teaching triple science: GCSE
physics

GCSE physics

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Preface

The Department for Children, Schools and Families (DCSF) has contracted with the Learning and Skills Network to support awareness and take-up of Triple Science GCSEs through the Triple Science Support Programme.

The programme aims to support the following policy objectives:

- to enable all young people with level 6 or above in science at Key stage 3 to study Triple Science GCSEs from September 2008
- to help specialist science schools offer Triple Science to their students from September 2008.

The Triple Science Support Programme comprises the following:

- the programme website: www.triplescience.org.uk
- a programme newsletter
- publications on: collaboration and partnership; raising attainment in Triple Science; curriculum modelling, timetabling and Triple Science, and three subject-specific resources on the separate sciences
- Triple Science networks of support for practitioners
- an audit of resources for Triple Science
- an offer of three days' consultancy per targeted school (around the topics above)
- a marketing campaign around Triple Science for schools.

This publication provides an introduction to teaching and learning approaches for the extension topics within GCSE Physics. It highlights some specific ideas that teachers can adopt and where to find further information. It also outlines issues for managing the change.

This programme has been funded by the DCSF. All publications, networks and newsletters will be delivered without charge to maintained secondary schools. The training and consultancy will be available to targeted Triple Science schools only.

If you wish to register an interest in the programme, please contact the LSN helpline on 0845 071 0800 or e-mail triplescience@LSNeducation.org.uk

Alan Goulbourne

Executive Manager
Triple Science Support Programme
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Section 1
The policy context

Background

The government believes that the future economic success of the United Kingdom is dependent upon a good supply of skilled scientists and engineers. It aims to secure this supply by creating an education and training environment that delivers the best in science teaching and learning at every stage.

Key priorities for the government

One of the key priorities for action is to increase availability of the three separate sciences at GCSE level. This will be achieved in the following ways:

- introducing, in September 2008, an entitlement for students achieving at least level 6 at Key stage 3 to study the three separate sciences to GCSE
- ensuring that by September 2008, all specialist science schools offer Triple Science, at least to all students achieving level 6+ at the end of Key stage 3
- strongly encouraging all schools to make Triple Science available to all students who could benefit.

Science at Key stage 4

GCSE Science (often called core or single science) is the single qualification that covers the statutory Programme of Study for science at Key stage 4.

Most students take, and should continue to take, the equivalent of at least two GCSEs in science. Choices available include Additional Science and Applied Science. These remain a viable route to A-level study in science.

Triple Science GCSEs are a combination of three GCSEs in biology, chemistry and physics. It provides the fullest coverage of these three subjects at Key stage 4 and, taken together, the subjects cover the Programme of Study for science. The courses cover an extensive range of subject matter and therefore prepare students well for progression to A-level.

The introduction of the new entitlement to Triple Science for students achieving level 6 or above at the end of Key stage 3, means that all schools will be strongly encouraged to make arrangements to meet it. The Triple Science Support Programme (TSSP) aims to provide resources, materials and training that will help schools not currently offering Triple Science to see the possibilities that exist and make the right decisions and curriculum arrangements within their own circumstances and for their own students. For details of the TSSP, please see Annex 5.

Section 2
About this publication

This is a subject-specific publication to support teachers in the delivery of the new Triple Science GCSEs. It focuses on GCSE Physics, and particularly on the content that extends Additional Science to the Triple Science GCSEs.

While this guide concentrates on the content and teaching and learning appropriate for GCSE Physics, there are also guides that explore:

- GCSE Chemistry
- GCSE Biology
- raising attainment
- curriculum modelling
- collaborative working
- resources for delivering Triple Science GCSEs.

The target audience is science teachers who are introducing Triple Science, including those teaching outside their specialism and the publication is particularly relevant to those teaching outside their specialism and subject leaders.

This guide provides an introduction to the extension topics for GCSE Physics and highlights some specific ideas that teachers can adopt. It is a starting point to provide support to teachers who will each have different needs, rather than a definitive guide. Further advice and support can be obtained from colleagues in school, the local authority, through the Triple Science Support Programme or from the organisations listed in this publication.

Section 3 outlines how Science, Additional Science and Extension Science (Physics) are structured, and Annex 1 compares the physics content for each specification, outlining what is required for Science, Additional Science and Extension Science.

Section 4 outlines effective teaching and learning approaches relevant to the extension topics in GCSE Physics and introduces:

- teaching and learning models to encourage active learning
- approaches to teach and assess How Science Works
- using investigations and demonstrations
- enhancing science with ICT
- links to other subjects
- engagement and attainment strategies.

Section 5 provides specific ideas for teaching and learning the key topics in the extension specifications. Each topic is described in terms of the subject knowledge required, the challenging concepts that arise and the most relevant opportunities for delivering How Science Works. A range of tried and tested teaching activities follows to exemplify the different teaching models introduced in Section 4. Ideas for investigations and demonstrations, additional activities and centre-marked assessment provide a taster of what other teachers recommend. There are also links to appropriate resources and organisations for each topic.

Section 6 outlines issues to consider when implementing GCSE Physics in a science department, such as staffing, continuing professional development, health and safety, and resource requirements.

Section 7 lists resources and organisations from where further information can be obtained.

Section 3
GCSE specifications for physics

Changes to the GCSE curriculum have provided schools – and students – with much greater choice and the opportunity to make GCSE Science more relevant to all students.

Schools introduced the new Programme of Study and associated specifications in September 2006.

The new GCSE Science and GCSE Additional Science, when taken together, are equivalent to the previous Double Science GCSEs. Specifications for GCSE Physics include the physics and How Science Works content from GCSE Science and GCSE Additional Science. In addition, they include further extension topics in physics. Taken together, GCSE Biology, GCSE Chemistry and GCSE Physics cover the entire science Programme of Study, plus the additional subject-specific content.

This publication refers to the five main specifications for GCSE Science:

- AQA
- Edexcel 360Science
- OCR Twenty First Century Science
- OCR Gateway
- WJEC.

A summary of the physics content for each of the GCSE Science specifications can be found in Annex 1.

Section 4
Effective teaching and learning approaches for GCSE Physics

Effective teaching and learning is clearly critical to students' engagement, attainment and progression.

Ofsted's annual report 2005–06 summarises neatly some key elements of effective practice:

Many schools have given consideration to pupils' preferred learning styles, and across a range of subjects it is evident that higher achievement is associated with active forms of learning. For example, where science was well taught, not only were basic concepts effectively addressed, lessons were also stimulating and enjoyable. In thinking about How Science Works, pupils researched and exchanged information, often making effective use of ICT, debating ideas and displaying knowledge and understanding of issues very relevant to their own and others' lives.

This contrasted sharply with the low achievement in schools where pupils went through the motions of practical work as instructed, rather than engaging in genuine scientific investigation.

Triple Science offers significant potential in terms of a course that can be challenging, engaging and successful in inspiring more students to study science post-16. It can also become a dry and uninspiring delivery, only serving to discourage students. The challenge to the science education community is to identify the steps that will take it towards the former and away from the latter, and put those into practice.

Teaching and learning models

Teaching and learning are complex processes and often good teachers teach different aspects of the curriculum in different ways. When asked, teachers cannot always explain why they chose one particular process over another. These teachers are unconsciously using different teaching and learning models to best fit the students they are teaching.

By developing knowledge of different teaching and learning models, teachers are able to understand why some approaches are better than others in particular situations. The explicit consideration of which teaching and learning models to use and when to use them will not only enhance students' learning but also provide the vocabulary for teachers to discuss and share their experiences with others, and so help develop their practice.

Deciding which teaching and learning model(s) to use when planning is not intended to be time consuming; rather an opportunity to adapt lessons consciously to make them more effective for the students. Some teaching and learning models have been developed based on theories of learning and educational research. Each can be expressed as a tightly structured sequence of activities that is designed to elicit and develop a specific type of thinking or response from students.

The teacher's choice of approach should be determined by the learning objective and the needs of students, recognising that some subjects and topics will draw more heavily on some models than others and that different models will suit different learners and help develop different thinking skills. Consistent and explicit use, as well as carefully selecting and combining approaches, has significant potential for improving students' learning. Coupled with a metacognitive approach to teaching for learning or 'thinking about learning' it will support students' understanding further.

This publication explores five specific teaching and learning models appropriate for delivering different aspects of GCSE Physics. The five teaching and learning models considered here are ones that lend themselves particularly to science and include:[1]

- **direct interactive teaching**

  The teacher leads students through a variety of planned activities to introduce new knowledge or a skill. The class review what has been learned.

- **constructing meaning**

  The teacher introduces a concept and identifies prior knowledge. Students are provided with examples that do not fit their current understanding and discuss their ideas and restructure their understanding to include the new examples. The class review the changes in their understanding.

- **enquiry (inductive)**

  Students particularly develop information-processing skills and gather, sort and classify data to suggest a hypothesis, similar to the process Darwin used to arrive at his theory of evolution. Data can be re-sorted to further test the hypothesis.

- **enquiry (deductive)**

  Students particularly develop information-processing skills; they are provided with a hypothesis and determine the best way to collect data and draw conclusions. Students decide whether more data is needed to support or refute the hypothesis.

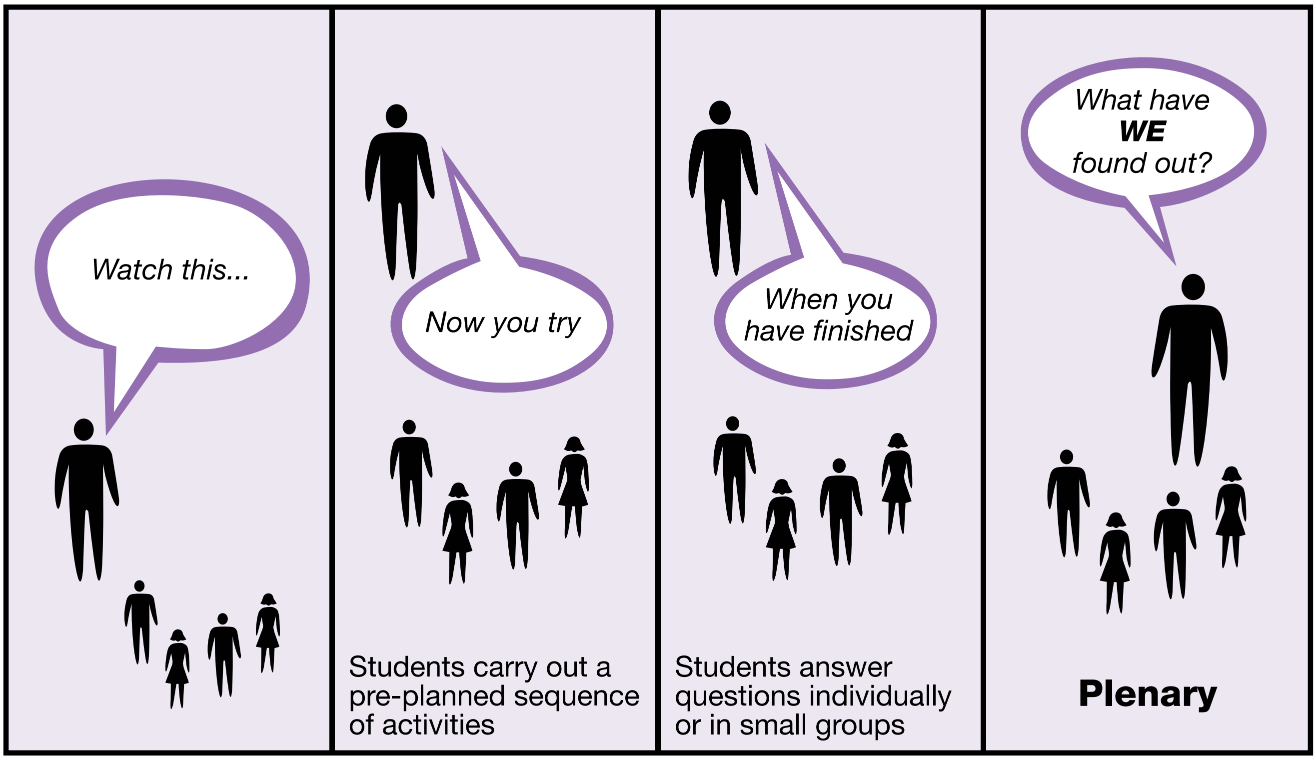
- **using models**

  Students are introduced to a model or idea. This is used initially to explain a phenomenon. Students begin to challenge the model and identify limitations. It is further refined to develop a 'better fit' model.

Each of these models is now described and exemplified in detail.

1
We gratefully acknowledge Gloucestershire Local Authority's work on teaching models, which has been adopted for this publication with the organisations permission. A list of further publications given in Section 7 also informed this section.

Direct interactive teaching



Direct interactive teaching is effective in helping young people to learn new skills and procedures and acquire academic knowledge.

The sequence often begins with whole-class exploration of features of the skill or knowledge to be acquired, with modelling, demonstration or illustration. Students then work individually or in pairs to remember the new knowledge and fit it into existing ideas, or they apply and practise the new skill, perhaps with some new additional guidance. The learning ends with a whole-class review, attempting to move students from dependence to independence.

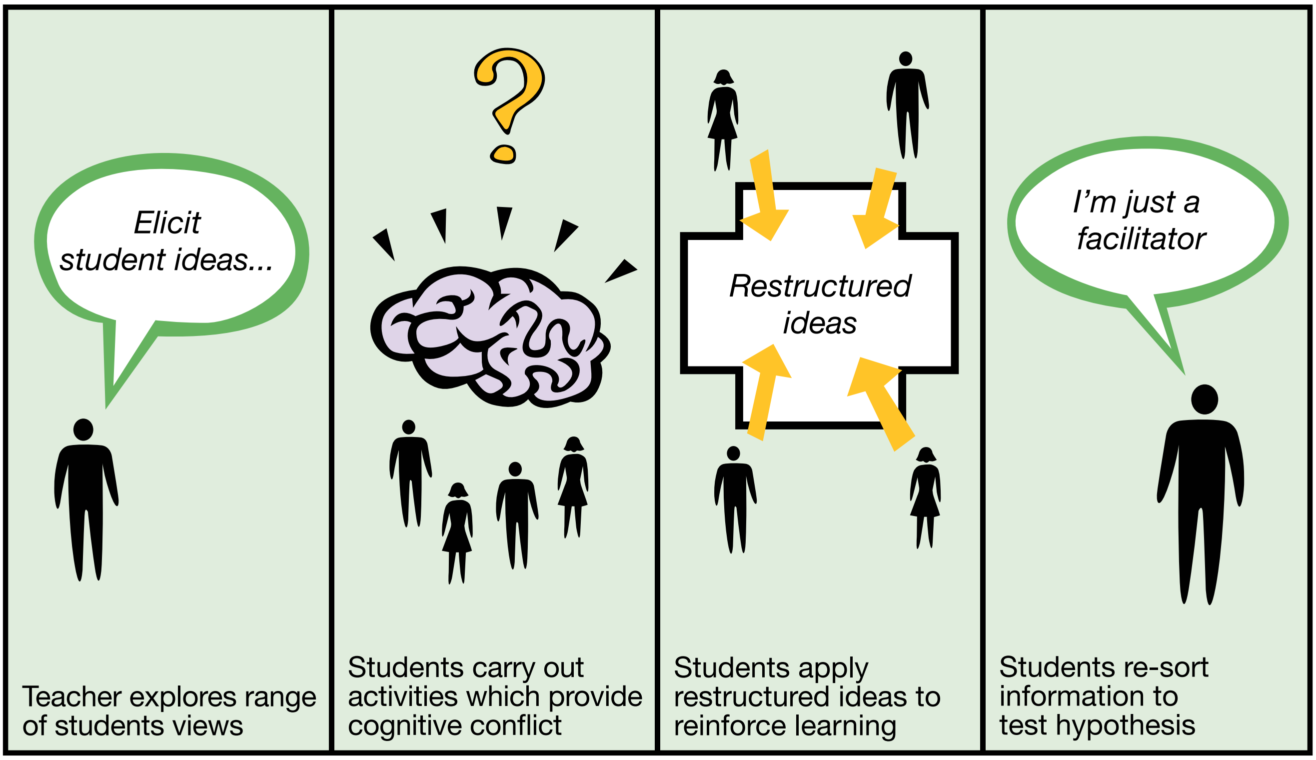
Teacher skills and techniques involve modelling, guiding, demonstrating, defining conventions, composing together, scaffolding first attempts, reviewing new learning, and mnemonics.

This model is practised effectively by many teachers and could be described as a default teaching model for some.

Example: teaching students about radioactive decay and isotopes using: computer simulations; diagrams; a demonstration of half-life with class questions; and an annotated flow chart to demonstrate what has been learned.

In this publication, teaching and learning activities based on the direct interactive teaching model are marked with this symbol.

Constructing meaning



Constructing meaning is a learning model that recognises that children already have ideas about the way they view the world. This is a constructivist approach that helps them reformulate and refine their understanding through metacognitive processes, providing opportunities to address and resolve misconceptions.

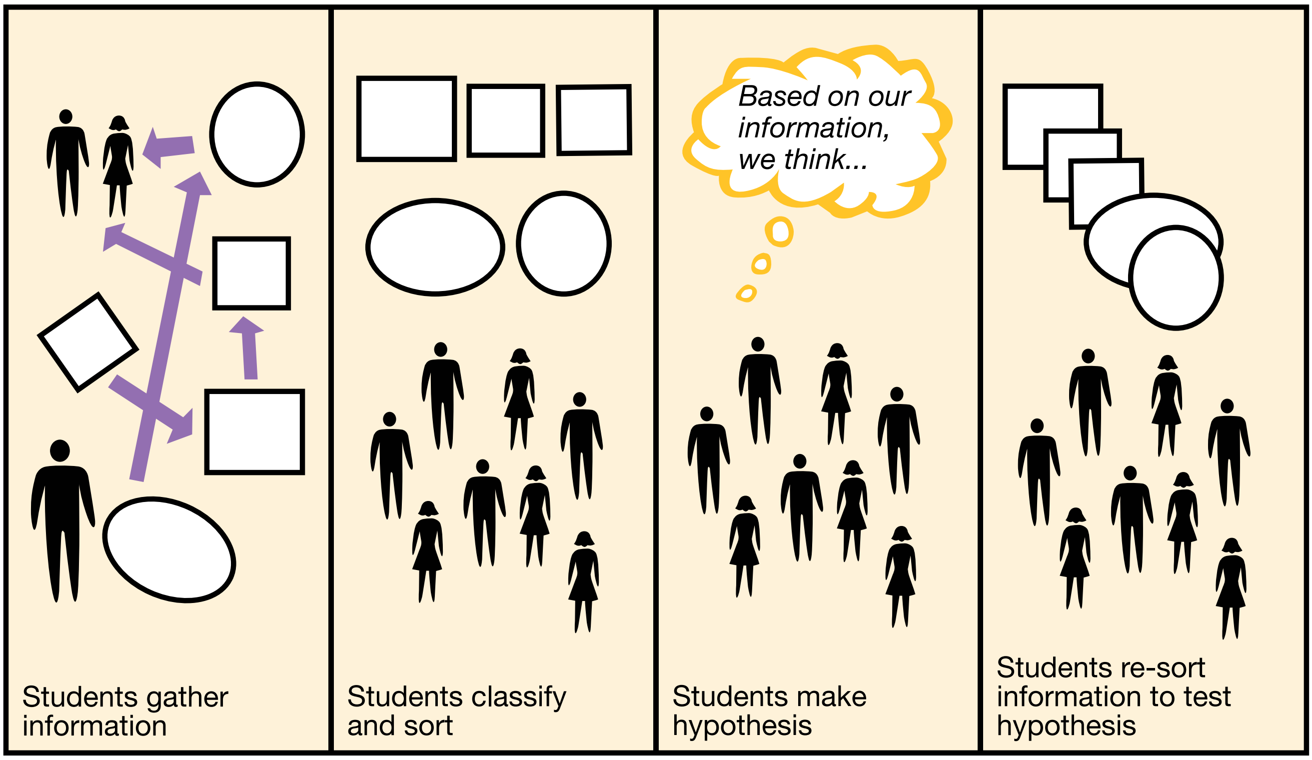
In this approach, students' ideas are made explicit so that the range of views can be explored. Providing examples that cannot be explained by students' ideas leads to cognitive conflict, which leads to clarification and evaluation of the students' views. These newly agreed, restructured views are then applied to test understanding in new situations. Finally, students review their understanding through discussion. The teacher often acts as a facilitator and manages the process, especially through providing scaffolding for students.

Teaching skills and techniques often employ the use of direct teaching, group discussion, concept-mapping, concept cartoons and experimentation.

Example: linking the models of molecules to explain the relationship between temperature and pressure of a gas.

In this publication, teaching and learning activities based on the constructing meaning model are marked with this symbol.

Enquiry (inductive)



Inductive teaching is a model that encourages students to categorise the subject knowledge, skills and understanding that they are learning, and to test and use those categories in challenging their level of understanding. This teaching model is very powerful in helping students to learn how to build knowledge, and as such is closely related to constructivism {constructing meaning} as a support for student learning.

The inductive model requires students to sort, classify and re-sort data to begin to make hypotheses that can be tested in future work. It is used when teachers want to explore the concepts that underpin subject knowledge, and want students to recognise the ways in which their knowledge is constructed.[2]

It is important to note that the enquiry (inductive) model can easily be developed into the enquiry (deductive) model if the hypotheses then go on to be tested with new data. Teachers must be conscious that the inductive model may be tested only by re-sorting original data.

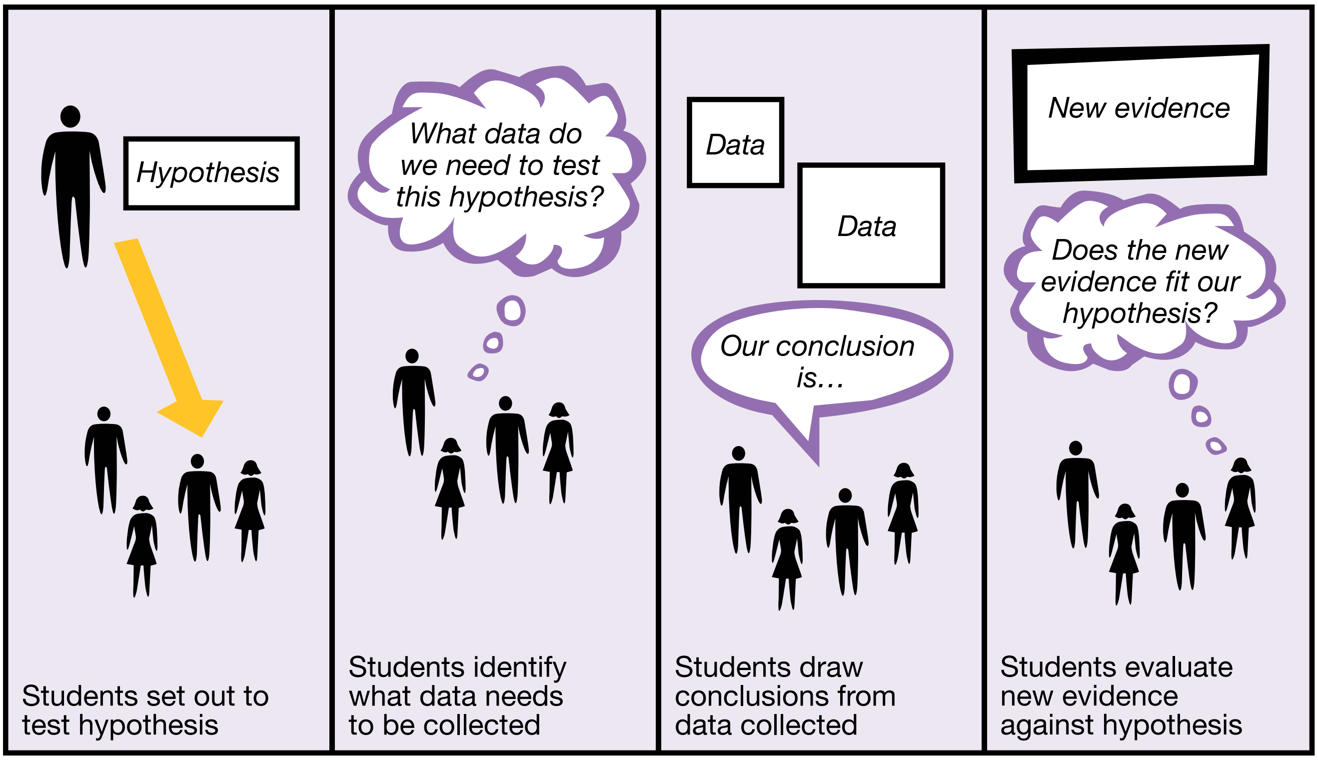
Teacher skills and techniques can include card sorts, categorising and rule building.

Example: learning about the refraction of light by undertaking practical activities, and sorting and classifying ideas to develop a hypothesis.

In this publication, teaching and learning activities based on the enquiry (inductive) model are marked with this symbol.

2
This is drawn from DfES (2004). *Pedagogy and practice: teaching and learning in secondary schools – Unit 2: Teaching models*, Department for Education and Skills (Ref: DfES 0425-2004 G).

Enquiry (deductive)



An enquiry (deductive) approach encourages students to solve problems using deductive reasoning. Deductive reasoning produces conclusions that are reached from previously known facts called premises. The assumption is that if a number of related premises are true, a conclusion that supports them should also be true.

Given a hypothesis, data is then collected directly or from secondary sources in order to confirm or refute it. Conclusions are then drawn and any new evidence is compared with the original hypothesis to see whether it also leads to the same conclusion or not. If not, the validity of the conclusion drawn needs to be questioned further. It is important to note that if the original hypothesis is refuted and the data is used to develop a new hypothesis, this enquiry model has moved to the inductive model.

