Physics

Teachers' handbook

Nuffield Advanced Science

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Nuffield Advanced Science

Nuffield Advanced Physics team

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Physics

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Nuffield Advanced Science
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Foreword

It is almost a decade since the Trustees of the Nuffield Foundation decided to sponsor curriculum development programmes in science. Over the past few years a succession of materials and aids appropriate to teaching and learning over a wide variety of age and ability ranges has been published. We hope that they may have made a small contribution to the renewal of the science curriculum which is currently so evident in the schools.

The strength of the development has unquestionably lain in the most valuable part that has been played in the work by practising teachers and the guidance and help that have been received from the consultative committees to each Project.

The stage has now been reached for the publication of materials suitable for Advanced courses in the sciences. In many ways the task has been a more difficult one to accomplish. The sixth form has received more than its fair share of study in recent years and there is now an increasing acceptance that an attempt should be made to preserve breadth in studies in the 16–19 year age range. This is no easy task in a system which by virtue of its pattern of tertiary education requires standards for the sixth form which in many other countries might well be found in first year university courses.

Advanced courses are therefore at once both a difficult and an interesting venture. They have been designed to be of value to teacher and student, be they in sixth forms or other forms of education in a similar age range. Furthermore, it is expected that teachers in universities, polytechnics, and colleges of education may find some of the ideas of value in their own work.

If the Advanced Physics course meets with the success and appreciation I believe it deserves, it will be in no small measure due to a very large number of people, in the team so ably led by Jon Ogborn and Dr Paul Black, in the consultative committee, and in the schools in which trials have been held. The programme could not have been brought to a successful conclusion without their help and that of the examination boards, local authorities, the universities, and the professional associations of science teachers.

Finally, the Project materials could not have reached successful publication without the expert assistance that has been received from William Anderson and his editorial staff in the Nuffield Science Publications Unit and from the editorial and production teams of Penguin Education.

K. W. Keohane
Co-ordinator of the Nuffield Foundation Science Teaching Project

Organizers' acknowledgements

The *Teachers' guides* and *Students' books* in the Nuffield Advanced Physics series are the work of many hands. The main contributors were the members of the Advanced Physics team, and for that reason they are listed in each volume.

The Organizers are particularly grateful to V. J. Long, who originated the work of the Project, both for that early work and for his continuing criticism and advice, which has always been acute, sympathetic, and perceptive. The overall shape of the course owes much to his original conception of it. They also thank B. R. Chapman, R. D. Harrison, Dr R. S. Longhurst, M. S. Smith, and E. J. Wenham, who contributed a great deal to the first ideas of the Project. B. R. Chapman has continued to help with advice.

The Organizers also wish to offer their particular thanks to the many teachers who, concealing their doubts and qualms, bravely embarked upon a new course with only preliminary material to help them. Their constant criticism has been of the first importance, and has resulted in substantial changes to the course. They too must be regarded as part authors of the volumes introduced here. The names of their schools appear in this *Handbook*.

Schools which took part in the trials have been greatly helped by those who visited them, and arranged the many local meetings of teachers taking part, which proved to be a most valuable aspect of the trials period. Such work was undertaken by W. F. Archenhold, B. R. Chapman, J. G. Jones, H. D. J. McKeown, I. Morrison, E. J. Wenham, and C. L. Williams, H.M.I., in addition to team members.

We would like to associate ourselves with Professor Keohane's thanks to the Consultative Committee and to add our thanks to the Oxford and Cambridge Schools Examination Board. Professor Keohane himself has earned our gratitude by his ready practical support, by his many and fruitful interventions on our behalf, and by his steady confidence in our proposals, both publicly and privately expressed.

We wish to thank the many institutions which have helped us, mainly by releasing people to work on the Project. Worcester College of Education willingly seconded Jon Ogborn to the Project, and its Physics Department uncomplainingly suffered many intrusions into its laboratories, to try out ideas for experiments and apparatus; besides this, it provided an office and the use of a further laboratory.

The University of Birmingham generously released P. J. Black from many duties for a considerable time; the Physics Department provided office facilities for two years for both Organizers; and many members of its staff gave their time and energy in innumerable informal discussions of the greatest value.

The Headmaster and Governors of Rugby School allowed G. E. Foxcroft to shed the greater part of his teaching responsibilities over several years, and showed much kindness and sympathy in helping him to cope with the strains of a double life. They

also gave hospitality to Martin Harrap for three years, and during this time placed the resources of the school's laboratories and workshops at his disposal. Chelsea College Centre for Science Education gave freely of the time of R. W. Fairbrother, John Harris, and A. L. Mansell. The Inner London Education Authority released A. W. Trotter for two years from Elliott School, and later allowed him to take time off from his work at the North London Science Centre. Garnett College generously released P. R. Lawton for two years, to work on studies of the evaluation of the Project. At an early stage in the Project, the Physics Department of the University of York sheltered V. J. Long and Martin Harrap, and gave them much assistance. The Education Department of the University of Leeds allowed B. R. Chapman to give much time to the Project.

A number of people not directly connected with the Project have also helped us. Five teachers not then engaged in trials agreed to give our ideas for individual investigations a pilot trial, fitting this work into their ordinary teaching. They were N. D. N. Belham of Worcester Grammar School for Girls, J. A. Crook of Bishop Vesey's School, M. East of the King's School, Worcester, G. E. Foxcroft of Rugby School, and C. Grant Dixon of the Grammar School, Ross-on-Wye. They helped a great deal to uncover the problems and to build confidence in the idea.

The group working on examinations and tests have had much help from P. J. Cox and G. W. Dorling, both of whom cast a fresh light on the problems of making up good questions and produced many good ones themselves, despite the many other demands on their time.

We thank the many University teachers who have given their time to a number of working parties, to a series of meetings which gave critical consideration to drafts of various parts of the course, and to many discussions of difficulties. They helped greatly to clarify our thinking, and, in passing, taught us a good deal of physics. Their names appear in the books with which they were particularly associated.

The Organizers wish to thank P. J. Lawton for his work on the problems of evaluating the results of trials and of planning and testing means of evaluating the final proposals. He has undertaken the analysis of the immense amount of data which has come in, and assisted with the analysis of written comments from students by Wesley Morgan. His work, which will be published elsewhere, will have a lasting value in assisting teachers to understand the effects of the course on students and to judge its overall impact. We are grateful to the Schools Council for the financial support of this work, and to their officers for much helpful advice.

The Project has been fortunate in its many secretaries, and we thank them all, particularly Mrs P. J. Laws and Mrs A. C. Pritchard, who coped with a large volume of work at a time when the Project staff had diminished in number but the flow of paper had, if anything, increased.

P. J. Black Jon Ogborn
Joint Organizers

Introduction

The purpose of this book

This *Handbook* is intended to give teachers an overall view of the Nuffield Advanced Physics course, to assist them in planning their work and in making provision for such things as apparatus, books, and films, and to offer suggestions about how the course might be taught so as to achieve certain aims.

Teachers will naturally want to know what the practical and financial implications of starting the course will be. Chapter 8, 'Guide to apparatus', lists all the equipment suggested for the experiments proposed, including items both from Nuffield O-level Physics lists and new items for the Advanced course. Listed with each item are the experiments it is needed for, in a form which shows which items are required for each Unit, so that teachers who wish to use only some Units can make their selection of apparatus. Lists of books, films, film loops, and slides complete the part of the book concerned with equipment.

The course leads to an examination, and teachers and students will want to know what they can expect. Chapter 5, 'Examinations', outlines the policy developed during the trial period and gives samples of examination questions, with some account of why such questions might be set. Class tests will no doubt form part of most teaching schemes, and Chapter 6 on this subject tries to help by offering sample questions.

All teachers will feel the need to know where they are in the course as a whole when they are teaching any one part, and many will wish to modify the order of the suggested material, or to omit some of it. The synopsis of the whole course in Chapter 2 attempts to meet the first need and to give assistance with the decisions arising out of the others.

The physics given in the synopsis is not the whole course. The course also includes individual investigations by students of topics of their own choice. Chapter 7, on 'Individual investigations', offers some guidance on the organizing of this work and gives a list of sample topics.

The content of the course could be taught in many ways. Some ways will be more helpful than others, so far as the aims of the course are concerned. Chapter 4, 'Teaching the course', besides discussing such problems as the links with earlier physics courses, also suggests some teaching methods which are likely to be relevant to the aims of the course. There is, of course, no suggestion that these methods are the only appropriate ones.

The examination, the teaching methods that stem from it, the design of the course, and many of the detailed choices of topics and of ways of approaching topics were all influenced by certain general aims. These have formed an important part, to us at least, of our thinking. Some of them were stated in our earliest policy papers, while others were clarified as the work of the Project went ahead and we could see, as it were, what we were trying to do. All, in the end, have guided the construction of the course, both in general and in detail. Chapter 3 on 'General aims' tries to set them out as clearly and simply as possible, so that teachers can make their own judgments as to how nearly our aims coincide with those that they have and believe in.

All these matters take up much space. This may be a book to read through once, and then to return to from time to time for practical information or for general guidance. Those whose need is for a brief survey of the course, linked to a review of the main decisions which shaped it, so that they may see whether this course is one in which they would be interested or so that they may quickly call to mind its general shape and purpose, should find some help in the first chapter, 'The Nuffield Advanced Physics course'.

Chapter 1

The Nuffield Advanced Physics course

'If a man burns to learn, and sets himself to comparing his ideas with experimental results in order that he may correct those ideas, every scientific man will recognize him as a brother, no matter how small his knowledge may be.'
C. S. Pierce

'It would be well if they could be taught everything that is useful and everything that is ornamental: but art is long and their time is short. It is therefore proposed that they learn those things that are likely to be most useful and most ornamental.'
Benjamin Franklin

'The first object of any act of learning, over and beyond the pleasure it may give, is that it should serve us in the future. Learning should not only take us somewhere; it should allow us later to go further more easily.'
Jerome Bruner

The Organizers, and the Nuffield Advanced Physics team, like to think that the books to which this volume is an introduction will enable teachers to improve their sixth form physics courses. Our own contribution is necessarily only a small part of the whole: clearly the success of the course will depend very much on the teachers teaching it and on their ability to transform the written word into an effective and exciting piece of education.

The making of a curriculum begins and ends with judgments of value. In constructing the course, we have asked ourselves what it is that we value most among the many things that a person might be led to know, to feel, to understand, or to experience. No doubt different people would have made different judgments, and would have produced different ideas for a course based on those judgments. We have done our best, guided by our particular vision of what physics is like, and of what education is for, having had the privilege of being given some time and resources with which to produce and try out new ideas for a sixth form physics course. We do not regard our materials as either perfect or final; indeed we are very conscious of the many problems we have left unsolved, and of the many avenues we have left unexplored. It is our hope that teachers will take these materials and extend, adapt, and improve on them. The task of making this course has been an enjoyable one, and we hope that some of that enjoyment will be shared by those who teach it and by those who study it.

Principles underlying the plan of the course

The general aims of the course are discussed at greater length later in this *Handbook*. The thinking behind the plan of the course and its aims is summarized below.

The Nuffield Advanced Physics course is intended to be useful to the student in his or her future life. Although a substantial proportion of sixth form students go on to further education, they do so in courses of a wide variety, though usually within some pure or applied science.

We believe that it is impossible to teach a sixth form student all the variety of things that he or she might be expected to know in the future. But we think that it is possible to select a limited number of important ideas, each of rather wide usefulness, and to teach these well. One of our basic decisions has been to sacrifice a wide acquaintance with many ideas for a deeper understanding of a few ideas. We have done this because we think that if the right ideas are chosen, and if students do understand them, they will be able to use these ideas in later learning of many sorts. It is certain that many different kinds of demands will be made on students, both in further education and in their careers. It is equally certain that many of these demands are unpredictable at the time students are at school, both because they do not know what they are going to do, and because of continual changes in science and technology. So in planning the course, we have tried to concentrate upon the deepest, most generally useful concepts and modes of thought within physics. We hope that a good grasp of these ideas will enable students to learn new ideas as they need them, in the future.

For the same reason, we have tried to build a course that could reveal the structure of physics: the kinds of argument physicists use and the kinds of problem they tackle. We hope, also, that students will be helped to learn in the future by finding that new problems fit into a recognizable framework.

But understanding fundamental ideas and knowing how they fit together are not enough to enable someone to learn effectively in the future. Some skill in learning and in thinking is also needed; in particular the skill required to enable one to learn from one's own reading, without the immediate assistance of a teacher. So the course attempts to develop this kind of ability, and the independence and maturity that go with it.

We have also tried to produce materials that will encourage students to become more thoughtful. While we see this as a valuable end in itself, we also see it as a necessary part of actually using ideas when one is faced with some problem, whether this arises as a part of further education or in one's later career. Furthermore, in physics, the ability to think effectively depends upon having some rather definite skills and knowledge, particularly on having some mathematical understanding. So our proposals include some teaching of mathematical ideas and techniques within the teaching of physics.

In short, the course is intended to hang together, to tell a connected story, and to make sense in ways which students will later find are a fair reflection of the shape of the subject. It is meant to show students which are the fundamental ideas, and to help them to become better at using these ideas.

We also think it important that the course should show that physics is useful, and should illustrate the kind of impact discoveries in physics have had on the way people live. More than that, we hope that parts of it will show something of the differences between the work of physicists and of engineers; the first continually probing and analysing, the second having to put things together for a purpose, using inventiveness and intuition especially where the problem is too complex to be analysed in terms of fundamental principles. Therefore some parts of the course are deliberately designed with this in mind, and nearly all parts are provided with background reading about the uses of the physics they discuss.

Planning the course

Figure 1 is a block diagram of the Advanced Physics course. While the final selection of material, its treatment, and its organization were much influenced by the experience gained in trials in schools, those features of the plan which reflect our basic approach to the job of constructing a course have been a constant part of the pattern proposed.

One of these features is the way the ten Units into which the course is divided lead towards a few end points. While each Unit is intended to be to some extent a complete thing in itself, and to be usable within a variety of patterns of teaching,

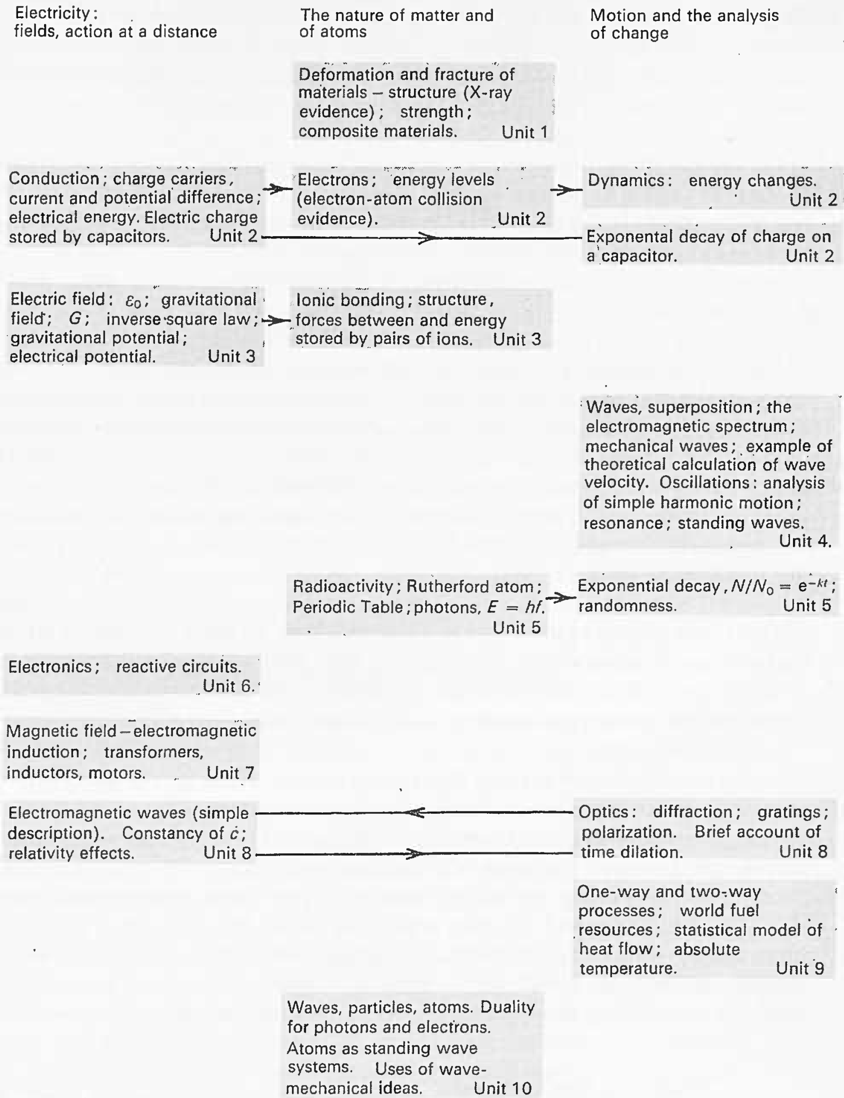

Figure 1
Block diagram of the course (omitting individual investigations).

the choice of the Units' content and their arrangement in this course are not arbitrary. Unit 10, *Waves, particles, and atoms* is an end point at which ideas first discussed in earlier Units (mainly Units 1 to 5) are brought together again to bear on a new problem, that of understanding the nature of atoms in terms of electrons behaving like waves trapped in an electrical potential well.

This and the other end points are intended, therefore, to produce a course which seems to be going somewhere for a purpose. The work on electronics in Unit 6, *Electronics and reactive circuits,* forms an end point of another sort, both drawing together ideas not used again elsewhere (mainly ideas to do with circuitry, oscillations, and pulses) and doing it in a way that reflects something that Unit 10 does not, the practical creative use that applied scientists can make of physical principles.

The other two end points are the descriptive work on electromagnetic waves, in Unit 8, *Electromagnetic waves,* and the statistical discussion of heat flow and of absolute temperature, in Unit 9, *Change and chance*. The former, while modest in scope, draws together ideas about fields and about waves, and illustrates the importance of the magnetic field. The latter is more ambitious, though still strictly limited in scope. It tries to show how crucial the idea of a statistical process is for much of science, and to give the concept of randomness something of its proper importance.

Themes running through the course

Figure 1 is divided vertically into three themes, which run through the course as a whole. We believe these to be important kinds of thinking within physics.

The blocks down the centre of figure 1, under the heading, 'The nature of matter and of atoms' all concern the continual shifts physicists make from looking at things on the large scale to looking at them on the small scale: the constant attempt to find a microscopic understanding of macroscopic events, or to create models of what matter or atoms might be like 'inside'.

A quite different theme runs down the left of figure 1. Most of the items there revolve around the problem of action at a distance and, in particular, they develop the various field concepts physicists use to help them to understand the interactions of one thing with another.

The third theme, running down the right of figure 1, is different again. Its concern is with the ways physicists and others handle, describe, and analyse problems involving the way things change. For example, it pays special attention to differential equations, treated in a simple way, these being vital tools in scientific thinking.

These themes are visited and revisited throughout the course. Some Units cover more than one theme, while others illustrate aspects of only one. Ideas from one theme are later found useful in handling problems in another, as when the electrical inverse square law and the idea of electrical potential prove helpful at once in studying ionic crystals, and later on in understanding Rutherford scattering. We hope that this too will help the course to seem to hang together and to make sense.

The selection of material

We have no reason to be sure that we have made the best possible selection of material for the course. What remains has had to compete with much that, in the end, found no place. For a topic to survive, it had to serve not one, but several of the purposes already outlined. For instance, work on magnetic fields is dispensable so far as most of the structure of the rest of the course is concerned. With some of it included, the course gives a more balanced picture of what physics is like, and the theme concerning fields and action at a distance is strengthened, especially if the ideas are linked by a description of electromagnetic waves.

But as strong a case could be made for many other topics that are not included. Therefore, to find a place, work on magnetic fields must offer something more. In this course it is used to give a much needed practical, technological bias to a part of the course, as is work in Unit 1 on materials and in Unit 6 on electronics. It also provides an occasion for some fairly accurate experimenting, unlike a number of other parts of the course. Given a few more virtues of this sort, especially those that redress deficiencies elsewhere in the course, we begin to think that such a topic might find a place.

We have also tried to choose material, and more especially to find ways of approaching it, which will make the study of physics an active, thoughtful process. We have tried to arrange that there will be experiences and problems out of which spring new arguments, new experiments, new problems, and new ideas. We have not necessarily followed a logical or a historical order. For example, energy levels appear early, in Unit 2, *Electricity, electrons, and energy levels*, the treatment being completely empirical. They are shown in Unit 5, *Atomic structure*, to raise problems for a Rutherford model of the atom, and in Unit 9, on the other hand, to be useful in a discussion of quantized energy of atoms in a solid. Finally, in Unit 10, some effort is made to resolve the question, using wave mechanical arguments.

Not every concept is developed fully at its first appearance; difficult ideas are given time to grow. For example, the methods used for studying differential equations appear in the course bit by bit, developing only as much as is needed on each occasion.

One overriding need is to end up with little enough material to allow time to teach it well, time to teach the skills of learning and of doing physics, and also some time to relax, to talk, and to follow up particular interests. We have tried to achieve this, but if we have not, we would prefer to see further cuts made than to see the addition of more topics whose omission is perhaps felt to be shocking.

Flexibility and the division of the course into Units

The discussion so far has emphasized a belief in the value of structure in a course, and may suggest a certain rigidity. Yet from the start of our work on the Project, it was clear that the sixth form pattern for which the course was to be designed might vanish almost as soon as the materials were published. What was not clear, and is still not clear at the time of writing, is the form a new pattern would take.

Our way of attempting to meet this situation has been to divide the course up into a number of Units. Each of these is to be thought of as a building brick which one may fit together with other Units to make a different course. If necessary, parts of several Units could be omitted, or be transferred to others. This division into Units may have the further advantage that teachers in colleges and universities can easily take from the course those Units which offer them something of value.

As they stand, Units 1 to 10 make up a two-year sixth form course that has been tested as far as possible, and has been modified in the light of that trial experience.

It is not essential to teach the course in numerical order of Units. The *Teachers' guide* for each Unit indicates the connections with other Units, and the possibilities for, and constraints upon, various rearrangements. In general, Units 2 to 5 contain introductory material needed later, and must come early. After that, the order is fairly free. Unit 1 is a special case, being designed specifically as an introductory Unit for the course as a whole. If it is not used as such, it will probably require considerable amendment.

Nevertheless, the course as it stands has, we believe, certain virtues of shape and structure. We do not wish to discourage teachers from reorganizing or modifying it, but we do wish to encourage them, when they do so, to build courses of their own with even more of these virtues.

