Version 1.0 0510

General Certificate of Secondary Education

Chemistry 4421
2012

Special Features

- Objective tests for Chemistry 1 are available as on-screen tests

Material accompanying this Specification

- The Teacher's Guide

SPECIFICATION

This specification will be published annually on the AQA Website (www.aqa.org.uk). If there are any changes to the specification centres will be notified in print as well as on the Website. The version on the Website is the definitive version of the specification.

Further copies of this specification booklet are available from:

AQA Logistics Centre, Unit 2, Wheel Forge Way, Ashburton Park, Trafford Park, Manchester, M17 1EH.
Telephone: 0870 410 1036 Fax: 0161 953 1177
or
can be downloaded from the AQA Website: www.aqa.org.uk

Set and published by the Assessment and Qualifications Alliance.

The Assessment and Qualifications Alliance (AQA) is a company limited by guarantee registered in England and Wales 3644723 and a registered charity number 1073334. Registered address AQA, Devas Street, Manchester, M15 6EX.

Contents

Key Skills and Other Issues

Centre-Assessed Unit

Awarding and Reporting

Appendices

Background Information

1 Revision of GCSE Sciences – an Outcome of the DfES 14–19 Strategy

Following the publication of the DfES '14–19: opportunity and excellence' policy document, changes to the key stage 4 National Curriculum for England have been announced. One change is a new Programme of Study for KS4 Science (published autumn 2004), and the consequent rewriting by QCA of the GCSE Criteria for Science. Further details of this are given in Section 1.1. Another change relevant to GCSE Science is a requirement to provide work-related learning for all students. This is described in the QCA document 'Changes to the key stage 4 curriculum – guidance for implementation from September 2004', and is discussed in Section 1.2. These changes have together necessitated the redevelopment of GCSE Science specifications by all awarding bodies for first teaching from September 2006.

1.1 Changes to the GCSE Criteria for Science

The new programme of study has been incorporated by QCA into the GCSE Criteria for Science. The revised Criteria outline the common characteristics and subject content for science GCSEs developed by all awarding bodies for first teaching from September 2006. The main points are as follows.

- Importance is attached to the knowledge, skills and understanding of how science works in the world at large, as well as in the laboratory (referred to as the procedural content in the specification).
- This is set in the context of knowing and understanding a body of scientific facts (referred to as the substantive content).
- In the programme of study, procedural and substantive content are given equal emphasis.
- There is a new single award GCSE Science incorporating all of the content in the programme of study.
- There is a new single award GCSE Additional Science, which together with GCSE Science allows progression to post-16 science courses.
- Alternative progression routes are available in the form of single award separate sciences (GCSE Biology, GCSE Chemistry and GCSE Physics) and an applied science route leading to a new single award GCSE Additional Applied Science.

- There is provision for students wishing to follow an applied route from the outset of KS4 through a revised double award GCSE Applied Science.
- Taken together, the three separate sciences cover the requirement to teach the new programme of study, as does the revised double award GCSE Applied Science.
- Through these new specifications the opportunity exists for candidates to study GCSE Science and one or more of the separate science GCSE courses.

In parallel with the GCSE developments, a new Entry Level Certificate specification for Science is being produced. This covers the breadth of the programme of study but in less depth than required for GCSE Science.

Further details of the suite of specifications developed by AQA to meet these requirements are given in Section 4.2.

1.2 Changes to the KS4 Curriculum

Requirement to teach programme of study

The revised programme of study for KS4 Science has been designed by QCA as a small core of content relevant to all students. It is a statutory requirement to teach the programme of study to all students at maintained schools. Since the start of teaching of the new specifications (September 2006), it has no longer been possible to disapply KS4 students from this requirement for the purposes of extended work-related learning.

Work-related learning

The removal of the provision for disapplication is linked to the statutory requirement for work-related learning for all students which was introduced in September 2004. With the greater emphasis in the revised programme of study on 'How Science Works', science teachers are enabled, if they wish, to make a larger contribution to work-related learning through the teaching of science.

1.3 Other Regulatory Requirements

Key Skills

All GCSE specifications must identify, as appropriate to the subject, opportunities for generating evidence for the Key Skills of Application of Number, Communication, Information and Communication Technology, Working with Others, Improving own Learning and Performance, and Problem Solving. Details for this specification are given in Section 14.

ICT

The subject content of all GCSEs must require candidates to make effective use of ICT and provide, where appropriate, assessment opportunities for ICT. In science in the wider world, ICT plays a crucial role, and teaching and learning in the GCSE Sciences should reflect this. Details of how the teaching of this specification can encourage the application and development of ICT skills are given in Section 9.3. However, ICT skills are not assessed by any component of this specification.

Communication

All GCSE specifications must ensure that the assessment arrangements require that, when they produce extended written material, candidates have to:

- ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
- present information in a form that suits its purpose
- use a suitable structure and style of writing.

Further details for this specification are given in Section 7.4.

Citizenship

Since 2002, students in England have been required to study Citizenship as a National Curriculum subject. Each GCSE specification must signpost, where appropriate, opportunities for developing citizenship knowledge, skills and understanding. Further details for this specification are given in Section 15.5.

Other issues

All specifications must identify ways in which the study of the subject can contribute to developing understanding of spiritual, moral, ethical, social and cultural issues, European developments, environmental issues and health and safety. Further details for this specification are given in Sections 15.1, 15.2, 15.3 and 15.4.

Wales and Northern Ireland

There is no longer any additional material that centres in Wales or Northern Ireland have to teach in order to meet the different requirements of the National Curriculum in these countries.

Therefore, centres may offer any of the AQA specifications without the need to supplement the teaching required in order to meet additional statutory orders applying to students outside England.

2 Specification at a Glance

Chemistry

This specification is one of a suite of GCSE Science specifications offered by AQA. The specification leads to a single award GCSE Chemistry. The award has four or five assessment units.

There are two tiers of assessment: Foundation (G–C) and Higher (D–A*). The centre-assessed unit is not tiered.

The objective tests are available as paper-based and on-screen tests in centres.

On-screen tests are undertaken by candidates sitting at a computer and keying their responses.

GCSE Chemistry	
Chemistry 1 Written paper 25% 45 minutes 45 marks	
or	
Chemistry 1a Matching/multiple choice questions Objective test 12.5% 30 minutes 36 marks	**Chemistry 1b** Matching/multiple choice questions Objective test 12.5% 30 minutes 36 marks
Chemistry 2 Written paper 25% 45 minutes 45 marks	
Chemistry 3 Written paper 25% 45 minutes 45 marks	
Chemistry Centre-Assessed Unit (C1, C2 or C3) based on normal class practical work 25% 40 marks Investigative Skills Assignment (an externally set, internally assessed test taking 45 minutes) + Practical Skills Assessment (a holistic skills assessment)	

GCSE Chemistry
4421

3 Availability of Assessment Units and Entry Details

3.1 Availability of Assessment Units and Subject Awards

Examinations based on this specification are available as follows.

	Chemistry 1	Chemistry 1a Chemistry 1b	Chemistry 2 Chemistry 3	Chemistry Centre-Assessed Unit	Subject Award
November		✓			✓
January	✓		✓		✓
March		✓			✓
June	✓	✓	✓	✓	✓

3.2 Entry Codes

Normal entry requirements apply, but the following information should be noted.

Each assessment unit has a separate unit entry code, as follows:

Chemistry 1	CHY1F or CHY1H
or	
Paper-based Objective Tests	
Chemistry 1a	CHY1AP
Chemistry 1b	CHY1BP
or	
On-screen Objective Tests	
Chemistry 1a	CH1ASF or CH1ASH
Chemistry 1b	CH1BSF or CH1BSH
Chemistry 2	CHY2F or CHY2H
Chemistry 3	CHY3F or CHY3H
Chemistry centre-assessed unit	CHYC

For Chemistry 1, Chemistry 2 and Chemistry 3 the entry code determines the tier taken. See section 3.3 for Chemistry 1a and Chemistry 1b.

The units which contribute to the subject award GCSE Chemistry are: Chemistry 1 or (Chemistry 1a and Chemistry 1b), Chemistry 2, Chemistry 3 and the Chemistry centre-assessed unit.

The Subject Code for entry to the GCSE Chemistry award is 4421.

3.3 Entry Restrictions

Each specification is assigned to a national classification code, indicating the subject area to which it belongs. Centres should be aware that candidates who enter for more than one GCSE qualification with the same classification code will have only one grade (the highest) counted for the purpose of the School and College Performance Tables.

The classification code for this specification is 1110.

The subject award GCSE Chemistry has common units with other specifications in the AQA GCSE Sciences suite. Chemistry 1 is common to GCSE Chemistry and GCSE Science B, and it has exactly the same content as Chemistry 1a and Chemistry 1b together. Chemistry 2 is common to GCSE Chemistry and GCSE Additional Science.

The Objective Tests for Chemistry 1a and Chemistry 1b are tiered, but the questions for both tiers are contained within the same question paper. Candidates choose at the time of the examination which tier to take. For on-screen tests, a tiered entry should be made.

It is **not** a requirement to take the same tier for every Objective Test or written paper. Candidates can opt to take different tiers for the different tests / written paper and can choose to resit a test / written paper at a different tier.

3.4 Private Candidates

This specification is available for private candidates. Private candidates should write to AQA for a copy of *Supplementary Guidance for Private Candidates*.

3.5 Access Arrangements and Special Consideration

We have taken note of equality and discrimination legislation and the interests of minority groups in developing and administering this specification.

Arrangements may be made to enable candidates with disabilities or other difficulties to access the assessment. An example of an access arrangement is the production of a Braille paper for a candidate with a visual impairment. Special consideration may be requested for candidates whose work has been affected by illness or other exceptional circumstances.

We follow the guidelines in the Joint Council for Qualifications (JCQ) document: *Access Arrangements, Reasonable Adjustments and Special Consideration: General and Vocational Qualifications*. This is published on the JCQ website (http://www.jcq.org.uk) or you can follow the link from our website (http://www.aqa.org.uk).

Applications for access arrangements and special consideration should be submitted to AQA by the Examinations Officer at the centre.

3.6 Language of Examinations

All assessment will be through the medium of English. Assessment materials will not be provided in Welsh or Gaeilge.

Scheme of Assessment

4 Introduction

4.1 National Criteria

This GCSE Chemistry specification complies with the following:

- the Statutory Regulation of External Qualifications in England, Wales and Northern Ireland 2004, including the common criteria for all qualifications and the additional criteria for GCSE
- the GCSE Criteria for Science
- the GCSE, GCE, Principal Learning and Project Code of Practice April 2010.

4.2 Background

This GCSE Chemistry specification is part of the AQA GCSE Science suite, which comprises:

GCSE Science A
GCSE Science B
GCSE Additional Science
GCSE Additional Applied Science
GCSE Biology
GCSE Chemistry (this specification)
GCSE Physics
GCSE Applied Science (Double Award)

A matching Entry Level Certificate specification for Science is also available.

The suite enables centres to offer a range of flexible progression routes from KS3 through KS4 Science to further studies.

As noted in Section 1.1, the GCSE Criteria for Science require a greater emphasis on 'How Science Works' in these new specifications. AQA is grateful to staff in the School of Education of the University of Durham for assistance in addressing this requirement. The procedural content of this specification draws substantially on pioneering work conducted at the University of Durham on 'Concepts of Evidence', using a subset of these concepts which are appropriate to GCSE Sciences. For more information about this work visit: www.dur.ac.uk/richard.gott/Evidence/cofev.htm

University staff have also assisted AQA senior examiners in developing the assessment of the procedural content in relation to the substantive content, in both the written papers and the centre-assessed unit. Initial pilot work by the University has helped significantly in designing assessments which are accessible to students at KS4. AQA acknowledges this indebtedness.

Rationale

The rationale of the six general science specifications (GCSE Science A, GCSE Science B, GCSE Additional Science, GCSE Biology, GCSE Chemistry and GCSE Physics) is the appropriate exploration of 'How Science Works' in contexts which are relevant to the role of science in society and which are able to serve as a foundation for progression to further learning. A body of content has been identified which underpins the knowledge and understanding of 'How Science Works' at all levels. This 'procedural content' relates to the processes of scientific activity. The 'substantive content' comprises the Biology, Chemistry, Physics or other science content. In these specifications the procedural content and the substantive content are presented in separate sections in order to ensure that there is a coherent and consistent understanding of what candidates are required to know, understand and be able to do. However, it is expected that delivery of the procedural content will be integrated.

Integrating 'How Science Works' (procedural content)

Although the procedural content is presented in a separate section in the general science specifications, it is not expected that it is taught separately from the substantive content. Teachers might teach a topic of substantive content (eg reflex action, fractional distillation, or features of electromagnetic waves) or of procedural content (eg methods of collecting scientific data) but often they will deliver a blend of procedural and substantive content (eg when teaching about the greenhouse effect and global warming).

In order to reflect this approach, each sub-section of substantive content has details of activities which enable candidates to develop their skills, knowledge and understanding of how science works (the procedural content), then details are given of the substantive contexts that need to be known and understood in order to undertake the activities. This is supplemented by signposting which highlights opportunities to develop the skills, knowledge and understanding of the investigative aspects of the procedural content, and opportunities to encourage knowledge and understanding of how scientific evidence is used. Further details about integrating the procedural content are given in Section 9.1.

Assessment in the written papers will also reflect this approach. Parts of questions may address procedural content, substantive content or a blend of both. Candidates will be expected to apply their procedural knowledge, understanding and skills in a wide range of substantive contexts.

Each of the specifications has particular features and these are described in the following paragraphs.

GCSE Science A and GCSE Science B

Students can begin KS4 with a general science course based on either GCSE Science A or GCSE Science B. These are both single award qualifications. They cover all aspects of a good science education: evaluating evidence and the implications of science for society, explaining, theorising and modelling in science, and procedural and technical knowledge of science practice, though with an emphasis on the first aspect, namely, evaluating evidence and the implications of science for society. The weighting given to the procedural content in these specifications is higher than in the other general science specifications, and the substantive contexts lend themselves to engagement with the societal implications of scientific knowledge at a level which is appropriate to key stage 4. Both these specifications therefore provide the opportunity for all students to develop the science knowledge, understanding and skills needed for adult life, but they also give a good basis for further study of science.

These specifications have identical content, covering the whole programme of study for KS4 Science, with the subject areas of Biology, Chemistry and Physics presented separately so that they can be taught by subject specialists if this suits the staffing and/or teaching strategy in the centre. The assessment styles for Science A and Science B are different, though they share a common model for centre assessment. Students who are successful in GCSE Science could study a level 3 science qualification such as AS Science for Public Understanding, but would find progression to GCE Biology, Chemistry, Physics and Applied Science difficult without further preparation. Many will undertake a level 2 course such as GCSE Additional Science or GCSE Additional Applied Science before continuing to level 3 courses.

GCSE Science A

The specific feature of this specification is that external assessment is available through 'bite size' objective tests. Each of the three units, Biology 1, Chemistry 1 and Physics 1, is divided into two equal sections and each section is examined in a separate 30 minute test. The tests are available in November, March and June. The objective tests are available as paper-based and on-screen tests in centres.

GCSE Science B

In contrast, GCSE Science B does not offer assessment through the 'bite-size' test route but has 45 minute written papers with structured questions. There is one paper for each of Biology 1, Chemistry 1 and Physics 1, available in January and June.

GCSE Applied Science (Double Award)

Alternatively, students embarking on KS4 and wishing from the outset to specialise in a vocational approach to science can be offered GCSE Double Award Applied Science. This is a qualification which has been developed from the previous GCSE Applied Science specification but unlike its predecessor it covers the whole programme of study for KS4 Science, enabling the requirement to teach the programme to be met (see Section 1.2). The assessment comprises four units; three portfolio units and one unit which is externally assessed.

ELC Science

Candidates who may not be ready to take GCSE Science at the same time as their contemporaries can study for the Entry Level Certificate in Science. This has the same breadth of content as GCSE Science, but less depth. Teaching for ELC Science can enable the requirement to teach the programme of study for KS4 Science to be met (see Section 1.2) and students can be taught alongside students preparing for GCSE Science (if they cannot be taught separately). Students who have succeeded in ELC Science can progress to GCSE Science. Assessment is through the completion of units of content with the success criteria being clearly focussed on skills rather than depth of knowledge.

GCSE Additional Science

This is a single award GCSE, separate from and taken after or at the same time as GCSE Science A or B. This award together with an award in GCSE Science provides the nearest equivalent to the previous GCSE Science: Double Award. The content follows on from that of GCSE Science, and the centre assessment follows the same model as used for Science A and Science B. However, the emphasis of this specification, and the three separate sciences, GCSE Biology, Chemistry and Physics, is somewhat different. Whereas GCSE Science A and B emphasise evaluating evidence and the implications of science for society, these specifications have a greater emphasis on explaining, theorising and modelling in science.

There are three 45 minute written papers with structured questions, one paper for each of Biology 2, Chemistry 2 and Physics 2, available in January and June. Courses based on this specification form a firm basis for level 3 courses in the sciences, such as AS and A Level Biology, Chemistry and Physics.

