**	1078	1299	13	59.40	0.33
17	701	**4403**	1924	512	6	58.35	0.46
9	1193	**4303**	1532	506	12	57.02	0.38
28	298	**4246**	2272	710	20	56.27	0.48
19	803	1083	1434	**4211**	15	55.80	0.53
3	**3741**	2139	553	1105	8	49.58	0.33
15	1375	1306	1206	**3652**	7	48.40	0.52
26	1721	699	1636	**3440**	50	45.59	0.51
27	**3403**	1739	1494	857	53	45.10	0.51
29	396	2189	**3392**	1532	37	44.95	0.38
30	**3385**	1206	1459	1413	83	44.86	0.43
18	1475	2572	**3300**	186	13	43.73	0.54
24	**3248**	1324	2086	862	26	43.04	0.46
12	1367	951	2052	**3159**	17	41.86	0.36
23	3368	632	671	**2838**	37	37.61	0.50
11	694	**2773**	2868	1199	12	36.75	0.31
4	2108	2421	629	**2354**	34	31.20	0.50
21	2745	799	**2265**	1705	32	30.02	0.34
22	**1848**	961	2738	1974	25	24.49	0.38
14	**979**	488	5622	438	19	12.97	-0.03

Number of candidates : 7546

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

- (1) 62% answered correctly with the idea that chalk and sand could form a homogenous mixture being the most common misconception.
- (2) Some teachers raised concern that a little more mental math was required for this calculation than usual however 65% answered this correctly and it did not appear to be an issue.
- (3) 50% correct with the most common misconception being that an inverse relationship is linear.
- (4) A poorly answered question. One teacher comment suggested that many students would know how to do the calculation but not in the format of this question. The most often chosen wrong answer does not support this as it incorrectly converts grams to mol and the discriminatory index shows it was handled better by higher scoring students.
- (5) This question had the highest correct percentage with no common misconception as all distractors seemed to have equal weight.
- (6) One teacher said frequency can also mean (number of blue lines) in addition to frequency (1/s). While this is correct and could have been made clearer it is also fairly obvious the question is referring to the hydrogen spectrum. Furthermore, it would not have influenced the answer as convergence at longer wavelengths is incorrect and in three of the possible answers.
- (7) 60% answered correctly and it had the highest discriminatory index on the test. Most of the incorrect responses correctly picked ionic bonding but had confusion on the properties.
- (8) 62% correct answers and also a high discriminatory index points to Topic 3 being one of the better answered topics in the paper. There was no one incorrect answer which really stood out.
- (9) Relatively well answered question about correct formula of ammonium phosphate.
- (10) 70% answered correctly with the biggest misconception being graphite is a lower conductor of electricity than diamond. There were a few misconceptions concerning delocalization throughout the exam.
- (11) Only 36% answered correctly with the common misconception being that NO_3^- has a lone pair rather than a double bond, yielding a trigonal pyramidal geometry.
- (12) One teacher thought it to be a bit tricky because propanone is only slightly polar. However, it was answered correctly by 42% of the candidates and the most common misconception being hydrogen bonding rather than London dispersion forces.
- (13) Nearly 70% answered this correctly with no common misconception. One comment suggest D could be correct depending on how the experiment was carried out, however the question clearly states a flame heating a glass beaker and not a calorimeter being used.
- (14) With only 13% correct answers this was by far the poorest answered question on the test. The misconception being the question asks for the answer in kJ mol^{-1} and the equation is for 2 mol of butane. This seemed confusing to all candidates.
- (15) The 2nd question on Topic 5 was answered better at 48% and had a relatively high discriminatory index. All three distractors were chosen nearly equally by candidates who chose the wrong answer.

- (16) Answered correctly by 63% of candidates. Some candidates believed that increasing volume of equal concentration of HCl would increase rate being the most frequently chosen wrong answer.
- (17) One teacher commented that activation energy not being influenced by temperature is HL, however only E_a calculations are HL. Understanding that increasing temperature does not alter E_a is a key concept of Maxwell-Boltzmann curve explanations.
- (18) Answered correctly by 44%. Almost the same number of candidates stated that doubling the coefficients in a balanced equation means one should double the rate constant as those correctly stating that the rate constant is squared.
- (19) 56% of candidates could correctly identify Bronsted-Lowry acids and bases. This question also had a fairly high discriminatory index.
- (20 A well answered question with 65% being able to pick the products of an acid base neutralization.
- (21) A very poorly answered question with the majority of candidates picking O in OF_2 has having been reduced, rather than oxidized by the fluorine. Many teachers also commented that the oxygen is reduced in $2F_2 + O_2 \longrightarrow 2F_2O$ and believed there to be 2 correct answers to this question.
- (22) This was the 2nd most missed question on the exam. Most candidates picked that calcium ions and bromide ions are products of electrolysis as opposed to the elements.
- (23) Only 38% answered this redox balancing equation correctly with the majority of candidates balancing the atoms but not the electrons.
- (24) 43% answered correctly, however many candidates believed that butanal had the formula $C_4H_{10}O$ despite having a double bond.
- (25) Well answered question with 68% correctly identifying products of the reaction between steam and hex-3-ene.
- (26) 48% could correctly pick the free radical mechanism reaction. The high discriminatory index shows this was handled better by higher scoring candidates.
- (27) The majority of higher scoring candidates had no problem identifying the products of oxidation of a primary alcohol by acidified potassium dichromate.
- (28) Correct use of significant figures was well done.
- (29) Identifying index of hydrogen deficiency was well done with no clear distractor chosen as a wrong answer.
- (30) There was one comment that students should not have to predict NMR spectrum from structure but the guide clearly states that integrated traces should be covered.

Recommendations and guidance for the teaching of future candidates

- Candidates need to be reminded that they should choose the best answer to each question and to leave no questions unanswered.
- Ensure the whole syllabus is taught as every topic is examined in this paper.
- Questions in paper one follow the order of the guide so candidates can begin at a topic they are confident in if Stoichiometric Relationships (Topic 1) is not their strongest choice.
- Candidates should read questions carefully and pay special attention to anything which is in bold. Question 14 was the most missed question on the exam probably due to not

answering specifically what was asked.

Higher level paper two

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 15	16 30	31 39	40 50	51 60	61 71	72 95

General comments

This was an accessible paper with the mean mark considerably higher than May 2017 and many more candidates reaching the highest mark. There was some evidence which demonstrated excellent knowledge of the subject. There was, however, also evidence that some candidates failed to grasp even the most basic chemical concepts. Despite having higher percentage of students receiving the top grade from the previous year, there was also a higher percentage of students earning the lowest grade.

There is evidence that candidates found it difficult to finish the paper, with the percentage attempting each part question falling in the region of question 7. This has been a worrying trend and as a result **Paper Two will be 90 marks instead of 95 beginning May 2019**.

62 teachers gave feedback from a total of 377 schools. 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
2	21	58	11	2

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

	Too easy	Appropriate	Too difficult
Level of difficulty / %	2	92	6

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

	V poor	Poor	Fair	Good	V good	Excellent
Clarity of wording	0	3	13	29	44	11

Presentation of the	0	0	5	29	39	27

In general, the paper seems to have been well received with comments such as “much fairer than last year” and “the analysis (critical thinking) questions this year were excellent”.

A few teachers commented on the length of question 1 as ‘off putting’. One teacher commented “some of the longer questions could be simplified further.” The length of the paper, with many 1 and 2 mark questions was a main concern by a number of teachers. This will hopefully be alleviated in May 2019 when the paper is reduced to 90 marks.