Table 1 shows some of the more important ways in which the various Units depend upon one another. It cannot be complete, but it may help to guide those who have either to construct a different course, or to modify the sequence of this one. The introduction to each Unit contains further remarks about how that Unit fits into the total pattern, and unexpected difficulties will only be avoided by using table 1 in conjunction with a more detailed consideration of the material in each Unit. Nevertheless, it will be clear from table 1 that, for example, Unit 10 depends upon Units 1 to 5 but not so much upon others, so that these others might be omitted from a shorter course leading towards Unit 10. It should be equally clear that if Unit 10 is not used as an end point, attention will need to be given to the content of Units 1 to 5 to remove material not now relevant to whatever other end points are being considered.

		Relevant parts of other Units
Unit 1	*Materials and structure*	
Unit 2	*Electricity, electrons, and energy levels*	Unit 1: existence of atoms, Avogadro constant.
Unit 3	*Field and potential*	Unit 1: crystal structure, forces between atoms, stress and strain. Unit 2: electric charge, potential difference, charge on an electron, work and energy.
Unit 4	*Waves and oscillations*	Unit 1: nature of X-rays, wave behaviour, force constant of an atomic bond in a solid. Unit 2: dynamics, differential equations. Unit 3: forces on ions in an ionic crystal, background ideas about fields.
Unit 5	*Atomic structure*	Unit 1: atoms in solids, size of an atom, Avogadro constant. Unit 2: charge on an electron, evidence for energy levels, energy, the exponential decay equation. Unit 3: electric field, electric potential, inverse square law.
Unit 6	*Electronics and reactive circuits*	Unit 2: electric current, potential difference, charge, capacitance, and exponential decay. Unit 4: period of an oscillator, existence of radio waves.
Unit 7	*Magnetic fields*	Unit 2: electric current, potential difference, ideas about rate of change (d/dt). Unit 3: field concept, measuring fields, superposition of fields. Unit 5: importance of magnetic deflection of moving charges.
Unit 8	*Electromagnetic waves*	Unit 2: electric charge, current, and potential difference. Unit 3: electric field (uniform field in a parallel plate capacitor), value of ε_0. Unit 4: wave properties, existence of electromagnetic waves. Unit 7: magnetic field, electromagnetic induction, field of a solenoid, value of μ_0.
Unit 9	*Change and chance*	Unit 1: crystal structure of solids, Avogadro constant. Unit 2: existence of energy levels, exponential change. Unit 4: frequency of oscillations.

		Relevant parts of other Units
		Unit 5: first ideas about randomness, exponential function, photons, and the Planck constant.
Unit 10	*Waves, particles, and atoms*	Unit 1: wave nature of X-rays, size of atom, Bragg's Law.
		Unit 2: charge on an electron, existence of energy levels, dynamics.
		Unit 3: inverse square law, electric potential.
		Unit 4: standing waves, mathematics for describing oscillations.
		Unit 5: nuclear atom model, photons, Planck constant, ionization energies, ideas about randomness, spectra, and energy levels.
		Unit 8: diffraction.
		Unit 9: ideas about probability.

Table 1
Connections of later Units with earlier ones.

Chapter 2

Synopsis of the course

This synopsis is intended to give teachers an overall view of the content of the course. It indicates the subject matter of each Unit briefly, and gives a short account of how this subject matter fits into the course as a whole.

The *Teachers' guide* for each Unit contains a fuller summary of the content of the Unit. Especially where novel proposals are involved, we have found that these summaries can easily mislead because of their brevity, while they remain valuable as a way of showing how the whole course develops. It may therefore be necessary to turn to the detailed text and commentary in a *Teachers' guide* to discover what is implied by parts of the synopsis that follows.

Unit 1 *Materials and structure*

Part One 'The variety and behaviour of materials'

The variety of mechanical properties of materials, and their uses.

Part Two 'X-rays and structure'

Models of the arrangement of atoms in solids. Use of X-rays to investigate the structure of solids (microwave analogue). Bragg's Law. The structure of copper.

Part Three 'Stretching and breaking'

The Young modulus and tensile strength. Forces between atoms. Interpretation of behaviour of glass, rubber, and copper in terms of structure. Slip in ordered structures; dislocations. Cracks. Design of new materials; composite materials.

This Unit serves to introduce many of the leading preoccupations of the course. The problems of applying physical principles to create something useful lie at the heart of the Unit. It is also about the use of microscopic ideas to explain the macroscopic behaviour of matter, and takes the opportunity to begin discussion of model building as part of physical inquiry.

The Unit also makes a start on encouraging students to read and to guess and speculate. Indeed, it is to be hoped that the Unit will help to establish very early in the course the practice of free discussion and argument.

Unit 2 *Electricity, electrons, and energy levels*

Part One 'Things which conduct'

Measurement of current and potential difference (puzzle boxes). Resistivity. Temperature effects. Insulators and semiconductors. The transport of electricity by charge carriers.

Part Two 'Currents in circuits'

Use of meters to investigate circuits (puzzle boxes). Use of the potentiometer to vary a potential difference. Handling and choosing meters. Meaning of potential difference.

Work on materials continues into a study of electrical properties. Brief theoretical speculation about conduction will be taken up later with a Hall effect experiment. The need for more evidence of the electrical nature of atomic structure is seen. The course shows a continuing concern with the theme of models and the structure of matter. The circuit puzzles emphasize the need for thinking about circuits, current, and potential difference and lead to a revision of O-level work on voltmeters.

Part Three 'Electric charge'

Circuits including capacitors. The conservation of charge. Charge measured in ampere seconds. Electrometer. Capacitance. Exponential *decay of charge on a capacitor, numerical solution of* $dQ/dt = -kQ$.

This Part reminds students of the need to understand electric charge, by way of experience with capacitors. It introduces the electrometer and gives an empirical check on its performance, so that it may be used later.

The first of a number of graphical–numerical methods appears here, serving to introduce the technique and to draw attention to the important mathematical model of exponential decay. (The explicit use of e^{-kt} will usually be delayed until later, however.) The theme of motion and change is touched on in a fresh context.

Part Four 'Stored energy'

Energy stored in a capacitor. Energy stored in a spring. Revision of work, kinetic energy, potential energy.

Energy considerations lead to a revision of the dynamical concept of energy, particularly the energy stored in a spring. These ideas are deliberately revised in the context of the new problem of stored electrical energy, to make an explicit link between parts of the course.

Part Five 'Electrons and energy levels'

Review of evidence for the existence of electrons. Electron-atom collisions; ionization. Evidence for energy levels from inelastic collisions. Revision of dynamics; momentum conservation; elastic and inelastic collisions.

This Part puts some of the earlier ideas to use. The course moves back to the theme of understanding the nature of matter and atoms. The opportunity is taken to present evidence from research papers (selected extracts), and to discuss connections between facts, evidence, and theories. This Part will also link up with several chemistry courses.

Unit 3 *Field and potential*

Part One 'The uniform electric field'

Electric field, uniform field, $E = V/d$. Field in a capacitor; dependence on charge, area, spacing, and potential difference. Value of ε_0. Use of flame probe to investigate potential variations.

Part Two 'Gravitational field and potential'

Fields, and action at a distance. Inverse square law; value of G. Gravitational potential difference (changes in kinetic energy of a coasting spacecraft). Field $= -\mathrm{d}V/\mathrm{d}x$. The $1/r$ variation of potential.

Part Three 'The electrical inverse square law'

Electric field and potential of point charges (use of flame probe). Analogy with gravitation. The constant $1/4\pi\varepsilon_0$. Uniform field from a flat sheet of point charges. Mapping fields.

This Unit is an (ambitious) attempt to introduce the ideas of field and potential early in the course. It compares and contrasts electricity and gravitation, to show how similar ideas are used in dissimilar problems. It tries to show how abstract ideas are invented to handle problems of action at a distance.

Part Four 'Ionic crystals'

Energy of pairs of ions. Energy of an assembly of ions. Forces of repulsion as well as of attraction. Arguments for the variation with distance of the repulsion term. Compressibility of an ionic crystal.

This Part puts the previous ideas of the Unit to a new use, and moves from the theme of fields and action at a distance to the theme of the nature of matter and atoms. The work is presented as a piece of independent study for students, using a semi-programmed text. Not all students need complete it; the intention is to interest them all and to stretch the most able.

Unit 4 *Waves and oscillations*

Part One 'Waves of many sorts'

Superposition. Radio waves, microwaves, light, and sound, investigated empirically. The speed of light. The electromagnetic spectrum. Infra-red and ultra-violet radiation.

Part Two 'Mechanical waves'

Superposition of pulses on springs and on a wave model. Theoretical prediction of the speed of compression waves. Speed of sound in steel. Review of other mechanical waves.

A start is made with waves, and with invisible waves, to interest students who have already studied waves with ripple tanks. The empirical study of the electromagnetic spectrum looks forward to the later development of ideas about electromagnetic waves (Unit 8). Work on mechanical waves shows a need for further study of mechanical oscillations. The speed of one sort of wave is calculated from first principles, as an example of the possibility of such calculations.

Part Three 'Mechanical oscillations'

Repetitive events; the idea of time. Simple harmonic motion; period independent of amplitude, dependent on mass and force constant. Construction of a mathematical model for simple harmonic motion. Numerical solution of $\Delta^2 s/\Delta t^2 = -(k/m)s$. Uses of $f = 2\pi\sqrt{k/m}$. Resonance. Standing waves.

This Part teaches both physics and mathematics, in the construction of a mathematical model for simple harmonic motion. The numerical integration technique is extended to a second order equation and the form of the curve produced is compared with the explicit form $s = A \cos \omega t$. This work is intended to deepen the understanding both of accelerated and harmonic motion, and of the use of mathematical models to represent them, and also to prepare the ground for later use in the work on *Waves, particles, and atoms* (Unit 10).

The Unit concludes by returning to interference, and linking it with oscillations in an empirical study of standing waves. A resonance apparatus is used to give students an opportunity to devise their own experiments. The standing waves offered include two-dimensional cases in preparation for the three-dimensional problem of the hydrogen atom.

The work on waves and oscillations has its eye very much on the future. The work at this point serves to extend experience, to raise new kinds of problems, and to develop new tools and concepts.

Unit 5 *Atomic structure*

Part One 'Radioactivity and the nature of atoms'

Radiations from radioactive substances, their nature, and their energy. Preliminary study of Rutherford scattering, and of radioactive decay, using reading from books and papers.

Part Two 'The Rutherford model of the atom'

Rutherford scattering. Test of the Rutherford model.

Part Three 'Exponential decay'

Chance and decay. $dN = -kN\,dt$. The form $N/N_0 = e^{-kt}$, approached by a numerical integration. Logarithmic graphs.

Part Four 'New ideas and problems about atoms'

Atomic number and nuclear charge. The nucleus; the neutron; isotopes and their uses; transmutation.

Ionization energies of the elements. Photons, the photo-electric effect, $E = hf$; photons and energy levels.

This Unit returns to the problem of building models of atoms. The work on radioactivity is kept to the minimum needed when considering evidence for a nuclear model and to throw a little more light on the electromagnetic spectrum. The discussion of alpha scattering avoids lengthy analysis by the use of a gravitational analogue of the $1/r$ potential.

Radioactive decay serves as a second example of exponential decay and the explicit form e^{-kt} is introduced here.

The Unit is built around individual tasks for students, involving much reading from books and papers. It ends with a look forward to problems that will be tackled in Unit 10, taking the opportunity to introduce the idea of a photon briefly, so as to prepare the ground and to make a link with work on energy levels from Unit 2.

Unit 6 *Electronics and reactive circuits*

Part One 'Building bricks'

Investigation of a multi-purpose module (containing one transistor); its input–output properties, switching, amplification, and other useful behaviour. Simple combinations of modules; astable and bistable circuits, gates for '*or*' and '*and*'. Amplifying and feedback.

Part Two 'Circuits containing capacitance'

Response of RC circuits to pulses and to sinusoidal inputs. Power in an alternating current circuit. Circuits that differentiate and integrate.

Part Three 'Circuits containing inductance'

Investigation of inductors; mechanical analogy. Oscillations and resonance in a parallel LC circuit. Radio sets.

Part Four 'Building electronic systems'

Use of the multi-purpose module (and others based on it) to create devices which will perform a wide variety of useful functions.

A systems approach to electronics is adopted, asking what the devices will do, and how they might be combined to do other things. By avoiding spending time on the explanation of the behaviour of specific devices, time is made for students to do some engineering of their own. In Part Two, the inductor is treated as a device with certain observable properties, which are explained more fully in Unit 7. If preferred, this part of Unit 6 could be transferred to Unit 7, especially if Unit 6 needs shortening.

Unit 7 *Magnetic fields*

Part One 'Forces on currents'

$F = BIL$, measuring a magnetic field. Force on moving charge, $F = Bqv$. Charge to mass ratio for electrons. Motion in a circle. Accelerators and mass spectrometers.

Part Two 'Electromagnetic induction'

Induced voltage in moving wires and in wires in changing fields. Effect of turns, area, and rate of change. Energy arguments. The idea of magnetic flux. Transformers, inductors, power transmission.

Part Three 'Flux near currents'

Measurement of fields near various current distributions. Field of a solenoid. Field of a long straight wire. Introduction of μ_0 and the definition of the ampere. Eddy currents. Induction motors.

So far as possible, this Unit is practical and technological in flavour. The B-field is regarded as something to measure and to use. Theoretical calculations are minimized, the work on fields near currents being used to illustrate accurate experimenting and the testing of laws against data. In addition, students are asked to read about devices such as accelerators and mass spectrometers.

Unit 8 *Electromagnetic waves*

Part One 'Looking through holes'

Diffraction of light passing through apertures. Comparison with radio waves. Simple theory of diffraction. Resolution. Radiotelescopes.

Part Two 'Spectra'

Diffraction grating. $n\lambda = d \sin \theta$. Observation of spectra. Sharpness of maxima.

Part Three 'Electrical waves'

Radio waves. Observation of the speed of a pulse on a coaxial cable. Observation of the transmission of a pulse on an LC line. Speed $c = \sqrt{1/\varepsilon_0 \mu_0}$ for a pulse on a parallel plate wave guide. Possible description of the propagation of electromagnetic waves in space. Polarization.

Part Four 'Relativity'

The constant speed c. Simple argument for time dilation. Possible connection between electric field and magnetic field.

So far as this Unit is concerned, light is a wave motion, though the mention of line spectra recalls work on photons and energy levels in Unit 5. Diffraction effects are used mainly as a medium for students to devise and try simple experiments, though a simple theory is given. The practical evidence of wave properties supports an attempt to show how one sort of electromagnetic wave may be described theoretically, and how its speed may be predicted. The constancy of the speed leads to as brief a look at relativity as possible. This is partly for interest, but partly to show how new and fundamental questions can arise out of seemingly innocent ideas.

Unit 9 *Change and chance*

Part One 'One way processes'

Examples of processes having a definite direction, such as mixing and burning, contrasted with those that (nearly) do not. Conservation of energy.

Part Two 'The fuel resources of the Earth'

The rate of use of fossil fuels. Growth in demand for fuel. The irreversibility of fuel-burning, despite energy conservation.

Part Three 'Diffusion and chance'

Examples of calculations of the chances favouring random processes. Introduction to the idea of the number of ways in which a state of affairs can arise.

Part Four 'Thermal equilibrium, temperature, and chance'

Thermal equilibrium, the zero-th law, temperature. A model of thermal equilibrium in a solid, based on a simulation game. Computer film of the game. Exponential (Boltzmann) distribution. Kelvin temperature. The specific heat capacity of a solid. The Boltzmann constant.

Part Five 'Counting ways'

Theoretical discussion leading to $T = \Delta Q/k\Delta \ln W$ and the Boltzmann factor. Kelvin temperature. Entropy change $\Delta S = k\Delta \ln W$.

Part Six 'Uses of thermodynamic ideas'

A selection of one or two uses of the ideas, drawn from: change of vapour pressure with temperature, behaviour of thermistor, rate of reaction, uses of entropy values, chemical equilibrium, inefficiency of engines, cells as energy sources.

It is hoped that a little acquaintance with the nature of thermodynamic ideas and problems will be of service to students later when they meet these ideas in physical science or engineering. Among other things, some of the language of statistical thermodynamics will seem less strange.

Not all students will complete the whole Unit. Some will stop at Part Four, having had a mainly intuitive introduction to the basic ideas. Little mathematics is used, and combinatorial analysis is avoided by the use of random simulation. The exponential function, met before, finds a new use. The significance of randomness in physics, chemistry, and engineering is given further emphasis.

This work also attempts to show how a very few basic ideas can yield new results of wide generality and great importance.

Unit 10 *Waves, particles, and atoms*

Part One 'Photons'

The dual description of light. Spectra and energy levels. The energy levels of hydrogen.

Part Two 'Electrons'

The dual description of electrons. Electron diffraction. $mv = h/\lambda$.

Part Three 'Waves in boxes'

Atoms as boxes confining a particle, described by a standing wave. Reasons for the existence and magnitude of energy levels. The Balmer rule ($1/n^2$) for the hydrogen levels. The Schrödinger equation in a simple form; numerical solution of the equation for the ground state of hydrogen. Computer film of other solutions.

Part Four 'The scope of wave mechanics'

Selection of one or two uses of wave mechanical ideas, from: the helium spectrum, X-ray spectra, comparison of He and Li, the Periodic Table, oscillating molecules, molecular bonding, the water molecule, alpha decay.

Not all students will complete the whole Unit. Some will stop at the simpler arguments in Part Three, with perhaps a look at one use of the ideas from Part Four.

This Unit draws together many threads. Ideas used before are revised, but are also seen in a startlingly new context, and one which has radically changed the face of physics. Techniques developed previously are called for, especially the methods of numerical integration, used now to predict the energy and size of the hydrogen atom.

It is hoped that the elementary discussion given here will be of use to pupils who later need to use the ideas in one of many subjects. The material is also important enough, we feel, to form part of the education of any scientifically inclined person.

One reason for taking this piece of work thus far is that it forces one to think seriously about the models one uses, and about whether they should be considered as reliable. The Unit reinforces and gives further attention to questions about the nature of inquiry in physics.

Chapter 3

General aims

'. . . it is only in a trivial sense that one gives a course to "get something across", merely to impart information. There are better means to that end than teaching. Unless the learner also masters himself, disciplines his taste, deepens his view of the world, the "something" that is got across is hardly worth the effort of transmission.'
Bruner, J. S. (1966) Toward a theory of instruction. *Belknap Press.*

Some of the general aims of the course were touched upon in Chapter 1, 'The Nuffield Advanced Physics course'. These aims are discussed more explicitly here, with examples of the objectives they imply, and ways in which the course tries to achieve those objectives.

These aims are not offered as ideal aspirations which are impossible to achieve with any but exceptional students. They are intended to imply practical objectives, to be developed in the course and to be tested in an examination.

Learning in the future

Few things are more certain than that students will need to learn more science – pure and applied – in the future. Many will go into further education, and after that will need to learn yet more for a career. Whether they do so or not, they will face, in their future lives in a changing society, the need for still further learning to adapt themselves to new careers. Nor is it now possible to predict all their future needs in detail. We hope that, as a result of the course, students will be able more successfully to meet such demands.

Language

One sort of objective that follows from this aim is the knowledge of enough of the language of science, particularly of physics, to enable students to read without undue difficulty, and to take part in discussions with their equals. There are two needs. They should be able to *recognize* some terms when they meet them: here we include elastic modulus, tensile strength, plastic, elastic, and resistivity, insulator, conductor, semiconductor, to take a few from early parts of the course. They should also be able to *use* a smaller number of terms clearly enough to make up effective arguments. Neither of these objects will be achieved simply by learning definitions, but by talking and reading about ideas, and by using them often.

Learning new ideas

It seems to us that later learning will be assisted by a first acquaintance with two kinds of ideas. One kind – the basic ideas like charge, field, and potential – already and rightly form part of school physics courses, though their difficulty is not always matched by an adequate amount of time being given to them. These are discussed more fully under the account of our second general aim, understanding physics.

The other kind of ideas are those – like quantum ideas – which have not previously been thought suitable for introduction at school with any degree of seriousness. It is certainly true that no school course could set an objective of fully understanding such ideas. We do think it likely to be helpful in the future if a student has at least met the ideas which form the basis of physics as it now is, and which will be used in a wide variety of fields, including chemistry and many applied sciences. At least, the student should be aware that physics contains these difficult, but powerful and deep, ideas. He should also be aware that he does not yet understand them, and that there is much in them left to explore. We hope a student will be left with the confidence that such a deeper future exploration of fundamental ideas will be possible and rewarding.

Reading

The general aim of assisting learning in the future implies other sorts of objective, concerned with the skill needed to learn effectively. We hope, as a result of the reading suggested as an integral part of the course, that students will become better at extracting information from books and from papers. We hope they will know that books differ in quality, and will be better able to find the ones that suit them. We hope also that students will have come to expect to find interesting new material in magazines, and will tend to seek more of it for themselves.

Arguing

Other skills are also relevant. Learning probably involves being able to sustain a discussion with others, and maybe with oneself. So we hope to find students willing to argue, and able to tolerate long or involved trains of thought. Here the emphasis in the course on reporting to other students on their reading and experimenting has an important part to play. The teacher's role will be decisive: in encouraging the first fumbling attempts to express ideas and arguments, and in discerning and building on what is of value in what students say. It is all too easy unintentionally to stifle discussion by well meant attempts to ensure that every error is dealt with, which in effect seem to prove to the student that he or she is incapable of effective argument.

Mathematics

Mathematical skills will often be needed in the future, and we think that the most generally useful ones are those connected with changes and rates of change. So simple approaches to first and second order differential equations are developed within the course, and the techniques are used again when opportunities arise. Partly with an eye on the growing importance of the computer, numerical methods tend to be used. We hope to find students able to think effectively about problems involving rates of change, and able more easily to learn how to cast such problems in mathematical form. They should be more fluent in their use of the symbolic language of $\mathrm{d}y/\mathrm{d}t$, and $\mathrm{d}^2y/\mathrm{d}t^2$.

Translating information

Much of the information a student will need to acquire in the future will come to him or her in a coded form. We have put a special emphasis on translating information between graphical, verbal, and numerical forms.

Independence

An important difference between learning in school and learning afterwards is that students need to become more independent and self-sufficient. No one school course can do very much about this, but we hope that various aspects of our course will help a little to promote independence and a mature approach. For example, it may be that where, as suggested, students are given separate individual tasks and asked to take on their own individual investigations, some positive help will be given them towards this end.

Understanding physics

This aim overlaps a good deal with the first, 'Learning in the future'. The aim is that students understand the important physical concepts and relationships taught in the course. These are: stress, strain, electric current, potential difference, resistance, electric charge, capacitance, kinetic and potential energy, energy conservation, electric and gravitational field and potential, the inverse square law, wave superposition, the analysis of oscillatory motion, rates of change, exponential decay, collisions and momentum conservation, evidence for electrons and energy levels, evidence for the existence and size of atoms, evidence for the nucleus, simple behaviour of reactive circuits, magnetic field and magnetic flux, electromagnetic induction, diffraction, the role of chance in deciding the direction of some processes, and the need to understand atomic structure in terms of wave and particle properties.