GCSE Additional Applied Science

This is another single award GCSE, which could be taken after or at the same time as GCSE Science A or B. It emphasises the procedural and technical knowledge of science practice, so is suitable for students who want to learn more about vocational contexts which are relevant to the modern world. The subject content is set in three vocational contexts: sports science, food science and forensic science. Together with GCSE Science, it would form a firm basis for level 3 courses in the sciences, such as GCE Applied Science.

GCSE Biology, Chemistry, Physics

Each of these single award GCSEs would provide the basis for the study of the corresponding GCE science. Like GCSE Additional Science, they emphasise explaining, theorising and modelling in science. Taken together, they include the whole programme of study for KS4 Science, enabling the statutory requirement to be met. Students could take courses based on these specifications directly after KS3 Science. Alternatively, some students may prefer to take GCSE Science to provide a general background in KS4 Science, then specialise in one or more separate science(s).

Centre-Assessed Unit

The general science GCSEs (Science A, Science B, Additional Science, Biology, Chemistry and Physics) share a common approach to centre assessment. This is based on the belief that assessment should encourage practical activity in science, and that practical activity should encompass a broad range of types of activity. The previous model of practical assessment based on 'investigations' has become a straightjacket to practical activity in the classroom, and it is the intention that the model adopted will avoid this.

The centre-assessed unit is a combination of practical skills assessment (a holistic assessment on a 6 point scale) and a written test. Before taking a test, candidates undertake practical work relating to a topic under normal class conditions and, during their work, they collect data. They bring their data to the test. The written test is taken in a subsequent lesson but under examination conditions. Tests are externally set, but internally marked, using marking guidance provided by AQA. Each test will have questions relating to the candidate's data and questions which relate to additional data provided in the question paper. Several tests relevant to each unit will be available at any one time, and the tests can be taken at times chosen by the teacher. Further details are given in Sections 16–18.

4.3 Prior Level of Attainment and Recommended Prior Learning

This key stage 4 GCSE specification builds on the knowledge, understanding and skills set out in the National Curriculum programme of study for KS3 Science. While there is no specific prior level of attainment required for candidates to undertake a course of study based on this specification, a level of scientific, literacy and numeracy skills commensurate with having followed a programme of study at key stage 3 is expected.

4.4 Progression

This qualification is a recognised part of the National Qualifications Framework. As such, GCSE is a level 2 qualification and provides progression from key stage 3 to post-16 studies.

A course based on this specification provides a worthwhile course for candidates of various ages and from diverse backgrounds in terms of general education and lifelong learning. It will follow naturally from a course based on the programme of study for KS3 Science. From a GCSE Chemistry course, students could progress to GCE Chemistry. Alternatively, students could progress to AS Science for Public Understanding.

5 Aims

A course based on this specification should encourage candidates to:

- develop their interest in, and enthusiasm for, science
- develop a critical approach to scientific evidence and methods
- acquire and apply skills, knowledge and understanding of how science works and its essential role in society
- acquire scientific skills, knowledge and understanding necessary for progression to further learning.

6 Assessment Objectives

6.1

The scheme of assessment will require candidates to demonstrate the abilities detailed under assessment objectives below in the context of the subject content in Sections 10–13.

6.2 Assessment Objective 1 (AO1)

Knowledge and understanding of science and how science works

Candidates should be able to:

a) demonstrate knowledge and understanding of the scientific facts, concepts, techniques and terminology in the specification
b) show understanding of how scientific evidence is collected and its relationship with scientific explanations and theories
c) show understanding of how scientific knowledge and ideas change over time and how these changes are validated.

6.3 Assessment Objective 2 (AO2)

Application of skills, knowledge and understanding

Candidates should be able to:

a) apply concepts, develop arguments or draw conclusions related to familiar and unfamiliar situations
b) plan a scientific task, such as a practical procedure, testing an idea, answering a question, or solving a problem
c) show understanding of how decisions about science and technology are made in different situations, including contemporary situations and those raising ethical issues
d) evaluate the impact of scientific developments or processes on individuals, communities or the environment.

6.4 Assessment Objective 3 (AO3)

Practical, enquiry and data handling skills

Candidates should be able to:

a) carry out practical tasks safely and skilfully
b) evaluate the methods they use when collecting first-hand and secondary data
c) analyse and interpret qualitative and quantitative data from different sources
d) consider the validity and reliability of data in presenting and justifying conclusions.

7 Scheme of Assessment

7.1 Assessment Units

The Scheme of Assessment comprises four or five units: Chemistry 1 or (Chemistry 1a and 1b), Chemistry 2, Chemistry 3 and the Chemistry centre-assessed unit.

The objective tests are available as paper-based and on-screen tests in centres.

Chemistry 1	Written Paper	45 minutes
25% of the marks		45 marks

The unit comprises a written paper with short answer questions. The questions assess the subject content in Sections 10 (up to 9 marks) and 11 (at least 36 marks). The paper is available at Foundation and Higher Tier. All questions are compulsory.

Either Chemistry 1 or (Chemistry 1a and Chemistry 1b) should be taken.

Chemistry 1a	Objective Test	30 minutes
12.5% of the marks		36 marks

The unit comprises an objective test with matching and multiple choice questions. The questions assess the content in Sections 10 (at least 7 marks) and 11a (up to 29 marks). The test is available at Foundation and Higher Tier. All questions are compulsory.

Chemistry 1b	Objective Test	30 minutes
12.5% of the marks		36 marks

The unit comprises an objective test with matching and multiple choice questions. The questions assess the content in Sections 10 (at least 7 marks) and 11b (up to 29 marks). The test is available at Foundation and Higher Tier. All questions are compulsory.

Chemistry 2	Written Paper	45 minutes
25% of the marks		45 marks

The unit comprises a written paper with short answer questions. The questions assess the subject content in Sections 10 (up to 9 marks) and 12 (at least 36 marks). The paper is available at Foundation and Higher Tier. All questions are compulsory.

Chemistry 3	Written Paper	45 minutes
25% of the marks		45 marks

The unit comprises a written paper with short answer questions. The questions assess the subject content in Sections 10 (up to 9 marks) and 13 (at least 36 marks). The paper is available at Foundation and Higher Tier. All questions are compulsory.

Chemistry Centre-Assessed Unit	
25% of the marks	40 marks

The unit comprises an Investigative Skills Assignment, which is normal class practical work followed by an externally set, internally assessed test taking 45 minutes, and a Practical Skills Assessment which is a holistic practical skills assessment. The unit assesses parts of the content in Section 10 (these are detailed in Section 17).

7.2 Weighting of Assessment Objectives

The approximate relationship between the relative percentage weighting of the Assessment Objectives (AOs) and the overall Scheme of Assessment is shown in the following table:

Assessment Objectives	Unit Weightings (%)				Overall Weighting of AOs (%)
	Chemistry 1	Chemistry 2	Chemistry 3	Chemistry Centre-Assessed Unit	
AO1	12	12	12	-	36
AO2	13	13	13	5	44
AO3	-	-	-	20	20
Overall Weighting (%)	25	25	25	25	**100**

Candidates' marks for each assessment unit are scaled to achieve the correct weightings.

7.3 Tiering and Assessment

The centre-assessed unit is not tiered. In the other assessments for this specification, the papers are tiered, with Foundation Tier being aimed at grades C–G, and Higher Tier being aimed at grades A*–D. Questions for the Higher Tier will be more demanding, requiring higher level skills, allowing candidates to access the higher grades. See Section 9.4 for information about tiering and subject content. Different tiers can be taken for different papers

In Chemistry 1a and Chemistry 1b, the questions for both tiers are contained within the same paper. Candidates choose at the time of the examination which tier to take.

The level of demand of questions depends on factors such as the nature of the underlying scientific concepts being tested, amount of cueing provided, including the plausibility of distractors, the context/application in which the question is contained, whether the response required is directed or open, and the extent to which reference material must be used in order to respond. Consideration of such factors allows GCSE science questions to be allocated to one of three levels of demand (low, standard and high). Foundation Tier papers contain low and standard demand questions, while Higher Tier papers contain standard and high demand questions.

7.4 Mathematical and Other Requirements

The knowledge and skills in mathematics which are relevant to science and which are given below will not be exceeded in making assessments in this specification. Candidates will not be prevented from demonstrating achievement in science by mathematics which is excessively demanding.

FT and HT

- The four rules applied to whole numbers and decimals
- Use of tables and charts
- Interpretation and use of graphs
- Drawing graphs from given data
- Reading, interpreting and drawing simple inferences from tables
- Vulgar and decimal fractions and percentages
- Scales
- Elementary ideas and application of common measures of rate
- Averages/means and the purpose for which they are used
- Substitution of numbers for words and letters in formulae (without transformation of simple formulae)

HT only

(in addition to the requirements listed above)

- Square and square root
- Conversion between vulgar and decimal fractions and percentages
- The four rules applied to improper (and mixed) fractions
- Expression of one quantity as a percentage of another; percentage change
- Drawing and interpreting of related graphs
- Idea of gradient
- Transformation of formulae
- Simple linear equations with one unknown
- Elementary ideas and applications of direct and inverse proportion.

Units, symbols and nomenclature

Units, symbols and nomenclature used in examination papers will normally conform to the recommendations contained in the following.

- *Signs, Symbols and Systematics – the ASE companion to 16–19 Science.* Association for Science Education (ASE), 2000. ISBN 0 86357 312 6
- *Signs, Symbols and Systematics – the ASE companion to 5–16 Science.* Association for Science Education (ASE), 1995. ISBN 0 86357 232 4

Any generally accepted alternatives used by candidates will be given appropriate credit.

Data sheet

A data sheet is provided with the Chemistry 2 and Chemistry 3 written papers. This includes a periodic table and other information. See Appendix D. Other data should **not** be provided to candidates for use during examinations.

Communication skills

AQA takes care that candidates are not prevented from demonstrating achievement in science by the use of language in question papers which is inappropriately complex and hinders comprehension. Similarly, while the assessment of communication is not a primary function of this specification, candidates are required to demonstrate scientific communication skills. These are described in Section 9.2.

Scientific communication skills are specifically targeted by questions in the Investigative Skills Assignment (ISA) part of the centre-assessed unit. The externally set test for every ISA has a question in which the scoring of marks is in part dependent on skills such as presenting information, developing an argument and drawing a conclusion.

In addition, candidates will have difficulty in scoring the marks for science in any of the written assessments if they do not:

- ensure that text is legible and that spelling, punctuation and grammar are accurate so that meaning is clear
- present information in a form that suits its purpose
- use a suitable structure and style of writing.

In presenting their answers, they will also need to use scientific conventions (including chemical equations) and mathematical language (including formulae) accurately and appropriately to score all the available marks.

Subject Content

8 Summary of Subject Content

8.1	How Science Works	10.1	The thinking behind the doing
		10.2	Fundamental ideas
		10.3	Observation as a stimulus to investigation
		10.4	Designing an investigation
		10.5	Making measurements
		10.6	Presenting data
		10.7	Using data to draw conclusions
		10.8	Societal aspects of scientific evidence
		10.9	Limitations of scientific evidence
8.2	Chemistry 1	11.1	How do rocks provide building materials?
	Chemistry 1a	11.2	How do rocks provide metals and how are metals used?
		11.3	How do we get fuels from crude oil?
	Chemistry 1b	11.4	How are polymers and ethanol made from oil?
		11.5	How can plant oils be used?
		11.6	What are the changes in the Earth and its atmosphere?
8.3	Chemistry 2	12.1	How do sub-atomic particles help us to understand the structure of substances?
		12.2	How do structures influence the properties and uses of substances?
		12.3	How much can we make and how much do we need to use?
		12.4	How can we control the rates of chemical reactions?
		12.5	Do chemical reactions always release energy?
		12.6	How can we use ions in solutions?
8.4	Chemistry 3	13.1	How was the periodic table developed and how can it help us understand the reactions of elements?
		13.2	What are strong and weak acids and alkalis? How can we find the amounts of acids and alkalis in solutions?
		13.3	What is in the water we drink?
		13.4	How much energy is involved in chemical reactions?
		13.5	How do we identify and analyse substances?

9 Introduction to Subject Content

9.1 Integrating the Procedural Content

The subject content of this specification is presented in four sections: the procedural content ('How Science Works'), and three sections of substantive content, Chemistry 1, Chemistry 2 and Chemistry 3. To aid understanding of the changes that have been introduced in the teaching, learning and assessment of science at key stage 4, the procedural content is stated separately in Section 10 from the Chemistry content in Sections 11–13. However, it is intended that the procedural content is integrated and delivered in the context of the content in Chemistry 1, Chemistry 2 and Chemistry 3.

The organisation of each sub-section of the substantive content is designed to facilitate this approach. Each of the sub-sections in Chemistry 1, Chemistry 2 and Chemistry 3 starts with the statement: 'Candidates should use their skills, knowledge and understanding of how science works (to)'. This introduces a number of activities, for example:

- considering the social, economic and environmental impacts of exploiting metal ores.

These are intended to enable candidates to develop many aspects of the skills, knowledge and understanding of how science works. In general, the activities address using scientific evidence. Other aspects of the skills, knowledge and understanding of how science works, particularly obtaining scientific evidence, will be better developed through investigative work, and it is expected that teachers will want to adopt a practical approach to the teaching of many topics.

In each sub-section, the contexts for the activities and associated practical work are introduced by the statement: 'Their skills, knowledge and understanding of how science works should be set in these substantive contexts'. Sentences such as this follow.

- Ores contain enough metal to make it economical to extract the metal and this changes over time.

These sentences define the scope of the Chemistry content.

In order to assist teachers in identifying sections of the content which lend themselves to the delivery of the procedural content, two symbols have been used.

The first, shown here, identifies parts of the content which lend themselves to extended investigative work of the type needed to explore Sections 10.3–10.7 of the procedural content. These sections are about obtaining valid and reliable scientific evidence. These parts of the content may form the contexts for Investigative Skills Assignments (see also Section 18.2).

? The second, shown here, identifies parts of the content which lend themselves to activities which allow Sections 10.2 and 10.8–10.9 to be considered. These sections are about using scientific evidence, for example, how scientific evidence can contribute to decision making and how scientific evidence is limited.

Further guidance about the delivery of 'How Science Works' in the context of the substantive content is being prepared for publication in the Teacher's Guide for this specification.

In the written papers, questions will be set which examine the procedural content in the context of the substantive content. Candidates will be required to use their knowledge, understanding and skills in both the procedural and substantive content to respond to questions. In some cases it is anticipated that candidates will use additional information which is given to them, and demonstrate their understanding by applying the principles and concepts in the substantive content to unfamiliar situations.

To compensate for the additional teaching time that will be involved in delivering 'How Science Works', the substantive content sections (Chemistry 1, Chemistry 2 and Chemistry 3) have been substantially reduced compared with the previous specifications.

9.2 Communication Skills

Throughout their GCSE Science course, candidates should be encouraged to develop and improve their scientific communication skills.

These include:

- recalling, analysing, interpreting, applying and questioning scientific information or ideas
- using both qualitative and quantitative approaches
- presenting information, developing an argument and drawing a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

These skills will be developed through the activities that candidates undertake during their course, including those required for this specification by the statements at the beginning of each section of the substantive content. Appropriate use of these skills will enable candidates to be successful in the written assessments for this specification.

There is further information in Section 7.4 about scientific communication in assessments, including the use of scientific, technical and mathematical language, conventions and symbols.

9.3 ICT Skills

In undertaking activities to develop their knowledge and understanding of how science works, candidates should be given opportunities to:

- collect data from primary and secondary sources, using ICT sources and tools
- present information, develop arguments and draw conclusions using ICT tools.

Opportunities to use ICT sources and tools occur throughout the content of this specification. They are signposted in Sections 11–13 by the symbol shown, and are listed below under four headings.