One teacher commented “This year's paper seems to cover a lot more of the content and not topic order. Students needed to be able to connect all aspects of chemistry to be able to answer the questions that pulled from many different topics”. Being able to see how the various topics of the curriculum relate to each other is essential and students should not expect to see Paper Two follow any particular topic order.

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

- Explanation of processes, such as how to find atomic mass from a mass spectrum, understanding of why TMS was used (and is still the reference) in ^{1}H NMR spectroscopy, how to monitor rate of a reaction, and how to determine Activation Energy.
- Predicting electron domains and molecular geometries.
- Description of how sigma and pi bonds are formed.
- Arithmetic errors and incorrect signs in calculations.
- Explaining, using appropriate equations, how a buffer solution works.
- Writing equations involving Lewis bases.
- Identifying similarities with S_N1 and S_N2 reactions.
- Explanations of bonding, such as the nature of an ionic bond or why calcium can conduct electricity.
- Emission spectra

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

- Stoichiometric calculations involving % composition and mass calculations.
- Most energetics calculations involving ΔH_f enthalpy, bond enthalpy, and entropy.
- Identifying bonds responsible for signals in an ^{1}H NMR spectrum.
- Writing equilibrium expressions.
- Explaining and predicting physical properties based on intermolecular forces
- Balancing equations.
- Estimating pH of solution.
- Stating environmental impact of acid rain.
- Predicting difference in rates of reaction with a strong or weak acid.

- Redox reactions, electrochemistry of voltaic cells.
- Deducing polymer repeating structure from a monomer of ethane.

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

Question 1

- (a)(i) Calculation of the percentage by mass of N in urea was generally well done with some candidates rounding off the molar mass of urea and others not listing the answer to two decimal places.
- (a)(ii) Very poorly done with few recognizing that nitrogen is the essential element in urea for use as a fertilizer. Many candidates believed that nitrogen in fertilizer is in a gaseous state requiring special measures for transport or stated that nitrogen is toxic. Only few could apply the concept of % composition by mass as it relates to cost of transport. A couple of comments suggested that the question did not test their chemistry knowledge, however applications of stoichiometric calculations is one of the foundations of chemical industries.
- (b) Many candidates struggled with the term electron domain geometry, instead giving bond angles or hybridization as an answer.
- (c) Generally well done with some finding incorrect moles due to not converting 50 cm^3 to 0.05dm^3 before multiply by molar mass.
- (d)(i) Generally well done; few did not include the concentration of water despite it being listed as gaseous. Some included [2NH_3] instead of $[NH_3]^2$ in the equilibrium constant expression.
- (d)(ii) Mostly good performance with mark missed because candidate answered about shift of equilibrium and not value of equilibrium constant.
- (d)(iii) Mediocre performance; either candidates did not know the equation to use ($\Delta G^{\ominus} = RT\ln K$) or used consistent units; some were not able to convert the ln*K* to *K.* One teacher commented that order of magnitude should not be asked for. The mark scheme allowed both order of magnitude and calculated answer.
- (e)(i) Generally good performance; some referred to heavier or greater mass rather than specifically suggesting urea has greater molar mass. Similarly, others made reference to greater intermolecular forces/IMFs instead of being specific or referred to the presence of C=O. One teacher commented that urea was a gas in the equilibrium expression but then listed as a solid at room temperature. The temperature in the equilibrium expression is not given so should be considered a gas in the expression as written.
- (e)(ii) Most scored at least one mark; however, some drew solid line or curly arrows to represent H-bonding; others included lone pairs on the N and O atoms but a lone pair was not always involved in the H-bonding. Some showed urea or H bonding between water molecules rather than ammonia-water interaction.
- (f) Generally well done. Some weaker candidates wrote N rather than N_2 as a product or simply wrote the formulae and made no attempt to balance the equation.
- (g) Generally well done; typical errors were not using the correct value of the molar volume or using the ideal gas equation without using STP values from the data booklet. Also, errors in using correct volume unit was an issue for some. One valid comment

was that “**in cm^3**” could have been bolded to make the units wanted clearer.

- (h) pair with the metal ion; others did not refer to coordinate or dative bonding. One teacher commented it was unclear as to if N or O was acting as the ligand, however neither were necessary to be mentioned and both were awarded the mark if they were.
- (i) Poorly done; few made reference to lone pair on N atom being donated to or shared with the C-N bond nor suggest the positive dipole on C due to the C=O. Others who identified a possible cause couldn’t express it properly stating “electrons are desired more or carbons wants to gain electrons or because N is more electronegative it pulls harder on the bond”. Scientific literacy and correct use of terminology was a consistent problem throughout the exam.
- (j) Most could deduce some fragment but few scored both marks. Typical answers were leaving out the + sign on the molecular ion (for m/z = 60) or the fragment at m/z = 44.
- (k) Very well done; few listed O-H as the bond with the absorption at 3450 cm^{-1}.
- (l)(i/ii) Mediocre performance; candidates either scored both for (i) and (ii) or neither. Candidates clearly understood the basics of ^{1}H NMR or they had no idea, often leaving the response blank.
- (l)(iii) Majority of candidates earned at least 1 mark for this question identifying it as a reference point or an inert substance. One comment suggested that the use of TMS in ^{1}H NMR spectroscopy should not be tested but it is clearly in the syllabus and a significant factor in using this technique.

Question 2

- (a) Satisfactory performance; many answers referred to ions being formed through electron transfer from metal to non-metal rather than the ionic bond as electrostatic attraction between oppositely charged ions.
- (b) Satisfactory performance; often description referred to the furthest molecular ion peak or to fragmentations instead of m/z values as identifying atomic mass of isotopes and using the frequency of each isotope to calculate the weighted average.
- (c) Poorly done. There was a widespread confusion between emission and absorption spectra with many even stating the colour seen is the complement of the colour absorbed. Few were able to explain why Ca and Na give different colours.
- (d)(i) Fair performance; some suggested difference in protons or electrons, others stated Ca is heavier or more massive without reference to atomic mass.
- (d)(ii) Good performance. Some candidates suggested because electrons can move through rather than calcium’s mobile electrons.
- (e) Generally good performance although a fair number of candidates did not show a steady rise in ionization energy with each successive ionization. One comment suggested that log I.E. should not have been the y-axis because the question stated to sketch the first 6 ionization energies and not their logs.
- (f) Very good performance with most candidates identifying a basic solution.
- (g)(i) A common question which was not done well. Description of both sigma and pi bonds needs reference to overlap of orbitals. Also, reference to internuclear axis overlap in sigma bond and overlap of parallel p orbitals in pi bond was not always clearly identified.
- (g)(ii) Generally very well done. In contrast to 2(g)(i) it is clear candidates can identify the sigma and pi bond in a diagram but have difficulty explaining them.