Time needed for teaching for understanding

This is not a short shopping list, but it might have been a much longer one: it must not be allowed to be. Teaching for understanding takes much time; time that is needed for students to try out their ideas in discussion, time to make mistakes and muddles and to get out of them again, and time to reflect and think privately. So we have deliberately tried to reduce the number of pieces of physics in the course as a whole, and to limit the time spent on less important byways.

Examination questions

The examination will try to reflect and encourage this aim. So that time is not spent on memorizing information better stored in books, most formulae, data, and other detailed information will be given with the question or on the front of the paper. Questions will usually ask for knowledge to be used rather than recalled and set down.

Understanding

To devise tests for understanding, one must have some idea of what 'understanding' means. We mean more than recall or recognition, but less than the ability to solve new problems. The latter serves well enough as a rough guide, but is too strong to be taken literally; every physicist is only too conscious of his or her incapacity in the face of a really novel difficulty. What seems to us to be the mark of competence is the ability to talk sense about a physical problem; to produce relevant, sensible thoughts rather than irrelevant, completely muddled ones. It is this level of understanding at which we aim: the ability to contribute effective arguments towards the solution of problems when the student has not been trained in complete, explicit rules for solving them.

Gradual development of concepts

If students are to grasp the basic concepts well enough to use them in argument, plenty of time must be given in the course to the teaching of each concept. For example, the simple but essential idea that electric charge is a quantity of something, not a strength or intensity, needs more than a passing mention. Indeed, Unit 2 contains a long piece of experimenting with capacitors intended to bring out this idea. Similarly, Unit 4 devotes time to experiments about what is summed up in saying that waves superpose. Some may feel that we have given these simple, largely qualitative principles too much time. We would prefer to have done that, than to give them too little.

We have also planned the course so that it returns again and again to the important concepts, developing each a little further at each meeting, or showing a new use in a fresh field. We hope that students will come to expect to be asked to use old ideas in new ways, besides finding that the renewed acquaintance strengthens their grasp of the ideas. For example, in Unit 2 ideas mainly from O-level, about electricity and about dynamics, come together while students are looking at evidence for energy levels in atoms. Later, the energy level idea is used to point to difficulties in the way of the Rutherford model of the atom. Later still, in Unit 9, the idea is used in arguments about the flow of heat. Finally, in Unit 10, some attempt is made to explain why atoms might have discrete energy levels.

Similarly, the electric field, developed in Unit 3, is given an immediate use in a discussion of the bonding of an ionic crystal. In Unit 5, it finds another use in the discussion of alpha particle scattering. Parts of Units 7 and 8 suggest that electric and magnetic fields may be connected, and in Unit 8 these fields, previously firmly attached to charges or currents, 'take off' on their own in an electromagnetic wave.

Teaching for understanding

It is the way the course is taught, not what is taught, that will contribute most to this aim. Much talk and discussion will need to be encouraged so that students can rehearse their ideas, make mistakes and correct them, and develop a belief that they can talk sense about physics. In the *Teachers' guides* we have tried to help by suggesting ways of promoting talk and discussion, and ways of approaching pieces of physics as problems deserving argument and experiment. Linguists have warned us against underestimating the value of talk in developing the ability to handle ideas adequately.

In suggesting work for students, we have assumed that the combination of apparatus on the bench and problems to think about arising out of experiment is a powerful means of encouraging understanding. We take it that trying to think for oneself is the best way of getting better at it.

As indicated previously, many examination questions will try to test the ability to think sensibly. The amount of recall, out of the context of any problem to be thought about, will be reduced as far as possible.

Understanding the nature of physical inquiry

We hope that students will become better able to talk sense about the various kinds of activity in scientific inquiry; about testing a theory, making a deduction, trying an experiment, or making a guess. In particular, we hope they will be able to recognize the differences between these activities. We do not see this as a matter of vague philosophizing, but as a matter of practical importance in deciding what is going on in an argument. For example, questions like the following might be asked.

1 How good a description of Rutherford's method of argument for a nuclear picture of the atom is each of the following?

A He imagined a model, and compared the consequences with experiment.

B He summarized a collection of experimental evidence in a simple law.

C He chose the simplest model, for lack of experimental evidence.

2 The following passage contains **a** a statement of a law, **b** a model being proposed, **c** facts quoted from other experiments. Pick out a sentence or phrase of each of these three kinds.

> 'Suppose that it is adequate to picture the collision between an electron and a gas atom as being like a collision between billiard balls. In such a collision, momentum will be conserved, and it follows that because electrons are much less massive than gas atoms, the electrons will lose practically no kinetic energy if the collisions are elastic.'

Discussion of theories and models

The course tries to make opportunities for the discussion of these matters. For example, in the opening work in Unit 1, a model of the copper structure made of polystyrene balls is used, and its qualities as a model are examined. Work on fields should draw attention to the value of inventing theoretical concepts, while the discussion of an ionic crystal shows these concepts at work. Towards the end of the course, especially in Unit 10, *Waves, particles, and atoms,* there is need for careful thought about what may be expected of a model, and what may not.

Work on the Millikan experiment, or on evidence for energy levels, is an opportunity to discuss the making of inferences from empirical evidence.

At several points, especially in work on oscillations in Unit 4, the role of mathematical models can be brought out, and questions asked about whether the real world does, or could, conform to an idealized model, or how far the model should conform to the way things are. Unit 10 raises even deeper issues about models.

The value of understanding what physics is like

We think this important for several reasons. We wish students to see physics as what it is, and not as (for example) magic, absolute truth, or arbitrary theory. In later learning students will often meet models, theories, experiments, and guesses. The conflict of wave and particle ideas is likely to recur for many, while others may have to think about the purpose of building a small scale test model of a bridge, or to assess a mathematical model of an industrial activity. A beginning in thinking about such situations can be made in school.

This aim is also connected with the aim of understanding physics, for it should be easier to argue effectively about a problem if one is clearer about what kind of problem it is. For example, the distinction between a model and the data it is used to throw light on, is crucial to understanding what is going on in most scientific arguments.

Guesses and estimates

Questions in the *Students' books* sometimes ask for guesses or estimates of orders of magnitude, illustrating the value of such methods as well as helping to develop better physical understanding.

Learning to inquire

Many students will do science of some kind in the future, at various levels ranging from research to industrial application and to tackling the practical problems of everyday life. We hope that they will become more successful at pursuing their own personal inquiries in physics.

We do not know how to teach people how to inquire, and the advice of Bruner seems the best:

> 'Practice in inquiry, in trying to figure out things for oneself is indeed what is needed – but in what form? Of only one thing am I convinced: I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry.'
> *Bruner, J. S. (1964)* On knowing, *page 94. Belknap Press.*

Much of the work of the course can be taught in an inquiring, rather than a didactic spirit. The work in Unit 2, for example, with puzzle boxes and with capacitors, is intended to help teach simple ideas in a problem-like way. Several Units begin with pieces of rather open experimenting, whose purpose is partly to give students a concrete idea of what is being talked about next, but partly also to introduce a feeling of openness and inquiry.

Investigations

Very many experiments in the course will, it is hoped, be undertaken in a spirit of investigation. But it is inevitable that, to achieve the ends in mind at each point, carefully designed apparatus has to be provided, which limits the possibility of 'wrong' paths of investigation and steers students towards the ideas which we hope will emerge.

By way of contrast we have introduced as part of the course some completely open investigations for students to undertake on their own. Here they will be expected to identify their own problems, invent their own (simple) experiments and deal themselves with the difficulties that arise. Topics will be very simple (or will seem so to teachers), but will be chosen so that there are likely to be many surprises and problems. We have in mind such problems as 'What happens when rubber bands are stretched?', 'How does water emerge from a jet as the speed of flow varies?' or 'How does a ball roll on a spinning turntable?'

These investigations, one in each year, form an integral part of the course. They aim to help students to become better at doing physics and not to teach them more physics, so the choice of topic can be very wide.

They are not a marginal item, to be omitted if time is short, but a fundamental part of the design of the course. In modifying the course, we have always been prepared to sacrifice some formal content, so as to keep open the modest amount of time required for investigations, because we felt sure that the value of such extra content would be small compared to the value of the unique contribution the investigation can make towards this important aim.

The investigations are discussed at greater length in Chapter 7.

Use of instruments

Another necessary part of being able to inquire for oneself is the possession of some practical skill. An objective here is that students should all come to handle competently the usual ranges of ammeters and voltmeters, and also oscilloscopes, as well as the simpler laboratory instruments. Other instruments, such as the electrometer and the scaler, should be familiar, but it would be wrong to expect students, who may not themselves have handled these intruments, to be quite so competent in their use.

Enjoyment – seeking to gain further understanding

Students will not learn more science in the future, nor will they learn much during the course, if they do not enjoy learning it now. We have tried to make the work of the course seem to students pleasurable, possible, and profitable, and we hope to find that after the course they are more likely to seek actively to use and extend their understanding in both pure and applied science.

This course is about physics, but the majority of the students will have to put whatever understanding of physics they have gained to use in other fields. It seems likely that without enjoyment, there is little hope of their trying to apply ideas and methods learned in physics to these other fields. So the aim of enjoyment seems necessary in order to achieve our other aims, especially those that look to the future, where the student will more and more have to find his own rewards and do without the external praise or blame of a teacher.

The work of the course involves many pieces of individual work for students, intended to be tasks at which they can succeed. Successfully solving a problem for oneself can be very rewarding, as well as contributing to other aims. We hope also that students will become sufficiently personally involved in their investigations to want to do more in the future.

Awareness of the social significance of physics

We think it would be wrong to expect students to acquire some one particular attitude towards the relationship of science and society, and it is too much to hope that they will develop a deep and lasting concern with such problems simply as a result of taking this course. But we do hope at least to find them conscious of the existence of questions about the influence of physics on society, about the ways in which physics can be applied to meet human needs, and about the need for people willing to apply their talents in that direction. We hope for example that some parts of the course will show students that there are opportunities open to people who want to work in engineering of one kind or another.

Unit 1, *Materials and structure*, includes an attempt to show students what sort of work a materials scientist might do, and may also help to illustrate some problems facing, say, civil engineers. Unit 6, *Electronics and reactive circuits*, is, we like to think, very much a piece of engineering, being concerned with the creation of useful electronic devices. Unit 7, *Magnetic fields*, is as practical in flavour as we could make it, and includes something on induction motors and on the transmission of electrical power. Too much must not be hoped for in this area. The impression, often given in school, that the pure physicist is a more interesting sort of person than the engineer is not an easy one to redress.

In addition to designing some parts of the course in an applied spirit, most Units include within the *Students' book* one or more articles about the applications of the physics within the scope of that Unit. Unit 1 has an article on 'Materials and their uses'; Unit 2, *Electricity, electrons, and energy levels*, has one on 'Electrochemical machining'; that for Unit 3, *Field and potential*, is on 'Thunderstorms', while Unit 4, *Waves and oscillations*, has an account of the designing of the Severn bridge. A number of these articles have been written by engineers, in industry or in universities.

Another aspect of the social significance of science is touched on in Unit 9, *Change and chance*, in the discussion of world fuel resources. We hope that students will be found ready to discuss the problems of the development of science as well as its advantages.

The examination will reflect this aim by asking some questions set in an applied context, while choosing these so that the answer does not depend on a previous knowledge of the particular application involved.

Chapter 4

Teaching the course

This chapter discusses the practical problems teachers may meet, the problems of matching the course to previous O-level courses, and teaching methods that seem likely to be useful.

Time required

The course is designed to fit into the average sixth form time allocation, which may be about seven periods per week (each of 40 minutes), or their equivalent. In planning, we assumed that a term contains ten useful weeks, and that there are five useful terms, thus, we hope, leaving time for desirable things like school plays and outings, for revision at the end of the course, and for teachers to develop their own interests at greater length.

Experimental and theoretical work go together in much of the course, and as much as possible of the teaching time should be spent in a laboratory. It would be difficult to teach the course at all if fewer than four of the seven periods were taught in a laboratory.

It is probably convenient if much of the work is timetabled in double periods, as is common practice; but a system which sets aside a long session for practical work and so makes practical work more difficult at other times is less convenient.

Laboratory requirements

Gas and water are not often needed; the main need is for plenty of mains electricity outlets. Two mains sockets per pair of students would not be too many.

Low voltage alternating or direct voltage supplies to the benches, permanently wired, need not be provided, if suitable portable sources are provided. Dry cells suffice for the vast majority of experiments. Further suggestions about power supplies appear in Chapter 8, 'Guide to apparatus'.

The laboratory needs to be blacked out from time to time. Full blackout is desirable, for the part of Unit 8 dealing with physical optics, but is otherwise not essential.

A laboratory design which allows very flexible use of space is ideal.

Links with Nuffield Advanced Chemistry

Whatever the merits or otherwise of various integrated forms of sixth form science courses, it is desirable that teachers working in the framework of a separate subject should be aware of the development of ideas in the teaching of other subjects, and seek opportunities to relate them to their own, to use them, and even, perhaps, to arrange for occasional joint teaching.

The problem is a difficult one, and not one that can be solved by those developing one science teaching project, for the number and variety of possible combinations of courses is too wide. In particular, there are many new mathematics courses, besides the variety of traditional ones, and there can be no way of matching a physics course to all of them. This is a matter that can only be dealt with in the particular school.

We have a particular responsibility to ensure that the Nuffield Advanced Physics and Chemistry courses fit together effectively, without doing it in such a way as to compel a school taking up one of the courses to take up the other, or to limit the possibilities of change in either course.

Schools teaching both Nuffield Advanced Physics and Chemistry will find much advantage in sharing the load where the courses overlap. The main overlaps, most of which fall within the first year, are as follows.

Nuffield Advanced Chemistry		**Nuffield Advanced Physics**
Topic 1	'Amount of substance'	Unit 1 *Materials and structure* (use of the mole)
Topic 3	'The masses of molecules and atoms; the Avogadro constant'	
Topic 8	'Structure and bonding'	Unit 1 *Materials and structure* (structures of solids using X-rays)
Topic 4	'Atomic structure'	Unit 2 *Electricity, electrons, and energy levels*
Topic 4	'Atomic structure'	Unit 5 *Atomic structure* (Rutherford atom)
Topic 7	'Energy changes and bonding'	Unit 3 *Field and potential* (ionic crystals)
Topic 17	'Equilibrium and free energy'	Unit 9 *Change and chance* (The treatment is complementary to Topic 17)

Previous O-level courses

The Nuffield Advanced Physics course is intended to be consistent with the aims and the content of the Nuffield O-level Physics course. About half the schools which took part in the trials were drawn from those whose students had taken at least part of the Nuffield O-level course, but the rest were not.

We have tried to indicate in the *Teachers' guides* places where the proposed treatment of material may need modification for students who have not taken the Nuffield O-level Physics course. Some are matters of detail; others raise larger issues, and these are outlined in the following pages.

Dynamics

The Advanced course contains no separate Unit on dynamics. Dynamics is taught, but it is treated as something to be used when a need for it arises, and to be revised or learned afresh if that then seems necessary. In other words, the tactics suggested are to proceed as if the class knows the dynamics that will be needed, while being well aware that they may not, and to wait to revise it until the need is apparent.

We think this makes sense, following the Nuffield O-level course's very full treatment of dynamics. It may not make so much sense for students with a different background. Teachers should be aware that if their students have a negligible background in dynamics, they will have to modify early parts of the course quite drastically, and will have to cut later parts to make time for extra work in this area.

Waves

Familiarity with the Nuffield O-level work with ripple tanks, and on diffraction gratings, is assumed in the way Unit 1, *Materials and structure*, is written, and in the way Unit 4, *Waves and oscillations*, is organized. Teachers will either have to defer Unit 1 and reorganize Unit 4, start off the course with some ripple tank experiments, or at least add a little on waves to Unit 1. Most of the schools in the trials which were in this position took the last course.

Kinetic theory of gases

As such, the kinetic theory of gases does not appear in the Advanced Physics course, though an acquaintance with its qualitative ideas is assumed from time to time.

One of the main functions of kinetic theory in education in physics seems to us to be to illustrate how the large scale behaviour of matter might be explained in terms of models of the small scale, invisible, world of atoms and molecules. In the Advanced course, we have chosen to use solids for this purpose. We start this, for example, in Unit 1 with evidence for the crystal structure of some solids, continue it in Unit 3 with a discussion of the bonding of an ionic crystal, and use the ideas in Unit 9 to illuminate the idea of thermal equilibrium and the concept of temperature in a model of a solid.

But we do not think that the kinetic theory of gases is a dispensable part of education in physics at school. Had the Nuffield O-level course not included it, it is probable that the strategy for the Advanced course would have been quite different, and that gases would have featured largely. We think that teachers whose students have not met the kinetic theory of gases previously ought to include it in their Advanced course, making an appropriate sacrifice of other material. Some teachers have included it in Unit 1, while dealing with other substances. It could displace the work on ionic crystals in Unit 3, though it would be better to bring it forward to go, for example, with the work on ionization of gases in Unit 2. Another way is to wait until Unit 9, and to sacrifice the latter part of that Unit, ending it with the kinetic theory, taken as far as showing that the absolute temperature is related to the mean energy per molecule.

Conservation of energy

Students who have not met energy conservation at all will be in considerable difficulties. The Advanced course provides many opportunities to revise O-level work but, as with dynamics, provides no special place for teaching about energy conservation. One solution would be to expand the early part of Unit 9 which, as written, assumes students are familiar with energy conservation, and probably to bring that part of Unit 9 forward into the first year of the course.

Optics

We think that the Nuffield O-level Physics course includes just about the right amount of geometrical optics, concentrating on the formation of images. We have added no more to the Advanced course, but it may be necessary for teachers to add some in the future if other O-level courses go any further in the omission of this material. Again, some appropriate sacrifice of Advanced work would be necessary.

Mathematics

Students who also take a sixth form course in mathematics should have no special difficulties. Parts of mathematics which we regard as especially valuable in the education of a scientist are taught within the physics course, along with the physics for which they are used. These are the handling of simple differential equations, and the exponential and the sinusoidal functions. Other pieces of mathematics, mainly various integrations, can be avoided, and ways of avoiding them are suggested. There is advantage in using mathematics when students have it, and many university physics teachers make a plea for this to be done. But there is a disadvantage in insisting on a formal treatment when it is not necessary to achieve a physical understanding of a problem, if students find the formal treatment opaque, difficult, or frightening.

It may be that we have erred too much on the side of informal, physical arguments, such as those used in Unit 3 to explain, without doing a formal integration, how a flat sheet of point charges, each giving an inverse square field, together produce a uniform field. But if we have to err, this is the side most of us prefer to err on. (Dirac, himself a mathematical physicist, made a good remark about this question. He said, 'I understand what an equation means if I have a way of figuring out the characteristics of its solution without actually solving it.')

Students not taking a sixth form course in mathematics may have two sorts of difficulty. They may have trouble with the bread and butter mathematics used in the course: proportion, powers of ten, logarithms, and so on. They may also need more practice with the mathematics taught within the physics course than there is time for.

The Teachers' Guide, *Supplementary mathematics,* is meant to help with these problems. It contains revision of mainly O-level mathematics, some introductory calculus, more practice with differential equations and with the functions needed in the course, and a little on statistics.

The time needed will vary with the particular students involved. We envisage a one-year course occupying less than four periods per week, for students not taking sixth form mathematics.

Teaching methods and organization of practical work

We do not know the best way of teaching the course; there probably isn't one. However, there are some methods which seem likely to help to achieve the aims of the course, some suggested directly by thinking about those aims, and others that have arisen out of the experience of teachers in trials. At the risk of offending those to whom these ideas are obvious, or to whom they are second nature, we outline below some of the methods that seem useful, together with other information about the organization of work, particularly of practical work.

Discussion

It would be unreasonable to expect a student to be able to talk sense about physics if he or she had not been encouraged to talk a good deal beforehand. What little is known about learning beyond the early years of life suggests that talking about ideas, thinking them through by oneself, trying them out on others and so discovering muddles in one's thinking, and having one's errors corrected by others who are more expert, are important ingredients in learning. It seems to be especially important in 'getting ideas inside oneself'. Most teachers have noticed that it is only when one tries to explain something to someone else that one finds out how little one understands it.

Another reason for being concerned to encourage discussion is that a subject breathes and has its life, not in books, but in conversation.

Therefore, we have tried to find ways of encouraging discussion that goes beyond question and answer exchanges between teacher and class and that shows some sense of the conjectures and dilemmas which are the essence of a living subject.

A number of questions in the *Students' books* are labelled *'For discussion'*. It may be wise to brief one student beforehand to prepare some ideas, or to ask all students to write down something.

Some demonstrations are best as a polished performance by the teacher, but many others can be arranged as the focus of a discussion, with students helping in the performance of the experiment, and doubtless hindering it with well meant suggestions. At other times, teachers who took part in the trials found it useful to ask a student to prepare a demonstration for a later lesson. It often happens that other students are more ready to be critical and thoughtful about a demonstration done in this way, than they are about one done by the teacher. The teacher is then also free to play the role of a critical, questioning physicist, without the double burden of doing this as well as trying to make a point with the apparatus.

Different experiments shared round the class: reporting back

On a number of occasions in the course, when several different but related experiments are suggested by previous ideas or are needed to open up a new topic, we have suggested that each pair of students do only one. For example, at the start of Unit 3, some problems about a parallel plate capacitor arise. The charge stored may depend on area, spacing, and potential difference. The charge can be measured with an electrometer, or with a vibrating charge–discharge switch. The vibrating switch needs to be checked to see if it works as it is supposed to. And it can be used to try capacitors in parallel or in series.

Each aspect can be studied by one pair of students, and each pair later reports its findings to the others. In practice, this has worked quite well, and sometimes the discussion becomes so heated that the teacher finds that his presence seems superfluous! Each student has, in this situation, to be very clear about what he or she has done. Others have to learn from him or her and, with encouragement, soon learn to ask searching questions about what has been found. The teacher has an important role; that of setting a standard of critical thought and questioning.

Teachers must expect the first one or two occasions when this is done to be very painful. Reports are ill prepared, data are presented in a confused way, and the experimenters reporting back blame everything but themselves. It may be that this is necessary; it does seem that students' desire to do well is strong enough to produce quite rapid improvements.

We hope that, besides stimulating discussion, this technique will help students to become a little more independent. It seems worth while giving them the responsibility not only of reporting verbally, but also of preparing a written summary of the experiment and of the results, for the rest, if the experiment is important enough. Again, criticism from the rest of the class can quite quickly improve the quality of such notes. It is necessary to arrange copying facilities. A spirit duplicator is suitable.

