An Roinn Oideachais agus Eolaíochta

PHYSICS

Leaving Certificate

Ordinary Level and Higher Level

GUIDELINES FOR TEACHERS

THESE GUIDELINES

The physics Syllabus

- *emphasis* • *structure and format*
- *content* • *differentiation*
- *strategies/resources/timetabling*
- *vocational emphasis* • *gender*

Science, Technology and Society

- *physics and the everyday world*
- *physics and careers* • *senior cycle curriculum*
- *interaction with other subjects*

Ordinary Level Physics

Higher Level Physics

Particle physics

- *student/teacher materials*
- *useful graphics*

Practical Work and Safety

- *notes on selected experiments*
- *lab organisation and maintenance*

Resources

- *ICT, mags and journals, books videos and web sites*

PLUS

teaching strategies,
worked problems,
lots, lots more...

National Council for Curriculum and Assessment
An Chomhairle Náisiúnta Curaclaim agus Measúnachta
NCCA

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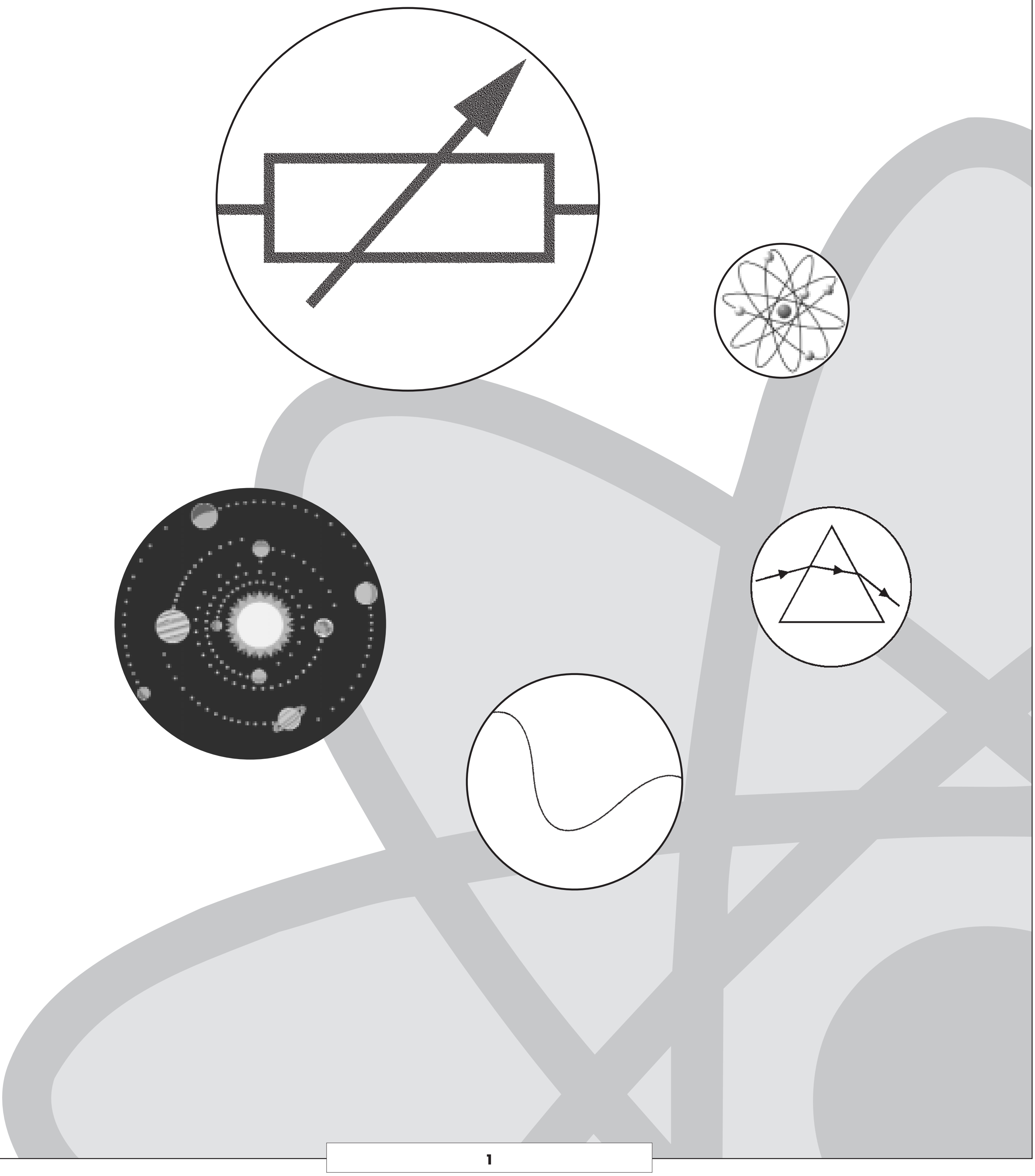


INTRODUCTION

The physics syllabus is a complete document. It is the definitive document in relation to syllabus content and depth of treatment. These teacher guidelines support the implementation of the syllabus by providing background information about aspects of the syllabus.

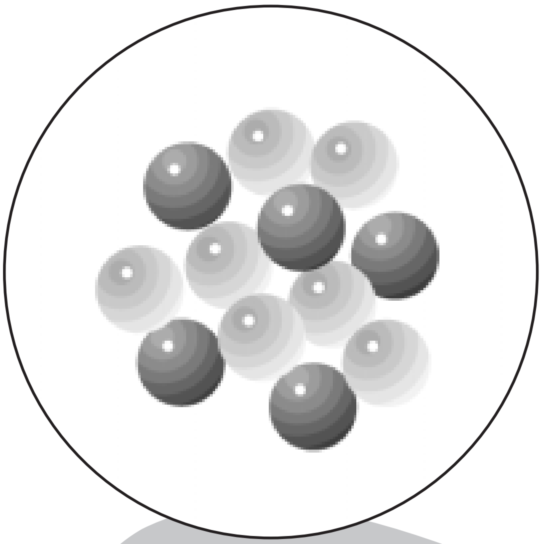
In Section 1, the physics syllabus is introduced and its main features identified. Section 2 includes a discussion on science, technology and society (STS). This section provides a rationale for the inclusion of STS in the syllabus and some suggestions for its teaching.

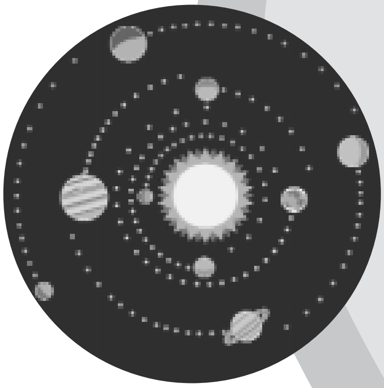
The syllabus is presented at two levels, Ordinary and Higher. The aims, objectives and emphasis of Ordinary and Higher level are discussed in Sections 3 and 4. Particle physics is an option at Higher level and section 5 provides an introduction to this topic.

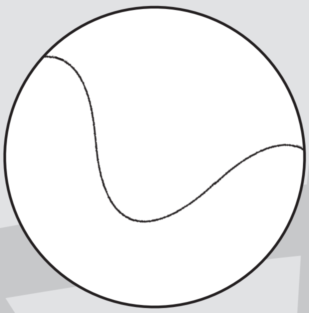
Practical work continues to be essential in the teaching and learning of physics. “Practical work” covers all teacher demonstrations, student experiments and any investigation that may take place in a school science laboratory. Safety in school laboratories is also important. Both are discussed in section 6. Resources for the teaching of physics are suggested in section 7.

It is intended that these guidelines will be useful for teachers. Any comments or suggestions will be very welcome. Please address them to the Physics Course Committee at the NCCA.

Section one
the physics syllabus







1.1 INTRODUCTION

These Teacher Guidelines accompany the revised physics syllabus. The previous Leaving Certificate physics syllabus was introduced into schools in 1984 and first examined in 1986. In the revised syllabus there are changes in emphasis, in structure, in format, and in content. The revision has taken into account the length of the 1984 syllabus, the changes to Junior Certificate Science introduced in 1989 and the need to increase the vocational emphasis in physics.

1.2 EMPHASIS

The aims and objectives of the syllabus provide a clear specification of the ethos of the syllabus. The syllabus emphasises the experimental nature of physics and its applications, thus highlighting the vocational aspects of the subject. The syllabus has the following components:

- pure science 70%
- applications of science 22.5%
- science for citizens 7.5%

These provide a context which facilitates students in understanding and applying physical laws and theories. Exemplars relevant to their own lives are included wherever possible. This approach ensures that physics contributes to a broad, balanced education.

1.3 STRUCTURE AND FORMAT OF THE SYLLABUS

The syllabus is presented at two levels–Ordinary level and Higher level. The Higher level includes two options, one of which must be taken. There are no options at Ordinary level.

The syllabus is presented in four columns:

- content
- depth of treatment
- activities
- science, technology and society (STS).

The syllabus document includes the mathematical requirements of the syllabus and a list of required physical quantities, their units and symbols. It also includes the formulas used in the syllabus and indicates which equations must be derived at Higher level. No derivations are required at Ordinary level.

1.4 MATHEMATICAL CONTENT

The mathematical requirements of the syllabus are clearly stated at both Higher and Ordinary level. Students are required to have an understanding of the concept of significant figures and to be able to use them as appropriate. Higher level Leaving Certificate mathematics is ***not*** required for physics. Further detail on the links between physics and mathematics is found in sections 3 and 4. The use of calculators is expected.

1.5 CONTENT

The content is drawn from the major areas in physics: mechanics, heat, waves (including light and sound), electricity, and modern physics. At Higher level option 1 is particle physics and option 2 is applied electricity.

1.6 DIFFERENTIATION BETWEEN HIGHER AND ORDINARY LEVEL

There are clear differences between the Higher and Ordinary level in structure, depth of treatment, and mathematical requirements. These differences are stated throughout the syllabus. The assessment of the syllabus will reflect the two levels. Throughout these teacher guidelines both levels are catered for, except in section 5 (particle physics) which is Higher level material only. Section 3 describes the approach required at Ordinary level, and section 4 describes the approach required at Higher level. It is expected that most physics classes will be mixed, i.e. Higher level and Ordinary level students in the same class.

1.7 TEACHING STRATEGIES

The syllabus needs to be taught in an active way that reflects the balance between pure physics (approximately 70%) and the applications of science and science for citizens (approximately 30%). The use of teaching aids such as computers, videos, slides etc. is encouraged. Active teaching strategies for STS are suggested in section 2. It is important that teaching strategies reflect the aims and objectives of the syllabus.

Practical work continues to be a priority. Students must follow a course of practical work. Required experiments are listed at the end of each section of the syllabus; there is a total of 22 such experiments at Ordinary level and 24 at Higher level. These experiments must be carried out and an adequate record of such work retained for the period of the course. Throughout the syllabus, teacher demonstrations and additional student experiments are listed. These are important, as they contribute to students' understanding of physics.

It is not intended that the syllabus be taught as a set of independent topics, but that the links and overall patterns occurring throughout the syllabus should be emphasised. It should be noted that the structure and order of the syllabus do not imply a particular teaching order.

1.8 EQUIPMENT

The laboratory equipment required for student experiments and teacher demonstrations is very similar to that required by the previous syllabus. The revised syllabus has few additional resource implications where a school was equipped to teach the previous syllabus. Laboratory access is essential for the full implementation of the syllabus. Ready access to information and communication technologies is highly desirable.

Details of resources, other than laboratory equipment, are given in section 7.

1.9 TIMETABLING

The syllabus requires 180 hours of teaching time over two years. This includes the time required for students' experiments, but excludes time lost to other school activities. This could be achieved by having five forty-minute class periods per week, two of which should be timetabled together to allow the students sufficient time to carry out the required experiments.

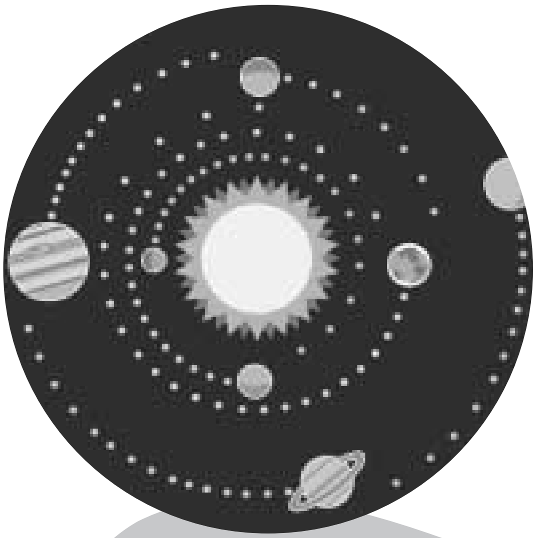
1.10 VOCATIONAL EMPHASIS

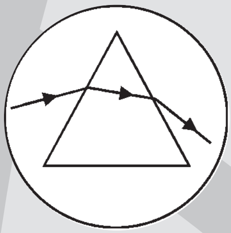
The inclusion of the applications of physics will enable students to see where physics applies in the world of work. For those taking the Higher level course, option 2 (Applied Electricity) may be particularly relevant in this regard. Physics is now included in the vocational subject groupings of the LCVP. Students taking physics as a subject in the LCVP may now, through the link modules, develop a deeper understanding of the vocational aspects of physics.

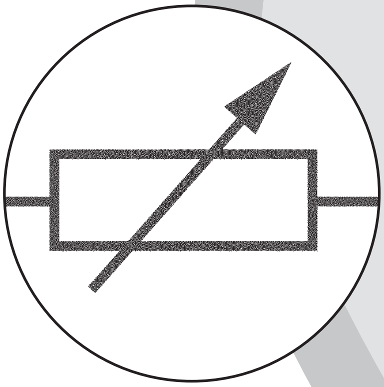
1.11 CONCLUSION

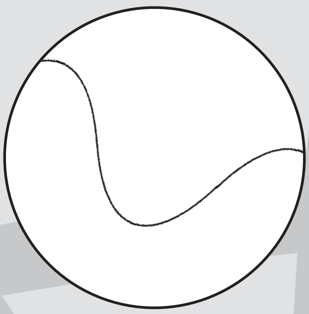
In this section, a brief introduction to the syllabus has been given and some implications for the teaching of the syllabus have been drawn out. The syllabus aims to give students an understanding of the fundamental principles of physics and their application to everyday life and technology. It also aims to develop an appreciation of physics as a creative activity and to develop an understanding of the beauty and simplicity of nature.

Section two
science, technology and society









2.1 INTRODUCTION

The different components of the syllabus, their proportion and recommended time allocation are shown:

- pure science 70%, 126.0 hours
- applications of science 22.5% 40.5 hours
- science for citizens 7.5% 13.5 hours

The applications of science and science for citizens can be considered under the heading of science, technology and society and are presented in column 4 of the syllabus. Many of the activities in column 3 will also reflect the applications of physics. The introduction and integration of science, technology and society in the physics syllabus is an important change. It has consequences for the teaching and the assessment of Leaving Certificate physics at both Ordinary and Higher level.

This section of the teacher guidelines includes a brief discussion of the nature of physics, its place in the everyday world, and its usefulness with regard to careers. Physics in the senior cycle curriculum is reviewed, and the interaction between physics and other subjects in the senior cycle is briefly discussed. The rationale for the introduction of science, technology and society is presented. Examples of both the "applications of science" and of "science for citizens" and the means by which they can be integrated into physics classes are discussed. Resources that may be useful in the teaching of science, technology and society are mentioned.

2.2 THE NATURE OF PHYSICS

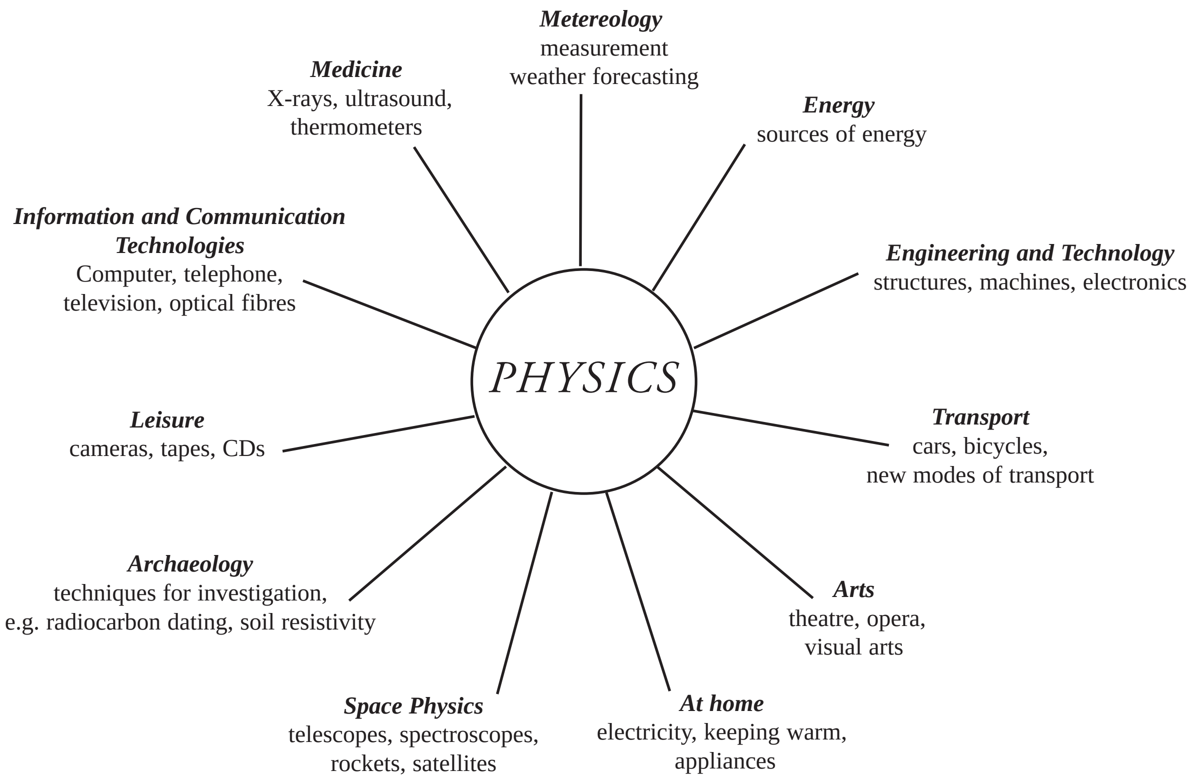
Physics is the branch of science that studies forces, matter, and energy. It was originally called natural philosophy. A knowledge of physics is fundamental to an understanding of the world around us. There is an accepted body of knowledge, which can be tested by experiment and verified or disproved. The "facts" are an agreed presentation of our understanding of the Universe. This understanding can be questioned and adapted if necessary. The presentation of some of the facts has to be adapted to the students' level of comprehension.

It is all too easy for students to think that there is only one "right" answer to each problem, and that physics has nothing to do with people. The opposite is the case: the study of physics is a social activity, and the truth of "facts" needs to be questioned. An awareness of the nature of science can help teachers to place people at the centre of physics and thus enable students to see how relevant physics is to themselves.