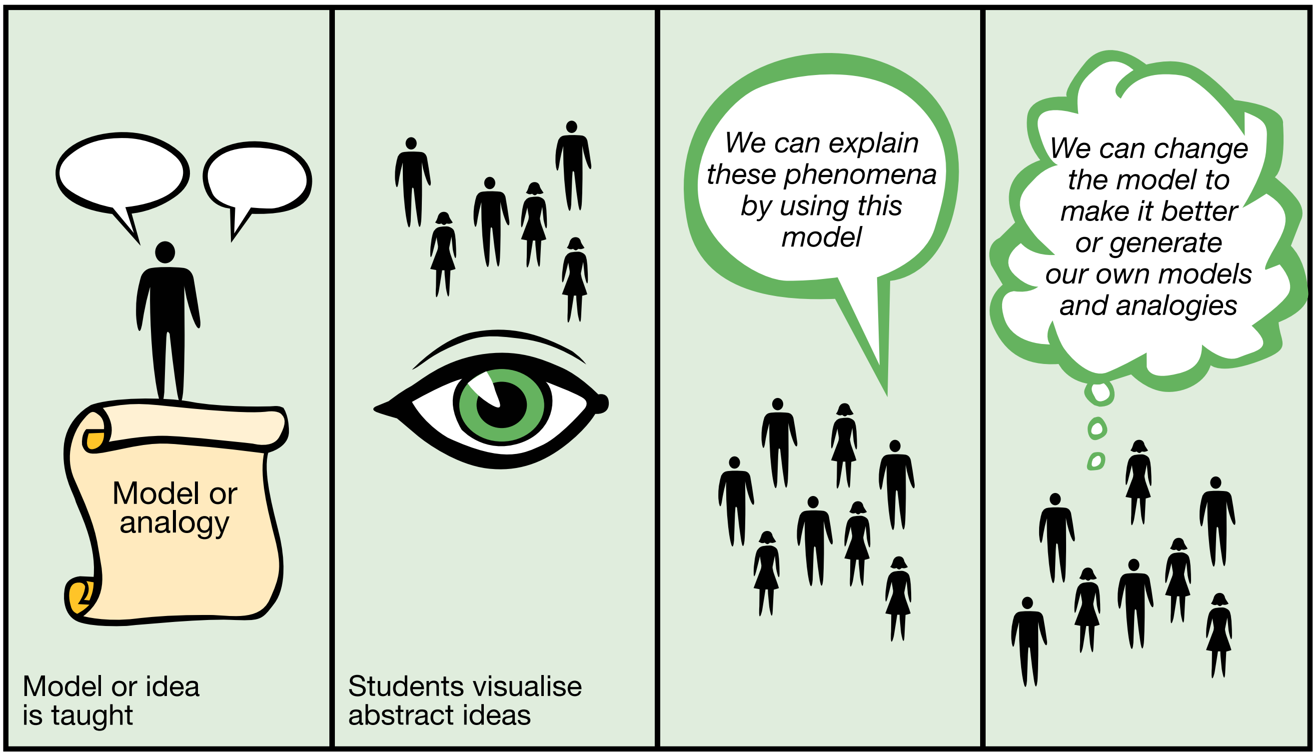
Teaching skills and techniques employ the use of experimentation, practical work, research and modelling each stage, and reasoning.

Example: looking at how secondary data from the orbits of satellites could support a predicted relationship based on orbital period and orbital radius.

e(d)

In this publication, teaching and learning activities based on the enquiry (deductive) model are marked with this symbol.

Using models



Models are an important mechanism for advancing understanding within the scientific community.

Teachers use modelling to help students make sense of observations, findings and abstract ideas through the visualisation of:

- objects that are too big (eg the solar system)
- objects that are too small or not seen easily (eg a cell)
- abstract ideas (eg energy transfer).

Teachers may just use a 'good enough' teaching model and neglect to allow students the opportunity to explore the limitations of models or analogies and develop them further. Allowing students to question, restructure and develop their own models to explain other phenomena helps reinforce understanding.

Scientific models are built by consensus within the scientific community. They are often pictorial and this can be two-dimensional (eg a diagram of the eye), three-dimensional (eg molecular models) or include a time dimension (eg animations to illustrate the particulate nature of matter). Mathematical models also provide representations and ways of explaining abstract phenomena.

Analogies are a subset of teaching models and are based on comparisons with familiar objects or processes. They are useful illustrations, but often have only superficial parallels with the abstract idea being illustrated.

Teaching skills involve card sorts, demonstration, physical construction and thinking analogously.

Example: modelling current flow and applying it to thermionic emission.

In this publication, teaching and learning activities based on using models are marked with this symbol.

How Science Works

Planning for How Science Works needs to address both teaching and assessment.

The teaching is based, of course, on the Programme of Study, mediated by the selected awarding body, and although there may be a different emphasis placed on this in different courses, it will be ultimately fairly similar. For example, the study of momentum is an opportunity to use data and other evidence to develop or support explanations, and the study of the lifecycle of stars gives an opportunity for students to 'tell the story' of our solar system, irrespective of which awarding body has accredited the course. Further exemplification of how the How Science Works Programme of Study can be taught in the context of the GCSE Physics extension topics is found in Section 5. A list of relevant resources, many of which support the How Science Works agenda, can be found in Section 7.

Assessment, however, is materially different and the way in which students gain credit for understanding How Science Works varies significantly depending on the specification; this needs to be borne in mind whilst using this guide. There is a more detailed treatment of the assessment of How Science Works in each specification in Annex 1.

In the material provided for each of the topics in Section 5 there are extracts from the Programme of Study for How Science Works. These have been selected to highlight principal opportunities within that topic: this is not to say that others couldn't be addressed in that context.

Many departments will, of course, have made substantial progress in their understanding and delivery of How Science Works since the GCSE courses were first prepared. One of the resources that was used in autumn 2006 was a set of materials from the Secondary National Strategy to support and encourage teachers to think about progression. These can be downloaded from www.standards.dfes.gov.uk/secondary/keystage3/all/respub/sci_sldev_26606

Using investigations and demonstrations

Investigations and demonstrations give students an opportunity to explore science in a way that leads to them becoming questioning adults. They are both opportunities to introduce scientific enquiry and can be taught throughout the whole of the science curriculum to promote students' thinking and questioning skills. They should move away from the student only doing practical work as part of a full investigation and towards enquiry being an integral part of lessons.

Practical work, like any other aspect of teaching, needs careful planning. There is much evidence to show that the various forms of practical work open to a teacher to use can be highly motivational for students; however, motivation and providing 'fun' activities are not sufficient justification for doing practical activity. The teacher, and therefore the students, should recognise the purpose of the activity, whether student-centred or led from the front in the form of a demonstration.

A short demonstration at the start of the lesson could:

- challenge the students to explain a phenomenon unfamiliar to them
- lead to further investigations which students themselves will conduct
- excite the students about a new topic they are about to encounter
- generate questions about the new topic.

Later on in the lesson, or at the end, a demonstration might help to summarise what the students have been learning during the session. In these cases, it is good practice to encourage students to link their learning with the observations they are making by attempting explanations of what is happening.

Again, where students are being asked to undertake an investigation, the teacher should think about the learning outcomes he or she wants to achieve from the investigation. Sometimes it is not necessary for students to conduct the whole investigation from the planning stage through to the conclusion. Depending on what the teacher wants to achieve, he or she may start or stop the investigation at different stages. For example:

- planning and evaluation of the plan
- carrying out the final plan
- collecting and analysing data (in terms of validity and interpreting its meaning)
- drawing conclusions (in terms of the validity of the investigation and the science that has been learnt from doing it).

Sometimes the teacher will use part of an investigation to enable the students to learn and practise new skills (both practical and enquiry skills); at other times, when the skills are familiar, the teacher may introduce an investigation to allow students to have an opportunity to explore and develop their understanding of a scientific concept, to see if they can offer their own explanation. Occasionally, the teacher might suggest a number of alternative explanations, and through investigation the students derive a view of which explanation best fits the evidence they have collected.

Whether the teacher is running an investigation or doing a demonstration, it is important that the teacher is familiar with the practical activity and should therefore practise anything unfamiliar in advance. This will ensure that teachers will feel competent and confident in their expectations of what will happen, it also ensures that they manage all the risks that might arise. All schools expect teachers to conduct a risk assessment prior to doing practical work. Even if the practical work is carried out regularly at the school, it is the teachers' responsibility to ensure that they have conducted their own assessment. This is not to reduce the amount of practical work being done in schools; it should lead to a greater range and variety of practical work encountered by students, all of which are managed safely. The Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS) will give guidance and advice to school science departments when they are introducing new practical work (see Section 6). It can also be useful for the students to build an awareness of safety by carrying out their own risk assessments.

Ideas for practical work come from:

- websites and publications provided by professional bodies, such as the Institute of Physics and the Association of Science Education
- published resources
- continuing professional development courses such as those provided by the national network of Science Learning Centres and its Resource Bank, which can be found on the portal www.sciencelearningcentres.org.uk and other websites such as those listed in Sections 5 and 7.

In all cases, new ideas should be tested before use with students, and the teacher must conduct a risk assessment for his or her own working environment. When unsure about an activity's safeness, CLEAPSS should be approached for advice. Section 5 in this document lists many sources that relate to physics teaching.

Enhancing science using ICT

Will ICT make the lesson easier, better or different? ICT should be chosen as a resource **only** if it will support the lesson's learning objectives (Betts, 2003).[3] Used appropriately, ICT can enhance learning and teaching, for example, by providing animations and video clips of scientific concepts which can help with students' understanding of scientific phenomena. ICT can be particularly useful for hard-to-teach topics, by providing 'concrete' examples of phenomena that are difficult to observe in a school laboratory or difficult to test using traditional experiments.

The Secondary National Strategy identifies the main applications of ICT in science as:

- simulations and modelling
- data logging
- databases, spreadsheets and graphical calculators
- information resources
- publishing and presentation software.

Simulations and modelling

ICT can give students and teachers an opportunity to use a model to change variables and investigate the effects in situations that are difficult to create in the classroom. For example, the teacher uses an animation to enable students to visualise the principles of an electric motor; within the animation, the current and field direction can be changed and the effects observed to improve students' understanding of how a motor works.

Data logging

Data logging helps students to record, present and analyse results. For example, when students use data loggers and light gates effectively in recording and displaying information about the movement of objects, this may well make a topic such as momentum more accessible.

Databases, spreadsheets and graphical calculators

These applications allow students to see data visually as well as organise, search, sort and display information in order to explore relationships, look for patterns and test hypotheses. For example, using a spreadsheet to model reaction speed and stopping distances of cars or using a database of planet data to investigate possible relationships between the variables, such as distance from the Sun and temperature, or distance from the Sun and period (orbit time).

Information resources

Using the internet and CD-ROMs, students are able to develop their knowledge and understanding of science. For example, students visit the Energy Saving Trust website to look at how energy is used in the home and actions that can be taken to reduce energy consumption. Then they can visit the Act on CO_2 website and make use of the carbon calculator to measure their own carbon footprint.

Energy Saving Trust:
www.energysavingtrust.org.uk

Act on CO_2:
http://actonco2.direct.gov.uk/index.html

Teachers may also use information resources to enrich their teaching. For example, introducing video clips to start a lesson can make the subject topical and relevant by showing science in the real world. News stories can introduce activities looking at How Science Works.

3
Betts S (2003). 'Does the use of ICT affect quality in learning science at Key stage 3?' *Studies in teaching and learning*, pp9–17.

Publishing and presentation software

Research shows that when students present their findings to their peers, their own understanding of the subject is improved. For example, if students are using PowerPoint to present ideas about the lifecycle of stars, they can be explicit about why they chose that application and how they used it to support their assignment. The visual nature of the presentation will help students demonstrate and share their own understanding of the topic covered.

One of the growing areas of ICT usage in physics is digital video to capture presentations and practical activities. This has a number of advantages, including:

- encouraging students to be clear, precise and concise in presenting ideas that they have developed
- providing an opportunity to analyse material in the lesson – for example, more sophisticated packages such as Dartfish allow users to analyse distance travelled by moving objects filmed
- providing an opportunity to revisit ideas and questions later in the lesson or series of lessons
- using footage with other teaching groups as exemplar material.

Interactive whiteboards are also an important classroom tool for many science teachers. Advice and guidance on how to use them effectively in science can be found in the spring 2007 Secondary National Strategy science subject leader development materials: www.standards.dfes.gov.uk/secondary/keystage3/downloads/sci_sldevspri07_1107_mats.pdf

Links to other subjects

Maths

The links between maths and science are many and obvious. Students not only need to be able to substitute values into formulae but also to manipulate the formulae themselves, such as with gas laws, transformers and equations of motion. Physics becomes more mathematical in Key stage 4 and some students may struggle with units, especially if they need converting.

There is also the need to be able to use graphs to illustrate and analyse relationships such as the half-life curve for radioactive decay. It is useful for there to be a dialogue between the maths team and the science team to identify a number of issues at the planning stage, such as when these particular topics are covered in maths and science and also what is meant by certain phrases, such as 'line of best fit'. It is also useful to be able to raise issues such as the difficulty that students may have with certain mathematical concepts, so that strategies to address these can be shared.

English

The Triple Science Support Programme's 'raising attainment' publication covers a number of issues here in some detail. In essence, there is a need to address four areas throughout the course.

The effective use of keywords is essential, and the awarding of assessment marks often hinges upon the use of such words. They need to be introduced, used and reinforced appropriately throughout. They can be raised in importance by their explicit use in starter activities and highlighted in the evaluation of conclusions, for example. Using writing frames to introduce keywords can be followed by peer assessment. Forces and motion is a good example where the accurate use of terminology is critical. Students may interchange words such as 'movement', 'speed' and 'velocity' and use phrases such as 'it's accelerating more quickly'. Without wanting to be pedantic or to stifle discussion, we still want students to become accurate and precise; there is a role here for the student in the re-drafting of their responses.

Speaking and listening are key skills in the learning process. If they are a strong feature of lesson design, students will learn more effectively. If they are not present or not structured appropriately, students will not have as good an opportunity to explore and internalise new ideas. Teachers need to be able to manage such activities effectively by, for example, the use of effective questioning.

Writing needs to have a clear purpose; where there is no clear purpose, students are rightly critical of the time and effort spent on it. Summaries for revision need to be brief and well structured, and all writing needs to actively engage the mind for it to be meaningful. Once written, text needs to be reviewed and assessed. A well-written (and re-written) conclusion to an experiment may well add significantly more to a student's learning than a whole experimental write-up never looked at again. Ideas need to be shared and re-worked so that, for example, an explanation of particle activity is clear and accurate.

Reading is also a key skill. Students need to be encouraged to read for a purpose and to be given ways of extracting information, such as highlighting key points and identifying the use of evidence to support an argument. English teachers are often very effective in using groupwork to present cases for and against issues, and it may be useful to observe others using this technique.

PSHE

A key aspect of PSHE is the development of individuals into confident and responsible people. This is obviously a function of the whole curriculum, but science has its part to play in this; it provides a number of contexts that give students an opportunity to develop and demonstrate skills and dispositions. For example, with a topic such as radioactive decay, students need to realise the significance and application of the ideas and to confidently present ideas about the opportunities and risks involved.

PSHE also involves students in being healthy and safe. Fundamental to this is students developing an understanding of how to manage their own lives so as to be healthy and safe. It is not only an understanding of what this might involve but also experience of assessing and managing risk. Students who have been kept safe but who don't know how to recognise and respond to hazards are less likely to remain safe. Students should therefore be involved in discussions about the nature of investigations they carry out and propose safety measures.

Citizenship

Responsible and effective citizens can conduct enquiries. Although this is obviously a wider area than scientific enquiry, science can offer a number of opportunities for students to formulate questions, design investigations, gather evidence and draw conclusions. The concept of learning from the evaluation of evidence is strong in science and is a key way in which it makes a contribution to the whole curriculum. It is therefore important that students are involved in the design of enquiry so that they see enquiry as a tool that they can use in life and in science.

Communication is also a fundamental aspect of citizenship and one that can be developed through science. Scientists need to be able to communicate their ideas effectively, and the subject provides contexts for the development of these skills. For example, students studying particle models need to be able to draw together ideas from a number of sources and synthesise an overall view. To do this effectively, students need to have a command of a range of communication skills, including speaking, listening, reading and writing.

Engagement and attainment

Progression and formative assessment

The concept and significance of progression is increasingly well established at Key stage 3; most teachers accept that students should be faced with challenges that progress as their learning develops and that the curriculum should be structured accordingly. Students go from simpler to more sophisticated models of the atom and from spotting simpler patterns to more complex relationships. However, at Key stage 4, the place of progression is not so well founded. It is sometimes a challenge to reconcile progression within the structure of a modular course. There are ways of achieving this, however, especially in terms of How Science Works. Contexts can be selected that are more complex and less familiar. Explanations can be developed that draw upon more than one model and involve synthesising ideas.

Formative assessment has a fundamental role in this: students and teachers need to know what current levels of understanding are and then to understand how improvement is possible. There is much good practice to draw upon to support this: the use of learning objectives to base lesson design upon, effective questioning, the use of data to set targets and the development of peer and self-assessment. There is a risk that this falls by the wayside if teachers and students are faced with a large amount of content and become mainly concerned with coverage.

Making learning meaningful

As well as being well structured in accordance with students' learning needs, it is also important that lessons support students in making sense of the world. Students need to feel that science is a tool they can use to make sense of the world, to understand it and to change it. The outcome from the course has to be not only in terms of completing tasks, passing exams and gaining qualifications but also in being empowered to make a contribution to society. Science, of course, offers much in this way. Extension Physics topics include, for example, the provision of communication systems, the monitoring of heartbeat for diagnostic purposes and the use of radioactive decay to provide energy for homes and tracers for medical applications. This needs to be apparent in the design and delivery of lessons.

Working in the world of science

Scientists work in a particular way (or ways) and it is their distinct approach that represents the particular contribution of science to the curriculum. This includes enquiry and the role of gathering primary data, but it goes further than that. There is content as well as process to How Science Works. Students need to learn how secondary data can be used, how explanations are constructed, how ideas are presented, and then how the scientific community works to review and validate new ideas. Students need to appreciate the provisional nature of scientific knowledge.

They need to see how this happens, and has happened, in practice. They won't find out how the scientific community functions simply by doing lots of experiments. There is a role here for outside speakers and mentors; if effective, they can give students an insight into how scientists operate and make progress. There are several organisations that can help identify suitable, trained researchers from industry and academia. These are listed in Section 7.

There is also a role here for off-site visits. Some students will have little idea about how a scientific workplace functions or how scientists go about their work. The learned societies can identify opportunities and put people in touch with each other. Some departments have a sound track record of inviting outside speakers who are effective and engaging. It is important to remember that not all students will see themselves as professional scientists in the future, so as well as speakers who fall into that category there is a role for people from other walks of life who are using science in their work.

Girls and physics

Many issues relating to inclusion are dealt with in the companion publication on raising attainment. However, there is an issue relating to the engagement and attainment of girls that is particularly related to physics and there is, therefore, discussion here.

There has been considerable interest in recent years in addressing the issue of girls in physics. There is evidence to suggest that girls who are capable of making considerable success of the subject at post-16 tend not to select it, and whereas all students have to make difficult choices at that stage, it is difficult to escape the conclusion that physics needs to be seen by girls as a more attractive option.

A number of studies and reports have been carried out; one of the most recent and authoritative is the 'Girls in the physics classroom' project commissioned by the Institute of Physics (see details at the end of this publication). The teachers' guide for action recommended five areas for action and these are worthy of consideration:

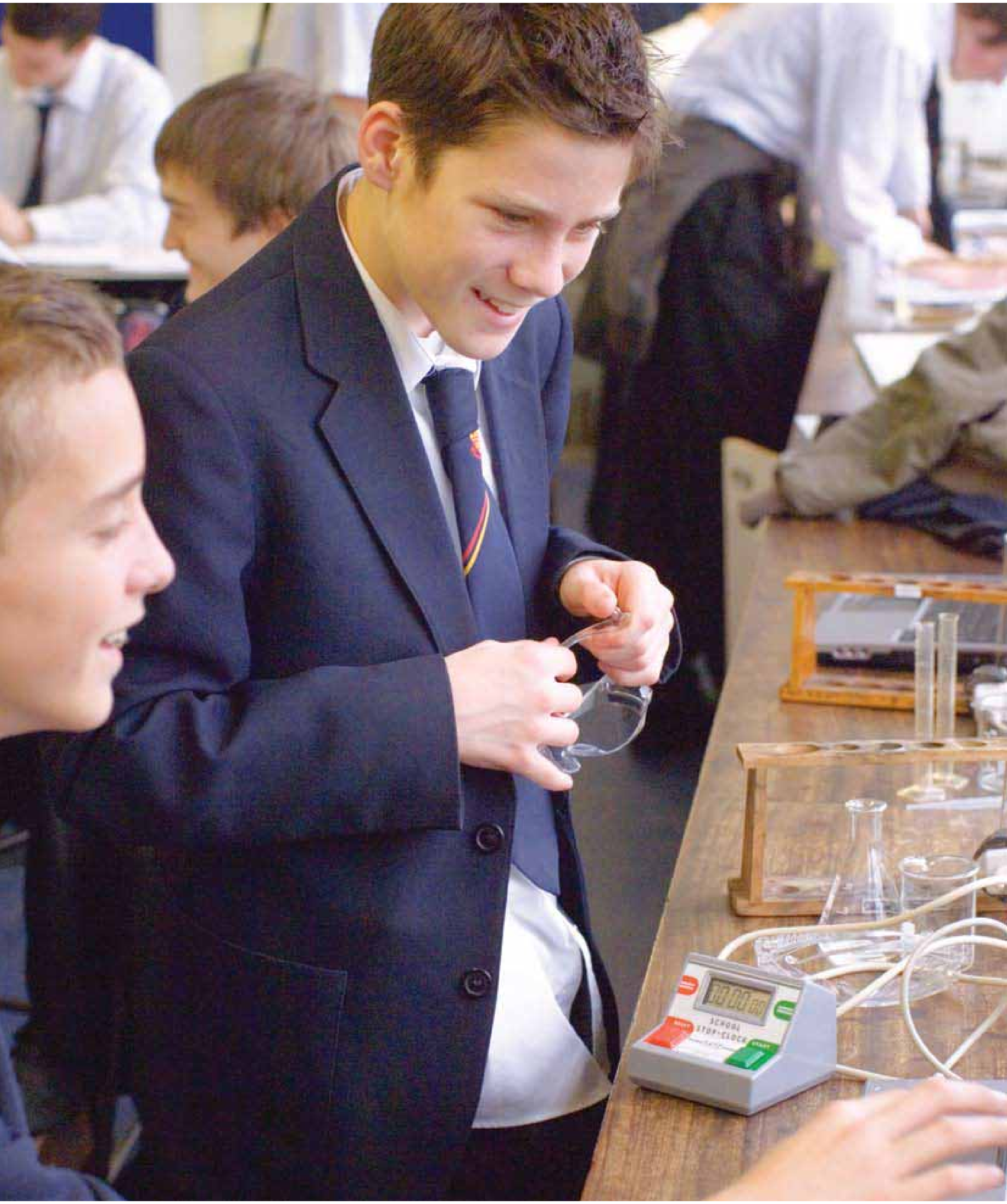
1. Accentuate the positive wherever possible and avoid portraying physics as an essentially hard subject. Girls in a mixed school are more likely to be deterred than boys.
2. Take positive steps to reduce the impact of stereotyping. All staff, not just physics teachers, need to be well informed about the issues. In particular, teachers must avoid reinforcing stereotypes, endeavouring not to use mostly male examples when talking about occupations or interests.
3. Make sure that physics is viewed as a valuable subject in its own right, not just regarded as a qualification for careers in science and engineering.
4. Encourage collaborative approaches to the teaching and learning of physics and avoid domination by individuals.
5. Invite staff to be proactive in discussing study options. They should not just give information; they should also give an insight into what studying physics will be like. Involve A-level students and encourage them to give an honest appraisal of their experience.

These areas dovetail well with the key messages of this publication and support good teaching and learning for boys as well as girls. In particular and with reference to the above:

1. Our task is to make physics accessible and attractive. It is a challenging subject, but it is a rewarding subject as well. Girls are no more likely than boys to be deterred by the prospect of hard work, but physics needs to be set in the context of being useful and worthwhile.
2. Quite often the challenge here is simply to come up with contexts that are accessible to all students. As the report points out, a shower curtain that clings to your leg is a familiar context, whereas bending the path of a football is not.
3. A subject is often seen by students as being defined by where it gets you, and if physics is presented repeatedly as an essential precursor for certain university courses, especially if they are ones that lead to male-dominated careers, then it will be perceived by students as such.
4. There is a clear message for inclusive teaching to be a priority for the benefit of all students; a key element of this is the teacher having the skills to manage the classroom so that all students are involved and engaged in active learning.
5. Physics opens doors and a teacher won't necessarily be familiar with all of these opportunities. Other people need to be involved in talking to students and presenting possible images of their future.

Supporting STEM subjects

Physics has a central position in the interplay between science, technology, engineering and mathematics. The knowledge and skills developed in physics are often relevant and valuable to these other subject areas; for example, students wanting to make progress in technology or engineering. It is worthwhile highlighting topics that have a direct bearing, such as electromagnetic induction on electrical engineering, gas laws on chemical engineering, and forces on mechanical and civil engineering. However, technology and engineering are about more than just the application of those ideas; in those subjects there is a central place given to problem solving and the adoption of a solution-based approach to questions. If it is possible to give students the experience of this, it will develop their insight into such subjects.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Section 5
Specific GCSE Physics topics

Extension Science (Physics) at a glance

A brief overview of the range and content of physics in Extension Science (see Annex 1 for single-page summaries of the physics in each specification overall).

	AQA	Edexcel360	OCR Twenty First Century Science	OCR Gateway	WJEC
Extension Science (Physics)	Physics 3	5: Particles in action 6: Medical physics	P7: Further physics – observing the universe	P5: Space for reflection P6: Electricity for gadgets	Physics 3
Forces and energy	Turning forces and stability. Balanced forces and Newton's first law. Unbalanced forces and circular paths – as in planets and artificial satellites. Centripetal force.	Absolute zero, Kelvin scale. Kinetic energy of gas particles, P/T = constant, $P_1V_1/T_1 = P_2V_2/T_2$ Power = work done/time taken. Work done is equal to energy transferred.		Satellites, gravity, circular motion, vectors, equations of motion, projectiles, momentum, satellite communication.	Measuring speed and position of accelerating objects. Collisions and changes in direction. Distance/time and velocity/time graphs and equations of motion. Momentum. Calculating kinetic energy. Circular motion.
Waves and radiation	Formation of images in optical devices such as cameras and magnifying glasses by mirrors and lenses. Sounds in frequency range 20Hz–20kHz. Ultrasound waves and their uses.	Refraction, total internal reflection, pulse oximetry, intensity = power of incident radiation/area, use 'radiation' to describe energy originating from a source.	Making a real image with a converging lens and the use of a second lens to create a telescope.	Nature of waves, refraction, optics.	Refraction of plane waves. Ultra-scans and other uses of ultrasound. Seismic waves and how they can be used to probe the structure of the Earth.

	AQA	Edexcel360	OCR Twenty First Century Science	OCR Gateway	WJEC
Atomic physics		Properties of alpha, beta, gamma, positron and neutron radiation; decay, fundamental particles. Thermionic emission, deflection of charged particle stream, uses of electron beams. Thermal neutron, momentum isotope formation. Positron emission, tomography scanning. Effects of radiation, treating tumours, palliative care.	Nuclear processes in stars.		Working out atomic structure. Radioactive decay and dating. Nuclear fission and its control in reactors.
Space	Gravitational forces responsible for the formation of galaxies and for stars such as the Sun having a long stable period. Life history of stars.		Observations of stars, planets and satellites. Spectra and brightness of stars; Cepheid variables; Hubble constant. Birth and death of stars. Using telescopes.		Nuclear fusion, energy processes in stars and the potential of fusion to provide energy on Earth.
Electricity	Currents produce magnetic fields and thus movement. If a conductor cuts magnetic field lines, a potential difference is induced. This generator effect is used to produce electricity. Transformers are used to alter AC potential differences	Basal metabolic rate, muscle cells generating potential differences and use in medical applications, how action potentials can be measured, the shape of an ECG in terms of heart action.		Resistors, motors, generators, transformers, AC, DC, logic circuits and their applications.	Electromagnetic induction and the use of generators to generate electricity. Using transformers to increase or decrease voltages.