Question 3

- (a)(i) Good performance; some incorrectly chose acid or did not name a specific catalyst.
- (a)(ii) Good performance; however too many candidates included double bonds in the polymer or did not include connecting lines at end of C atoms.
- (b) Average performance; chlorination of benzene was unknown to many candidates. One teacher commented that alkynes are not part of the syllabus and should not be tested but the question clearly states ethyne reacts in a similar way as ethene.
- (c)(i) Well done by most. Candidates usually identified that the answer could be found by using ‘bonds broken-bonds formed’ with some using incorrect data for C to C bonds in benzene.
- (c)(ii) Well done. Quantitative questions were generally handled fairly well.
- (c)(iii) Good performance; some did not refer to bond enthalpy values being averages or $\Delta H^{\ominus}$ values are specific to the compound and many did not specify that benzene is in two different states.
- (c)(iv) Well done. Quantitative questions were generally handled fairly well.
- (c)(v) Kelvin scale or inconsistent use of units for $\Delta S^{\ominus}$. Some did not comment on the spontaneity of the reaction.
- (d) Poor performance; some referred to delocalization without stating all carbon-carbon bonds being equal or referred to equal bonds without mentioning C-C bonds or stated chemical evidence. Many responded to what the formula should be as opposed to physical evidence for it being incorrect.

Question 4

- (a) Average performance; reference to disappearing $CaCO_3$, gas bubbles, amount of gas, release of CO_2 or colour change did not score points. However, progress could be monitored through monitoring loss of mass or by measuring volume or pressure of gas produced.
- (b)(i) Candidates found this a tough question to answer. Many candidates displayed a lack of good experimental observation skills in this and other questions. Most candidates struggled and failed to suggest a reason for point D out of the line. Very few gained the mark for “reaction is very fast and difficult to measure accurately”, however, many were capable of suggesting that HCl is no longer the limiting reactant at that concentration.
- (b)(ii) Good performance; some did not draw a line of best fit though the origin and some drew exponential curves. Candidates should recognize that 0 concentration and 0 rate could be considered a data point for use in the best fit line.
- (b)(iii) Good performance; however, some suggested rate increases as concentration does without reference to proportionally.
- (b)(iv) Fair performance although some had $[CaCO_3]$ term in the rate expression and others had rate = $k[HCl]^2$ despite writing direct proportion in 4b(iii).
- (b)(v) Generally done well but some problem with ECF using units from rate expression as written in 4b(iv)
- (c) Good performance by most with some forgetting to include the $\times 10^{-3}$ from the y-axis in the answer. Others read the rate of reaction / 10^{-3} mol dm^3 as divided by rather than the slash meaning units.

- (d) Poorly done. The majority of candidates struggled in describing how the activation energy for a reaction could be determined and failed to gain three marks. Those who recognized the Arrhenius equation for this could not identify the measurements needed, what to graph, or how to use the formula for only 2 different temperatures without graphing.

Question 5

- (a) Very well done. A few stated that HCl would react more completely as opposed to faster.
- (b) Very well done. The vast majority of the candidates could state an environmental effect with incorrect answers losing the mark due to be too vague, such as answering “pollution”.
- (c) Poor performance; many were able to write the correct equation for ammonia acting as a Brønsted-Lowry base but very few an equation to show it acting as a Lewis base, either with BF_3 or complex ion formation with transition metal ion.
- (d) Poor performance; many used the Henderson-Hasselbalch equation and assumes pH was equal to pK_a or were not able to solve it for $[H^+]$.
- (e) Mediocre performance at best; many did not write appropriate equations to explain buffer action and others simply stated generic answers. Some wrote reactions of the acid with water showing dissociation but not reactions with and acid or base showing it as a buffer.

Question 6

- (a) Generally well done. Identifying the salt bridge was done very well but its function sometime not properly explained, instead stating things such as ‘keep electrons flowing.’
- (b) Generally well done but some disappointing concept gaps in the mistakes, such as showing two oxidations or two reductions.
- (c) Very good performance. Some incorrect answers included arrows showing electron flow the wrong way or electrons flowing through the salt bridge rather than the wire.
- (d) Generally well done though some did find negative answers.
- (e) Done poorly by most. Many worked on ratio of masses or simply assumed it to be conservation of mass. Some who had the mol ratio correct had the wrong electrode losing/gaining mass despite having the correct equations in 6(b).

Question 7

- (a) Average performance; although the difference in the mechanisms of a primary and tertiary halogenoalkane with sodium hydroxide was typically answered well, candidates had difficulty identifying two similarities.
- (b) Relatively good performance. Many candidates stated larger atom or electronegativity difference rather than weaker C-X bond with Br.
- (c) (i) Good performance with a few candidates simply stating butanol instead of butan-1-ol.
- (c) (ii) Poorly done with few candidates actually knowing the reduction with $LiAlH_4$.
- (c) (iii) Relatively good performance with no common misconceptions. Incorrect answers varied widely, including naming the compound instead of identifying the class of compound.

Recommendations and guidance for the teaching of future candidates

- Teachers need to be explicit in the use of correct terminology and candidates should be well practised in constructing detailed explanations. Avoid anthropomorphic explanations such as “ions like to have complete octets.”
- Practice common sense applications such as % nitrogen by mass in fertilizer as it relates to transportation cost.
- Practice bond representation; dashed lines for hydrogen bond, curly arrows for electron pair movement, solid lines for covalent bond.
- Elicit examples of Lewis bases from candidates.
- Give students simple everyday problems to improve common sense skills.
- Allow ample laboratory experiences. While many students could perform calculations which they might find in an experiment, few were able to explain procedure or answer questions which involved interpretation and evaluation skills.
- Allow an appropriate amount of time for organic chemistry

Standard level paper two

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 7	8 14	15 20	21 26	27 31	32 37	38 50

General comments

There were 92 teachers’ comment forms received commenting on the exams. Most of these respondents felt that the paper was at an appropriate standard and similar in difficulty to 2017. Also, the respondents indicated that the paper was well presented and did not present any access problems for students with additional learning needs.

However, when marking the paper, it was found that there were a number of students who were not sufficiently prepared and scored very poorly on what was a generally straightforward and accessible paper.

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

- Practical problems of transporting chemicals and very little knowledge of the chemistry on nitrogen. Many thought that it was still elemental in urea, or that it was toxic/explosive/dangerous and required specialist transportation.
- Not mentioning electrostatic attraction, when describing bonding.
- Organic chemistry in general- conditions for reactions, mechanisms and physical data

for benzene

- Electron domain geometry
- Analysing data from techniques such as mass spectroscopy and NMR
- Describing practical experiments in brief and explaining experimental data obtained.
- Explanation of colours from heating metal salts
- Hydrogen Bonding and explanation of state in terms of IMFs
- Half equations.

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

- Calculations of % nitrogen; mass of urea in a volume of solution; and ΔH from equations
- Molecular geometry but not electron domain geometry which seemed to be a term not covered
- Relating enthalpy changes to equilibrium although many students failed to state the effect on the equilibrium constant (which was what the question had asked)
- Electron configuration of ions
- IR spectral analysis
- Knowing that bond enthalpies were average values.
- Purpose of salt bridges.

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

Question 1

- (a)(i) This was generally answered well apart from miscalculation of the molar mass or rounding errors for the final answer.
- (a)(ii) It was very rare to have a correct answer even with stronger candidates. Most common mistake was mixing up transport of nitrogen with that of urea. Commonly nitrogen was thought to be heavy, toxic, corrosive, explosive, dangerous, or it would vaporise and so need extra precautions so cost would in each case be higher for a higher % N.
- (b) Mostly incorrect for electron domain geometry where a range of answers were seen e.g. angles, permutations of the correct answers or it was just left blank.
- (c) Mostly correct except for weaker candidates who left this blank
- (d) Great confusion here and rare for a candidate to score 2 marks. Some correctly identified the forward reaction as exothermic but then forgot to say K_c would decrease. Weaker candidates thought that K_c would shift to the left or right confusing it with the equilibrium position.
- (e)(i) Calculation of the mass of urea was generally well done.
- (e)(ii) Hydrogen bonding was not well known and lone pairs on N and O were rarely shown. Some had solid lines or arrows whilst others completely misinterpreted the question and wrote equations for the formation of ammonium hydroxide. Weaker candidates made up incorrect formulae of water such as HO_2.
- (f) About half the students had a correct equation but some thought nitrogen was monatomic; and others forgot to add oxygen to the LHS as a few did not realise that

combustion meant reaction with oxygen. Surprisingly quite a few who managed to have all the reactants and products were unable to balance the equation.

