Chemistry
Open-ended Questions
Support Materials

[HIGHER]
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Open-ended questions

Assessing insight, rewarding creativity

The Higher Chemistry examination has always contained a range of question types. Some test knowledge and recall of chemical facts, whilst others assess the student’s ability to carry out calculations, interpret data, write short explanations or design experiments. One type of question that is new to the revised Higher is the open-ended question.

The purpose of this document is to introduce teachers to the key features of open-ended questions, to advise on how they can be used for teaching and learning, and to provide guidance on assessment.

1. The need for open-ended questions

In addition to providing students with a sound knowledge and understanding of key chemical facts and concepts, the Higher Chemistry course develops a range of transferable skills identified as essential by both employers and higher education.

To assess a student’s overall attainment, a range of different questions types is employed in the course examination. Fixed-response, short-answer and extended-answer questions, along with detailed marking instructions, provide a reliable and robust assessment of a student’s ability to recall key subject knowledge and to apply numerical and problem-solving skills within chemistry contexts. These question styles will continue to form the core of the course examination for the revised Higher Chemistry.

A principle objective of this revision of Higher Chemistry is to promote a deeper understanding of the subject. Examination papers have traditionally contained ‘explain-type’ extended-answer questions to probe deeper understanding. However, this type of question might sometimes be answered by recall of a well-rehearsed ‘stock-explanation’ without a student necessarily possessing an understanding of the underlying chemical principle(s).
The new-style open-ended question can be used to assess whether or not a student has truly grasped a chemical concept. In this type of question, the student is required to draw on his/her understanding of key chemical principles in order to solve a problem or challenge. The ‘open-ended’ nature of these questions is such that there is no unique correct answer. In addition to testing the extent of a student’s chemical insight, these questions promote and reward creativity and analytical thinking. The less prescriptive marking instructions focus on rewarding students for their understanding of chemistry.

2. **What makes a good open-ended question?**

Open-ended questions present a scenario or challenge that invites students to demonstrate their chemical insight.

1. A good open-ended question presents a real-life context that is interesting and relevant to the student.

2. All open-ended questions must have more than one possible answer. Different students may write totally different responses. However, as long as these responses meet the assessment criteria then full marks are obtainable. This set of criteria is demonstrated in section 4.

3. Students should be able to answer an open-ended question in around 5 minutes, so the question should be economically worded.

4. The role of the open-ended question is to assess the key underlying concepts of chemistry rather than the recall of a particular fact. Students should not be prevented from answering the question by failing to recall a key piece of information. There should be several routes into a good answer.

3. **Preparing students to answer open-ended questions**

Pilot trials of open-ended questions were carried out in a range of Scottish schools in 2010. These trials demonstrated that as well as being an effective stimulus for discussion of key chemical concepts, open-ended questions also provide excellent formative assessment opportunities within the Higher Chemistry classroom.

The trials also indicated that the greatest challenge faced by students when tackling open-ended questions is in deciding what is being asked and formulating an answer containing enough relevant chemistry to gain full marks.
The skills needed to make a success of open-ended questions can be developed in the supportive context of a team-based activity. An open-ended question is firstly presented to the whole class by the teacher/lecturer. Teams of students are then challenged to answer the question within a 5-minute period. Each team shares their answers with the whole class. In this way, students gain an appreciation of the variety of ways in which an open-ended question can be answered correctly.

In order to enable students to gain an understanding of the assessment of open-ended questions, teams can also be provided with a sample of student answers to a particular open-ended question and asked to sort them into rank order from ‘no understanding’ to ‘good understanding’.

Open-ended questions can also be used effectively for revision or consolidation purposes, to promote discussion and review of a topic or concept.

In preparing for the course assessment, the following advice may prove useful to pass on to students:

1. In Higher Chemistry examinations open-ended questions will always be identified by the wording ‘Using your knowledge of chemistry, comment on…’.
2. Read the question carefully. Pay attention to diagrams, structural formulae or equations that have been included to help you answer the question.
3. There will not be a single ‘correct’ answer. Markers will reward your understanding of chemistry.
4. Reflect on the information provided in the question. Make sure that you answer exactly what the question is asking.
5. Show your understanding of chemistry by drawing structural formulae, identifying functional groups, writing chemical equations or working out formulae.
6. You may choose to present your answer as a paragraph, a set of bullet points or even as a diagram.
7. If you have time at the end of the examination, check to see if what you have written answers the question asked.