- Use the internet (and other primary and secondary sources) to find information or data about:
  - use of limestone, cement, concrete and glass as building materials (Section 11.1)
  - reserves of metal ores and recycling of metals (Section 11.2)
  - metals as smart materials (Section 11.2)
  - development of alternative fuels to hydrocarbons (Section 11.3)
  - uses and recycling of polymers (Section 11.4)
  - making ethanol for use as a fuel (Section 11.4)
  - vegetable oils as fuels (Section 11.5)
  - benefits and drawbacks of additives in food (Section 11.5)
  - prediction of earthquakes (Section 11.6)
  - development and application of new materials including nanoscience (Section 12.2)
  - atom economy and sustainable development (Section 12.3)
  - conditions used in industrial processes in terms of energy required (Section 12.5)
  - effect of conditions on position of equilibrium in reversible reactions (Section 12.5)
  - development of the modern periodic table (Section 13.1)
  - properties of transition elements (Section 13.1)
  - comparison of energy produced by different fuels/foods (Section 13.4)
- Use sensors and dataloggers to capture data in practical work
  - acid/alkali titrations (Section 13.2)
- Use spreadsheets or databases for data analysis, for modelling or to explore patterns
  - products of the burning of fuels (Section 11.3), and their impacts on the environment (Section 11.6)
  - periodic table and atomic structure (Section 12.1)
  - rates of reaction (Section 12.4)

- Use electronic resources, eg software simulations, video clips
  - extraction of iron (Section 11.2)
  - modelling the structure of metal alloys (Section 11.2)
  - removal of sulfur from fuels (Section 11.3)
  - cracking of hydrocarbons (Section 11.4)
  - polymerisation (Section 11.4)
  - extraction of plant oils (Section 11.5)
  - plate tectonics (Section 11.6)
  - changes in the Earth's early atmosphere (Section 11.6)
  - atomic structure – electrons in energy levels (Section 12.1)
  - chemical bonding and structure (Section 12.1)
  - relationship between structure and properties (Section 12.2)
  - yield in chemical reactions and atom economy (Section 12.3)
  - reversible reactions (Section 12.3)
  - electrolysis (Section 12.6)
  - trends in reactivity (Section 13.1)
  - solubilities of substances (Section 13.3)
  - soft/hard water (Section 13.3)
  - quality of drinking water (Section 13.3)
  - energy transfer during chemical reactions (Section 13.4)
  - instrumental methods of chemical analysis (Section 13.5)

9.4 Tiering and Subject Content

In this specification there is additional content needed for Higher Tier candidates. Questions in the Higher Tier papers will also be more demanding, allowing candidates to access the higher grades.

HT ❖ Shown like this, HT indicates the additional material needed only by Higher Tier candidates.

10 How Science Works – the Procedural Content

This section contains a statement of the procedural content that candidates need to know and understand in order to be successful in any of the assessment units of this specification. It should be read in conjunction with Sections 11–13, where cross-references to this section have been included to show activities in the context of chemistry which can be used to develop candidates' skills, knowledge and understanding of how science works.

Candidates should be encouraged to carry out practical work throughout the course and to collect their own data carefully. They should work individually and in groups and should always consider the safety aspects of experimental work.

10.1 The thinking behind the doing

Science attempts to explain the world in which we live. It provides technologies that have had a great impact on our society and the environment. Scientists try to explain phenomena and solve problems using evidence. The data to be used as evidence must be reliable and valid, as only then can appropriate conclusions be made.

A scientifically literate citizen should, amongst other things, be equipped to question, and engage in debate on, the evidence used in decision-making.

The reliability of evidence refers to how much we trust the data. The validity of evidence depends on the reliability of the data, as well as whether the research answers the question. If the data is not reliable the research cannot be valid.

To ensure reliability and validity in evidence, scientists consider a range of ideas which relate to:

- how we observe the world
- designing investigations so that patterns and relationships between variables may be identified
- making measurements by selecting and using instruments effectively
- presenting and representing data
- identifying patterns, relationships and making suitable conclusions.

These ideas inform decisions and are central to science education. They constitute the 'thinking behind the doing' that is a necessary complement to the subject content of biology, chemistry and physics.

The sections below introduce the key ideas relating to evidence that underpin scientific practice.

10.2 Fundamental ideas

Evidence must be approached with a critical eye. It is necessary to look closely at how measurements have been made and what links have been established. Scientific evidence provides a powerful means of forming opinions. These ideas pervade all of 'How Science Works'.

Candidates should know and understand

- It is necessary to distinguish between opinion based on valid and reliable evidence and opinion based on non-scientific ideas (prejudices, whim or hearsay).
- Continuous variables (any numerical values, eg weight, length or force) give more information than ordered variables (eg small, medium or large lumps) which are more informative than categoric variables (eg names of metals). A variable may also be discrete, that is, restricted to whole numbers (eg the number of layers of insulation).
- Scientific investigations often seek to identify links between two or more variables. These links may be:
  - causal, in that a change in one variable causes a change in another
  - due to association, in that changes in one variable and a second variable are linked by a third variable (eg an association noted between soil acidity and crop growth may be the effect of a third variable, fertiliser type and quantity, on both)
  - due to chance occurrence (eg increase in the early 20^{th} century in radio use was accompanied by an increase in mental illness).
- Evidence must be looked at carefully to make sure that it is:
  - reliable, ie it can be reproduced by others
  - valid, ie it is reliable *and* answers the original question.

10.3 Observation as a stimulus to investigation

Observation is the link between the real world and scientific ideas. When we observe objects, organisms or events we do so using existing knowledge. Observations may suggest hypotheses and lead to predictions that can be tested.

Candidates should know and understand

- Observing phenomena can lead to the start of an investigation, experiment or survey. Existing theories and models can be used creatively to suggest explanations for phenomena (hypotheses). Careful observation is necessary before deciding which are the most important variables. Hypotheses can then be used to make predictions that can be tested. An example is the observation that shrimp only occur in parts of a stream. Knowledge about shrimp and water flow leads to a hypothesis relating the distribution to the stream flow rate. A prediction leads to a survey that looks at both variables.
- Data from testing a prediction can support or refute the hypothesis or lead to a new hypothesis. For example, the data from the shrimp survey could suggest that, at slow flow rates, oxygen availability might determine abundance.
- If the theories and models we have available to us do not completely match our data or observations, we need to check the validity of our observations or data, or amend the theories or models.

10.4 Designing an investigation

An investigation is an attempt to determine whether or not there is a relationship between variables. Therefore it is necessary to identify and understand the variables in an investigation. The design of an investigation should be scrutinised when evaluating the validity of the evidence it has produced.

Candidates should know and understand

- An independent variable is one that is changed or selected by the investigator. The dependent variable is measured for each change in the independent variable.
- Any measurement must be valid in that it measures only the appropriate variable, for instance colour change in a pH indicator to measure respiration in woodlice could be affected by their excretion.

Fair Test

- It is important to isolate the effects of the independent variable on the dependent variable. This may be achieved more easily in a laboratory environment than in the field, where it is harder to control all variables.
- A fair test is one in which only the independent variable affects the dependent variable, as all other variables are kept the same.
- In field investigations it is necessary to ensure that variables that change their value do so in the same way for all measurements of the dependent variable (eg in a tomato growth trial, all plants are subject to the same weather conditions).
- When using large-scale survey results, it is necessary to select data from conditions that are similar (eg if a study is to survey the effect of age on blood pressure, a group of people with approximately the same diet or weight could be used).
- Control groups are often used in biological and medical research to ensure that observed effects are due to changes in the independent variable alone (eg in drug experiments, a placebo drug is used as a control).

Choosing values of a variable

- Care is needed in selecting values of variables to be recorded in an investigation. A trial run will help identify appropriate values to be recorded, such as the number of repeated readings needed and their range and interval. For example, in an investigation of the effect of temperature on enzyme activity it is necessary to:
  - use a sufficient amount of enzyme so that its activity can be detected
  - use a sensible range of temperatures
  - have readings 'closer together' (at smaller intervals) where a change in pattern is detected.

Accuracy and precision.

- Readings should be repeated to improve the reliability of the data. An accurate measurement is one which is close to the true value.
- The design of an investigation must provide data with sufficient accuracy. For example, measures of blood alcohol levels must be accurate enough to be able to determine whether the person is legally fit to drive.
- The design of an investigation must provide data with sufficient precision to form a valid conclusion. For example, in an investigation into the bounce of different balls, less precision is needed to tell if a tennis ball bounces higher than a squash ball than if you wanted to distinguish between the bounce of two very similar tennis balls.

10.5 Making measurements

When making measurements we must consider such issues as inherent variation due to variables that have not been controlled, human error and the characteristics of the instruments used. Evidence should be evaluated with the reliability and validity of the measurements that have been made in mind.

A single measurement

- There will always be some variation in the actual value of a variable no matter how hard we try to repeat an event. For instance, if a ball is dropped and doesn't land on exactly the same point on its surface there will be a slight difference in the rebound height.
- When selecting an instrument, it is necessary to consider the accuracy inherent in the instrument and the way it has to be used. For example, expensive thermometers are likely to give a reading nearer to the true reading and to be more accurately calibrated.
- The sensitivity of an instrument refers to the smallest change in a value that can be detected. For example, bathroom scales are not sensitive enough to detect the weekly changes in the mass of a baby, whereas scales used by a midwife are sensitive enough to permit a growth chart to be plotted.
- Even when an instrument is used correctly, human error may occur which could produce random differences in repeated readings or a systematic shift from the true value which could, for instance, occur due to incorrect use or poor calibration.
- Random error can result from inconsistent application of a technique. Systematic error can result from consistent misapplication of a technique.
- Any anomalous values should be examined to try and identify the cause and, if a product of a poor measurement, ignored.

10.6 Presenting data

To explain the relationship between two or more variables, data may be presented in such a way as to make the patterns more evident. There is a link between the type of graph used and the type of variable represented. The choice of graphical representation depends upon the type of variable they represent.

Candidates should know and understand

- The range of the data refers to the maximum and minimum values.
- The mean (or average) of the data refers to the sum of all the measurements divided by the number of measurements taken.
- Tables are an effective means of displaying data but are limited in how they portray the design of an investigation,
- Bar charts can be used to display data in which the independent variable is categoric and the dependent variable continuous.
- Line graphs can be used to display data in which both the independent and dependent variables are continuous.
- Scattergrams can be used to show an association between two variables (eg water content of soil and height of plants).

10.7 Using data to draw conclusions

The patterns and relationships observed in data represent the behaviour of the variables in an investigation. However, it is necessary to look at patterns and relationships between variables with the limitations of the data in mind in order to draw conclusions.

Candidates should know and understand

- Patterns in tables and graphs can be used to identify anomalous data that require further consideration.
- A line of best fit can be used to illustrate the underlying relationship between variables.
- The relationships that exist between variables can be linear (positive or negative, eg height of wax remaining in a candle and time it has been burning) or directly proportional (eg extension of a spring and applied force). On a graph, the relationship could show as a curve (eg velocity against time for a falling object).
- Conclusions must be limited by the data available and not go beyond them. For example, the beneficial effects of a new drug may be limited to the sample used in the tests (younger men perhaps) and not the entire population.

Evaluation

- In evaluating a whole investigation the reliability and validity of the data obtained must be considered. The reliability of an investigation can be increased by looking at data obtained from secondary sources, through using an alternative method as a check and by requiring that the results are reproducible by others.

10.8 Societal aspects of scientific evidence

A judgement or decision relating to social-scientific issues may not be based on evidence alone, as other societal factors may be relevant.

Candidates should know and understand

- The credibility of the evidence is increased if a balanced account of the data is used rather than a selection from it which supports a particular pre-determined stance.
- Evidence must be scrutinised for any potential bias of the experimenter, such as funding sources or allegiances.
- Evidence can be accorded undue weight, or dismissed too lightly, simply because of its political significance. If the consequences of the evidence might provoke public or political disquiet, the evidence may be downplayed.
- The status of the experimenter may influence the weight placed on evidence; for instance, academic or professional status, experience and authority. It is more likely that the advice of an eminent scientist will be sought to help provide a solution to a problem than that of a scientist with less experience.
- Scientific knowledge gained through investigations can be the basis for technological developments.
- Scientific and technological developments offer different opportunities for exploitation to different groups of people.
- The uses of science and technology developments can raise ethical, social, economic and environmental issues.
- Decisions are made by individuals and by society on issues relating to science and technology.

10.9 Limitations of scientific evidence

Science can help us in many ways but it cannot supply all the answers.

We are still finding out about things and developing our scientific knowledge. There are some questions that we cannot answer, maybe because we do not have enough reliable and valid evidence. For example, it is generally accepted that the extra carbon dioxide in the air (from burning fossil fuels) is linked to global warming, but some scientists think there is not sufficient evidence and that there are other factors involved.

And there are some questions that science cannot answer at all. These tend to be questions where beliefs and opinions are important or where we cannot collect reliable and valid scientific evidence. For example, science may be able to answer questions that start ‘How can we ..’ such as ‘How can we clone babies?’ but questions starting ‘Should we ..’ such as ‘Should we clone babies?’ are for society to answer.

11 Unit Chemistry 1

At the beginning of each sub-section, activities are stated which develop candidates' skills, knowledge and understanding of how science works. Details are then given of the substantive contexts in which these skills, knowledge and understanding should be set. It is expected that, where appropriate, teachers will adopt a practical approach, enabling candidates to develop skills in addition to procedural knowledge and understanding.

Note that objective test Chemistry 1a examines Section 11.1 – 11.3 and objective test Chemistry 1b examines Sections 11.4 – 11.6.

11.1 How do rocks provide building materials?

The exploitation of rocks provides essential building materials. Limestone is a naturally occurring resource that provides a starting point for the manufacture of cement, concrete and glass. Throughout Unit Chemistry 1, candidates should know that atoms are held together in molecules and lattices by chemical bonds, but no detailed knowledge of the types of chemical bonding is required. Candidates should be able to interpret chemical equations in symbol form and should be able to balance equations in terms of numbers of atoms.

Candidates should use their skills, knowledge and understanding of how science works:

- to consider and evaluate the environmental, social and economic effects of exploiting limestone and producing building materials from it
- to evaluate the developments in using limestone, cement, concrete and glass as building materials, and their advantages and disadvantages over other materials.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- All substances are made of atoms. A substance that is made of only one sort of atom is called an element. There are about 100 different elements. Elements are shown in the periodic table. The groups contain elements with similar properties.
- Atoms of each element are represented by a chemical symbol, eg O represents an atom of oxygen, Na represents an atom of sodium.
- Atoms have a small central nucleus around which there are electrons.
- When elements react, their atoms join with other atoms to form compounds. This involves giving, taking or sharing electrons and the atoms are held together by chemical bonds. (No further knowledge of ions, ionic and covalent bonding is required in this unit.)
- Atoms and symbols are used to represent and explain what is happening to the substances in chemical reactions.
- The formula of a compound shows the number and type of atoms that are joined together to make the compound.

- No atoms are lost or made during a chemical reaction so the mass of the products equals the mass of the reactants and we can write balanced equations showing the atoms involved.
- Limestone, containing the compound calcium carbonate ($CaCO_3$), is quarried and can be used as a building material.
- Calcium carbonate can be decomposed by heating (thermal decomposition) to make calcium oxide (quicklime) and carbon dioxide.
- Carbonates of other metals decompose on heating in a similar way.
- Quicklime (calcium oxide) reacts with water to produce slaked lime (calcium hydroxide).
- Limestone and its products have many uses, including slaked lime, mortar, cement, concrete and glass.

11.2 How do rocks provide metals and how are metals used?

Metals are very useful in our everyday lives. Ores are naturally occurring rocks that provide an economic starting point for the manufacture of metals. Iron ore is used to make iron and steel. Copper can be easily extracted but copper rich ores are becoming scarce. Aluminium and titanium are useful metals but are expensive to produce.

Candidates should use their skills, knowledge and understanding of how science works:

- to consider and evaluate the social, economic and environmental impacts of exploiting metal ores, of using metals and of recycling metals
- to evaluate the benefits, drawbacks and risks of using metals as structural materials and as smart materials
- to explain how the properties of alloys (but not smart alloys) are related to models of their structures.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Ores contain enough metal to make it economical to extract the metal and this changes over time.
- Unreactive metals such as gold are found in the Earth as the metal itself but most metals are found as compounds that require chemical reactions to extract the metal.
- Metals that are less reactive than carbon can be extracted from their oxides by reduction with carbon, for example iron oxide is reduced in the blast furnace to make iron. (Details of the blast furnace are not required.)
- Iron from the blast furnace contains about 96% iron. The impurities make it brittle and so it has limited uses.
- Removing all of the impurities would produce pure iron. Pure iron has a regular arrangement of atoms, with layers that can slide over each other, and so is soft and easily shaped, but too soft for many uses.

- Most iron is converted into steels. Steels are alloys since they are mixtures of iron with carbon and other metals. The different sized atoms added distort the layers in the structure of the pure metal, making it more difficult for them to slide over each other, and so alloys are harder. Alloys can be designed to have properties for specific uses. Low carbon steels are easily shaped, high carbon steels are hard, and stainless steels are resistant to corrosion.
- Many metals in everyday use are alloys. Pure copper, gold, and aluminium are too soft for many uses and so are mixed with small amounts of similar metals to make them harder for everyday use.
- Smart alloys can return to their original shape after being deformed.
- The elements in the central block of the periodic table are known as transition metals. Like other metals they are good conductors of heat and electricity and can be bent or hammered into shape. They are useful as structural materials and for making things that must allow heat or electricity to pass through them easily.
- Copper has properties that make it useful for electrical wiring and plumbing. Copper can be extracted by electrolysis of solutions containing copper compounds. (No details are required of the extraction process.) The supply of copper-rich ores is limited. New ways of extracting copper from low-grade ores are being researched to limit the environmental impact of traditional mining.
- Low density and resistance to corrosion make aluminium and titanium useful metals. These metals cannot be extracted from their oxides by reduction with carbon. Current methods of extraction are expensive because:
  - there are many stages in the processes
  - much energy is needed.
- We should recycle metals because extracting them uses limited resources and is expensive in terms of energy and effects on the environment.