There are difficulties in organizing such experiments: apparatus is unfamiliar, it fails to work, or students cannot think what to do. To meet the first difficulty, the *Students' laboratory book* contains a number of notes on 'Tools of the trade'. These give instructions for handling and checking most of the instruments that will be in use. For some such groups of experiments, especially where there is much variety among them, it also contains notes on the purpose of the experiments sufficient to get most students started off. It is convenient to keep the copies of this book in the laboratory.

Individual exploratory experiments

The essence of an experiment is that one decides to try something, not knowing what will happen. The conventional school experiment is, in these terms, barely an experiment at all. Everything is decided beforehand, and what will, or 'should' happen is easy to guess, if it is not already obvious.

We think that sometimes, not always, students ought to have to decide for themselves what to do with some apparatus, and see for themselves what happens. This can only be done if the apparatus is simple, and is best if almost anything a student can do with the apparatus is interesting in some way.

A few experiments in the course are planned in this way. For example, before electric charge is discussed in Unit 2, students can be given, say, one capacitor, a single dry cell, and a single milliammeter. If they connect them in series, the meter gives a single flick, returns to zero, and stays there. Breaking and making the circuit produce no further change (indeed, some may miss the initial flick). Several things may suggest themselves. Connecting the capacitor and meter together without the cell produces a flick in the opposite direction, after which the first experiment 'works' again. A second meter shows that there is an equal current pulse in each lead to the capacitor. Further cells on offer suggest more experiments.

The teacher can control events by rationing or issuing apparatus, or by offering to provide what is wanted if a reason for wanting it is given.

There will be failures. Just as, if students are given clear instructions, some will not follow them, so, if they are asked to decide for themselves what do do, some will find it hard. Sometimes failure can be turned to advantage. The confusion that results when one has no plan can bring out how an experiment involves deciding what to do (as the value of following instructions can be illustrated by the consequences of not doing so).

Long experiments

The following experiments are suggested as fairly long term exercises for individual students. We think each student should do one; to do more than one or two may bring no great extra reward.

The Millikan experiment (charge on an electron)	Unit 2
The gravitational force constant G	Unit 3
Measuring a voltage without a voltmeter	Unit 2

The measurement of ε_0	Unit 3
The speed of light	Unit 4
The speed of microwaves	Unit 4 or 8
Measurement of the Planck constant h	Unit 5
Measurement of e/m for electrons	Unit 7
The Hall effect for aluminium (number of charge carriers per atom)	Unit 7
Absolute measurement of current	Unit 7
Energy balance of a d.c. motor dynamo	Unit 7

Very full instructions for these are given in the *Students' laboratory book*. It is hoped that they will give a student the satisfaction of having completed a job of some substance, and of overcoming a number of difficulties on the way.

The experiments vary in length and difficulty. The gravitational force constant and the speed of microwaves are extremely difficult and, if given to students at all, should be used to try the patience of the very best. The Hall effect and the Millikan experiment are quite hard, while the rest are within the capacities of most students. The Millikan experiment is long, as are the two very hard ones, while the speed of light can be quite short.

These long experiments can be fitted into the course in several ways. Some teachers have set aside one or two occasions on which all students try one or other of them. Others have assigned them at odd times to interested students, expecting them to keep up with the other work of the class. Those which did not fit in in this way were made into demonstrations, or were added to another group of experiments. There is much to be said for showing the main features of the experiments as demonstrations, and then leaving an interested student to pursue them further, to obtain more and better results. It is often useful to have work of this sort to stretch the abilities of the best students.

Reading and textbooks

We think it important that students should read books and papers. One reason is that the skills of extracting information from scientific writing are not trivial ones, and need practice. Books will, after all, be the main source of knowledge for students once they leave school.

Another reason concerns authority. Only by looking at several sources can students find out which things are commonly agreed, and which are not. For this reason, we have suggested both a variety of textbooks, not one, and also a variety of other reading, from paperbacks to original papers. It is by reading papers and books other than standard textbooks that students will discover that scientists communicate in more than one tone of voice, and not only in the level monotone of many a textbook.

A good way of failing to get students to read is merely to exhort them to do so. We think that reading must be built into the course, and have suggested some ways of doing this. Early in the course, in Unit 1, there is an opportunity for students to be sent away to find out about modern, strong materials. Each can have a different task, one to read about reinforced concrete, another about fibreglass, and so on. Later, each can be asked to summarize what has been found, for the others.

Unit 2 can include some reading of a different sort. Short, selected extracts from original papers on electron-atom collision experiments are provided in the *Students' book*, with notes on points of difficulty. The teaching of energy levels can be built around the study of these extracts.

In Unit 5, a more extensive exercise is suggested. Each student can be given an individual task, involving an experiment and some reading, and be left to work on his own. Later parts of the Unit need the information gained in these tasks, and students can be asked to contribute what they have found, when it is needed.

Units 7 and 10 contain further places where such reading exercises can be used. The emphasis on individual tasks is a way of making it more likely that they will be done, and also a way of encouraging the growth of mature independence. We do not know the best place for such work in a course, nor how much or how little is needed. Our suggestions, together with the extracts reproduced in the *Students' books*, references collected and annotated, and lists of books, are an attempt to make it practicable for teachers to try out this way of helping students to learn how to read, and to discover how to do it better.

Textbooks are included among the sources suggested for reading tasks. The *Teachers' guides* also contain references to a limited number of textbooks, indicating which of them contain good material on the various parts of the course. No one textbook covers the course, and even if one did, we would not recommend it alone. Sooner or later, students must find out that books differ in their adequacy on various topics, and that their treatments suit different individuals. Where no suitable text material exists, as in Units 9 and 10, we have felt it necessary to provide it in the form of the combined *Students' books* and *Teachers' guides.* But it is to be hoped that alternative texts will, in time, appear.

The teaching of theory

An American teacher once said that the best audio-visual teaching aid she had ever seen was 'a teacher on her own hind legs, her back to the blackboard, a piece of chalk in her hand, talking *with* her class about something that mattered to all.'*

* Quoted by Jennings F. G., in Miles, M. B. (Ed.) (1964) *Innovation in education*, page 565, Bureau of Publications, Teachers' College, Columbia University.

When theory is taught at the blackboard, the clarity, precision, and sweep of a scientific argument can be given powerful expression.

But such teaching has its dangers. Too often one finds one person at the front doing all the work, facing a dozen other people whose minds are not engaged with the matter in hand. If questions are asked, answers tend to come from those who answered the time before (and the time before that) unless the teacher adopts the useful strategem of asking everybody to write down an answer.

We think that some pieces of theory can be dealt with in other ways. All the important theoretical arguments in the course are covered in structured questions in the relevant *Students' book*. These are intended to lead a student, step by step from what he or she already knows, to some new result. They are not self-contained learning programmes, and it will be necessary to spend time after students have tried them, clearing up difficulties. It will also be important to help students to go beyond the detail, to see the character of the arguments as a whole, asking such questions as, 'What physical ideas went into the argument?', and 'What ideas of value came out?'

Sometimes it will be best to use such a question on its own, sometimes to use it before talking through the theory, and sometimes after doing so. We suggest that teachers should try all of these methods, if only to introduce some variety.

Unit 3, Part Four (on ionic crystals) is covered by a section in the *Students' book* which is intended to enable students to work through the theory by themselves. In this case, the theory itself is not something to be learned; what is important is the sort of argument involved, the kinds of idea that go into it, and the way in which they are used. An important part of the argument is the moving back and forth between force and energy, a move crucial to understanding the difference betweer the two. So here we do suggest that students be left alone, the teacher acting as a consultant rather than an instructor, so that students may make these moves for themselves.

Unit 5, Part Three (on exponential decay), has a similar but less tightly organized section in the *Students' book*. It, too, may be an occasion for leaving students to learn at their own rate.

Making notes

The existence of questions covering pieces of theory reduces the need for notes, though there is still a case for having a written summary of the more important arguments.

Views about the importance of notes are easy to find, but evidence is not. Some research suggests that students do as well without notes as with them, in some contexts.

One thing is clear: students cannot simultaneously take notes of an argument and contribute to discussion. To do so involves too large an overloading of a person's linguistic capacities. One useful method is to appoint one or two students to take notes of discussion between the teacher and the rest, later producing a summary which is duplicated and circulated. This method can only be used from time to time, as one person's notes will not always please another. But it has the virtue of drawing attention to the quality of the notes, so that their very inadequacy can be turned to advantage.

Many of the suggested teaching methods imply an awareness of the importance of language. Teachers will find much of practical value in a book from the Schools Council Programme in linguistics and English teaching: Doughty, P., Pearce, J., and Thornton, G. (1971) *Language in use,* Edward Arnold. This provides excellent classroom material, some of it directly useful in science teaching.

In the end, it is the teacher who counts

Being only human, we would like to think that the above suggestions for teaching methods add up to a recipe for successful teaching. We know that they do not. We know that there is as yet no clear, objective evidence that they will work well, though teachers in the trials have said that, on the whole, they think that these methods have made a difference both to their students and to themselves as teachers.

We hope it is clear that, although we believe in no one simple maxim or recipe for good teaching, we do believe that changes in methods of teaching and in the roles of teachers and students will be very important in achieving the aims of the course. We are sure that our material, taught only in a traditional way, will fail to achieve these aims. In our view, it is the business of teachers, not to follow some policy imposed from outside, but to think hard about the aims of what they are doing, and to experiment with a variety of methods, in various mixtures, watching carefully to see what happens. Teaching is so personal a matter that each teacher will have to make the aims and methods his own, in his own way.

The last word goes to Professor Michael Oakeshott.

> 'And if you were to ask me the circumstances in which patience, accuracy, economy, elegance and style first dawned upon me, I would have to say that I did not come to recognize them in literature, in argument or in geometrical proof until I had first recognized them elsewhere; and that I owed this recognition to a Sergeant gymnastics instructor who lived long before the days of "physical education" and for whom gymnastics was an intellectual art – and I owed it to him, not on account of anything he ever said, but because he was a man of patience, accuracy, economy, elegance and style.'
> *From Peters, R. S. (Ed.) (1967)* The concept of education, *page* 176. *Routledge & Kegan Paul.*

Chapter 5

Examinations

The Advanced level examination

One of the important tasks in the construction of the new sixth form course has been the development of an examination which is appropriate to the course, but which also fits into the framework of the current A-level examining system. Under arrangements agreed jointly between all of the examining boards in England and Wales, the Physics A-level examination is the responsibility of the Oxford and Cambridge Schools Examination Board. Individual schools enter for the examination through the Board which they normally use, so that, although the examining is done centrally by one Board, there is no need to make a special approach to that Board in the first instance.

The Board has the task of producing examinations which do justice to the aims and spirit of the course, and which are fair and just to students and their schools. The examination must give results that the Board, acting on behalf of all the Boards, can certify to be comparable in standards to those attained on conventional courses. Members of the Nuffield team have been closely involved in the Board's work, although others not directly involved in constructing the course have also been asked to help in constructing and criticizing examination proposals and in marking examinations and setting standards. This chapter gives an account of arguments and ideas which have formed the basis for the Nuffield A-level papers. Although no radical changes in this pattern are foreseen at the time of writing, new circumstances, ideas, or evidence could lead to changes in the future. The examining Boards have, however, undertaken to make special provision for candidates on Nuffield courses for as long as a demand for these exists in the schools.

Guiding principles

Many criteria or constraints have had an important part in determining the examination pattern. The most important of these are discussed in the following paragraphs.

The examination should call for responses which are related to the aims of the course; it is essential to test, for example, for points indicating an understanding of the nature of inquiry in physics, but it might be wrong to test directly for some aims, such as enjoyment.

The examination will set a target for students and teachers, and so its 'backwash' effects should, as far as possible, be effects which would reinforce rather than detract from the aims of the course. Thus, if it could be shown that the existence of a comprehension passage in the examination led teachers and students to work systematically on arguments about the meaning of passages of scientific writing, this would be an argument in favour of retaining that part of the examination.

In spite of this second principle, it will rarely be true that good teaching can arise from policies designed solely to increase the examination marks earned by students, but a few teachers may want, and many more may be under pressure, to operate in this way. It would help to overcome this difficulty if an examination were rather less like conventional examinations, for which 'cramming' is profitable, and became rather more like an I.Q. or aptitude test which depends very little on cramming and tests the skills and qualities the candidate possesses.

All main aspects of the course and all the main topics ought to be tested in some way; techniques which allow many topics to be covered may be a fairer way of testing the sixth form work than those which are limited to exploring only a few issues.

No method of examining is perfect. Any one method of examining will demand qualities that are irrelevant to the test in hand, or that differentiate unfairly between candidates. For example, essay type questions will favour those who write quickly. A system which combines marks obtained by a variety of methods will be less seriously affected by the special demands made by any one method, and it may be fairer to candidates if their abilities are challenged in several different ways and in several different contexts.

There was neither time nor resources, within the lifetime of the Project, to develop and test radically new examination methods, and the methods had to be chosen to fit within normal constraints of examination administration and timetables. Thus, for example, any attempt to present examination results as a profile rather than as a single grade would have required extensive research to justify and establish the new methods required. At a more practical level, suggestions which required more than three three-hour sessions in the examination timetable were ruled out because the Boards are rightly reluctant to add to the overall length of their timetables.

Types of test used

Coded answer

A paper in which students can be asked to indicate a choice of answer on about forty different items in an hour has the outstanding advantages that it is possible to cover many topics and abilities in a short time and that it can be marked reliably. Variation in the level of difficulty and in the types of ability tested is justified if all questions have to be attempted. The outstanding disadvantage is that the candidate cannot explain himself, although it may be held that (say) forty unexplained choices can give better information about ability than the number of explanations that a candidate could write out in the same examining time. A special feature of this disadvantage is that a candidate is at the mercy of ambiguities in the question, so that such questions demand high standards of precision and care in their construction. Coded answer questions make no demand on ability to communicate to others, and a quick-thinking candidate who is poor at self-expression might show his strength in them.

Short answer

These are structured questions calling for a brief response to short, definite, and limited questions. Such questions are easier to construct than coded answer questions. They are of particular value in testing simple comprehension skills and the use of arguments involving simple numerical calculations. As explained for coded answer questions, there is an advantage in putting the questions together in a paper on which no choice is allowed. The present examination includes a short answer paper composed of about nine questions to be answered in 90 minutes.

Long answer

Neither coded nor short answer questions call for any substantial initiative from the student, nor do they allow him to show his ability to follow through a connected piece of thinking by concentrating on one theme for some time. Any paper which looks for these abilities must also call for communication of the candidate's ideas, in an extended piece of prose writing. A paper in which candidates are asked to attempt about three questions in an hour and a half, chosen out of about six, is at present used to concentrate on these skills. Questions are of an essay type, and may call for judgments of a broader or more synthetic kind, such as describing the main ideas involved in a specific piece of physics or proposing a plan for an experimental investigation, or for the ability to follow through a connected piece of argument presented by a more detailed structured question. Long answer questions appear to be the only way to test some important objectives, so we think it is essential to retain them in spite of the difficulty of marking them reliably.

Comprehension

The ability to grasp the essence of a scientific communication is not tested by the kinds of paper described above. Questions based on a passage in which physics developed in the course is taken for granted, but is used to explain new ideas or evidence, can also be a good test of the understanding of the basic ideas of the course because they test these ideas in the context of a connected argument rather than in the artificial context of a short examination item. This type of examination is a good example of a test for which short-term cramming may be of little value, but which might encourage valuable work throughout the course.

Examining experimental physics

It is notoriously difficult to test abilities in experimental work under examination conditions. For this reason, about one half of the assessment in this area is based on teacher assessment of work done by students on their second investigation: further details of this are given in the chapter on investigations. We are also trying to see whether it is practicable and fair to test particular skills by a sequence of short tests, so that in a 90-minute examination a student might circulate around eight short exercises, each testing a specific skill, such as choice of meter, adjustment of an oscilloscope, or testing a hypothesis quantitatively. Each question briefly and clearly defines the work to be recorded. The two forms of assessment, of investigations and of single, simpler skills, are concerned with different aspects of experimental work and should provide different but complementary evidence about the ability of candidates in experimental work.

Examples of questions used

The examples and commentary which make up the rest of this chapter are intended to illustrate the application of the general principles given above, and to expose criteria which A-level examiners might use in composing and selecting questions. (The collection offered is illustrative but not exhaustive; it cannot commit examiners either to use, or avoid using, or restrict themselves to the types of question quoted.) Naturally, in assembling a complete set of papers the examiners would attempt to balance the types, styles, content, and level of difficulty of questions over the examination as a whole. Complete sets of papers for previous Nuffield A-level examinations may be obtained from the Oxford and Cambridge Board. The examples given below are taken from two sources. The first is the 1970 A-level examination set by the Board. Such questions are labelled 'O. and C. 1970'; these and the accompanying figures (figures 2–6, 9, 12–15, 18, 23, and 26) are reproduced by permission of the Board, but the Board is not responsible for the comments offered in the discussion of the questions. The second source is a trial examination, composed for use in schools taking part in the trials, in January 1970. Such questions are labelled '1970 trial': these questions are the responsibility of the Nuffield Advanced Physics Project.

Coded answer examples

Example 1 O. and C. 1970

The following are some of the important properties of an atom:

A Ionization potential.
B Atomic radius.
C Charge carried by the nucleus.
D Atomic mass
E Radioactive half-life.

For **each** of the following experiments, select from the list above the **one** property which is most **directly** measured in the experiment.

1 Inelastic collision experiments with accelerated electrons.
2 Scattering of α-particles through large angles.
3 Use of X-ray diffraction in determining crystal structure.

Example 2 1970 trial

The five statements that follow are all about electric potential; which one of these statements is *wrong*?

A Potential is a scalar quantity – it has magnitude but no direction.
B The potential difference between two points is the change in energy when

a unit of charge is moved from one point to the other.

C The potential is zero wherever the electric field is zero.

D The potential due to a point charge varies as $1/r$ (where r is distance from the point charge).

E Its gradient (change of potential per unit distance) is proportional to the strength of the electric field.

The first example is in a form, known as the *grouped response* form, which enables several (in this case three) questions to be based on one set of data, so that less thinking and reading time is required. The questions call for some thought about the purpose of the experiments quoted, but mainly involve the recall of information. This is justified if the facts or ideas to be remembered are of basic importance in physics and there are not too many such questions. This set of questions was placed near the beginning of the paper in which it appeared, where examiners would like to have the easier questions in order to help candidates to settle down.

The second example is in a simpler form. It again involves mainly recall and is about an important concept which receives considerable attention in the course.

The element of recall characteristic of the above examples would not play such a prominent part in most of the questions set. In the following examples, the information given specifies both the problem and the principles or models which might be applied in dealing with it.

Example 3 O. and C. 1970

Here are five characteristics of electromagnetic waves:

A They may change speed on passing from one medium into another.

B They are sometimes polarized.

C They show a regular periodicity, of frequency equal to that of the electrical oscillations in the transmitter.

D They may exhibit interference.

E They may convey energy.

For **each** of the following statements select the **one** of the above characteristics which you would use in explaining the statement:

1 A lens made from wax may be used to focus short radio-waves (microwaves).

2 A person walking up to an indoor aerial being used to receive BBC 2 transmissions may cause the TV picture to fluctuate.

3 When a transistor radio tuned to a medium wave station is turned so that its ferrite rod aerial is vertical, the receiver output drops.

Example 4 O. and C. 1970

Light is not normally seen to bend round obstacles (that is, to be diffracted). Which one of the following statements explains this?

A Light energy is really carried by a stream of particles.
B The wavelength of light waves is very small.
C Light is a transverse wave motion.
D Ordinarily, light is **not** monochromatic.
E Light travels with a high velocity.

In examples 3 and 4, candidates are asked to select the appropriate idea rather than to recall or invent; it is characteristic of many types of coded answer question that they present information and ideas and call for selection. In the next example, the collection of ideas in the distractors is of a more diverse character.

Example 5 1970 trial

The equation $c = f\lambda$ gives a relationship between the speed c, frequency f, and wavelength λ of a wave motion. Which **one** of the following statements about the equation is correct?

A It only applies in a vacuum.

B It shows that if a light wave slows down in passing from air to glass its wavelength in glass is shorter than in air.

C It shows that waves with the largest frequency always travel with the largest speed.

D It shows that X-rays have a lower frequency than visible light or radio waves.

E It only applies to electromagnetic waves because these all travel at the same speed.

For the Nuffield Advanced Physics course, item **B** is not a recall item, and thought about several of the others involves both general information about waves and thought about the functional form of the equation. Questions with this diversity often turn out to be too difficult (although the one above produced satisfactory results). The next example tests the understanding of a single idea, frequency, and the power to apply it to a range of common phenomena.

Example 6 O. and C. 1970

Here is a list of things involving oscillations:
1 The tide at London Bridge.
2 The alternating mains voltage in your home.
3 A pendulum 1 metre long.
4 Ultra-violet light.
5 A note about the middle of the piano.

Which **one** of the following correctly places them in order of increasing frequency?
A 13254.
B 13524.
C 13542.
D 13245.
E 12354.

The placing of **1** as first in the row of every sequence is a substantial clue: it would be possible to make a similar but harder question by omitting **1** altogether.

A physics examination should also test the application of principles in problems involving numerical calculations: coded answer questions are probably not as useful for this purpose as short answer questions, for if the calculation involves several steps, the candidate should behave like any other physicist and write these out. If he is spending time doing this, the examiner ought to see his efforts. The next two examples are quantitative, but the calculation in each involves only a single step and the questions are mainly tests of the application of the appropriate physical principle.

Example 7 O. and C. 1970 (slightly altered from its original form)

A helium nucleus, which carries a charge which is twice as large as that on an electron, is accelerated in a vacuum so that it acquires a kinetic energy of 10^6 electronvolts. Which **one** of the following is the value of the potential difference which must have been applied across the accelerating tube?

A 4×10^6 volts.
B 2×10^6 volts.
C 10^6 volts.
D $10^6/2$ volts.
E $10^6/4$ volts.

Example 8 O. and C. 1970

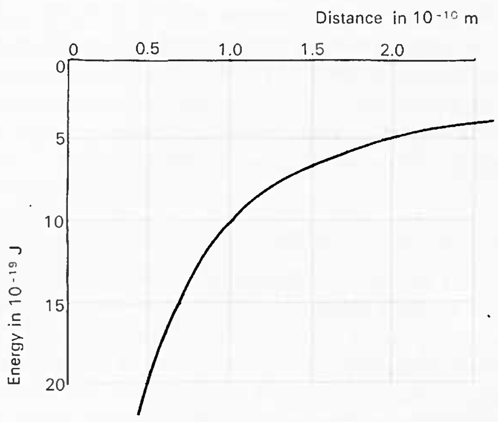

Figure 2

The electric potential energy of an electron at distances between 0.5×10^{-10} m and 2.0×10^{-10} m from a small positive charge is shown in the graph in figure 2. The scale of energy is marked in units of 10^{-19} J.