Forces and energy: Circular motion and centripetal force

Subject knowledge and challenging concepts

- Circular motion is the result of two forces: one, centripetal force, is towards the centre of the circle; the other, tangential force, is provided by the means of propulsion of the mass. The centripetal force is greater if the mass is greater and if the speed is greater, but becomes less if the radius is greater. The formula linking the centripetal force with the mass of the object in circular motion, its velocity and the radius of the orbit is $F = mv^2/r$.
- If a mass were attached to a string and caused to orbit a person, it would describe a circular path. If the string were to snap, the flight path of the mass would be a straight line at a tangent to the circle. It would not be a line radial to the circle.
- Circular motion is a problematical concept because, in common with a number of forces topics at this level, it is counter-intuitive. Someone experiencing circular motion, such as driving round a roundabout or riding on a fairground roundabout, can feel themselves being forced outwards and so they will want to explain this with terms such as centrifugal force. This is a misconception, but like all misconceptions it is best dealt with by having a climate for learning in which students feel safe to express ideas and feel that they won't be 'thought less of' for holding such ideas. Establishing what students really think is a strong teaching approach; subsequent challenges, activities and inputs can then be focused on. Centripetal force pulls an object in circular motion towards the centre of the circle and has to be present. Centrifugal force is an illusion caused by the perception that such an object is attempting to move in a radial direction.
- Gravity is a universal force of attraction between any two masses, and is greater if those masses are greater and is less if the distance between them is greater. This attraction is part of the reason why objects, such as the Earth and Moon, orbit each other. They are accelerating towards each other but also have a tangential motion, the result being motion in orbits. Planets in the solar system have orbits that are elliptical, with the Sun at one focus. The further a planet is from the Sun, the greater its period of orbit.
- A useful thought experiment to summarise this is credited to Newton. Imagine standing on top of a hill and firing a cannon. The ball flies out and falls to Earth. Fire subsequent cannon balls with progressively greater force so that they travel further before landing. Eventually one would travel with such force that it would be in Earth's orbit. A greater force still would enable it to move away from the Earth.

Figure 1. A 'thought experiment' of Newton's

- When an artificial satellite is put into orbit there is a precise connection between the height of the satellite above the Earth and the correct speed to keep it in orbit. The greater the height, the less the speed to keep it in orbit. This means that a low orbiting satellite has a relatively high speed, taking only an hour or so to orbit the Earth. Such satellites are useful for applications such as imaging of land and weather systems.
- There is one particular height at which the speed means that the satellite is orbiting the Earth once every 24 hours. If it is arranged that this is in the same direction that the Earth is rotating then, relative to a fixed point on the Earth, the satellite appears to be stationary. This is known as geostationary or geosynchronous. Such satellites are particularly useful when it comes to telecommunications as they provide a continuous link, and weather images from these satellites will cover a larger area than the polar orbiting ones.
- A comet has an orbit that is often highly elliptical; as it approaches the Sun its speed increases, and as it heads off further out again, the speed decreases.

Teaching model examples

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1 Students are presented with a number of ideas and experiences, such as the demonstration with a mass on a cord or the flying toy on a string, and information about satellites.

2 By means of Q&A and structured discussion, the teacher and students draw together key features of circular motion, including:

- there is a force acting tangentially to the path of motion
- there is a force acting towards the centre of the circle described by the path of motion.

3 An overall summary of circular motion is produced by the class and can then be applied to various new contexts.

cm

1 The teacher commences the teaching sequence by asking the students in small groups to share and present ideas about circular motion based on questions such as:

- What are the forces acting on a satellite in orbit around the Earth?
- What would happen to the satellite if it were to speed up or to slow down in its path?
- What would happen to it if the Earth's gravitational field were suddenly to cease to exist?

2 The teacher then presents students with a number of ideas, such as:

- setting up a vehicle travelling in a circle on the floor due to a cord linking it to a central point. The cord is released and the vehicle's path noted
- video clips of cars on skid pans.

3 Students are challenged to assimilate the new evidence into their ideas and diagrams.

4 The teacher draws together the key points made and the students produce a summary.

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1 The teacher takes an example of circular motion (eg flying toy on a string), demonstrates it and explains how the object's motion can be understood with reference to the various forces acting on it.

2 The key points are summarised.

3 The students then apply those points to a range of other contexts, starting with simpler and more familiar ones then moving on to more complex and less familiar ones.

4 The teacher gathers feedback from students to gain a picture of how effectively they have understood those ideas.

Examples of investigations and demonstrations

- There are children's toys, often in the form of an aeroplane with a motorised propeller, which will fly around in circles suspended from the ceiling. This gives opportunities for questions to be posed, such as 'What is the direction of the force that keeps it flying in a circle?'
- The Practical Physics website (www.practicalphysics.org) includes three demonstrations to illustrate that the path of an object that was describing a circular path will be tangential and not radial if the centripetal force is removed:
  - Sparkler in a drill bit
  - Rubber bung on a string
  - Marble in a plastic cylinder on an OHP.

  For more details on these, go to www.practicalphysics.org ▸ Forces and motion ▸ Circular motion.

Additional classroom activities

- Video clip of a 'Wall of Death' in which motor cycles are driven around the inside of a large, vertical wooden drum, and of satellites in orbit around the Earth; followed by a discussion of the forces acting on them.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how interpretation of data, using creative thought, provides evidence to test ideas and develop theories.

Practical and enquiry skills

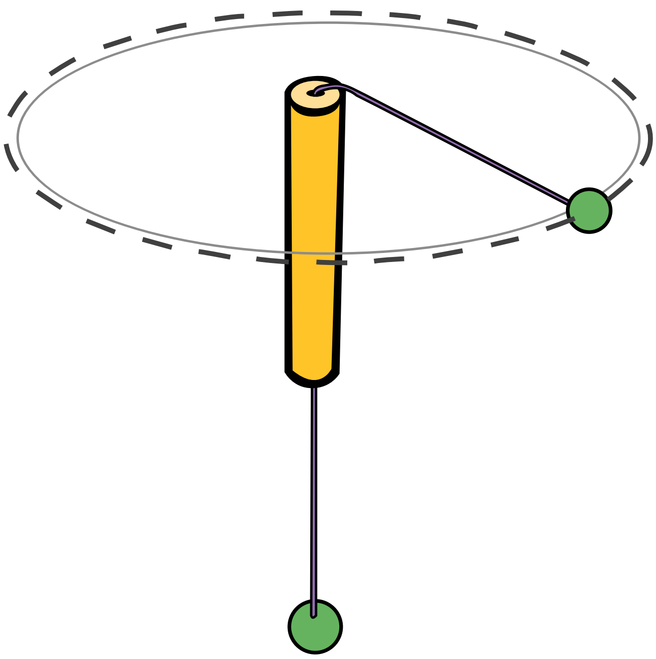
2 Students should be taught: to collect data from primary or secondary sources, including using ICT sources and tools; to work accurately and safely, individually and with others, when collecting first-hand data; and to evaluate data collection methods and consider their validity and reliability as evidence.

3 Students should be taught to use both qualitative and quantitative approaches.

Centre-marked assessment opportunities

- An experiment that can be set up to demonstrate some of the aspects relating to circular motion and generate some data is as follows. On one end of a thin cord attach a mass such as a rubber bung, and on the other end a weight carrier. The cord needs to go through a metal tube (see Figure 2). The person using the equipment puts weights on the carrier and holds the tube vertically, rotating it so that the bung is describing a circular path. There are obvious implications here in terms of safety. There are several questions that can now be explored initially in discussion but then with the use of the equipment:
- What happens if the number of weights is increased and the rotational speed kept the same?
- What happens if the number of weights is increased and the radius kept the same?
- What is happening in these two situations in terms of centripetal force?

Figure 2. Experiment to investigate centripetal force



Forces and energy: Momentum, impact and collisions

Subject knowledge and challenging concepts

- Momentum is possessed by a moving object and is what will keep it moving. It is proportional to mass and velocity. A car travelling at a greater speed has more momentum than one travelling at a lesser speed. However, it has less momentum than a heavy truck travelling at the same speed. Momentum is calculated as the product of mass and velocity: momentum = mass x velocity.
- Momentum is a concept that needs careful consideration. It is a useful concept but there are opportunities for confusion, especially with notions of kinetic energy and force.
- In an impact between two objects, each exerts the same force on the other. This comes from Newton's third law of motion. Students may not find this easy to accept. A skateboarder hitting a wall will not find it hard to believe that the wall has exerted a force on him or her but may find it harder to believe that the wall has had an equal force exerted on it.
- A key idea that will assist with this is that force is equal to the rate of change in momentum. This in fact helps with making the previous idea more accessible: as momentum is a product of mass and velocity, the impacting objects will not rebound with equal speeds (unless the masses are identical and initial velocities equal and opposite). The skateboarder being (in all probability) of a far smaller mass than the wall means that he or she will experience a far greater change in velocity. An understanding of momentum can help with making sense of a number of situations, however. Injury is caused to bodies in a road traffic accident due to the rate of change of momentum: if this is reduced, such as by the use of crumple zones or air bags, it means that the force upon the body is less.
- Momentum is conserved in an impact: the total momentum after the collision is the same as the total momentum before. This explains a number of situations such as the recoil from a gun. When the gun is fired, the missile flies forwards and the gun moves back. The greater mass of the gun means a proportionately smaller velocity.
- This has implications in a number of situations, such as, for example, collisions. In an impact between two vehicles it can reasonably be assumed that the impact is elastic and, therefore, that the total momentum afterwards is the same as that before. This is bad news for a small car hitting a large truck; its lesser mass means its change in velocity will be greater.
- Similarly, there are applications in sport. Hitting or catching a ball are actions that involve change in momentum. Sudden impacts can result in injury. Sports players learn to 'follow through' when hitting a ball, for example in tennis, and to move their hands when catching to reduce the 'sting'.

Teaching model examples

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1 The fundamental concept here is that of conservation of momentum. This can be presented as: total momentum before impact = total momentum after impact, or $m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$.

2 The class then explore how this can be applied to various impact situations, which consist of a mixture of sources of primary and secondary data, such as using linear air track demonstrations, computer simulations and video clips.

3 The class then decide if the model is a useful one and to which situations it can be applied.

4 Students then use the model to solve problems in which one of the pieces of information is missing.

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1 The teacher shows examples of momentum and impacts, such as a pair of dynamics trolleys being pushed apart with a spring-loaded plunger, and a video clip of a collision between vehicles.

2 The teacher then explains how such situations can be analysed by using the concept of conservation of momentum. The total momentum before the impact is the same as that after, as long as the impact was elastic. As the momentum can be calculated from mass x velocity, it is possible to calculate the velocity of one of the objects.

3 Students are then given other situations to analyse using the same approach.

4 The group then share their experiences and clarify the learning that has taken place.

Examples of investigations and demonstrations

- A linear air track is useful. This supports vehicles on a cushion of air, so that they can move along the track. As their direction is determined by the track, it is straightforward to use data logging equipment to measure speeds. Therefore, a pair of vehicles can be made to collide and their speeds before and after impact measured.
- Details can be found at www.practicalphysics.org ▸ Forces and motion ▸ Momentum ▸ Investigating Momentum during collisions.
- A similar arrangement can be achieved with dynamics trolleys. This is cheaper but less accurate as there is less control over direction. However, this can be a good way of promoting discussion about qualitative evidence. Some trolleys have spring-loaded plungers and it is possible with these to release the plunger so as to force two adjacent trolleys apart and observe the relative motion. If this is repeated with one of the trolleys loaded, a difference can be seen and questions stimulated in terms of challenging students to consider mass and velocity and therefore discuss momentum.
- If a pair of trolleys are fitted with Velcro pads they can be made to combine following an impact. This is a useful means of demonstrating conservation of momentum. One of the trolleys is stationary and the other collides with it. The pair stick together and move as one. With two light gates it can be shown how the speed has changed. If the trolleys are weighed the momentum before the impact can be compared with the impact afterwards.

Additional classroom activities

- ICT simulations in which the behaviour of moving objects can be modelled will be useful in this topic. Examples include Sunflower Learning, Crocodile Physics and Krucible. Sunflower Learning, for example, has a section with a virtual representation of a linear air track.
- There are also opportunities here for students to explore the implications of such ideas in the context of sport. The teacher may choose to select certain applications or may challenge the students to come with instances from sports of their choice. This might include, for example, looking at questions such as 'Describe a situation in which the momentum of a moving object has to be absorbed and describe a strategy for doing so' or 'Why might someone in sport want to maximise momentum and how would they do so?' It might be useful to have various balls, bats and clubs available.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2 Students should be taught to collect data from primary or secondary sources, including using ICT sources and tools.

Communication skills

3 Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols, and ICT tools.

Centre-marked assessment opportunities

- It is unlikely that a school would have the capacity for students to collect first-hand data from an experiment on momentum, but there is scope for a study into the application of such concepts in areas such as speed and road safety. Students could explore, for example, questions such as 'Why are there different speed limits for different classes of vehicles on major roads and should that gradation be extended to other roads?' or 'Should weight limits for heavy goods vehicles be changed so there are fewer but heavier vehicles, or more lighter vehicles, on the roads?'

Resources

For example: websites, books, organisations/schemes/visits, multimedia ICT, etc.

- Video clips of impacts between vehicles. Also clips of sports activities that involve people using techniques such as 'following through'.
- Computer simulations such as Crocodile Physics, Sunflower Learning and Krucible have sections on momentum; the Sunflower Learning one having a computer simulation showing a linear air track that enables virtual experiments to be conducted.
- www.practicalphysics.org is a useful source of information about practical work on momentum.

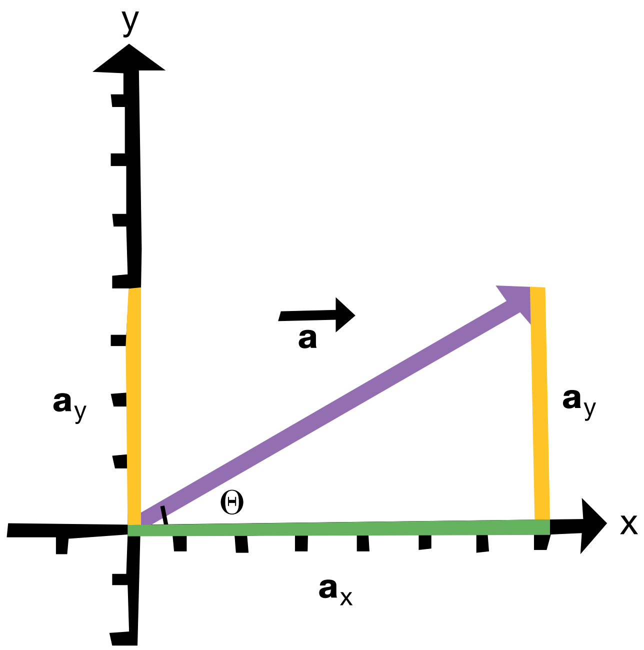
Forces and energy: Equations of motion

In a situation in which motion is changing, there are various quantities that can be measured. For example, when a space shuttle takes off it has a starting velocity (of zero), and over a certain period of time it will travel a certain distance and reach a final velocity. It will have accelerated during this time. The equations of motion allow these variables to be linked. For example, if the shuttle has an acceleration of 20m/s² for the first 5 minutes (having started from rest), the equations will allow us to calculate the distance it has travelled and its velocity at the end of that period of time.

Subject knowledge and challenging concepts

- Some variables are scalars and some are vectors. Scalar quantities such as mass have magnitude but no direction. Vector quantities such as force have both magnitude and direction. This is the distinction between speed and velocity: speed is a scalar quantity but velocity is a vector as it includes reference to direction. This is important in this topic as there may be situations with objects travelling in different directions or with changes in direction.
- Variables such as force and velocity that are vector quantities may be combined in the following ways (it is important to clarify which direction is being regarded as positive).
  - If they are in the same direction, they are added.
  - If they are in opposite directions, they are subtracted.
  - If they are at right angles they are combined by moving one vector (maintaining its length and orientation) so that the tail of one vector touches the tip of the other. The resultant vector goes from the tail of the first vector to the head of the second (see Figure 3).

Figure 3. Combining vectors at right angles



- There are four equations of motion which describe the relationship between five variables relating to an object in motion.
  - a = acceleration, in metres per second squared (m/s²)
  - s = distance, in metres (m)
  - t = time, in seconds (s)
  - u = initial velocity, in metres per second (m/s)
  - v = final velocity, in metres per second (m/s).
- Each of the equations links four of these variables:
  - $v = u + at$
  - $s = ut + \frac{1}{2}at^2$
  - $v^2 = u^2 + 2as$
  - $s = \frac{(u + v)}{2}t$
- Therefore, if three of the variables are given, by selecting the appropriate formula, the fourth can be calculated.
- The variables have to be entered using units, such as metres, kilograms and seconds, and students need to be confident and consistent with these. If, for example, the object is in free fall, the acceleration will be that due to gravity, normally taken as 10m/s². This means that distance has to be in metres and velocity in m/s.

- Velocity and acceleration are vector quantities and these need to be reflected with the use of a negative sign if the direction of any of those quantities is reversed. This includes the acceleration of an object that is still travelling in a positive direction but slowing down.
- As well as relating to large, spectacular objects such as spacecraft, velocity and acceleration also apply to regular everyday objects such as supermarket trolleys. For example, if a loaded trolley were pushed and allowed to roll until it comes to rest, if its initial velocity and the distance were known, its acceleration (which will have a negative value) and the time taken could be calculated.
- This has a particular relevance to road safety. Highway Code braking distances can be used to calculate the time of journey during braking and the acceleration. Speeds may have to be converted to appropriate units for some students.

Teaching model examples

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1 The teacher introduces the idea of linking variables describing motion in order to calculate additional information.

2 They then introduce the equations and explain about the symbols and units. They demonstrate how the equations can be used to solve problems and arrive at answers.

3 The students then try applying the equations to other problems to develop their skills.

4 The key learning points are then summarised by the students and the teacher so that the learning is consolidated.

Examples of investigations and demonstrations

- It is useful if earlier work on motion has been supported by practical and demonstration work, though it is unlikely that many departments will be able to illustrate all of the equations of motion using primary data. Measuring velocity and acceleration on the same ‘run’ is tricky. However, illustrating $s = ut + ½at^2$ or $s = (u + v)t/2$ is more practical as the experiment can start from rest and run over a measured distance, leaving time and either acceleration or final velocity to be logged. There is an argument, however, for avoiding the potential complications of such work if it does not provide ‘model data’ and instead focusing upon the skills of calculation.

Opportunities for How Science Works

Communication skills

Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Additional classroom activities

- Some students find the manipulation and application of formulae quite difficult, especially if part of the issue is knowing which formula to use. There is scope here for getting successful students involved with explaining their effective strategies.

Forces and energy: Gas laws

Subject knowledge and challenging concepts

- The absolute temperature scale is measured in Kelvin (K). The particles of a material at the temperature of 0 K are completely stationary: they have no kinetic energy at all. A temperature change of 1°C is the same as a temperature change of 1K (note this is one Kelvin, not one degree Kelvin). Absolute zero, 0 K, is just below -273°C. Thus the conversion factor is 273 (ie subtract 273 to turn K into °C, or add 273 to convert °C into K).
- In a gas, the particles are moving around at speed. If the temperature of the gas is increased, the particles will move around at a greater speed – they will have more kinetic energy. If the temperature is measured on the (absolute) Kelvin scale then the temperature of the gas will be directly proportional to the average kinetic energy of the molecules.
- If a gas is in a closed container it will exert a pressure on the sides of the container. Students need to be able to explain this in terms of the behaviour of particles. As the particles move, they will collide with each other and with the perimeter of the container. The collisions with the perimeter are the pressure being applied. If more gas is in the container there will be more collisions per second and the pressure will be greater. If the temperature of the gas increases, the particles of the gas will have more kinetic energy, will transfer more energy to the perimeter upon colliding and so the pressure will be greater.
- If a gas is in a sealed container and its temperature is measured in absolute terms, it will be directly proportional to the pressure it exerts. This relationship can be summarised by the equation P/T = constant. It can also be written as $P_1/T_1 = P_2/T_2$. This is useful as it enables, for a fixed mass of gas at constant volume, the temperature change to be calculated if the pressure alters (or the pressure change to be calculated if the temperature alters).
- If a fixed mass of gas is in a container whose volume is not fixed, the formula has to be modified. It still needs the temperature to be in absolute units. The formula is $P_1V_1/T_1 = P_2V_2/T_2$.

Teaching model examples

cm

1 Students working in small groups are asked to explore and come up with some responses and explanations to questions such as:

- Do you think there is a minimum temperature below which it isn't possible to go?
- What do you think happens to the particles in a substance as the temperature drops lower and lower?
- If you trap gas in a container and heat it up, what do you think it will do? How will the particles behave?

2 The teacher then organises various experiments, demonstrations and suggestions supported by other evidence to address these various ideas.

3 Students identify the key learning points from the activities.

4 They then compare the learning points with their earlier ideas and modify them accordingly.

um

1 The teacher presents the students with a model of how molecules behave in a gas and how this model can explain concepts such as pressure. This is reinforced by strategies such as the use of computer simulations of molecular motion.

2 The students then apply this model to a variety of situations, such as the heating of a container and the plotting of temperature and pressure, to develop meaningful explanations. They also extrapolate the pressure/absolute temperature back to zero pressure to ascertain a value for absolute zero.

3 The key points of learning are established, with the students explaining what they have learned and the teacher helping to clarify this.

dit

1 The teacher explains how the behaviour of particles in a gas is understood and how this is thought to vary as the temperature alters. The concept of absolute zero is explained.

2 The teacher then uses this to explain what is going on in a particular situation, such as a demonstration of a 'constant volume' apparatus (see below).

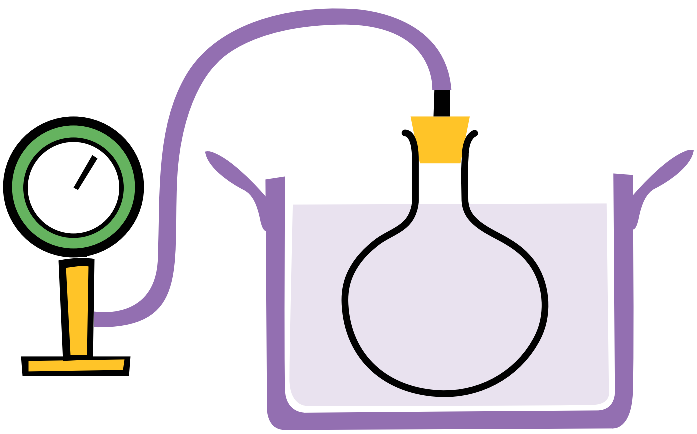
3 The students then apply their knowledge and understanding to other situations, such as the exploding tin can.

4 Teachers and students draw together the key learning points from the activities.

Examples of investigations and demonstrations

- This is a straightforward but very effective demonstration to show that pressure increases with temperature. The tin needs to have a well-fitting lid and not to have been used for the storage of any substance that will ignite or release toxic vapours upon heating. Safety screens and appropriate management of students is essential. A (very small) amount of water in the can helps. Heat from beneath with a Bunsen Burner. Await bang. Details are at www.practicalphysics.org ▸ Molecules in motion ▸ Gas pressure rises with temperature.
- Some science departments have a piece of equipment that causes ball bearings in a cylinder to vibrate and to strike a disc resting on top of them. As they vibrate with more energy, they cause the disc to rise higher.
- If the flask shown in Figure 4 is heated, the pressure change can be recorded. The volume of the flask is, of course, constant. If the pressure and absolute temperature are recorded and plotted on a graph, the data can be extrapolated to get a value for absolute zero. Details are at www.practicalphysics.org ▸ Molecules in motion ▸ Pressure of air at constant volume.

Figure 4. Investigating the relationship between pressure and temperature



Additional classroom activities

- The use of students to model particle behaviour is useful in that it helps to embed certain ideas such as the relationship between temperature of a gas, kinetic energy and pressure.
- There are several ICT applications that show graphic representations of the behaviour of particles in closed containers. These are useful in that they help students to visualise the succession of impacts of particles into the boundary as an application of pressure.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2 Students should be taught to evaluate methods of data collection and consider their validity and reliability as evidence.

Communication skills

3 Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols, and ICT tools.

Applications and implications of science

4 Students should be taught how uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

Centre-marked assessment opportunities

- The constant volume apparatus will generate a set of data that can be analysed. This is useful in that it not only gives opportunities for skills such as recording and graphing but also for tying in data with models. Students should be able to discuss reliability and validity.

Resources

- Software to model particle kinaesthetics, including Multimedia Science School, AtomScope and Sunflower Learning.
- AtomScope is a particle simulation program for teaching at Key stages 3 and 4. It features 28 simulations that each reflects a key idea in the science of atoms and molecules. It has supporting worksheets and an interactive system for following and labelling particles on the screen. See www.visualsimulations.co.uk

Waves and radiation: Nature of radiation

Subject knowledge and challenging concepts

- Radiation means anything that travels in rays, or waves. Hence light, heat (as infrared) and sound are all examples of radiation.
- Radiation originates from a source and transfers energy from that source. So, for example, a bulb is a source of light, a human body radiates heat and a loudspeaker radiates sound. It is a common misconception that the term 'radiation' means something that is inherently dangerous. It is often used as a synonym for ionising radiation, which can lead to confusion.
- As the radiation leaves the source so it will tend to become dissipated. This doesn't mean that the energy becomes less, but that it becomes more spread out. This isn't inevitable: light, for example, can be gathered and focused by means of lenses or mirrors.
- The intensity of the radiation is therefore directly proportional to the power and indirectly proportional to the area. This can be summarised as Intensity = power of incident radiation/area, or I = P/A. The medium through which the radiation travels will affect the intensity as well.

Teaching model examples

e(i)

1 Students gather various pieces of information and ideas from a range of experiments and demonstrations, such as those indicated in this section.

2 The teacher and the students work together to assemble these into a coherent explanation of radiation.

3 They then test this overall explanation by applying it to another context such as radiation from the Sun affecting the Earth.

e(d)

1 The teacher provides students with a general model of radiation emanating from a source, possibly starting with the light bulb demonstration described below.

2 The students are then challenged to apply this model to various contexts, such as infrared radiation and sound transmission.

3 The students then summarise the generic characteristics and how these apply.

cm

1 In this approach the teacher might start off by asking students to propose answers to questions such as:

- If we move the 'detector' further away from the lamp, what will happen to the reading?
- If we move it twice as far away, what will happen to the reading?
- Will this pattern work for heat? For sound? For seismic waves?
- Does this mean that some of the energy has 'gone'? If so, where has it gone?
- Would it make any difference if there was something in between the transmitter and the detector, such as smoke?

2 The teacher then asks the students to do certain experiments, and conducts certain demonstrations designed to address ideas expressed.

3 The students and teacher then review the key points from the practical work and other inputs.

4 Students review their ideas and refine as appropriate.

Examples of investigations and demonstrations

- If a light bulb is set on the bench and turned on in a dimmed room, a photovoltaic cell and voltmeter can be used to detect the level of light being transmitted. As the pV cell is moved further away from the bulb, the reading becomes less. However, if one imagines the pV cell as part of the surface of a sphere with the bulb at the centre, it is possible to see that, by moving the cell out, the sphere is larger and therefore that the proportion of the sphere represented by the cell is smaller. Less energy is being detected because it has become spread out over a larger area. The amount of energy is the same but its intensity is less.
- Using a bulb, pV cell and meter, students can measure and graph the relationship between energy gathered and distance. Ideally this would produce an inverse square law, but students should be able to suggest why their results won't be entirely reliable. Certainly the organisation of equipment in the room will need some careful planning and students can play a full part in this.
- Parallels with infrared energy can be achieved by using an electric radiant heat source and a number of thermometers, each with blackened bulbs and set various distances away from the source. Again, one of the most important aspects of this is the consideration by students of the limitations of the experiment.