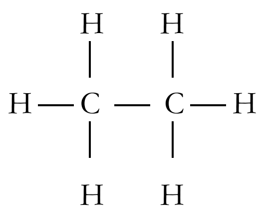
11.3 How do we get fuels from crude oil?

Crude oil is an ancient biomass found in rocks from which many useful materials can be produced. Crude oil can be fractionally distilled. Some of the fractions can be used as fuels.

Candidates should use their skills, knowledge and understanding of how science works:

- to evaluate the impact on the environment of burning hydrocarbon fuels
- to consider and evaluate the social, economic and environmental impacts of the uses of fuels
- to evaluate developments in the production and uses of better fuels, for example ethanol and hydrogen.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Crude oil is a mixture of a very large number of compounds.
- A mixture consists of two or more elements or compounds not chemically combined together. The chemical properties of each substance in the mixture are unchanged. It is possible to separate the substances in a mixture by physical methods including distillation.
- Most of the compounds in crude oil consist of molecules made up of hydrogen and carbon atoms only (hydrocarbons). Most of these are saturated hydrocarbons called alkanes, which have the general formula C_nH_{2n+2}
- Alkane molecules can be represented in the following forms:
  - C_2H_6
  - 
- The many hydrocarbons in crude oil may be separated into fractions, each of which contains molecules with a similar number of carbon atoms, by evaporating the oil and allowing it to condense at a number of different temperatures. This process is fractional distillation.
- Some properties of hydrocarbons depend on the size of their molecules. These properties influence how hydrocarbons are used as fuels.
- Most fuels contain carbon and/or hydrogen and may also contain some sulfur. The gases released into the atmosphere when a fuel burns may include carbon dioxide, water (vapour), carbon monoxide and sulfur dioxide. Particles may also be released.
- Sulfur dioxide causes acid rain, carbon dioxide causes global warming, and particles cause global dimming.
- Sulfur can be removed from fuels before they are burned, for example in vehicles. Sulfur dioxide can be removed from the waste gases after combustion, for example in power stations.

11.4 How are polymers and ethanol made from oil?

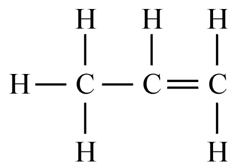
Fractions from the distillation of crude oil can be cracked to make smaller molecules including unsaturated hydrocarbons such as ethane. Unsaturated hydrocarbons can be used to make polymers and ethene can be used to make ethanol.

Candidates should use their skills, knowledge and understanding of how science works:

- to evaluate the social and economic advantages and disadvantages of using products from crude oil as fuels or as raw materials for plastic and other chemicals
- to evaluate the social, economic and environmental impacts of the uses, disposal and recycling of polymers

- to evaluate the advantages and disadvantages of making ethanol from renewable and non-renewable sources.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Hydrocarbons can be broken down (cracked) to produce smaller, more useful molecules. This process involves heating the hydrocarbons to vaporise them and passing the vapours over a hot catalyst. A thermal decomposition reaction then occurs.
- The products of cracking include alkanes and unsaturated hydrocarbons called alkenes. Alkenes have the general formula C_nH_{2n}
- Unsaturated hydrocarbon molecules can be represented in the following forms:
  - C_2H_4
  - 
- Some of the products of cracking are useful as fuels.
- Ethene can be reacted with steam in the presence of a catalyst to produce ethanol.
- Alkenes can be used to make polymers such as poly(ethene) and poly(propene). In these reactions, many small molecules (monomers) join together to form very large molecules (polymers).
- Polymers have properties that depend on what they are made from and the conditions under which they are made. For example, slime with different viscosities can be made from poly(ethenol).
- Polymers have many useful applications and new uses are being developed, for example: new packaging materials, waterproof coatings for fabrics, dental polymers, wound dressings, hydrogels, smart materials, including shape memory polymers.
- Many polymers are not biodegradable, so they are not broken down by microorganisms and this can lead to problems with waste disposal.

11.5 How can plant oils be used?

Many plants produce useful oils which can be converted into consumer products including processed foods. Vegetable oils can be hardened to make margarine. Biodiesel fuel can be produced from vegetable oils.

Candidates should use their skills, knowledge and understanding of how science works:

- to evaluate the effects of using vegetable oils in foods and the impacts on diet and health
- to evaluate the benefits, drawbacks and risks of using vegetable oils to produce fuels
- to evaluate the use, benefits, drawbacks and risks of ingredients and additives in foods.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Some fruits, seeds and nuts are rich in oils that can be extracted. The plant material is crushed and the oil removed by pressing or in some cases by distillation. Water and other impurities are removed.
- Vegetable oils are important foods and fuels as they provide a lot of energy. They also provide us with nutrients.
- Oils do not dissolve in water. They can be used to produce emulsions. Emulsions are thicker than oil or water and have many uses that depend on their special properties. They provide better texture, coating ability and appearance, for example in salad dressings and ice creams.
- Vegetable oils that are unsaturated contain double carbon carbon bonds. These can be detected by reacting with bromine or iodine.
- Vegetable oils that are unsaturated can be hardened by reacting them with hydrogen in the presence of a nickel catalyst at about 60 °C. The hydrogenated oils have higher melting points so they are solids at room temperature, making them useful as spreads and in cakes and pastries.
- Processed foods may contain additives to improve appearance, taste and shelf-life. These additives must be listed in the ingredients and some permitted additives were given E-numbers.
- Chemical analysis can be used to identify additives in foods. Artificial colours can be detected and identified by chromatography.

11.6 What are the changes in the Earth and its atmosphere?

The Earth and its atmosphere provide everything we need.

The Earth has a layered structure. Large-scale movements of the Earth's crust can cause changes in the rocks. The Earth's atmosphere was originally very different from what it is today. It has been much the same for the last 200 million years and provides the conditions needed for life on Earth. Recently human activities have produced further changes.

Candidates should use their skills, knowledge and understanding of how science works:

- to explain why the theory of crustal movement (continental drift) was not generally accepted for many years after it was proposed
- to explain why scientists cannot accurately predict when earthquakes and volcanic eruptions will occur
- to explain and evaluate theories of the changes that have occurred and are occurring in the Earth's atmosphere
- to explain and evaluate the effects of human activities on the atmosphere.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- The Earth consists of a core, mantle and crust.
- Scientists once thought that the features of the Earth's surface were the result of the shrinking of the crust as the Earth cooled down following its formation.

- The Earth's crust and the upper part of the mantle are cracked into a number of large pieces (tectonic plates). Convection currents within the Earth's mantle, driven by heat released by natural radioactive processes, cause the plates to move at relative speeds of a few centimetres per year.
- The movements can be sudden and disastrous. Earthquakes and/or volcanic eruptions occur at the boundaries between tectonic plates.
- For 200 million years, the proportions of different gases in the atmosphere have been much the same as they are today:
  - about four-fifths (80%) nitrogen
  - about one-fifth (20%) oxygen
  - small proportions of various other gases, including carbon dioxide, water vapour and noble gases.
- The noble gases are in Group 0 of the periodic table. They are all chemically unreactive gases and are used in filament lamps and electric discharge tubes. Helium is much less dense than air and is used in balloons.
- During the first billion years of the Earth's existence there was intense volcanic activity. This activity released the gases that formed the early atmosphere and water vapour that condensed to form the oceans.
- Some theories suggest that during this period, the Earth's atmosphere was mainly carbon dioxide and there would have been little or no oxygen gas (like the atmospheres of Mars and Venus today). There may also have been water vapour and small proportions of methane and ammonia.
- Plants produced the oxygen that is now in the atmosphere.
- Most of the carbon from the carbon dioxide in the air gradually became locked up in sedimentary rocks as carbonates and fossil fuels.
- Nowadays the release of carbon dioxide by burning fossil fuels increases the level of carbon dioxide in the atmosphere.

12 Unit Chemistry 2

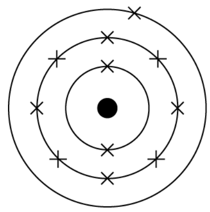
At the beginning of each sub-section, activities are stated which develop candidates' skills, knowledge and understanding of how science works. Details are then given of the substantive contexts in which these skills, knowledge and understanding should be set. It is expected that, where appropriate, teachers will adopt a practical approach enabling candidates to develop skills in addition to procedural knowledge and understanding.

12.1 How do sub-atomic particles help us to understand the structure of substances?

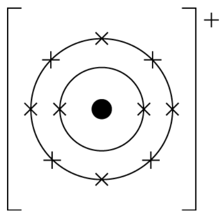
Simple particle theory is developed in this unit to include atomic structure and bonding. The arrangement of electrons in atoms can be used to explain what happens when elements react and how atoms join together to form different types of substances.

Candidates should use their skills, knowledge and understanding of how science works:

- to represent the electronic structure of the first twenty elements of the periodic table in the following forms:

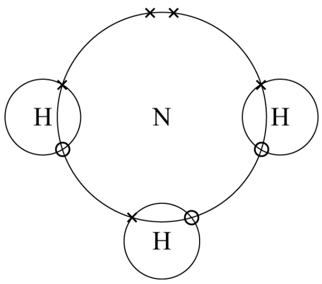
for sodium  and 2,8,1

- to represent the electronic structure of the ions in sodium chloride, magnesium oxide and calcium chloride in the following forms:

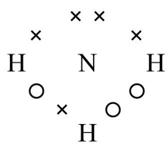
for sodium ion (Na^+)  and $[2,8]^+$

- to represent the covalent bonds in molecules such as water, ammonia, hydrogen, hydrogen chloride, chlorine, methane and oxygen and in giant structures such as diamond and silicon dioxide in the following forms:

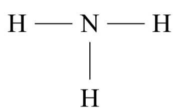
for ammonia (NH_3)



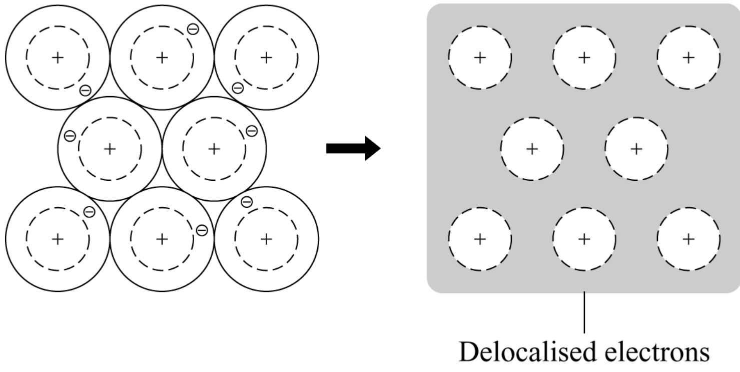
and/or



and/or



HT ❖ to represent the bonding in metals in the following form:



HT ❖ to write balanced chemical equations for reactions.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Atoms have a small central nucleus made up of protons and neutrons around which there are electrons.
- The relative electrical charges are as shown:

Name of particle	Charge
Proton	+1
Neutron	0
Electron	–1

- In an atom, the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge.
- All atoms of a particular element have the same number of protons. Atoms of different elements have different numbers of protons.
- The number of protons in an atom is called its atomic number (proton number). Atoms are arranged in the modern periodic table in order of their atomic number (proton number).
- Electrons occupy particular energy levels. Each electron in an atom is at a particular energy level (in a particular shell). The electrons in an atom occupy the lowest available energy levels (innermost available shells). (Though only energy levels are referred to throughout this specification, candidates may answer in terms of shells if they prefer.)
- Elements in the same group in the periodic table have the same number of electrons in the highest energy levels (outer electrons).
- Compounds are substances in which atoms of two, or more, elements are not just mixed together but chemically combined.
- Chemical bonding involves either transferring or sharing electrons in the highest occupied energy levels (shells) of atoms.

- When atoms form chemical bonds by transferring electrons, they form ions. Atoms that lose electrons become positively charged ions. Atoms that gain electrons become negatively charged ions. Ions have the electronic structure of a noble gas (Group 0).
- The elements in Group 1 of the periodic table, the alkali metals, have similar chemical properties. They all react with non-metal elements to form ionic compounds in which the metal ion has a single positive charge.
- The elements in Group 7 of the periodic table, the halogens, have similar chemical properties. They react with the alkali metals to form ionic compounds in which the halide ions have a single negative charge.
- An ionic compound is a giant structure of ions. Ionic compounds are held together by strong forces of attraction between oppositely charged ions. These forces act in all directions in the lattice and this is called ionic bonding.
- When atoms share pairs of electrons, they form covalent bonds. These bonds between atoms are strong. Some covalently bonded substances consist of simple molecules such as H_2, Cl_2, O_2, HCl, H_2O and CH_4. Others have giant covalent structures (macromolecules), such as diamond and silicon dioxide.

HT ❖ Metals consist of giant structures of atoms arranged in a regular pattern. The electrons in the highest occupied energy levels (outer shell) of metal atoms are delocalised and so free to move through the whole structure. This corresponds to a structure of positive ions with electrons between the ions holding them together by strong electrostatic attractions.

12.2 How do structures influence the properties and uses of substances?

Substances that have simple molecular, giant ionic and giant covalent structures have very different properties. Ionic, covalent and metallic bonds are strong. The forces between molecules are weaker, eg in carbon dioxide and iodine. Nanomaterials have new properties because of their very small size.

Candidates should use their skills, knowledge and understanding of how science works:

- to relate the properties of substances to their uses
- to suggest the type of structure of a substance given its properties
- to evaluate developments and applications of new materials, eg nanomaterials, smart materials.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Substances that consist of simple molecules are gases, liquids or solids that have relatively low melting points and boiling points.

HT ❖ Substances that consist of simple molecules have only weak forces between the molecules (intermolecular forces). It is these intermolecular forces that are overcome, not the covalent bonds, when the substance melts or boils.

- Substances that consist of simple molecules do not conduct electricity because the molecules do not have an overall electric charge.

- Ionic compounds have regular structures (giant ionic lattices) in which there are strong electrostatic forces in all directions between oppositely charged ions. These compounds have high melting points and high boiling points.
- When melted or dissolved in water, ionic compounds conduct electricity because the ions are free to move and carry the current.
- Atoms that share electrons can also form giant structures or macromolecules. Diamond and graphite (forms of carbon) and silicon dioxide (silica) are examples of giant covalent structures (lattices) of atoms. All the atoms in these structures are linked to other atoms by strong covalent bonds and so they have very high melting points.
- In diamond, each carbon atom forms four covalent bonds with other carbon atoms in a giant covalent structure, so diamond is very hard.
- In graphite, each carbon atom bonds to three others, forming layers. The layers are free to slide over each other and so graphite is soft and slippery.

HT ❖ In graphite, one electron from each carbon atom is delocalised. These delocalised electrons allow graphite to conduct heat and electricity.

HT ❖ Metals conduct heat and electricity because of the delocalised electrons in their structures.

- The layers of atoms in metals are able to slide over each other and so metals can be bent and shaped.
- Nanoscience refers to structures that are 1-100 nm in size, of the order of a few hundred atoms. Nanoparticles show different properties to the same materials in bulk and have a high surface area to volume ratio, which may lead to the development of new computers, new catalysts, new coatings, highly selective sensors and stronger and lighter construction materials.

12.3 How much can we make and how much do we need to use?

The relative masses of atoms can be used to calculate how much to react and how much we can produce, because no atoms are gained or lost in chemical reactions. In industrial processes, atom economy is important for sustainable development.

Candidates should use their skills, knowledge and understanding of how science works:

- to calculate chemical quantities involving formula mass (M_r) and percentages of elements in compounds

HT ❖ to calculate chemical quantities involving empirical formulae, reacting masses and percentage yield

[?] HT ❖ to calculate the atom economy for industrial processes and be able to evaluate sustainable development issues related to this economy.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Atoms can be represented as shown:

  Mass number 23

  Na

  Atomic Number 11

- The relative masses of protons, neutrons and electrons are:

Name of particle	Mass
Proton	1
Neutron	1
Electron	Very small

- The total number of protons and neutrons in an atom is called its mass number.
- Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element.

HT ❖ The relative atomic mass of an element (A_r) compares the mass of atoms of the element with the ^{12}C isotope. It is an average value for the isotopes of the element.

- The relative formula mass (M_r) of a compound is the sum of the relative atomic masses of the atoms in the numbers shown in the formula.
- The relative formula mass of a substance, in grams, is known as one mole of that substance.
- The percentage of an element in a compound can be calculated from the relative mass of the element in the formula and the relative formula mass of the compound.

HT ❖ The masses of reactants and products can be calculated from balanced symbol equations.

- Even though no atoms are gained or lost in a chemical reaction, it is not always possible to obtain the calculated amount of a product because:
  - the reaction may not go to completion because it is reversible
  - some of the product may be lost when it is separated from the reaction mixture
  - some of the reactants may react in ways different to the expected reaction.

HT ❖ The amount of a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.

- The atom economy (atom utilisation) is a measure of the amount of starting materials that end up as useful products. It is important for sustainable development and for economical reasons to use reactions with high atom economy.
- In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented:

$$A + B \rightleftharpoons C + D$$

For example:

ammonium chloride ⇌ ammonia + hydrogen chloride

HT ❖ When a reversible reaction occurs in a closed system, equilibrium is reached when the reactions occur at exactly the same rate in each direction.