Which one of the following is the best rough estimate of the energy at a distance of 0.01×10^{-10} m?

A 10^{-14} J.
B 10^{-16} J.
C 10^{-18} J.
D 10^{-20} J.
E 10^{-22} J.

Example 8 involves the use of information presented as a graph. The ability to understand graphs and to translate information between graphical and other forms, such as verbal, mathematical, or diagrammatic forms, is also tested in the following examples.

Example 9 O. and C. 1970 (slightly altered from its original form)

Figure 3 is a sketch of a trolley, held by a spring on each end, oscillating between extreme positions XX.

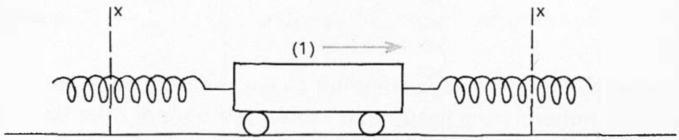

Figure 3

At moment (1) in figure 3, the trolley is midway between XX and its velocity is shown by the arrow.

At a later moment, (2), the trolley is at the place shown in figure 4.

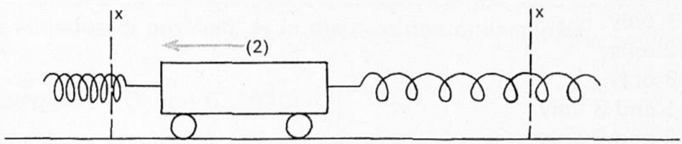

Figure 4

If point Y on the graph in figure 5 represents (1), which **one** of the points A, B, C, D, E, represents (2)?

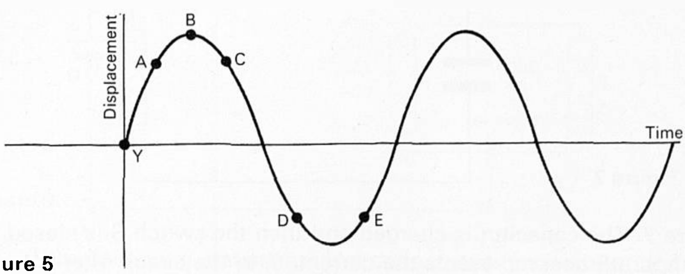

Figure 5

Example 10 O. and C. 1970 (slightly altered from its original form)

See figure 6. A mass m is placed on the top of a spring and the spring is compressed a distance x. The mass is then released and consequently flies up into the air a measured distance s. The experiment is repeated for various compressions x of the spring. The energy stored in a spring is proportional to x^2. The results are used to draw three graphs:

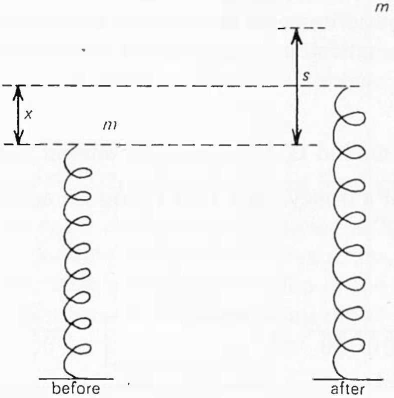

Figure 6

1 x against s.
2 x^2 against s.
3 $\log x$ against s.

Which of these graphs would you expect to give a straight line? (You may ignore any effects due to the mass of the spring.)

A 1 only.
B 2 only.
C 3 only.
D 1 and 3 only.
E 2 and 3 only.

Example 11 1970 trial

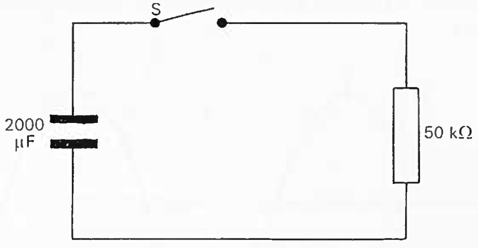

Figure 7

See figure 7. The capacitor is charged and then the switch S is closed. Which curve in figure 8 best represents the current, I, in the circuit after the switch is closed?

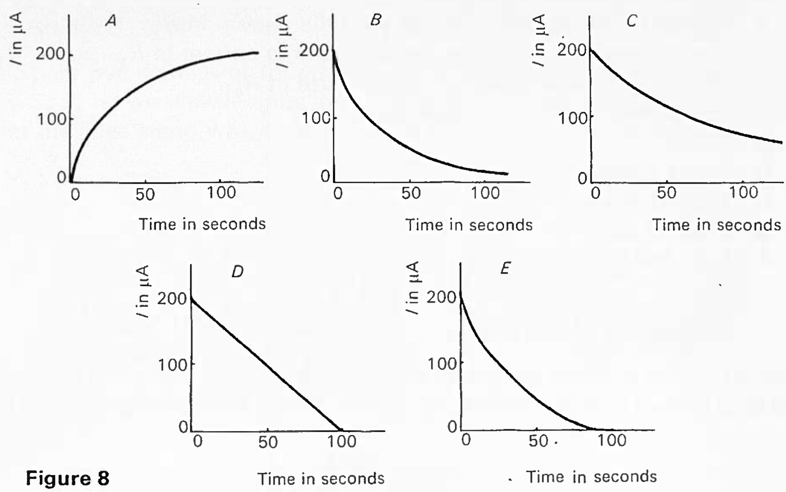

Figure 8

Each of examples 9, 10, and 11 tests a different aspect of the use of graphs: the first is concerned with the representation of an oscillatory motion, the second with translating a function into graphical form (and also with the use of ideas about energy), and the third with recognition of an appropriate form and a quantitative check with a rough calculation of a time constant.

Example 10 introduces a new form of question, *the multiple completion* form, which usually calls for a connected set of judgments rather than the single choice offered by the preceding example. Such questions can be used to probe different aspects of a situation or problem, as in the next pair of examples.

Example 12 O. and C. 1970

In the circuit shown in figure 9, the cell has negligible internal resistance.

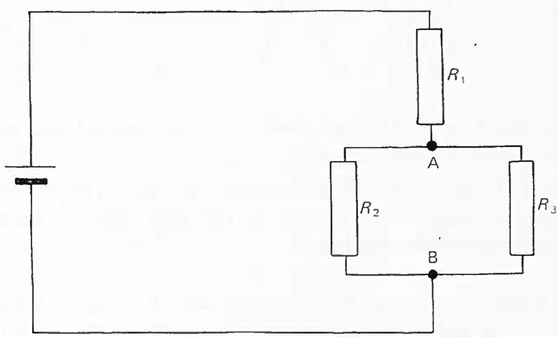

Figure 9

One or more of the following statements is a correct deduction about the circuit as given.

1 The current in R_2 must be less than the current in R_1.
2 The current in R_2 must be greater than the current in R_3.
3 The p.d. across AB depends on the size of R_1.

Which of the above statements **must** be correct?

A 1 only.
B 1 and 2 only.
C 1 and 3 only.
D 2 and 3 only.
E 1, 2, and 3.

Example 13 1970 trial

Figure 10 shows a circuit using two diodes. Points X and Y may be connected either to a battery or to an alternating supply. R may be joined to P or to Q.

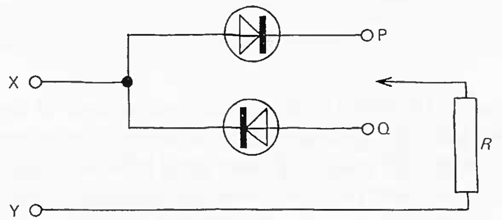

Figure 10

1 If XY is connected to a battery, the current through R is not the same when R is connected to P as when it is connected to Q.

2 If XY is connected to an alternating supply, the current through R is a fluctuating direct current, whether R is connected to P or to Q.

3 If XY is connected to an alternating supply, and R to both P and Q, the alternating current through R has twice the frequency of the supply.

Which of the above statements is/are correct?

A 1 only.
B 2 only.
C 3 only.
D 1 and 2.
E 1 and 3.

In each of examples 12 and 13, the candidate who could think out the selection of the correct response would probably have a thorough understanding of the properties of the circuit concerned. The interdependence of the ideas presented might be arranged to help the candidate, in the way that numbers 1 and 2 in example 13 might help with number 3.

Diagrams have a particular value in questions which must be answered in a short time, because they present information economically and quickly; each of the following examples is based on diagrams.

Example 14 1970 trial

S_1 and S_2 are two sources of sound of equal intensity vibrating in phase. The distance $S_1 S_2$ is two wavelengths long. On which diagram do the lines drawn best represent the lines along which the resultant sound intensity is a maximum?

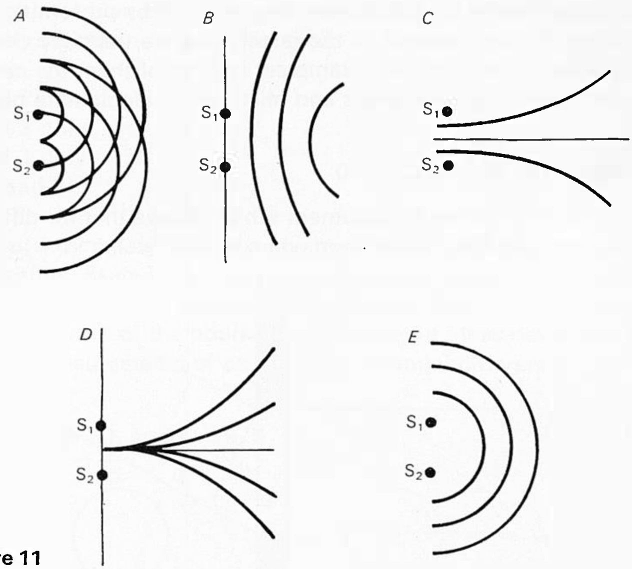

Figure 11

Example 15 O. and C. 1970

Each of the diagrams in figure 12 represents two alpha particles of the same energy being scattered by a gold nucleus. Which diagram is correct?

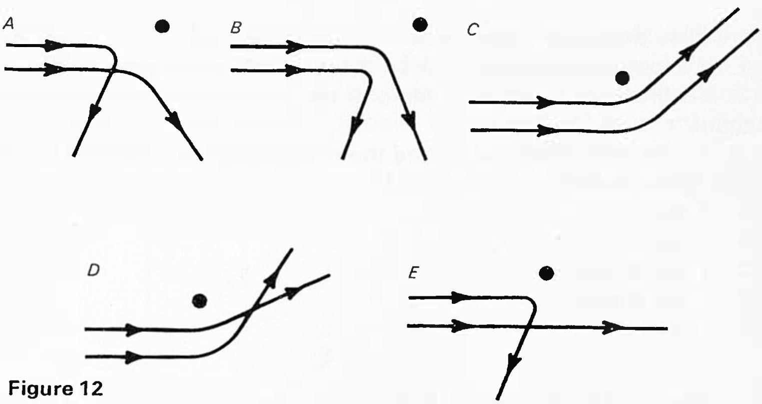

Figure 12

In both cases it is possible that the correct alternative might be selected by calling on a photographic memory, but it is more likely that a candidate will have to decide which features of the diagrams are essential to a correct representation. It is to be hoped that, if a wide variety of such questions can be constructed and if the distractors can be effectively chosen, attempts to memorize diagrams will not seem to be worth while.

Understanding of familiar situations, which may be passages of theoretical argument or experimental situations, can be examined by presenting the situation and asking about the implications of the results that are normally derived from them. This is done in the next two examples: in both of them the candidate has to distinguish between valid deductions and mistaken or illegitimate ones.

Example 16 O. and C. 1970

Figure 13 is used to illustrate an argument which shows that for diffraction from a single slit, the intensity first falls to zero when $d \sin \theta = \lambda$.

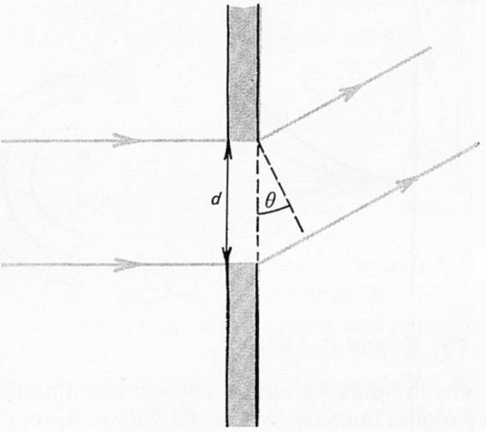

Figure 13

Here are three deductions made from this result.

1 If a longer wavelength is used the main diffraction peak will be broader.

2 If white light is used the edges of the main diffraction peak will be coloured.

3 If a slit with smaller d is used the main diffraction peak will be broader.

Which of these deductions is/are true?

A 1 only.
B 2 only.
C 1 and 2 only.
D 1 and 3 only.
E 1, 2, and 3.

Example 17 O. and C. 1970

This question concerns the photo-electric effect and the ideas about radiation (such as the equation $E = hf$) which can arise from a study of the energy with which electrons are emitted from surfaces on which light falls.

Here are three statements about the ideas summarized in this equation:

1 Radiation energy arrives in packets each of identical energy for a given frequency.

2 The energy delivered per second by a beam of blue light must be greater than the energy delivered per second by a beam of red light.

3 A photon of blue light has more energy than a photon of red light.

Which of the above statements is/are correct?

A 1 only.
B 1 and 2 only.
C 2 and 3 only.
D 1 and 3 only.
E 1, 2, and 3.

Questions about experiments can also examine the handling or interpretation of experimental results. Example 18 asks for selection of possible (not *correct*) hypotheses to account for an observed discrepancy. Example 19, however, is nearer to standard work of the course in asking about ideas developed in thinking about results of measurements of current and potential difference.

Example 18 O. and C. 1970

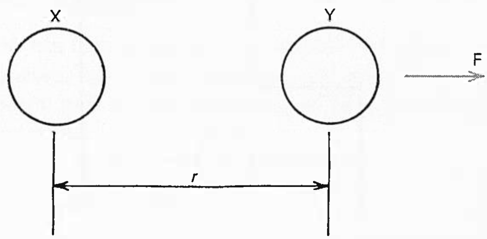

Figure 14

In an experiment to test the inverse square law for electrical forces, balls X and Y in figure 14 were each charged from a high voltage supply. The force F on one ball was measured for various values of the distance r between their centres and a graph of F against $1/r^2$ was plotted. The point P does not lie near the straight line, as shown in figure 15.

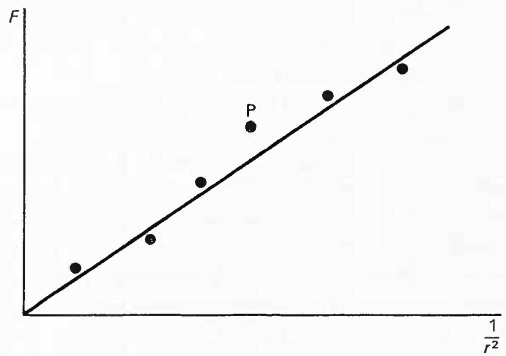

Figure 15

Here are three suggested explanations which might account for result P.

1 The force F was overestimated.

2 A charge larger than that used in the other measurements was given to one or both balls.

3 The distance r was overestimated.

Which of the above suggestions could explain the result P?

A 1 only.
B 3 only.
C 1 and 2 only.
D 1 and 3 only.
E 1, 2, and 3.

Example 19 1970 trial

(See figure 16.) In an experiment to find how the current I through five two-terminal boxes varies as the potential difference V across them is varied, each box was connected as shown; readings were taken both with the circuit as drawn, and with the direction of the p.d. reversed. The graphs shown in figure 17 were plotted from the results.

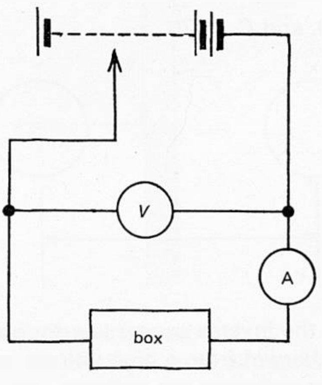

Figure 16

Below are given descriptions of circuits inside three of the boxes. For each of the descriptions, state which **one** of the graphs in figure 17 you would expect to obtain.

13 A torch bulb.

14 A diode and a resistance in series.

15 A pair of resistances (which don't get hot) connected in parallel.

Example 19 could be a recall question, particularly if, as a result of seeing such a question, candidates were to conclude that they could do better in the examination by learning the results of all such experiments by heart. If a sufficiently wide and varied range of questions can be constructed in future, it ought to be clear that the only way to be prepared for all the possible questions that can be asked is to concentrate on understanding. It is because coded answer questions do provide this variety of ways of testing the ability to think sensibly about a well defined problem that they can serve in testing and reinforcing the aims of the course.

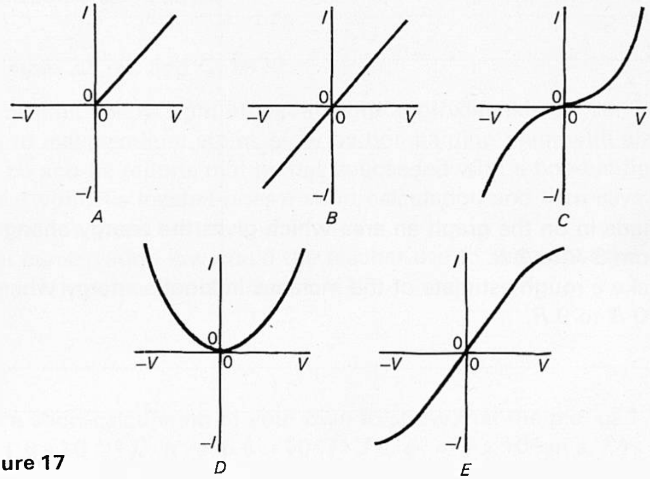

Figure 17

Short answer questions

Many questions set in this format test the same abilities, often on the same problems, as coded answer questions. Examples 20 and 21 are on the interpretation and use of a given graph, and on the construction of a graph to represent results which are described verbally.

Example 20 O. and C. 1970

The graph in figure 18 shows how the force of attraction on a 1 kg mass towards the Earth varies with its distance from the centre of the Earth. It shows that the force at a distance equal to the radius R of the Earth is 10 newtons.

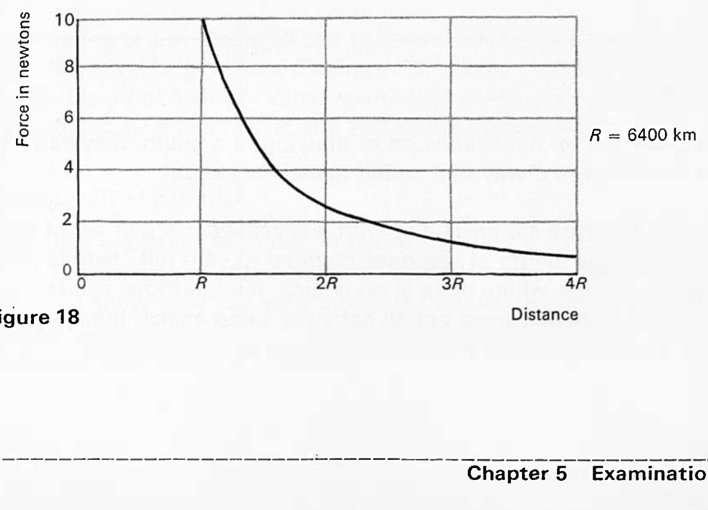

Figure 18

a Calculate the force on the mass at distances of (1) 9 R, (2) 10 R from the Earth's centre.

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b Shade in on the graph an area which gives the energy change in moving the mass from 3 R to 2 R.

c Make a rough estimate of the increase in kinetic energy when the mass falls from 10 R to 9 R.

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Example 21 1970 trial

'The resistance R of a lamp is constant at low currents, but as the current I is increased, the lamp warms up and the resistance increases.'

Sketch on the axes given in figure 19 curves for R against I and V against I to fit the above description of the behaviour of a lamp.

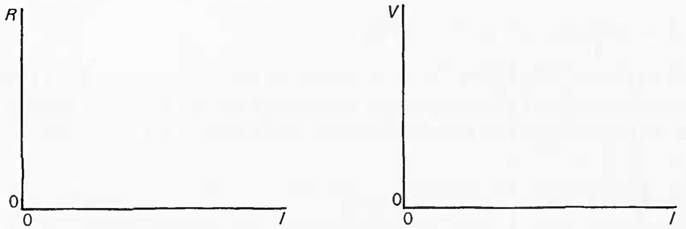

Figure 19

Because these ask for indications on or drawing of a graph, they call for initiative from the candidate in a way that coded questions cannot.

Questions of this type are presented with a specified space or set of lines for the answers so that the length of response required to earn full credit is indicated to the candidate. In a paper where there is no choice, the questions can be of varying length and difficulty and need not all carry the same marks; the relative lengths will usually be a rough guide to the relative weights of the questions.

In example 20, parts **a** and **c** also call for short calculations, and this type of question is the best way of testing the ability to deal with these. The next example also involves such a calculation.

Example 22 O. and C. 1970

Sodium atoms emit yellow light of wavelength approximately 6×10^{-7} m. A student tries to make sodium atoms glow by bombarding them with electrons in a discharge tube and he reports that he has succeeded with a bombarding potential difference of 1 volt. His teacher does a short calculation and then says this potential difference **must** be too low.

a What conservation law could the teacher use to show that the accelerating p.d. **must** be greater than 1 V?

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b Do a short calculation of your own to show that the p.d. of 1 V is too small. ($e = 1.6 \times 10^{-19}$ C, $h = 6.6 \times 10^{-34}$ J s, $c = 3 \times 10^{8}$ m s^{-1}.)

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In this example, the candidate is guided in two ways: he is set the definite target of explaining a particular prediction and he is also constrained to select and state the principle he will use before setting out the calculation.

The economy and speed of diagrams can be exploited in these questions by asking candidates to complete or construct diagrams. The rather easy first part of example 23 asks for the design of a simple experiment to be shown by a circuit diagram. This part is followed by a more searching test of the understanding of the circuit.

Example 23 1970 trial

a You have available, as shown in figure 20, a 1.5 V cell and a 15 ohm resistor which can be tapped at any point. In the space below, draw a labelled circuit diagram to show how you would connect up the apparatus to supply a p.d. which can vary between 0 and 1.5 V. Label with the word OUTPUT the pair of terminals at which the varying p.d. appears.

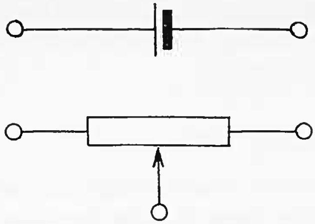

Figure 20

b You want to run a 1 V, 0.3 A lamp from your circuit. You set your circuit so that a voltmeter at the output terminals reads 1 V. But when you connect the lamp it is only dimly lit. Why is this?