- (g) Lots of missing + signs for the fragments so it was rare for students to score both marks.
- (h) Most students could correctly identify the IR absorptions except weaker candidates suggested OH, aldehydes, bases or left it blank.
- (i) NMR was obviously difficult for students and very rarely correct as most common answers were 2,3,4 or 8 instead of 1 as there was only one environment.

Question 2

- (a) Many left out electrostatic attraction from their definition and others confused ionic with covalent or metallic bonding.
- (b) Most candidates could successfully write the electron configuration of the calcium ion.
- (c) Students generally could not identify the source of the colours as movement of electrons from a higher to a lower energy levels. Some confused emission of the energy with that of absorption of energy. Very few gained the second point by explaining that different atoms would have different energy levels and so give rise to different colours.
- (d)(i) The explanation of the difference in density was reasonable but many either only mentioned that molar mass was greater for Ca, or its atomic radius was smaller. The main mistakes were just to say larger mass or larger atom- which was too vague.
- (d)(ii) Most students knew that calcium was a good electrical conductor because it has a sea of delocalised electrons. However, weaker candidates thought ions moved or mentioned difference in electronegativity.
- (e) Most candidates realised the solution would be basic and as long as they had a pH above 7 (and below 14 as it is a weak alkali) the mark was awarded.

Question 3

- (a)(i) Students were unfamiliar with the conditions for the hydrogenation reaction so most scored 1 mark for heat or high temperature or pressure. Only a few could suggest a suitable catalyst such as nickel.
- (a)(ii) Drawing the polymer chain of 3 repeating units was very poorly done. There were multiple brackets in the chain, C=C in the middle of the chain, missing Hs, equations with more or less than 3 repeat units given, and missing continuation bonds.
- (b)(i) Many candidates did not use the correct values for benzene carbon to carbon bonds so many only gained the ECF mark for reactants – products.
- (b)(ii) This question was generally done well and candidates successfully subtracted reactants from products but weaker candidates forgot to multiply the reactants by 3.
- (b)(iii) Very few were able to describe the differences in the values obtained to gain 2 marks, but some did notice the different phases of benzene in the two calculations. Some explained that as average bond enthalpies had been used the valued could be unreliable.
- (c) Many students could not explain the physical evidence for why the Kekulé structure was incorrect and instead mentioned resonance or flickering C double bonds or 'hasn't got the right bonds'
- (d) This was answered very poorly as although some identified the mechanism as substitution, very few knew it was electrophilic substitution and instead answered

nucleophilic substitution; others had no idea and wrote addition or hydrogenation.

Question 4

- (a) Students did not generally answer the question posed - how a measurement of change over time could be monitored. Instead they often said observe gas bubbles or the mass rather than measure the increase in volume of CO_2 produced or measure the decrease in mass.
- (b) Students didn't understand the practical evidence related to point D nor did they provide a mathematical relationship for points A-C. Most just stated rate increases as concentration of HCl increases, but some correctly had a directly proportional or linear relationship; but others had positive correlation which was not accepted.

Question 5

- (a) Generally this question was well answered as they knew that hydrochloric acid was stronger than ethanoic acid. However, some thought HCl wouldn't remove limescale as it was basic.
- (b) The question on acid rain was generally well answered

Question 6

- (a) Pleasingly most students knew that the salt bridge was missing and what its purpose was.
- (b) Very few correct equations were written. If they were correct they were often at the wrong electrodes. Also, some strange ions appeared such as: Ag^{3+} or Ag^{-} or Mg^{-}
  Most of the weaker candidates left this question blank.
- (c) Generally students correctly showed the electron flow.

Recommendations and guidance for the teaching of future candidates

- Allocate time to practical work and to drawing out the significance of what have been measured, how the results can be interpreted and whether the conclusion reached is accurate and/or valid.
- Study more organic chemistry and learn the terms and conditions for reactions.
- Revise mass spectra and NMR so that students understand what the principles are behind the methods used.
- Ensure students learn correct terminology so that they can accurately explain and describe concepts such as bonding.

Higher level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7

Mark range:	0 5	6 11	12 17	18 21	22 26	27 30	31 45

General comments

Many candidates were well prepared and performed well on this paper, although some appeared quite unfamiliar with the subject material. The mean score was 17.27 out of 45.

62 teachers submitted teachers' comment forms following the examination. 85.48% of respondents (53 teachers) have rated the difficulty of the paper as appropriate. 12.9% (8 teachers) rated it as too difficult. These same 62 teachers said that the paper was of similar standard to last year (40 respondents), a little more difficult (11) and much more difficult (2). Only 5 thought the paper was easier than last year.

Significantly, 14 of these teachers felt that the clarity of wording was below par (4 stating it was poor and 10 that it was fair). However, they were more than balanced by teachers who rated the clarity of wording positively.

Most candidates answered Section A and one option from Section B, although there were a small number who did not attempt Section A. Most candidates confined themselves to only one option. Option D was the most popular, followed by Option Cs and B (very similar in popularity). Very few answered Option A.

Candidates seemed to have had adequate time to answer all questions.

Many candidates appeared to not read the question properly and missed key points.

Candidates were often not specific enough or scientific enough in their use of terminology. In many cases, answers were either too general or too vague and attention to detail was generally lacking.

Candidates had difficulty articulating answers, not just including the right key words, but also determining what information was necessary to answer the question and what facts were related to the question but not necessary for scoring marks.

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

- Intermolecular forces
- Uncertainties
- Production of nanotubes
- Superconductors
- Relationship between intermolecular forces and boiling points
- DNA – triplet code concept
- Significance of Michaelis constant
- Hydrolytic rancidity of lipids
- Structure of cellulose fibres
- Colour explanations of anthocyanins
- Uranium enrichment

- Critical mass
- Lithium ion battery – half equations
- DSSCs
- Explanation of how a polarimeter can be used to determine the relative proportion of two enantiomers
- Radiotherapy
- Principles of fractional distillation

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

- Performing numerical calculations
- Use of state symbols
- Dipeptide structure
- Solubility of vitamin A
- Enzyme-catalysed reactions
- Nuclear fission
- Bioavailability of aspirin
- IR spectroscopy
- Outlining how strong analgesics function
- Use of Raoult's law

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

Section A

There were many comments about Section A. This section consists of data analysis of an unfamiliar topic and questions relating to practical activities with which candidates should have had some experience. Candidates should expect to have a question on new material which requires them to think analytically. Many respondents felt that the first question was too difficult, but thought the second question was appropriate. One suggested that the first question favoured Biology students and another that it favoured Physics students. Thank you to the person who "really liked Section A's questions" because they "seemed to test knowledge of scientific reasoning".

Question 1

Many candidates correctly circled all of the hydrophilic part of palmitic acid molecule. Some were careless and drew lines that did not include complete atoms or did not stop at the C-C bond. Several candidates drew circles around only the OH group or around all of the hydrogen atoms on the hydrocarbon chain.