Additional classroom activities

- A useful context for students to consider is the situation regarding radiation from the Sun reaching the Earth. This radiation includes infrared, light and ultraviolet; there are a number of useful ideas to draw together here, including UV radiation being able to reach the surface or being blocked, and light being partially absorbed and partially reflected.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how interpretation of data, using creative thought, provides evidence to test ideas and develop theories.

Practical and enquiry skills

2 Students should be taught to evaluate methods of data collection and consider their validity and reliability as evidence.

Communication skills

3 Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Centre-marked assessment opportunities

- There is an opportunity here for students to explore a mathematical relationship, use it as a model and recognise its limitations. The gathering of data on the relationship between intensity and distance is one that will produce evidence that can be charted, graphed and explained. It can also be used to model the way in which the Sun's energy becomes dissipated as it travels further away.

Resources

- *Medical physics: exploring, treating, understanding*. Cook and Gibson

  This is a free pack, produced by the Institute of Physics and Engineering in Medicine and EPSRC. It includes a textbook, teacher's notes, posters and CD-ROM. The material is linked to the website, www.teachingmedicalphysics.org.uk

- *Radiation and the environment*. Richard Boohan, Liz Coppard and Pete Hollamby

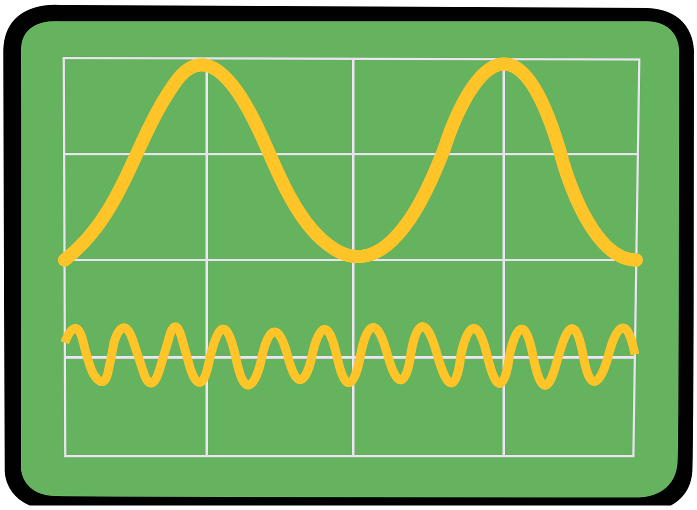
  The focus is on a scientific understanding of the effects of radioactivity and microwave radiation, and on interpreting media reporting and people's attitudes to the issues. In the activities students can analyse data and research for information.

Waves and radiation: Sound and ultrasound

Subject knowledge and challenging concepts

- Sound is caused by vibrations travelling through the air (or some other medium) to our ears. These vibrations, or waves, may vary with respect to:
  - frequency or the number of waves arriving at the ear per second, which affects the pitch. Frequency is inversely proportional to wavelength: the more waves per second the less the distance between successive waves. Frequency is measured in Hertz (Hz): 1 Hz is one wave per second
  - amplitude or the amount of energy in each wave. This manifests itself as the loudness of the sound.
- It is useful to represent a sound wave as a transverse wave.
- Figure 5 shows a variety of characteristics associated with a wave. The wavelength is clearly displayed, as is the amplitude. It is also convenient in that a display of a sound wave, via a CRO (Cathode Ray Oscilloscope) or the software equivalents will clearly show how the wave changes if the pitch or loudness change. The shape of the waveform is also important as this indicates the quality of the note.
- CRO traces are thus important and comparisons between them can convey much information. The two traces seen in Figure 5, for example, show the inputs from two simple sounds. The upper one is louder (as shown by the greater amplitude) and lower (as shown by the longer wavelength). The same analysis can be done on ultrasounds.
- A common misconception among students is that a sound wave is a transverse wave (as in the diagram above), unsurprisingly as this is how it is often represented. It is important to emphasise that whereas this is a useful way of displaying sound, sound is in fact a longitudinal or compression wave.

Figure 5. Sound waves on a CRO



- This has a implications for sound waves that make them behave differently to transverse waves such as light. Sound waves need a medium and travel quicker if the medium is denser. However, many of the properties are similar: sound waves can be reflected, refracted and diffracted.
- In general terms the audible range of frequencies for humans is 20 Hz to 20 kHz (20,000 Hz). However, this will vary from one person to another. Generally speaking, the upper limit decreases with age, so whereas many Key stage 4 students will be able to hear up to or slightly above 20 kHz, a person a generation older may not be able to hear above around 15 kHz. Other animals have different audible ranges: dog can hear up to 45 kHz and a cat up to 64 kHz.
- Frequencies above the human audible range are referred to as ultrasound. Ultrasound has the same general properties as sound but is particularly useful in a number of applications, including medical imaging, as it is much less dangerous than x-rays and gamma rays.
- Other applications include cleaning and medical and industrial scanning. The cleaning is effective because ultrasound consists of vibrations, which will loosen grime and dirt. The scanning works because ultrasound, being a wave, is partially reflected by any change in density, such as a bone in flesh or a crack in a casting. An example of this can be found at: www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/MeasurementTech/cracktip.htm

- These images show how the position and height of a crack in a piece of metal can be detected. The frequency value must be kept between 0.1 to 1 MHz (one million cycles per second) and the wave velocity must be between 0.1 and 0.7 cm/microsecond. For example, railway lines can develop cracks inside that can weaken them, with disastrous consequences. The technique also has applications in checking the soundness of bridges. Ultrasonic crack detection allows the detection of such faults.
- The wave formula, frequency = velocity x wavelength, applies to sound and ultrasound waves.

Teaching model examples

cm

1 Students are asked in small groups to share ideas and come up with explanations in diagrams and words to answer questions such as:

- How does sound travel from one place to another?
- Does sound travel faster or slower through a solid than through air?
- How could we show that sound travels slower than light?
- How can a note be made higher/louder?

2 The teacher then reviews the ideas being shared by the students and identifies areas of understanding and misconceptions.

3 The teacher identifies and uses demonstrations, experiments and discussions to address the misconceptions and give students the opportunity to develop their understanding.

4 Students review the answers to their questions and modify their explanations accordingly.

um

1 The teacher presents students with a model of particles in a medium vibrating and thus transferring kinetic energy from one to another.

2 The students are then presented with situations such as listening to a note from a loudspeaker, listening to the bell jar demonstration and seeing beads in the loudspeaker cone.

3 The students then have to use the model and apply it to these situations to produce a convincing and detailed explanation of how sound travels.

4 They may be able to then extend this model to explain why some notes have a higher pitch than others, why sound travels faster in water than in air and why sounds are harder to hear if the source is further away.

dit

1 The teacher explains, using diagrams, models and demonstrations, how sounds are formed and how they travel.

2 The teacher then uses the ideas, applying them to a particular situation to construct an explanation.

3 The students are then given other situations that they have to construct explanations for, using the ideas presented.

4 The teacher and the students then review the learning that has taken place to identify and consolidate the key points.

Examples of investigations and demonstrations

- A signal generator and loudspeaker are useful to be able to make sounds of particular frequencies. The concept of audible range can be explored therefore by making a series of notes between say 14 kHz and 23 kHz at 1 kHz intervals (but not in ascending or descending order) referring to them as 1 to 10 and asking students to write down which they can hear. No one will be able to hear all of them (and it's very unlikely that anyone will hear none of them). It's also very likely that the teacher will be the one with the lowest upper limit.
- Using the signal generator and loudspeaker and linking a microphone to a CRO enables the sound travelling through the air from the speaker to the mic to be displayed. The amplitude of the wave displayed can then be observed as the distance between the speaker and the mic is increased. Details are given at www.practicalphysics.org▸Electric circuits and fields▸Using a CRO to show acoustic waveforms.
- An effective demonstration that shows that sound and light travel at significantly different speeds is to take students outdoors into a wide open area and arrange for someone to be some distance away and to do something which will both be visible and audible, such as hit two blocks of wood together, and seeing the disparity between the sight and sound of the impact.
- A way of measuring the speed of sound is to find an open area outdoors with one (and only one) large upright reflecting surface, such as a wall. Standing some distance away from the wall, two blocks of wood are banged together and this is repeated when the echo is heard to arrive. The time interval between bangs and the distance to the wall are measured and recorded, remembering in the calculations that the sound has to travel to the wall and back. This does need a large area as being 300m away will only give a 2s interval and multiple echoes from different buildings will make it impossible. The accepted value of the speed of sound in air is 330 m/s.
- A slinky spring is useful to demonstrate the difference between transverse waves and longitudinal waves. If it is laid on a table and held still at one end, moving the other end from side to side will produce transverse waves. Moving the end in and out (so as to compress and stretch the slinky) will produce longitudinal waves. Attaching a bright object such as a small yellow tag to one of the coils then makes it easier to ask questions such as:

1 Describe the motion of that part of the slinky.

2 Where is energy being transferred to by the slinky?

- A key point to establish early on is that sound is a series of vibrations. This can be effectively demonstrated by getting a loudspeaker with the cone exposed, laying it down so it faces upwards and putting a number of very small expanded polystyrene beads in the cone. If a note of constant (low) pitch (such as from a signal generator) is played, the beads will be seen to bounce up and down.
- Another useful demonstration with a loudspeaker is to illuminate the cone with a strobe light. Again, a steady low frequency input from a signal generator is needed. If the strobe frequency, is similar to the loudspeaker frequency the motion of the cone will be (apparently) slowed right down, making it much more apparent. The room needs to be dimmed. Care needs to be taken with strobe lighting if any students in the group are affected by epilepsy and precautionary advice studied.
- A commonly used demonstration is that of the electric bell in the bell jar. The bell is set ringing and the jar evacuated. As the air is removed from the bell jar, the bell seems to get progressively quieter. Depending upon the equipment, the sound doesn't completely disappear and students may be able to suggest why not.
- There are various devices, such as Dr Daq from PicoTech, that enable a sound to be detected and displayed by a computer as a CRO trace. These are often significantly cheaper than a CRO.

Additional classroom activities:

- A useful model of the way that sounds travel is to arrange a line of students with their hands on their hips but with their arms interlinked. Moving a student at one end will cause energy to be transferred down the line. Comparisons can be drawn with air and other media. Filming a video of this may be useful for future reference.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2 Students should be taught to plan to test a scientific idea, answer a scientific question, or solve a scientific problem.

Communication skills

3 Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Applications and implications of science

4 Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Centre-marked assessment opportunities

- The use of blocks to measure the speed of sound activity can be used and students involved in deciding how to run it best, possibly comparing it subsequently with an electronic approach.

Resources

- It may be useful to have pictures, video clips or recordings of various different sounds to stimulate discussion about what sound is, how it is made and transmitted and how sounds vary.
- *Medical physics: exploring, treating, understanding*. Cook and Gibson.

  This is a free pack, produced by the Institute of Physics and Engineering in Medicine and EPSRC. It includes a textbook, teacher's notes, posters and CD-ROM. There are three lessons aimed at GCSE, including: the electromagnetic spectrum, radioactivity and ultrasound. The lessons have a PowerPoint presentation for your use. The material is linked to the website www.teachingmedicalphysics.org.uk This resource can be used for the extension topics that include medical physics, but the examples are also exciting ones to use to illustrate a number of physics concepts.

- Seismic Waves: www.geol.binghamton.edu/faculty/jones/#Seismic%20Waves

  Seismic Waves is a Windows® program that illustrates how waves propagate from an earthquake hypocentre to seismic stations across the Earth. One sees waves propagating out from the epicentre on three-dimensional and cross-sectional views of the Earth. These two-wave propagation views are synchronized with actual event waveforms so that as a particular phase arrives at a station, one sees the effect on the seismogram.

Waves and radiation: Refraction

Subject knowledge and challenging concepts

- Refraction occurs when the density of the medium that waves are travelling through alters. It affects the speed and direction. Waves entering a denser medium will slow down and bend towards the normal (drawn at right angles to the boundary). The opposite happens when entering a less dense medium.
- Students will often accept that light bends when passing from one medium to another and will have encountered such examples as swimming pools appearing to be shallower than they really are. However, explaining why this should be is rather more problematical. We need to use the wave model and emphasise that what we represent as a ray may need to be thought of as a succession of waves.
- Waves entering a denser medium will slow down (so light travels slower in glass than in air) and if they approach the denser medium other than along the normal route (ie at right angles to the surface), one end of a particular wave will be slowed down before the other and this will result in a change in direction. The wavelength of the waves becomes less.
- This will need reinforcing; there are good computer simulations and other techniques for illustrating this. Ripple tanks are useful, although they can be tricky to use to produce convincing results. Generally speaking they are more successful if students know what they are looking for. A skilful demonstration may achieve more than a class practical. It is also possible to model the effect using 'waves' of students marching from 'air' into 'water'.
- The extent to which light travels slower in a particular medium is known as the refractive index (n) and is calculated thus:

  $$n = \frac{\text{speed of light in air}}{\text{speed of light in medium}}$$

- For example, glass has a refractive index of 1.5n. A denser medium has a greater refractive index, will bend light by a greater amount and will slow it down more.

Wave refraction gives a good context for developing a theoretical model that can then be applied to a number of situations. What is particularly important is that the model is best developed or explained in a context where individual waves can be seen and then applied to other situations where they can't be.

Teaching model examples

1. The teacher shows the students several different examples of refraction. At this point the term refraction isn't defined. The lesson is couched in terms of 'Let's see what happens when a wave enters a different medium'. This might include:
   - watching a short video clip of water waves being refracted
   - seeing a demonstration with 3 cm-wave equipment
   - using ray box lamps and rectangular blocks.
2. Students sketch a diagram from each context showing the direction of wave travel and the direction in which it bends.
3. Students are then challenged to develop a general rule to say what happens when a wave enters a denser medium.
4. This is then tested in another context to see if it is valid. This might be using, for example, light passing through a tank of water.

e(d)

1 The teacher explains the hypothesis, possibly by using a number of students in rows as wave fronts and showing what happens when the wave fronts meet a ‘denser medium’ or a ‘less dense medium’.

2 Students then see if they can apply this to another context. They might start with a teacher demonstration of a ripple tank in which the individual waves can be seen and then progress to another context such as light.

3 In the discussion, the teacher draws out from students their understanding of how the initial set of ideas can be applied to a number of contexts.

4 The teacher could then introduce a different example, such as the apparent depth of a swimming pool, for the students to apply their understanding to.

um

1 The teacher presents a model of wave refraction by means of diagrams and words, showing how the speed and wavelength are reduced.

2 Students are then presented with a succession or collection of situations in which they have to use the model to explain the situation.

3 They could then use the model to predict the outcome of another situation.

4 In a discussion, the model is then reviewed to evaluate how useful it is.

cm

1 This might start with, for example, students working in small groups, each group with a large sheet of paper. On the paper they draw a series of straight waves approaching an area of shallower water. For the first part of the activity the waves could be parallel to the edge of the shallow region. The students have to compose a suggestion as to what will happen to the waves and why. Ideas are shared. The activity is then repeated for straight waves not parallel to the shallow region. Ideas are shared and the teacher develops an idea of the students’ level of understanding.

2 Depending upon the students’ understanding, so various activities are provided, each with the idea that students will use them to test out their own views. For example, this might include the ripple tank, video clips of waves, use of a program such as Krucible and use of light rays and rectangular transparent blocks.

3 Students are then encouraged to assimilate the new ideas with their earlier view. This is less of a ‘Let’s see if we were right’ session than a ‘How can our understanding be developed?’ session.

dit

1 The teacher demonstrates a phenomenon such as wave refraction in a ripple tank and then uses the theory of refraction to explain why that happens.

2 The class then consider another context and use the theory to explain that.

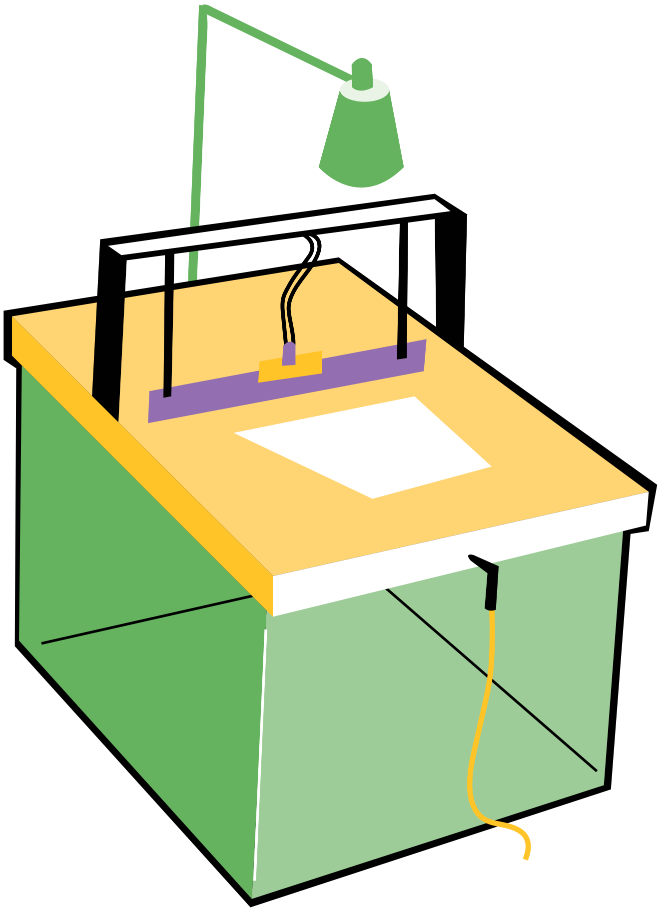
3 The class develop responses to share.

4 In the plenary, the students show how they have succeeded and the teacher sees the extent to which the lesson has been successful.

Examples of investigations and demonstrations

- There are a number of demonstrations that can be carried out to show refraction.
  - A ripple tank consists of a shallow tray of water with a transparent base and a method of projecting an image of the waves onto a screen. The more basic design has the tray supported about 40cm above a white screen. A light shines down through the water onto the screen. Other (demonstration) designs have the light shining up to project the image onto a high level screen. In either case, waves are produced and observed. If the water is made shallower in one area (eg by putting a transparent plate into the tank) the waves travelling over it are refracted. This becomes apparent as the wavelength decreases, and, if the edge of the plate is not parallel to the waves, their direction changes too. Details are at www.practicalphysics.org ▸ Waves ▸ Refraction of ripples entering shallow water.
  - 3cm-wave equipment will transmit and receive microwaves. If a Perspex prism is filled with paraffin and placed between the transmitter and receiver, the receiver can be moved to explore the path of the waves. It is found that the transmitter and receiver are not 'in line' for this to happen; the wave path has changed due to refraction.
  - A laser shining through a tank of water with a little milk in it will produce a ray of light that can be seen and (if the angles are correct) is not 'in line' with the incoming ray. This requires care and practice in order to get the right concentration and to avoid unwanted reflections; the CLEAPSS guidance should be consulted.

Figure 6. Investigating refraction using a ripple tank



- There are also practical activities:
  - A good starter activity is to put a pencil into a beaker of water. The pencil appears to be bent because light rays being reflected by the part of the pencil under water are refracted when they reach the glass side and the air.
  - The most common activities involve ray box lamps and rectangular Perspex (or glass) blocks. The ray path in and out of the block is drawn and therefore the one through the block added, showing which way the refracted ray has been bent. The incident ray is varied in angle to see what the effect on the ray path is. From this the refractive index can be calculated, using the sines of the angles. This can also be done with prisms, semi-circular and lens-shaped blocks.

Additional classroom activities

- Developing a model or teaching sequence to show how wave refraction works. This would involve students working in groups to devise a way of showing other students why it is that waves are refracted in a medium with a different density. It might be a model, a diagram, a cartoon, a role play, or whatever they think will be effective.
- Using the model to explain a number of situations, such as why a swimming pool looks shallower when viewed from the poolside than it really is.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 How interpretation of data, using creative thought, provides evidence to test ideas and develop theories.

Practical and enquiry skills

2 To collect data from primary or secondary sources, including using ICT sources and tools.

Communication skills

3 To recall, analyse, interpret, apply and question scientific information or ideas.

Centre-marked assessment opportunities

- Students investigating refraction could plan, gather and analyse data on refraction from, say, air to a medium such as glass or transparent plastic. There is opportunity to process data, such as finding the sine of each of the angles, to spot patterns, such as identifying the critical angle and the trends above and below it, and to spot anomalies.
- ‘Can-do’ tasks could be based on what students had done in practical work in this topic.

Resources

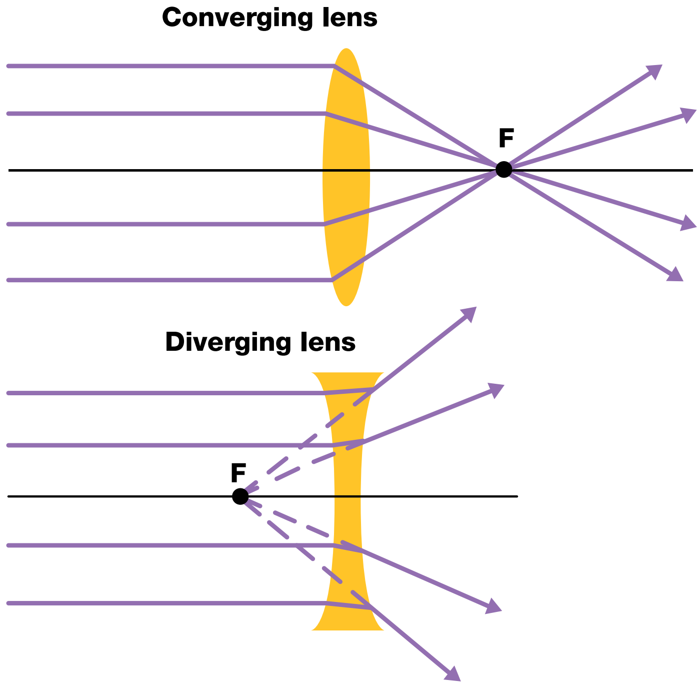
- Krucible is a program that has the facilities for reproducing wave patterns and viewing them in a variety of ways. It is a very versatile program that needs an investment of time but will pay it back manifold with the clarity and effectiveness of the images. More details at www.immersiveeducation.com/krucible
- Crocodile Physics software enables you to simulate and manipulate a number of situations, including ones with waves. More details from www.crocodile-clips.com/crocodile/physics
- GCSE.com has a section on wave properties at www.gcse.com/waves.htm as does BBC Bitesize at www.bbc.co.uk/schools/gcsebitesize/physics/waves/ and S-cool at www.s-cool.co.uk/topic_index.asp?subject_id=16

Waves and radiation: Image formation

Subject knowledge and challenging concepts

- The formation of images is a product of the refraction of light rays. Rays are redirected so as to converge at a particular place; this process is referred to as focusing and happens as a result of curved mirrors or lenses.
- There are two types of image – real and virtual. A real image is one that can be projected onto a screen, such as one produced by a data projector. It is an inversion of the object. A virtual image is one that can be seen by the viewer looking into an optical device, such as with a microscope. It cannot be projected onto a screen but is the right way up.
- A convex lens causes the paths of light rays to converge. If this is sufficient to make the rays meet (diverging rays may simply be made less diverging or parallel) an image will be formed. A concave lens causes rays of light to diverge.
- Figure 7 shows image formation by convex and concave lens.
- The focal length is the distance beyond the lens that parallel rays going into the lens are brought to meet. The nature of the image produced by a convex lens depends upon the distance between the object and the lens. (A concave lens also has a focal length: it is the distance from the lens to the point from which the diverging rays appear to be emanating.) Examples include:
  - a magnifying glass making rays converge to produce a virtual image that can be seen by looking into the lens
  - a camera lens causing an image to form on the film or the CCD by making the rays converge on it
  - a projector causing rays to converge on a screen.
- Focusing involves altering the distance between the object and the lens. This alters the point at which the rays meet, so that they can be made to meet on the back of the camera or the screen.

Figure 7. Convex and concave lenses refracting parallel rays of light



- Image formation is usually shown in three ways:
  - By using lenses or mirrors set up to model an arrangement or device. For example, a pair of convex lenses can be used to model a telescope.
  - By using a ray box lamp with a multi-slot plate (to produce several rays) and cylindrical lenses and mirrors. In a dimmed room the rays are then reflected and refracted to show their paths. Students can then see how they are made to converge.
  - By using ray diagrams. There are various conventions used in the production of these diagrams; the diagrams show the ray paths.
- Optical diagrams are tricky to produce; if the angles are slightly wrong the diagram may well be completely wrong. One way forward is for students to complete incomplete ray diagrams; another is to ask students to answer questions, either individually or in small groups, about the diagrams. The important thing is for students to interact with the diagram.
- The relative size of the image and the object is the magnification. It can be calculated by measuring and dividing thus: magnification = image size/object size.

Teaching model examples

e(i)

1 Giving students the opportunity to draw together various ideas from experiments, demonstrations and teaching inputs. This might include:

- using a ray box lamp and cylindrical lens to look at ray paths
- focusing an image onto a screen using a convex lens
- using or looking at a computer simulation or diagram of rays being focused to form an image.

2 Drawing together various ideas, including:

- light travels from an object we can see, to our eyes
- lenses 'bend' light rays
- light rays can be made to meet
- if some of the rays leaving one part of an object are brought together, this will form an image.

3 Assembling, by questioning and discussion, an understanding of image formation.

4 Applying this model to another situation, such as a projector, a telescope or a magnifying glass.

dit

1 The teacher demonstrates a situation in which light rays are being focused to form an image, such as using two convex lenses to form a telescope.

2 They then show how this situation can be understood by using diagrams and words, emphasising appropriate conventions.

3 Students then use the approach to make sense of similar and then different situations.

4 Key learning points are drawn together to summarise the learning that has taken place.

cm

1 Students use a convex lens and a white screen in a dim room to project an image of the window and the landscape beyond it onto the screen.

2 The teacher then asks the students to work in groups to construct a diagram showing what they think is happening to the light rays for the image to be formed.

3 Students use a ray box lamp and cylindrical lens to find out how the rays are focused to meet.

4 Students use a program such as 'Crocodile Physics' (in which it is possible to arrange optical apparatus to show ray paths) to reproduce the arrangement in point 1 (above) and other arrangements.

5 Students then return to and revise their diagrams.

um

1 Get students to use a ray box lamp and cylindrical lens to find out how the rays are focused to meet.

2 Students then use a convex lens and a white screen in a dim room to project an image of the window and the landscape beyond it onto the screen. The image formation concept is developed by the teachers and the class to explain what is happening.

3 The students then apply this model to other phenomena, such as:

- a ray box lamp and cylindrical mirror
- two convex lenses working as a telescope
- a program such as 'Crocodile Physics' (in which it is possible to arrange optical apparatus to show ray paths) to reproduce the two arrangements above.

4 The class then draw together their ideas to show how their concept of image formation by rays converging applies to a variety of other applications.