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Many questions in this format will present information or experimental results and ask for explanations or interpretations. The first of the next pair of examples, examples 24 and 25, deals with a topic which could be tested by a question starting 'Describe and explain an experiment . . .'; the version in example 24 is preferred because in explaining the situation it gives more help to the candidate's memory and it can therefore concentrate on asking for understanding of the ideas involved.

Example 24 1970 trial

The graph in figure 21 shows how the maximum energy E of the electrons emitted by the photosensitive surface of a photo-electric cell varies with the frequency f of the light falling on it. It is said that this graph provides evidence in support of the following ideas:

1 That the energy E of a photon is given by $E = hf$.

2 That long wavelength light cannot release photo-electrons from the surface.

a Explain how the graph supports idea **1**.

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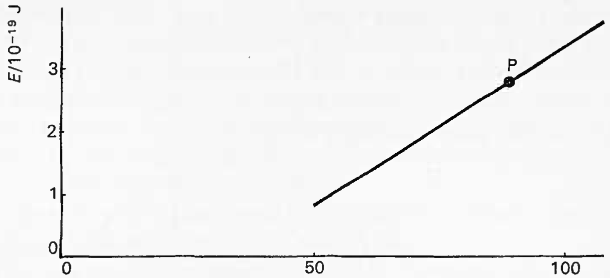

Figure 21

b Explain how the graph supports idea **2**.

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c Consider the measurement indicated by point P. How, if at all, would this measurement be shifted if the light source used were replaced by one giving twice the intensity at this frequency?

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Example 25 1970 trial

a An electron in a vacuum (or in a gas at extremely low pressure) moves in a circle if a uniform magnetic field is applied at right angles to the direction of motion of the electron. The radius r of the circle and the strength of the magnetic field B (flux density) can both be measured. How could the momentum of the electron be worked out from these measurements? (Force = Bqv, acceleration = v^2/r.)

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b It is possible, in a cloud chamber or similar apparatus, to observe the path followed by a high speed electron in a uniform magnetic field. The diagram shows such a path: the electron moves in the plane of the diagram and the magnetic field is at right angles to the plane. Try to suggest and explain a reason for the fact that the track is a flat spiral and not a circle.

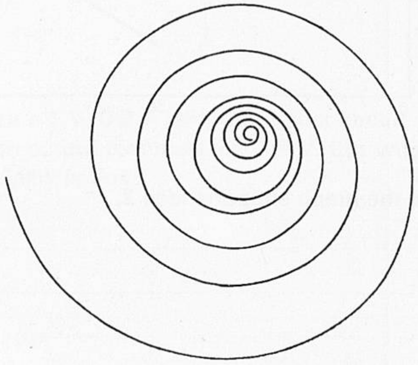

Figure 22

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Example 25 also asks in its first section for deduction from information supplied, whilst the second section is a modest exercise in the application of the ideas to a novel problem. The student is only expected to apply these ideas to show that the spiral indicates loss of energy. It would not be necessary to discuss reasons for the energy losses from charged particles.

One of the general aims of the course, to understand the nature of inquiry in physics, ought to be examined in the way that most of the other aims are examined. Because this aim is not commonly adopted in school courses, questions specifically concerned with it, of which the following is an example, will look more unusual than most of those given so far. This question tests for a specific objective, the classification of elements in a scientific argument, which falls within the general aim.

Example 26 O. and C. 1970

This question is about describing different kinds of scientific statements. Here are some possible descriptions of such statements:

'It states an experimental fact.'
'It makes a hypothesis.'
'It quotes a scientific law.'

'It is a rough estimate.'

'It is a deduction from earlier statements.'

You are asked to give a brief description of each of the numbered statements in the passage below. Your descriptions should use phrases like those given above; you may use, combine, or adapt the phrases above or invent others of your own.

1 If we assume that in a gas the atoms have a radius of about 10^{-10} m and a mean separation of about ten atomic diameters . . .

2 . . . it is clear that an alpha particle, in traversing several centimetres of the gas, must encounter some thousands of atoms of gas.

3 Only a minute fraction of such encounters, however, produce any appreciable deflection of the alpha particle.

4 It is difficult to avoid the conclusion that the greater part of the atomic volume is effectively empty.

Statement **1**

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Statement **2**

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Statement **3**

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Statement **4**

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Questions of this type do not have unique correct answers and a student's thinking can only be assessed on the quality of the ideas he produces: thus this aim cannot be tested by coded answer questions.

The final example, example 27, is taken from an A-level Special paper. It is also concerned with a quite specific objective, the making of rough estimates of quantities using either data supplied or knowledge obtained from everyday observation.

Example 27 O. and C. 1970

In each of the parts **a** to **e** that follow you are asked to estimate the size of something. To help you in making your estimate, some data are given at the head of this paper from which you may choose what you need: you might also need to make rough estimates of your own for some common dimensions (e.g. the size of a rubber ball) – you will receive full credit for any estimate which is not a gross over- or under-estimate. Most of the marks go for combining the data in a sensible way.

Estimate

a the resistance of a 3 kW electric fire;
b the energy transformed when a match burns away;
c the resistance of a gold wedding ring (considered as a one-turn coil);
d the recoil velocity of the Earth resulting from the impact on the floor of a rubber ball dropped by a child;
e the time for which a rubber ball, dropped on a hard floor, is in contact with the floor.

The rubric for this paper included the following information: the Young modulus E for rubber, the density ρ of rubber, the mass of the Earth, the resistivity of gold and the equation

$$v = \sqrt{E/\rho}.$$

For a short answer question, a question about estimates might have fewer and simpler examples, but the above sample does serve to illustrate the testing of an ability in physics which is very relevant to the practice of science and which ought to be encouraged.

Long answer questions

The brief for a question of this type can only state that it should require about thirty minutes of thinking and writing, that it should test abilities which are not assessed by the tests of other types, and that it might include in these abilities the construction of a connected prose communication. Within this brief many types of question, demanding a considerable variety of abilities, are possible, as the following examples should show.

The first is a structured question calling for a set of answers about a single problem.

Example 28 O. and C. 1970

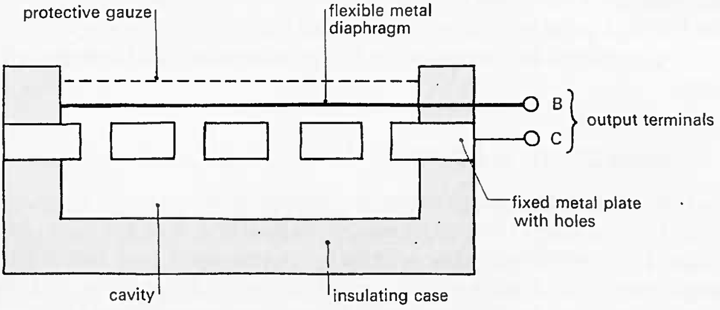


Figure 23

Figure 23 shows a section through a type of microphone called a 'capacitor microphone'. Figure 24 is a circuit which shows how the microphone may be connected for use. (The output from the microphone could be taken from terminals B and C, which would be connected to a suitable amplifier.)

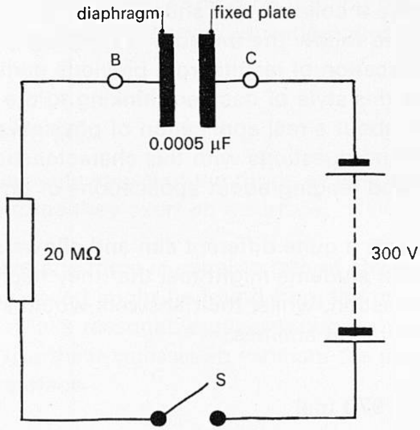


Figure 24

a If the switch S were closed for a few seconds, then opened again, and the diaphragm were then pushed slightly inwards, explain:

1 what would happen to the capacitance of the microphone;

2 what would happen to the p.d. between B and C.

b Explain what would now happen if, with the diaphragm still pushed in, the switch S were closed.

c Why is the instrument constructed so that the diaphragm is as close to the first plate as possible?

d What is the time constant of this circuit?

e Assuming that switch S is closed, state the changes of p.d. between B and C that you would expect to occur if a compression wave moved the diaphragm inwards in a time:

1 which was short compared with the time constant of the circuit – say in about 10^{-5} second;

2 which was long compared with the time constant of the circuit – say in about 1 second.

f Two sources of sound, one having a frequency of 10000 Hz, the other of 50 Hz, are each found to produce the same amplitude of mechanical vibration in the diaphragm.

1 Why is the amplitude of the resulting variations of p.d. across BC smaller for the 50 Hz vibrations than for the 10000 Hz vibrations?

2 Explain what change you could make in the circuit to bring the amplitude of the electrical output from the microphone, when responding to the 50 Hz note, to approach more closely that produced by the 10000 Hz note.

You may find the following formulae useful in dealing with some parts of this question:

$$C = \frac{Q}{V}, \qquad C = \frac{\varepsilon_0 A}{d}.$$

Example 28 is rather like a collection of short answer questions, but is different in that the candidate has to follow the thread of a long argument, so that each new part might require application of results from previous parts. It might appeal to candidates who prefer this style of detailed thinking to the construction of an essay. The question is about a real application of physical principles, one not studied in the course, and questions with this characteristic would be included to encourage interest in and reading about applications of physics.

The next example reflects a quite different aim and allows scope for a far wider variety of answers. Most students might feel that they had done themselves justice after answering this question, whilst their answers would still give the examiners evidence about their different abilities.

Example 29 1970 trial

It has been suggested that the drag experienced by an object pulled along the surface of water depends upon the width d of the channel through which it passes, if the channel is a narrow one.

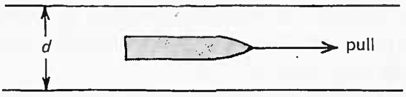


Figure 25

Say how, in a school laboratory, you would hope to set out to test this suggestion. Outline your ideas for simple apparatus and say what measurements you would expect to make.

Many factors other than the width of the channel affect the drag on objects when they are pulled through water. Choose two such factors and discuss how you might investigate the effect of each on the drag.

The question poses a definite effect to be tested, asks for specific features in the answer, defines the context as that of a school laboratory, and asks for further thought and discussion about a definite number of additional features. A question which said 'Say how you would investigate drag on boats' might appear to serve the same purpose. However, the wider variety of answers which this would produce would be harder to assess fairly, both because of their diversity, and because a candidate will often discuss one feature rather than another.: the reason is that he has had to make guesses about which features the examiners might require or value; this does not necessarily mean that he is unable to discuss the aspects omitted. The tackling of investigational problems is an important feature of the course and this example tests the preliminary thinking and design which should be an important stage in this work.

The next example, example 30, includes a smaller part on investigation. The detailed understanding of the physics, of drag on floating objects, was not required in the example above, whereas the following question concentrates first on the physics involved.

Example 30 1970 trial

It is suggested that the average speed of raindrops as they strike the earth might be found by measuring the force they exert on a surface.

Use the principle that 'average force is equal to rate of change of momentum' to explain how the raindrop speed might be found from the measured force and any other quantities needed. Make reasonable guesses about the speed and other quantities involved and use these guesses to estimate the magnitude of the force on one square metre of surface.

Discuss the problems you might have to consider in designing an apparatus to measure this force.

The principle required is specified and the student is asked to discuss its application in some detail, to make some rough quantitative estimates, and to use these results in thinking about a method of measurement. This is, formally, a more complete test of the powers needed to tackle some types of scientific problem, although very little can be expected on the experimental design and procedures, because so much is expected in the discussion of the underlying ideas.

The explanation of principles can be tested by examining their use in a particular context and both the principles and the context can be set out for the candidate by offering a short passage on the topic, as in example 31 below.

Example 31 O. and C. 1970

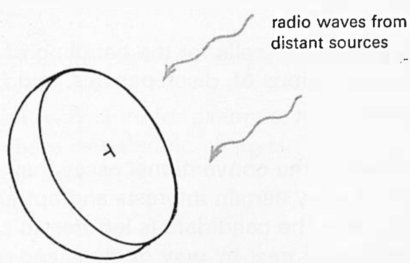


Figure 26

Write a short essay or set of notes suitable for another sixth form student, amplifying and explaining the following passage:

'A major problem in designing reflecting radio telescopes is making them large enough. If the reflecting dish is too small, weak radio sources are hard to detect and their directions are hard to determine exactly. It is diffraction which limits the accuracy of direction finding. For example, a telescope dish 10 metres in diameter using radio waves of wavelength 0.1 metre will give a response over an angle of up to roughly $\frac{1}{100}$ (0.01) radian (0.5 degree) on either side of the true direction of a small radio source, and will also give further maxima and minima of response at larger angles.'

Candidates often find such questions difficult because they find it hard to distinguish the essential features and underlying principles from the less basic aspects, so that it is a useful device in some questions to put certain phrases in italics and ask that particular attention be paid to them, although it might also be argued that the ability to make such distinctions is an important part of the test.

Another context in which ability to think and write sensibly as a physicist is called for is in the analysis of experimental results. The following is taken from a Special paper.

Example 32 O. and C. 1970

It is proposed to find the half-life of a radioactive gas emitting alpha particles by puffing a little of the gas into a cloud chamber and photographing the tracks every 15 seconds. The following set of results was obtained when the number of tracks in each photograph was counted: 50, 36, 40, 30, 24, 21, 19, 15, 12, 13.

Plot a graph of the logarithm of the number of tracks counted against the time and draw a best straight line through the points. From this graph determine the half-life of the radioactive gas. Why do several of the points depart so much from the best straight line?

Would there be any merit in continuing the experiment for a longer period of time?

Describe an alternative experiment which might give a more accurate value for the half-life. Explain why your experiment might be expected to give greater accuracy.

This example has value because it calls for the handling of numerical data, for judgments about, and explanations of, discrepancies, and for the construction of new hypotheses or plans.

Questions which are closer to the conventional essay may also have value in encouraging students to display certain interests and aptitudes. The following example is quite open, in that the candidate is left free to choose his own topics and emphasis, although a great deal by way of clues and reminders is given in order to diminish the effects of the artificial examination situation (the absence of all clues, references, and opportunities for discussion with colleagues is a condition encountered mainly by examinees and castaways on desert islands).

Example 33 O. and C. 1970

Write a short essay on 'strong' materials. Your essay might include discussion of such topics as: the need for strong materials, why some materials are weak, how the weaknesses can be avoided, composite materials such as plywood, reinforced concrete, and fibreglass, and the new technology of composite materials. These are only suggestions: you might write about a few of them, or, if you prefer, about all of them, and you may of course discuss other related issues if you wish.

Such a question will produce a wide variety of answers and the difficulty of marking these reliably has to be set against the virtue of allowing candidates free rein in concentrating on any interest they might have in a broad field of applications of physics.

Example 34 is similar, in the aim that it serves, to example 26. One or two questions of this type – and not more than one in any one section – ought to be enough to do justice to this aim in an examination.

Example 34 O. and C. 1970

Consider the following description of physics.

'In one sense all of physics could be written down on a single sheet of paper, by giving *the fundamental laws, principles, and facts*. In another sense, physics could fill a large and growing library, for these few fundamental ideas *can be used to explain very many things* and *each new explanation is liable to suggest several new problems*.'

You are asked to discuss this passage, paying particular attention to the three phrases in italics. You should illustrate your view of each with particular examples. You may agree or disagree with the ideas expressed in the passage, but you are expected to support your views with arguments based on the examples you choose. Illustrations drawn from any **two** of the following topics would be enough for an answer; you may use other topics as examples if you wish.

Possible topics

The study of inelastic collisions between accelerated electrons and gas molecules (Franck-Hertz type of experiments).
The study of compression waves in, for example, metal bars.
The study of the forces between electric charges.
The study of gravitational attraction.
The study of radioactivity.

As explained for several of the other examples, the question itself is long because it tries to give definite guidance about the criteria for a good answer; the question specifies the ideas to be discussed and the need for discussion of examples, suggests such examples and advises the use of two of them, and makes clear that the quality of the arguments rather than adherence to, or disagreement with, a particular view will determine the credit earned.

An outstanding problem about this paper is that it allows for choice (usually three questions out of six) amongst questions of different types which will give evidence of quite different abilities. It is hard to judge that any, let alone several, of these types ought not to be part of the examination, and it is therefore impossible to demand that every candidate should attempt one example of each of the types of question which is thought to be valuable. It is the present view that, given the absence of choice in all other parts of the examination, the choice in this paper is justified and allows each candidate to show his particular strengths. Any A-level result expressed as a single mark or grade is in any case an addition of quite different achievements from individual candidates. There remains the considerable difficulty of marking the different types of question on some fair common basis; the fact that for any pair of questions there will be a substantial number of candidates who will have attempted both might provide some aid to the examiners' judgments in relating standards.

Comprehension paper

The following is the comprehension passage set in the 1970 A-level examination. It is quoted from Hadden, H. Burrell (1964) *Practical stereophony*, Iliffe.

Example 35 O. and C. 1970

Theories of hearing and methods of creating a stereophonic effect

Location of a sound

Early theories

The precise method by which a human being is able to discover the location of a particular sound in relation to himself has exercised the minds of scientists for many years. Lord Rayleigh in his *Theory of sound*, published in 1896, comments briefly on the theory prevalent at that time. This was that the effect of the bulk of the head between the two ears produced a sound shadow, and thereby caused an amplitude difference in the sound reaching the two ears from a given source. Rayleigh pointed out that this theory could only operate at frequencies above 700–1000 Hz, that is, frequencies above that at which the physical distance between the ears was equal to one wavelength. He suggested that a possible explanation for the perception of sound direction at low frequencies might be the difference in time of arrival of the sound wave from a source at the two ears, but apparently did not attempt to prove this.

Early workers conducting investigations into sound localization were very limited in their activities by the fact that they had no electrical generating apparatus. They were, therefore, forced to use clicks and other noises as sound sources. Furthermore, the rooms which they used for their experiments were far from good acoustically, and so the positions of the sound sources were confused by reverberation effects. However, the early experimenters established that it is possible to locate noises more easily than pure tones: that it is possible to distinguish sounds appearing from right or left, and that the precise location of a sound at the side of the head is perceived with the least accuracy.

Stevens and Newman, in 1934, attempted to sort out some of the theories prevalent at that time, and devised an open air experiment in order to overcome the difficulties of sound reflections. They mounted a swivel chair on top of a ventilator shaft above the roof of one of the buildings at Harvard University. The source of sound was mounted at the end of a 12 ft [about 4 m] arm which with careful adjustment could be moved noiselessly in a complete circle on a horizontal plane level with the listener's ears. The sound generator was a loudspeaker to which pure tones and various noises, such as clicks, could be applied. It was found that the listener hardly ever confused the positions of sounds which were to the right or left, but, depending upon the type of sound used, fairly frequent confusion of whether the sound was in front or behind took place. It was found that pure tones at low frequencies could be localized with reasonable accuracy, as could tones at very high frequencies, but there was a band of middle frequences between 2000 and 4000 Hz where localization appeared to be more difficult. Stevens and Newman concluded that the observed results from their experiments were 'consistent with the hypothesis that the localization of low tones is made on the basis of phase difference at the two ears, and that the localization of high tones is made on the basis of intensity differences.' These experimental results seemed to confirm the earlier theories attributed to Rayleigh and others, and it was not until much more recently that any work was carried out which produced any new evidence on the subject.

Recent investigations

During the 1950s, and continuing to the present time, the problem was being tackled from quite a different angle, by a research team working at Imperial College, University of London. Cherry, Sayers, and Leakey have been investigating the means whereby the brain takes the slightly different sounds received by the two ears and fuses the two sets of information so gained into an awareness of one sound in a particular place. Their method of experiment was quite different from that of the earlier work by Stevens and Newman, in that, whereas the earlier experimenters used a loudspeaker as a sound source, moving it round the listener, Cherry and his team used headphones, feeding different sounds to the two earpieces in carefully controlled ways. By this method, using pure tones, it was possible to feed the two ears with sounds whose amplitudes differed by carefully controlled amounts, without there being any phase or time differences between them; and conversely, it was possible to arrange that the sounds arriving at the two ears differed in time of arrival, but were identical in amplitude. It was also possible to present to the ears sounds which contained amplitudes and time differences in controlled amounts at the same time.

Examples of questions asked on the preceding passage follow.

1 Draw simple graphs or give a few words of explanation to show what you understand by the following:

a An amplitude difference in the sound reaching the two ears (lines 5–6).

b Phase difference at the two ears (lines 37–38).

c Pure tones (line 28).

d Clicks (line 29).

2 This question is about the first paragraph of the passage (lines 1–12).

a Why does the frequency have to be above 700–1000 Hz for the amplitude difference effect to be important?

b Draw a simple diagram with a sentence of explanation to show how a ripple tank can be used to illustrate the explanation mentioned in **2a** above.

c The information in this paragraph would enable you to estimate the velocity of sound provided that you could make one further simple measurement. Explain what this measurement is, make a rough estimate for the result of the measurement, and hence estimate the velocity of sound.

d If the ear does detect direction by differences in times of arrival at the ears, make a rough estimate of the sort of time difference our hearing mechanism must be detecting.

3 Paragraphs 2 and 3 explain why Stevens and Newman worked in the open air. What are the 'difficulties of sound reflections' (lines 23–24) found in rooms which are 'far from good acoustically' (line 16)?

4

a If you were asked to repeat the experiments of Cherry, Sayers, and Leakey, draw a labelled diagram of the equipment you would need, showing how it would be connected to the earphones. Your diagram should indicate a set of boxes, showing how they are connected together, and indicating for each box the function of that box.

b What disadvantages of the methods of early workers (line 13) were Cherry, Sayers, and Leakey able to overcome using modern 'electrical generating apparatus'?

The example illustrates several criteria which guide the selection of such a passage and the choice of questions on it. The article is about an application of physical principles; the principles involved are ones that are central to the course but the application is in a field about which students are not expected to have any previous knowledge.

Some of the questions test whether a student's command of the language is adequate to the task of reading scientific prose with understanding. Some questions ask for information to be extracted from the passage and to be used in a new way. The questions as a whole try to test whether a student can learn a little about a new field, using ideas studied in the course. Thus, they bear directly upon the general aim concerned with learning in the future.

Practical examination

The detailed rules about the organization of this examination for the 1970 A-level examination are explained in the following extract from the instructions provided for supervisors by the Oxford and Cambridge Board. It should not be assumed that the detailed rules will be the same in subsequent years, but major changes in the organization are not contemplated at present.

> *Instructions to supervisors* (extract) O. and C. 1970
>
> 'The questions are to be answered in numerical cyclic order, 11 minutes being spent on each question. After 9 minutes of this period, candidates are to be instructed to stop using the apparatus so that it may be arranged as they found it, and supervisors must verify that the apparatus has indeed been arranged as it was set out at the commencement of the examination. At the end of the 11-minute period, candidates are to be instructed to proceed to the next place in the laboratory to answer the next question.
>
> 'Before the examination, supervisors should arrange candidates in groups of not more than eight and decide the numerical cyclic order of answering the questions for each candidate.
>
> 'Not more than 5 minutes before the examination proper is to commence, the candidates should be assembled in the laboratory and given copies of the question paper. Candidates should not be allowed to inspect the apparatus. They should be told at which question they are to commence, together with the ensuing numerical cyclic order for the remaining questions.
>
> 'The attention of candidates must be drawn to the requirement that all rough work must be done on the answer paper. Extra paper is not to be supplied for this purpose.'