4. The marking of open-ended questions

Trials in Scottish schools confirmed that open-ended questions stimulate students to think creatively. An impressively diverse range of answers demonstrating a very broad and deep understanding of chemical ideas was produced. A sample of these answers is illustrated in section 6 of this document.
Given this diversity, it is impossible to predict all of the answers students will provide to produce a point-by-point marking scheme. As a result, a marking model that dissects answers into lists of ‘correct facts’ and ‘mistakes’, each carrying certain rewards or penalties, is unlikely to prove practical or fair.

Whilst detailed point-by-point marking instruction will continue to be provided for other parts of the Higher Chemistry examination, responses to open-ended questions will instead be marked against a set of criteria. This relies on a marker’s professional judgment to assess the extent of chemical knowledge and insight demonstrated by the student, and to assign a mark accordingly.

It will not be necessary for a student to produce an answer that is correct in all respects to be awarded full marks. If an answer provides clear evidence that a student has a good understanding of the chemistry relating to the question, it is entirely appropriate to award full marks.

A student’s response to an open-ended question should be assigned a mark according to how his/her understanding of chemistry matches the statements below.

0 marks: The student has demonstrated no understanding of the chemistry involved. There is no evidence that the student has recognised the area of chemistry involved or has given any statement of a relevant chemistry principle. This mark would also be given when the student merely restates the chemistry given in the question.

1 mark: The student has demonstrated a limited understanding of the chemistry involved. The student has made some statement(s) that is(are) relevant to the situation, showing that at least a little of the chemistry within the problem is understood.

2 marks: The student has demonstrated a reasonable understanding of the chemistry involved. The student makes some statement(s) that is(are) relevant to the situation, showing that the problem is understood. There might also be a statement of a chemistry principle such as an organic process, eg oxidation or hydrolysis, or of a relevant relationship between the variables involved in the problem.

3 marks: The maximum available mark will be awarded to a student who has demonstrated a good understanding of the chemistry involved. The student shows a good comprehension of the chemistry of the situation and has provided a logically correct answer to the question posed. This type of response might include a statement of the principles involved, a relationship
or an equation, and the application of these to respond to the problem. This does not mean the answer has to be what might be termed an ‘excellent’ answer or a ‘complete’ one.

5. Example questions

1. Hydrogen peroxide is used in gels to whiten teeth. The ion–electron equation for the oxidation of hydrogen peroxide is:

\[ \text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2\text{H}^+ + 2\text{e}^- \]

Using your knowledge of chemistry, comment on possible methods for measuring and comparing the concentration of hydrogen peroxide present in two different gels.

2. A student makes the following statement:

‘Sugar can be used to produce alcohol, a carboxylic acid and the ester ethyl ethanoate’

Using your knowledge of chemistry, comment on the accuracy of the student’s statement.

3. Aspirin is a widely used medicine. It is advised that it is stored in dry, cool conditions.

Using your knowledge of chemistry, comment on the reasons why aspirin should be stored under these conditions.

4. The Periodic Table groups together elements with similar properties. In most Periodic Tables hydrogen is placed at the top of Group 1, but in some it is placed at the top of Group 7.

Using your knowledge of chemistry, comment on the reasons for hydrogen being placed above either Group 1 or Group 7.
5. Oxygen gas speeds up the rate at which food is spoiled. To improve the shelf-life of foods, food manufacturers use several methods to remove oxygen from inside the food packaging. In one method, an enzyme is added that catalyses a reaction between oxygen and the glucose which is often present in foods.

\[
glucose + oxygen + water \rightarrow \text{gluconic acid} + \text{hydrogen peroxide}
\]

Using your knowledge of chemistry, comment on why this method may not be suitable to improve the shelf-life of all foods.