2.3 PHYSICS AND THE EVERYDAY WORLD

Physics is an integral part of the everyday world. It is through linking the study of physics to the everyday world that it becomes a meaningful part of a general education. Some of the links are shown in Fig. 2.1 opposite. Many subjects draw on the techniques developed by physics to lead to a new understanding of their field. Instruments developed by physicists have led to a new understanding of the human body and to many new medical treatments.

Fig. 2.1 Physics and the everyday world



2.4 PHYSICS AND CAREERS

Physics contributes to a student's future career in many ways. It helps, in conjunction with the other Leaving Certificate subjects, to provide a broad, balanced education for any student. Physics teaches students to think logically and enables them to express their thoughts in a concise manner. The skills and knowledge developed through their study of physics can be useful in a wide variety of situations.

Physics is a useful subject for many courses and careers and a good foundation for a broad range of scientific and technical careers. Many careers benefit from the logical and numeracy skills developed by the study of physics. Many technical courses involve components of physics.

Students may move into employment or into further study following their two years of physics. They may choose a post Leaving Certificate course (PLC) or move on into third level. Physics and physics-related courses may be taken at certificate, diploma and degree level in third-level institutions.

For students who are interested in proceeding further with physics, the Institute of Physics provides information on the range of careers that students can follow after their study of physics at third level (see section 7.9).

2.5 PHYSICS AND THE SENIOR CYCLE CURRICULUM

Physics helps students understand the world in which they live. The concepts of physics explain many of the wonders of our everyday lives. It is the role of physics in the general education of Leaving Certificate students that is emphasised in the syllabus and is supported, in particular, by the science, technology and society component of the syllabus. A further aim is to help them develop the ability to understand certain social issues that they, as citizens, may encourage in their lives. The syllabus also introduces students to the world of physics and aims to interest them in proceeding with further studies in physics or the technical areas of engineering, which can be considered as applied physics. Physics contributes in an important way to providing students with a broad general education, as well as preparing them for further education.

2.6 INTERACTION OF PHYSICS WITH OTHER SUBJECTS

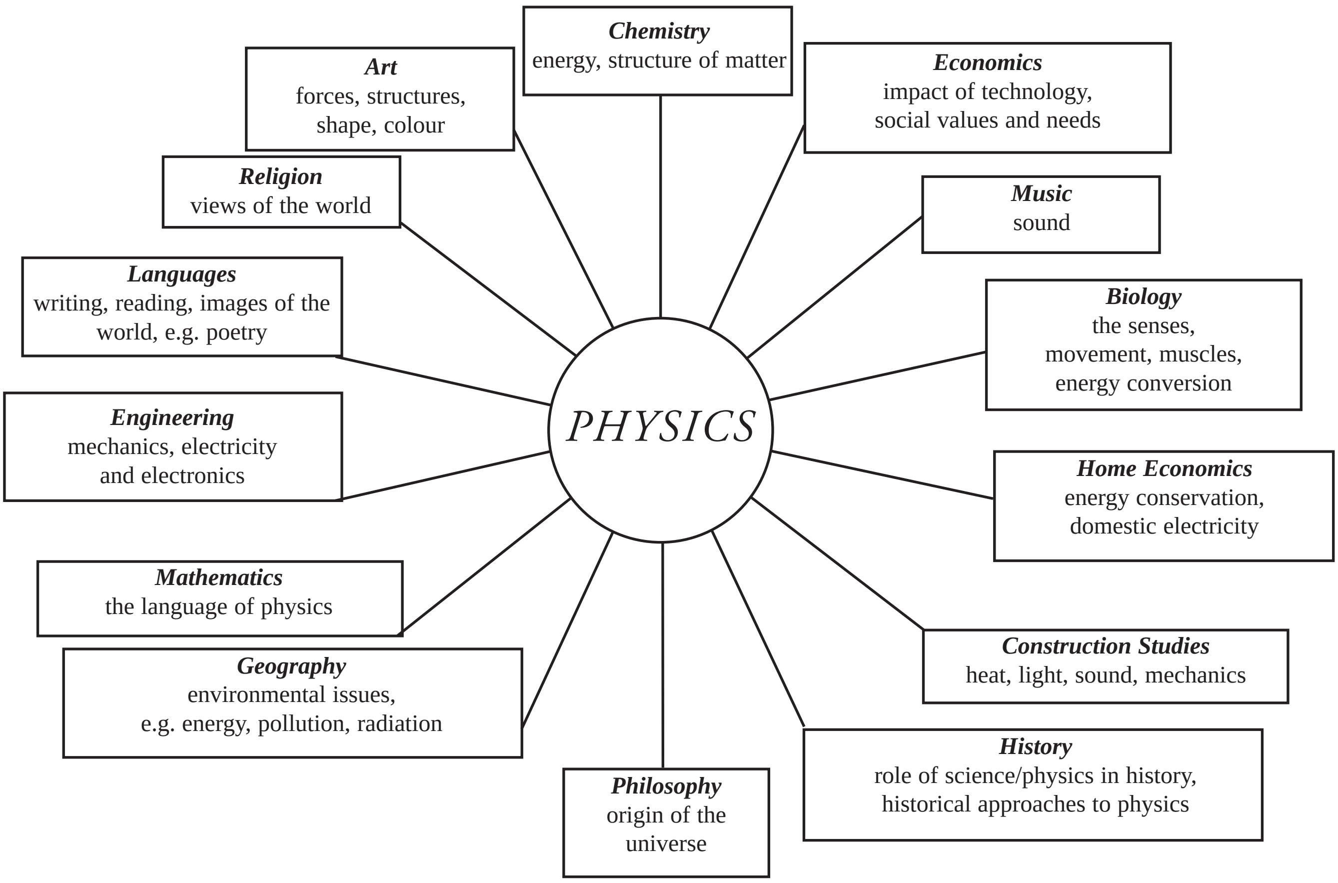
There are links between physics and many subjects, including languages, music, and art. Fig. 2.2 shows some possible areas of overlap. Philosophy is included, as it is an important area of knowledge that underpins the curriculum, although it is not a senior cycle subject.

One new opportunity for links with other subjects is the Action Projects in Junior Certificate civic, social and political education (CSPE). Where CSPE students have chosen an Action Project that requires an understanding of basic physics (for example, the problem of radon levels in an area) physics students could be a resource in helping them understand the basic concepts.

There are plenty of examples of cross-curricular links. In the poem 'Among School Children' W. B. Yeats refers to Pythagoras, whom he considers a great artist because he discovered the relationship between the length of vibrating strings and the frequency of musical notes.

Other poets who draw on scientific ideas to provide metaphors or similes for their poems include Shakespeare and Wordsworth. On the other hand, Joyce's rich and inventive language has provided physics with the name for the quark, which is believed to be a fundamental particle in the structure of matter.

Fig. 2.2 Interaction of physics with other subjects



2.7 SCIENCE, TECHNOLOGY, AND SOCIETY

Science, technology and society was introduced as a component of the syllabus to allow teachers the time to develop the students' interest in the applications of physics and its place in their world. Science, technology and society (STS) puts physics into context, reinforces theory with practical examples and applications from everyday life, and should help to broaden students' understanding of physics. It should help to develop positive attitudes towards physics.

STS includes both the "applications of physics" and "science for citizens". The structure of the syllabus includes science, technology and society as an integral component in column 4. The examples given in the syllabus are illustrative, and additional relevant applications will be acceptable. It is important to include personal, medical, biological, historical and social examples of the applications of physics as well as technical examples.

It is through STS that a number of the objectives of the syllabus can be met. STS should help students to interpret popular science writing and to relate scientific concepts to issues in everyday life. It will help them to explain the science underlying familiar facts, observations and phenomena and to suggest scientific explanations for unfamiliar facts.

Social, economic and environmental issues that can arise from the teaching of physics include: energy efficiency and energy conservation, nuclear energy, radon levels in buildings and electromagnetic fields in the vicinity of power lines. Some of these issues may be highly controversial, but it is through a critical analysis of such issues that students learn to make balanced, well-informed judgements about contemporary issues related to physics. The need to discuss events such as the Chernobyl accident and to interpret the information given in the media in a balanced way demands that teachers are themselves up-to-date and informed. Controversial and other social issues are evident in newspaper and magazine articles, television and radio programmes. Advertisements can also reflect social issues related to physics. Teachers need to be able to cope with a wide range of views on such issues. Students, through debate, should be encouraged to respect other views, to evaluate divergent opinions and, with all the relevant facts, complete their judgements.

Linking the concepts of physics to the everyday world helps students to relate to physics, to see its relevance, and to decide whether or not they wish to proceed with further studies or to seek employment in an area where their knowledge of physics would be beneficial.

2.8 TEACHING STS

The teaching of the science, technology and society component of the syllabus should be an integral part of the teaching of physics and will require new teaching strategies. It will require from teachers an openness, a willingness to learn, to keep up to date and to admit to the limits of knowledge. Teachers will need to feel comfortable with the STS component of the syllabus in order to cope with it in the classroom.

In a particular syllabus topic, applications and possible social issues should be considered. They can be used in a variety of ways: as an introduction to new concepts, to reinforce concepts already learnt, or to apply physical principles to solving problems.

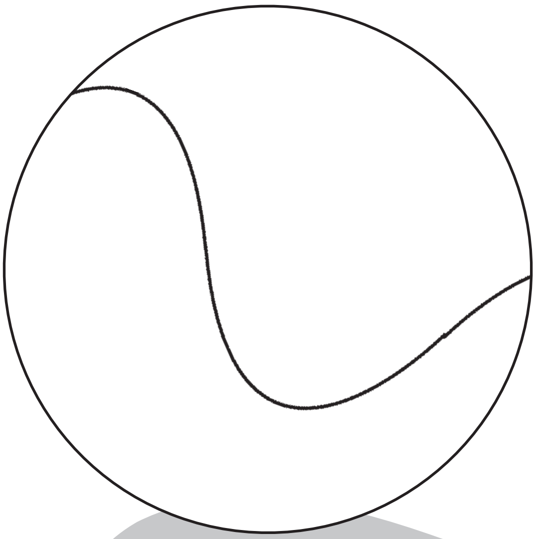
STS can be introduced in the classroom by a range of teaching strategies, including class discussions; debates; projects; role-playing; research using newspapers and magazines; analysis of videos; visits to local industries, hospitals, museums, etc.; and active reading. Students could discuss the role of X-rays in medicine and how their use affects humans through an increased level of exposure to ionising radiation. Role-playing may be used to set up a situation that would enable students to understand the time in which some of the scientific work was carried out; SATIS 16—19 *(see section 7)*, for example, has a useful one on the trial of Galileo. Students could meet local Civil Defence units to find out how they prepare to detect radiation in the event of a nuclear emergency.

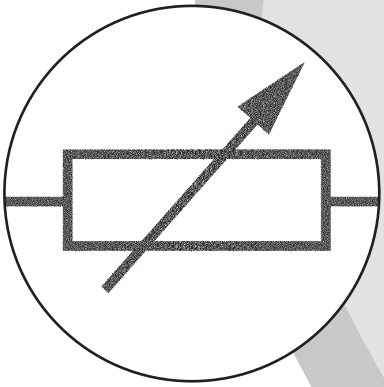
The generation of electricity through electromagnetic induction has changed the way people live and it could be a task to ask students to review how it has changed one aspect of their life. Students taking history, music, economics or engineering, could look at how the development of electricity affected these subjects; and a class review would enable all students to appreciate the social and environmental effects of this application of physics.

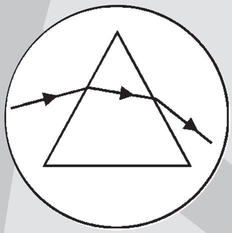
2.9 MATERIALS FOR TEACHING STS

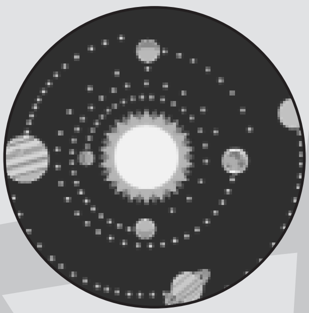
Many of the materials for the teaching of STS have been developed in other countries and need to be adapted for use in Ireland. Newspapers, magazines, radio and television programmes are also resources that can be tapped. A science noticeboard that is changed regularly might also be useful in highlighting issues in the media and in forthcoming science events, including television programmes. Some suitable materials and relevant addresses are given in section 7 of this document.

Section three
ordinary level physics









3.1 INTRODUCTION

Ordinary level physics provides an introduction to many physical concepts that are applied in industry, medicine, and everyday life. New approaches in the syllabus are identified and discussed. Issues such as language, mathematics and the teaching of physics at Ordinary level are also discussed.

3.2 ORDINARY LEVEL PHYSICS

Ordinary level physics provides an introduction to, and an overview of, physics. Students are expected to develop an understanding and appreciation of the fundamental laws and principles and their application to everyday life. The syllabus aims to stimulate students' interest and to challenge them to consider questions about the everyday world.

Ordinary level physics provides opportunities for students to develop skills and knowledge in a wide variety of areas. Practical work develops their understanding of concepts and their manipulative skills. Problem-solving develops both the students' numerical skills and their ability to think logically. The STS aspect of the syllabus will enable them to relate fundamental physical concepts to everyday life. This will enable them to appreciate the importance of physics as a fundamental science. Studying physics contributes to the personal development of students.

The vocational emphasis in the syllabus will enable students to appreciate that many courses and careers benefit from a basic knowledge of physics. Scientific, engineering and technical courses and careers and many jobs in new technological industries, such as electronics, benefit from an understanding of the physical concepts provided by Ordinary level physics.

3.3 NEW APPROACHES IN THE SYLLABUS

The syllabus is a revised syllabus rather than a completely new one. However, there are areas where a change of approach was considered necessary or appropriate. In this section these new approaches are outlined. There is a change of approach at Ordinary level in the following topics:

- conditions for equilibrium
- temperature and thermometers
- sound intensity level
- sources of emf
- conduction in materials
- electronics
- ionising radiation and health hazards.

Each of these is reviewed.

3.3.1 CONDITIONS FOR EQUILIBRIUM

The conditions for equilibrium include consideration of both the forces and the moments. Students are required to appreciate that, for equilibrium, forces are balanced, that is, that the sum of the forces in any direction equals the sum of the forces in the opposite direction, and also the sum of the moments about any axis is zero. It is important that students realise that the conditions apply in static situations, for example hanging a metre stick and weight from a stand, and in dynamic situations, for example a falling parachute when it has reached terminal velocity. Appropriate calculations involve forces in opposite directions and moments about one axis. The associated experiment is discussed in section 6.3.

3.3.2 TEMPERATURE AND THERMOMETERS

The definition of the kelvin was revised in 1990, and the precise definition is beyond the scope of the syllabus. Temperature is defined as a measure of the hotness or coldness of a body. A similar approach is taken to the unit of temperature as is taken to the units of mass, length, and time i.e., the definition is not required. The Celsius scale is the practical temperature scale, and it is defined in terms of the kelvin.

Thermometric property is defined, and a variety of thermometric properties are identified. In a school laboratory it is appropriate to use mercury-in-glass thermometers as standard thermometers, since they are portable, react quickly, have a suitable range, and can be clearly seen. A range of practical thermometers is also

considered: for example, it is appropriate to measure a child's temperature with a clinical thermometer or a colour thermometer. Thermometers do not always agree.
The activity described in the syllabus links this approach with the traditional reference points for the Celsius scale. The associated experiment is discussed in section 6.3.

3.3.3 SOUND INTENSITY LEVEL

An awareness of sound intensity levels and noise pollution is important to students as citizens. Students are to be introduced to the threshold of hearing and the frequency response of the ear. This can be easily demonstrated using a signal generator and loudspeaker. Individual differences and changing frequency responses with age need to be emphasised. Students can use sound level meters to measure sound intensity levels (in dB(A)) in a variety of local environments. Through this section students can begin to appreciate the effect of different sound intensity levels on hearing and how to protect their own hearing.

3.3.4 SOURCES OF EMF

The syllabus requires students to understand the definition of potential difference and to know that it is measured in volts. The fact that pd and voltage are different names for the same quantity is to be appreciated. When a voltage is applied to a complete circuit it is called an emf. This is also measured in volts. Sources of emf are to be reviewed.

3.3.5 CONDUCTION IN MATERIALS

The approach taken is to investigate conduction in circuit components through measurement of the current, *I*, and the pd, *V*, in appropriate circuits. The different *I-V* graphs lead to an appreciation of the nature of the materials and the charge carriers. The associated experiment is discussed in section 6.3.

3.3.6 ELECTRONICS

There is no separate section on electronics in the Ordinary level syllabus. Students are introduced to semiconductors as one of the materials studied in relation to conduction. This is followed by an overview of intrinsic and extrinsic conduction and the p-n junction.

3.3.7 IONISING RADIATION AND HEALTH HAZARDS

This approach in the syllabus extends the appreciation of health hazards associated with ionising radiation to include the type of source, the activity of the source, the time of exposure, and the type of tissue irradiated. The aim is to enable students to appreciate how exposure to ionising radiation can harm health and yet how ionising radiation can be used in the treatment of disease.

3.4 ISSUES IN ORDINARY LEVEL PHYSICS

Three aspects of Ordinary level physics are discussed in this section. They are language, mathematics and the teaching of physics at this level.

3.4.1 LANGUAGE

Learning physics requires appropriate language skills on the part of the student. Firstly, a reasonable command of a student's first language is required: students need to be able to understand and use words such as *estimate, phenomenon, illustrate, initial* and *accurate* or their equivalent in other languages. These non-technical words may be a barrier to students' understanding.
Secondly, students need to understand and be able to use technical words. Words such as *conservation, amplitude* and *force* are essential for working with the subject. At this level, students have to be able to distinguish between the everyday meaning of words such as *work, energy, pressure*, and *power*, and their technical meaning. Finally, students have to comprehend the language used in examinations and then convey their understanding of physics in writing.

As a general principle, it is agreed that students should be assessed on their knowledge, understanding and skills in physics, not their first language. However, it is important that they can use the language needed to display their knowledge, understanding, and skills.

Strategies for developing students' language confidence and competence are essential if Ordinary level students are to feel that they can 'do' physics. A number of approaches are possible. Students' comprehension of both technical and non-technical words can be helped by developing appropriate teaching strategies. These might include using illustrations and diagrams to complement the spoken word, compiling a glossary of technical terms as part of the summary or revision work on a topic, and providing opportunities for students to talk or write using the words in a range of contexts. This may seem to take up valuable classroom time, but if students do not comprehend the words used in class then they can make little sense of the work.

3.4.2 MATHEMATICS

Mathematics is the other language of physics. The mathematics required for Ordinary level physics is detailed in the syllabus, with the exception of the final bullet under geometry and trigonometry on page 45 of the syllabus. Skills in arithmetic, algebra, geometry, trigonometry, and drawing and interpreting graphs are required. The mathematics required is well within the demands of Leaving Certificate Ordinary level mathematics.