Explanations of the formation of a fatty acid monolayer were generally poorly done. Despite the question prompting answers in terms of intermolecular forces these were rarely forthcoming.

In part (b), very few candidates seemed to understand the use of the Longmuir trough apparatus or how to interpret a graph of surface pressure against surface area. Answers frequently referred to gas laws or the evaporation of the solvent.

Calculations of the number of molecules in a drop of palmitic acid and the area occupied by a single molecule were generally answered well. It is alarming that candidates who calculated incorrectly seemed quite unaware of the enormous surface area they had determined.

Question 2

Some sections of this question were generally answered well and other sections proved difficult for the majority of the candidates.

Most candidates correctly annotated the equation with state symbols. Common errors were HCl(l) and H_2O(aq).

Outlining a method to determine the initial rate was more challenging. Some candidates had clearly performed a similar experiment and comfortably described what to do. Others either had difficulty articulating a method, did not refer to “at different times”, or had not experienced an experiment to determine the rate of reaction with CO_2(g) product. Several comments stated that this question was unfair as schools with economic disadvantages would have limited access to the equipment required for this experiment. One suggested that it was only tangentially related to required practicals, and another that this was a poor choice to assess understanding of lab work. We feel that the choice of hydrochloric acid reacting with marble chips is a reasonable one that most schools should be able to access. Simulations also exist.

Most candidates understood the impact of a limiting reagent and of surface area on reaction rate. However, several candidates did not read the question correctly, and gave temperature as a factor which could vary between marble chips of exactly the same mass.

Most candidates attempted to answer (d)(i) in terms of propagation of uncertainties rather than realizing that there was a very large variation in individual time measurements. Topic 11 in the Chemistry Guide refers to human reaction times in ‘Understandings’.

A significant number of candidates doubled the time when reaction rate was doubled, indicating a lack of understanding of rate experiments.

Part (d)(iii) required candidates to identify an error as systematic or random and to give a reason. Some candidates gave the reason but failed to score because they neglected to identify the error. Some candidates correctly stated ‘systematic’ but could not adequately articulate their reason.

Section B

Option A – Materials

Question 3

This question was answered reasonably well. Most candidates scored at least one mark for the structure of aluminium. They could identify a composite material and one physical property of HDPE that is affected by incorporating carbon nanotubes. One comment stated that it was unfair to integrate carbon nanotubes into HDPE and liquid crystals, however candidates should be able to apply their knowledge, and in fact many did so.

Several candidates had difficulty describing the formation of carbon nanotubes by chemical vapour deposition, and identifying the property of carbon nanotubes that enables them to form a nematic liquid crystal phase.

Question 4

When comparing the structures of HDPE and LDPE most candidates scored a mark by referring to the branching of the polymers. A physical property that differed because of this structural difference was correctly identified by most.

Most candidates correctly outlined how homogeneous catalysts “reduce” activation energy.

The majority of the candidates scored a default mark for identifying mass spectroscopy as a suitable method to determine the concentration of metal in HDPE.

The majority of candidates successfully drew a monomer from which nylon-6 is produced and deduced the relative atom economy of condensation and addition polymerization.

Obstacles to be overcome in plastic recycling and in classifying plastics were less well understood.

Question 5

Calculations of the mass of aluminium produced in electrolysis, and of the separation of layers of aluminium atoms, were done well. The significance of the unit cell was less well understood. A comment stated that the diagram on the unit cell was confusing. In fact, the question could have been answered without looking at the diagram.

In part (d), most candidates recognised that aluminium is a superconductor at low temperatures but fewer stated that it is type 1. Explaining why the resistance of aluminium increases above 1.2K was poorly done, with several candidates referring to electrons being affected rather than thermal vibrations disrupting the Cooper electron pairs.

Most candidates correctly calculated the maximum concentration of aluminium ions in drinking water.

Option B – Biochemistry

There was one comment that Option B was “fair and tested the breadth of the syllabus” and another which listed several sub-topics that were not included on the paper. Teachers, and candidates, are reminded that it is not possible to assess every single point every session but that all sub-topics are examined in every examination as per a ratio of recommended teaching hours.

Question 6

Most candidates successfully drew the structural formula of the dipeptide although a few connected the amino acids through the R groups instead of the main chain.

Intermolecular forces were again an issue, with most responses indicating that both pairs of amino acid residues would have hydrogen bonding between them.

The majority of candidates scored the default mark for “from *R*f” when outlining how amino acids may be identified using paper chromatography. One respondent felt that it was unfair to test the use of paper chromatography to separate amino acids. The Guidance section of the Chemistry Guide for Option B includes: “Explanation of the processes of paper chromatography and gel electrophoresis in amino acid and protein separation and identification”.

Of concern was the difficulty most candidates had with describing how DNA determines the primary structure of a protein. Many candidates obviously study biology and gave answers in terms of mRNA, transcription and translation. It clearly states in the Chemistry Guide that different forms of RNA and the process of DNA replication are not required. It also states that “The sequence of bases in DNA determines the primary structure of proteins synthesized by the cell using a triplet code, known as the genetic code, which is universal”. Candidates must ensure that they use correct Chemistry explanations in a Chemistry examination and not an answer more suited to a Biology examination.

Question 7

Many candidates seemed unfamiliar with hydrolytic rancidity and the structural feature of lipids that causes it.

Clearly many candidates had used past exam questions for revision and were able to explain why stearic acid has a higher melting point than oleic acid. Common failings were a lack of comparisons and no mention of the packing of the molecules.

Most candidates could state the impact on health of consuming omega-3 fatty acids, and could predict the solubility of retinol in body fat.

An inability to express ideas restricted marks for explaining high levels of mercury and PCBs in sharks and swordfish: it was necessary to refer to the (often) non-biodegradable nature of the compounds or their accumulation in fat (or bodies) of animals which consume them, and to the increase in concentration of these compounds along a food chain. Many responses simply referred to prey organisms consuming the compounds which are then passed along to predators.

Similarly, inarticulate responses were given to outline how plastics can be made more biodegradable. Many candidates did not seem to understand the nature of the command term ‘outline’ and simply said ‘use corn’ or ‘add starch’. Greater detail is required to indicate that starch could be added to the plastic during manufacture, for instance.

Question 8

A comparison of properties of glucose and starch was poorly done. Many candidates scored one mark out of two for stating that glucose is water soluble or that it provides an immediate source of energy, or for stating that starch is a long-term energy storage.

Similarly, outlining why cellulose fibres are strong proved difficult. Many candidates referred to the polymerization of β-glucose molecules head to tail which did not answer the question. Some indicated branching of the polymer chain which is incorrect. Very few referred to hydrogen bonding between long chains.

Question 9

This question on a non-competitive inhibitor was generally well answered, but fewer candidates could outline the significance of the Michaelis constant, with the inverse relationship not mentioned.

Question 10

Few candidates could outline why anthocyanins are coloured or could explain why the colour changes as pH decreases. Commonly candidates referred to an increase in $H^+(aq)$ but protonation of the molecule was required for the mark. Candidates frequently omitted to state that electron transitions occur, instead stating that “light is absorbed”. In part (b), the decrease in conjugation and increase in the energy of the electron transitions was almost never stated.

Option C – Energy

Although some respondents felt that this option was much easier than the others, candidate marks did not support this notion.

Question 11

Candidates were required to identify a naturally occurring greenhouse gas and its natural source. Several missed the key word natural here and referred to ozone as part of photochemical smog. A common mistake was NO_2 for N_2O. The most common answer was methane produced by cows. Writing an equation to show how H^+ ions are produced from aqueous carbon dioxide proved challenging for many. H_2CO_3 was not an acceptable product, nor was HCO_3 with no charge.