HT ❖ The relative amounts of all the reacting substances at equilibrium depend on the conditions of the reaction.

- Although reversible reactions may not go to completion, they can still be used efficiently in continuous industrial processes, such as the Haber process that is used to manufacture ammonia.
- The raw materials for the Haber process are nitrogen and hydrogen. Nitrogen is obtained from the air and hydrogen may be obtained from natural gas or other sources.
- The purified gases are passed over a catalyst of iron at a high temperature (about 450 °C) and a high pressure (about 200 atmospheres). Some of the hydrogen and nitrogen reacts to form ammonia. The reaction is reversible so ammonia breaks down again into nitrogen and hydrogen:

  nitrogen + hydrogen ⇌ ammonia

- On cooling, the ammonia liquefies and is removed. The remaining hydrogen and nitrogen is re-cycled.

HT ❖ The reaction conditions are chosen to produce a reasonable yield of ammonia quickly.

12.4 How can we control the rates of chemical reactions?

Being able to speed up or slow down chemical reactions is important in everyday life and in industry. Changes in temperature, concentration of solutions, surface area of solids and the presence of catalysts all affect the rates of reactions.

Candidates should use their skills, knowledge and understanding of how science works:

- to interpret graphs showing the amount of product formed (or reactant used up) with time, in terms of the rate of the reaction
- to explain and evaluate the development, advantages and disadvantages of using catalysts in industrial processes.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- The rate of a chemical reaction can be found by measuring the amount of a reactant used or the amount of product formed over time:

$$\text{Rate of reaction} = \frac{\text{Amount of reactant used or amount of product formed}}{\text{Time}}$$

- The rate of a chemical reaction increases:
  - if the temperature increases
  - if the concentration of dissolved reactants or the pressure of gases increases
  - if solid reactants are in smaller pieces (greater surface area)
  - if a catalyst is used.

- Chemical reactions can only occur when reacting particles collide with each other and with sufficient energy. The minimum amount of energy particles must have to react is called the activation energy.
- Increasing the temperature increases the speed of the reacting particles so that they collide more frequently and more energetically. This increases the rate of reaction.
- Increasing the concentration of reactants in solutions and increasing the pressure of reacting gases also increases the frequency of collisions and so increases the rate of reaction.

HT ❖ Concentrations of solutions are given in moles per cubic decimetre (mol/dm^3). Equal volumes of solutions of the same molar concentration contain the same number of moles of solute, ie the same number of particles.

HT ❖ Equal volumes of gases at the same temperature and pressure contain the same number of molecules. (Candidates will not be expected to find concentrations of solutions or volumes of gases in this unit.)

- Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts.
- Catalysts are important in increasing the rates of chemical reactions used in industrial processes to reduce costs.

12.5 Do chemical reactions always release energy?

Chemical reactions involve energy transfers. Many chemical reactions involve the release of energy. For other chemical reactions to occur, energy must be supplied. In industrial processes, energy requirements and emissions need to be considered both for economic reasons and for sustainable development.

Candidates should use their skills, knowledge and understanding of how science works:

- to describe the effects of changing the conditions of temperature and pressure on a given reaction or process
- to evaluate the conditions used in industrial processes in terms of energy requirements.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- When chemical reactions occur, energy is transferred to or from the surroundings.
- An exothermic reaction is one that transfers energy, often as heat, to the surroundings. Examples of exothermic reactions include combustion, many oxidation reactions and neutralisation.
- An endothermic reaction is one that takes in energy, often as heat, from the surroundings. Endothermic reactions include thermal decompositions.
- If a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction. The same amount of energy is transferred in each case. For example:

$$\text{hydrated copper sulfate (blue)} \underset{\text{exothermic}}{\overset{\text{endothermic}}{\rightleftharpoons}} \text{anhydrous copper sulfate (white)} + \text{water}$$

The reverse reaction can be used as a test for water.

HT ❖ When a reversible reaction occurs in a closed system, equilibrium is reached when the reactions occur at exactly the same rate in each direction.

HT ❖ The relative amounts of all the reacting substances at equilibrium depend on the conditions of the reaction.

HT ❖ If the temperature is raised, the yield from the endothermic reaction increases and the yield from the exothermic reaction decreases.

HT ❖ If the temperature is lowered, the yield from the endothermic reaction decreases and the yield from the exothermic reaction increases.

HT ❖ In gaseous reactions, an increase in pressure will favour the reaction that produces the least number of molecules as shown by the symbol equation for that reaction.

HT ❖ These factors, together with reaction rates, are important when determining the optimum conditions in industrial processes, including the Haber process.

- It is important for sustainable development as well as economic reasons to minimise energy requirements and energy wasted in industrial processes. Non-vigorous conditions mean less energy is used and less is released into the environment.

12.6 How can we use ions in solutions?

Ionic compounds have many uses and can provide other substances. Electrolysis is used to produce alkalis and elements such as chlorine and hydrogen. Oxidation-reduction reactions do not just involve oxygen. Soluble salts can be made from acids and insoluble salts can be made from solutions of ions.

Candidates should use their skills, knowledge and understanding of how science works:

- to predict the products of electrolysing solutions of ions
- to suggest methods to make a named salt
- to explain and evaluate processes that use the principles described in this unit

HT ❖ to complete and balance supplied half equations for the reactions occurring at the electrodes during electrolysis.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- The state symbols in equations are (s), (l), (g) and (aq).
- When an ionic substance is melted or dissolved in water, the ions are free to move about within the liquid or solution.
- Passing an electric current through ionic substances that are molten or in solution breaks them down into elements. This process is called electrolysis.
- During electrolysis, positively charged ions move to the negative electrode, and negatively charged ions move to the positive electrode.

- At the negative electrode, positively charged ions gain electrons (reduction) and at the positive electrode, negatively charged ions lose electrons (oxidation).
- If there is a mixture of ions, the products formed depend on the reactivity of the elements involved.

HT ❖ Reactions at electrodes can be represented by half equations, for example:

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

- The electrolysis of sodium chloride solution produces hydrogen and chlorine. Sodium hydroxide solution is also produced. These are important reagents for the chemical industry.
- Copper can be purified by electrolysis using a positive electrode made of the impure copper and a negative electrode of pure copper in a solution containing copper ions.
- Insoluble salts can be made by mixing appropriate solutions of ions so that a precipitate is formed. Precipitation can be used to remove unwanted ions from solutions, for example in treating water for drinking or in treating effluent.
- Soluble salts can be made from acids by reacting them with:
  - metals - not all metals are suitable, some are too reactive and others are not reactive enough
  - insoluble bases – the base is added to the acid until no more will react and the excess solid is filtered off
  - alkalis - an indicator can be used to show when the acid and alkali have completely reacted to produce a salt solution.
- Salt solutions can be crystallised to produce solid salt.
- Metal oxides and hydroxides are bases. Soluble hydroxides are called alkalis.
- The particular salt produced in any reaction between an acid and a base or alkali depends on:
  - the acid used (hydrochloric acid produces chlorides, nitric acid produces nitrates, sulfuric acid produces sulfates)
  - the metal in the base or alkali.
- Ammonia dissolves in water to produce an alkaline solution. It is used to produce ammonium salts. Ammonium salts are important as fertilisers.
- Hydrogen ions $H^+(aq)$ make solutions acidic and hydroxide ions OH^- (aq) make solutions alkaline. The pH scale is a measure of the acidity or alkalinity of a solution.
- In neutralisation reactions, hydrogen ions react with hydroxide ions to produce water. This reaction can be represented by the equation:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l).$$

13 Unit Chemistry 3

At the beginning of each sub-section, activities are stated which develop candidates' skills, knowledge and understanding of how science works. Details are then given of the substantive contexts in which these skills, knowledge and understanding should be set. It is expected that, where appropriate, teachers will adopt a practical approach enabling candidates to develop skills in addition to procedural knowledge and understanding.

13.1 How was the periodic table developed and how can it help us understand the reactions of elements?

The periodic table was developed to classify elements before atomic structure was understood. It is a powerful aid to understanding the properties and reactions of the elements.

Candidates should use their skills, knowledge and understanding of how science works:

- to explain how attempts to classify elements in a systematic way, including those of Newlands and Mendeleev, have led through the growth of chemical knowledge to the modern periodic table
- to explain why scientists regarded a periodic table of the elements first as a curiosity, then as a useful tool and finally as an important summary of the structure of atoms.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Newlands, and then Mendeleev, attempted to classify the elements by arranging them in order of their atomic weights. The list can be arranged in a table so that elements with similar properties are in columns, known as Groups. The table is called a periodic table because similar properties occur at regular intervals.
- The early periodic tables were incomplete and some elements were placed in inappropriate Groups if the strict order of atomic weights was followed.
  Mendeleev overcame some of the problems by leaving gaps for elements that he thought had not been discovered.
- When electrons, protons and neutrons were discovered early in the 20th century, the periodic table was arranged in order of atomic (proton) numbers. When this was done, all elements were placed in appropriate groups.
- The modern periodic table can be seen as an arrangement of the elements in terms of their electronic structures. Elements in the same Group have the same number of electrons in their highest occupied energy level (outer shell).

HT ❖ The trends in reactivity within Groups in the periodic table can be explained because the higher the energy level:
  - the more easily electrons are lost
  - the less easily electrons are gained.

- The elements in Group 1 of the periodic table (known as the alkali metals):
  - are metals with low density (the first three elements in the Group are less dense than water)

- react with non-metals to form ionic compounds in which the metal ion carries a charge of +1. The compounds are white solids which dissolve in water to form colourless solutions
- react with water releasing hydrogen
- form hydroxides which dissolve in water to give alkaline solutions.

- In Group 1, the further down the group an element is:
  - the more reactive the element
  - the lower its melting point and boiling point.

- The elements in Group 7 of the periodic table (known as halogens):
  - have coloured vapours
  - consist of molecules which are made up of pairs of atoms
  - form ionic salts with metals in which the chloride, bromide or iodide ion (halide ion) carries a charge of –1
  - form molecular compounds with other non-metallic elements.

- In Group 7, the further down the group an element is:
  - the less reactive the element
  - the higher its melting point and boiling point.

- A more reactive halogen can displace a less reactive halogen from an aqueous solution of its salt.

- In the periodic table between Groups 2 and 3 is a block of elements known as the transition elements. These elements are all metals.

HT ❖ The transition elements have similar properties and some special properties because a lower energy level (inner shell) is being filled in the atoms of the elements between Groups 2 and 3. This is because the third energy level can hold up to 18 electrons, once two electrons have occupied the fourth level.

- Compared with the elements in Group 1, transition elements:
  - have higher melting points (except for mercury) and higher densities
  - are stronger and harder
  - are much less reactive and so do not react as vigorously with water or oxygen.

- Many transition elements have ions with different charges, form coloured compounds and are useful as catalysts.

13.2 What are strong and weak acids and alkalis? How can we find the amounts of acids and alkalis in solutions?

Acids and alkalis vary in strength as well as concentration. Titrations can be used to find the amounts of acid or alkali in a solution.

Candidates should use their skills, knowledge and understanding of how science works:

HT ❖ to evaluate the contributions of Arrhenius, Lowry and Brønsted to our understanding of acid-base behaviour

[?] HT ❖ to suggest why the work of some scientists, for example Arrhenius, took much longer to be accepted than the work of others, for example, Lowry and Brønsted

HT ❖ to calculate the chemical quantities in titrations involving concentrations (in moles or mass per unit volume) and masses.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

HT ❖ An acid can be defined as a proton donor. A base can be defined as a proton acceptor.

- Water must normally be present for a substance to act as an acid or as a base.
- Acids produce hydrogen ions in aqueous solution. The H^+ ion is a proton. In water this proton is hydrated and is represented as $H^+(aq)$.
- Alkalis produce hydroxide ions, $OH^-(aq)$, in aqueous solutions.
- Acids and alkalis are classified by the extent of their ionisation in water.
  - A strong acid or alkali is one that is completely ionised in water. Examples of strong acids are hydrochloric, sulfuric and nitric acids. Examples of strong alkalis are sodium and potassium hydroxide.
  - A weak acid or alkali is only partially ionised in water. Examples of weak acids are ethanoic, citric and carbonic acids. An example of a weak alkali is ammonia solution.
- The volumes of acid and alkali solutions that react with each other can be measured by titration using a suitable indicator:
  - strong acid + strong alkali – any acid-base indicator
  - HT ❖ strong acid + weak alkali – methyl orange indicator
  - HT ❖ weak acid + strong alkali – phenolphthalein indicator.

HT ❖ If the concentration of one of the reactants is known, the results of a titration can be used to find the concentration of the other reactant.

13.3 What is in the water we drink?

The water we drink is not pure water because it contains dissolved substances. It should be safe to drink, which means it does not contain anything that could cause us harm. Some of the dissolved substances are beneficial to our health but some cause hard water.

Candidates should use their skills, knowledge and understanding of how science works:

- to interpret solubility curves and explain when crystallisation may occur
- [?] to consider and evaluate the environmental, social and economic aspects of water quality and hardness.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Water in rivers, lakes and the oceans is evaporated by the heat of the Sun. This forms water vapour that rises in the atmosphere and cools so that it condenses to form clouds. The water droplets in the clouds join together to produce rain. This is known as the water cycle.
- Many substances dissolve in water. Most ionic compounds are soluble in water. Some molecular substances are soluble but many covalent compounds are insoluble in water.

- The solubility of a solute in water, or any other solvent, is usually given in grams of solute per 100 grams of water (or solvent) at that temperature.
- The solubility of most solutes that are solids increases as the temperature increases.
- A saturated solution is one in which no more solute will dissolve at that temperature. When a hot saturated solution cools, some of the solute will separate from the solution.
- Many gases are soluble in water. Their solubility increases as the temperature decreases and as the pressure increases.
  - Dissolving carbon dioxide in water under high pressure makes carbonated water. When the pressure is released, the gas bubbles out of the solution. Carbonated water is used to make fizzy drinks.
  - Dissolved oxygen is essential for aquatic life. If the temperature of the water increases, the amount of oxygen that is dissolved decreases.
- Soft water readily forms lather with soap. Hard water reacts with soap to form scum and so more soap is needed to form lather.
- Hard water contains dissolved compounds, usually of calcium or magnesium. The compounds are dissolved when water comes into contact with rocks.
- Using hard water can increase costs because more soap is needed. When hard water is heated it can produce scale that reduces the efficiency of heating systems and kettles.
- Hard water has some benefits because calcium compounds are good for health.
- Hard water can be made soft by removing the dissolved calcium and magnesium ions. This can be done by:
  - adding sodium carbonate which reacts with the calcium and magnesium ions forming a precipitate of calcium carbonate and magnesium carbonate
  - using an ion exchange column containing hydrogen ions or sodium ions which replace the calcium and magnesium ions when hard water passes through the column.
- Water of the correct quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microorganisms. This is achieved by choosing an appropriate source, passing the water through filter beds to remove any solids and then sterilising with chlorine.
- Water filters containing carbon, silver and ion exchange resins can remove some dissolved substances from tap water to improve the taste and quality.
- Pure water can be produced by distillation.

13.4 How much energy is involved in chemical reactions?

Knowing the amount of energy involved in chemical reactions is useful so that resources are used efficiently and economically. It is possible to measure the amount of energy experimentally or to calculate it. Controlling the amount of energy intake in our diet is important in avoiding obesity.

Candidates should use their skills, knowledge and understanding of how science works:

- to compare the energy produced by different fuels and foods
- to consider the social, economic and environmental consequences of using fuels
- to interpret simple energy level diagrams in terms of bond breaking and bond formation (including the idea of activation energy and the effect on this of catalysts)
- HT ❖ to calculate the energy transferred in reactions, using simple energy level diagrams or supplied bond energies.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- The relative amounts of energy released when substances burn can be measured by simple calorimetry, eg by heating water in a glass or metal container. This method can be used to compare the amount of energy produced by fuels and foods.
- Energy is normally measured in joules (J). Some dietary information is given in calories, which are equal to 4.2 joules.
- Different foods produce different amounts of energy. Foods with high proportions of carbohydrates, fats and oils produce relatively large amounts of energy.
- Eating food that provides more energy than the body needs can lead to obesity.
- The amount of energy produced by a chemical reaction in solution can be found by mixing the reagents in an insulated container and measuring the temperature change of the solution. This method can be used for reactions of solids with water or for neutralisation reactions.
- During a chemical reaction:
  - energy must be supplied to break bonds
  - energy is released when bonds are formed.

  These changes can be represented on an energy level diagram.
- In an exothermic reaction, the energy released from forming new bonds is greater than the energy needed to break existing bonds.
- In an endothermic reaction, the energy needed to break existing bonds is greater than the energy released from forming new bonds.

13.5 How do we identify and analyse substances?

A range of chemical tests can be used for the detection and identification of elements and compounds. Instrumental methods that are quick, accurate and sensitive have been developed to identify and measure substances, often in very small samples. These methods are used to monitor products, our health, the environment and in forensic science.