Students need to be confident in using scientific notation and powers of 10, clear about the concept of significant figures, and able to solve numerical problems. Derivations of equations are not required at Ordinary level. Using calculators to make calculations in scientific notation is an essential skill for students.

Physics has different mathematical demands from those of mathematics. Using significant figures is not as important in mathematics as in physics; and students need to understand why this system is used and how to work with significant figures. Although students use calculators in mathematics, this may not transfer to physics classes. Practice in working with relevant equations and in solving numerical problems is essential if students are to become competent. Graphics calculators and computer simulations may also help teachers and students understand how mathematics provides models of the physical world.

A positive attitude to mathematics in physics classes is important. There is a fine balance between doing sufficient mathematical work for students to become competent and deterring them with too much mathematics. The mathematical requirements of the physics syllabus may need to be reinforced in the physics class.

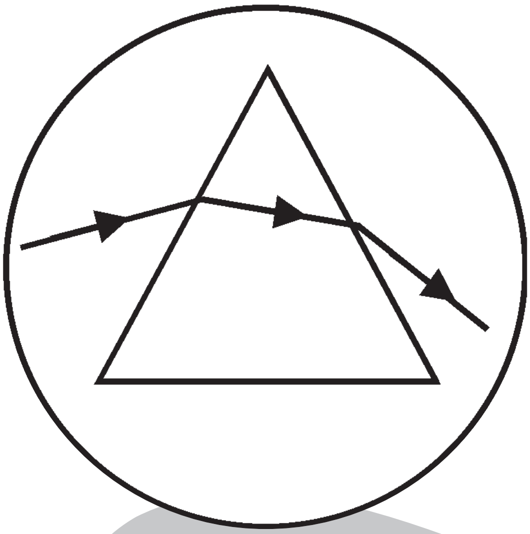
3.4.3 TEACHING ORDINARY LEVEL PHYSICS

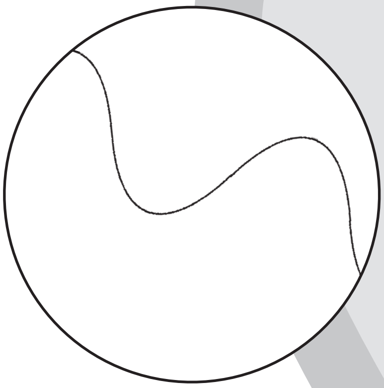
The revised syllabus is designed so that the Ordinary level syllabus may be taught in parallel with the Higher level syllabus. Ordinary level is seen as a broad general introduction to basic concepts in physics. The Ordinary level syllabus is set out with a clear set of objectives. The depth of treatment is clear, and the mathematical demands of the syllabus have been stated.

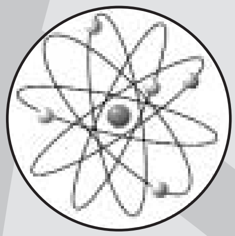
Teaching physics at Ordinary level is a challenge. The knowledge, understanding and skills to be developed are often demanding for students. Practical work has to be done. In practice, most teaching of physics takes place in mixed classes of Ordinary level and Higher level students. The consequence of this may be that Ordinary level may be invisible as a course, because the emphasis is on the Higher level from the start. There may be little time to explain concepts and develop understanding at the appropriate level, as the pace may be determined by the demands of Higher level. Parallel to this, exposure to Higher level may have an effect on students' self-esteem: they may feel inadequate if they cannot understand what is going on in the classroom. It is intended that the separate presentation of the Ordinary level and Higher level syllabuses should be helpful to teachers in this situation.

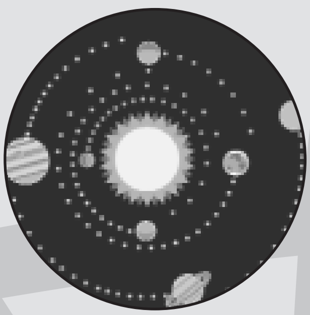
The revised syllabus should enable teachers to identify suitable activities for Ordinary level students to help them to develop the knowledge, understanding and skills required. In particular, STS provides a context within which physics relates to the everyday world.

Section four
higher level physics









4.1 INTRODUCTION

Higher level physics provides a foundation for many physical concepts that are developed and studied in industry, medicine, and everyday life. New approaches in the syllabus are identified and discussed. Issues such as language, mathematics and the teaching of physics at Higher level are also discussed.

4.2 HIGHER LEVEL PHYSICS

Higher level physics provides a deeper, more quantitative treatment of physics. Students are expected to develop an understanding and appreciation of the fundamental laws and principles and their application to everyday life. The syllabus aims to stimulate students' interest and to challenge them to consider questions about the everyday world.

Higher level physics provides opportunities for students to develop skills and knowledge in a wide variety of areas. Practical work develops their understanding of concepts and their manipulative skills. Problem-solving develops the students' numerical skills and their ability to think logically and to apply physical laws. The STS aspect of the syllabus will enable them to relate fundamental physical concepts to everyday life. This will help them to appreciate the importance of physics as a fundamental science. Studying physics contributes to the personal development of students.

The vocational emphasis in the syllabus will enable students to appreciate that many courses and careers benefit from a basic knowledge of physics. Some of these are outlined in section 2. Scientific, engineering and other technical and medical courses and careers require an understanding of physics, for which Higher level is a good foundation. Option 2, applied electricity, provides a particular opportunity for students to develop the vocational aspect of the Higher level course.

4.3 NEW APPROACHES IN THE SYLLABUS

The syllabus is a revised syllabus rather than a completely new one. However, there are areas where a change of approach was considered necessary or appropriate. In this section these new approaches are described. There is a change of approach at Higher level in the following topics:

- addition of vectors
- conditions for equilibrium
- simple harmonic motion
- temperature and thermometers
- sound intensity level
- sources of emf
- conduction in materials
- electronics
- ionising radiation and health hazards.

Each of these is reviewed.

4.3.1 ADDITION OF VECTORS

The addition of vectors has been restricted to perpendicular vectors. This means that vector addition can be done using scale diagrams or the theorem of Pythagoras. The vector nature of physical quantities such as force is to be emphasised. The resultant of perpendicular vectors can be found using newton balances or pulleys and weights. The practical measurement of the resultant should agree with the results obtained by either of these two methods.

4.3.2 CONDITIONS FOR EQUILIBRIUM

The conditions for equilibrium include consideration of both the forces and the moments. Students are required to appreciate that, for equilibrium, the vector sum of the forces in any direction is zero and also the sum of the moments about any axis is zero. It is important that students realise that the conditions apply in static situations, for example hanging a metre stick and weight from a stand, and in dynamic situations, for example a falling parachute when it has reached terminal velocity. Appropriate calculations involve forces in opposite directions and moments about an axis. The concepts here are very similar to those at Ordinary level, but the language used is more formal. The associated experiment is discussed in section 6.3.

4.3.3 SIMPLE HARMONIC MOTION

Students can observe a variety of oscillating systems, for example an oscillating spring, a swinging pendulum, an oscillating magnet, a ball moving on a curved track, etc. Those that oscillate with simple harmonic motion can be identified. The importance of such motion in everyday life could then be reviewed, for example oscillating air particles transfer sound energy, oscillating particles in a solid transfer heat energy. The importance of being aware of such motion in any system can be conveyed by watching the *Tacoma Narrows Bridge* video. The theory of SHM is approached through Hooke's law. As this is not on the Junior Certificate science syllabus it may be necessary for students to experience through experiment the fact that the extension of a spiral spring is proportional to the force applied to it. Another way of expressing this is that the restoring force is proportional to the displacement from rest. As these are in opposite directions,

$$F \propto -s$$

$$F = -ks$$

$$ma = -ks$$

$$a = -(k/m)\,s = -\omega^2 s$$

This approach leads to the standard definition of SHM. It can then be deduced that systems that obey Hooke's law execute simple harmonic motion with a periodic time of $T = 2\pi/\omega$. The value of the constant ω depends on the system.

4.3.4 TEMPERATURE AND THERMOMETERS

The definition of the kelvin was revised in 1990, and the precise definition is beyond the scope of the syllabus. Temperature is defined as a measure of the hotness or coldness of a body. A similar approach is taken to the unit of temperature as is taken to the units of mass, length, and time i.e., the definition is not required. The Celsius scale is the practical temperature scale, and it is defined in terms of the kelvin.

Thermometric property is defined, and a variety of thermometric properties are identified. In a school laboratory, it is appropriate to use mercury-in-glass thermometers as standard thermometers since they are portable, react quickly, have a suitable range, and can be clearly seen. A range of practical thermometers is also considered: for example, it is appropriate to measure a child's temperature with a clinical thermometer or a colour thermometer. Thermometers do not always agree. The activity described links this approach with the traditional reference points for the Celsius scale. The associated experiment is discussed in section 6.3.

4.3.5 SOUND INTENSITY LEVEL

Sound intensity as a physical quantity and its unit are defined. Students are to be introduced to the threshold of hearing and the frequency response of the ear. The frequency limits of audibility can be demonstrated using a signal generator and loudspeaker. Individual differences and changing frequency responses with age need to be emphasised. The decibel as a unit of sound intensity level is to be introduced and examples of sound intensity levels discussed and if possible demonstrated. Students can use sound level meters to measure sound intensity levels (in dB(A)) in a variety of local environments. Through this section students can begin to appreciate different sound intensity levels, their effect on hearing and how to protect their own hearing. In particular, attention should be drawn to the fact that an increase of 3 dB in sound intensity level is caused by a doubling of sound intensity. An awareness of sound intensity levels and noise pollution is important to students as citizens.

4.3.6 SOURCES OF EMF

The syllabus requires students to understand the definition of potential difference and to know that it is measured in volts. The fact that pd and voltage are different names for the same quantity is to be appreciated. When a voltage is applied to a complete circuit it is called an emf. This is also measured in volts. Sources of emf are to be reviewed.

4.3.7 CONDUCTION IN MATERIALS

The approach taken is to investigate conduction in circuit components through measurement of the current, *I,* and the pd, *V,* in appropriate circuits. The different *I-V* graphs lead to an appreciation of the nature of the materials and the charge carriers. The associated experiment is discussed in section 6.3.

4.3.8 ELECTRONICS

Students are introduced to semiconductors as one of the materials studied in relation to conduction. This is followed by an overview of intrinsic and extrinsic conduction and the p-n junction. Option 2, applied electricity, examines the applications of diodes, the transistor, and some basic circuits, including logic gates.

4.3.9 IONISING RADIATION AND HEALTH HAZARDS

The approach in the syllabus extends the appreciation of health hazards associated with ionising radiation to include the type of source, the activity of the source, the time of exposure, and the type of tissue irradiated. The aim is to enable students to appreciate how exposure to ionising radiation can harm health and yet how ionising radiation can be used in the treatment of disease.

4.4 ISSUES IN HIGHER LEVEL PHYSICS

Three aspects of Higher level physics are discussed in this section. They are language, mathematics, and the teaching of physics at this level.

4.4.1 LANGUAGE

Higher level physics requires appropriate language skills on the part of the student. Firstly, a reasonable command of a student's first language is required: that is they need to be able to understand and use words such as *estimate, phenomenon, illustrate, initial* and *accurate* or their equivalent in other languages. Secondly, students need to understand and be able to use technical words. Words such as *conservation, amplitude* and *force* are essential in working with the subject. At this level, students have to be able to distinguish between the everyday meaning of words such as *work, energy, pressure* and *power*, and their technical meaning. Finally, students have to comprehend the language used in examinations and then convey their understanding of physics in writing.

As a general principle it is agreed that students should be assessed on their knowledge, understanding and skills in physics, not their first language. However, it is important that they can use the language needed to display their knowledge, understanding, and skills.

Strategies for developing students' language confidence and competence are essential if Higher level students are to feel that they can 'do' physics. A number of approaches are possible. Students' comprehension of both technical and non-technical words can be helped by developing appropriate classroom strategies. These might include using illustrations and diagrams to complement the spoken word, compiling a glossary of technical terms as part of the summary or revision work on a topic, providing opportunities for students to talk or write using the words in a range of contexts. This may seem to take up valuable classroom time but if students do not comprehend the words used in class then they can make little sense of the work.

4.4.2 MATHEMATICS

Mathematics is the other language of physics. The mathematics required for Higher level physics is detailed in the syllabus. Skills in arithmetic, algebra, geometry, trigonometry, vectors, and drawing and interpreting graphs are required. Leaving Certificate Higher level mathematics is not required, but a level of competence and confidence is essential if students are to cope with the mathematical demands of Higher level physics.

Students need to be confident in using scientific notation and powers of 10, clear about the concept of significant figures, and able to solve numerical problems. A number of derivations of equations are required at Higher level; those equations that must be derived are indicated clearly in the syllabus. Deriving an equation is important if students are to appreciate how laws and principles are developed.

Physics has different mathematical demands from those of mathematics. At Higher level, students are expected to use significant figures and calculators accurately. Practice in working with equations and solving numerical problems is essential if students are to become competent. Graphics calculators and computer simulations may also help teachers and students understand how mathematics provides models of the physical world. The mathematical requirements of the physics syllabus may need to be reinforced in the physics class.

A positive attitude to mathematics in physics classes is important. If students can appreciate the relevance of mathematics, they may find it easier to do the work needed to master the necessary skills. Using mathematics appropriately in a physical context is an important skill.

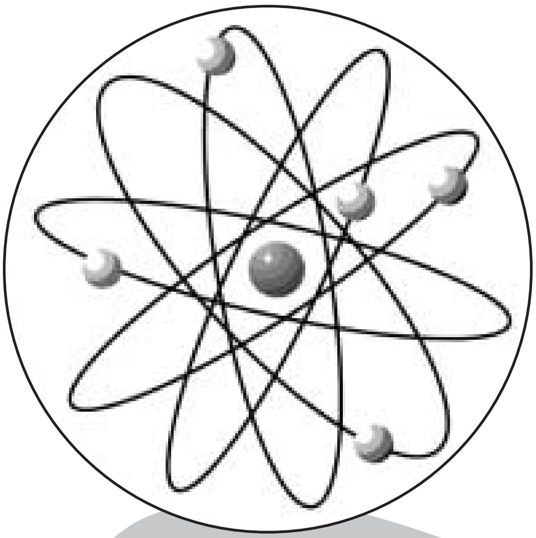
4.4.3 TEACHING HIGHER LEVEL PHYSICS

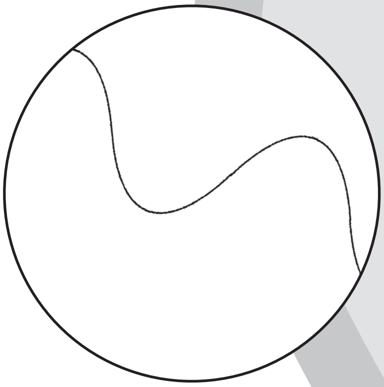
Higher level physics is intellectually demanding. Students need to understand the concepts and apply them in different contexts. The Higher level syllabus is set out with a clear set of objectives. The depth of treatment is clear, and the mathematical demands of the syllabus have been stated.

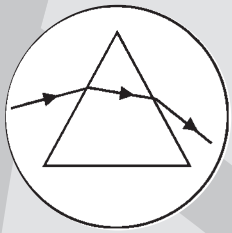
Teaching physics at Higher level is challenging. The knowledge, understanding and skills to be developed are often demanding for students. Practical work has to be done. The Higher level syllabus is an extension and deepening of the Ordinary level syllabus. In practice, most teaching of physics takes place in mixed classes of Ordinary level and Higher level students. It is intended that the separate presentation of the Ordinary level and Higher level syllabuses should be helpful to teachers in this situation.

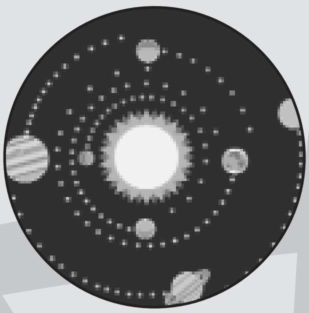
The revised syllabus should enable teachers to identify suitable activities for Higher level students to enable them to develop the knowledge, understanding and skills required. In particular, STS provides a context within which physics relates to the everyday world.

Section five
particle physics
option 1: higher level





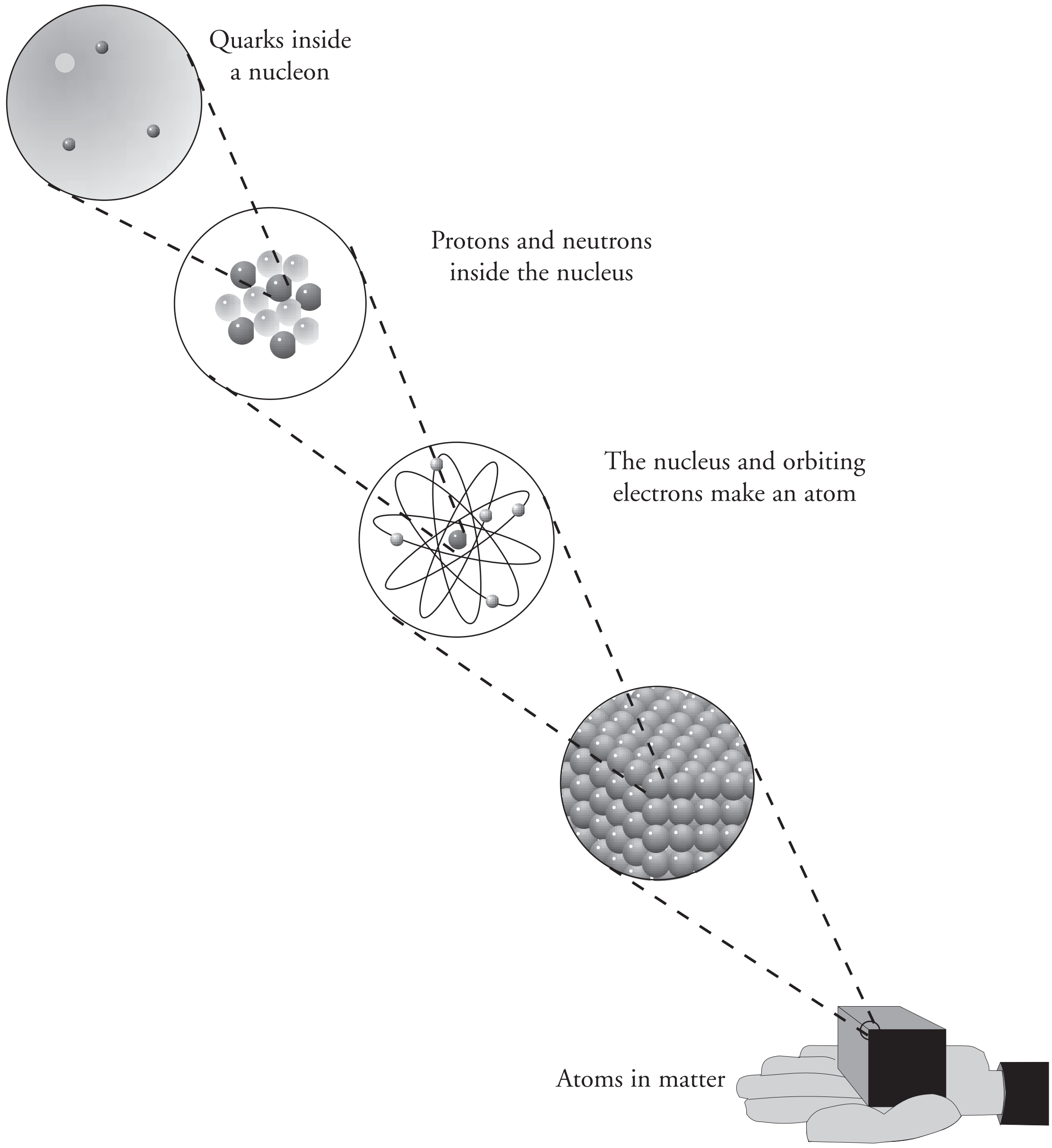




5.1 INTRODUCTION

Particle physics is one of the most dynamic areas of research in physics in recent years. This option aims to reflect, at an appropriate level, the current ideas in particle physics and is completely new to the syllabus. This section includes student materials, teacher materials, worked problems and graphics to support the introduction of particle physics in the classroom.