A common explanation of why oxygen and nitrogen do no absorb infrared radiation was that they do not stretch asymmetrically. For a diatomic molecule this is impossible. Simply stating that the molecules are non-polar was also unacceptable: it was necessary to state that there was no change in polarity or dipole moment.

Question 12

Explaining the principles of fractional distillation was very challenging with very few marks scored here. Few candidates have an understanding of the role of intermolecular forces in this process. However, the calculations of specific energy and energy density were done well, as was the explanation of why the energy obtained in a combustion engine is less than the theoretical values.

Question 13

The majority of candidates identified the major technical problem with using vegetable oil directly as a fuel and could name the chemical conversion to overcome this but had difficulty in stating the formula of a fuel produced.

Question 14

Writing half-equations for a lithium ion battery was poorly answered. A few candidates scored for correctly identifying the species which move between the electrodes.

Most could state the factor that limits the maximum current and how electrodes are designed to maximize the current.

Part (b) was about nuclear fission. Nearly all candidates named mass spectroscopy as a technique that could be used to determine relative abundances of uranium isotopes. Very few could explain uranium enrichment or critical mass but more correctly explained chain reactions.

Responses to community opposition to the use of nuclear fission reactors were again rather general and non-specific. Common answers referred to radioactivity but failed to include the details of this having a long half-life.

Question 15

Few candidates could correctly identify p-type semiconductors with a reason based on the electronic structure of indium. Lack of understanding of photovoltaic cells was evident with answers suggesting that an advantage of DSSCs is that they use solar energy and not fossil fuels. Candidates who correctly predicted which dye absorbed light of longer wavelength usually gave a correct reason.

Option D – Medicinal chemistry

Question 16

Candidates generally showed good understanding of the use and bioavailability of aspirin, although many candidates used the term ‘amount’ and not ‘fraction’, ‘proportion’ or ‘percentage’ when stating the meaning of bioavailability. The mark was not awarded for the incorrect terminology. There were some comments about 16(b)(ii) which required candidates to outline how the bioavailability of aspirin could be increased. We accepted making aspirin ionic although we were pleased that many candidates suggested intravenous injection.

Most candidates correctly compared the IR spectrum of aspirin with that of salicylic acid but a common mistake was to identify functional groups but not the absorption wavenumbers. The question referred candidates to the spectrum and section 26 of the data booklet, so wavenumbers were clearly required.

Candidates correctly described how penicillin combats bacterial infections and most could outline consequences of over-prescribing penicillin. However, candidates should take care to state that it is the bacteria which develop resistance to penicillin and not the person taking the antibiotic. It should also be emphasized that resistance and tolerance are not the same concept. Most candidates scored a mark for stating how penicillins can be modified to increase their effectiveness.

Outlining how strong analgesics function was answered well but suggesting why codeine is used more widely than morphine was not. Many candidates thought it was less addictive or not as strong instead of stating that codeine has a wider therapeutic window.

Most candidates had difficulty explaining how a polarimeter can determine the relative proportions of two enantiomers. Many had the incomplete statement that enantiomers rotate the plane of light in equal and opposite directions. Many seemed to think that the sample or the enantiomer rotated and not the plane of the light. Statements were quite general and lacked clarity and it was difficult to determine if the candidate had written anything worthy of a mark.

Question 17

Despite almost being given this equation in Section A which was already balanced, many candidates had difficulty identifying the products and balancing their equation. When determining the mol of HCl neutralised by one antacid tablet, several candidates only worked out the value for the magnesium carbonate and not for the calcium carbonate as well. Some respondents suggested this question was misleading but in the question ‘one antacid tablet’ was in bold.

There were some very good explanations of how omeprazole (Prilosec) reduces stomach acidity. Several incorrect answers referred to H2/histamine receptors which are targeted by Ranitidine. Some candidates simply wrote that the acid was neutralized, and a few even suggested that alginates were added to form a raft on the stomach contents.

Question 18

This question on how oseltamivir (Tamiflu) and zanamvir (Relenza) function against flu viruses was answered well by the majority of the candidates.

Question 19

Questions on radiotherapy proved very difficult. Very few candidates could describe how ionizing radiation destroys cancer cells or outline how Targeted Alpha Therapy (TAT) treats cancers that have spread throughout the body. Those who answered correctly usually achieved full marks for this question. Many candidates stated that alpha particles travelled around the body or simply repeated the stem of the question that TAT was useful to treat cancers that had spread throughout the body.

Question 20

Some teachers queried the inclusion of this question on the exam. “How is this relevant to medicinal chemistry?” This question “places undue emphasis on a relatively minor point in the syllabus.” Analytical processes are a significant aspect of this option and indeed of chemistry in general. According to the Teacher Support Material, D.9 Drug detection and analysis accounts for 16% of Option D and 40% of the additional HL material. The calculation involving Raoult’s law was done very well by the majority of candidates. The principles of fractional distillation were poorly understood with many references to solubility or chromatographic principles.

Recommendations and guidance for the teaching of future candidates

- Students should be encouraged to write legibly. Some handwriting was very difficult to decipher which makes it very difficult for examiners to award marks when the wording of the response is not exactly as expected.
- It is critical that core chemical principles are brought to the fore in the options, especially biochemistry and medicinal chemistry which have a biological focus.
- Students should be advised to use appropriate chemistry terminology and expressions so that there is no ambiguity about the meaning of the answer.
- Students should learn appropriate chemical equations for the processes studied in the options.
- 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 in an option and students are required to know the steps then it should be performed in class or by simulation.
- Students should work through past examination questions and markschemes carefully. Candidates need exposure to data-based scientific problems involving unfamiliar situations. They must be able to interpret graphical representations, critique and interpret data and draw logical conclusions involving scientific methodologies.
- Students should be trained to read the question very carefully and then direct their answer to the requirements of the question. Command terms should be emphasized throughout the teaching of the course.
- Teachers should make sure that all aspects of an option are taught as some sub-topics appeared to be poorly understood. Nature of Science parts of the syllabus should be covered along with the chemistry understandings.
- Environmental chemistry should be integrated in linked topics throughout the delivery of the programme. This strand is present in all four options and is of prime importance in the syllabus.

Standard level paper three

Component grade boundaries

Grade:	1	2	3	4	5	6	7
Mark range:	0 4	5 9	10 12	13 16	17 19	20 23	24 35

General comments

Candidates often find applying fundamental chemical concepts to novel situations rather challenging and so it proved with the first question in Section A. It was however reassuring to find that many candidates are now capable of carrying out straightforward calculations. The second question tested familiarity with an experiment similar to one they should have encountered. Whilst many candidates gained respectable scores, these were not always on the parts that had been anticipated as straightforward.

In Section B the performance of the candidates was even more variable with some showing an excellent knowledge of their chosen option. There was possibly less difference than in previous years on the attainment of candidates tackling the different options.

Overall, mainly as a result of the challenges imposed by Section A, there were very few high marks (<0.5% scored 30+!), though many did enough to display a sound knowledge of the subject. At the other end there was the usual distressing number of students who seem to have been entered for the examination in spite of having virtually no knowledge of chemistry.