6. Rasputin, often referred to as the ‘mad monk’, was a very powerful figure in the life of Alexandra, the last Tsarina of Russia. His enemies decided to kill him using a cyanide compound. Cyanide compounds are deadly poisons. Using a bottle of potassium cyanide, they attempted to poison a cake and some wine. Rasputin ate the cake and drank the wine and yet was not harmed. Although his followers claimed this was a sign of Rasputin’s supernatural powers, there are chemical explanations.

Using your knowledge of chemistry and the following information, comment on possible chemical reasons as to why the cake and wine did not poison Rasputin.

\[
\text{potassium cyanide} + \text{acid} \rightarrow \text{potassium salt} + \text{hydrogen cyanide gas}
\]

7. Concentrated solutions of hydrogen peroxide are used in the propulsion systems of torpedoes. Hydrogen peroxide decomposes naturally to form water and oxygen:

\[
2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\ell) + \text{O}_2(\text{g}) \quad \Delta H = -196.4 \text{ kJ mol}^{-1}
\]

Transition metal oxides act as catalysts in the decomposition of the hydrogen peroxide.

Unfortunately, there are hazards associated with the use of hydrogen peroxide as a fuel in torpedoes. It is possible that a leak of hydrogen peroxide solution from a rusty torpedo may trigger an explosion.

Using your knowledge of chemistry, comment on why this could happen.
8. An internet discussion board called ‘Bad Chemistry on TV’, has an entry referring to an episode of the television drama *CSI: Miami*.

‘The episode of *CSI: Miami* last night had the deceased victim floating in a swimming pool contaminated with sodium hydroxide. The concentration was high enough to eat through glass. When the CSI guys realised it was an alkali, they knew they needed to neutralise it in order to retrieve the body. So they sent one of the team to the local grocery store for vinegar. They proceeded to pour the vinegar from four litre jugs into the pool, dropping the pH from almost 13 to exactly 7·0 – all within a few seconds, and without any stirring!’

The volume of the swimming pool is 100,000 litres.
Vinegar is approximately a 1·0 mol l\(^{-1}\) solution of ethanoic acid.

Using your knowledge of chemistry, comment on whether or not the events described in the episode of *CSI: Miami* could take place.

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6. **Student responses to a sample of questions**

A number of open-ended questions were trialled by Higher Chemistry students from a broad range of Scottish schools. A range of student responses obtained, along with a commentary on the marking of these responses, is shown below.

Responses were marked according to the following criteria:

The student has shown **no understanding** of the chemistry involved 0 marks

The student has shown a **limited understanding** of the chemistry involved 1 mark

The student has shown a **reasonable understanding** of the chemistry involved 2 marks

The student has shown a **good understanding** of the chemistry involved 3 marks
OPEN-ENDED QUESTIONS

Question asked

1. Hydrogen peroxide is used in gels to whiten teeth. The ion–electron equation for the oxidation of hydrogen peroxide is:

\[ \text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2\text{H}^+ + 2e^- \]

Using your knowledge of chemistry, comment on possible methods for measuring and comparing the concentration of hydrogen peroxide present in two different gels.

Student responses with commentary on marks awarded

0 marks awarded because the student has shown no understanding of the chemistry involved. The student merely restates the chemistry given in the question.
0 marks awarded because the student has shown no understanding of the problem and the response has no relevant chemistry included.

Although limited understanding is shown, the student has recognised that \( \text{H}_2\text{O}_2 \) will react to produce \( \text{H}^+ \) ions in the solution. By suggesting measuring the pH, the student has suggested an indirect method of measuring the concentration of peroxide. This response is awarded 1 mark.
A full explanation of the procedure has not been provided, but the student has recognised that the oxygen being given off would produce ‘froth’, which could be quantified. This shows **limited understanding** and is enough to warrant 1 *mark*. 
This answer gains **2 marks** since the student has interpreted the ion–electron equation to correctly predict the products of the electrolysis of $\text{H}_2\text{O}_2$. He/she has also proposed appropriate apparatus to use for the experiment, including the selection of carbon as a relatively inert electrode for the discharge of hydrogen. Furthermore, the student has correctly provided a method for measuring the average rate at which hydrogen is produced by the electrolysis process. The rate of electrolysis will be directly proportional to the current used, as selected by the variable resistor shown, and will be independent of the concentration of hydrogen peroxide. Although he/she has not really answered the question, his/her response shows a **reasonable understanding** of chemistry, and so 2 marks are awarded.
This answer gains **2 marks** because the student has provided three methods (two of which should work well in practice) that could be used to answer the question. However, the detail is vague and the response does not explain how these methods would be used to measure or compare concentrations. The answer shows a **reasonable understanding** of chemistry.
This response absolutely answers the question, and gains 3 marks. In the three methods discussed, the student has given detail and has brought in the idea that this is to compare and measure the concentration of hydrogen peroxide present. The student shows a **good understanding** of chemistry, and brings in areas of chemistry not provided in the question.
Question asked