The student materials provide the details for the teaching of particle physics, a useful newspaper article, and a problem sheet for presenting to students. The student materials conclude with a summary of the principal points in particle physics and a glossary of terms. The student materials are accompanied by teacher materials including solutions to the problems, and graphics.



5.2 STUDENT MATERIALS

The world around us is made of chemical elements and compounds, which are really just combinations of molecules and atoms. The atoms themselves are made up of protons, neutrons, and electrons. Empedocles has said that all things are made of earth, air, fire, and water. We now know much more about the ultimate building blocks of matter than the Greeks did in 400 BC, but the search for fundamental particles, i.e. particles that have no constituents, goes on.

At the beginning of the 1930s the problem appeared to be solved. There appeared to be just three ultimate building blocks: the proton, the neutron, and the electron. These made up the atoms of the various elements; and combinations of atoms made up molecules of chemical compounds. A very simple picture of the nature of all matter appeared to be established.

CONSERVATION OF ENERGY AND MOMENTUM IN NUCLEAR REACTIONS

In alpha decay of a given type of radioactive nucleus, it is observed that all the alpha particles are emitted with the same energy. This is because the disintegration gives rise to two particles, the alpha particle moving one way and the recoiling nucleus moving in the opposite direction. The situation is similar to that of a bullet fired from a gun, which recoils in the opposite direction. The amount of energy available is fixed, and the principle of conservation of momentum determines how the energy is divided.

In the case of beta decay, the energy of the emitted electrons is distributed over a given range. This led to the prediction that a third particle must be present, which takes up some of the energy and ensures that energy and momentum are conserved, as required. This particle was called the “neutrino”. It has no charge and is very difficult to detect directly. Its existence was deduced by Wolfgang Pauli in 1932 from the principle of conservation of momentum. The neutrino was first observed in 1956.

ACCELERATION OF PROTONS

The experimental study of the atomic nucleus took a great stride forward in 1932, when Cockcroft and Walton developed a linear accelerator in which protons could be accelerated through a potential difference of 700 000 V. (This gave them an energy of 0.7 MeV.) When these protons were used to bombard a lithium target, a very surprising thing happened. Alpha particles were observed on a fluorescent screen. The first induced nuclear transformation using artificially accelerated particles had taken place. The proton collided with the lithium nucleus, to produce the *nuclear reaction:*

$$ {}^{1}_{1}\text{H} + {}^{7}_{3}\text{Li} \rightarrow {}^{4}_{2}\text{He} + {}^{4}_{2}\text{He} + Q \text{ (17.3 MeV)} $$

The energy Q was shared equally between the two alpha particles that emerged in opposite directions, each with a range of 8.3 cm in air, corresponding to an energy of 8.65 MeV.

CONVERTING MASS INTO OTHER FORMS OF ENERGY

Two very interesting and fundamental things had happened in the Cockroft-Walton experiment. The first was that the *nucleus* of the lithium atom had been split, producing an entirely different element — helium. The second was the fact that more energy came out than had been put in. *Nuclear energy* had been released. Where does this energy come from?

In 1905, Albert Einstein, in his *Special Theory of Relativity*, had stated that mass is a form of energy and mass can be changed into other forms of energy. The rate of exchange deduced by Einstein was given by the equation $E = mc^2$. Since the value of c is very large, the equation predicts that a very large amount of energy would be obtained if it were possible to annihilate even a small amount of mass. Einstein was unable to test his equation experimentally, but the nuclear reaction above is an example of mass being converted into another form of energy, on a small scale. We can see how the “accounts balance” in this reaction by using the table of nuclear masses below.

TABLE 1. NUCLEAR MASSES

${}^{1}_{1}\text{H}$	1.0073 u
${}^{4}_{2}\text{He}$	4.0015 u
${}^{7}_{3}\text{Li}$	7.0143 u

Since mass is a form of energy, it is possible to use the same units for both. The conversion factor is 1 atomic mass unit (u) = 931.5 MeV.

Note: $1 \text{ u} = 1.66 \times 10^{-27}$ kg
$1 \text{ eV} = 1.6 \times 10^{-19}$ J

NUCLEAR ACCOUNTS

proton	1.0073 u	$2 \times {}^{4}_{2}He$ = 8.0030 u
${}^{7}_{3}Li$	7.0143 u	
	8.0216 u	

Mass “lost” = 0.0186 u = 17.3 MeV

Note: The percentage of mass converted into other forms of energy in this reaction is only 0.23%.

CONVERTING OTHER FORMS OF ENERGY TO MASS

Converting mass to other forms of energy is obviously of great practical importance if it can be achieved in a controlled fashion and with proper safeguards. The opposite process—converting other forms of energy to mass—is something that became possible with the advent of large circular accelerators *(synchrotrons)* capable of accelerating protons to energies many thousands of times greater than those achieved in the Cockcroft and Walton machine.

The idea behind the design of synchrotrons is to make a batch of charged particles (usually protons) travel many times, in a circular path, in a tube that is highly evacuated. At various points, special devices called “cavities” provide alternating electrical fields to accelerate the protons. The oscillations of the electrical forces in each cavity have to be synchronised with the arrival of the batch of particles, so that each time they pass through they gain energy—hence the name of the machine. The force to keep the particles travelling in a circular track is provided by powerful magnets placed around the path.

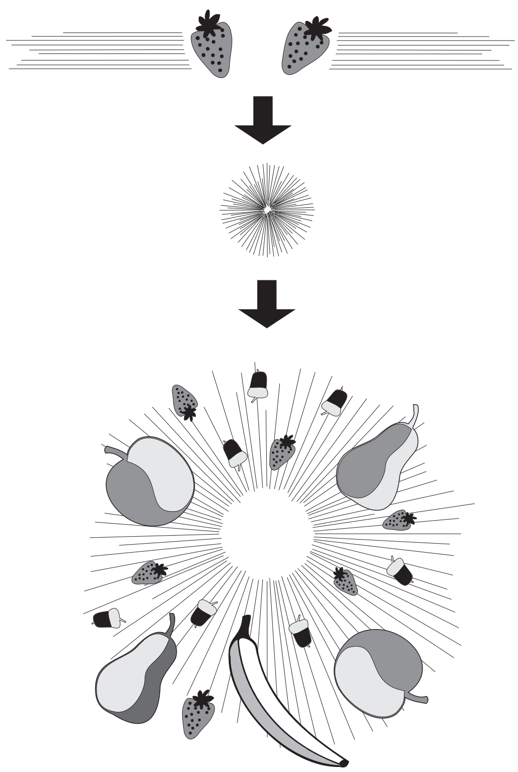
The energies obtained in modern accelerators are so high that they are usually expressed in giga-electron-volts (GeV) rather than mega-electronvolts (MeV).

$$1 \text{ GeV} = 1000 \text{ MeV} = 10^{9} \text{ eV}$$

Among the modern accelerators are the Super Proton Synchrotron (SPS) and Large Electron-Positron collider (LEP), both at the *European Organisation for Nuclear Research* (CERN) near Geneva. It is hoped to develop the Large Hadron Collider LHC, at CERN in the next ten years.

COLLISION OF UNBREAKABLE OBJECTS

In the Super Proton Synchrotron at CERN, built in 1980, protons of energy 450 GeV collide with stationary protons in a target. The result is quite different from what happens in a collision of two snooker balls, or even in the Cockcroft-Walton experiment, where a proton interacts with a complex lithium nucleus. Two protons are generally unbreakable objects: neither can fragment into anything smaller. Part of the tremendous energy of the collision is converted into mass, fundamental particles are created, and these fundamental particles continue forward with velocities close to the speed of light. Some of these particles may be known already; some are entirely new. We have no control over what kinds of particles are created in any particular interaction.



(CERN)

FUNDAMENTAL FORCES OF NATURE

The four forces of nature are gravitation, electromagnetism, the strong nuclear force, and the weak nuclear force. All are "actions at a distance". Gravitation and forces between charges are governed by an inverse square law, which is of unlimited range. Nuclear forces fall off much more quickly with distance and are negligible outside nuclear distances (10^{-15} to 10^{-14} m).

Fundamental forces	***Relative Strength***
Gravitational force	1
Weak nuclear force	10^{25}
Electromagnetic force	10^{35}
Strong nuclear force	10^{38}

The gravitational interaction between the particles at nuclear distances is so weak that it can be neglected.

FAMILIES OF PARTICLES

It is through collisions of particles in accelerators that a large number of new fundamental particles have been discovered. This is sometimes called the "Particle Zoo". The particles are symbolised by Greek and Roman letters. Some particles are positively charged, some are negatively charged, and some are neutral.If charged, the charge is always one unit, that is ±e.

A typical high energy proton reaction may be:

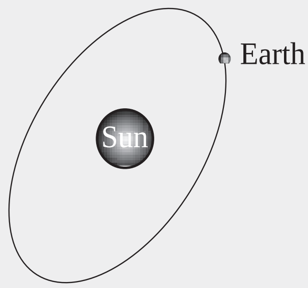
$$p + p \rightarrow p + p + \pi^{+} + \pi^{-} + \pi^{o} + ...$$

A large number of π mesons are created in this reaction. The meson is a particle with a mass intermediate between that of the electron and that of the proton. The π meson was in fact originally discovered in 1947 in an interaction caused by a cosmic ray proton at the top of the atmosphere.

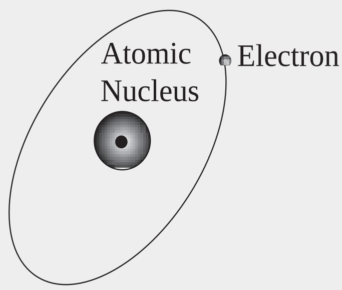
In the 1950s and early 1960s hundreds of fundamental particles were discovered and studied. Practically all of them are unstable, and decay spontaneously to other particles, with mean lifetimes sometimes as short as 10^{-23} s. They are subject to the four fundamental forces of nature.

FUNDAMENTAL FORCES OF NATURE

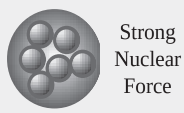
Gravitation: Keeps Earth and planets in orbit. Gives rise to weight.



Electromagnetism: Forces between charges. Binds atoms together. Gives rise to chemical reactions between atoms and molecules.



Strong nuclear force: Basic force between quarks. Binds protons and neutrons together.



Weak nuclear force: Involved in radioactive decay.

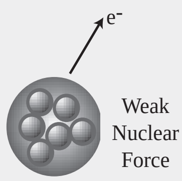


TABLE 2. BETTER-KNOWN MEMBERS OF THE PARTICLE ZOO

Class	Name	Symbol	Mass *(mass of electron = 1)*	Mean life	Year of discovery
LEPTONS	Neutrino	ν	$< 10^{-3}$	stable	1956 (predicted 1931)
	Electron	e	1	stable	1897
	Heavy Electrons – muon	$\mu^- \mu^+$	207	2×10^{-6} s	1937
	Heavy Electrons – tau	$\tau^- \tau^+$	3500	10^{-12} s	1975
MESONS	Pi meson	$\pi^+ \pi^-$	273	2.6×10^{-8} s	1947
		π^o	264	8.4×10^{-17} s	
	K meson	$K^+ K^- K^o$	≈ 970		1947
BARYONS	Proton	p	1 836	$> 10^{32}$ yrs	1897
	Neutron	n	1 839	960 s	1932
Hyperons	Lambda	Λ^o	2 183	2.6×10^{-10} s	1947
Hyperons	Sigma	$\Sigma^+ \Sigma^- \Sigma^o$	2 327	approx. 10^{-10} s	1953
Hyperons	Chi	$\Xi^+ \Xi^- \Xi^o$	2 573	approx. 10^{-10} s	1954
Hyperons	Omega	Ω^-	3 272	approx. 10^{-10} s	1964

The particles have been classified into groups according to their properties. All particles feel the gravitational force, although it is so weak that it can be ignored. All classes of particles that carry electric charge are subject to the electromagnetic force in addition to the nuclear force.

One of the most important properties of ***leptons*** is that they feel the weak nuclear force and do not participate in strong nuclear interactions.

Neutrinos feel only the weak force. Their interactions are so weak that most cosmic ray neutrinos go right through the Earth. Their mean free path in matter is approximately 10^6 km.

Mesons and ***baryons*** feel the strong nuclear force. If charged, they also feel the weak force and the electromagnetic force. Mesons and baryons can be grouped together as hadrons.

ANTIMATTER

When Paul Dirac set out in 1927 to combine Einstein's theory of relativity with quantum theory he obtained an extraordinary result: the equations gave two solutions, with positive and negative values for the energy of a free electron. The temptation was to dismiss the negative solution as "non-physical", but Dirac was not prepared to do this. He suspected that "the equations were trying to tell us something".

The most obvious explanation for the particular result that came from the mathematics was the existence of a particle with "opposite properties" to that of the electron, the particle under consideration in Dirac's equations. At first Dirac did not dare to postulate the existence of such a particle, as the whole climate of opinion in those days was against the addition of new entities to the list of the "fundamental building blocks of matter". Finally, it became obvious that there must be a physical reality corresponding to the results given by the mathematics. Dirac predicted an "antiparticle" to the electron. Its properties, such as electric charge, would be equal in magnitude but opposite to those of the electron.

Some years later Carl C. Anderson observed exactly such a particle when he identified the tracks of an “electron-positron” pair created out of energy by cosmic radiation. We now know that not only the electron but every particle of matter has a twin composed of antimatter. Our part of the universe is composed of what we call “matter”, but examples of antimatter on our planet are present on a very small scale, as discussed below.

Some radioactive elements decay by beta emission of a positron. For example:

$$^{15}_{8}O \rightarrow \, ^{15}_{7}N + e^{+} + \nu$$

In medical imaging (positron emission tomography, PET) such elements are used as tracers to monitor, for example, the dissipation of a drug in the human body. When the positron is emitted it very quickly meets an electron, to produce the annihilation reaction

$$e^{+} + e^{-} \rightarrow \gamma + \gamma$$

The two gamma rays go off in opposite directions and can be detected to give an accurate fix on the position of the tracer.

In high-energy accelerators, pairs of protons and anti-protons can be produced in reactions such as

$$p + p \rightarrow p + p + p + \bar{p} + \pi^{+} + \pi^{-}$$

The antiproton ($\bar{p}$) has negative charge and a mass exactly equal to that of the proton.

It is quite conceivable that some of the distant galaxies are composed of antimatter. There is no reason why even living organisms should not exist in these galaxies. It may also be conjectured that at the 'big bang' of creation, matter and antimatter were created in equal amounts and then dispersed throughout the universe. If matter and antimatter were to meet, mutual annihilation would occur resulting in the release of great amounts of energy.

THE THREE-QUARK MODEL
How to bring order to the Particle Zoo

In 1964 Murray Gell-Mann and George Zweig introduced the idea that all the ***mesons*** and ***baryons*** in the Particle Zoo could be expressed in terms of three basic constituents, called ***quarks***.

TABLE 3. PROPERTIES OF QUARKS

Quark		Charge	Anti-quark	Charge
up	u	$+\frac{2}{3}$	$\bar{u}$	$-\frac{2}{3}$
down	d	$-\frac{1}{3}$	$\bar{d}$	$+\frac{1}{3}$
strange	s	$-\frac{1}{3}$	$\bar{s}$	$+\frac{1}{3}$

By combining the quarks in various ways all the mesons and baryons in the Particle Zoo can be constructed. The leptons are not composed of quarks and are fundamentally indivisible.

TABLE 4. CONSTITUENTS OF SOME OF THE BARYONS AND MESONS ACCORDING TO THE QUARK MODEL

Particle		Constituents
pi-meson	π^{+}	$u\bar{d}$
	π^{-}	$\bar{u}d$
K-meson	K^{+}	$u\bar{s}$
proton	p	uud
anti-proton	$\bar{p}$	$\bar{u}\bar{u}\bar{d}$
neutron	n	udd
lambda	Λ^{0}	uds
omega	Ω^{-}	sss

By adding the electric charges of the quarks it is possible to verify that the combinations in table 4 give the correct charge of the parent particles. The electric charge is just one property of the quarks in the model: there are many properties that all have to add up to give the right values. The model proved very successful and in fact predicted the existence of the last particle in table 2, the omega, which at the time had not been discovered. In 1969 Murray Gell-Mann was awarded the Nobel Prize for “his contributions and discoveries concerning the classification of elementary particles and their interactions”.

THE SIX-QUARK MODEL

While the three-quark model gave a very good picture of the structure of all the particles known to exist in the 1960s, evidence for a new kind of particle appeared in 1974, which pointed to the existence of at least one more quark. We now know that three other quarks exist (making six in all). These new quarks, which make up some very rare particles, have been given rather original names: ***charm, bottom*** (or beauty), and ***top*** (or truth). Again, these names have absolutely no significance and are simply products of the vivid imagination of physicists. The first direct observation of a track that showed the creation and decay of a particle containing a “charmed quark” was made in 1976 at the Fermilab accelerator near Chicago in an experiment carried out by a group of research teams from European universities including UCD. The bottom quark has been observed in the interaction of particles noted in Fermilab in 1977. The top quark was observed in 1994, again in Fermilab.

CONCLUSION

At present the six-quark model of fundamental particles and the parallel family of leptons form what is called the Standard Model. There are many questions left unanswered.

The cost of the research has been enormous, and the need for even bigger accelerators grows. In America, work on an instrument called the Superconducting Super Collider, which began in 1989, was halted in 1994. Approval for the Large Hadron Collider (LHC) at CERN, in Geneva, was given in December 1994, and experiments are due to start in 2004.

The syllabus contains just a glimpse of the world of particle physics. The story is still unfinished.

Irish Times, 24 April 1994

DISCOVERY OF TOP QUARK CONFIRMS KEY ATOMIC THEORY

William J. Broad
New York

The quest begun by philosophers in ancient Greece to understand the nature of matter may have ended in Batavia, Illinois, with the discovery of evidence for the top quark, the last of 12 subatomic building blocks now believed to constitute all of the material world.