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

- Using chemical understanding to interpret novel situations
- Explanation of phenomena in terms of the intermolecular forces present
- Relating graphical data to the behaviour of the sub-microscopic particles that give rise to it
- Describing how the initial rate of a given reaction might be determined
- Estimating a reasonable order of magnitude for the uncertainty of data
- Uses of inductively coupled plasma spectroscopy
- The intermolecular forces between non-polar amino acid residues in a protein
- Fractional distillation - a tendency to confuse with cracking
- Explaining why some molecules do not absorb IR radiation
- Writing the structure of the biofuel produced by transesterification of a given vegetable oil
- Techniques to determine the ratio of different isotopes
- The importance of neutron capture in nuclear fission chain reactions
- Identifying ways in which the IR spectra of related molecules will differ

- The difference between “tolerance” and “resistance”
- Differentiating between the mode of action of various anti-viral drugs

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

- Calculating the number of particles in a given volume of solution of known concentration
- Comparing how different techniques would be affected by a specified uncertainty
- Identifying how solid samples of a given mass might differ
- Differentiating between random and systematic errors and explaining the basis for this
- Physical properties affected by the incorporation of carbon nanotubes
- Understanding the meaning of the term “thermoplastic”
- Describing the difference in structure and physical properties of LDPE and HDPE
- Electrolysis calculations
- Drawing the structural formula of a dipeptide formed from given amino acids
- The class of reaction that splits proteins into their constituent amino acids
- Factors that increase the rate of rancidity
- Benefits of including omega-3 fatty acids in a diet
- Concept of “biomagnification” - though the underlying mechanism was less well understood
- The production of biodegradable plastics
- Greenhouse gases and their natural sources
- Reactions that make aqueous carbon dioxide acidic
- Minor elements present in fossil fuels
- Reasons why engines are not 100% efficient
- Potential hazards of nuclear fission reactors
- Use of aspirin as an anticoagulant
- Common features of IR spectra of related molecules
- Resistance to antibiotics as a consequence of over-prescription of antibiotics
- Calculation of amount from mass and molar mass
- Problems of relying on natural products as sources of medicinal precursors

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

Section A

Judging by comments made on the examination, many teachers do not realise Section A is supposed to test students’ ability to apply their knowledge of chemistry to novel situations.

Question 1

- (a)(i) Though about half the candidates correctly identified the carboxylate group as being the hydrophilic part of the molecule, it was a more challenging question than had been anticipated and many seem rather confused by the concept.
- (a)(ii) Very few candidates gained any marks for explaining why a unimolecular layer forms. Even though the question clearly stated “*in terms of intermolecular forces*”, most answers were framed in terms of polarity.

- (b)(i) Again very few students gained any marks because, even though the question asked about the "increase in the surface pressure as the area is reduced", most students described the situation rather than the reason for the increase.
- (b)(ii) Many students correctly calculated the number of molecules in a drop from its volume and concentration, though interconversion of dm^3 and cm^3 resulted in quite frequent power of ten errors.
- (b)(iii) The calculation of the cross-sectional area of a molecule proved a little more challenging and candidates did not seem to be worried by answers with positive, rather than negative, powers of ten.

Question 2

- (a) Inserting state symbols into the equation was expected to give most students a mark, but surprisingly less than half took advantage of it. Many candidates seemed to think that 1 mol dm^{-3} hydrochloric acid is HCl(l) not HCl(aq) and, most surprisingly, H_2O(g) was not infrequently encountered.
- (b) Very few candidates seemed to have carried out experiments to determine initial rate. Even those who realised that a graph was required, were unclear as to what was to be plotted against time, or suggested graphing concentration, which cannot be directly recorded, rather than mass or volume of CO_2, which can.
- (c)(i) This was relatively well answered with about two-thirds of students correctly identifying Method 2 as being the least affected by uncertainty in the mass of the chips, with most correctly giving the reason that they were in excess. Oddly many students referred to "*marbles*", as if they were the glass spheres used in children's games, rather than "*marble*", a mineral with the composition $CaCO_3$.
- (c)(ii) The confusion regarding "*between marble chips*" implying a difference in the chips themselves (such as surface area), rather than a difference in general reaction conditions (such as temperature), appeared to extend well beyond those not working in their first language.
- (d)(i) Again a question where very few gained a mark, with almost all discussing the propagation of the uncertainty from individual values to an average, rather than noting its value (±0.01 s) was much less than the spread of individual results or what could possibly be realistic for a person using a stop-watch.
- (d)(ii) Whilst probably realising that the reaction rate increased, about half the candidates doubled the time taken for the reaction to complete, rather than halving it.
- (d)(iii) Most students realised it was a systematic error and many correctly justified it by at least implying it was a consistent mistake in the method, or that it would always affect the final result in the same direction, or that it could not be reduced by further repetition.

Section B

Option A

Question 3

- (a) It was rare to find students discussing that the particles formed a close-packed lattice and that this left no space for water molecules pass between them.
- (b)(i) Most correctly recognised this description of a composite material.
- (b)(ii) It would be difficult to think of a physical property not affected by the incorporation

of nanotubes, with rigidity being the one most commonly selected.

- (b)(iii) Most candidates gained some marks for describing the process of CVD as being the decomposition of a carbon containing gas, diluted with an unreactive gas, to form nanotubes on the surface of a heated metal catalyst.
- (b)(iv) Many correctly identified the rod-shape of the molecules as being the required property.

Question 4

- (a) Many correctly stated that thermoplastics soften and can be moulded when heated.
- (b)(i) Quite a few candidates do not realise that "*compare and contrast*" requires a similarity as well as a difference, failing to point out that both polymers are comprised of hydrocarbon chains. Most were aware that LDPE has a much more branched structure than HDPE.
- (b)(ii) Most students realised that HDPE is stronger, more rigid and has a higher melting point than LDPE, though some appeared not to know the meaning of "*physical property*".
- (c)(i) This question was a little more challenging with less than half of the candidates knowing that the formation of some type of intermediate is critical to homogeneous catalysis.
- (c)(ii) Again, only a small number of students identified ICP spectroscopy, with any method of detection, as being the method of choice for identifying trace amounts of metals.
- (d) Quite a few students gained some credit here by referring to issues such as sorting plastics into different types or separating them from non-plastic waste. Some referred to toxic products being produced by burning plastics, even though combustion is not part of normal recycling.
- (e) Most students described one of the classification methods listed, rather than stating that the different classifications are useful for comparing different aspects of plastics.

Question 5

- The calculation of the mass of product in the electrolytic production of aluminium was often well done with the most common error being overlooking that 3 electrons are required to reduce each Al^{3+}.

Option B

Question 6

- (a) This was generally well answered with many students being able to select the required amino acids from the data booklet and correctly join them with a peptide bond, however if examiners had been less generous, many would have lost marks for lack of precision in the positioning of bonds in structural formulae.
- (b) Relatively few students recognised London dispersion forces as the major attractive force between the side chains of phenylalanine and valine, though rather more correctly identified hydrogen bonding between glutamine and asparagine.
- (c)(i) Almost all students realised that the breaking of a protein into amino acids involves hydrolysis.
- (c)(ii) Most students realised the importance of the R_f value for identifying amino acids,

though some discussed the mechanics of chromatography and the developing of the spots. Only a minority of students mentioned the importance of comparing the R_f with known amino acids under similar conditions.