Each of the eight exercises in this examination is meant to test a specific well-defined skill in about ten minutes of examining time. The examples here do not illustrate all of the possible skills which might be tested and, as for the examples offered above for the other examinations, they do not form a balanced or complete set.

In example 36, the question read by the candidate is given together with the instructions which the supervisor will have received some time before the examination.

Example 36   O. and C. 1970

Question

Determine the value of the unknown frequency using the oscilloscope and the 50 Hz standard frequency. Say how you arrive at your value.

Instructions

Each experiment will need:

1 oscilloscope, preferably the class oscilloscope, Nuffield O-level Physics item no. 158.

1 audio-frequency oscillator.

1 cardboard box big enough to hold the oscillator and labelled **unknown frequency.**

1 power pack or transformer which will provide a 50 Hz output at about 3 V peak to peak.

1 cardboard box big enough to hold the power pack and labelled **standard frequency – 50 Hz.**

Connecting leads.

Candidates are required to calibrate an oscilloscope and then measure the frequency of an a.c. supply.

Allow plenty of time for the audio-frequency oscillator to warm up and then set it to give a sine-wave output of frequency 100 Hz and about 6 V peak to peak, both of these values being measured on the oscilloscope. Place the oscillator in the cardboard box, securing it so that the scale and control knobs are not accessible. Provide some ventilation holes if necessary. The output leads should be permanently attached, the earth lead being clearly labelled. Leave the oscillator switched on.

The power pack should be similarly concealed in its cardboard box.

At the start of each experiment set the brightness and focus of the oscilloscope to give a sharp trace, turn the Y-gain as low as possible, and switch the time-base to about the middle of its range. Leave the oscilloscope switched on.

If the oscilloscope is provided with stabilization and trigger level controls, first stabilize the trace and switch the trigger level to auto and then tape up these controls so that they cannot be changed.

Further comments on the question

The candidate is only required to state very briefly what he did and to record his measurements. The questions for the examination are presented to the candidate in an answer book and a definite space is allotted for each answer.

The question tests the ability to use an oscilloscope, which is regarded as one of the instruments that all students should be able to use. Others include ammeters and voltmeters, but instruments like the electrometer or scaler, which may not have been handled by every student, are excluded as they are things to be manipulated with skill.

The rotation system makes it possible to set such a question, without requiring that a school should have a large number of oscilloscopes in working order at the time of the examination.

Some of the controls are preset and fixed in position, to make the problem feasible within the time.

Example 37 is a fairly direct test of a conventional procedure.

Example 37 1970 trial

Using the apparatus provided, arrange a narrow beam of light to fall normally onto the diffraction grating.

From your observations on the first order diffraction spectrum, calculate the grating spacing.
(Average wavelength of light is 550 mm.)
(Grating formula $n\lambda = d\sin\theta$.)

It is useful to have one or two such plain, straightforward questions in the paper, as long as there are not too many and it is possible to devise enough of them to make it hard to predict them well enough in advance. All that the candidate need record is the observations and the result calculated from them, so that credit is given for the readings taken, for the interpretation of these readings, and for reasonable, but not great accuracy.

Experimental arrangements which would be quite new to candidates might be needed for testing some skills, as in example 38 below.

Example 38 1970 trial

(See figure 27.) Lightly clamp the table tennis ball so that its lower point is 0.5 m above the glass block. Release the ball and observe the height to which it bounces. bounces.

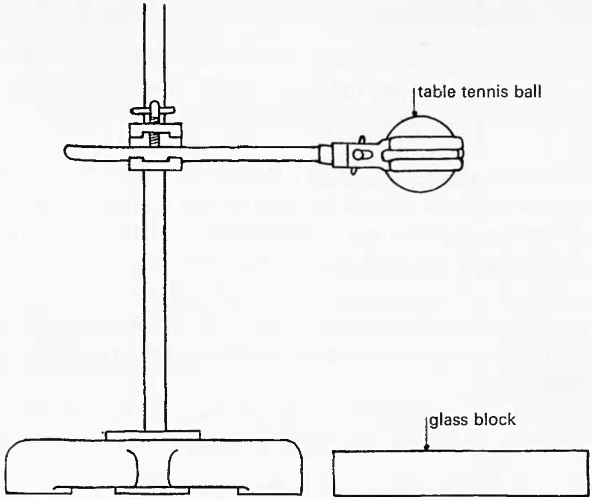


Figure 27

Explain in detail your technique for ensuring that your readings are as accurate as possible.

Most of the marks for this question are allocated to this explanation.

This is concerned with accurate observation, although the assessment is based mainly on the candidate's account of how he achieved accuracy. Another way of testing this aspect is to ask for measurement of two quantities for which it is not clear to the candidate whether they ought to be identical or ought to have a significant difference. The candidate can then be asked to comment on what his measurements establish.

Treatment of measurements is another skill which can be tested on written papers but which ought also to be tested in the context of a candidate's own observations. The next example attempts to do this.

Example 39 O. and C. 1970

The loop of nylon fishing line has a load of 0.2 kg hanging from the bottom. Hang on a further load of 0.2 kg and measure and record the change in length.

Use the micrometer screw gauge to measure the diameter of the nylon.

Show how you would use your values to work out the ratio of force per unit cross-sectional area to the fractional increase in length. Do **not** do the arithmetic required to obtain a final number.

The procedures are specified, the use of technical terms such as 'stress', 'strain', 'modulus' is avoided, as is the final arithmetic, so that only the readings and their manipulation to produce the appropriate expression are called for.

The ability to select appropriate apparatus is of general importance and example 40 tests the selection of electrical equipment of the type and variety used by candidates in the course.

Example 40 O. and C. 1970

Measure the current through the lamp for potential differences across the lamp of 0.5 V, 1.0 V, 1.5 V, 2.0 V, 2.5 V. Select what apparatus you need to do this from the apparatus available on the bench. You will gain credit in this experiment for selecting the most appropriate pieces of apparatus. Tabulate your results and draw a circuit diagram showing how you connected the apparatus you used. Indicate on the diagram which pieces you selected from the range available.

The apparatus provided for this item included 0–1 A and 0–5 A d.c. ammeters, 0–5 V and 0–10 V d.c. voltmeters, a rheostat of about 10–15 Ω, and a 5 kΩ linear potentiometer.

A quite different skill is tested in example 41 below.

Example 41 1970 trial

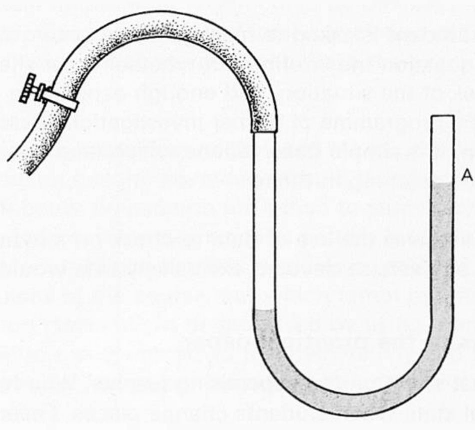


Figure 28

(See figure 28.) Blow gently down the U-tube until the water level rises to about the position of A. Then release the pressure and observe what happens.

Write an account of what you observe. In your account, try to use the technical words and phrases which physicists use in discussing motions of this type.

The experiment is a simple one, but it does not appear in the course and should be novel to most candidates. The test is concerned with the power to observe as a scientist and to use the language of the subject in order to describe one's observations.

For example 42, pupils were provided with strips of paper handkerchief tissue, all cut to a standard size with strengthening tape fixed at each end; holes in this tape enabled pieces to be hung quite readily from a hook and various weights could be attached at the lower ends. Thus, several rough tests could be made within a minute or two.

Example 42 1970 trial

'Stays strong when wet', say the advertisements.

Start an investigation to check this claim by obtaining a value for the strength of the paper when dry and a value for the strength when wet. Give the two results for these preliminary measurements.

Describe what you would do if you had time to do a more detailed and prolonged investigation.

The initial investigation is meant to give you ideas for the description of the more prolonged investigation, and most of the marks for the question are allocated to this description.

In this question, a student is asked to make just one or two very simple observations. The question tries to find out whether he or she has enough grasp of the physical realities of the situation, and enough experience of planning ahead, to be able to suggest a programme of further investigations based on those observations. Often, it is simple observations which take a scientifically informed eye and mind to see anything in them.

The question also involves the use of data to check on a hypothesis, although to do justice to this skill an exercise devoted exclusively to it would be required.

Problems of the practical paper

This paper is a great strain on the supervising teacher, who has to restore apparatus to the proper initial state when students change places. Fears that for students, it would become a panic-stricken race with time are not borne out so far. Indeed, one problem with the marking of the first paper set was the relative ease and lack of discrimination of most questions.

It seems probable that the combination of the practical paper and the assessed investigation makes up a reasonable test of practical ability. Separately, they would seem likely to be testing different aspects of practical skill, initiative, and judgment, and the low correlation between the marks gained on the two examinations seems to support this view. Together, their combined weight in the examination can be larger than the weight usually given to a practical examination by itself.

However, the arguments for this combination deserve long-term critical study. Much will depend upon the trustworthiness of the assessment of investigations by teachers, and on the degree to which they can fairly and consistently discriminate between their own students' performances. Other factors involve the difficulties of the practical examination in practice, whether or not it turns out to be reasonably reliable, and whether its effects in terms of what is done in schools preparing for the examination seem to be desirable ones or not.

Other Nuffield Advanced Science projects have tried other means of assessing practical work, whether by way of a project alone, or of 'test case' experiments in the course, assessed by the teacher. All have promise. We thought it right to broaden the base of experience in this field by trying yet another pattern, so that in due course a judgment may be made of the right way to proceed, which is based on as much evidence as possible.

Review

It is not claimed that the examples given above are free from defects; indeed, they have many. It should also be made clear that this chapter is written at a time when the detailed analyses of the data from the first A-level examinations are not available. It is hoped that information which could be obtained from such features as the relative difficulty, discrimination, and inter-correlation of the various items will suggest changes that might be necessary to make the examinations more effective.

The style and techniques of examining might need modification for another reason. A new examination has the advantage that in the absence of precedents there appears to be no better preparation for it than to study physics in the manner recommended for the course. If the examination pattern is stable, then a study of papers for the first few years might suggest teaching procedures which might have little relevance to the aims of the course, but which tempt by offering at least the illusion that examination marks might be increased by using them. It will be a considerable challenge to the examiners to maintain variety and flexibility in order to avoid the stereotyping which can make cramming for an examination appear advantageous.

None of the developments described in this chapter is particularly novel. A great deal has been gleaned and used from the experience of Nuffield O-level and of the other Advanced Science projects, and also from developments in and studies of examining being undertaken by several examining boards.

Chapter 6

Class tests

Class tests serve several functions, including:

Informing students of their progress.

Informing teachers of students' progress.

Diagnosing difficulties.

Practising for examination questions.

Communicating aims.

Time is limited, and tests must be short, so it is best not to try to make any one test serve all possible functions, but to make up a test which serves the function that seems most important at the time. If the students feel that they 'haven't learned much', try a series of coded answer questions covering many aspects of what has been studied. If the class or the teacher is worried about the writing of, say, essay answers in the long answer paper, sacrifice coverage to practice and set an essay covering what has been done from a new angle. If the class feels that making rough estimates is beneath the dignity of a physicist, set a series of such estimates covering recent work. If the work seems hard to understand, try a series of related short questions leading up to an idea, to find out where difficulties arise.

Types of test

Only rarely can more time than one lesson and its associated homework be afforded for a test, such as might be given at the end of a Unit. It can contain, then, either a number of coded answer questions, or three or four short answer questions, or one long question. Sometimes, homework can include the study of a passage for comprehension.

Coded and short answer questions

The evidence is that a little practice is a help to students in making them able to handle questions in coded form but that extensive practice produces very little further effect. It is important that the questions used should both be technically sound, and reflect the course well. Advice on making up technically sound questions is to be found in many books, which discuss such matters as making the questions explicit and definite, avoiding ambiguity, avoiding clues like the qualifications to be found in correct statements but not in false ones, avoiding double negatives, and so on.

The best way of ensuring that questions are technically sound is to test them, first on one's colleagues, and then on students.

Technically sound questions are not necessarily good questions. They may, by their nature, give a wrong impression of the aims or the content of the course. A good question may, however, assist those aims by expressing them. The main problem is one of achieving enough variety of things asked, especially of things that go beyond the factual content of what has been taught.

Besides asking questions about the ideas taught, experiments that have been done, effects that might be observed and explained, and apparatus that might be used, one can ask about where information might be found, how a student would start to investigate a problem, or about the principles behind an application.

For example:

a What information, in what sort of book, could you look for to find out whether steel or copper conducts electricity better?

b How would you begin to investigate the suggestion that the resistance of a wire depends upon how much it is stretched?

c What factors would be important in the choice of a material for wires to be used to carry hundreds of amperes of electric current for long distances, suspended from pylons?

Another sort of question asks the student to clarify, to criticize, or to summarize a statement or a passage. For example:

a 'Glass is very strong, but breaks easily.' Clarify this seemingly contradictory statement.

b 'Stress is how hard you pull, strain is how much it gives when you do.' Criticize this statement, and put it into a form clear enough for someone to calculate the stress and strain in a specimen.

Besides requiring students to use formulae and data to make calculations, questions can also exercise them in making order of magnitude estimates, and in looking for flaws in calculations. For example:

a Estimate the stress under the tip of a compass point pressed hard enough onto a copper block to make a dent in it.

b How fast does human hair grow, in metres per second? How many atoms per second is that? How many hair cells per second?

c A bar of steel 10 mm $\times$ 10 mm, 1 m long, contains some 10^{24} atoms, as an atom is of the order of 10^{-10} m across. So if the bar sustains a longways tension of 10^4 N, each atom must pull on its neighbours with a force of $10^4/10^{24} = 10^{-20}$ N. Find what is wrong with this 'deduction'. A fairer answer would be 10^{-10} N.

It is often convenient, and is a good thing, to give information in graphical form, so that students learn to translate it more easily from one form to another. Graphs can often be the basis for questions about the results of an experiment. Do the results support a hypothesis? What reasons can be suggested for an apparent error in one result? Could the results reasonably be supposed to follow the same pattern outside the range of the experiment?

Although the examples above are written in a form requiring a short written answer, some can be put into coded answer form.

Passages for comprehension

Suitable passages can often be found in magazines, such as *Scientific American*, or *New scientist.* Others are to be found in books, especially in paperbacks for the scientifically inclined general reader, like Gordon, *The new science of strong materials,* or Graham-Smith, *Radio astronomy,* and in other books about the applications of physics, such as Bishop, *Vibration* (see Chapter 9 for details). Some newspapers run special features which can be used.

Most passages need some editing, to avoid unnecessary complications.

A useful general rule is to look for a passage about some application of physical principles, which requires knowledge of the principles taught recently. Some useful forms of question include:

Questions about the principles involved; what they are, how they apply.

Questions requiring the use of data in the passage.

Questions about the meaning of terms.

Questions requiring the student to extract and summarize ideas in the passage.

Questions about investigations suggested by the passage.

This kind of use of passages of scientific prose goes beyond what is ordinarily meant by 'comprehension'. We would have used another term if we had thought of one.

Long answer or essay questions

There will usually only be time for one such question in a test, and other forms of test will usually be more helpful in the early stages of the course. Nearer the end, there is a case for setting an occasional essay, intended to survey a broad area of the course. Not the least of the reasons for setting such questions is their presence in the examinations.

The main problem in setting such questions is to make them definite enough, without constraining the answer too much. The question, 'Are the ideas of electric charge, field, and potential useful in physics generally?' is too vague. Perhaps it should be more like the following:

'In discussing the bonding of a crystal like sodium chloride, one needs to know the charge on the ions, and their spacing, to calculate the force between the ions, and the energy stored by a pair of ions of opposite charge. To do those things, one must know how to calculate the electric field, and the electric potential, at any distance from a point charge.

'Explain in more detail what calculations are involved in this example, what fundamental laws are involved, and what experimental facts are needed.

'Think of one other different example in physics, or in the applications of physics, where the laws governing electric charge, field, and potential are needed. Explain why they are needed, and how they are used.'

The type of question which is long and consists of many short items is more suitable for class tests. Example 28 in Chapter 5 'Examinations', is an instance of this kind of question. Others are not too hard to make up, on the lines of similar questions in the *Students' books*.

Sample test questions

The following are examples of questions used in class tests during trials of the Advanced Physics course.

Unit 1

As a certain substance is stretched it is fairly easy to extend at first but after some stretching it becomes much harder to stretch further. Sketch a load-extension graph which would represent this behaviour.

Unit 1

Complete the two blanks in the following estimate of the size of a copper atom
Avogadro constant $= 6 \times 10^{23}$ mol^{-1}.

Density of copper $=$ 9000 kg m^{-3}

Atomic mass $=$ 64 g mol^{-1}

Volume of .... $= \dfrac{64 \times 10^{-3}}{9000}$ m^3

Volume of .... $= \dfrac{64 \times 10^{-3}}{9000 \times 6 \times 10^{23}}$ m^3

If each atom is a sphere of radius r then

$$\frac{64 \times 10^{-3}}{9000 \times 6 \times 10^{23}} = \frac{4}{3}\pi r^3$$

whence $r = 0.14$ nm.

This estimate makes an unstated assumption about the packing of the atoms of copper.

What is this assumption?

Unit 2

Five changes, **a, b, c, d,** and **e,** are listed down the side of table 2. Above the columns in the table are listed seven numbered statements, which might be consequences of the suggested changes.

Write T opposite each change for those statements which you think to be true consequences of the change. One has been done as an example. Some statements may apply once, more than once, or not at all.

	1 Its resistance would become four times as large.	**2** Its resistance would be doubled.	**3** Its resistance would increase but not double.	**4** Its resistance would not alter significantly.	**5** Its resistance would decrease but not be halved.	**6** Its resistance would be halved.	**7** Its resistance would fall to one quarter of its original value.
a A length of copper wire has its temperature raised from 20 °C to 40 °C.							
b A piece of copper wire twice as long is used.		T					
c A length of constantan (or eureka) wire has its temperature raised from 20° C to 40° C.							
d A piece of constantan (or eureka) wire having twice the diameter is used.							
e The potential difference applied to a dimly glowing tungsten filament lamp is doubled.							

Table 2

Unit 2

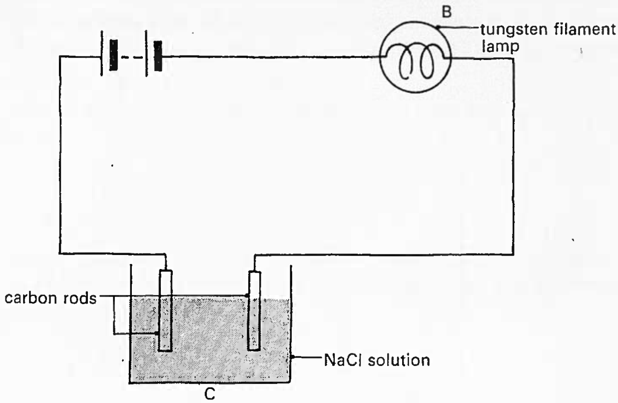


Figure 29

Figure 29 shows a circuit in which a steady current is flowing. You have met the equation $I = NAvq$ in which

I is the current flowing

v is the drift velocity of the charge carriers

N is the number of charge carriers per unit volume

A is the area of cross-section of the conductor

q is the charge on each charge carrier.

a Answer the following questions and give a one-sentence justification for each answer.

1 What carries the charge in B?

....

....

2 What carries the charge in C?

....

....

3 Is the current in B the same as the current in C?

....

....

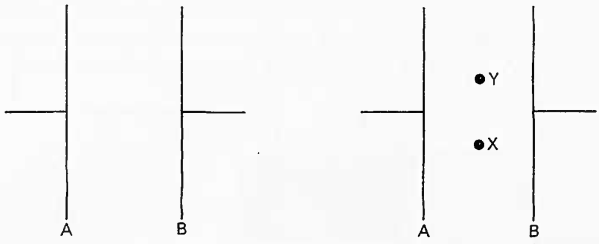
4 Is the value of v in the tungsten filament the same as the value of v in thick tungsten wires which lead to the filament?

....

....

b Calculate approximately the number of electrons passing any point in the copper connecting wires in one second if the p.d. across the bulb is 2 volts and it is dissipating 1 watt. (The charge on one electron is 1.6×10^{-19} C.)

Unit 3



Figures 30 and 31

a See figure 30. A and B are two plates of a parallel plate capacitor, placed 10 mm apart, and A is charged to a potential which is 100 V more positive than B. What is the change of energy of an electron which is moved from plate A to plate B? (Electronic charge = 1.6×10^{-19} C.)
b See figure 31. Explain why the energy of an electron moved from X to Y does not change.

Unit 3

In a Coulomb's Law experiment, the force F between two charged balls is measured for various values of the distance r between them. The experiment was intended as a test of the inverse square law of force between point charges, and a graph of F against $1/r^2$ was expected to be a straight line.

A student did this experiment with two positively charged expanded polystyrene spheres, the surfaces of which were covered with a conducting layer of aluminium. He argued that, as the balls came very close together, their charges could not be uniformly spread over the two surfaces.
a Why should the charge be spread uniformly over each sphere when they are well separated from each other?
b How and why would the even distribution of charge be upset when the balls were very close?

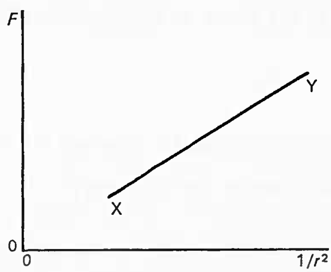


Figure 32

c Figure 32 shows the 'ideal' graph for F against $1/r^2$ covering a range of results from r very small to very large. If some of the experimental results were in error because of the effect mentioned in **a** and **b** above, would the graph deviate from a straight line near X or near Y? Explain.

d Would this part of the graph of the experimental results lie below or above the ideal straight line?

Unit 4

A student who is trying to measure the wavelength of sound by a two-source method is surprised to find that the interference pattern he observes between two loudspeakers looks as illustrated in figure 33.