An international team of 439 scientists working at the Fermi National Accelerator Laboratory announce the finding yesterday bringing nearly two decades of searching to a dramatic conclusion.

The Fermilab discovery, if confirmed would be a major milestone for modern physics because it would complete the experimental roof of the grand theoretical edifice known as the Standard Model, which defines the modern understanding of the atom.

The discovery, in all likelihood, will never make a difference to everyday life, but it is a high intellectual achievement because the Standard Model, which it appears to validate, is central to understanding the nature of time, matter and the universe.

If the top quark could not be found, the Standard Model of theoretical physicists would collapse, touching off an intellectual crisis that would force scientists to rethink three decades of work in which governments around the globe had invested billions.

All matter is made of atoms, but nearly a century ago physicists discovered that atoms, long considered to be the smallest units of matter, were themselves composed of smaller, subatomic particles like protons and neutrons. These particles later showed signs of being made of yet smaller building blocks.

The field was plunged into confusion for many years until a grand unifying theory pioneered by Dr Murray Gell-Mann, a physicist at the California Institute of Technology, sought to explain the structure of particles like protons and neutrons in terms of new units that he named quarks.

His theory called for the existence of six different kinds of quarks, named up and down, charm and strange, top and bottom. The quark family parallels a six-member family of lighter particles, known as leptons, that includes the electron. Various combinations of these 12 particles are thought to make up everything in the material world.

Five of the six quarks: were eventually found but the sixth remained painfully absent. For nearly two decades rival teams of scientists around the world have sought the top quark by performing ever-more-costly experiments on increasingly large machines that accelerate tiny particles almost to the speed of light and then smash them together in a burst of energy. The resulting fireball can yield clues to nature's most elementary building blocks.

The experiment was run on Fermilab's Tevatron, a four-mile, circular accelerator in an underground tunnel that hurls counter rotating beams of protons and antiprotons at each other with a combined energy of 1.8 trillion electron-volts. It is currently the highest-energy accelerator in the world.

Dr Melvyn J. Shochet, the team spokesman, said the mass of the top quark, its most important attribute, was calculated to be 174 billion electron-volts, plus or minus 17 billion electron-volts. "That's quite heavy," he said. "It's almost as heavy as an entire gold atom. It's by far heavier than any other elementary particle that's been observed, which is why it's taken so long to find."

Dr Gell-Mann took the word quark from a line in "Finnegans Wake" by James Joyce: "Three quarks for Muster Mark". So too, Dr Gell-Mann predicted that quarks in normal matter came in groups of three.

Protons would be made of two up quarks and one down quark; neutrons of two down quarks and one up quark. Dr Gell-Mann's ideas were radical and strongly resisted, partly because the fractional charges of his quarks seemed implausible. But his theories explained much, and were soon partly confirmed by particle discoveries. In 1969 he won the Nobel Prize in Physics.

Low-mass quarks, the up and down, are the only ones thought to ordinarily exist in this world. Physicists believe that the higher mass ones, charm and strange, top and bottom, were present naturally only for a tiny fraction of a second at the beginning of time during the Big Bang – the primordial explosion thought to have given rise to the universe.

Top quarks, having the highest mass of all, are believed to have vanished from the universe after existing for less than a billionth of a second.

Thus, a time machine is needed to see most quarks. Particle accelerators slam together tiny bits of matter to create intense fireballs almost as hot as those that existed at the beginning of time, creating streams of nature's most rudimentary particles.

- *(New York Times Service)*

PARTICLE PHYSICS: PROBLEM SHEET

1 Imagine that a molecule of water occupies a volume which can be approximated to a sphere of diameter 2×10^{-10} m.

(a) How many such spheres laid out end to end would make a chain of 1 cm in length?

(b) How many such spheres would make up a volume of 1 cm^3?

2 You wish to design a scale model of the hydrogen atom. The nucleus is to be represented by a marble of diameter 1 cm. What would be the radius of the orbit of the electron?

radius of proton, $r = 0.85 \times 10^{-15}$ m
radius of smallest orbit of electron, $R = 5.29 \times 10^{-11}$ m

3 The rest mass of an electron is 9.1×10^{-31} kg.
(a) What is the rest mass in joules?
(b) What is the rest mass in mega-electronvolts?

4 Helium is created in the sun via the fusion reaction

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + n$$

How much energy is released?

How is the energy divided between the products of the reaction?

Rest energies 1 u = 931.5 MeV
n: 1.00899 u
d: 2.01474 u
He: 3.01698 u

5 The energy of a proton in a large accelerator is 400 GeV.
(a) What is the energy in joules?
(b) How does it compare with the kinetic energy of an insect of mass 0.01 g travelling at a speed of 0.1 m s^{-1}?

6 Two protons each with a kinetic energy of 1 GeV, travelling in opposite directions collide to give the reaction

$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^+ + \pi^-$$

(a) What is the total kinetic energy of the π mesons?
(Mass energy of π meson = 139.6 MeV)

(b) What is the maximum number of π mesons that could be created in such a collision?

7 A lambda-hyperon comes to rest and decays by the reaction

$$\Lambda^o \rightarrow p^+ + \pi^-$$

What is the total energy of the decay products?

Mass energies Λ^o: 1115.6 MeV
p: 938.2 MeV
π^-: 139.6 MeV.

8 A positron (emitted in beta decay) comes to rest and interacts with an electron. They annihilate in the reaction

$$e^+ + e^- \rightarrow \gamma + \gamma$$

(a) What is the total energy released, in joules?

(b) What is the wavelength of the gamma rays?

(Mass of the electron = 0.511 MeV,
$h = 6.63 \times 10^{-34}$ J s)

9 A beam of charged π-mesons is travelling at speed of $v = \frac{1}{3}c$ (where c is the speed of light in vacuo).
What is the mean distance travelled before decay?
(Mean life of π-meson = 2.6×10^{-8} s,
speed of light: $c = 3 \times 10^8$ m s^{-1})

10 A quark and an antiquark combine to form a meson. The π meson family is made up of u and d quarks and antiquarks only. Write down the possible combinations, and deduce the charge of the resulting particles.

PARTICLE PHYSICS: KEY POINTS

The belief that all *matter* is composed of fundamental particles underlies research in particle physics.

In a *particle accelerator,* electric fields are used to increase the kinetic energy of the particles, and magnetic fields are used to guide the beams of particles.

Only *charged particles* can be affected by electric and magnetic fields.

There are *four fundamental forces:* gravitation, electromagnetic, strong nuclear and weak nuclear.

Leptons do not feel the strong nuclear force, but they feel the weak nuclear and gravitational forces; only charged leptons feel the electromagnetic force.

Baryons and mesons feel the strong nuclear force.

Each *fundamental particle* has a corresponding antiparticle that has the same mass as the particle but is opposite in all its other properties.

Quarks are fundamental constituents of baryons and mesons and feel all the fundamental forces.

Baryons are composed of three quarks.

Mesons are composed of a quark and an antiquark.

PARTICLE PHYSICS: GLOSSARY OF TERMS

ANTIPARTICLE A particle that has the same rest mass as the corresponding particle but opposite values of all other properties, such as charge. The antiparticle that corresponds to a fundamental particle is also fundamental.

BARYONS Particles that feel the strong nuclear force. According to the quark model, each baryon is composed of three quarks.

BIG BANG All the universe, all of space, matter, energy and time started with a huge explosion from a tiny size, which is called the Big Bang, according to the theoretical model.

COSMIC RAYS High-energy particles (mainly protons) that originate in distant parts of the universe, probably in the explosions of stars. They usually decay high in the Earth's atmosphere.

ELECTRON A fundamental particle that is part of every atom. The charge on the electron is 1.602×10^{-19} C. The electron is a member of the lepton family.

HADRON A particle that feels the strong nuclear force.

LEPTON A particle that does not feel the strong nuclear force but does feel the weak nuclear force and gravitation. Charged leptons feel the electromagnetic force. There are believed to be three types of lepton (the electron, the muon, and the tau, each with its associated neutrino.) Leptons are believed to be fundamental particles.

LINEAR ACCELERATOR A device that accelerates charged particles in straight lines.

MESON A particle that feels the strong nuclear force and, according to the quark model, is composed of a quark and an antiquark.

NEUTRINO A lepton that has zero charge and nearly zero rest mass. A different type of neutrino is associated with each type of electron.

PARTICLE PHYSICS The branch of physics that is concerned with fundamental particles and their interactions.

QUARK A type of particle that is a constituent of hadrons. Quarks are believed to be fundamental particles.

STRONG NUCLEAR FORCE The force that binds protons and neutrons in nuclei. The strong force is felt by all hadrons.

SYNCHROTRON A circular accelerator of charged particles.

WEAK NUCLEAR FORCE The force responsible for radioactive beta decay.

5.3 TEACHER MATERIALS

The particle physics option should take about 12 hours. This section provides support for teachers teaching this option.

Prior work will be needed in mechanics and atomic and nuclear physics. The concepts of energy and momentum and the principles of conservation of energy and momentum need to be known and understood by the students. The structure of the atom and the nucleus need to be known. The forces of gravitation and electromagnetism, their action at a distance and their inverse square law relationship are required.

A number of general principles apply to work in particle physics. The students need to be given an idea of the size of the atom with respect to everyday things and the size of the nucleus compared with the size of the atom. The diameter of the atom is approximately 10^{-10} m and the diameter of the nucleus is approximately 10^{-15} m. One analogy is that there are approximately as many teaspoons of water in the Atlantic Ocean as there are molecules in a teaspoon of water.

$$\text{Atlantic} \xrightarrow{\;10^{23}\;} \text{teaspoon} \xrightarrow{\;10^{23}\;} \text{1 molecule}$$

Another useful analogy is that if a marble in the middle of a football pitch is the nucleus, the electrons will be orbiting the stands. There are graphics for these two analogies in the student materials.

The conservation laws of energy and momentum still apply at this level of the very small.

At this level the standard unit of energy, the joule, is very large: the electronvolt (eV), with the multiples of mega-electronvolt (MeV) and giga-electronvolt (GeV) are more useful.

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$$

$$1 \text{ MeV} = 10^{6} \text{ eV} = 1.60 \times 10^{-13} \text{ J}$$

$$1 \text{ GeV} = 10^{9} \text{ eV} = 1.60 \times 10^{-10} \text{ J}$$

The unit of mass, the kilogram, is also very large, and therefore the atomic mass unit (u) may be used. Since mass and energy are equivalent, it is possible to use the same units for both.

1 atomic mass unit (u) = 931.5 MeV.

Students need to know general principles, not precise details. As our understanding of the world of particle physics increases, this section of the syllabus may have to be reviewed. The quark model is very much up-to-date: the top quark was found in 1994.

Particle physics is still a new field, with many discoveries. Students should be encouraged to think about the huge scale of machines such as LEP (Large Electron-Positron collider) and the proposed LHC (Large Hadron Collider) and to consider the cost of such projects. The cost and size of the projects mean that countries must come together to finance them. The best example is that of CERN, the *European Organisation for Nuclear Research,* in Geneva. Seventeen countries are members of CERN, and experiments on particle physics are carried out there by many teams of scientists from all over the world. Ireland is not a member of CERN, although Irish scientists do work there.

A useful resource for this option is the Institute of Physics *Particle Physics* pack (if available). The pack is accompanied by the Open University's S102 A Science Foundation Course unit 32, *The search for fundamental particles.*

5.4 WORKED PROBLEMS

Suitable problems are provided in the student materials. The problems and their solutions are provided in this section. These worked problems relate to the syllabus sections in particle physics, as follows:

background calculations of sizes and magnitudes
questions 1, 2 ,and 3

conservation of energy and momentum in nuclear reactions
question 4

acceleration of protons
question 5

converting mass into other forms of energy
question 6, 7, and 8 (also question 4)

families of particles
question 9 (also question 7)

quark model
question 10

1 Imagine that a molecule of water occupies a volume that can be approximated to a sphere of diameter 2×10^{-10} m.

(a) How many such spheres laid out end to end would make a chain of 1 cm in length?

(b) Approximately how many such spheres would make up a volume of 1 cm^3?

Answer

(a) 2×10^{-10} m = 2×10^{-8} cm

$1 \div (2 \times 10^{-8}) = 0.5 \times 10^8 = 5 \times 10^7$

1 cm contains 5×10^7 molecules

(b) 1 cm^3 contains $(5 \times 10^7)^3 = 125 \times 10^{21}$

$= 1.25 \times 10^{23}$ molecules.

Note: This shows that a teaspoon (5 cm^3) contains 6.25×10^{23} molecules, i.e. approximately Avogadro's number of molecules.

2 You wish to design a scale model of the hydrogen atom. The nucleus is to be represented by a marble with a diameter of 1 cm. What would be the diameter of the orbit of the electron?

radius of proton, $r = 0.85 \times 10^{-15}$ m
radius of smallest orbit of electron, $R = 5.29 \times 10^{-11}$ m

Answer

$$\frac{R}{r} = \frac{\text{model diameter}}{\text{marble diameter}}$$

$$\frac{R}{r} = 5.29 \times 10^{-11}/0.85 \times 10^{-15} = 6.22 \times 10^4$$

Model diameter $= 6.22 \times 10^4$ cm = 622 m

3 The rest mass of an electron is 9.1×10^{-31} kg.
(a) What is the rest mass in joules?
(b) What is the rest mass in mega-electronvolts?

Answer

(a) Rest energy: $mc^2 = 9.1 \times 10^{-31} \times (3 \times 10^8)^2$

$= 81.9 \times 10^{-15}$ J

(b) 1 eV $= 1.60 \times 10^{-19}$ J

1 MeV $= 1.60 \times 10^{-19} \times 10^6 = 1.60 \times 10^{-13}$ J

$m_e = 8.19 \times 10^{-14}/1.60 \times 10^{-13}$

$= 0.511$ MeV

4 Helium is created in the sun by the fusion reaction

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + n$$

How much energy is released?

How is the energy divided between the products in the reaction?

Rest energies 1 u = 931.5 MeV

n: 1.00899 u
d: 2.01474 u
He: 3.01698 u

Answer

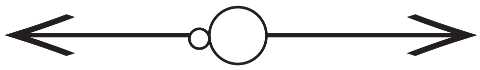
2×2.01474 = 4.02948

1.00899 + 3.01698 = <u>4.02597</u>

Energy released = 0.00351 u = 3.27 MeV

How is the energy divided between the products of the reaction?

$(3m)V$ $\quad$ mv



$\Rightarrow 3V = v$

$V = v/3$

Total kinetic energy $= \frac{1}{2}(3m)V^2 + \frac{1}{2}mv^2$

$= \frac{1}{2}(3m)v^2/9 + \frac{1}{2}mv^2$

Ratio of kinetic energy of helium nucleus to kinetic energy of neutron

$= \frac{1}{2}(3m)v^2/9 \div \frac{1}{2}mv^2$

$= \frac{1}{3}/1$

Energy is divided as 1:3

He gets $\frac{1}{4} \times 3.27 = 0.82$ MeV

n gets $\frac{3}{4} \times 3.27 = 2.45$ MeV

5 The energy of a proton in a large accelerator is 400 GeV.

(a) What is the energy in joules?

(b) How does it compare with the kinetic energy of an insect of mass 0.01 g travelling with a speed of 0.1 m s^{-1}?

Answer

(a) $1 \text{ eV} = 1.60 \times 10^{-19}$ J

$400 \text{ GeV} = 400 \times 10^9$ eV

$= 400 \times 10^9 \times 1.60 \times 10^{-19}$ J

$= 6.4 \times 10^{-8}$ J

(b) Insect

$\frac{1}{2}mv^2 = \frac{1}{2} \times 10^{-5} \times (0.1)^2$

$= 5 \times 10^{-8}$ J

Conclusion: The two energies are approximately the same. (Energy of proton = 1.28 × kinetic energy of insect.)

6 Two protons each with a kinetic energy of 1 GeV, travelling in opposite directions collide to give the reaction

$$p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^+ + \pi^-$$

(a) What is the total kinetic energy of the π mesons?
(Mass energy of π meson = 139.6 MeV)

(b) What is the maximum number of π mesons that could be created in such a collision?

Answer

(a) Total kinetic energy available
= 2 GeV = 2000 MeV

Mass energy of of π mesons $= 4 \times 139.6$
$= 558.4$ MeV

Kinetic energy of π mesons: $2000 - 558.4 = 1441.6$ MeV

(b) Maximum number of π mesons possible

$2000/139.6 = 14.33$

$\Rightarrow$ 14 is the maximum number

7 A lambda-hyperon comes to rest and decays by the reaction

$$\Lambda^o \rightarrow p^+ + \pi^-$$

What is the total energy of the decay products?

Mass energies $\quad \Lambda^o$: 1115.6 MeV

p: 938.2 MeV

π^-: 139.6 MeV

Answer

Total rest energy:

LHS	RHS
1115.6	938.2 + 139.6 = 1077.8

Kinetic energy of decay products

= 1115.6 – 1077.8 = 37.8 MeV

8

A positron (emitted in beta decay) comes to rest and interacts with an electron. They annihilate in the reaction

$$e^{+} + e^{-} \rightarrow \gamma + \gamma$$

(a) What is the total energy released, in joules?

(b) What is the wavelength of the gamma rays?

(Mass of the electron = 0.511 MeV,
$h = 6.60 \times 10^{-34}$ J s)

Answer

(a) 2×0.511 MeV = 1.022 MeV

$= 1.022 \times 1.6 \times 10^{-13}$ J

$= 1.64 \times 10^{-13}$ J

(b) γ rays go off with equal energies in opposite directions.

Energy $= 2hf = 1.64 \times 10^{-13}$

$\Rightarrow f = 1.64 \times 10^{-13} / 2 \times 6.60 \times 10^{-34}$

$= 0.123 \times 10^{21}$ Hz

$\Rightarrow \lambda = c/f = 3.0 \times 10^{8} / 0.123 \times 10^{21}$

$= 2.43 \times 10^{-12}$ m = 2.4 pm

9

A beam of charged π mesons is travelling at a speed of $v = \frac{1}{3}c$ (where c is the speed of light in vacuo).

What is the mean distance travelled before decay?
(Mean life of π meson $= 2.6 \times 10^{-8}$ s,
speed of light, $c = 3.0 \times 10^{8}$ m s^{-1})

Answer

Mean distance $= 2.6 \times 10^{-8} \times 3.0 \times 10^{8} \times 1/3 = 2.6$ m

10

A quark and an antiquark combine to form a meson. The π meson family is made up of u and d quarks and antiquarks only. Write down the possible combinations, and deduce the charge of the resulting particles.