4. The Periodic Table groups together elements with similar properties. In most Periodic Tables hydrogen is placed at the top of Group 1, but in some it is placed at the top of Group 7.

Using your knowledge of chemistry, comment on the reasons for hydrogen being placed above either Group 1 or Group 7.

Student responses with commentary on marks awarded

Although the student has given two correct pieces of information regarding hydrogen, his/her answer contains no detail and therefore only shows a limited understanding. It is important to recognise that giving two pieces of information does not equate to two marks; these questions are designed to test a deep understanding of chemistry and this answer only gives the briefest response. The student gains 1 mark.
Hydrogen is very reactive so it can be placed in group 1 with the very reactive alkali metals. As it is a gas however, it can be placed with the other gases in group 7. Also it is diatomic so goes in group 7 with the other diatomic molecules. Also hydrogen has an electron arrangement of just 1 and the alkali metals each have one electron in their outer shells, just like hydrogen so it could be in group 1.

This answer contains a lot of correct information, and the student has shown a reasonable understanding of hydrogen as an element. However, the answer lacks a more in-depth discussion of the chemistry. The student gains 2 marks.
Hydrogen has an electron arrangement of $1s^1$. Only has one electron in the outer shell which gives it similar properties to the alkali metals, for instance it is highly reactive. However, it also only requires one electron to complete its outer electron shell making it stable, which is similar to the group 7 elements. This means that when forming compounds it will behave similarly to the group 7 element. Also, it forms ions with the same charge as the group 7 element. Hydrogen also forms diatomic molecules with covalent intermolecular bonds which is the same as most of the group 7 elements.

This answer provides ample evidence that the student has a **good understanding** of the chemistry of hydrogen. The answer includes information about electron arrangement, ion formation, bonding in molecular hydrogen and the reactivity of hydrogen gas, amongst other things. This student would gain **3 marks**.
Question asked

6. Rasputin, often referred to as the ‘mad monk’, was a very powerful figure in the life of Alexandra, the last Tsarina of Russia. His enemies decided to kill him using a cyanide compound. Cyanide compounds are deadly poisons. Using a bottle of potassium cyanide, they attempted to poison a cake and some wine. Rasputin ate the cake and drank the wine and yet was not harmed. Although his followers claimed this was a sign of Rasputin’s supernatural powers, there are chemical explanations.

Using your knowledge of chemistry and the following information, comment on possible chemical reasons why the cake and wine did not poison Rasputin.

\[
\text{potassium cyanide} + \text{acid} \rightarrow \text{potassium salt} + \text{hydrogen cyanide gas}
\]

(white powder) \hspace{1cm} (white powder)

Student responses with commentary on marks awarded

The student has tried to use ‘chemistry’ terms but the answer shows **no understanding** and, indeed, contains a lot of wrong information. The student would receive **0 marks**.
This answer contains irrelevant information, but the student has recognised that the gaseous hydrogen cyanide would escape from the mixture, and therefore Rasputin would only be eating harmless potassium salt. This shows a limited understanding, and is enough to gain 1 mark.

The student has shown a good understanding of the chemical reaction producing potassium salt and hydrogen cyanide. He/she has given a convincing explanation as to why Rasputin may not have been poisoned by the cake or the wine, and, indeed, has also brought in a suggestion of the effect of heat in the baking of the cake. It is obvious from this answer that the student has a good understanding of chemistry, worthy of 3 marks.