Examples of investigations and demonstrations

- Pinhole cameras are a useful way of introducing students to image formation. These are usually made in black card as a simple box shape (10cm x 10cm x 20cm long will work well). One end needs to be made from translucent paper. The other end needs to have holes made in it, so a good strategy is to have the end largely open and a piece of black card inserted (it's easier to change the card end than the whole box).
- A good way to set the room up is to have it dim and with several mains voltage 60W clear (as opposed to pearl) light bulbs switched on. Making a pinhole in the front will produce an image of the filament on the screen. If the bulbs are clear it will be obvious that the image is inverted.
- Making multiple pinholes will result in multiple images. Enlarging the pinhole will result in a brighter but fuzzier image. Replacing the front panel with a convex lens will produce a complete inverted image showing more than the pinhole did, as the lens has gathered in light from a larger area.
- Unlike the pinhole, though, the distance between the lens and the screen is critical – the camera needs to be focused. A good way of doing this is to have a more sophisticated pinhole camera consisting of a front part and a rear part, and have the two parts designed so that one can slide into the other. This alters the distance between the lens and the screen. This is the way that a 'proper' camera works (though not the way the eye works, which achieves the same effect – focusing – by altering the profile of the lens). For more details go to www.practicalphysics.org▸Optics▸ Pinhole camera and lens camera.
- Most science departments will have ray box lamps with the facility to produce single or multiple rays. These are useful for students to use to investigate at first hand what happens to light rays when they meet mirrors and lenses.
- A straightforward way of getting students used to the idea of focal length is to ask them to measure the distance between a convex lens and a screen on which the lens has focused an image of a distant object, such as the view out of a window. The rays coming in from a distant object will be nearly parallel. If this is repeated with different strengths of lenses, it will be seen that a thicker lens is a stronger lens and brings the parallel rays to a focused image a shorter distance away.
- This can then be extended into seeing what the image is like if the object is placed:
  - beyond 2F (where F is the focal length)
  - at 2F
  - between 2F and F
  - between F and the lens.

  For each of these it can be noted where the image is, its size compared with the object and whether it is the right way up or inverted. Note that the last one will give a virtual image, seen by looking into the lens.
- It is possible to conduct demonstrations using an optics bench. This enables lenses to be held upright in a particular place. By this means it is possible to show how some optical instruments work and also to give students some hands-on experience with lenses.
- Alternatively, lenses can be attached to a metre rule with modelling clay. This is much cheaper, but care needs to be taken to ensure that the arrangement of the lenses is correct and also that the lenses don't get damaged. For example, an astronomical telescope can be set up by using a long-focus convex lens (a thinner lens, which will have a longer focal length) to form an image of a bulb filament on a screen (the objective lens). A shorter focus lens is then set up on the other side of the screen, positioned so that the image on the screen can be clearly seen through it (the eyepiece lens). Then the screen is removed. A Galilean telescope uses a short-focus concave lens as the eyepiece instead of a convex lens.
- It is possible to demonstrate reflection and refraction of rays using a high intensity light source and a smoke filled box. Details are given at www.practicalphysics.org▸Optics▸ Real and virtual images in a smoke box.

- It may be possible to show various pieces of optical equipment so that students can see the lenses and/or mirrors that are in use. Equipment might include a microscope, a telescope or binoculars.
  - It may be possible to set up a manual focus 35mm camera (or even better, a medium or large format camera) with the shutter locked open, the back open, and a piece of translucent paper (greaseproof can be used) taped across the back. This will produce an inverted image on the paper.
- There are various ways of showing how the human eye forms an image. One is to fill a very large round-bottomed flask with water tinted with fluorescein and to shine a powerful light source with diverging rays at the side. A convex lens is attached to the front of the 'eye' and the resulting effect is that the rays are seen to converge on the inside of the back of the 'eye', corresponding to the retina. See www.practicalphysics.org▸Optics▸The eye.
- An ICT package such as Crocodile Physics allows for the demonstration of some core ideas.

Opportunities for How Science Works

Practical and enquiry skills

2 Students should be taught to work accurately and safely, individually and with others, when collecting first-hand data.

Communication skills

3 Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Centre-marked assessment opportunities

Students can gather data from work with lenses to investigate the relationship between the position of the object and the nature of the image and relate this, through the use of ray diagrams, to ideas about the behaviour of light rays.

Resources

- A good enrichment activity for this topic is to make links with astronomy. The local astronomical society may be able to offer students opportunities to examine telescopes to see how light gathering and focusing happens in practice. A practical observational session would be an added bonus.
- The comments also apply to microscopy: a local club may be able to offer some insights and may well enhance other parts of the science course as well.
- Molecular expressions (optics): www.micro.magnet.fsu.edu/optics/index.html This website covers topics related to light, optics and colour. There is a student site with a variety of excellent interactive activities, instructions and worksheets. There is also a teacher's site that provides further resources and ideas.
- Optics bench applet: www.hazelwood.k12.mo.us/~grichert/sciweb/bench.htm This site provides an excellent animation of an optical bench that is very easy to use. Using this animation you can start by showing what lenses and mirrors do and progress through to telescopes. You need to try this animation to appreciate it. There are four separate activity worksheets ranging from an introduction to using the optics bench, to detailed work on lenses and plane and curved mirrors.
- Further ideas, including some rather unconventional ones, on using pinhole photography can be found at http://pinholephotography.org/
- www.giantcamera.com is a website dedicated to the camera obscura in San Francisco, which is an application of the same principle.

Atomic physics: Radioactive decay

Subject knowledge and challenging concepts

- Radioactive emissions are ionising, in other words they have the potential to turn other atoms into ions, which may represent a hazard to life.
- Some stable elements have unstable isotopes. The unstable isotope is identical to the stable isotope in every way, except that it has a different number of neutrons (difficult to detect as they are uncharged) in the nucleus of the atom. This affects its mass and makes it unstable. For example, Carbon 12 is stable but Carbon 14, which has two additional neutrons in its nucleus, is unstable and will decay. As it decays its level of activity decreases, so by measuring the level of activity, the age of the sample can be calculated. It is impossible to predict when a particular atom will decay; it is a random process. However, a particular sample of a radioactive element will become less active as time goes by, as there will be fewer atoms left that haven't decayed.
- Unstable elements will decay into other elements with the emission of alpha particles, beta particles, or gamma rays. The new element formed may or may not be radioactive, depending upon what the previous element was. If it is radioactive, it too will decay, so there may be a whole sequence. This is explained in more detail at www.practicalphysics.org ▸ Atoms and nuclei ▸ Developing a model of the atom.
- The decay of Carbon 14 can be represented by a nuclear equation:

  $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

  This is beta decay and it can be seen that the products are nitrogen (same number of nucleons but one more proton) and an electron.
- Radioactivity can be measured by count rate. This is the number of radioactive emissions in a set period of time and is measured using a Geiger-Müller (G-M) tube. The time taken for the count rate to halve is the half-life and for a particular element this is a constant, irrespective of the mass of the element or how long it has been decaying for. If, for example, the half-life of an element is 14.2 days, its level of radioactivity will always halve in that amount of time.
- This constant rate of decay can be used in calculating the age of certain artefacts. All living material contains carbon, and as the half-life of Carbon 14 is just over 5700 years, this is very useful for determining the age of artefacts from, for example, early human settlements. As different radioactive elements have significantly different half-lives, some are useful in dating rocks and determining the age of the Earth and the solar system, whilst having quite different uses. For example:

Table 1. Half-lives of some typical radioisotopes

Radioisotope	Half-life
Polonium-215	0.0018 seconds
Bismuth-212	60.5 seconds
Sodium-24	15 hours
Iodine-131	8.07 days
Cobalt-60	5.26 years
Radium-226	1600 years
Uranium-238	4.5 billion years

- When an atom decays it will emit one of the following:
  - an alpha particle, which consists of two protons and two neutrons and is therefore a helium nucleus. This is comparatively massive; although its range is restricted, it is strongly ionising
  - a beta particle, which is an electron. Its mass is around 8000 times less than an alpha particle; it is more penetrating but less ionising

  - a gamma ray, which has no mass but is electromagnetic radiation, like light and infrared, but with a very short wavelength. It is more penetrating but less ionising than the particles described
  - a positron, which is an electron with a positive charge. It is the antiparticle for an electron, and if they collide, each wipes the other out
  - a neutron, which has no charge and a mass slightly greater than a proton.

- A G-M tube detects radioactive decay as the emission causes ionisation in the tube. Each count represents one atom that has decayed.

- It is possible to plot a graph showing the number of neutrons against the number of protons for stable elements. From this it can be seen that isotopes not lying on this curve are unstable and will decay.
  - Nuclei with more than 82 protons usually undergo alpha decay, which involves releasing a helium nucleus. Its loss reduces the mass number by four and the atomic number by two.
  - Isotopes above the curve will emit beta radiation: one of the neutrons has split into a proton and an electron, and the electron has been released. The mass number will be the same, but the atomic number will have been increased by one due to the additional proton.
  - Isotopes below the curve will emit beta+ radiation: one of the protons has split into a neutron and a positron, and the positron has been released. The mass number will be the same, but the atomic number will have been decreased by one due to the lost proton.
  - Either kind of beta decay often results in a rearrangement of the nuclei with the loss of energy as gamma radiation. There is no change to the mass or atomic numbers.

Teaching model examples

e(i)

1. The teacher carries out demonstrations to show various aspects of radioactive decay, such as ionisation, penetration and the various types of emission.
2. The students then draw together these ideas to produce an overall picture of radioactive decay.
3. They then apply this to explain various applications, such as the use of radioactive tracers in medical work.

e(d)

1. The teacher explains the theory of radioactive decay and the nature of the various types of radioactive emissions.
2. The teacher then demonstrates the penetrating properties of the various sources.
3. The students then have to apply their understanding of alpha, beta and gamma emissions to the results to try to work out what kind of emissions are coming from which source.

dit

1. The teacher demonstrates various aspects of radioactive decay and constructs a set of ideas.
2. The teacher then applies these ideas to various applications, such as the irradiation of food, and explains how the ideas can explain the situation.
3. The students then apply this approach to other contexts and learn how to develop explanations.
4. The students and the teacher summarise the key points of the learning that has taken place.

Examples of investigations and demonstrations

- Students below the age of 16 are not allowed to handle radioactive sources, so any work at Key stage 4 is therefore likely to be demonstration based. It is nevertheless important that students do see and discuss the nature of radioactive materials: the insights granted to medical staff by the use of tracers are based on the same principles as the fallout from an accident at a nuclear power station. Obviously there are implications for departmental management. The definitive guide is the CLEAPSS Guide L93 *Managing ionising radiations and radioactive substances*, which can be downloaded from www.cleapss.org.uk/download/L93.pdf It is also on the CLEAPSS CD-ROM and is being revised in 2008.
- The principle of radioactive decay can be explained using a large number of dice, say 50. The dice are rolled; the 'sixes' are counted, recorded and removed before the remaining dice are thrown again. This is repeated until only a handful remains. This can provide ideas and evidence to enable students to answer questions such as:
  - What is the general pattern of the results?
  - If there is one throw per minute, what would the half-life be?
  - If a group were to repeat the experiment, would the new results look like the old ones?
  - How does one group's results compare with another group's?
  - What are the similarities and differences between the dice and radioactive decay?
- The spark counter is a simple demonstration of the ionising properties of radioactive emissions. The spark counter apparatus consists of a metal gauze with a parallel wire; a large potential difference is placed across them. A cup source is held near; the radioactive emissions ionise atoms in the air, resulting in a conducting path, and sparks are seen. If the lights are dimmed the effect is quite striking. Care needs to be taken due to the high voltage (note that the gauze is earthed and the safety resistor in the circuit). Question students here about what is happening and why. Details are at www.practicalphysics.org▸Atoms and nuclei▸The spark counter
- A standard demonstration is that of using various cup sources, a G-M counter and various barriers to show the relative penetration of the three types of emission. Each barrier in turn is placed between the source and the detector and the count rate measured. This can be correlated with the type of source (alpha, beta, or gamma) from elements such as americium, strontium and cobalt. Details are at www.practicalphysics.org▸Atoms and nuclei▸Identifying the three types of ionising radiation.
- A protactinium generator can be used to produce data to enable students to plot a decay curve and estimate the half-life of protactinium. Details are in CLEAPSS Guide L93. Some schools have commercially produced protactinium generators, which are simply inverted to start the process. The G-M tube is held close and the reading taken every, say, 10s. Other schools have constructed generators using uranyl nitrate, concentrated hydrochloric acid and iso-butyl methyl ketone or amyl acetate. As long as they are constructed, used, maintained and stored in accordance with guidelines they are a useful resource. Students can then plot the data to show the number of emissions in each time period and plot these points. A smooth curve of best fit can be drawn and from this the half-life calculated by seeing how long it took for the activity to drop from any level to half that level. Details are at www.practicalphysics.org▸Atoms and nuclei▸Measuring the half-life of protactinium.

- The concept of radioactive decay has very real implications for the use of radioactive materials. It means, among other things, that some waste products will remain hazardous for very long periods of time. This represents both technical and moral challenges.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Practical and enquiry skills

2 Students should be taught to collect data from primary or secondary sources, including using ICT sources and tools.

Applications and implications of science

3 Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Centre-marked assessment opportunities

- The protactinium generator or penetration demonstrations yield data that can be analysed and evaluated.

Resources

- BNFL (British Nuclear Fuels Ltd) www.bnfleducation.com/index.html and British Energy www.british-energy.com/pagetemplate.php?pid=84 both produce educational resources that are worth reviewing, particularly with respect to how decay occurs. They obviously have an interest in presenting radioactive materials as being manageable.
- Other perspectives on the use of radioactive materials are represented by pressure groups such as Greenpeace www.greenpeace.org.uk/ and Friends of the Earth www.foe.co.uk/
- *Medical physics: exploring, treating, understanding*. Cook and Gibson

  This is a free pack, produced by the Institute of Physics and Engineering in Medicine and EPSRC. It includes a textbook, teacher's notes, posters and CD-ROM. There are three lessons aimed at GCSE including: the electromagnetic spectrum, radioactivity and ultrasound. The lessons have a PowerPoint presentation for your use. The material is linked to the website www.teachingmedicalphysics.org.uk This resource can be used for the extension topics that include medical physics, but the examples are also exciting ones to use to illustrate a number of physics concepts. Available from the Institute of Physics www.teachingmedicalphysics.org.uk

- *Radiation and the environment*. Boohan, Coppard and Hollamby

  The focus is on a scientific understanding of the effects of radioactivity and microwave radiation, and on interpreting media reporting and people's attitudes to the issues. In the activities, students can analyse data and research for information. Groupwork, discussion and display are all used. Available from the Science Enhancement Programme www.sep.org.uk

Atomic physics: Fission and fusion

Subject knowledge and challenging concepts

- In order to understand both fission and fusion, students need to have an understanding of atomic structure.
- Fission is when the nucleus of an atom splits (fissures) into parts. This may happen because the nucleus is unstable or it may happen because the nucleus has been struck by a sub-atomic particle. Uranium 238 and Plutonium 239, for example, are both capable of spontaneous fission but fission can be induced if they are hit by neutrons. The resulting particles may subsequently strike other nuclei, causing them to fissure. This is a chain reaction. If it is uncontrolled, it may cause other fissures to take place at an increasing rate.
- Nuclear weapons cause destruction by causing uncontrolled chain reactions from induced fission; this releases large amounts of energy.
- Nuclear reactors involve the release of energy from controlled chain reactions. This control comes from moderator materials absorbing some of the sub-atomic particles and thus limiting the rate at which fission takes place.
- Fission results in the release of a wide range of unstable neutron-rich products with a wide range of half-lives.
- Fusion is when smaller atomic particles such as hydrogen and helium are combined to produce larger, heavier ones. The conditions for this are extremely high temperature (millions of °C) and pressure. Energy is released. Nuclear fusion takes place in the Sun and other stars and it is the release of energy that causes, amongst other things, the emission of light.
- Producing the necessary conditions for fusion has been extremely difficult on Earth. However, one of the reactants, deuterium, has been found in the oceans in large quantities. The reaction this is used for is:

$^{2}_{1}H + ^{3}_{1}H = ^{4}_{2}He + ^{1}_{0}n$

Teaching model examples

1. The teacher explains what is meant by nuclear fission and how this might take place in, for example, Uranium 235, using diagrams and computer-generated images.
2. The students then apply this approach to various situations to strengthen their understanding of it.
3. Students identify key features of the process to summarise and consolidate their learning, by, for example, producing a concept map or flow diagram, for which they have had to discuss and process the ideas from earlier.

Examples of investigations and demonstrations

- For obvious reasons, this is not a common feature. However, students may be able to devise models that demonstrate principles of nuclear processes.

Additional classroom activities

- Computer simulations of fission and fusion.
- The SoHo satellite project has been tremendously successful at gathering data and images from the Sun, and these can be used to illustrate teaching points being made about processes going on in the Sun. See http://sohowww.nascom.nasa.gov/home.html
- The website http://sohowww.nascom.nasa.gov/classroom/for_students.html also has ideas for activities for students based on interpreting evidence provided, including ‘Tracking sunspots’, ‘Measuring coronal mass ejections’ and ‘Matching magnetic activity and active regions’.
- Producing a PowerPoint demonstration that explains the processes.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Communication skills

2 Students should be taught to present information, develop an argument and draw a conclusion, using scientific, technical and mathematical language, conventions and symbols and ICT tools.

Applications and implications of science

4 Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Centre-marked assessment opportunities

- As fission is the process in nuclear reactors, this topic may act as a starting point for informing discussion, debate, and written work on the desirability of nuclear power.

Resources

- There are various teaching resources available from organisations such as British Nuclear Fuels that explain about fission and fusion. See www.bnfleducation.com/index.html
- British Energy operates the UK's eight most modern nuclear power stations. See www.british-energy.com/index.php It produces various teaching materials including 'The Power Game'. Visit www.british-energy.com/powergame.php?pid=207
- It may be possible to arrange a visit to a nuclear power station.

Atomic physics: Thermionic emission

Subject knowledge and challenging concepts

- Thermionic emission involves the production of a stream of electrons from a heated cathode. It is an important concept because it demonstrates a number of characteristics of the electron and this understanding is fundamental to atomic and nuclear physics.
- A filament in an evacuated tube is negatively charged (so it has a surplus of electrons) and heated (so that the electrons are in an excited state). An anode in another part of the tube has a large positive voltage on it. As a result, a stream of electrons will travel through the tube from the cathode to the anode. This is a cathode ray and the effect is thermionic emission. This ray is a flow of current: the current flow is proportional to the rate of electron flow down the tube. As the electrons are travelling they have kinetic energy and this is proportional to their charge and to the accelerating voltage. This can be written as $KE = e \times V$ and used in calculations.
- The 'Maltese cross' tube uses a cylindrical anode to produce a broad stream of electrons, which then travel towards a (positively charged) Maltese cross. Some hit that, but others miss and strike a fluorescent screen on the end of the tube. The image of the Maltese cross on the screen has sharp edges and is deflected by a magnet. This shows that:
  - cathode rays travel in straight lines
  - cathode rays are affected by magnetic fields.

- The deflection tube also produces a cathode ray, but the fluorescent screen is set inside the tube and at an angle to the ray. The screen has metal plates at the top and bottom, which can be charged. There is also a pair of coils that are placed either side of the tube; passing a current through these produces a magnetic field. The cathode ray appears on the screen as a horizontal straight line. When opposite charges are applied to the plates or a current passed through the coils, the ray is deflected. This shows that:
  - cathode rays are attracted by positive charges and repelled by negative charges
  - cathode rays are deflected by magnetic fields
  - this technology is useful as it can be used to control the direction of inkjet particles if they are charged.
- The cathode ray oscilloscope (CRO) uses the principles established so far to control a cathode ray travelling down a tube and striking a fluorescent screen, thus causing a dot to appear on the screen. Pairs of metal plates are positioned above and below the tube, and also on either side. Thus it is possible to direct the spot anywhere on the screen.
- The CRO has a facility called a 'time base', which sends the spot from left to right across the screen at a variable rate. At a lesser rate the spot can be seen to traverse the screen, but as it is increased it is seen as a line. Students may be familiar with similar images from TV programmes in which heart monitoring equipment is used. Conventional (ie cathode ray tube (CRT), not flat screen) televisions and computer monitors use the same technology. In a television, the picture is built up from 625 lines, each formed by a cathode ray scanning the screen.
- Another use of cathode rays is to produce x-rays. An x-ray tube involves cathode rays being fired at a metal object. The angle of the object means that the x-rays produced by the impacts are released through the side of the tube. The rest of the tube is well shielded as this ionising radiation is hazardous.

Teaching model examples

e(i)

1 The teacher running a succession of demonstrations using CRTs and the class building up certain pieces of information about electrons.

2 The group drawing together a summary of their learning.

3 The group then suggesting how those ideas could be used to carry out a useful task, such as to produce an image on a TV screen.

um

1 The students are presented with a summary of the key points about the characteristics of electrons.

2 They then have to explain, in each of the demonstrations, how these points are observed and how the observations are consistent with the theory.

3 Students then have to decide whether the model is an effective one and can explain each of the observations.

dit

1 The teacher runs a demonstration of, say, the Maltese cross tube, and explains what the key points are. This is then repeated with the deflection tube, and so on. The teacher produces a summary of the key points about electrons.

2 The teacher then applies these ideas to an application such as a heart monitor trace and shows how an understanding of cathode rays has enabled them to be used.

3 The class then apply the idea to another application, such as a CRT computer monitor.

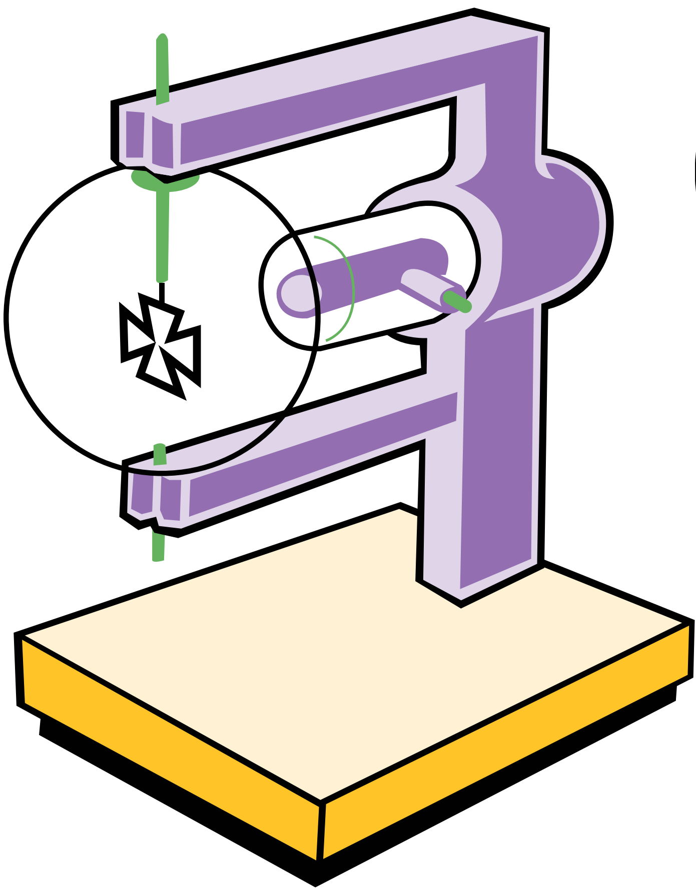
Examples of investigations and demonstrations

- There are a number of CRTs that are important demonstrations to conduct. The tubes need care in handling and in wiring up, not least due to the high voltages involved. It is essential that their use is practised beforehand and that the wiring for each demonstration is checked and tested. The room needs to be dim (not blacked out).

  Details of the demonstration are given at www.practicalphysics.org▸Atoms and nuclei▸Maltese cross: casting shadows.

- The Maltese cross tube needs to be operated to show that:
  - the light from the filament itself causes an image of the cross – this is not the one we are interested in
  - the image from the cathode rays is caused by the anodes attracting electrons from the cathode
  - the image has sharp edges, indicating straight line paths away from the electrodes
  - the image is distorted by a magnetic field.

Figure 8. The Maltese cross tube

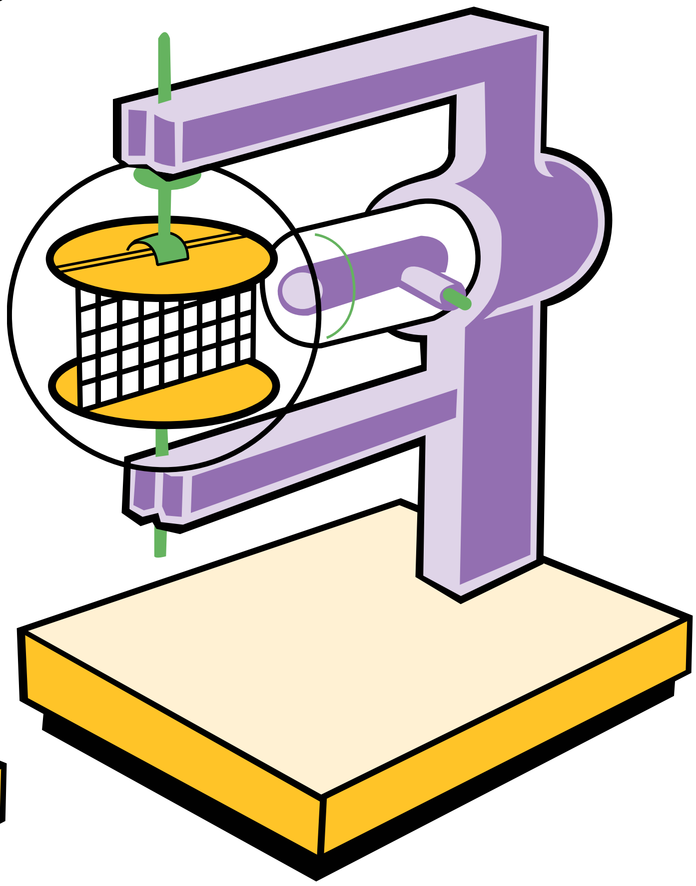


Details of the demonstration are given at www.practicalphysics.org▸Atoms and nuclei▸Electron Beams. Several demonstrations using the deflection tube are shown here.

- The deflection tube needs to be operated to show that:
  - electrons are attracted by a positive charge and repelled by a negative charge
  - the cathode ray can also be deflected by a magnetic field and that reversing the field reverses the deflection.

- A CRO can be used to show how it has a dot on a screen made by a cathode ray and that the dot can be made to move, either by altering the settings or by providing some external input. In either case, it is by deflecting the stream of electrons. Details are at www.practicalphysics.org▸Electric circuits and fields▸Using a CRO to show different waveforms.