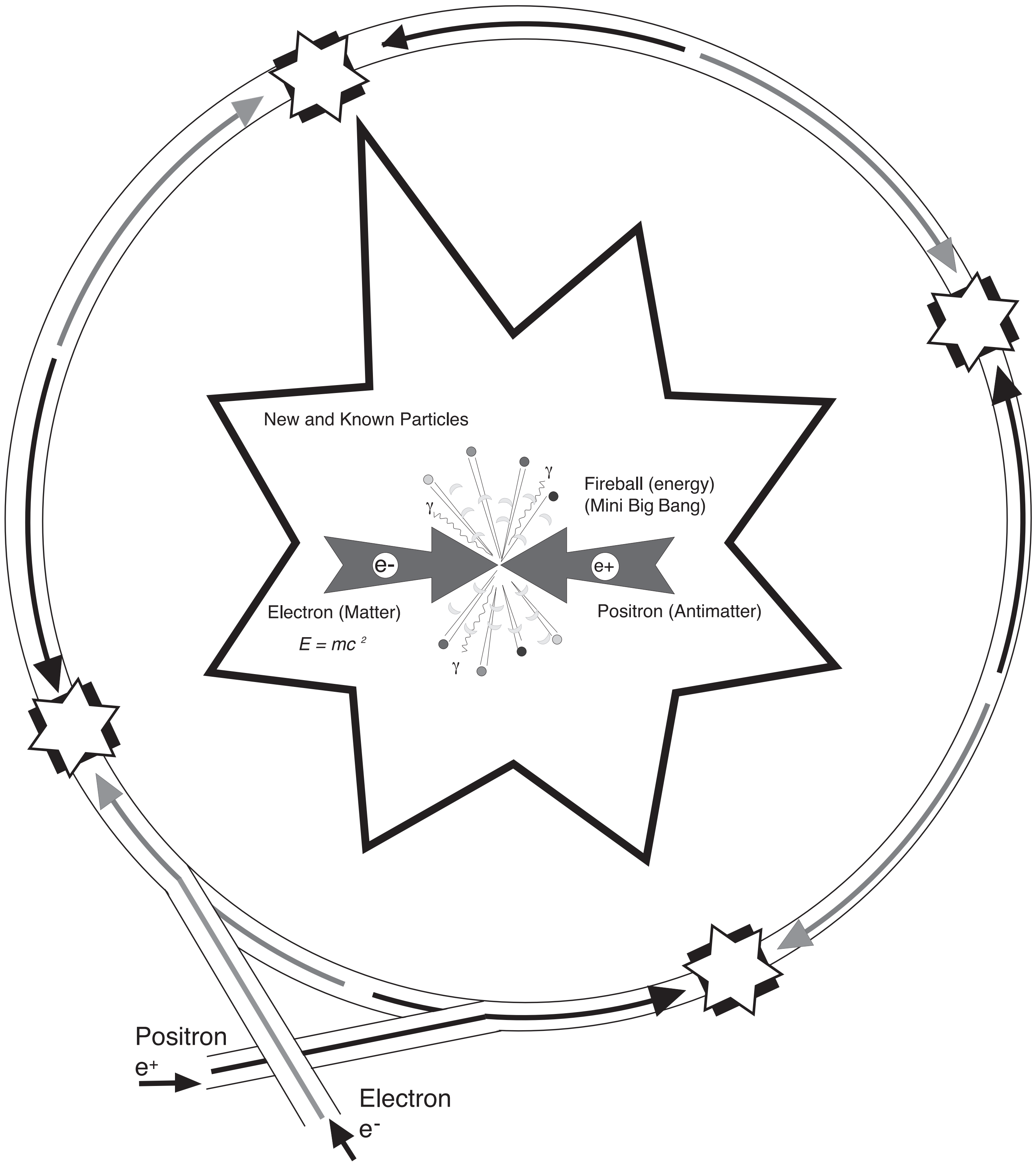
Answer

	$u\bar{d}$	$\bar{u}d$	$u\bar{u}$	$\bar{d}d$
Charge	$+\frac{2}{3} +\frac{1}{3}$	$-\frac{2}{3} -\frac{1}{3}$	$+\frac{2}{3} -\frac{2}{3}$	$-\frac{1}{3} +\frac{1}{3}$
Total	+ 1	-1	0	0
	π^{+}	π^{-}	π^{o}	π^{o}

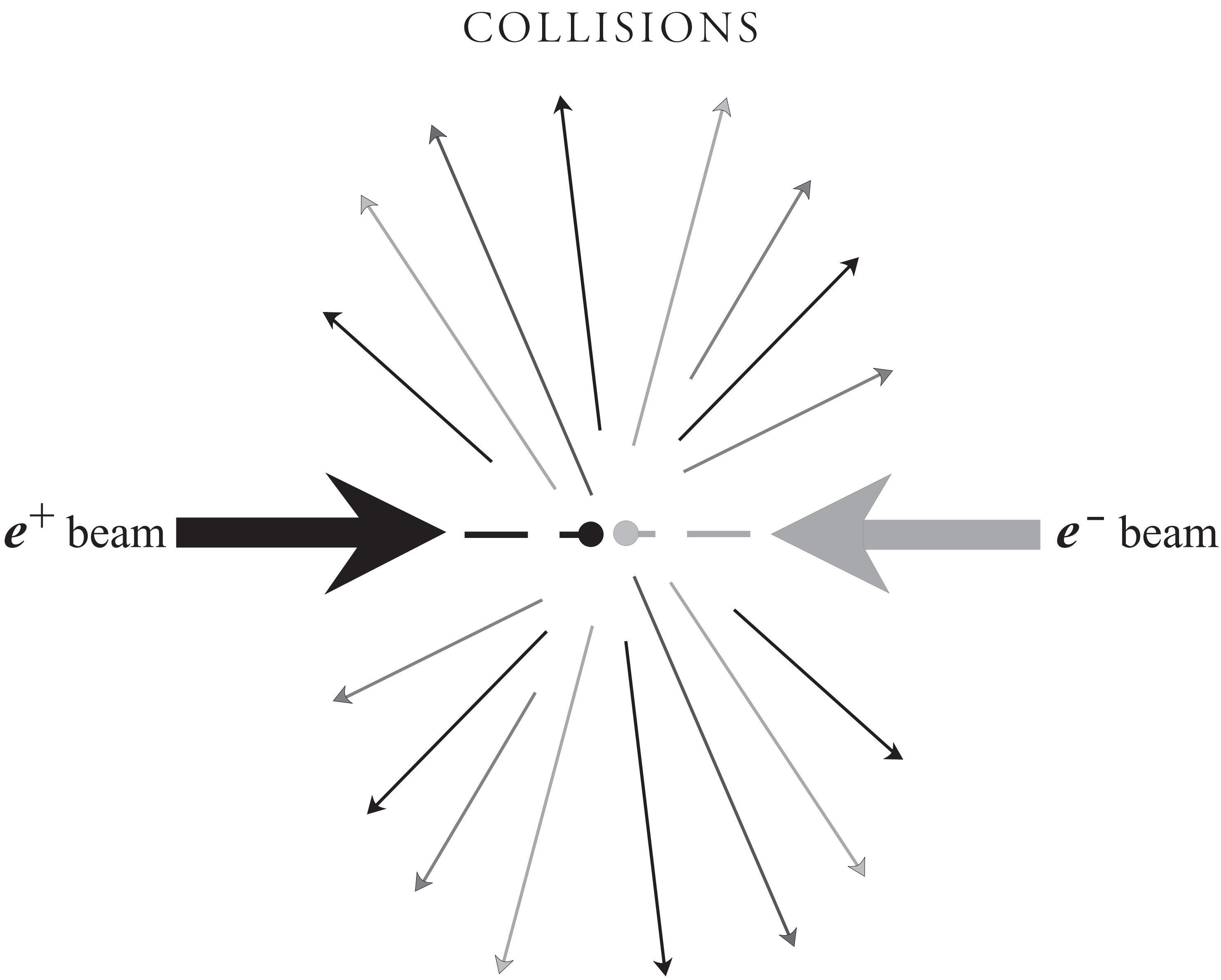
5.5 GRAPHICS

LEP, the largest colliding beam accelerator in the world, has the form of a circle of approximately 27 km in circumference. The beams of electrons and positrons circulate in separate orbits inside a vacuum tube and are brought into collision at four particle detectors around the circle.

LEP

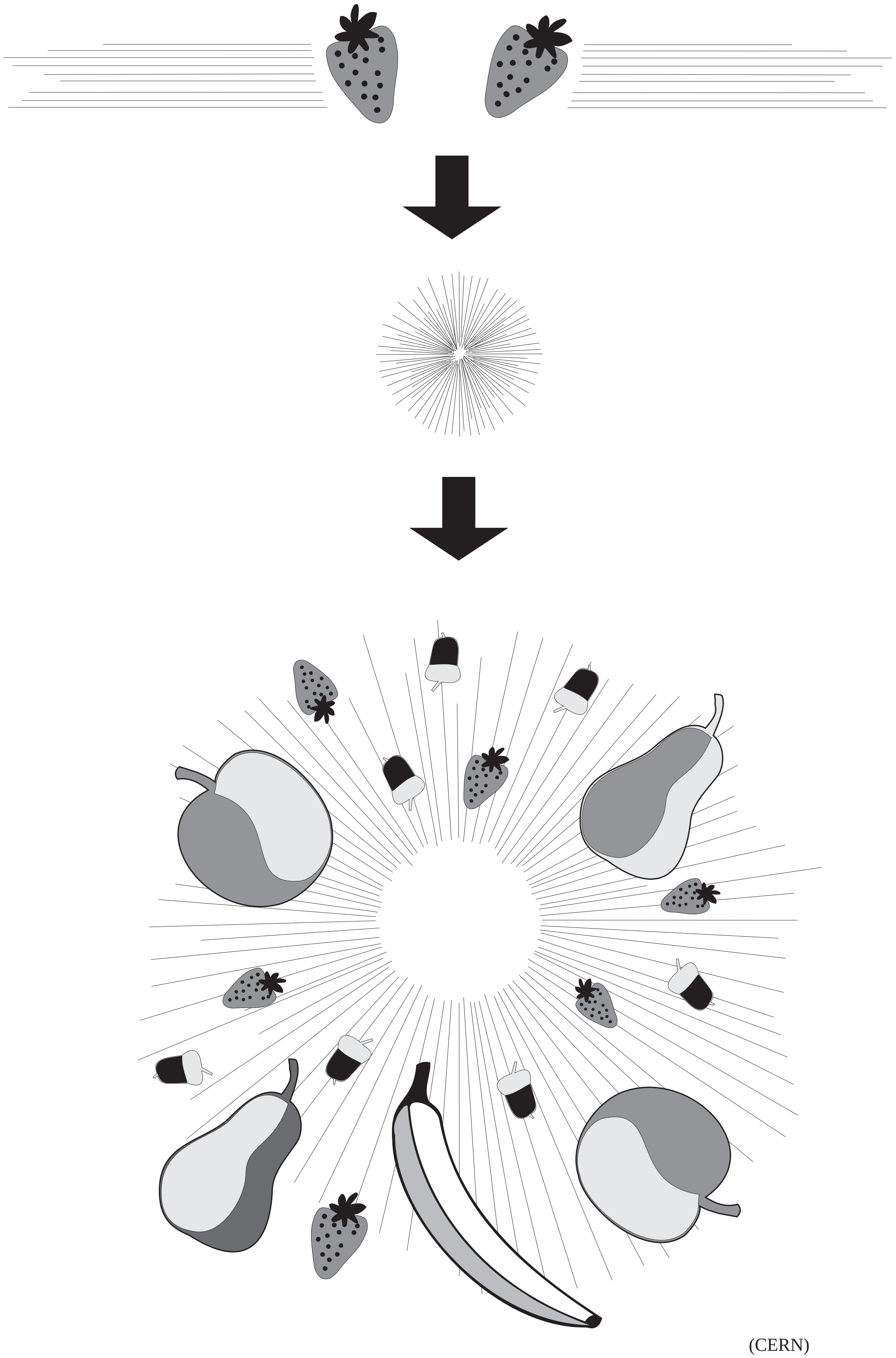


Particle detectors are designed to study the nature and frequency of the different processes that occur in collisions between beams of electrons and positrons that circulate around a circular path.



(CERN)

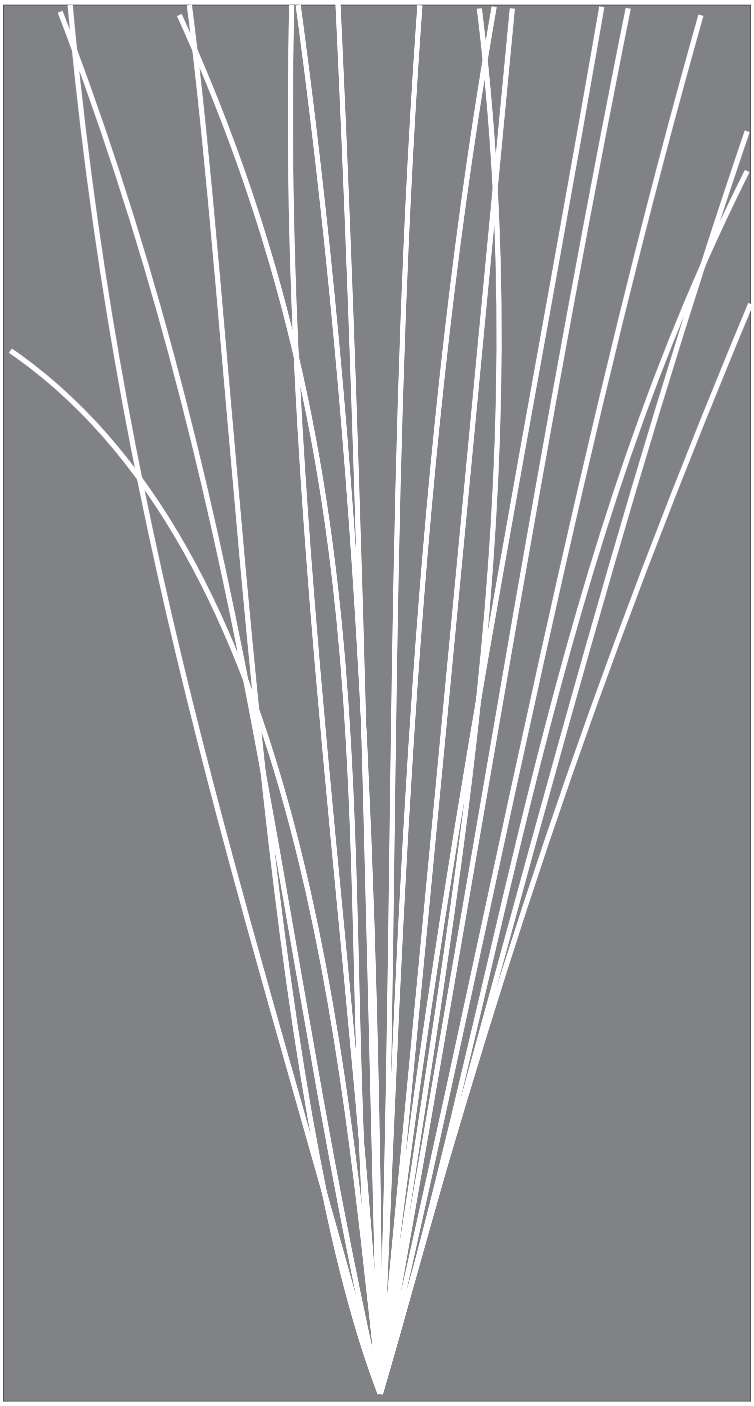
COLLISION OF UNBREAKABLE OBJECTS



(CERN)

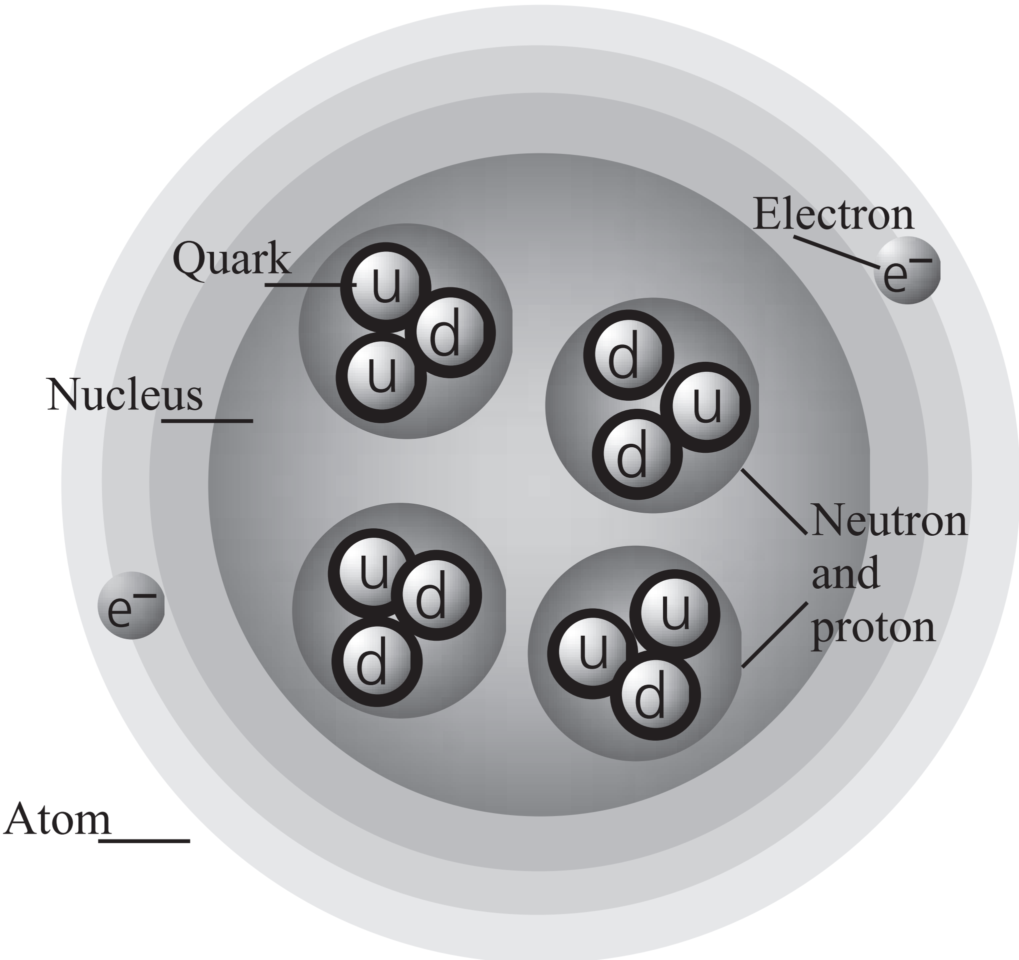
CREATION OF MATTER

The energy of a single particle entering at the bottom of the chamber has been transformed into eighteen other particles. The diagram represents the trajectories (paths) of the particles as they pass through a liquid contained in a type of detector known as a bubble chamber.