Candidates should use their skills, knowledge and understanding of how science works:

- to interpret results of the chemical tests in this specification
- to evaluate the advantages and disadvantages of instrumental methods of analysis and the features that influence that development
- to interpret and evaluate the results of instrumental analyses carried out to identify elements and compounds for forensic, health or environmental purposes.

Their skills, knowledge and understanding of how science works should be set in these substantive contexts:

- Flame tests can be used to identify metal ions. Lithium, sodium, potassium, calcium and barium compounds produce distinctive colours in flame tests.
- Carbonates react with dilute acids to form carbon dioxide. Carbon dioxide turns limewater milky.
- Copper carbonate and zinc carbonate decompose on heating and can be identified by the distinctive colour changes.
- Aluminium, calcium and magnesium ions form white precipitates with sodium hydroxide solution but only the aluminium hydroxide precipitate dissolves in excess sodium hydroxide solution.
  Copper(II), iron(II) and iron(III) ions form coloured precipitates with sodium hydroxide solution.
- Halide ions in solution produce precipitates with silver nitrate solution in the presence of dilute nitric acid. Silver chloride is white, silver bromide is cream and silver iodide is yellow.
- Sulfate ions in solution produce a white precipitate with barium chloride solution in the presence of dilute hydrochloric acid.
- Ammonium ions react with sodium hydroxide solution to form ammonia.
  Ammonia gas turns damp litmus paper blue.
- Nitrate ions are reduced by aluminium powder in the presence of sodium hydroxide solution to form ammonia.
- Organic compounds burn or char when heated in air.

HT ❖ The empirical formula of an organic compound can be found from the masses of the products formed when a known mass of the compound is burned.

- Unsaturated organic compounds containing double carbon carbon bonds decolourise bromine water.
- The development of modern instrumental methods has been aided by the rapid progress in technologies such as electronics and computing.

- Elements and compounds can be detected and identified using a variety of instrumental methods. Instrumental methods are accurate, sensitive and rapid and are particularly useful when the amount of a sample is very small.

HT ❖ Some instrumental methods are suited to identifying elements, such as atomic absorption spectroscopy used in the steel industry. Other instrumental methods are suited to identifying compounds, such as infrared spectrometry, ultraviolet spectroscopy, nuclear magnetic resonance spectroscopy, and gas-liquid chromatography. Some methods can be adapted for elements or compounds, such as mass spectrometry.

(Details of how the instruments work are not required.)

Key Skills and Other Issues

14 Key Skills – Teaching, Developing and Providing Opportunities for Generating Evidence

14.1 Introduction

The Key Skills Qualification requires candidates to demonstrate levels of achievement in the Key Skills of *Application of Number, Communication* and *Information and Communication Technology*.

The units for the 'wider' Key Skills of *Improving own Learning and Performance, Working with Others* and *Problem-Solving* are also available. The acquisition and demonstration of ability in these 'wider' Key Skills is deemed highly desirable for all candidates, but they do not form part of the Key Skills Qualification.

Copies of the Key Skills units may be downloaded from the QCA web site (http://www.qca.org.uk/keyskills).

Copies of the Key Skills specification may be downloaded from the AQA website (www.aqa.org.uk).

14.2 Teaching, Developing and Providing Opportunities for Generating Evidence

Areas of study and learning that can be used to encourage the acquisition and use of Key Skills, and to provide opportunities to generate evidence, are signposted in the tables below. Key Skills signposting indicates naturally occurring opportunities for the development of Key Skills during teaching, learning and assessment. Candidates will not necessarily achieve the signposted Key Skill through the related evidence.

Application of Number Level 1

What you must do …	Signpostingof Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	**Chemistry 1**	**Chemistry 2**	**Chemistry 3**
N1.1 Interpret information from **two** different sources. At least **one** source must include a table, chart, graph or diagram.	✓	✓	✓	✓
N1.2 Carry out and check calculations to do with: a. amounts or sizes b. scales or proportions c. handling statistics.	✓	✓	✓	✓
N1.3 Interpret results of your calculations and present your findings – in **two** different ways using charts or diagrams.	✓	✓	✓	✓

Application of Number Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	**Chemistry 1**	**Chemistry 2**	**Chemistry 3**
N2.1 Interpret information from a suitable source.	✓	✓	✓	✓
N2.2 Use your information to carry out calculations to do with: a. amounts or sizes b. scales or proportions c. handling statistics d. using formulae.	✓	✓	✓	✓
N2.3 Interpret the results of your calculations and present your findings.	✓	✓	✓	✓

Communication Level 1

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
C1.1 Take part in either a **one-to-one** discussion or a **group** discussion.	✓	✓	✓	✓
C1.2 Read and obtain information from at least **one** document.	✓	✓	✓	✓
C1.3 Write **two** different types of documents.	✓	✓	✓	✓

Communication Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
C2.1a Take part in a group discussion.	✓	✓	✓	✓
C2.1b Give a talk of at least four minutes.	✓	✓	✓	✓
C2.2 Read and summarise information from at least **two** documents about the same subject. Each document must be a minimum of 500 words long.	✓	✓	✓	✓
C2.3 Write **two** different types of documents each one giving different information. One document must be at least 500 words.	✓	✓	✓	✓

Information and Communication Technology Level 1

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
ICT1.1 Find and select relevant information.	✓	✓	✓	✓
ICT1.2 Enter and develop information to suit the task.	✓	✓	✓	✓
ICT1.3 Develop the presentation so that the final output is accurate and fit for purpose.	✓	✓	✓	✓

Information and Communication Technology Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
ICT2.1 Search for and select information to meet your needs. Use different information sources for each task and multiple search criteria in at least one case.	✓	✓	✓	✓
ICT2.2 Explore and develop information to suit the task and derive new information.	✓	✓	✓	✓
ICT2.3 Present combined information such as text with image, text with number, image with number.	✓	✓	✓	✓

Improving own Learning and Performance Level 1

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
LP1.1 Confirm your targets and plan how to meet these with the person setting them.	✓	✓	✓	✓
LP1.2 Follow your plan, to help meet targets and improve your performance	✓	✓	✓	✓
LP1.3 Review your progress and achievements in meeting targets, with an appropriate person.	✓	✓	✓	✓

Improving own Learning and Performance Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
LP2.1 Help set targets with an appropriate person and plan how these will be met.	✓	✓	✓	✓
LP2.2 Take responsibility for some decisions about your learning, using your plan to help meet targets and improve your performance.	✓	✓	✓	✓
LP2.3 Review progress with an appropriate person and provide evidence of your achievements.	✓	✓	✓	✓

Working with Others Level 1

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
WO1.1 Confirm you understand the given objectives, and plan for working together.	✓	✓	✓	✓
WO1.2 Work with others towards achieving the given objectives.	✓	✓	✓	✓
WO1.3 Identify ways you helped to achieve things and how to improve your work with others.	✓	✓	✓	✓

Working with Others Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
WO2.1 Plan work with others.	✓	✓	✓	✓
WO2.2 Work co-operatively towards achieving the identified objectives.	✓	✓	✓	✓
WO2.3 Review your contributions and agree ways to improve work with others.	✓	✓	✓	✓

Problem Solving Level 1

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
PS1.1 Confirm with an appropriate person that you understand the given problem and identify different ways of tackling it.	✓	✓	✓	✓
PS1.2 Confirm with an appropriate person what you will do and follow your plan for solving the problem.	✓	✓	✓	✓
PS1.3 Check with an appropriate person if the problem has been solved and how to improve your problem solving skills.	✓	✓	✓	✓

Problem Solving Level 2

What you must do …	Signposting of Opportunities for Generating Evidence in Subject Content			
	Chemistry Centre-Assessed Unit	Chemistry 1	Chemistry 2	Chemistry 3
PS2.1 Identify a problem, with help from an appropriate person, and identify different ways of tackling it.	✓	✓	✓	✓
PS2.2 Plan and try out at least one way of solving the problem.	✓	✓	✓	✓
PS2.3 Check if the problem has been solved and identify ways to improve problem solving skills.	✓	✓	✓	✓

15 Spiritual, Moral, Ethical, Social, Cultural and Other Issues

15.1 Spiritual, Moral, Ethical, Social and Cultural Issues

The study of science can contribute to an understanding of spiritual, moral, ethical, social and cultural issues. The following are examples of opportunities to promote candidates' development through the teaching of science.

Spiritual

Through candidates sensing the natural, material and physical world they live in, reflecting on their part in it, exploring questions such as the patterns shown by the reactions of the different elements, and experiencing a sense of awe and wonder at the natural world. Sections 11.6, 12.1 and 12.2 are relevant.

Moral and Ethical

Through helping candidates see the need to draw conclusions using observation and evidence, rather than preconception or prejudice, and through discussion of the implications of the uses of scientific knowledge, including the recognition that such uses can have both beneficial and harmful effects. Exploration of values and ethics relating to applications of science and technology is possible. Sections 10.8, 11.1, 11.2, 11.3 and 11.4 are relevant.

Social

Through helping candidates recognise how the formation of opinion and the justification of decisions can be informed by experimental evidence, and drawing attention to how different interpretations of scientific evidence can be used in discussing social issues. Sections 10.8, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 12.2, 12.4, 12.5, 13.1, 13.3, 13.4, and 13.5 are relevant.

Cultural

Through helping candidates recognise how scientific discoveries and ideas have affected the way people think, feel, create, behave and live, and drawing attention to how cultural differences can influence the extent to which scientific ideas are accepted, used and valued. Sections 10.2, 10.8, 11.3, 11.4, 11.5, 12.2, 13.1 and 13.2 are relevant.

15.2 European Dimension

AQA has taken account of the 1988 Resolution of the Council of the European Community in preparing this specification and associated specimen papers.

There are opportunities in this specification to relate the study of topics to wider European or global contexts. In particular, a broader European context could be used in relation to Sections 11.6, 12.2, 13.3 and 13.4.

15.3 Environmental Issues

AQA has taken account of the 1988 Resolution of the Council of the European Community and the Report *"Environmental Responsibility: An Agenda for Further and Higher Education"* 1993 in preparing this specification and associated specimen papers.

This specification allows responsible attitudes to environmental issues to be fostered. In particular, environmental issues can be considered in relation to Sections 11.1, 11.2, 11.3, 11.4, 11.5, 12.5, 13.3 and 13.4.

15.4 Health and Safety

Teaching about health and safety during practical science forms part of the teaching requirements for this specification (see Section 18.3). However, more general teaching requirements about health and safety are as applicable to science as to other subjects. Examples can be found in Sections 11.3, 11.5, 12.2, 12.3, 12.4, 12.5, 12.6, 13.1, 13.2, 13.3, 13.4 and 13.5.

When working with equipment and materials, in practical activities and in different environments, including those that are unfamiliar, candidates should be taught:

- about hazards, risks and risk control
- to recognise hazards, assess consequent risks and take steps to control the risks to themselves and others
- to use information to assess the immediate and cumulative risks
- to manage their environment to ensure the health and safety of themselves and others
- to explain the steps they take to control risks.

Centres are reminded of requirements to make their own risk assessments under COSHH regulations in relation to the many materials and processes involved in the teaching of this subject.

15.5 Citizenship

This specification allows treatment of aspects of citizenship through the contribution made to candidates' moral, ethical, social and cultural development (see Section 15.1), through opportunities to teach about the European dimension (see Section 15.2) and through opportunities to promote an understanding of, and responsible attitudes towards, environmental issues (see Section 15.3).

15.6 Avoidance of Bias

AQA has taken great care in the preparation of this specification and associated specimen papers to avoid bias of any kind.

15.7 Use of Organisms

Nothing in this specification requires candidates or teachers to kill animals. Live animals brought into the laboratory for study should be kept unstressed in suitable conditions and should, wherever possible, be returned unharmed to their habitats. Studies of animals and plants in their habitats should aim at minimal disturbance.

Centre-Assessed Unit

16 Nature of the Centre-Assessed Unit

Candidates should be encouraged to carry out practical and investigational work throughout the course. They should work safely and accurately, both individually and in groups. This work should cover the skills and knowledge in Section 10: fundamental ideas, observation, investigation design, measurement, data presentation, identifying patterns in relationships and any social aspects of scientific evidence.

AQA identifies some areas of the specification suitable for investigational work and provides ISAs (Investigative Skills Assignments) in the form of written tests relating to these areas of the specification. Candidates are required to carry out practical work beforehand and bring their own data with them. Teachers use their judgement and the marking guidance from AQA to mark each ISA. Teachers are also required to make a holistic assessment of the general practical and safety skills of each candidate. The best ISA mark and the general practical and safety skills assessment are needed for the mark for this unit. It counts for 25% of the total marks for the award.

17 Investigative Knowledge and Skills for Centre-Assessed Unit

17.1 Introduction

The knowledge and understanding which are assessed by the centre-assessed unit are detailed in full in Section 10. The following is a summary of the Procedural Content which teachers and candidates may find useful in preparing for this unit. It contains the following sections:

Fundamental ideas
Observation
Designing an investigation
Making measurements
Presenting data
Identifying patterns and relationships in data
Societal aspects of scientific evidence
Limitations of scientific evidence

A Glossary of Terms relating to 'How Science Works' is provided in Appendix D.

17.2	Fundamental ideas	Candidates should be able to understand what is meant by scientific evidence and thus be able to distinguish between opinions based on scientific facts and opinions based on hearsay evidence or bias.
17.3	Observation	Candidates should be able to recognise key features and make observations in a rational and unbiased manner. They should realise that observations are often the starting point of investigations and may be used as a basis for classification. They should realise that observations can lead to hypotheses and predictions, and that data from observations may support, refute or lead to new hypotheses.
17.4	Designing an Investigation	
	Design of investigations: Variable structure	Candidates should be able to distinguish between the dependent and the independent variable. They should also know the difference between categoric and continuous variables.
	Design: Validity, 'fair tests' and controls	Candidates should be able to describe the attributes of a 'fair test', ie one in which only the chosen independent variable has been allowed to influence the dependent variable. They should also be able to identify other key variables that must either be controlled or, if that is not possible, at least monitored. They should appreciate that in field investigations and surveys there are particular requirements to ensure a fair test, and that control groups are often appropriate to ensure that changes are due to the independent variable.
	Design: Choosing values	Candidates should be able to specify the range of, and interval between, readings to be taken and to appreciate that these can often be determined by means of a preliminary trial run. They should also be able to specify the number of readings to be taken.
	Design: Accuracy and precision	Candidates should be able to explain how an investigation can be designed so that it will render data which is sufficiently accurate and precise as to enable a sensible conclusion to be drawn.
	Reliability and validity of the design	Candidates should be able to evaluate the design of an experiment or investigation by commenting on the ways in which the experimenter did or did not achieve reliability and validity.
17.5	Making Measurements	
	Measurement	Candidates should be able to identify situations in which natural inherent variation in a measurement has been caused by uncontrolled variables, human error or the characteristics of the instrument used.
	Instruments: Underlying relationships	Candidates should be able to explain how a measuring instrument can utilise the relationship between two variables, eg that the length of the mercury column in a thermometer is related directly to the temperature.

Instruments: Calibration and error

Candidates should be able to explain that a measuring instrument is calibrated before use, eg a scale is marked on it by using some known, fixed points. They should know that a measuring instrument may have a zero error and that the smallest scale divisions must be smaller than the value that they are trying to measure. They should realise that the sensitivity of the instrument should be taken into account. They should realise that random errors can result from an inconsistent technique.

Reliability and validity of a single measurement

Candidates should know that the reliability of a measurement may be improved by data from secondary sources, by others repeating the investigation or by using another instrument as a crosscheck. They should understand that for a measurement to be valid the instrument or technique must be actually measuring that which is intended.

The choice of an instrument for measuring a datum

Candidates should be able to distinguish between precision and accuracy. An accurate measurement is one which is close to the true value . Precision is related to the smallest scale division on the measuring instrument that you are using.

In the examples below, measurements were taken of the length of a laboratory bench. Each vertical line on the scale represents a reading.

Diagram (a) shows a set of results which is very precise but not very accurate.

Diagram (b) shows a set of results which is very accurate but not very precise.

Diagram (a)

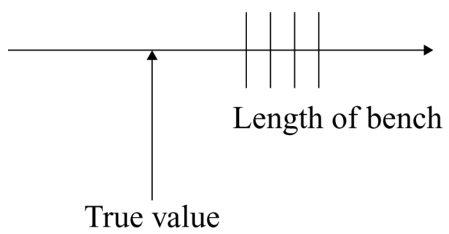
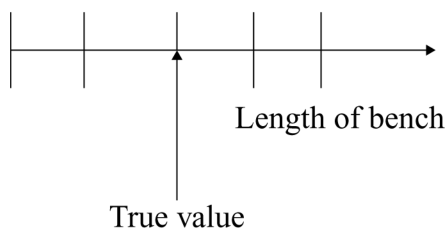


Diagram (b)



Sampling a datum

Candidates should be able to determine the optimum number of measurements and repeats to be made, and to identify any anomalous results.

Statistical treatment of measurements of data

Candidates should be able to state the range of the measurements that have been made, quoting the maximum and minimum values and to calculate the mean.