Figure 9. The deflection tube



Additional classroom activities

- Drawing a concept map showing the various pieces of evidence about electrons and where they came from.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Communication skills

3 Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Applications and implications of science

4 Students should be taught how uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

Resources

- CERN is the European Organisation for Nuclear Research, the world's largest particle physics centre. It sits astride the Franco-Swiss border near Geneva. CERN is a laboratory where scientists unite to study the building blocks of matter and the forces that hold them together. CERN exists primarily to provide them with the necessary tools. These are accelerators, which accelerate particles to almost the speed of light, and detectors to make the particles visible. http://public.web.cern.ch/Public/Content/Chapters/Education/Education-en.html

Space: Lifecycles of stars

Subject knowledge and challenging concepts

- Our Sun is a star, one of billions in our galaxy, the Milky Way. This is one of billions of galaxies in the universe. The Sun is a main sequence star, which is to say that it is a star with a mass typical of many other stars. Stars go through a lifecycle with distinct phases. There are different lifescycles, according to the mass of the star. In the night sky the observer sees different stars at different stages of the lifecycle and stars on different lifecycles.
- The Sun uses hydrogen to make helium by the process of nuclear fusion. This process only occurs at extremely high temperatures and pressures, but releases huge amounts of energy. These reach us in various forms, including infrared, visible light and ultraviolet.
- Stars are formed when gas and dust gather together. As each particle has its own gravitational attraction, each will attract the other and as the mass increases so does gravity. If it gets to the temperature required for fusion to occur it has become a star. There is a balance of forces between the radiation pressure and gravity. Areas in space where this happens are called stellar nebulae. If the mass reached is insufficient for fusion there may still be sufficient mass for it to form a planet and be caught in an orbit around a star.
- A main sequence star starts off as a yellow dwarf, as our Sun is now. When no more hydrogen is left to be used in fusion, the star cools, expands and becomes a red giant. It then contracts to become an incredibly dense white dwarf and cools first to a red and then a black dwarf.
- However, if the initial mass is considerably larger then a different sequence of stages is followed. A much more massive star becomes a blue supergiant, such as Rigel, in the 'left foot' of Orion, and then a red supergiant, such as Betelgeuse, also in Orion. This is followed by exploding into a supernova and then collapsing to form a neutron star, unless it is extremely massive, in which case it will become a black hole.

- In the very early days of the universe there was a predominance of hydrogen and little else. However, the fusion processes in stars have produced a large variety of different elements. Stellar fusion reactions are the only way that these other elements are formed.

Teaching model examples

e(i)

1 Students have images of stars at various stages in the main sequence and various pieces of information about fusion of elements, to assemble an overall sequence.
2 Also have information about the position of the solar system within the galaxy and the galaxy within the universe.
3 Students present an overall summary of our place, our past and our future in the universe.

cm

1 Students are asked to work in small groups and produce ideas, as text or diagrams on a poster, to answer various leading questions such as:
- What is happening in the Sun to release energy?
- Will the Sun continue in its current form?
- How does our solar system feature in the universe overall?

2 The teacher sees from the ideas being drawn together the level and detail of understanding and organises various learning activities to address this. These might be video clips, direct explanations, computer animations, or text.
3 Students then identify how their view needs to change to accommodate these new ideas.
4 An overall view is then drawn together and shared.

dit

1 The teacher explains how evidence has been used to draw conclusions about our position in the universe and the lifecycle of stars.
2 The teacher uses this to tell the story of the history and future of our Sun.
3 Students then apply these ideas to other stars to suggest what their future will be.
4 Key learning points are drawn together in the plenary.

Additional classroom activities

- One of the aspects of this topic that students sometimes fight difficulty is the correct sequencing of the stages. A good learning activity is for students to have a set of cards, some with pictures of the various stages and some with captions for the pictures. The students' task is to correctly match and sequence the cards.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Communication skills

3 Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Applications and implications of science

4 Students should be taught how uncertainties in scientific knowledge and scientific ideas change over time and about the role of the scientific community in validating these changes.

Resources

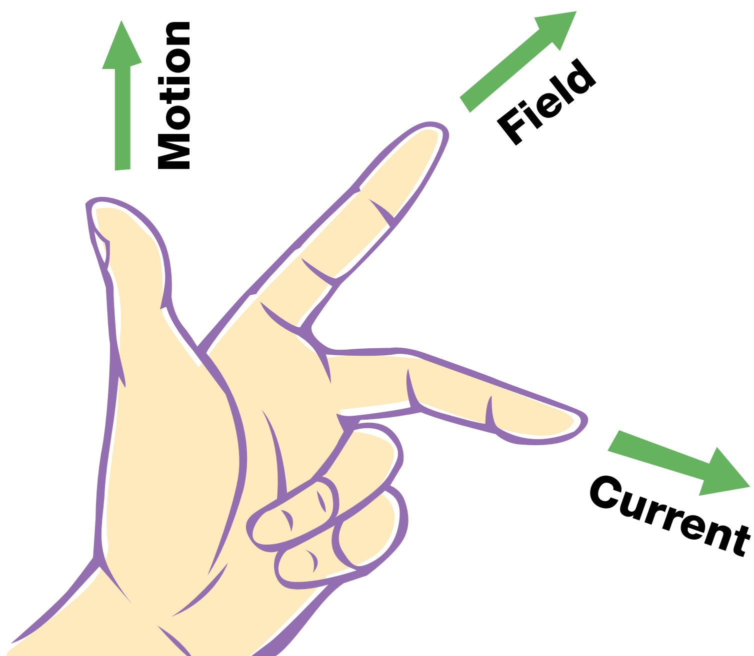
- The SoHo satellite project has gathered data and images from the Sun and these can be used to illustrate teaching points including images and animations. http://sohowww.nascom.nasa.gov/home.html
- The website http://sohowww.nascom.nasa.gov/classroom/for_students.html also has ideas for activities for students based on interpreting evidence provided, including 'Tracking sunspots', 'Measuring coronal mass ejections' and 'Matching magnetic activity and active regions'.
- Celestia: www.shatters.net/celestia Celestia provides a virtual chunk of the galaxy. It needs a powerful computer to do the software justice. This is a real-time space simulation that lets you experience the universe in three dimensions. One can fly through the solar system or to the edge of the Milky Way, or beyond our galaxy.
- Maris Technologies: www.maris.com/content/applets The site contains animations demonstrating the company's expertise, and as such is not accompanied by any explanatory material. There are 10 applets on the topics of: Hubble constant, Sunrise with seasons, Falling bodies, Parallax in space, The seasons and the Earth's orbit, Cepheid variables, Sunspot activity, Magnetic field and planet core, Star lifetime and the Hertsprung Russell diagram. Animations on these topics are not easily available elsewhere.
- Mystarslive.com: www.mystarslive.com This is an interactive star chart that can be set for major cities in countries all over the world. If one specifies the time, date and direction of view, a chart is produced showing the star map for that location with moon and planets identified as well.
- The NASA website has a range of materials available for teachers and students. A useful index of these is at: www.nasa.gov/audience/foreducators/topnav/materials/listbysubject/index.html

Electricity: Electric motors and electromagnetic induction, including generators and transformers

Subject knowledge and challenging concepts

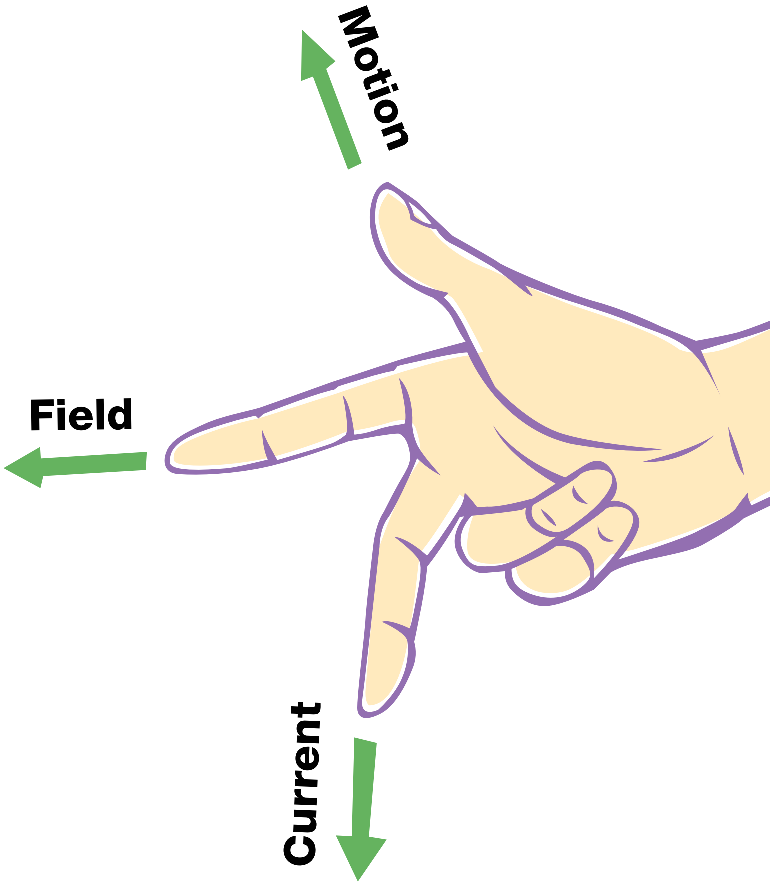
- Motors work because of the interrelationship between the flow of current, magnetic field lines and motion. Current flowing along a wire will produce a magnetic field. The shape of the magnetic field will depend upon the shape of the wire; magnetic fields can attract or repel, depending on their polarity. The forces can be reversed by changing the direction of current flow or the polarity of the magnets.
- The direction of the force can be predicted using Fleming's left-hand rule. The thumb, forefinger and second finger of the left hand are held mutually at right angles. The 'm' in thumb represents motion, the 'f' in forefinger force and the 'c' in second finger current. See Figure 10.
- A motor uses a supply of current to produce a magnetic field, which alternately attracts and repels another magnetic field (due to permanent magnets in simple motors) in order to produce rotation. The current-carrying wire is at right angles to the magnetic field and so experiences a force. It is therefore transferring energy from the electrical supply to movement.

Figure 10. Fleming's left-hand rule



- The current supplied flows around a coil of wire, which is then attracted by the permanent magnets. As the coil is free to rotate it will turn. The coil is connected to the power supply via an arrangement of contacts called the split ring commutator. This reverses the connections every half turn so that the repeated attraction and repulsion causes the coil to rotate. Electric motors have a wide variety of applications, including dishwashers, fans, car starter motors and CD players.
- The motor can be made more powerful by:
  - making a larger current flow in the coil
  - putting more turns on the coil
  - having a stronger magnetic field.
- Commercial motors have curved magnetic poles, which produces a radial magnetic field. This results in the force on the coil being more consistent.
- A generator uses a rotating coil of wire to cut magnetic field lines, which causes a voltage. It is therefore transferring energy from the movement supplied to the electrical output. The rotation induces a voltage in the coil, which then becomes the output. The quicker the coil turns, the more turns there are on the coil; and the stronger the magnetic field, the greater the electrical output will be. The output is also greater if the area of the coil is greater. Such a generator has slip rings and brushes to connect the coil with the output terminals.
- The relationship between motion supplied, magnetic field direction and current induced is given by Fleming's right-hand rule. The thumb indicates the motion, the forefinger the field (North to South) and the second finger the current. See Figure 11.
- Generators are used to produce the mains electricity supply and also supply electricity to run various devices in a car while the engine is running.
- A generator can also be constructed from making a magnet rotate inside a coil of wire, thus producing an alternating current. It is a version of this, with an electromagnet, that is used in power stations. Altering the speed of rotation affects the voltage and frequency of the output, and altering the number of turns on the electromagnet coils affects the voltage.

Figure 11. Fleming's right-hand rule



- A transformer uses AC in a coil of wire (the primary coil) to produce a changing magnetic field. This induces a changing magnetic field in an adjacent coil (the secondary coil) to produce an alternating current. There is an iron core that runs through the centres of the two coils. The relative proportion of the voltages is determined by the relative numbers of turns on the two coils.
- The function of a transformer is to change one voltage into another. It will only function on AC (a changing flow of current is needed to produce the changing magnetic field). Transformers are a useful way of changing the mains voltage into any other voltage needed.
- If a transformer has a greater number of turns on the secondary coil, the output voltage will be increased and it is a 'step-up' transformer. If it has a greater number of turns on the primary coil, the output voltage will be reduced and it is a 'step-down' transformer.

The relationship between the turns on the coils and the input and output voltages is given by:

Number of turns on primary coil =
Primary voltage

Number of turns on secondary coil =
Secondary voltage

- The power loss in transmission lines is proportional to the square of the current. This means that the loss will be significant unless steps are taken to reduce the current. The voltage at the start of the transmission line is stepped up (thus reducing the current by the same factor) and stepped down again at the other end.
- The current is inversely proportional to the voltage – increasing the voltage reduces the current. This can be expressed as:

Primary voltage x primary current =

Secondary voltage x secondary current

- Power supply leads for devices such as games machines have transformers in them. Many other appliances such as DVD players have transformers inside to turn the supply voltage from the mains into the correct voltage. In the case of a television, (CRT – not flat screen) this means stepping the voltage up to power the tube.
- The other reason for using a transformer is to supply an AC voltage but without having a direct electrical connection. Isolating transformers have the same number of coils on the primary and secondary coils (and so have the same input and output voltages) but as such there is no electrical connection. A bathroom shaver socket is an example of such an application; it reduces the likelihood of shorting out the live lead with the earth.

Teaching model examples

e(i)

1 Students being presented with evidence, such as:

- the shape of the magnetic field pattern between opposite poles
- a current-carrying wire producing a magnetic field
- attraction and repulsion between magnetic fields.

2 The class then use these to label a diagram of a simple motor.

3 Students assembling a flow chart of ideas to explain how a motor works.

um

1 The teacher uses a diagram to explain a model of magnetic field lines being cut and thus, current being generated.

2 Students then apply this to predict and then explain the effect of moving a wire linked to a galvanometer through a magnetic field:

- across the lines of force
- parallel to the lines of force
- through a stronger field.

3 They are then challenged to apply it to a different arrangement – a bar magnet and a coil of wire, for example.

4 They then apply it to a real or diagrammatical representation of a generator.

dit

1 The teacher demonstrates how a transformer works and explains the calculations to, for example, select the turns ratio in order to step down 240V AC to 12V.

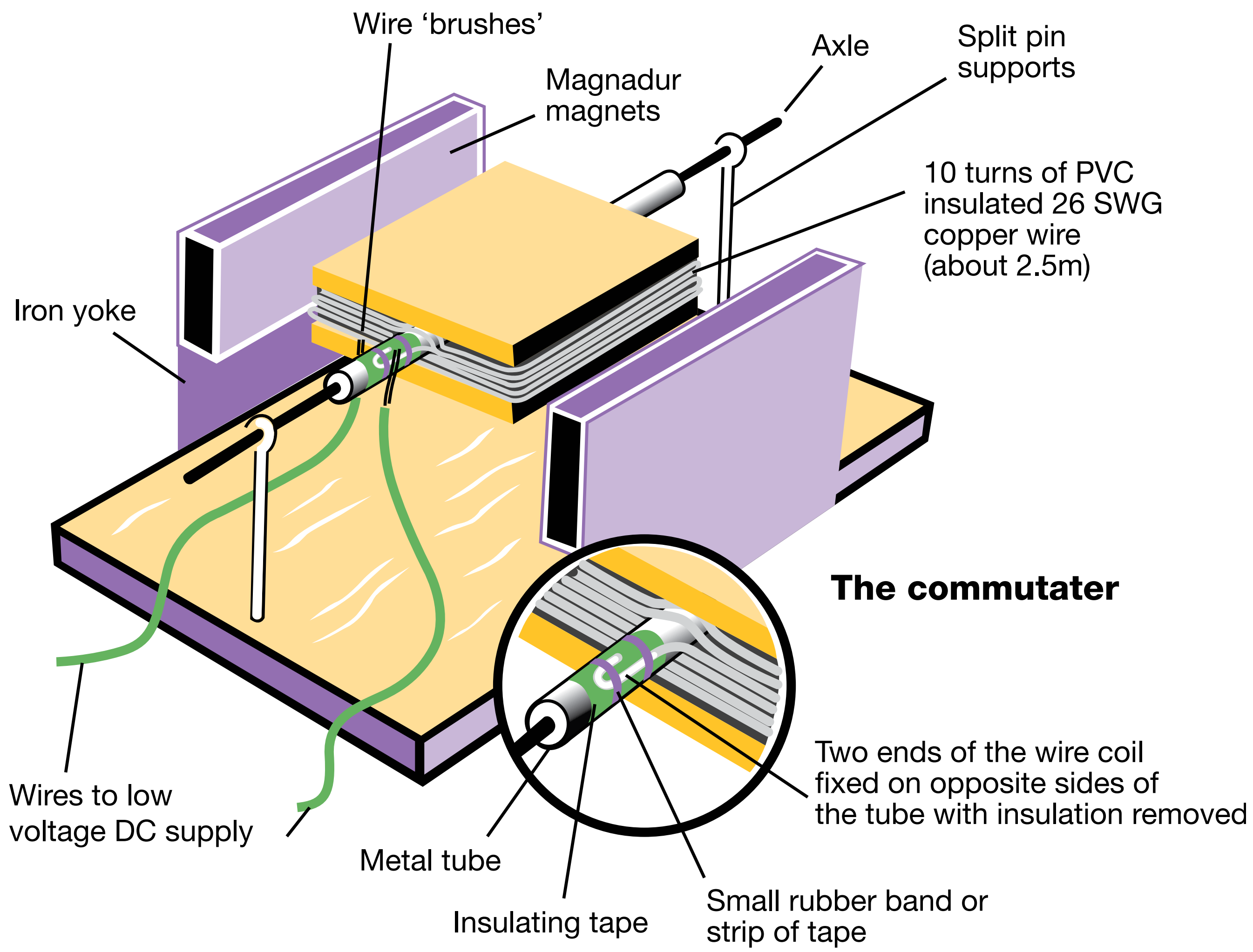
2 The students then apply the principle to another step-down situation, and then to a step-up one.

3 The class then summarise and records the learning that has taken place.

Examples of investigations and demonstrations

- The simplest demonstration of the motor effect (but quite an important one) is to connect either end of a length of wire to a power supply and place the wire between the poles of a strong horseshoe magnet. The wire should have some slack in it so that it can move. When the current is switched on the wire will twitch. This needs to be set up with care, as it involves shorting out the terminals of the power pack. It should be a brief demonstration. The power pack needs to have a reasonably high current rating and it helps if the wire is of a reasonable length.
- A variation on this demonstration is to use a low-voltage, high-current power pack. Such power packs typically have an output of one or two volts, but a higher current rating than most 12V packs. (These are useful for practical work on electromagnetism.) Attach two pieces of stout bare wire, one to each terminal, and bend them so that they are horizontal and parallel, but turned up at the end (make sure they won't come into contact with any other terminals). Lay a third piece of similar wire across these and bend the ends down. Turn the power on and bring the poles of a powerful horseshoe magnet near, with the faces of the poles parallel to the third wire, which will move quite clearly. Turn the magnet over and repeat.

Figure 12. Motor kit for students to assemble



- Some schools have motor kits for students to assemble and test. If these are of the old Nuffield design, the arrangement of the commutator is critical. They can be quite fiddly but there's a sense of achievement in having completed them. Having 'one you made earlier' that works will be helpful, and students have to get the commutator right for it to work so it will assist with their understanding.
- Details at www.practicalphysics.org ▸ Electromagnetism ▸ The electric motor.
- A moving coil loudspeaker uses the motor effect in order to produce movement from current flow. An old one, supported by appropriate diagrams, can be of assistance.
- A demountable motor kit is useful as it clearly shows the various components.
- The demountable motor kit can also be connected to a voltmeter and spun by hand to show that it produces electricity. This is the generator effect.
- The generator effect can also be shown by connecting a length of wire to the terminals of a galvanometer (sensitive ammeter) and moving the wire between the poles of a horseshoe magnet. The effect is not great, so the magnet has to be powerful and the meter sensitive, but it clearly shows that:
  - the wire has to be moved
  - it has to be moved across the field lines (moving the wire from pole to pole doesn't cut field lines and so won't generate a current)
  - moving the wire quicker generates more current.
- This also works with a coil of wire (such as from a transformer kit) connected to the galvanometer and a bar magnet moved in and out of it. Again, this demonstrates that:
  - the magnet has to keep moving in order to keep a current flowing
  - changing the direction in which the magnet moves changes the direction of current flow
  - making the magnet move quicker generates a larger current.
- A transformer kit consists of a number of coils with different numbers of turns on the coils. Mains voltage is fed into the primary and the voltage across the secondary measured. This shows very well how different voltages can be produced. Care must be taken though to ensure that the output voltage is low: it is quite reasonable to demonstrate various voltages up to 12V.

Additional classroom activities

- The topic of electromagnetic induction has some good historical stories associated with it. Michael Faraday made a number of the key breakthroughs in this area and some of the demonstrations are based on his work.

Opportunities for How Science Works

Data, evidence, theories and explanations

1 Students should be taught how explanations of many phenomena can be developed using scientific theories, models and ideas.

Communication skills

3 Students should be taught to recall, analyse, interpret, apply and question scientific information or ideas.

Applications and implications of science

4 Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Resources

- See references to ICT resources, including Multimedia Science School, Boardworks and Sunflower Learning.
- *Motors and electromagnetism*. Miriam Chaplin

  This booklet provides a source of ideas and information about motors and electromagnetism, as well as suggesting classroom activities and materials that can be used in existing schemes of work. Sections include: the motor effect; construction of motors; investigating the performance of motors; stepper motors; the dynamo effect; and student activities. Gatsby Science Enhancement Programme, www.sep.org.uk
- *Super magnets: exploring the properties and uses of rare earth magnets*. Richard Boohan

  This booklet provides a source of ideas and information about super magnets, as well as suggesting classroom activities and materials. Sections include: an introduction to super magnets and suggestions for how they could be used in teaching about magnetism; student activities including teachers' notes; student resources; the background science. At the end of the booklet there are references to useful websites, links to PowerPoint slides and Word worksheets, and information on how to obtain the practical resources. Gatsby Science Enhancement Programme, www.sep.org.uk
- *Molecular expressions: electricity and magnetism*. www.micro.magnet.fsu.edu/electromag/java/index.html

  This site contains interactive Java tutorials on a range of topics such as CDs, metal detectors, cathode ray tubes, hard drives and generators.

Electricity: Electrocardiograms

Subject knowledge and challenging concepts

- Voltage is also referred to as 'potential difference'. For example, the difference in potential between the terminals of an AA cell is 1.5V.
- Potential differences arise in nature as well as in man-made artefacts. Muscle cells in the body generate potential differences, and these can be measured and displayed. The potential difference varies according to the cell activity.
- As the heart is a specialised muscle, its activity also generates potential differences. These are known as action potentials and can be displayed on an electrocardiogram (ECG).
- Normal heart action has a very characteristic shape. Deviations from this shape are useful in terms of diagnosing problems with the action of the heart.

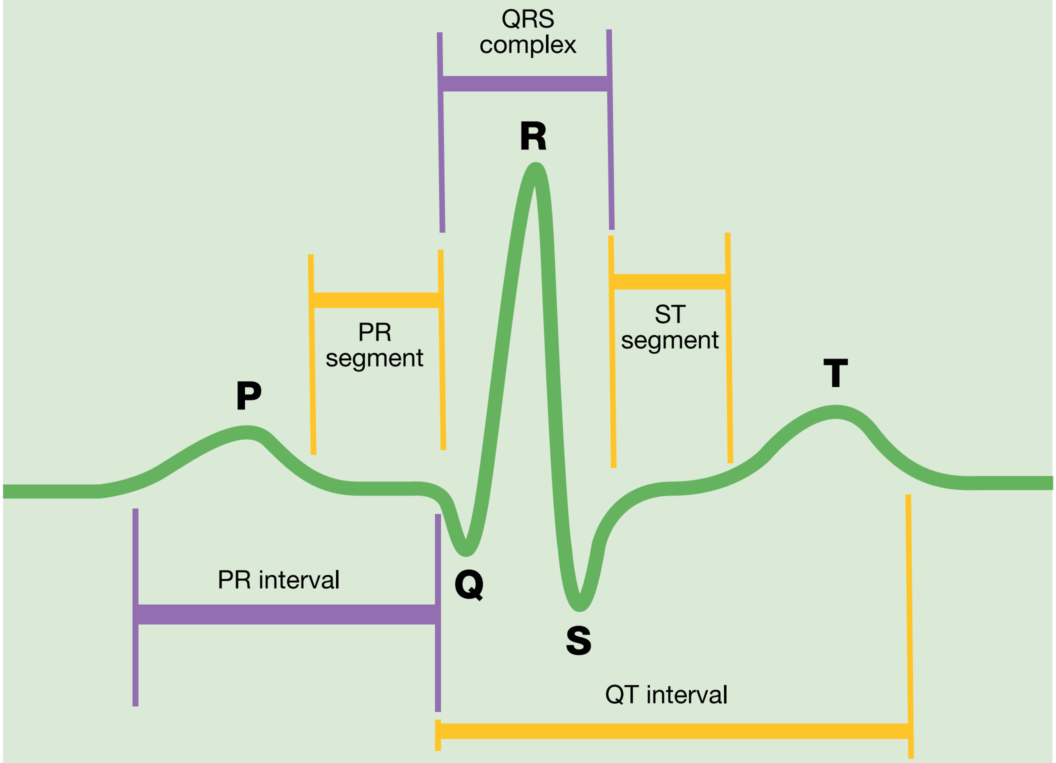
The normal ECG

A typical ECG tracing of a normal heartbeat consists of a P wave, a QRS complex and a T wave.

The P wave is the current that causes atrial contraction. Its relationship to QRS complexes determines the presence of a heart block. The QRS complex corresponds to the current that causes contraction of the left and right ventricles, which is much more forceful than that of the atria and involves more muscle mass, thus resulting in a greater ECG deflection. The duration of the QRS complex is normally less than or equal to 0.10 second.

The T wave represents the repolarisation of the ventricles. Electrically, the cardiac muscle cells are like loaded springs: a small impulse sets them off, they depolarise and contract. Setting the spring up again is repolarisation. The information here has been edited from original text from Wikipedia. For more on ECG traces and their interpretation go to http://en.wikipedia.org/wiki/ECG

Figure 13. A typical ECG trace



Teaching model examples

1. Students could be presented with, or research, various pieces of information about the working of the heart. Understanding about action potentials, they could then start to suggest what a trace might look like, with reasons.
2. They then propose what difference to the trace a situation such as a heart blockage might make.
3. Students are then shown what an actual ECG trace is like and compare it with their ideas.

1. Students are presented with an ECG trace from a healthy patient and the various features are explained.
2. They are then presented with various heart defects and asked to suggest how they would affect the ECGs.
3. ECGs from patients with heart conditions are then displayed and students study and compare them with their ideas.

1. The teacher explains how an ECG works and demonstrates how it can produce traces.
2. The teacher then models how the analysis can be applied to other traces.
3. The students then apply the analysis to other traces.
4. Key learning points are then summarised.

Examples of investigations and demonstrations

- It may be useful to have a CRO to remind students about how the time base can cause the 'spot' to traverse. If this is set to a long period and the y shift altered, students will be able to see how an input from a heart probe can be used to produce a trace.
- If the department possesses a heart monitor, it may be a useful prompt as to the role of electronic monitoring of the heart.
- A good starting point would be to show a video clip from a documentary or drama in which an ECG is used, followed by a discussion about why such equipment is useful and speculation about how it works.