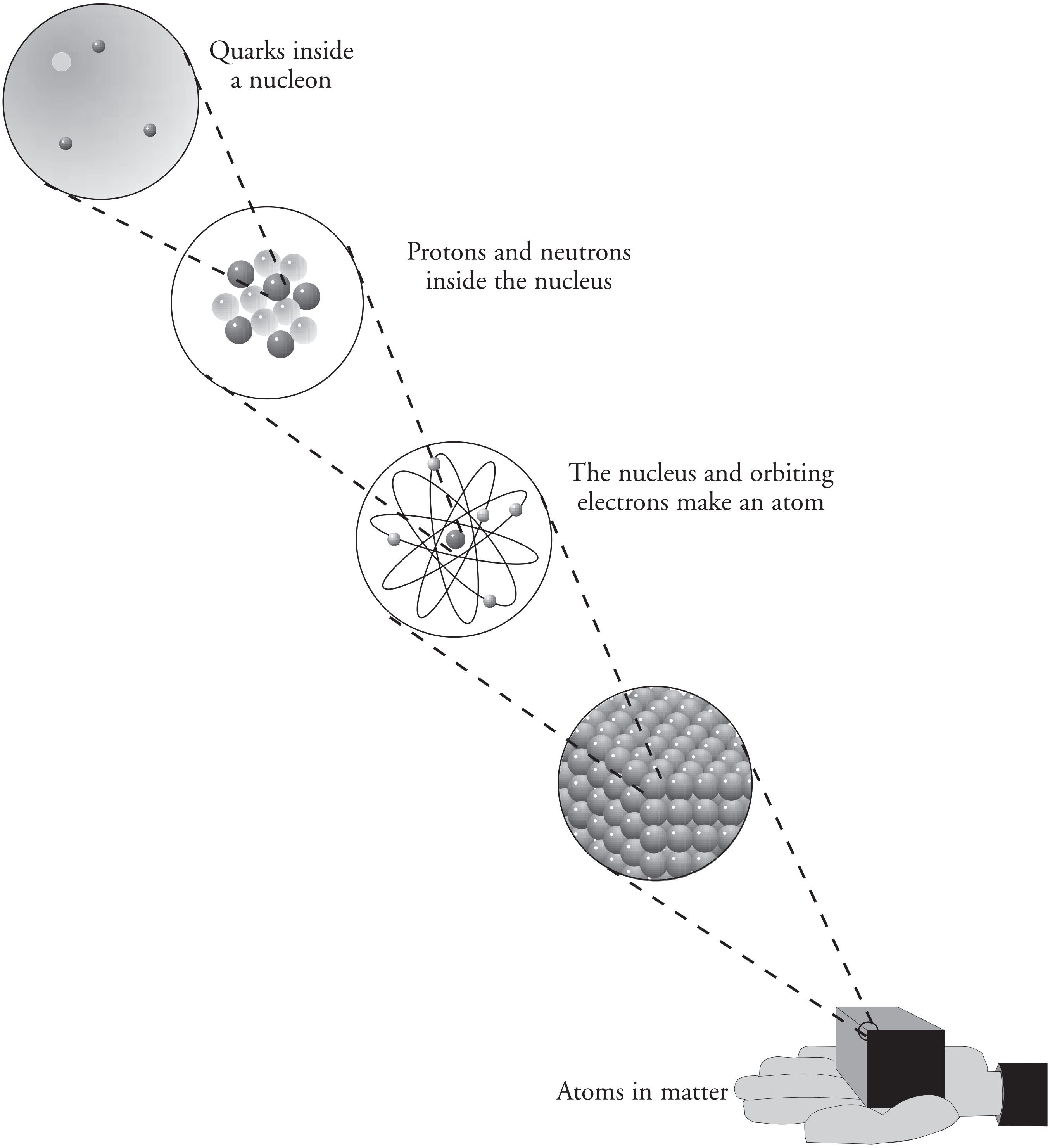


(CERN)

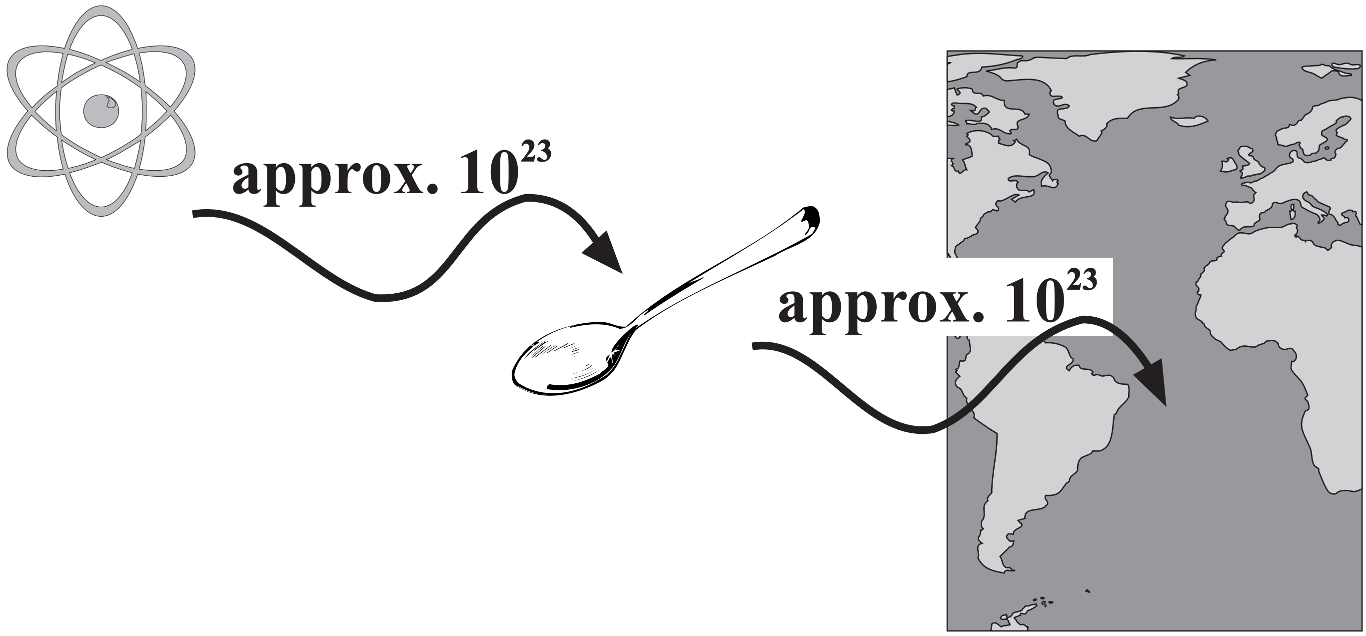
STRUCTURE WITHIN THE ATOM



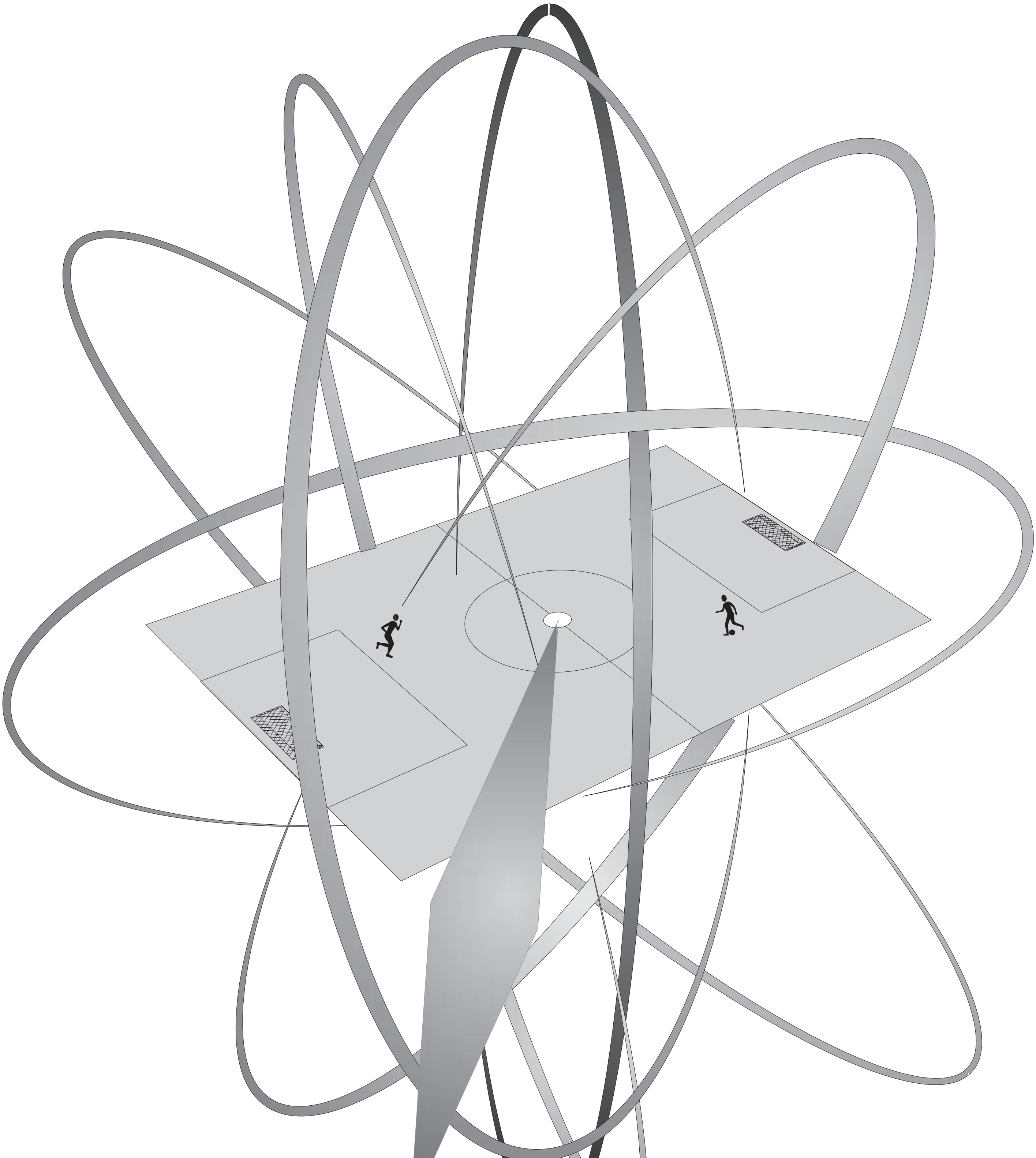
THE STRUCTURE OF MATTER



SIZE OF A MOLECULE



SIZE OF AN ATOM



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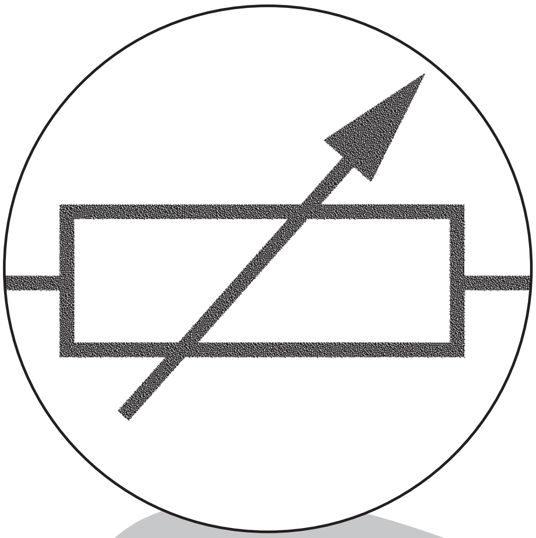
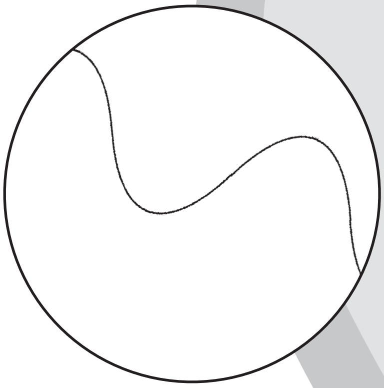
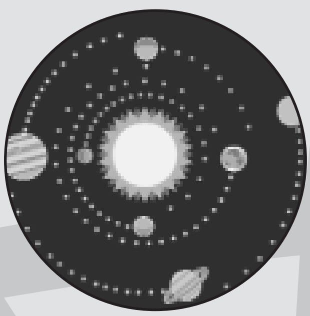
Section six
practical work and safety







6.1 INTRODUCTION

The term "practical work" covers all teacher demonstrations, student experiments, and any investigations that may take place in a school science laboratory. This can occur only in a properly organised and safely run laboratory. The practical work required by the syllabus is reviewed. Notes on selected experiments are given. The treatment of errors is discussed. This is followed by a brief review of laboratory organisation and maintenance. Finally, safety is discussed.

6.2 PRACTICAL WORK

The syllabus specifies a number of teacher demonstrations and student experiments; these should be done. The syllabus also recommends that, wherever possible, additional practical work should be used in the teaching of physics. The recording of such additional experiments is at the teacher's discretion. Practical work can facilitate students in developing an understanding of the concepts involved. Any suitable and safe method for an experiment is acceptable. The journals mentioned in section 7 are a useful source of ideas for experiments, demonstrations and projects.

6.2.1 STUDENT PRACTICAL WORK

The required student experiments are important in that they develop the practical skills involved in setting up and adjusting equipment and taking measurements. The required experiments are listed at the end of the appropriate section of the syllabus. These experiments must be completed and recorded by the students. Any suitable and safe method is acceptable.

6.3 NOTES ON SELECTED EXPERIMENTS

The following are the experiments that have been amended.

Mechanics 2.	To show that $a \propto F$
Mechanics 6.	Investigation of the laws of equilibrium for a set of co-planar forces.
Mechanics 7.	Investigation of the relationship between period and length for a simple pendulum and hence the calculation of *g*. (Higher level only.)
Heat 1.	Calibration curve of a thermometer using the laboratory mercury thermometer as standard.
Electricity 5.	To investigate the variation of current *(I)* with pd *(V)* for *(a)* metallic conductor *(b)* filament bulb *(c)* copper sulfate solution with copper electrodes *(d)* semiconductor diode.

In some cases the change is to reduce the number of variables to be measured. For Newton's second law (Mechanics 2) it is no longer necessary to investigate how the acceleration varies with mass. Establishing the relationship between the acceleration of an object and the applied force is sufficient.

For Mechanics 6 the experiment is extended from the principle of moments to the conditions for equilibrium. This means that the forces acting on any system have to be considered as well as the moments about an axis. These forces can be measured using newton balances.

In Mechanics 7 the emphasis shifts from using the simple pendulum to measure *g*, to establishing the relationship between the length and the periodic time. This means that students should analyse the data obtained from changing the length of a simple pendulum and measuring the periodic time. This data could be plotted on a graph and the curve obtained discussed. The graph of T^2 against l could then be plotted. From the slope of the graph, a value for *g* can be obtained.

In Heat 1 the calibration curve of a thermometer is plotted. The value of a thermometric property over a range of temperatures, as measured on a laboratory mercury thermometer, is plotted against temperature. This can be done for a variety of thermometric properties, as outlined in the syllabus.

In Electricity 5 the patterns shown by the *I – V* graphs for the different circuit elements is the central idea. The circuits used are similar, yet each circuit element has its own characteristic graph. Ohm's law, as a special case for metallic conductors at constant temperature, becomes evident.

ADDITIONAL NOTES

In the experiment to verify Joule's law (Electricity 1) it is important, particularly at Higher level, that students understand how the straight-line graph of $\Delta\theta$ against I^2 verifies the law. The relationship between the change in temperature of the water and the heat energy supplied can be shown as follows:

heat energy gained by water = heat energy supplied

$$mc\Delta\theta = I^2 Rt$$

If the mass of water, the resistance of the heater element and the time for which the water is heated are constant, then

$$\Delta\theta \propto I^2$$

In the experiments involving the measurement of resistance (Electricity 2, 3, 4) it is expected that an ohmmeter will be used at Ordinary level and that both an ohmmeter and a metre bridge will be used at Higher level. Higher level students need to appreciate the different levels of precision provided by the two instruments.

6.4 ERRORS AND THEIR TREATMENT IN STUDENT PRACTICAL WORK

The students are required to have an appreciation of the errors inherent in practical work and the precautions that should be taken to reduce such errors. No quantitative treatment of errors is required.

There are many causes of error in physics experiments: instrumental errors, such as zero error on a micrometer screw gauge or a meter; adjustment errors, such as an incorrectly adjusted spectrometer; and observational error. Students need to understand the difference and the appropriate precautions taken to reduce them. Students should appreciate that a measurement has a certain level of error, and the concept of percentage error could be mentioned, although calculation is not required. Students should appreciate that the measured value may be different from the accepted value for the quantity.

6.5 LABORATORY ORGANISATION AND MAINTENANCE

The laboratory should make it possible for the experiments required by the syllabus and any other practical work to be carried out in a safe manner.
It is important to note that apart from the requirement of access to a computer, a video recorder and television, the laboratory equipment required for the revised syllabus is similar to that of the previous syllabus. A catalogue of the available equipment is an essential part of the physics laboratory. It is important that regular maintenance of laboratory equipment be carried out and that equipment be stored safely when not in use.

A basic tool kit makes it possible for simple repairs to be carried out. A suitable tool kit for the physics laboratory could include:

Screwdrivers – various

Phase-tester

Wire-strippers

Soldering iron and solder

Wire-cutters

Pliers

Files

6.5.1 EQUIPMENT

There are many ways of doing both the student experiments and the teacher demonstrations given in the syllabus. The following is a short list of useful equipment.

Power supply, 0–20 V or laboratory d.c. supply
Cathode ray oscilloscope

Signal generator

Ticker-tape timer and dynamics trolleys and/or Linear air track

Ripple tank

Microwave kit

Ray boxes

Light demonstration kit

Laser

Sonometer

Spectrometer

Spectrum tubes

Van de Graaff generator

Joulemeter

Multimeters

Metre bridge

Electronics kit

Demonstration meters

Induction coil

Transformer kit

Cathode ray deflection tubes

EHT supply

Geiger counter

A list of equipment suggested for the Leaving Certificate physics syllabus may be obtained from the Post-Primary Building Unit of the Department of Education and Science in Tullamore. An equipment list may also be obtained from the Irish Science Teachers' Association.

6.6 SAFETY

The general principles of safe laboratory working apply to Leaving Certificate physics. The school safety statement, as required under the Safety, Health and Welfare at Work Act (1989), should outline the principles involved. A basic set of safety rules should be drawn up in the school, displayed in each laboratory, and a copy should be given to each student every year. Appropriate protective clothing and equipment must be available and used as necessary.

The physics laboratory should be equipped to cope with possible hazards such as fire, gas leakage and electric shock. Convenient isolation switches should be provided for gas and electricity. A first aid kit must be available and there must be access to washing facilities. Students should be aware of the correct procedures to be followed in the event of a fire or other hazard. They should also take appropriate precautions when using electricity, ionising radiation, and lasers. The detailed safety precautions required for the use of such equipment are beyond the scope of this document but teachers should ensure that they have a clear understanding of the safety issues concerned. A list of references is given below.

6.6.1 SAFE USE OF IONISING RADIATION

The careful use of sources of ionising radiation is essential. It is also necessary to be aware when equipment may produce ionising radiation. Attention is drawn to the guidelines issued by the Radiological Protection Institute of Ireland.