Reliability and validity of a datum

Candidates should be able to ascertain whether a measurement or observation is (a) reliable, ie has it been crosschecked and (b) valid, ie has the appropriate variable been measured?

17.6 Presenting Data

Tables	Candidates should be able to draw up a results table such that data can be presented in a meaningful and easy to understand way.
Data presentation	Candidates should be able to decide upon the most appropriate method of presenting and analysing data. Such methods include tables, bar charts, line graphs, scattergrams, histograms and pie charts.

17.7 Identifying Patterns and Relationships in Data

Patterns and relationships in data	Candidates should be able to recognise and describe patterns in data and draw conclusions from them. Such patterns include linear and proportional relationships, curves and empirical relationships. They should be capable of drawing and interpreting lines of best fit. They should also be aware that anomalous data may need to be excluded before such a pattern is identified.
Reliability and validity of the data in the whole investigation	Candidates should be able to explain why further evidence may be needed in order to draw a firm conclusion and how this extra evidence may be obtained.

17.8 Societal Aspects of Scientific Evidence

Relevant societal aspects	Candidates should be able to explain how the consequences of scientific experiments may impinge upon society. They should understand that the credibility of scientific research may suffer as the result of any bias by the experimenters. They should also be aware of the consequences of scientific research and understand that acceptability is influenced by a range of other factors, such as ethical, social, economic and environmental issues.

17.9 Limitations of Scientific Evidence

Candidates should realise that it is sometimes difficult to collect sufficient evidence to answer a question. There are also questions that cannot be answered by looking at scientific evidence alone, for example, questions where moral judgements are involved.

18 Guidance on Managing the Centre-Assessed Unit

18.1 Outline

The total marks for this unit are derived in two ways.

Investigative Skills Assignment (ISA)

During the course, candidates carry out practical work on any aspect of science relevant to the specification. When the candidate has carried out practical work on one of the topics listed by AQA as being available for assessment, the teacher may assess the candidate on investigative skills. In a normal timetabled lesson, but under controlled conditions, the candidate is provided with an ISA, supplied by AQA. The maximum time allowed for each ISA is 45 minutes. The candidate must be provided in this session with the data that he or she has collected during the practical work. The ISA is in two parts.

(a) Section 1

This consists of a number of questions relating directly to the candidate's own data. This data must be stapled to the answer sheet.

The number of marks allocated to this section is between 14 and 20.

(b) Section 2

At the start of this section, candidates are supplied with another set of data, relating to the same topic from the specification in which the candidate has conducted his or her practical work. A number of questions relating to the analysis and evaluation of this data then follow. Candidates are expected to make appropriate comparisons between their own and the presented data.

The number of marks allocated to this section is between 14 and 20.

Candidates may attempt any number of the ISAs supplied by AQA, in any of the contexts of Chemistry 1, Chemistry 2 or Chemistry 3 and the best mark obtained is submitted.

Practical Skills Assessment (PSA)

Candidates are assessed throughout the course on the implementation of practical work, using a scale from 0 to 6.

The mark submitted for practical skills should be judged by the teacher over the duration of the course. Teachers may wish to use this section for formative assessment and keep an ongoing record of each candidate's performance, but the mark submitted should represent the candidate's practical abilities over the whole course.

Work to be Submitted

The work to be submitted for each candidate consists of their best Investigative Skills Assignment (ISA) and a Candidate Record Form showing the marks for this ISA and the Practical Skills Assessment (PSA).

18.2 Investigative Skills Assignments (ISA)

Candidates will be expected to carry out practical work within certain specified areas of the content of the specification for Chemistry 1, Chemistry 2 or Chemistry 3. AQA will provide assignments and marking guidance on topics from the specification such as the following.

Suitable topics

Unit Chemistry 1

- Limestone and its products have many uses, including slaked lime, mortar, cement, concrete and glass.

  Typical investigation: Testing the strength of concrete.

- Polymers have properties that depend on what they are made from and the conditions under which they are made. For example, slime with different viscosities can be made from poly(ethanol).

  Typical investigation: Compare the viscosity of different oils.

Unit Chemistry 2

- The amount of a product obtained is known as the yield. When compared with the maximum theoretical amount as a percentage, it is called the percentage yield.

  Typical investigation: Measurement of yield of ammonia in the Haber process using a computer simulation.

- The rate of a chemical reaction increases:
  - if the temperature increases
  - if the concentration of dissolved reactants or the pressure of gases increases
  - if solid reactants are in smaller pieces (greater surface area)
  - if a catalyst is used.

  Typical investigation: Investigate how the rate of reaction between calcium carbonate and hydrochloric acid depends upon concentration or temperature.

- Passing an electric current through molten ionic substances or solutions of ions, breaks them down into elements. This process is called electrolysis.

  Typical investigation: Factors that affect the deposition of copper when electrolysing copper sulfate solution.

Unit Chemistry 3

- If the concentration of one of the reactants is known, the results of a titration can be used to find the concentration of the other reactant.

  Typical investigation: Acid / base titration.

- Hard water contains dissolved compounds, usually of calcium or magnesium. The compounds are dissolved when water comes into contact with rocks.

  Typical investigation: Comparing the hardness of samples of water from different places.

- The relative amounts of energy released when substances burn can be measured by simple calorimetry, eg by heating water in a glass or metal container.

  Typical investigation: Comparing the energy values of different fuels using a spirit burner.

In Sections 11–13 this symbol is used to identify topics which are suitable for extended investigative work. These topics, in addition to those listed, may form the basis for future ISAs. However, the list and the signposted topics are not intended to be exhaustive – both are provided for illustrative purposes only. Nonetheless, practical work in these areas will provide a good preparation for formal assessment in the centre-assessed unit including the ISAs.

Getting started

A suitable strategy would be to teach the knowledge that underlies Section 10 and the skills that provide for the gathering of data. Candidates should gain an understanding of the application of these concepts by applying them to supported practical studies and practice tests. Candidates should then be assessed when they apply these abilities in the formal ISA situation.

The proposed task should allow for candidates to work individually to obtain data suitable for analysis or, if working in groups, allow the contribution of individual candidates to be identified and assessed.

Candidates may include supportive second-hand data and whole-class data. It is important, however, that the candidate identifies the data that has been collected under his or her direction. Whilst some practical situations can only be effectively conducted in groups, each candidate must have completed a set of data that has been derived under their own direction. Candidates should keep an independent record of the raw data collected in preparation for the ISA.

The assignments, setting guidance and marking guidance are made available to centres at the beginning of each academic year. They should be kept locked away securely until used. If they are to be used on more than one occasion, then centres must ensure security between sessions. AQA is issuing two tests in the first year that each centre-assessed unit for a specification is available. At least one extra test is issued each year so that centres have a choice of which test to offer. Each test is available for two years.

Using the assignments

Whilst carrying out the practical work, candidates are expected to make and record detailed observations in a suitable way. Measurements should be made with an appropriate level of precision and accuracy and the data recorded logically in an appropriately constructed table. Candidates should use ICT where appropriate.

Candidates should be supplied with an outline method and asked to make their own results table. The outline method and instructions should not be too prescriptive. Centres are provided with setting guidance which will detail any particular requirements. As far as possible AQA does not put any restriction on the method to be used in the investigation.

Candidates must present, while the work is in progress, the data collected in a suitable table. They should not be assessed using evidence from formal reports written after the completion of the practical work. For certain ISAs, candidates are also required to process the data into a graph or chart. Where this is the case, teachers are notified in the setting guidance. Teachers should collect the table of data (and graphs or charts if appropriate) from each candidate at the end of the practical session and store it in readiness for the ISA.

The ISA should be taken as soon as possible after completion of the practical work, in a suitable timetabled lesson. Candidates should work on their own and in silence. Each candidate is provided with an ISA to which the teacher has stapled the candidate's own data record.

Section 1 of the ISA contains questions concerning the candidate's own data. Section 2 provides the candidate with additional data on the same topic which the candidate is required to analyse, evaluate and comment upon. Answers to both sections are written on the question paper. At the end of 45 minutes, the papers are collected from the candidates. Teachers are required to mark these papers, using a set of marking guidelines provided by AQA.

Candidates absent for the preliminary practical work

If a candidate is absent for the practical work, the teacher may supply the candidate with some data to use in Section 1 and the teacher can mark it, but the mark for Section 1 cannot be submitted. However, a mark for Section 2 on its own may be submitted.

Security of assignments

When teachers have marked the ISAs, they may tell candidates their marks but they may not return the papers. Completed ISAs should be treated like examination papers and kept under secure conditions while the ISA is valid.

Practice ISAs from specimen or training material can be used to teach candidates the skills required, feeding back their marks as formative assessment. However, ISAs which are currently valid cannot be given back to the candidates. Candidates may sit any number of ISAs and the best mark can be submitted for certification.

18.3 Practical Skills Assessment (PSA)

This assessment may be made at any time during the course of a candidate's normal practical work.

The nature of the assessment

Since the skills in this section involve implementation, they must be assessed while the candidate is carrying out practical work. In order to provide appropriate opportunities to demonstrate the necessary skills, instructions provided must not be too prescriptive but should allow candidates to make decisions for themselves, particularly concerning the conduct of practical work, their organisation and the manner in which equipment is used.

Centres should bear in mind that a high performance should reflect the ability to work methodically and safely, demonstrating competence in the required manipulative skills and efficiency of managing time.

The assessment criteria

Candidates should:

- use apparatus and materials in an appropriate and careful way
- carry out work in a methodical and organised way
- work with due regard for safety and with appropriate consideration for the well-being of living organisms and the environment.

Descriptors are provided for 2, 4 and 6 marks. These descriptors should be used to judge the mark which best describes a candidate's performance.

IMPLEMENTATION OF PRACTICAL WORK	
PERFORMANCE LEVEL	**SKILLS**
2	*Practical work is conducted:* • safely, but with help to work in an organised manner. *The candidate:* • uses the apparatus with assistance.
4	*Practical work is conducted:* • safely and in a reasonably organised manner. *The candidate:* • uses the apparatus skilfully and without the need for assistance.
6	*Practical work is conducted:* • safely and in a well-organised manner. *The candidate*: • uses the apparatus skilfully in a demanding context.

NB In order to gain 5 or 6 marks, a candidate must:

- demonstrate competence with a range of equipment, some of which is quite complex
- take all measurements to an appropriate level of accuracy
- present, while the work is in progress, the data collected, in a suitable table.

Descriptors are designed to be hierarchical so that a description at a particular mark subsumes descriptions at lower marks. Use should be made of intermediate marks (1, 3 and 5) when performance exceeds one description but only partly satisfies the next.

At each of the marks (2, 4 and 6) there are two bullet points. If **neither** of the bullet points for 2 marks is matched, the candidate should be awarded zero marks. If **either** of the bullet points for 2 marks is matched, the candidate will score 1 mark. If **both** bullet points for 2 marks are matched, the candidate will score 2 marks.

Once 2 marks have been awarded, consideration may be given to the two bullet points for 4 marks: matching either one will allow 3 marks to be awarded, both will result in 4 marks. Similarly, once 4 marks have been gained, consideration may be given to the two bullet points for 6 marks, in order to determine whether the candidate should be awarded 5 or 6 marks.

18.4 Further Support

Apart from material published in the specification, support for this unit is provided in a number of ways:

- **A Teacher's Guide** published by AQA includes information and advice from the Principal Moderator. This will be supplemented by further booklets containing examples of work.
- **Centre-Assessed Unit Advisers** are appointed by AQA and are available to give centres advice. Details are sent to the Head of Department at individual centres, or may be obtained from the Subject Department at AQA's Guildford office. Advice will normally be given in response to telephone or e-mail enquiries but will be restricted to:
  - issues relating to the carrying out of assignments for assessment
  - standards of marking
  - administrative issues
  - discussion of feedback from moderators.

  Advisers do not mark work.
- **Annual meetings** will be held on a regional basis, usually at the beginning of the academic year. These meetings discuss aspects of internal assessment which have given rise to concern and provide opportunities to standardise procedures and marking. Attendance in the first year of a new programme of assessment is compulsory, as is attendance by centres where there has been serious misinterpretation of the requirements of the specification. Centres will be informed directly if they are required to attend.

19 Supervision and Authentication

19.1 Supervision of Candidates' Work

The centre-assessed unit comprises an Investigative Skills Assignment (ISA) and a Practical Skills Assessment (PSA) for each candidate. It is expected that the preliminary practical work for the ISAs and the work assessed for the PSA are carried out under normal class conditions, with a degree of supervision of candidates corresponding to those conditions. However, ISAs should be taken under controlled conditions with candidates working in silence. They may sit the ISA in their usual classroom (or laboratory) providing this allows them to be suitably spaced to avoid the possibility of cheating.

19.2 Unfair Practice

At the start of the course, the supervising teacher is responsible for informing candidates of the AQA regulations concerning malpractice. The penalties for malpractice are set out in the AQA regulations. Centres must report suspected malpractice to AQA.

19.3 Authentication of Candidates' Work

Both the candidate and the teacher are required to sign declarations confirming that the work submitted for assessment is the candidate's own. The teacher declares that the work was conducted under the specified conditions, and records details of any additional assistance.

20 Standardisation

20.1 Standardising Meetings

Annual standardising meetings will usually be held in the autumn term. Centres entering candidates for the first time must send a representative to the meetings. Attendance is also mandatory in the following cases:

- where there has been a serious misinterpretation of the specification requirements
- where the management of the centre-assessed unit by a centre has been inappropriate
- where a significant adjustment has been made to a centre's marks in the previous year's examination.

Otherwise attendance is at the discretion of centres. At these meetings support will be provided for centres in the development of appropriate preliminary practical work and assessment procedures.

20.2 Internal Standardisation of Marking

The centre is required to standardise the assessments across different teachers and teaching groups to ensure that all candidates at the centre have been judged against the same standards. If two or more teachers are involved in marking the centre-assessed unit, one teacher must be designated as responsible for internal standardisation. Common pieces of work must be marked on a trial basis and differences between assessments discussed at a training session in which all teachers involved must participate. The teacher responsible for standardising the marking must ensure that the training includes the use of reference and archive materials such as work from a previous year or examples provided by AQA. The centre is required to send to the moderator the Centre Declaration Sheet, duly signed, to confirm that the marking of centre-assessed work at the centre has been standardised. If only one teacher has undertaken the marking, that person must sign this form.

A specimen Centre Declaration Sheet appears in Appendix B.

21 Administrative Procedures

21.1 Recording Assessments

Teachers should keep records of their assessments during the course in a form which facilitates the complete and accurate submission of final centre assessments at the end of the course. Candidates may undertake a number of ISAs. Candidates should complete the details required on the front cover of each ISA in full. The data collected by each candidate in the preliminary practical work should be firmly attached (ie stapled or by treasury tag) to the candidate's ISA script. The candidates' work must be marked according to the marking guidelines provided by AQA, and the marks entered on the front cover. Towards the end of the course, the teacher must select the ISA with the highest mark and must award a mark for the PSA, using the criteria in the grid in Section 18. This mark and the mark for the ISA should be entered on a Candidate Record Form, together with supporting information and details of any additional help given, in the spaces provided. The completed Candidate Record Form for each candidate must be attached to the work and made available to AQA on request.

Candidate Record Forms are available on the AQA website in the Administration area. They can be accessed via the following link http://www.aqa.org.uk/admin/p_course.php. The exact design may be modified before the operational version is issued and the correct year's Candidate Record Forms should always be used.

21.2 Submitting Marks and Sample Work for Moderation

The total mark for the centre-assessed unit for each candidate must be submitted to AQA on the mark sheets provided or by Electronic Data Interchange (EDI) by the specified date. Centres will be informed which candidates' work is required in the samples to be submitted to the moderator.

21.3 Factors Affecting Individual Candidates

Teachers should be able to accommodate the occasional absence of candidates by ensuring that the opportunity is given for them to make up missed assessments.

Special consideration should be requested for candidates whose work has been affected by illness or other exceptional circumstances. Information about the procedure is issued separately.

If work is lost, AQA should be notified immediately of the date of the loss, how it occurred and who was responsible for the loss. AQA will advise on the procedures to be followed in such cases.

Where special help which goes beyond normal learning support is given, AQA must be informed so that such help can be taken into account when assessment and moderation take place.

Candidates who move from one centre to another during the course sometimes present a problem for a scheme of centre assessment. Possible courses of action depend on the stage at which the move takes place. Teachers should note that centre assessment in GCSE Sciences is no longer a common component across all awarding bodies, and therefore there is less flexibility than before in transferring credit for centre assessment undertaken for a specification of an awarding body other than AQA. Centres should contact AQA at the earliest possible stage for advice about appropriate arrangements in individual cases.

21.4 Retaining Evidence

The centre must retain all the work of all candidates, with Candidate Record Forms attached. These must be kept under secure conditions from the time they are assessed, to allow for the possibility of an enquiry about results. This includes ISAs other than the one with the highest mark. If an enquiry about results is to be made, the work must remain under secure conditions until requested by AQA.

Beyond that time, it is preferred that candidates' work is shredded. In particular, centres must ensure that the security of ISA question papers which are still valid is not compromised.