Opportunities for How Science Works

Communication skills

3 Students should be taught to use both qualitative and quantitative approaches.

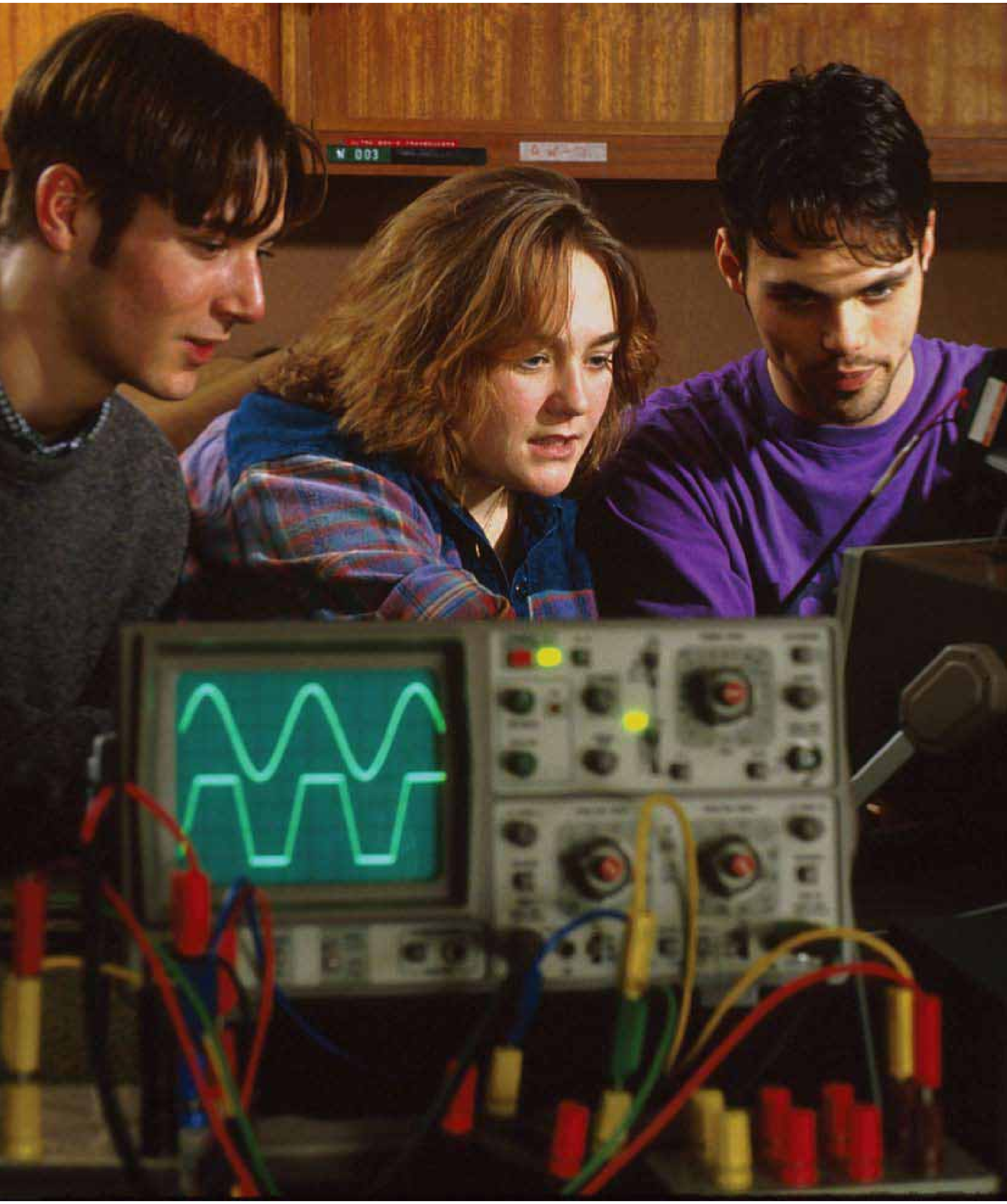
Applications and implications of science

4 Students should be taught about the use of contemporary scientific and technological developments and their benefits, drawbacks and risks.

Resources

- A Google search on 'ECG traces' should produce a good crop of images with associated diagnoses.
- *Sensors*. Butlin for the Science Enhancement Programme

This CD-ROM includes details of practical activities to give a sense of how scientists use observations of phenomena in real applications. Topics include: thermistors, LDRs, microphones, force sensors and potential dividers. The resources include teacher's notes, technical advice and student notes in PDF format as well as in editable Word document format. Science Enhancement Programme, www.sep.org.uk



Section 6
Managing a department to deliver Triple Science

For some departments, the provision and delivery of Triple Science will not be seen as a major area of development, especially if the school has a sixth form and if it has a successful track record of curriculum design and innovation. The curriculum coverage and resources may already be available and the confidence to approach this area may be strong.

However, for other departments it may be more of a challenge. They may be just as successful in terms of student attainment, but it may be that there are some aspects that cause particular issues, such as time management, funding, or staff expertise. It is also the case that the requirement for all students with level 6 or higher in Key stage 3 Science SATs to be offered Triple Science has arrived at a time when there are other significant changes in secondary science.

The desirable outcome, of course, is being able to offer an alternative curriculum pathway at Key stage 4, and one that may meet the learning needs and aspirations of a particular group of students. The pitfall, of course, is that if not delivered well it may only serve to dissuade students from studying science at A-level.

Here are some issues to consider.

Planning

As a department, consider your short-, medium- and long-term objectives for introducing Triple Science. How will these be achieved? Who will be involved, and how will you tell if you have been successful? It is important to brief all staff about the rationale behind the change and to engage everyone in identifying and overcoming challenges and concerns.

Consideration should be given both to topics and the teaching and learning strategies that will be used. Regular meetings should be scheduled throughout the year to evaluate the impact of the changes and identify issues. Information can be shared and made accessible for future reference.

Issues relating to curriculum modelling and timetabling are considered in detail in the Curriculum modelling publication.

Skills and expertise of staff

Staff delivering Triple Science need time for planning and preparation. Often the immediate concern is in terms of subject knowledge and there is seen to be a need for subject specialists. Remember that it is equally important to have the skills and tools to teach the subject effectively, which include:

- understanding key ideas from within the subject and how these are related to one another
- pedagogical content knowledge or knowing how to explain ideas and design effective learning activities
- enquiry activities, or knowing how to run demonstrations, manage experiments, and ask and answer associated questions.

There needs to be a clear view as to which of these is (or are) the significant development needs. Teachers being taught the subject knowledge in great detail by someone more knowledgeable in that subject may be no better off at the end if teaching and learning are not considered as well. It is likely to be teaching strategies and practical activities that are major stumbling blocks.

The wider team

Teaching assistants (TAs) will also need support. It may be that many of the students traditionally receiving more intensive support from a TA don't choose to do Triple Science, but some may, and students with a physical disability or at some points on the Autistic Spectrum may do so too. There are several points to make here:

- There is a good case for one or more TAs being HLTAs (higher level teaching assistants) and for support on Triple Science being part of their role. There is a greater range of concepts to address and a wider range of experiments to cover. The Training and Development Agency (TDA) for Schools is currently running support programmes for HLTAs. For further details, contact your local authority HLTA officer or go to the TDA website at www.tda.gov.uk/support/hlta.aspx
- As some schools have Triple Science as a well-established and successful course, there may be scope from TAs from one school to visit another school to see how support is best managed. This needs setting up carefully to ensure that there is good practice to be seen in the host school.
- Some schools have made tremendous progress in publishing, often on the school's intranet, schemes of work. This is a huge help, especially when joint planning time may be limited.
- Lab technicians may well find themselves faced with preparing experiments and demonstrations with which they are not familiar. The second and third points above apply equally to lab technicians. It is also important to ensure that technicians have immediate and direct access to the current version of the CLEAPSS health and safety CD-ROM and to the internet. There are some highly effective e-mail networks that some technicians use and these can be very useful in the exchange of ideas. Go to www.biology4all.com/scitech.asp

Continuing professional development (CPD)

Support from within the department

CPD needs arising from the introduction of Triple Science need to be identified and addressed, and this should be considered in the context of the TDA's Professional Standards and performance management framework (www.tda.gov.uk/teachers/professionalstandards).

There may well be a need for identifying off-site CPD opportunities, for planning CPD activities with a team of staff and for building in planning and evaluation time. This needs to be done realistically and invoking senior leadership team (SLT) support. School managers may well not be able to give everything they've been asked for, but it shouldn't be assumed that they can't give anything.

There are likely to be CPD opportunities within the department and school. This may mean working with another teacher to develop subject knowledge or observing lessons in your own subject or another. Explore new practical activities using a circus of experiments for both teachers and technicians to gain confidence, understand the key ideas and discuss concepts that will be difficult to teach. It may also be possible to arrange visits to other schools where Triple Science has been established.

It is worthwhile approaching CPD managers at school, local network, local authority and Science Learning Centre level to see what is available. The Specialist Schools and Academies Trust and the Secondary National Strategy also offer a range of support, guidance and advice.

One of the most valuable outcomes of CPD is informal networking. The Triple Science Support Programme will provide training and consultancy for targeted schools, as well as networks, resource packs and an online community. Look out for meetings, events and conferences offered by the Association of Science Education, the Institute of Physics and the awarding bodies.

Specific CPD programmes to develop subject knowledge and pedagogy are being piloted by the TDA. See www.tda.gov.uk/teachers/continuingprofessionaldevelopment/science_cpd

Resources

The additional content may not always require additional equipment, and there is an opportunity to revisit and update some of the experiments already in the department's schemes of work.

There will, however, need to be some clear advance planning with respect to equipment and consumables.

- Again, it is important that the SLT are kept informed so that they have the opportunity to offer support where possible.
- It may be that there are opportunities to share or loan some pieces of equipment, for example, cathode ray tubes and linear air tracks. Be careful with radioactive sources, however, as there are forms to check, complete and lodge if sources are moved from one site to another (CLEAPSS L93 gives guidance on this).
- With resources it is important that the course doesn't become a succession of teachers' 'show and tell', with a heavy emphasis upon demonstration and fewer opportunities for students to consolidate learning. Resources provision needs to include materials that teachers can use with students to encourage speaking and listening, as well as the effective exploration of ideas.
- Consider new ways to incorporate internet resources. For example, the use of video clips is becoming widespread with the growth of web 2.0 and the provision of video projectors. Sites such as YouTube, blinkx.com and Planet Sci-Cast have meant that the ICT-confident teacher can now use a wide range of clips as stimulus material for discussions.

Detailed advice and equipment lists can be found on the CLEAPPS and the Practical Physics websites, and support may be found through schools already offering Triple Science.

Health and safety

If Triple Science is a new development for a department it is likely that there will be practical activities being undertaken that are less familiar to teachers and lab technicians. It is therefore particularly important that the safety considerations are taken into account. In many cases, teachers and technicians will be drawing upon guidance included in published schemes of work. Often this is clear and well founded. CLEAPSS is regularly consulted by publishers. However, consultation doesn't always happen and it shouldn't be assumed; there have been a crop of issues as new practical and demonstration activities are proposed. CLEAPSS guidance on these is combined in one publication but is being repeatedly updated. It can be downloaded from the website (www.cleapss.org.uk) as PS67 – *Practical activities in the new science GCSEs*.

Section 7
Resources

For full details of these publications and more, please refer to the LSN publication *Resources for your Triple Science courses: GCSEs in biology, chemistry and physics*.

Textbooks (general)

Longman GCSE Physics
Pearson Longman
www.longman.co.uk

New GCSE Physics for you
Nelson Thornes
www.nelsonthornes.co.uk

GCSE Physics
Hodder Murray
www.hoddereducation.co.uk

Textbooks (specification based)

AQA

AQA GCSE Physics: student's book
Hodder Murray
www.hoddereducation.co.uk

AQA Science GCSE Physics, teacher's book and student book
Nelson Thornes
www.nelsonthornes.co.uk

Science Foundations: Physics
Cambridge University Press
www.cambridge.org

Science uncovered: AQA Physics for GCSE student book
Heinemann Educational
www.harcourt.co.uk

Longman Science for AQA: students' book with activebook
Pearson Longman
www.longman.co.uk

Edexcel

Edexcel GCSE Science
Hodder Murray
www.hoddereducation.co.uk

Edexcel 360Science: student's book with activebook
Pearson Longman
www.longman.co.uk

OCR

Twenty First Century Science

Oxford Twenty First Century Science series, GCSE Physics textbook
University of York Science Education Group and Nuffield Curriculum Centre
Oxford University Press
www.OxfordSecondary.co.uk

Twenty First Century Science: students' book with activebook
Pearson Longman
www.longman.co.uk

Gateway

Gateway Science: OCR Physics for GCSE, student book, revision guide
Heinemann Educational
www.harcourt.co.uk

Gateway Science for OCR
Cambridge University Press
www.cambridge.org

Gateway Science Biology, Chemistry and Physics
Collins Educational
www.collinseducation.com

Revision guides

AQA Physics revision guide and workbook
Lonsdale
www.lonsdalesrg.co.uk

AQA Science GCSE Physics: revision guide
Nelson Thornes
www.nelsonthornes.co.uk

GCSE Physics: the revision guide, workbook
Coordination Group Publications
www.cgpbooks.co.uk

Physics revision guide
Heinemann Educational
www.harcourt.co.uk

Twenty First Century Science GCSE Science revision guide
Oxford University Press
www.OxfordSecondary.co.uk

GCSE flashrevise cards, Science and Additional Science Physics
Philip Allan Updates
www.philipallan.co.uk

50 colour cards, with four short questions on the front, with a brief explanation of the concept or topic and the answers to the questions, together with an examiner's note, on the back. These could be used by teachers to revise or recap with the whole class, or individual students could work through selected cards as an alternative to textbooks.

BBC Bitesize

www.bbc.co.uk/schools/gcsebitesize

Bitesize is an online revision site covering a range of subjects at various levels. Each subject includes revision notes and test questions.

S-cool

www.s-cool.co.uk

S-cool is an online revision site with revision materials for a range of subjects, including GCSE Physics. Each topic includes a checklist of the key ideas, a study guide, questions to try out and a revision summary.

ICT resources

Krucible

www.immersiveeducation.com/krucible

Explore waves, energy and forces: students run virtual experiments on-screen, taking measurements and plotting results, or explore 300 prepared activities and challenges in real time.

Krucible's four virtual laboratories create an environment for learning and investigation with graphic simulations. Students can:

- plot experiment simulation data with a dynamic graph plotter
- use a notepad to record observations
- save and share experimental outcomes
- complete over 150 activities and apply knowledge to more than 150 real-life challenges.

Krucible aims to:

- demonstrate difficult physical concepts clearly
- encourage students to question and explore
- teach experimental method and observational skills
- be ideal for whole-class or individual learning
- allow students to apply theory to real-life challenges.

Crocodile physics

www.crocodile-clips.com/crocodile/physics

Crocodile physics is a simulator that replicates a range of models in electricity, motion and forces, optics and waves. By dragging parts from the toolbars at the side of the screen they start simulating straight away. Settings can be edited and graphs plotted to analyse data from experiments. Version v605 includes 46 lesson kits designed for the new science curriculum.

Boardworks

www.theboardworks.co.uk/sciences/index.php

For interactive whiteboards and projectors: designed for whole-class teaching for GCSE Science 2006. Thousands of multimedia slides matched to the new 2006 GCSE Science specifications, including momentum, motors and generators, radioactive decay and atomic energy.

Multimedia Science School

www.science-school.co.uk/home.php

The software provides 'tools' (basically topic areas) that can be purchased individually or in sets. The tools are generally more suited to whole-class teaching, though some are suitable for student use; they are ideal for use with an interactive whiteboard. The price includes a full site licence. The bookmarking facility can be used to create bespoke presentations to illustrate concepts in specific ways.

The CD-ROM contains curriculum-focused, interactive teaching tools that cover topics in biology, chemistry and physics with accompanying worksheets, background notes and lessons.

Each tool has been developed in collaboration with science teachers to illustrate concepts in the classroom.

Sunflower Learning

www.sunflowerlearning.com

Sunflower for science is a suite of curriculum-focused programs designed to help tackle difficult topics in secondary biology, chemistry and physics. They can be tried before purchasing. Each consists of a CD-ROM with the programs bought, a set of teacher's notes, worksheets, activities and examples, and a full site licence so you can run programs on a network or any machines in school. With 'Sunflower for anywhere' a licence allows use of the programs by any teachers and students on any computer. The content can thus be accessed over the internet from either Sunflower's website or through a school's own VLE, giving significant potential for producing integrated e-learning for students, particularly those with internet access at home. Physics programs include Forces and motion, Motors and generators, and Sound.

Science investigations

www.focuseducational.com

Fully functioning interactive experiments, allowing students to practise enquiry skills. Although this program pre-dates 2006, it is very simple to use, and students can easily learn how to manipulate variables. It would be particularly useful for whole-class teaching with an interactive whiteboard.

Websites[4]

Exploratorium

www.exploratorium.edu/snacks

This is a museum of science, art and human perception in San Francisco. The 'snacks' part of the site provides online versions of some of the museum's most popular exhibits.

This website includes instructions for each experiment, an explanation of the science and methods to extend the experiments.

Java applets on physics

www.walter-fendt.de/ph14e/index.html

This site contains Java applets on a range of physics topics. They are simple applets but cover some advanced topics. Categories include mechanics, oscillation, waves, electrodynamics and optics. All Java applets can be downloaded as one large file or individually. They also have information about the physics and how to use the applet.

Korean Java applets

www.mully.net/lee/index.html

This site is written in Korean but it is a treasure trove of physics applets, many of which are excellent. It requires a little patience to learn what they all do as often the controls in the applets are not in English, but the time spent is worth it. All branches of physics are dealt with. The applets are of high quality and illustrate the topics well.

Learn physics using Java

www.ngsir.netfirms.com/englishVersion.htm

This site has very simple and clear graphics, with an explanation below each animation of how the applet works. There is an excellent animation of a simple electric circuit in which one adds resistors and meters and checks the resulting values.

4 Note that some browsers may open more than one window for the Japanese and Korean sites and readers need to toggle between these to access the content.

NTNUJAVA virtual physics laboratory

www.phy.ntnu.edu.tw/ntnujava/index.php

This site is a forum for use by teachers and contains a very wide range of Java simulations, many of which are above GCSE standard. They are useful for relatively simple and quick demonstrations of some basic physics principles. Registration on the site is necessary, but files can be downloaded for offline use. The large number of simulations covers many aspects of physics including kinematics, dynamics, waves, thermodynamics, electromagnetism, optics, modern physics, etc. Most have relatively simple graphics, but all are free. You can also read different opinions about the resources and how they can be used.

Physics education technology

http://phet.colorado.edu

This site has a set of applets and Flash animations that cover a wide range of topics. Topics include: masses on springs, projectile motion, gas properties, waves on a string, sound, electric circuits, static electricity, optics and colour. The whole suite can be downloaded and run offline, or individual animations can be selected for a particular use.

Physics for you

www.physics4u.co.uk

This site promotes the Physics4u series of books and links to other Nelson Thornes publications, but there are also some free PowerPoint presentations from Keith Johnson linked to How Science Works, which can be downloaded. There are also extra files for teachers to download including summaries, questions and answers. Additionally, there is a free application, Lesson Loaders V1.5, originally to go with the *Physics for you* CD-ROMs but which can be used independently.

Physics 2000

www.colorado.edu/physics/2000/index.pl

Physics 2000 is a site designed to give an appreciation of the accomplishments of 20th-century physics. The site is therefore an interactive one, aimed at all ages and relying heavily on applets. The Science Trek section contains the most resources for GCSE level.

Schoolphysics

www.schoolphysics.co.uk

This is a website for both students and teachers of physics, whether studied as a single subject or as part of a combined science course. It has superseded the Resourcefulphysics website and is also available on a CD-ROM that contains additional material. A large number of resources is provided in Word format and can be selected by Key stage and topic. Tests, lesson plans and other resources are also available. The site is searchable for easy access. There is a useful collection of photos, lesson plans, data sheets, historical lists, a dictionary and teacher's section.

Other resources

Giant leaps

John Perry and Jack Challoner

This book covers a series of great inventions; for each there is a front page from the *Sun* newspaper and an information page written by the Science Museum. Topics include x-rays, Marie Curie, splitting the atom, climate change and nuclear power. This book would be useful to place GCSE topics such as radiation and climate change in a fun context to prompt further discussion and thinking.

Boxtree Ltd
www.panmacmillan.com

The cartoon guide to physics

Larry Gonick and Art Huffman

This book uses straightforward, fun illustrations to communicate the basic principles of science.

HarperCollins
www.harpercollins.com

The flying circus of physics with answers

Jearl Walker

This book contains a variety of problems, set in the everyday world, on many different topics in physics. They are sorted by topic and by keywords. It provides questions in an interesting and fun context and encourages lateral thinking. The questions can be applied to a variety of age ranges, as they have different levels of complexity.

John Wiley and Sons
www.wiley.com

The Model Project: practical physics at work

The Model Project resource provides ideas for practical physics activities with student instructions and worksheets, together with guidance for teachers and technicians. The activities are supported by related video sequences on the supplied CD-ROM, which show people using physics in the jobs they do. The major sections cover topics in: harnessing energy; optics; sound; materials; electricity; and medical physics. Much of the practical work makes use of new materials such as nitinol, rare-earth magnets and thermo film. All instructions are highly detailed. The examples are often linked to real-life situations, which will add interest and motivation for students.

Institute of Physics
www.iop.org

Teaching physics to Key stage 4 (a non-specialist's handbook)

Elizabeth Ann Jerram

A good book for those that need support in teaching physics at Key stage 4 for the first time or as a non-specialist.

Hodder Murray
www.hoddereducation.co.uk

Teaching secondary physics

David Sang (editor)

This book consists of chapters written by very experienced and respected teachers and specialists in physics education. There are chapters on: energy; sound, light and waves; forces; electricity and magnetism; Earth in space; and radioactivity. Each chapter contains a content map, suggested teaching routes, student misconceptions, advice about practical work and suggestions for other resources. This could be a reference for non-specialist colleagues, or a source of fresh inspiration for the jaded specialist.

Association for Science Education
www.ase.org.uk

Thinking physics

Lewis Carroll Epstein

This book contains a variety of questions and answers on many different topics in physics. It provides questions in an interesting context and encourages lateral thinking.

Insight Press
www.appliedthought.com/InsightPress/index.html

Our planet – our future

This CD-ROM is a video of the 2005 Institute of Physics schools' lecture and highlights six topics relevant to GCSE courses. These are: energy from the atom; recycling materials; hydrogen fuel technology; environmentally friendly engines; severe weather; and seismology. The six parts of the lecture can be viewed as separate sequences, making it possible to use them as 10-minute video introductions to that part of the specification.

Engineering and Technology Board
www.scenta.co.uk/schoolslecture

The virtual physical laboratory v5.0

John Nunn

This CD-ROM contains 170 animations that cover GCSE, GCE and beyond, but they can be used as a stimulus for more able students and to explain the concepts quickly in some more complex experiments. All of the simulations allow the user to change various parameters and observe the result.

Virtual Physical Laboratory
www.vplab.co.uk

Science Enhancement Project

SEP supports science education in the UK by developing innovative, high-quality resources for secondary science at low cost, making them affordable and accessible to schools. It supports science teachers by providing materials and development opportunities to improve classroom practice.

www.sep.org.uk

Channel 4 Learning ClipBank

Video clips can enhance lessons in a way that no other teaching resource can. If you want to use television in the classroom but don't have the time for sourcing, cueing and viewing videos, then use ClipBank – all the hard work is done for you.

ClipBank is a digital library of the very best educational television clips, selected from over 800 hours of award-winning programmes. ClipBank for science is packed with around 250 high-quality television clips.

www.channel4.com

Visits

Science centres and museums

There is a wide range of museums devoted to science and natural history across the UK regions that organise interesting visits for students of science GCSEs. For current exhibitions and access to all museums, visit www.24hourmuseum.org.uk

Ecsite-uk: the UK Network of Science Centres and Museums represents over 80 science centres, museums and discovery centres in the UK.

Ecsite-uk's purpose is to raise the profile of science centres and to establish their role as a forum for dialogue between science specialists and the public and as an informal learning resource for learners of all ages.

A regional selection of science museums includes:

Science Museum (London)

www.sciencemuseum.org.uk

Natural History Museum (London)

www.nhm.ac.uk

Explore At-Bristol (South West)

www.at-bristol.org.uk

Birmingham Science Museum (West Midlands)

www.thinktank.ac.uk

Catalyst Science Museum (Widnes)

www.catalyst.org.uk

Museum of Science and Industry (North West)

www.msim.org.uk

Whitby Wizard (Yorkshire and Humberside)

www.whitbywizard.com

Other resources

Institute of Physics

The Practical Physics website, run by the Institute of Physics, is at www.practicalphysics.org and includes ideas about practical activities and demonstrations to support effective teaching and learning in physics.

The Institute of Physics is a leading international professional body and learned society, established to promote the advancement and dissemination of physics. Education is a key priority in its work. The Physics.org website is at www.physics.org and it answers questions with a series of relevant and accurate websites from its database of refereed resources. Additionally, there is information for careers guidance and interactive games/animations to further pursue knowledge. There are also links to events and activities to further motivate students.

'Girls into physics' is a project that the institute has undertaken and more details can be found at www.iop.org/activity/education/Making_a_Difference/Policy/page_22188.html The institute has established that there is a significant proportion of girls who are very able scientists but who are not taking physics to A-level.

The Institute of Physics has a comprehensive support service for schools that includes a range of features:

- a schools' affiliation scheme
- professional development activities
- courses
- teacher network
- e-mail lists

Resources, websites and publications include:

- www.teachingmedicalphysics.org.uk – a science teaching pack using medical physics
- www.iop.org – sign up for physics mailing and discussion lists by following our activities ▸ schools and colleges ▸ teacher support ▸ teachers' network
- www.BigBangBlogs.org for students to find out about physics.

The institute also engages in research and lobbying and offers grants to support school-based activities.

Nuffield Curriculum Centre

www.nuffieldcurriculumcentre.org

The Nuffield Curriculum Centre explores new approaches to teaching and learning by developing, managing and supporting curriculum projects such as Twenty First Century Science (in partnership with the Science Education Group at the University of York). The Nuffield Foundation also offers bursaries for students to experience real research.

Secondary National Strategy

The strategy has developed many resources and materials for Key stages 3 and 4 that will be relevant to teaching and learning for Triple Science courses. Many of these are available online at www.standards.dfes.gov.uk/secondary

STEMNET

STEMNET aims to ensure that more young people in the UK make a choice to enter science, technology, engineering and mathematics (STEM) related careers at all levels, and that future generations are properly informed about the science and technology that surrounds them. With the support of a wide range of partners, STEMNET brings science, technology, engineering and mathematics activities, experiences and excitement into classrooms throughout the UK, enhancing and enriching the national STEM curriculum. Its science and engineering ambassadors are available to work with schools to inspire young people. STEMNET is particularly strong on linking those companies and other organisations that employ STEM-educated people with schools, in such a way that young people can get a clear idea of the diverse and exciting range of careers available to them.

Research Councils UK

www.rcuk.ac.uk/sis/linksci.htm

Research Councils UK (RCUK) is a strategic partnership between the eight UK Research Councils. Its 'Science in society' programme has several different strands to support teachers in bringing contemporary research and researchers into the classroom. Of note is the 'Researchers in residence' initiative and the Nuffield bursaries.

Annex 1
GCSE Physics specifications at a glance

The following tables show at a glance how the content of GCSE Science, GCSE Additional Science and GCSE Physics (Extension) is broken down in each of the specifications offered by the awarding bodies.