6.6.2 LASER SAFETY

Lasers are a useful resource in the teaching of waves and light. However, there are hazards associated with their use. In particular, there is a need to be careful with specular reflection.

6.6.3 REFERENCES

Everett, K. and Jenkins, E.W.
A Safety Handbook for Science Teachers, 4th edition.
London: John Murray (Publishers) Ltd., 1991.

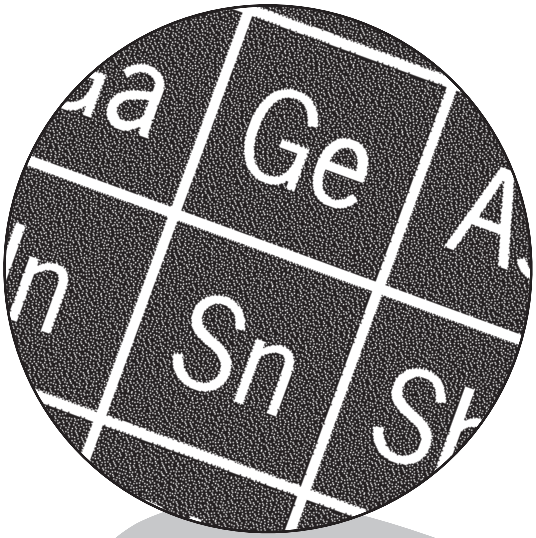
Association for Science Education
Safety in the Lab. Hatfield: ASE, 1990.

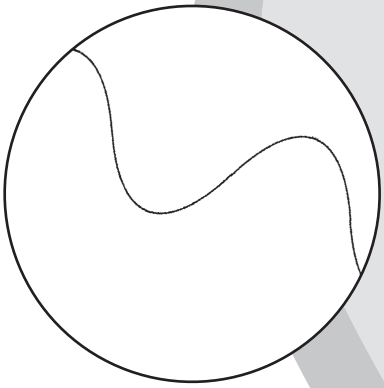
Association for Science Education
Safeguards in the School Laboratory.
Hatfield: ASE, 1996.

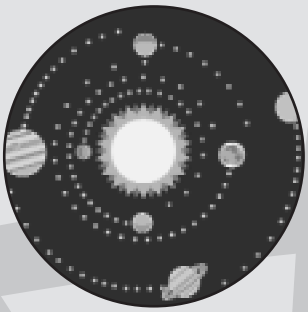
Department of Education
Safety in School Science.

Safety in the School Laboratory: Disposal of Chemicals.
Dublin: Department of Education, 1996.

Section seven resources







7.1 INTRODUCTION

The term "resources" is used here to cover anything that supports the teaching of physics other than laboratory equipment. Many resources are available for the teaching of physics at Leaving Certificate level. This section suggests how such resources may be found and evaluated. The use of information and communications technology in the teaching of physics is briefly considered. This is followed by a list of magazines and journals, books, videos, software and useful addresses, which will support the teaching of the syllabus. These lists are not exhaustive. Some of the material will be suitable for teachers; other material will be suitable for use with the students.

7.2 FINDING AND EVALUATING RESOURCES

Resources can be found in a number of ways through the journals of the Irish Science Teachers' Association, the Association for Science Education, and the Institute of Physics. These journals review books, posters, videos, and software. All contain relevant articles on different aspects of physics or science and are an excellent source of ideas. As suggested in section 2, newspapers and magazines are also a valuable source of ideas. Newspapers such as the *Irish Times* and the *Guardian* have special days for education, or science, and may contain articles relevant to the syllabus. Television and radio programmes, both schools' programmes and programmes of special interest, are also suitable resources. Many large industries and public companies also have educational resources. Useful addresses are given in section 7.9.

All resources need to be evaluated, and some may need to be adapted for use in an Irish context. For example, English material on the generation of electricity may refer to the mains voltage (rms value) as 240 V, while in Ireland the mains voltage (rms value) is 230 V. It is always useful to re-evaluate any resource after a period of time to ensure that it is still useful.

7.3 INFORMATION AND COMMUNICATIONS TECHNOLOGY

The use of information and communications technology in the teaching of physics has been explored for many years. The syllabus suggests that the use of spreadsheets, datalogging, computer-aided learning, modelling and simulation may be helpful in the teaching of physics. These suggestions can be gradually incorporated in the physics teacher's repertoire. Other uses of ICT that can be explored are CDs, email, and the internet.

7.3.1 ICT AND THE PHYSICS CLASSROOM

Datalogging equipment is a valuable, new resource in the physics laboratory. It can facilitate the collection, recording and analysis of data from a wide range of experiments. The utility of datalogging equipment can be extended by using a computer to enhance the presentation of results. Word-processors may be used in writing physics notes or experiments, while spreadsheets may be used to analyse data and see the patterns in a given set of data. Modems may be used to communicate and interact with other schools. Modelling and simulations may be useful where the concepts discussed are beyond the scope of the school laboratory. Educational software is often reviewed in the journals mentioned below.

7.3.2 REFERENCES FOR ICT

There are excellent resources and web sites that explore in more detail the use of ICT in physics teaching. Note that the web addresses given are correct at time of printing, but may change without notice. The references include books and articles.

Association for Science Education
School Science Review – Theme Issue on ICT and Science Education
Vol. 79, No. 287, December 1997.

Frost, Roger
The IT in Secondary Science Book
London: IT in Science, 1994.

Frost, Roger
The IT in Science of Datalogging and Control
London: IT in Science,1995.

The Chalkface Project
Applying IT to Science
Milton Keynes: The Chalkface Project, 1997.

7.3.3 WEB SITES

Organisation	*Address*	*Comment*
Association for Science Education (ASE)	www.ase.org.uk	Excellent resources for science education
Eric Clearinghouse for Science, Maths and Environmental Education	www.ericse.org	Excellent resource for teaching strategies in science
Institute of Physics	www.iop.org www.tcd.ie/iop	Excellent physics resources
Internet for Girls: Worldwide resources list	www.sdsc.edu/~woodk-a/resources.html	Science and technology resources for students, parents, and teachers
Particle Physics	hepweb.rl.ac.uk/ppUK	Excellent site for particle physics
ScoilNet	www.scoilnet.ie	Site for Irish schools
The Physics Guide	members.tripod.co.uk/Physics/index.html	Excellent site for physics links, set up by a physics teacher
American Association of Physics Teachers (AAPT) Physical Science Resource Centre	www.psrc-online.org	Well-presented site with plenty of resources and links for physics teachers
Science, Technology and Innovation Awareness Program	www.science.ie	Information on science-related events and useful links.

7.4 MAGAZINES AND JOURNALS

SCIENCE

This is the journal of the Irish Science Teachers' Association. It contains articles of general interest to science teachers and reviews of books, videos and other resources for the teaching of science in schools. It is published three times per year and is free to members.

SCHOOL SCIENCE REVIEW

This is the journal of the Association for Science Education in the UK. It is similar to SCIENCE and is free to members of the ASE. Copies are available in most university libraries. It is published four times per year.

PHYSICS EDUCATION

This is the education journal of the Institute of Physics and is free to all affiliated schools. It is published six times per year.

PHYSICS REVIEW

This is published by Phillip Allan Publishers and is aimed at A-Level students. It is available by subscription only from the publishers. The articles are often very useful.

AN tEOLAÍ

Seo nuachtlitir eolaíochta atá ar fáil saor in aisce i ngach iar-bhunscoil. Aistriúcháin ar ailt ar an eolaíocht ó fhoinsí ar fud an domhain.

TECHNOLOGY IRELAND

This is the magazine of the science and technology community in Ireland. It is published by Enterprise Ireland six times per year and contains articles of general scientific and technological interest.

NEW SCIENTIST

This is the magazine of the scientific community in UK and is an excellent resource for keeping up to date in science. It is published weekly.

7.5 BOOKS

The following lists contain some suggestions that may prove useful in the newer components of the syllabus. They are grouped into STS, particle physics, and background reading.

7.5.1 SCIENCE, TECHNOLOGY AND SOCIETY

Andrews, David
Science, Technology and Society
Cheltenham: Stanley Thornes (Publishers) Ltd., 1992.

ASE
SATIS 16—19
Hatfield: Association for Science Education, 1992.

ASE
Beyond the Visible: One hundred years of X-rays
Hatfield: Association for Science Education, 1995.

ASE
One hundred years of the electron
Hatfield: Association for Science Education 1997.

Bloomfield, Louis A.
How Things Work: The Physics of Everyday Life
New York: John Wiley & Sons, 1997.

Campbell, Peter (ed.)
Shaping the Future 1. Making Physics Connect
Bristol: Institute of Physics Publishing, 1999.

Jos Draijer and John Lakey
Radiation and Radiation Protection. A Course for Primary and Secondary Schools
Brussels: Commission of European Communities, 1994.

Hussey, Matt
Nod don Eolach: Gasaitéar Eolaíochta
Baile Átha Cliath: An Gúm, 1999.

O'Dea, John
Exposure: Living with Radiation in Ireland
Dublin: Irish Reporter Publications, 1997.

Sang, David, Sutcliffe, Jill and Whitehouse, Mary
Henri Becquerel and radioactivity
Hatfield: Association for Science Education, 1997.

Walker, Jearl
The Flying Circus of Physics with Answers
London: John Wiley & Sons, 1977.

Williams, Susan
Advanced Questions on Everyday Physics
Walton-on Thames: Nelson Blackie, 1993.

7.5.2 PARTICLE PHYSICS

Boixader, Georges and Southworth, Brian
The World of Particles
Geneva: CERN, 1991.

How energy becomes matter–A first look at the world of particles
Geneva: CERN, 1986.

Open University
S102: A Science Foundation Course, Unit 32 The search for fundamental particles
Milton Keynes: Open University, 1989.

Institute of Physics
Particle Physics Project
London: IOP, 1992.

Science & Engineering Research Council
Big Bang Science, exploring the origins of the universe
London: SERC, 1989.

7.5.3 SAFETY

Everett, K. and Jenkins, E.W.
A Safety Handbook for Science Teachers (4th edition).
London: John Murray (Publishers) Ltd., 1991.

ASE
Safety in the Lab
Hatfield: Association for Science Education, 1990.

ASE
Safeguards in the School Laboratory.
Hatfield: Association for Science Education, 1996.

Department of Education
Safety in School Science
Safety in the School Laboratory: Disposal of Chemicals
Dublin: Department of Education, 1996.

7.5.4 BACKGROUND READING

Bronowski, J.
The Common Sense of Science
London: Pelican Books, 1960.

Carey, John (ed.)
The Faber Book of Science
London: Faber and Faber, 1995.

Coleman, James A.
Relativity for the Layman.
London: Penguin, 1974.

Dixon, Bernard (ed.)
From Creation to Chaos
London: Basil Blackwell, 1989.

Feynmann, Richard
Surely You're Joking Mr. Feymann
London: Unwin, 1986.

Feynmann, Richard
What do you care what other people think?
London: Unwin, 1988.

Feynmann, Richard
Six Easy Pieces
Wokingham: Addison Wesley, 1995.

Garvin, W. and O'Rawe, D.
Northern Ireland Scientists and Inventors
Belfast: The Blackstaff Press, 1993.

Lightman, Alan
Dance for two. Selected essays
London: Bloomsbury, 1996.

Maury, Jean-Paul
Newton. Understanding the Cosmos.
London: Thames and Hudson, 1992.

McWilliams, Brendan
Weather Eye
Dublin: The Lilliput Press, 1994.

Mollan, C., Davis, W. and Finucane, B.
Some People and Places in Irish Science and Technology
Dublin: Royal Irish Academy, 1985.

Stannard, Russell
Uncle Albert and the Quantum Quest
London: Faber and Faber, 1994.

7.6 TEXTBOOKS

The following is a selection of textbooks, excluding Irish textbooks, that teachers may find useful. It is not intended to be exhaustive. There are also series of textbooks, for example Bath 16–19 series, SLIPP Supported Learning in Physics Project, Salters' Horners' Advanced Physics and the Institute of Physics Advancing Physics.

ASE
Signs, Symbols and Systematics
The ASE Companion to 5-16 Science
Hatfield: Association for Science Education, 1995.

Bush, Dave and Drumgoole, Bob
Access to Advanced Level Physics Second Edition
Cheltenham: Stanley Thornes (Publishers) Ltd., 1996.

Chapple, Michael
The Complete A–Z Physics Handbook
London: Hodder & Stoughton, 1997.

Duncan, Tom
Advanced Physics Fifth Edition
London: John Murray, 2000.

Fullick, Patrick
Physics
Oxford: Heinemann Educational Publishers, 1994.

Ireson, Gren
Physics through investigation
London: Hodder & Stoughton, 1998.

Johnson, K.
Physics for You National Curriculum Edition for GCSE
Cheltenham: Stanley Thornes(Publishers) Ltd., 1991.

Lambert, Andrew.
Maths for Advanced Physics.
Walton-on-Thames: Nelson, 1993.

Nelkon, M. and Parker, P.
Advanced Level Physics
London: Heinemann Educational Books, 1977.

Jardine, Jim (ed.)
Physics through Applications
Oxford: Oxford University Press, 1989.

7.7 THE TEACHING OF PHYSICS

The following is a selection of books on the teaching of physics and science. It is intended as a guide for teachers.

Centre for Science Education, Sheffield City Polytechnic.
Active Teaching and Learning Approaches in Science
London: Collins Educational, 1992.

Carson, Simon (ed.)
Shaping the Future 2. Physics in a Mathematical Mood
Bristol: Institute of Physics Publishing, 1999.

Fullick, Patrick and Ratcliffe, Mary (eds.)
Teaching Ethical Aspects of Science
Southampton: The Bassett Press, 1996.

Gibbs, Keith
The Resourceful Physics Teacher
Bristol: Institute of Physics Publishing, 1999.

Institute of Physics Education
Girls and Science–A Better Deal
A Resource Pack for Science Teachers
London: Institute of Physics, 1986.

Jerram, Ann
Teaching Physics to KS4
London:Hodder & Stoughton, 1999.

Millar, R. and Osborne J.
Beyond 2000: Science Education for the Future
London: Kings' College School of Education, 1998.

Osborne, Jonathan and Freeman, John
Teaching Physics: a guide for the non-specialist
Cambridge: Cambridge University Press, 1989.

Parkinson, John
The Effective Teaching of Secondary Science
Harlow: Longman Group Plc, 1994.

Ratcliffe, Mary (ed.)
ASE Guide to Secondary Science Education
Hatfield: Association for Science Education, 1998.

Sang, David (ed.)
Teaching Secondary Physics
Hatfield: Association for Science Education, 2000.

Solomon, Joan
Teaching Science, Technology and Society
Buckingham: Open University Press, 1993.

7.8 VIDEOS

There are videos that support the teaching of Leaving Certificate physics. All need to be reviewed before using them with a class. Some have accompanying teachers' notes. Many are available through the video loan service. Further details are available on the Institute of Physics (Irish Branch) web site.

7.9 USEFUL ADDRESSES

Irish Science Teachers' Association

Blackrock Education Centre
Kill Avenue
Dún Laoghaire
Co. Dublin

The ISTA is the professional association for science teachers in Ireland. It publishes SCIENCE, has representatives on all NCCA science course committees at junior and senior cycle level and holds an annual meeting in the spring of each year.

Enterprise Ireland

Glasnevin
Dublin 9
Phone: (01) 8370101

Enterprise Ireland is the state agency for science and technology.

Understanding Electricity

Millbank
London SW1P 4RD
England

Understanding Electricity
PO Box 44
Wetherby
West Yorkshire LS23 7ES
England

ESB Understanding Electricity

Public Relations Officer
ESB
Lower Fitzwilliam Street
Dublin 2
Web site: www.esb.ie

Understanding Electricity is the educational service of the electricity supply industry. There are many fine posters, etc., often free. A catalogue is available in most schools.

Radiological Protection Institute of Ireland

3 Clonskeagh Square
Dublin 14
Web site: www.rpii.ie

National Centre for Technology in Education

Dublin City University
Glasnevin
Dublin 9
Phone: (01) 7048200
Web site: www.ncte.ie

The NCTE was set up in 1998 as part of the IT 2000 initiative to develop the use of ICT in schools. As part of the NCTE's work the web site ScoilNet has been set up. Other projects include investigating the use of datalogging in the science classroom.

Health and Safety Authority

10 Hogan Place
Dublin 2
Web site: www.hsa.ie

Women in Technology and Science (WITS)

PO Box 3783
Dublin 4
Web site: www.witsireland.com

WITS actively promotes women's participation in science and technology. It has published a role model booklet for girls and *Stars, Shells and Bluebells* a book on women pioneers in science and technology.

Institute of Physics

76 Portland Place,
London W1B 1NT
England
Web site: www.iop.org.uk

There are many resources available from the Institute of Physics, including a superb set of posters. The institute runs an affiliation scheme for schools.

Association for Science Education

College Lane
Hatfield
Herts AL10 9AA
England
Phone: 00 44 1707 283000
Web site: www.ase.org.uk

This is the association for science teachers in the UK. It publishes *School Science Review* and holds an annual meeting in January each year.

BNFL Education Unit

Risley
Warrington WA 3 6AS
England
Web site: www.bnfl.com

This is the Education Unit of British Nuclear Fuels and has a number of resources available for schools, many of them free.

NRPB

Chilton
Didcot
Oxfordshire OX11 0RQ
Web site: www.nrpb.org.uk

This is the Radiological Protection Board for the UK. It has a schools information pack, which consists of a wall chart, leaflets and worksheets on radiation and radiation protection. The pack is available at a cost to schools.

CLEAPSS School Science Service
Brunel University
Uxbridge UB8 3PH
England
Web site: www.cleapss.org.uk

CLEAPSS runs a school science service for schools in the UK and specialises in information on the maintenance, repair and safe use of science equipment. Membership of CLEAPSS is available to Irish schools.

PPARC
Particle Physics and Astronomy Research Council
Polaris House
North Star Avenue
Swindon
Wiltshire SN2 1SZ
Phone: 00 44 1793 442000
Web site: www.pparc.ac.uk
The council publishes material on particle physics.

Classroom Video 1992
Web site: www.classroomvideo.com.uk

Philip Allan Publishers
Web site: www.philipallan.co.uk

AVP
Web site: www.avp.co.uk

Viewtech Film & Video
Web site: www.viewtech.co.uk

This company has a science catalogue, and some of the videos may be found suitable.

7.10 PHYSICS SUPPORT SERVICE

The Physics and Chemistry Support Service, established under the Physical Sciences Initiative of the Department of Education and Science, provides support for the implementation of the revised Leaving Certificate Physics syllabus. The administration and organisation of the support service is hosted by Limerick Education Centre. A team of trainers, under a National Co-ordinator, provides in-service training and support for physics teachers in the form of cluster meetings, workshops, school visits and the preparation of resource materials.

Address: Limerick Education Centre
Park House
Parkway Centre
Dublin Road
Limerick
Tel. 061 419918
Email physchem@lec.ie
Web www.lec.ie

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