22 Moderation

22.1 Moderation Procedures

Moderation of the centre-assessed unit is by inspection of a sample of candidates' work, sent by post from the centre to a moderator appointed by AQA. The centre marks must be submitted to AQA and the sample of work must reach the moderator by the specified date in the year in which the qualification is awarded.

Following the re-marking of the sample work, the moderator's marks are compared with the centre marks to determine whether any adjustment is needed in order to bring the centre's assessments into line with standards generally. In some cases it may be necessary for the moderator to call for the work of other candidates. In order to meet this possible request, centres must have available the work and Candidate Record Form of every candidate entered for the examination and be prepared to submit it on demand. Mark adjustments will normally preserve the centre's order of merit, but where major discrepancies are found, AQA reserves the right to alter the order or merit.

22.2 Post-Moderation Procedures

On publication of the GCSE results, the centre is supplied with details of the final marks for the centre-assessed unit.

The candidates' work is returned to the centre after the examination with a report form from the moderator giving feedback on the accuracy of the assessments made, and the reasons for any adjustments to the marks.

Some candidates' work may be retained by AQA for archive purposes.

Awarding and Reporting

23 Grading, Shelf-Life and Re-Sits

23.1 Qualification Titles

The qualification based on this specification has the following title: AQA General Certificate of Secondary Education in Chemistry.

23.2 Grading System

The qualification will be graded on an 8-point grade Scale A*, A, B, C, D, E, F and G. Candidates who fail to reach the minimum standard for grade G will be recorded as U (unclassified) and will not receive a qualification certificate.

23.3 Grading of Unit Results and Subject Awards

The achievement of each candidate on each unit is reported as a grade on the scale A*–G and as a UMS (Uniform Mark Scale) score.

UMS scores are related to grades as follows:

Range of UMS scores			
Objective test	**Written paper**	**Centre-assessed unit**	**Grade**
45–50	90–100	90–100	A*
40–44	80–89	80–89	A
35–39	70–79	70–79	B
30–40	60–69	60–69	C
25–29	50–59	50–59	D
20–24	40–49	40–49	E
15–19	30–39	30–39	F
10–14	20–29	20–29	G
0–9	0–19	0–19	U

The relationship of raw marks to UMS scores is determined separately for each unit and, where appropriate, for each tier (see Section 23.4), through the awarding procedures for each series. This allows for any variation in the demand of the assessments between series to be taken into consideration. Raw marks which represent the minimum performance to achieve a grade are chosen, and these boundary marks are assigned the minimum UMS score for the grade. Between boundaries interpolation is used to relate raw marks to UMS scores.

When a candidate is entered for a subject award, the grade for the qualification is obtained by adding together the UMS scores for the units which contribute to the subject award, and using the following relationship between total UMS score and grade:

Range of total UMS score	Grade
360–400	A*
320–359	A
280–319	B
240–279	C
200–239	D
160–199	E
120–159	F
80–119	G
0–79	U

23.4 Grading and Tiers

The centre-assessed unit is not tiered and the full range of grades A*–G is available to candidates for this unit.

For the other units, candidates take either the Foundation Tier or the Higher Tier. For candidates entered for the Foundation Tier, grades C–G are available. For candidates entered for the Higher Tier, A*–D are available. There is a safety net for candidates entered for the Higher Tier, where an allowed grade E will be awarded if candidates just fail to achieve grade D. Candidates who fail to achieve a grade E on the Higher Tier or grade G on the Foundation Tier will be reported as unclassified.

For these tiered units, candidates cannot obtain a UMS score corresponding to a grade which is above the range for the tier entered. For example, the maximum UMS score for candidates on a Foundation Tier written paper, such as Chemistry 1, is 69. In other words, they cannot achieve a UMS score corresponding to grade B. Candidates who just fail to achieve grade E on the Higher Tier receive the UMS score corresponding to their raw mark ie they do not receive a UMS score of zero.

During the awarding procedures the relationship between raw marks and UMS score is decided for each tier separately. Where a grade is available on two tiers, for example grade C, the two raw marks chosen as the boundary for the grade on the two tiers are given the same UMS score. Therefore candidates receive the same UMS score for the same achievement whether this is demonstrated on the Foundation or the Higher Tier assessments.

23.5 Shelf-life of Unit Results

The shelf-life of individual unit results, prior to certification of the qualification, is limited only by the shelf-life of the specification.

23.6 Re-Sits

Each assessment unit may be re-taken an unlimited number of times within the shelf-life of the specification. The best result will count towards the final award. However, marks for individual externally assessed units may be counted once only to a GCSE award.

23.7 Minimum Requirements

Candidates will be graded on the basis of work submitted for assessment.

23.8 Awarding and Reporting

This specification complies with the grading, awarding and certification requirements of the current GCSE, GCE, Principle Learning and Project Code of Practice April 2010, and will be revised in the light of any subsequent changes in future years.

Appendices

A Grade Descriptions

The following grade descriptions indicate the level of attainment characteristic of the given grade at GCSE. They give a general indication of the required learning outcomes at each specific grade. The descriptions should be interpreted in relation to the content outlined in the specification; they are not designed to define that content.

The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives (see Section 6) overall. Shortcomings in some aspects of the examination may be balanced by better performances in others.

Grade A

Candidates demonstrate a detailed knowledge and understanding of science content and how science works, encompassing the principal concepts, techniques and facts across all areas of the specification. They use technical vocabulary and techniques with fluency, clearly demonstrating communication and numerical skills appropriate to a range of situations.

They demonstrate a good understanding of the relationships between data, evidence and scientific explanations and theories. They are aware of areas of uncertainty in scientific knowledge and explain how scientific theories can be changed by new evidence.

Candidates use and apply their knowledge and understanding in a range of tasks and situations. They use this knowledge, together with information from other sources, effectively in planning a scientific task, such as a practical procedure, testing an idea, answering a question, or solving a problem.

Candidates describe how, and why, decisions about uses of science are made in contexts familiar to them, and apply this knowledge to unfamiliar situations. They demonstrate good understanding of the benefits and risks of scientific advances, and identify ethical issues related to these.

They choose appropriate methods for collecting first-hand and secondary data, interpret and question data skilfully, and evaluate the methods they use. They carry out a range of practical tasks safely and skilfully, selecting and using equipment appropriately to make relevant and precise observations.

Candidates select a method of presenting data appropriate to the task. They draw and justify conclusions consistent with the evidence they have collected and suggest improvements to the methods used that would enable them to collect more valid and reliable evidence.

Grade C Candidates demonstrate a good overall knowledge and understanding of science content and how science works, and of the concepts, techniques and facts across most of the specification. They demonstrate knowledge of technical vocabulary and techniques, and use these appropriately. They demonstrate communication and numerical skills appropriate to most situations.

They demonstrate an awareness of how scientific evidence is collected and are aware that scientific knowledge and theories can be changed by new evidence.

Candidates use and apply scientific knowledge and understanding in some general situations. They use this knowledge, together with information from other sources, to help plan a scientific task, such as a practical procedure, testing an idea, answering a question, or solving a problem.

They describe how, and why, decisions about uses of science are made in some familiar contexts. They demonstrate good understanding of the benefits and risks of scientific advances, and identify ethical issues related to these.

They carry out practical tasks safely and competently, using equipment appropriately and making relevant observations appropriate to the task. They use appropriate methods for collecting first-hand and secondary data, interpret the data appropriately, and undertake some evaluation of their methods.

Candidates present data in ways appropriate to the context. They draw conclusions consistent with the evidence they have collected and evaluate how strongly their evidence supports these conclusions.

Grade F Candidates demonstrate a limited knowledge and understanding of science content and how science works. They use a limited range of the concepts, techniques and facts from the specification, and demonstrate basic communication and numerical skills, with some limited use of technical terms and techniques.

They show some awareness of how scientific information is collected and that science can explain many phenomena.

They use and apply their knowledge and understanding of simple principles and concepts in some specific contexts. With help they plan a scientific task, such as a practical procedure, testing an idea, answering a question, or solving a problem, using a limited range of information in an uncritical manner. They are aware that decisions have to be made about uses of science and technology and, in simple situations familiar to them, identify some of those responsible for the decisions. They describe some benefits and drawbacks of scientific developments with which they are familiar and issues related to these.

They follow simple instructions for carrying out a practical task and work safely as they do so.

Candidates identify simple patterns in data they gather from first-hand and secondary sources. They present evidence as simple tables, charts and graphs, and draw simple conclusions consistent with the evidence they have collected.

B

Record Forms

Candidate Record Forms and Centre Declaration Sheets are available on the AQA website in the Administration area. They can be accessed via the following link http://www.aqa.org.uk/admin/p_course.php

C

Overlaps with other Qualifications

Specifications covering the Programme of Study

Many of the specifications in the AQA GCSE Sciences suite described in Section 4.2 cover the programme of study for KS4 Science, and there is therefore significant overlap between them. The content in GCSE Science A and GCSE Science B is identical, and all the content in these specifications can be found in GCSE Applied Science (Double Award). In addition, each of the nine units, Biology 1–3, Chemistry 1–3 and Physics 1–3 is identical, regardless of the specification to which it contributes. The procedural content in Section 10 of all the general specifications is the same.

The entry restrictions in Section 3.3 reflect this overlap.

Relationship to Other Subjects

Some of the knowledge, skills and understanding included in this specification may also be encountered by candidates following courses leading towards other subject qualifications. This is a feature of National Curriculum provision and means that the specification can complement other subjects and enable candidates to consolidate their learning. Some overlap exists with the following GCSE subject:

- Environmental Science.

D Data Sheet

Data Sheet

1. Reactivity Series of Metals

Potassium	most reactive ↑
Sodium	
Calcium	
Magnesium	
Aluminium	
Carbon	
Zinc	
Iron	
Tin	
Lead	
Hydrogen	
Copper	
Silver	
Gold	
Platinum	least reactive ↓

(elements in italics, though non-metals, have been included for comparison)

2. Formulae of Some Common Ions

Positive ions

Name	Formula
Hydrogen	H^{+}
Sodium	Na^{+}
Silver	Ag^{+}
Potassium	K^{+}
Lithium	Li^{+}
Ammonium	NH_4^{+}
Barium	Ba^{2+}
Calcium	Ca^{2+}
Copper(II)	Cu^{2+}
Magnesium	Mg^{2+}
Zinc	Zn^{2+}
Lead	Pb^{2+}
Iron(II)	Fe^{2+}
Iron(III)	Fe^{3+}
Aluminium	Al^{3+}

Negative ions

Name	Formula
Chloride	Cl^{-}
Bromide	Br^{-}
Fluoride	F^{-}
Iodide	I^{-}
Hydroxide	OH^{-}
Nitrate	NO_3^{-}
Oxide	O^{2-}
Sulfide	S^{2-}
Sulfate	SO_4^{2-}
Carbonate	CO_3^{2-}

3. The Periodic Table of Elements

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1	2											3	4	5	6	7	0
							1 **H** hydrogen 1										4 **He** helium 2
7 **Li** lithium 3	9 **Be** beryllium 4											11 **B** boron 5	12 **C** carbon 6	14 **N** nitrogen 7	16 **O** oxygen 8	19 **F** fluorine 9	20 **Ne** neon 10
23 **Na** sodium 11	24 **Mg** magnesium 12											27 **Al** aluminium 13	28 **Si** silicon 14	31 **P** phosphorus 15	32 **S** sulfur 16	35.5 **Cl** chlorine 17	40 **Ar** argon 18
39 **K** potassium 19	40 **Ca** calcium 20	45 **Sc** scandium 21	48 **Ti** titanium 22	51 **V** vanadium 23	52 **Cr** chromium 24	55 **Mn** manganese 25	56 **Fe** iron 26	59 **Co** cobalt 27	59 **Ni** nickel 28	63.5 **Cu** copper 29	65 **Zn** zinc 30	70 **Ga** gallium 31	73 **Ge** germanium 32	75 **As** arsenic 33	79 **Se** selenium 34	80 **Br** bromine 35	84 **Kr** krypton 36
85 **Rb** rubidium 37	88 **Sr** strontium 38	89 **Y** yttrium 39	91 **Zr** zirconium 40	93 **Nb** niobium 41	96 **Mo** molybdenum 42	[98] **Tc** technetium 43	101 **Ru** ruthenium 44	103 **Rh** rhodium 45	106 **Pd** palladium 46	108 **Ag** silver 47	112 **Cd** cadmium 48	115 **In** indium 49	119 **Sn** tin 50	122 **Sb** antimony 51	128 **Te** tellurium 52	127 **I** Iodine 53	131 **Xe** xenon 54
133 **Cs** caesium 55	137 **Ba** barium 56	139 **La*** lanthanum 57	178 **Hf** hafnium 72	181 **Ta** tantalum 73	184 **W** tungsten 74	186 **Re** rhenium 75	190 **Os** osmium 76	192 **Ir** iridium 77	195 **Pt** platinum 78	197 **Au** gold 79	201 **Hg** mercury 80	204 **Tl** thallium 81	207 **Pb** lead 82	209 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111	Elements with atomic numbers 112–116 have been reported but not fully authenticated						

* The Lanthanides (atomic numbers 58 –71) and the Actinides (atomic numbers 90–103) have been omitted.

Cu and **Cl** have not been rounded to the nearest whole number.

E

Glossary of Terms

Accuracy	An accurate measurement is one which is close to the true value.
Calibration	This involves fixing known points and then marking a scale on a measuring instrument, between these fixed points.
Data	This refers to a collection of measurements. *For example: Data can be collected for the volume of a gas or the type of rubber.*
Datum	The singular of data.
Errors,	
- random	These cause readings to be different from the true value. Random errors may be detected and compensated for by taking a large number of readings. *For example: Random errors may be caused by human error, a faulty technique in taking the measurements, or by faulty equipment.*
- systematic	These cause readings to be spread about some value other than the true value; in other words, all the readings are shifted one way or the other way from the true value. *For example: A systematic error occurs when using a wrongly calibrated instrument.*
- zero	These are a type of systematic error. They are caused by measuring instruments that have a false zero. *For example: A zero error occurs when the needle on an ammeter fails to return to zero when no current flows, or when a top-pan balance shows a reading when there is nothing placed on the pan.*
Evidence	This comprises data which have been subjected to some form of validation. It is possible to give a measure of importance to data which has been validated when coming to an overall judgement.
Fair test	A fair test is one in which only the independent variable has been allowed to affect the dependent variable. *For example: A fair test can usually be achieved by keeping all other variables constant.*
Precision	The precision of a measurement is determined by the limits of the scale on the instrument being used. Precision is related to the smallest scale division on the measuring instrument that you are using. It may be the case that a set of precise measurements has very little spread about the mean value. *For example, using a ruler with a millimetre scale on it to measure the thickness of a book will give greater precision than using a ruler that is only marked in centimetres.*
Reliability	The results of an investigation may be considered reliable if the results can be repeated. If someone else can carry out your investigation and get the same results, then your results are more likely to be reliable. One way of checking reliability is to compare your results with those of others. The reliability of data can be improved by carrying out repeat measurements and calculating a mean.
True Value	This is the accurate value which would be found if the quantity could be measured without any errors at all.

Validity

Data is only valid for use in coming to a conclusion if the measurements taken are affected by a single independent variable only. Data is not valid if for example a fair test is not carried out or there is observer bias.

For example: In an investigation to find the effect on the rate of a reaction when the concentration of the acid is changed, it is important that concentration is the only independent variable. If, during the investigation, the temperature also increased as you increased the concentration, this would also have an effect on your results and the data would no longer be valid.

Variables,

- categoric

A categoric variable has values which are described by labels.

When you present the result of an investigation like this, you should not plot the results on a line graph; you must use a bar chart or pie chart.

For example: If you investigate the effect of acid on different metals, eg copper, zinc and iron, the type of metal you are using is a categoric variable.

- continuous

A continuous variable is one which can have any numerical value.

When you present the result of an investigation like this you should use a line graph.

For example: If you investigate the effect on the resistance of changing the length of a wire, the length of a wire you are using is a continuous variable since it could have any length you choose.

- control

A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation. This means that you should keep these variables constant; otherwise it may not be a fair test. If it is impossible to keep it constant, you should at least monitor it; in this way you will be able to see if it changes and you may be able to decide whether it has affected the outcome of the experiment.

- dependent and independent variables

Often in science we are looking at 'cause' and 'effect'. You can think of the independent variable as being the 'cause' and the dependent variable as being the 'effect'. In other words, the dependent variable is the thing that changes *as a result* of you changing something else.

- dependent

The dependent variable is the variable the value of which you measure for each and every change in the independent variable.

- independent

The independent variable is the variable for which values are changed or selected by the investigator. In other word, this is the thing that *you deliberately change* to see what effect it has.

- discrete

You may sometimes come across this term. It is a type of categoric variable whose values are restricted to whole numbers.

For example, the number of carbon atoms in a chain.

- ordered

You may sometimes come across this term. It is a type of categoric variable that can be ranked.

For example, the size of marble chips could be described as large, medium or small.