AQA

Physics	Science: Physics 1	Additional Science: Physics 2	Extension Science: Physics 3
Forces and energy	Heat transfer and the factors affecting the rate. Efficient use of energy, useful electrical devices.	Speed, velocity, acceleration. Distance/time and velocity/time graphs. Newton's laws of motion and road safety. Kinetic energy, work, momentum.	Turning forces and stability. Balanced forces and Newton's first law. Unbalanced forces and circular paths – as in planets and artificial satellites. Centripetal force.
Waves and radiation	Uses and hazards of the electromagnetic spectrum.		Formation of images in optical devices such as cameras and magnifying glasses by mirrors and lenses. Sounds in frequency range 20 Hz–20 kHz. Ultrasound waves and their uses.
Atomic physics	Uses of, and dangers from, radioactive substances.	Atomic structure, ions, isotopes. Radioactivity, nuclear fission and fusion.	
Space	Origins of, and changes in, the universe.		Gravitational forces responsible for the formation of galaxies and for stars such as the Sun having a long stable period. Life history of stars.
Electricity	Generating electricity, paying for electricity.	Static electricity, electric current and circuits (series and parallel), circuit components, current/potential difference graphs, Ohm's law, mains electricity and safety, electrical appliances, charge and energy transferred.	Currents produce magnetic fields and thus movement. If a conductor cuts magnetic field lines, a potential difference is induced. This generator effect is used to produce electricity. Transformers are used to alter AC potential differences.

Note that AQA offers two specifications (A and B). There are differences in the assessment structure but no differences in the content.

Edexcel360

Physics	Science	Additional Science	Extension Science
	9: Producing and measuring electricity 10: You're in charge 11: Now you see it, now you don't 12: Space and its mysteries	9: As fast as you can! 10: Roller coasters and relativity 11: Putting radiation to use 12: Power of the atom	5: Particles in action 6: Medical physics
Forces and energy	Renewable energy, efficiency, power. Mass, weight, gravity and acceleration.	Newton's laws, equations of motion, graphs, terminal velocity, road safety, momentum. Potential and kinetic energy, work done, power, conservation of energy, circular motion, relativity.	Absolute zero, Kelvin scale. Kinetic energy of gas particles, P/T = constant, $P_1V_1/T_1 = P_2V_2/T_2$. Power = work done/time taken. Work done is equal to energy transferred.
Waves and radiation	Reflection, refraction, absorption. Electromagnetic radiation – uses and hazards. Analogue and digital signals and uses. Wave terms and formula. Seismic waves.		Refraction, total internal reflection, pulse oximetry. Intensity = power of incident radiation/area Use 'radiation' to describe any form of energy originating from a source.
Atomic physics		Ionising radiation, properties and uses, half-life, decay, radioactive dating, background radiation and safety precautions. Nuclear reactors, chain reactions, fusion and fission.	Properties of alpha, beta, gamma, positron and neutron radiation, decay, fundamental particles. Thermionic emission, deflection of charged particle stream, uses of electron beams. Thermal neutron, momentum conservation, radioactive isotopes formation. Positron emission, tomography scanning. Effects of radiation, treating tumours, palliative care.
Space	Space exploration and probes. Black holes, stellar evolution, comets, galaxies. Search for intelligent life, dark matter, origin and fate of the universe.		
Electricity	AC and DC, electromagnetic induction, voltage, current and resistance, Ohm's law, LDRs and thermistors. Motor effect, solar cells, financial and environmental cost of electricity, safety devices.	Electrostatics, charge mechanisms, uses and dangers.	Basal metabolic rate, muscle cells generating potential differences and use in medical applications, how action potentials can be measured, the shape of an ECG in terms of heart action.

OCR Twenty First Century Science

Physics	Science	Additional Science	Extension Science
	P1: The Earth in the universe P2: Radiation and life P3: Radioactive materials	P4: Explaining motion P5: Electric circuits P6: The wave model of radiation	P7: Further physics – observing the universe
Forces and energy		How speed is measured and represented graphically and velocity. Identifying, describing and using forces to explain simple situations. Resultant forces and changes in momentum. Work done, gravitational potential energy and kinetic energy.	
Waves and radiation	General model and risks of radiation. Electromagnetic spectrum. Radiation from the Sun vital to life, ozone layer as natural protection from harmful radiation. Evidence of global warming and links to carbon cycle.	Describing waves. Reflections and refractions of water as models for the behaviour of light and sound. Electromagnetic spectrum, properties and contemporary uses of different waves. Modern communications systems.	Making a real image with a converging lens and the use of a second lens to create a telescope.
Nuclear	Nature, use and risks of radioactive materials. Ways that electricity could be generated and that nuclear waste could be disposed of.		Nuclear processes in stars.
Space	Discoveries in the solar system and beyond. Lifecycle of a star. Scale of the universe. Whether we are 'alone'. Changes in Earth's crust and how these impact on human life. Explaining, predicting and coping with or averting earthquakes, volcanoes and asteroid impact.		Observations of stars, planets and satellites. Spectra and brightness of stars, Cepheid variables, Hubble constant. Birth and death of stars. Using telescopes.
Electricity	Electricity generation.	Current as flow of electrons. Useful models of charge in circuits driven by voltage and against a resistance. Voltage as potential difference. Concepts of current and voltage in generation. Power and efficiency of electrical appliances.	

OCR Gateway

Physics	Science	Additional Science	Extension Science
	P1: Energy for the home P2: Living for the future	P3: Forces for transport P4: Radiation for life	P5: Space for reflection P6: Electricity for gadgets
Forces and energy	Heat and temperature, specific heat capacity, efficiency and insulation. Conduction, convection and radiation. Energy from the Sun, power stations. Advantages and disadvantages of nuclear power.	Speed, road safety, acceleration. Forces and motion, work and power, kinetic energy and energy sources. Collisions, falling, games and theme park rides.	Satellites, gravity, circular motion, vectors, equations of motion, projectiles, momentum, satellite communication.
Waves and radiation	Uses and dangers of electromagnetic radiation (infrared wireless communication, light). Wireless technology. Earthquakes, ozone, global warming.	Ultrasound and its uses, medical physics.	Nature of waves, refraction, optics.
Atomic physics	Ionising radiation and how it occurs. Radioactive waste.	Radioactivity, uses of radioisotopes, nuclear fission.	
Space	The solar system, cosmic rays, solar flares, asteroids, near-Earth objects. Big Bang theory.		
Electricity	Generators, power stations, National Grid. Magnetic fields.	Sparks and uses of electrostatics, safe electricals.	Resistors, motors, generators, transformers, AC, DC, logic circuits and their applications.

WJEC

Physics	Science: Physics 1	Additional Science: Physics 2	Extension Science: Physics 3
Forces and energy	Energy sources. Heating and home, energy, temperature and the transfer of heat energy. Electrical energy and the home, cost of energy in the home, energy efficiency.	Distance, speed, acceleration, effect of forces, gravity, potential and kinetic energy, road safety.	Measuring speed and position of accelerating objects. Collisions and changes in direction. Distance/time and velocity/time graphs and equations of motion. Momentum. Calculating kinetic energy. Circular motion.
Waves and radiation	The characteristics of waves; the electromagnetic spectrum – energy transfer, information transfer, communication by microwave and infrared. Total internal reflection.		Refraction of plane waves. Ultra-scans and other uses of ultrasound. Seismic waves and how they can be used to probe the structure of the Earth.
Atomic physics		The existence of radioactivity, types of radioactive emissions, half-life, uses and dangers of radioactivity.	Working out atomic structure. Radioactive decay and dating. Nuclear fission and its control in reactors. Nuclear fussion.
Space	The solar system, stars and the universe.		Nuclear fusion, energy processes in stars and the potential of fusion to provide energy on Earth.
Electricity	Voltage, current and power. Generation and transmission of electricity.	Simple electrical circuits, Ohm's law, variation of current, mains wiring and safety.	Electromagnetic induction and the use of generators to generate electricity. Using transformers to increase or decrease voltages. Magnetic fields.

Annex 2
Teaching and learning models: bibliography and further reading

DfES (2004). *Pedagogy and practice: teaching and learning in secondary schools – Unit 2: Teaching models*, Department for Education and Skills (Ref: DfES 0425-2004 G).

DfES (2006). *Science subject leader development materials: Summer 2006*. Secondary National Strategy, Department for Education and Skills (Ref: 0274-2006DOC-EN).

DfES (2007). *Pedagogy and personalisation*. Department for Education and Skills (Ref: 00126-2007DOM-EN).

Gloucestershire LA (2007). *Pedagogy and practice – using different teaching models to support How Science Works*, Gloucestershire Local Authority (Ref: www.gloucestershire.gov.uk/science).

Joyce B, Calhoun E and Hopkins D (2002). *Models of learning: tools for teaching*, Open University Press (ISBN: 0335210155).

Secondary National Strategy (2006). *Theories of learning – a summary paper*. SNS Science Consultant Days 1 and 2, September 2006.

Annex 3
Assessment of How Science Works in different GCSE Science courses

AQA

AQA assesses How Science Works (HSW) by means of written papers, practical skills assessment and an investigative skills assignment. It isn't, therefore, necessary to look for, select and run lesson activities for the purpose of assessing HSW objectives (although it will be necessary to deliver lessons that prepare students for their assessment).

Edexcel

Edexcel's Extension Physics P3 can be assessed either by a structured examination paper or a centre-devised internal assessment, which may be one integrated piece of work or several portfolio items. These pieces will be centre assessed and externally moderated by an examiner appointed by Edexcel. Candidates will be assessed on their ability to:

- distinguish between and use primary and/or secondary data
- demonstrate understanding of topics 'Particles in action' and 'Medical physics'
- discuss and evaluate evidence and data
- consider the ethical, contemporary and social issues.

OCR Twenty First Century Science

OCR's Twenty First Century Science course has the Extension Physics in Unit P7, which is assessed by means of terminal examination. Students also conduct (as part of GCSE Physics, but not necessarily drawing on contexts from Extension Physics) either a practical investigation or a practical data analysis task and a case study. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless, contexts could be drawn from those in P7 and so possibilities will be identified.

In the **data analysis task**, candidates either singly or collaboratively take part in a practical procedure in order to collect primary data. Candidates are assessed on their ability to analyse and evaluate the data collected and the limitations of the techniques used.

The **case study** should arise naturally from work on the course or from an issue that arises while candidates are following the course. It should be related to an aspect of science that involves an element of controversy, in terms either of the interpretation of evidence, or of the acceptability of some new development. Topics for study should be selected by candidates in discussion with teachers, and should be seen as an extension or consolidation of studies undertaken as a normal part of the course.

The **practical investigation**, in addition to confirming the predicted effect of a variable on a system over a range, also includes more speculative investigation of systems where no clear prediction can be made in advance, for example where there is little relevant explanatory theory available in the course, or where the experimental material is likely to be variable, for example in surveys of distribution of species. It will be assessed on the strategy deployed, the collection and interpretation of data, evaluation and presentation.

OCR Gateway

OCR's Gateway course has the Extension Physics in Units P5 and P6, which are assessed by means of terminal examination. Students also conduct (as part of GCSE Physics, but not necessarily drawing on contexts from Extension Physics) either 'can-do' tasks and 'Science in the news', or a research study, data tasks and practical skills. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless, the context could be drawn from those in P5 and P6 and so possibilities will be identified.

'Can-do' tasks provide opportunities to demonstrate practical capabilities and explore the ways in which scientific evidence is collected. These are monitored and recorded throughout the course as the candidate fulfils them.

The report on **'Science in the news'** aims to give candidates an insight into how science is reported to the public, the validity of underlying research, and claims or recommendations made based on the research. Candidates are required to use stimulus material provided by OCR and other sources of information to research the way in which scientific data and ideas are dealt with by the media. The number of reports attempted is at the discretion of the centre, but the results of only one may be submitted.

In the **research study**, candidates are required to use stimulus material provided by OCR and other sources of information to research scientific ideas.

In the **data task**, candidates are required to analyse and evaluate data and to plan further work (which will not be carried out).

For **practical skills**, the ability to carry out practical tasks safely and skilfully is assessed holistically.

WJEC

WJEC's Extension Physics, Physics 3, is assessed by means of terminal examination. The internal assessment for GCSE Science and GCSE Additional Science consists either of practical work provided by WJEC or work written by centres for completion wholly during class time and marked by teachers according to a marking scheme provided/approved by WJEC, or of a centre-assessed extended report. In addition, candidates for GCSE Physics may, as an alternative, submit a written 'investigatory planning exercise', marked by the centre using awarding body criteria. For each of the separate science qualifications, Biology, Chemistry and Physics, no more than one extended report or investigatory planning exercise may be submitted. It is likely that, at least to start with, students will be asked to use contexts drawn from the modules common to Science or Additional Science to ease internal standardisation practices. Nevertheless, contexts could be drawn from those in P3 and so possibilities will be identified.

In the **assessment of the practical task**, the candidate is guided through a practical activity, which could be laboratory- or field-based and which arises from the relevant subject content of the specification. The awarding body provides a range of such activities for each of the specifications, including a specific candidate worksheet, a list of laboratory or field requirements, teacher guidance and a marking scheme.

A second aspect of the internal assessment scheme is the **extended report**. Various aspects of the specifications lend themselves to a different style of enquiry-based approach, with students investigating, discussing and reporting. This is especially, but not exclusively, the case with those areas of the specification that involve social, ethical and political issues and effects, such as GM technology, the siting of wind farms or mobile phone masts, for which science informs but does not determine the debate.

The '**investigatory planning exercise**' recognises the greater experience of candidates in scientific investigatory work and takes the form of a paper exercise in which the candidate plans an experimental activity involving either an investigation into the relationship between variables or a forensic-style investigation. The stimulus for this activity arises out of the experience of Sc1 investigations and is to enable candidates to demonstrate their scientific competence arising from carrying out their own investigations previously.

Annex 4
LSN science publications

Triple Science GCSEs: collaborative approaches

The Triple Science Support Programme (TSSP) will provide advice and guidance on models of effective collaborative delivery between providers, in the form of a booklet that deals with science at Key stage 4. The booklet will be essential reading for all who have an interest in developing and sustaining partnerships.

Learning and Skills Network, 2007
Free
Tel 0845 071 0800
www.triplescience.org.uk

Triple Science GCSEs: curriculum planning and design

This publication will provide managers and others with practical advice on how to plan, develop and model the Triple Science requirement – taking into account all the critical factors that need to be considered.

Learning and Skills Network, 2007
Free
Tel 0845 071 0800
www.triplescience.org.uk

Resources for your Triple Science courses

LSN's guide will list many of the resources available for delivering Triple Science courses. Sections will cover books; non-books, such as multimedia packs and CD-ROMs; websites; national organisations; and nationally available continuing professional development programmes.

Learning and Skills Network, 2007
ISBN 9781845726472
Free
Tel 0845 071 0800
www.triplescience.org.uk

Teaching Triple Science: GCSE Biology
Teaching Triple Science: GCSE Chemistry

LSN has commissioned another two subject-specific publications aimed at helping practitioners tackle some of the main issues in delivering the separate sciences. Written by acknowledged experts in these subject areas, the books will provide practitioners with up-to-date and useful guidance on:

- the major differences between Double and Triple Science
- teaching and learning modules, particularly focusing on areas known to be delivered poorly in schools
- teaching resources and assignments to promote student-centred problem-solving activities.

Learning and Skills Network, 2007
Teaching Triple Science:
GCSE Biology ISBN 9781845726485
Teaching Triple Science:
GCSE Chemistry ISBN 9781845726492
Free
Tel 0845 071 0800
www.triplescience.org.uk

Annex 5
Triple Science Support Programme frequently asked questions

What is Triple Science?

Triple Science is a combination of three GCSEs in biology, chemistry and physics. It will normally be a course of study for students in Years 10 and 11. It provides the fullest coverage of these three subjects at Key stage 4, including all of the compulsory Programme of Study for science, provided all three are taken during the Key stage.

What's new about Triple Science?

In September 2006, new science GCSEs, including Biology, Chemistry and Physics, were introduced. These incorporated a new Programme of Study for Key stage 4 and included a wider range of science GCSEs (see below). From September 2007, there will be a new statutory entitlement for all students to study science courses leading to at least two GCSEs. From September 2008, all students achieving at least level 6 at Key stage 3 will be entitled to study Triple Science. This need not all be in their own school, for example, it could be through collaborative arrangements with other schools, FE colleges and universities. Also from September 2008, all specialist science schools will be required to offer Triple Science at least to all students achieving level 6+ at the end of Key stage 3.

How does Triple Science relate to other science GCSEs?

Awarding bodies (examination boards) have devised suites of qualifications that can be studied to three different extents. The minimum required science (sometimes called 'the core'), which covers the required Programme of Study, is a single science GCSE including some biology, chemistry, physics, astronomy, environmental and Earth sciences. The expected normal extent of science study (previously 'double award') includes a second 'Additional Science' GCSE, with more of all these areas of science. The separate GCSEs in biology, chemistry and physics add further content to this. This enables science classes to be taught common content and then for some students to cover additional material.

What are the differences between Triple Science and other science GCSEs?

The difference is only one of extent of coverage of the subject. There are differences between GCSE suites in the content to be covered and the nature and timing of the assessment, but these apply to the single science and Additional Science GCSEs as well as the separate sciences. Features that were emphasised in the 2006 revision of Key stage 4 science, such as 'How Science Works' and a requirement for contemporary applications of science, apply to all courses. All GCSEs have a common grading system for standards.

What are the advantages of studying Triple Science?

The courses cover a more extensive range of subject matter and provide the best preparation for entry to A-level in the respective subjects. The government is encouraging the take-up of Triple Science because there is evidence that such students are more likely to continue to study science at the post-compulsory stage. This is an important element in the government's economic strategy.

What extra science do students study compared with a two-science GCSE course?

Awarding bodies are free to select the additional content for these courses and therefore the content varies widely. Full details are available on their websites (see below). Here are some examples:

- **Biology**: Micro-organisms (AQA, OCR Gateway, WJEC); Biotechnology (Edexcel, OCR C21st, WJEC); Behaviour (Edexcel); Transport in plants and animals (AQA, WJEC); Human physiology (OCR C21st).
- **Chemistry**: Analysis (most); Chemical production (Edexcel, OCR Gateway, WJEC); Energy changes (AQA, OCR C21st); Organic (OCR C21st, WJEC).
- **Physics**: Electromagnetic induction (AQA, WJEC); Motion (AQA, WJEC); Particle and nuclear physics (Edexcel, WJEC); Astronomy (AQA, OCR C21st); Satellite technology (OCR Gateway); Medical physics (Edexcel); Electronics (OCR Gateway).

What ways are there of timetabling the study of Triple Science?

Most schools and colleges run the three separate subjects in parallel through Years 10 and 11. This can be partially combined with a course leading to a single or two-science GCSE because of the common content (see above). Where the subjects are taught in collaboration between centres, other arrangements may be needed. The support materials provide case study examples of these: http://publications.teachernet.gov.uk/eOrderingDownload/DfES%200678-200MIG1303.pdf

Can students study a single separate science (ie only biology, chemistry or physics)?

All Key stage 4 students (Years 10 and 11, aged 14–16) are required to cover the Programme of Study for science. A single science subject, other than GCSE Science itself, will not do this. However, it can be studied in conjunction with the single 'core' science, or by a student over the age of 16.

Who offers Triple Science qualifications?

The following awarding bodies offer the full range of science GCSEs:

OCR www.ocr.org.uk

AQA www.aqa.org.uk

Edexcel www.edexcel.org.uk

WJEC www.wjec.co.uk

Any centre can register for any course but because of the interconnected way that suites of qualifications are offered (see above), centres may prefer to choose the same suite for single science, Double Science and Triple Science.

What about entry level?

These are qualifications, usually called ‘Certificate of Science’, suitable for those who are not likely to gain GCSE passes at either grades A*–C (Level 2) or D–G (Level 1). They are covering the Programme of Study for Key stage 4 but have a very different assessment system.

What help is available to introduce Triple Science?

The DCSF has contracted with LSN to raise awareness of, and provide support for, increased take-up of Triple Science GCSEs, through the Triple Science Support Programme.

What is LSN?

The Learning and Skills Network is an independent, not-for-profit organisation committed to making a difference in post-14 education and training. We support schools, colleges and other learning providers. We do this through delivering government-funded quality improvement and staff development programmes; through research, training and consultancy; and through providing high-quality resources for teachers and lecturers.

What is the Triple Science Support Programme (TSSP)?

The Triple Science Support Programme has been set up to support the following DCSF policy objectives:

- to enable all young people with level 6 in science at Key stage 3 to study Triple Science GCSEs from September 2008
- to help specialist science schools offer Triple Science to their students from September 2008.

These aims arise directly from the ‘Science and innovation investment framework 2004–2014: next steps’ discussion paper, which outlines strategies to halt the decline in young people doing Physics and Chemistry A-level and therefore increase the numbers of professional scientists in the UK. This programme has been funded by the DCSF. All publications, networks and newsletters will be delivered without charge to maintained secondary schools. The training and consultancy will be available to targeted Triple Science schools only.

When is it available?

The programme is being prepared now and should be up and running from September 2008. Detailed information will be added to the website as it becomes available.

What does TSSP offer?

The TSSP comprises the following:

- the programme website: www.triplescience.org.uk
- a programme newsletter
- publications on: collaboration and partnership; raising attainment in Triple Science; curriculum modelling, timetabling and Triple Science
- three subject-specific resources on the separate sciences
- Triple Science networks of support for practitioners
- an audit of resources for Triple Science
- an offer of three days' consultancy per targeted school (around the topics above)
- a marketing campaign around Triple Science for schools.

If you wish to register an interest in the programme information, please contact the LSN helpline on 0845 071 0800 or e-mail triplescience@LSNeducation.org.uk

How will LSN target schools for training and consultancy?

LSN will be offering training and consultancy to a set of 300 schools that seem particularly suited to offering the full Triple Science but currently do not. Among the criteria being used to identify the potential schools will be whether they:

- offer one or two of the three science GCSEs
- have a critical mass of students attaining level 6+ science but not offering all three science GCSEs.

LSN will also consult with its partners on the selection.

What's on the TSSP website?

- Triple Science content
- How Science Works
- Teaching and learning
- Managing Triple Science
- The Triple Science community
- LSN support.

What other forms of support are available?

Events and CPD opportunities from the Secondary National Strategy, ASE, Science Learning Centres and the awarding bodies may help in implementing your choices and developing a greater understanding of 'How Science Works'. An overview of information about these can be found on the ASE website. QCA has also set up a forum, allowing you to raise questions and share ideas, that can be accessed online at www.qca.org.uk/science/forum Other groups are identifying resources that support the new approaches and, within the ASE, some are looking at existing materials (such as Science upd8 and SATIS) to see how these can be matched to the new specifications.

Where is further information available on current developments in science at Key stage 4?

Association for Science Education
www.ase.org.uk

The Royal Society
www.royalsoc.ac.uk/education

Institute of Physics
www.iop.org

Royal Society of Chemistry
www.rsc.org/education

Institute of Biology
www.iob.org

Qualifications and Curriculum Authority
www.qca.org.uk/science

Twenty First Century Science Project
www.21stcenturyscience.org/home

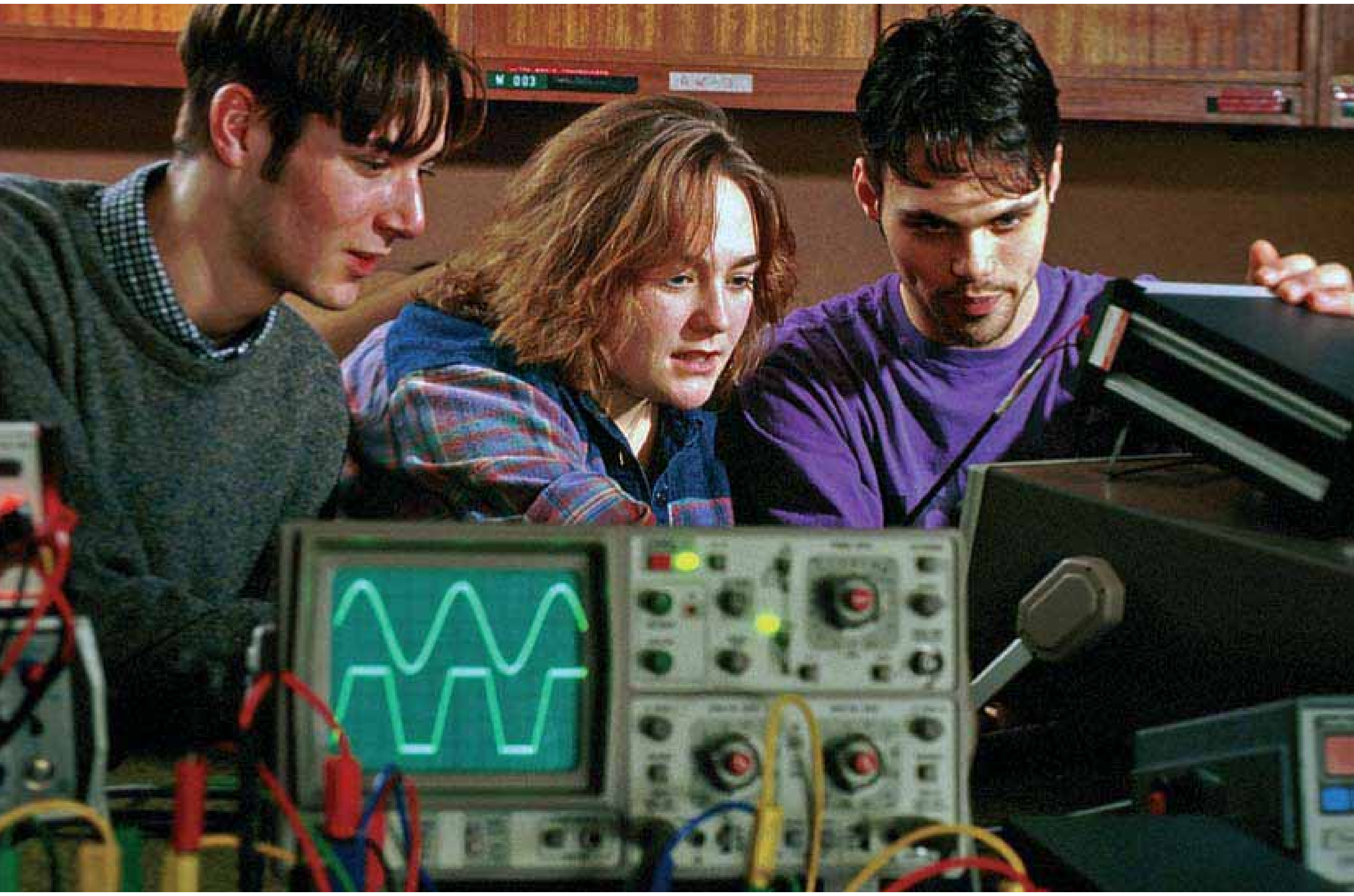
OCR www.ocr.org.uk

AQA www.aqa.org.uk

Edexcel www.edexcel.org.uk

WJEC www.wjec.co.uk

CCEA www.ccea.org.uk



This is a subject-specific publication to support teachers in the delivery of the new Triple Science GCSEs. It focuses on GCSE Physics, and particularly on the content that extends Additional Science to the Triple Science GCSEs. For science teachers, those teaching outside their specialism and subject leaders responsible for implementing Triple Science GCSEs in their departments. The book includes: effective teaching and learning approaches; ideas for delivering key topics through investigations, demonstrations and other activities; and comparisons of awarding body specifications for Science, Additional Science and Extension Science (Physics).

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