Question 7

- (a)(i) Quite a few students recognised the importance of hydrolytic rancidity in the decomposition of saturated lipids and a number of these realised this involved the ester group.
- (a)(ii) Almost all students could identify a factor that would increase the rate of rancidity, with temperature being the most common, though quite a lot benefitted from this being accepted even if it did not state higher/increased temperature.
- (b) Most candidates gained some marks, through pointing out that that the straighter chains of saturated lipids, such as stearic acid, allowing closer packing of the chains and hence stronger London dispersion forces between them. Full marks for including all points were however relatively rare, with the final one being the most commonly omitted.
- (c)(i) Most students correctly identified a benefit of omega-3 fatty acids, with reduction of the risk of heart disease and their effect on HDL and LDL cholesterols being most often cited.
- (c)(ii) Over half the students appeared not to read that it was the solubility in fat, as a result of having a long, non-polar hydrocarbon chain, that was being asked and many discussed its aqueous solubility.
- (c)(iii) The term “biomagnification”, and to a lesser extent the concept it refers to, seemed to be well known. Mentioning that this occurs because these pollutants are (mostly) not biodegradable, so they accumulate in the fatty tissue of both predator and prey species was rare.
- (c)(iv) Many students correctly stated that starch could be used as, or incorporated into, plastics. There were fewer answers discussing other biodegradable polymers such as PLA based ones.

Question 8

- (a) Many students correctly identified the glycosidic linkage between sugar monomers.
- (b) About half the candidates realised that, being water soluble, glucose readily passes through the intestine and so provides an almost immediate energy source. A similar number, though not always the same ones, noted that starch provides longer term energy storage because it requires breaking down.

Option C

Question 9

- (a) About half of the candidates could name another greenhouse gas and most could give a natural source.
- (b) Many students could write an acceptable equation, or series of equations, to show how CO_2 forms H^+ in aqueous solution, though some gave the product as H_2CO_3.
- (c) Only a handful of students stated that no vibrations of these molecules resulted in a change of polarity/dipole moment. Quite a few attributed it to nitrogen and oxygen being non polar, but a number of non-polar molecules (most notably CO_2) do absorb

IR radiation through bending and asymmetric stretching.

Question 10

- (a) Most students could identify an element, other than C and N, found in fossil fuels, with N, O and S being the most popular choices.
- (b) There were very few answers that gained full marks for this question and a significant proportion of candidates confused fractional distillation with cracking. Almost all the students who did gain some credit referred to commercial, "tower condensation", fractional distillation rather than the laboratory process. Many knew it depended on differing boiling points, but few related this back to chain length and the strength of intermolecular forces. The products liquefying at different heights was also generally well known, but again rarely related back to the drop in the temperature going up the fractionation tower.
- (c)(i) Over half the students tackling this option correctly calculated the specific energy of octane and slightly fewer the energy density. A number of students incorrectly gave negative answers, presumably confusing it with ΔH for these are exothermic reactions.
- (c)(ii) Most of the candidates identified that energy loss to the surroundings, through heat or sound, results in a drop of efficiency.

Question 11

- (a)(i) Many students correctly identified high viscosity as the problem with the direct use of vegetable oils in engines (though a significant minority benefitted from a decision to assume the "high" if not stated!) and transesterification as the conversion used to remedy the issue.
- (a)(ii) Given the number of students who stated "transesterification" for the previous question, it was surprising hardly any could write the formula of the product of such a reaction.
- (b) Only a few students explained that crops grown to produce biofuels absorb CO_2 as they grow, with most relying on the acceptance of "renewable" as a summary of this.

Question 12

- (a)(i) Less than half the candidates identified mass spectrometry as the best technique for determining natural abundances of various isotopes.
- (a)(ii) Most students struggled to give an accurate description of nuclear fission, often stating that "*neutrons hit a uranium atom*" showing little grasp of its absorption into the nucleus triggering fission. Many had a basic understanding of a chain reaction, but the concept of "critical mass" often seemed rather vague.
- (b) Most students could accurately identify a reason for opposition to fission reactors, though sometimes when discussing radioactivity they failed to identify the very long half-lives of the products as the critical issue.

Option D

Question 13

- (a) Most students could identify a use of aspirin other than for pain relief; almost always its use as an anticoagulant to reduce the risk of strokes and heart attacks.
- (b)(i) Many identified bioavailability as relating to the drug reaching the blood stream or

site of action, but quite a few lost the mark by referring to the amount that did this, which is dose dependent, rather than the fraction or percentage.

- (b)(ii) Many candidates gained the mark through conversion of aspirin into "soluble aspirin" by reaction with an alkali such as sodium hydroxide, which was accepted even though it has minimal effect owing to the reprecipitation of aspirin in the acidic conditions of the stomach. A significant minority realised that intravenous administration was probably a better answer.
- (c)(i) Most students correctly identified an absorption common to both spectra, most commonly that of the carbonyl group at 1700-1750 cm^{-1}. Only a handful correctly identified the phenol O-H absorption at 3200-3600 cm^{-1} as the only absorption present in just one spectrum. Many thought that the C-O absorption at 1050-1410 cm^{-1} would only occur in aspirin, even though the carboxylate group also involves a C-O bond.
- (c)(ii) Even though this has been frequently asked in the past, many candidates were unable to provide complete answers, though some were aware of the breaking of the strained beta-lactam ring, some of interference with transpeptidase and some of bursting as a result of water absorption through osmosis.
- (c)(iii) Most students were aware of the problem of drug resistance, though a number failed to differentiate this from tolerance. Correctly identifying a second negative consequence proved a little more challenging.
- (c)(iv) About half the students tackling this option realised that making penicillin more effective involved modification of the side chain, though sometimes the way this was expressed lacked precision.
- (d)(i) The blocking of pain receptors in the brain by strong analgesics was quite widely known.
- (d)(ii) Many gained the mark by stating that codeine was less potent or had a wider therapeutic window, more however had the incorrect impression that codeine is less addictive.

Question 14

- (a)(i) Most candidates could write the correct equation for this reaction, maybe prompted by Question 2a, though incorrectly giving H_2CO_3 as a product was quite common.
- (a)(ii) A significant number of students did not read the question fully and only calculated the amount neutralised by the $MgCO_3$. Overall however the calculation was quite well done.
- (b) Many students correctly identified omeprazole as a proton pump inhibitor, though a few confused its mode of action with that of ranitidine, which is a H2/histamine blocker.

Question 15

- (a) There seems to be some confusion regarding which anti-viral drugs operate in which way. Just under half the candidates realised that oseltamivir and zanamivir both inhibit neuraminidase, preventing viruses being able to break down the host cell wall after replication, preventing the infection of other cells.
- (b) Many candidates were aware of difficulties in relying on star anise as a source of these drugs, with limited supply and the difficulty of extracting the low levels of the drug precursors being those most commonly cited.

Recommendations and guidance for the teaching of future candidates

- Giving candidates more practice in dealing with the novel situations they are likely to encounter in Section A of Paper 3, as often the candidates did not seem capable of applying their chemical knowledge to interpreting the situations presented. IA data from former candidates can provide good examples.
- Carrying out more exercises in which candidates are required to deal with experimental uncertainties or reflect on weaknesses in practical techniques.
- Devoting more time to the teaching of the Option, as the results show that many were ill prepared to answer questions on them.
- 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.
- Encouraging candidates to show their working in calculations so ECF can be applied.
- Practicing writing answers to questions frequently asked so as to avoid making similar mistakes to those made in the past, particularly with regard to the precise use of language.
- Noting that the Nature of Science sections of the syllabus are examinable.
- Ensuring candidates clearly discriminate between intramolecular and intermolecular interactions, and when these are broken, as well as the circumstances in which different types of intermolecular forces occur.