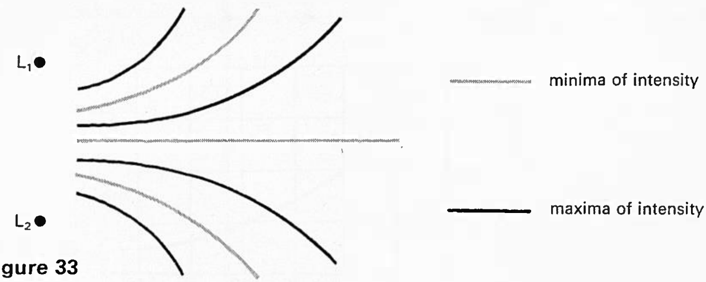


Figure 33

a Why do you think he finds that the sound is a *minimum* along the straight line between the two speakers?

b Indicate on figure 33 distances which he can measure to determine the wavelength and explain how the wavelength is obtained from these measurements.

Unit 4

A trolley is at rest on a horizontal table. Equal masses are attached by cords to the trolley as shown. The masses just reach the floor. The trolley is pushed to the right and then released.

a Is the subsequent motion of the trolley simple harmonic motion? Explain.

b Suggest two reasons why the trolley ultimately stops moving.

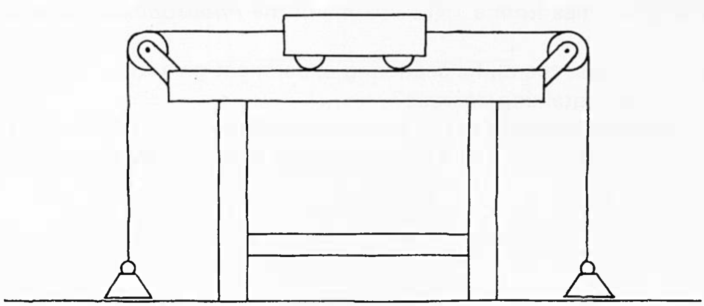


Figure 34

Unit 5

The graph in figure 35 shows how the activity of a sample of a radioactive isotope changes with time.

a What is the initial rate of decay?

b It is suggested that the activity decays exponentially with time. How can you check to see if the decay is exponential?

c How would the number of radioactive atoms left after 10 s compare with the number left after 30 s?

d What would be the shape of a graph of the activity, at an instant, against the number of active atoms left at the same instant?

e How would the graphs of **1** activity against time and **2** activity against number of atoms left differ from those above if the half-life of the radioactive isotopes were twice as great?

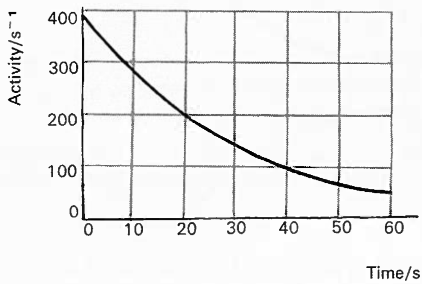


Figure 35

Unit 5

Geiger and Marsden, in reporting on their alpha particle scattering experiments, wrote:

> 'The results of our investigations are in good agreement with the theoretical deductions of Professor Rutherford, and afford strong evidence . . . that an atom contains a strong charge at the centre, of dimension small compared with the diameter of the atom.'

This quotation comes from a 1913 volume of the *Philosophical magazine*.

What evidence does the alpha scattering experiment give for

a Atoms containing *charges*?

b The charges being at the *centre* of atoms?

c The centre being *small* compared with the diameter of the atom?

Unit 6

How would you arrange:

- **a** a 1000 Hz oscillator
- **b** a 500 Hz oscillator
- **c** a slow astable multivibrator (flip flop) – about 2 Hz
- **d** a loudspeaker
- **e** *and*-gates

to produce a two-tone siren such as police cars use?
What else might you need?

Unit 6

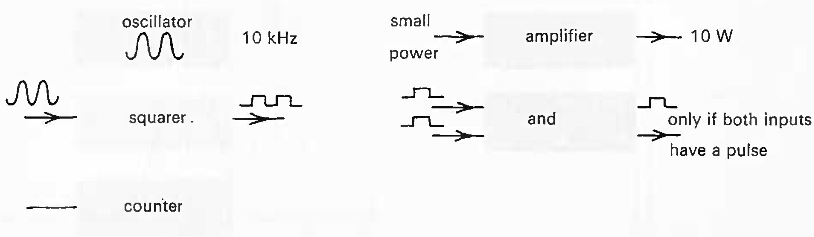


Figure 36

Devise a system using blocks of the type illustrated in figure 36, and other *simple* components (loudspeaker, switches, batteries) to test the time a person takes to react to a sound signal.

Unit 7

The device illustrated in figure 37 gives a meter reading that is proportional to the rate of rotation of the dynamo (generator) and hence can be used as a speedometer.

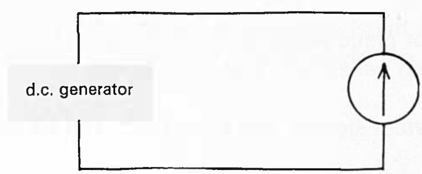


Figure 37

Explain why the device in figure 38 can be used to measure acceleration.

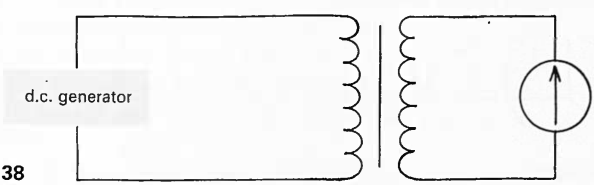


Figure 38

Unit 7

One definition of a magnetic field might be to say that it exerts an *extra* force on a *moving* charged particle (that is a force additional to any force exerted on the *stationary* particle by an electric field).

Describe three ways of detecting a magnetic field, and for *one* of them explain how the operation of the device is connected with the extra force on a moving charged particle.

Unit 8

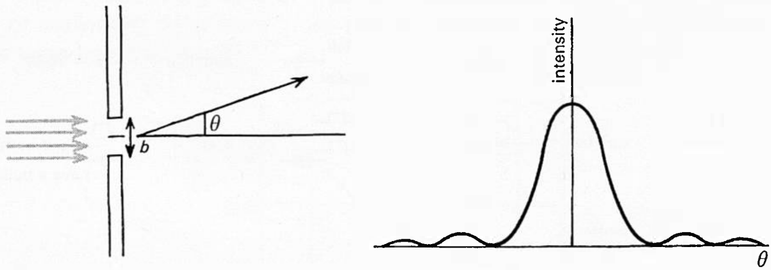


Figure 39

The sketch in figure 39 shows variation of light intensity with angle θ for light (wavelength λ) diffracted from a slit (width b).

Sketch curves showing the situation
- **a** if b were doubled
- **b** if λ were doubled (but b had the same value as in the graph in figure 39)
- **c** if both b and λ were doubled.

Unit 8

In figure 40, a pulse of plane polarized electromagnetic waves is shown travelling in **a** to dipole television aerials and **b** to loop aerials.

Why do **a1** and **b1** detect signals, but **a2**, **a3**, **b2**, and **b3** not?

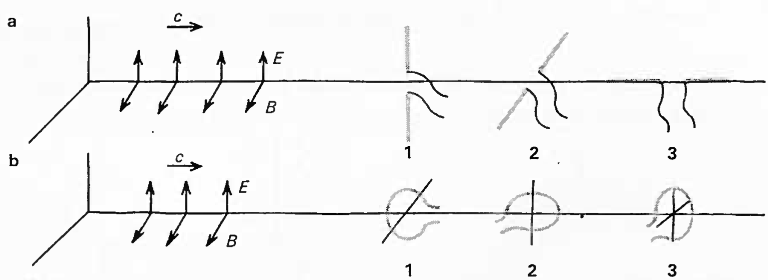


Figure 40

Unit 9

When a film is shown backwards, some events look as if they could (or nearly could) have happened that way, while others look like events that could not have happened that way.

a Give one example of the first kind.

b Give one example of the second kind.

c Explain why you think the second is an example of an event that could not happen.

Unit 9

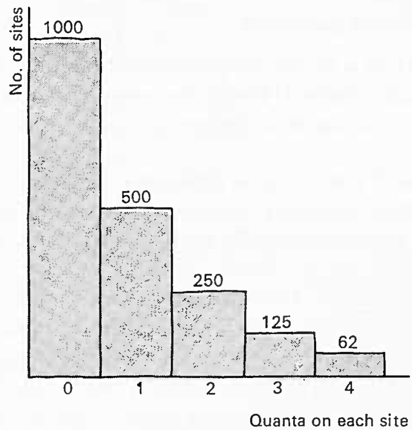


Figure 41

a How would the histogram differ for a solid at a lower temperature?

b What would happen to the value of the ratio

$$\frac{\text{number of sites with no quanta}}{\text{number of sites with one quantum}}$$

if the solid represented by the histogram in figure 41 (solid A) were put in contact with one (solid B) at a lower temperature? How would the total number of quanta in solid A change?

Unit 10

'Cathode rays are a stream of fluid – like a jet of water.'
Or 'Cathode rays are a stream of particles – like a hail of bullets.'
Which (**3**, **2**, **1**, or none) of the following experiments *could be explained* by saying cathode rays are a stream of particles?
Which *can only be explained* in this way?

1 Casting a shadow as in a Maltese cross tube.

2 Effect of bursts setting a vane in oscillation.

3 Deflection in magnetic fields.

What would you say to someone who claimed that, if there is an experiment that can *only* be explained in terms of particle properties, the idea that cathode rays (electrons) have wave properties can be ruled out?

Unit 10

Some crystals have spaces between groups of atoms, with atoms clustered around an empty region. A foreign atom can be trapped in such a space. Suppose such an atom, mass 10^{-26} kg, is trapped in a space 10^{-9} m across. What can you say about the kinetic energy this atom *necessarily* must have?

$$mv = h/\lambda, \qquad h \approx 7\times10^{-34}\ \text{J s}. \qquad \text{Kinetic energy} = \tfrac{1}{2}mv^2.$$

Comprehension passage

The following example of a short comprehension passage illustrates a further possible addition to class tests. This one is suitable for Unit 2. It may be convenient to give it to students to answer at home, after a written test in class.

The following passage is based on an article by Mickelsen, W. R., and Kaufman, H. R., 1964, 'Electrostatic thrustors for space propulsion, present and future', *Journal of the British Interplanetary Society,* **19**, No. 8, p. 321.

'In the electron-bombardment thrustor, propellant atoms are ionized by electron impact. A plasma is thus created in the ion chamber. Propellants of interest in present thrustors are caesium and mercury atoms and heavy molecules of various sorts. (The propellant is first obtained in atomic form by being vaporized in a small "boiler"; from this the vapour then enters the main body of the thrustor unit.) The ions are extracted from the plasma by virtue of the electric field in the accelerator section of the thrustor. The main thrust is then obtained as a result of the acceleration of these ions through a considerable potential difference – of 100 kV upwards – and their ejection into space from the thrustor in the form of a jet.

'Electrons removed from the particles of the propellant are drawn from the high-potential charging chamber by the electrical generator, and injected into the charged-particle exhaust jet.

'A plasma is a collection of particles, generally a gas, an appreciable proportion of which are electrically charged. It is, however, electrically neutral, and this means that positively- and negatively-charged particles must be present in electrically balanced numbers, and must be uniformly mixed throughout the gas. It is essential that the charged-particle exhaust be neutralized. This neutralization requires equal rates of ejection of opposite charges to avoid building up a large charge on the space vehicle. Early theoretical analyses predicted that beam neutralization would be a serious problem; however, early experimental operation in vacuum units indicated that the exhaust beams were in fact neutralized. In a series of definitive experiments, Sellen and Kemp showed that ion beams up to 3 m in length could be neutralized under closely-simulated free-space conditions. From these experiments it appears that beam neutralization will not be a fundamental problem.'

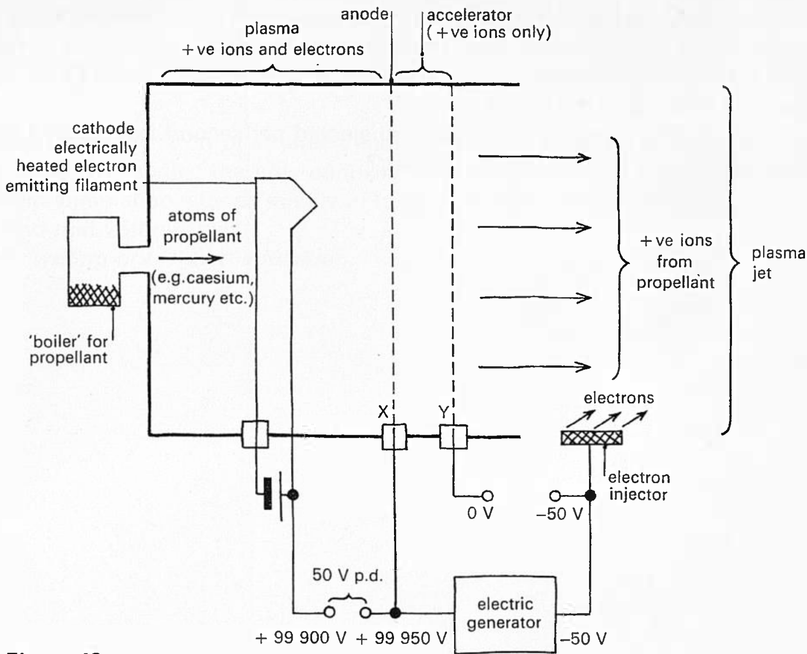


Figure 42
Electrostatic thrustor.
Based on Mickelsen and Kaufman, 1964.

1 Refer particularly to lines 1 and 2 and examine the details of the first section of the thrustor where the plasma is generated (i.e. between the point of entry of the propellant, and the perforated electrode marked 'anode').

a What sort of process is implied by the phrase 'ionized by electron impact'?

b What is the function of the 50 volt p.d. shown between the 'cathode' and the 'anode', and what factor or factors determine the value of p.d. which is needed between them?

c Explain how it comes about that a *plasma* is generated in this first section of the thrustor.

2 Explain what is happening to the positive ions in the 'accelerator' section and what part the electrical conditions in the region (due to the potentials on the perforated electrodes X and Y at its ends) play in this.

3 The excerpt describes what happens to the propellant particles in each stage of the electrical unit, but does not explain how it is that this causes the unit actually to produce thrust. Write a clear, brief explanation of this which would be a suitable accompaniment to the excerpt.

4 Refer to lines 13–17 and try to suggest – both in terms of what would happen electrically and in terms of the effect that this would have on the unit as a mechanical propulsion device – what would happen if the accelerated ions were rejected into space *without* being neutralized.

5a Calculate approximately how fast a caesium ion would be travelling relative to the thrustor unit, as it emerged from the accelerator, if the accelerator had a p.d. of 10^5 volts across it. (Mass of caesium atom 2.2×10^{-25} kg; charge on a caesium ion, 1.6×10^{-19} coulomb.)

b If 10^{18} atoms of caesium were ejected per second from such a unit what propulsive force would it be generating?

Chapter 7

Individual investigations

'It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom; without this it goes to wrack and ruin without fail.'
Einstein, writing of his own education.

This chapter discusses the investigations by students that form part of the course. It begins by outlining the reasons for including investigations in the course, and by describing what sort of work is involved, and what is not involved. Then some of the many practical difficulties that will arise are discussed, with suggestions for organizing the work so as to reduce them to a tolerable level. An assessment by the teacher of one investigation forms part of the Advanced level examination, and the method of assessment and its moderation that has been tried is described. Finally, a list of possible topics for investigation is provided, so as to indicate the kind of thing we have in mind and to act as a source of ideas.

What are investigations?

About ten per cent of the teaching time of the Advanced Physics course has been set aside for individual investigations by students. In these investigations, students choose their own problems, devise their own methods, select or make their own apparatus, decide for themselves what to measure and how carefully to do it, and make up their own minds about the direction of their work – what to do next, when to abandon an unpromising line, or how much time to invest in any one aspect.

Time

The time allocated, equivalent to a total of four to five weeks of teaching time and the normal time for work at home, is split into two sessions of about two weeks each, for one investigation in the first year and another in the second year. The second investigation is assessed by the teacher, and his assessment is moderated by the Examining Board, and used by their awarders in arriving at an overall grade. The first investigation is not used for examination purposes, but should help students to learn what the task involves, and what counts as a good performance. (As suggested below, students are likely to have quite wrong ideas about what deserves a good grade: they may well, for example, suppose that 'getting a good answer' is a necessary, perhaps even a sufficient condition.)

Each investigation thus occupies about 15 periods, or a little more, together with some work at home. The investigations are a part of the course, not something added on to the total time needed. It is important, especially in view of the increasing use of various types of project work in many subjects, that students should not be asked to take on work that can only be achieved by a substantial commitment of otherwise free time. Students should not feel that they must work far beyond the call of duty in order to do well. If, as time goes by, it is clear that the other content of the course is, or has grown, too large to allow genuine course time to be set aside for investigations, then the content of the course should be pruned.

Why include investigations in the course?

Investigations are especially relevant to several of the general aims of the course, for example, 'Learning to inquire', 'Understanding the nature of physical inquiry', and 'Enjoyment – seeking to gain further understanding' (see Chapter 3, 'General aims'). We think that investigations have contributions to make to these aims that cannot easily be made in other ways.

Learning to inquire

Inquiry is a subtle art, and the best way of learning some of that art seems to be to try to practise it. The art involves deciding what to do, without quite knowing what will happen. It involves a certain scientific watchfulness; seeing what happens, and recognizing peculiar or interesting results. It requires one to make choices: when to try something roughly, and when to make more accurate measurements; or when to try a simple method as opposed to a more sophisticated one. It demands that one should look out for one's own mistakes, and do something about them. No students will achieve all these things, but each student can be expected to begin to see the need for them, and to become a little better at doing some of them.

Improvement in the art of inquiry cannot easily be brought about solely through the normal experiments in the course, though these can help a good deal if they are undertaken in an investigational spirit. These experiments have to be constrained so as to limit wrong paths, and to direct attention to the points under consideration. The apparatus has to be provided, pretty well ready made, with many of the more interesting problems ironed out beforehand. Someone else has previously made most of the interesting decisions. So we think that investigations have a place, to provide experience that ordinary experiments cannot.

Understanding the nature of inquiry

Physics as it appears in school is not altogether like physics as it is really done. The investigations can redress the balance a little. Some may bring out how important, and yet how dangerous, it is to have a theory of what is going on. Without some theory, the results of experiments are just unintelligible raw data; with a wrong theory, their meaning may be misinterpreted. Another investigation may illustrate how some experiments, but not all, really help to tell the difference between two views about what is going on. One may show the occasional need for precision; many will illustrate the value of a rough preliminary trial. They can show how physicists proceed by trying to make sense of what happens, in ways that do not conflict with known facts or with further tests. Some will show that there is often more than one way of explaining things, and that it may be quite hard to choose amongst them.

The investigations can help to show some of the untidiness, even muddle, inherent in doing something new for oneself.

Enjoyment and involvement

Most physicists do physics because they like doing it, and they like doing it because they become personally and intellectually involved in problems. So also do engineers, with the added motive of producing something useful to other people. We think that investigations are a powerful way of helping students to become personally involved with a problem, and to give them an opportunity to enjoy exercising their minds and their practical skills. While this is important for all, it is particularly important for those who will not go on to do more physics later on. We want them to know that physicists and engineers are thoughtful, active people, engaged in trying to understand things and put them to use.

Those students who fail the examination ought to be able to take from the course something of value, and we think that investigations have much to offer them by way of enjoyment and involvement. Out of some 500 students who took part in the early trials, hardly any produced investigations that their teachers thought worthless. It seems clear that many students of modest ability can produce work of good quality, and can become personally involved with a piece of physics – 'their own piece', as it were. We value the work for this, as well as for enabling some students to develop and use their personal attributes in ways not possible in other parts of the course.

Not the least valuable aspect of this work is the handing of responsibility to the student. The evidence so far suggests that investigations are at least one instance of people liking what is good for them: a situation rare enough to be worth encouraging.

Simple problems involving thought

Large scale or exotic projects do not, we think, offer so much for these aims as do smaller, simpler problems. The former can be valuable, certainly, but their place in the economy of the Advanced Physics course must be small.

Simple problems usually demand thought sooner than do large ones, in which the first steps are often the acquisition of much background knowledge, materials, or apparatus. If the problem is, say, 'How does water drip from a jet?', it is easy to set up something on the bench quite quickly. As soon as there is something on the bench, the problems begin. What is worth investigating – drop shape or drop size, perhaps? Is the change from drops to steady flow interesting? When does it happen? How big should the jet be? Does the material of the jet matter? Decisions have to be made, using what physical understanding one has. Books offer some help, but rarely solve all the problems. Measurements can be begun, and as soon as they are, new questions develop. Are they reliable – is the drop weight really constant, for example?

Because decisions have to be made, the problem must be simple enough for a student to be able to make sensible decisions. Only when he or she begins to think, has an inquiry begun, so the problem must be simple enough for ordinary students to begin quickly to think about them. Measurements are the main source of new puzzles, so the problem should suggest some measurements that can be made soon after one begins.

Too complicated or exotic a problem can only be tackled by getting answers from other people. So the problem must be simple enough for the sensible strategy to be for the student to try something himself. (We do not mean that it is bad to go elsewhere for information, only that, if the work is to show what inquiry is like, it has got to be an inquiry.)

Inquiry is hard, demanding, and discouraging, because mistakes and failures are all part of the game. Therefore, the problem must seem simple enough to a student, so that he or she expects to be able to tackle it, and can in fact make progress. To exaggerate a little, the best problems are those which many students would initially despise as too easy. (One of the outstanding investigations in trials was one into the properties of glued joints, and the teacher involved nearly managed to dissuade the student from it on the grounds that it was not worthy of his powers. The same investigation topic also produced a near failure in another school, so simplicity is not a sufficient condition!)

The problem must be simple enough not only so that students can think about it, but also because, since enjoyment and success go hand in hand, some kind of success must be possible. It may not be the success expected, of course. There is a difficulty of involvement with problems that seem too footling, for which one remedy is to try it and see, because it is rare that anything is as easy as it looks. Certainly teachers will have to use their knowledge of their students to encourage each to choose a problem which will suit that individual.

How it is done matters more than what is achieved

All the relevant aims are concerned with the process of inquiry; the production of an answer is not in itself of great importance. A good investigation can produce no answer, other than that this or that line of inquiry looks promising, or even that no answer can be got with the available resources. Most investigations, like much research, go off in unexpected directions. Here, even more than in research, the initial problem is a stimulus rather than a goal. It must be made quite plain to students that they need not stick to the original problem at all; indeed that they must expect to find that only a part of it can be begun in the time. An investigation that has got as far as sorting out a few relevant variables, getting one or two under control, and has raised one or two definite problems out of measurements, has achieved all that anyone would expect in a couple of weeks. Indeed, one university physicist said to us that a month was, 'about long enough for a research student to make his first big mistake, *if* he is a fast worker'.

As time goes by, and examples from earlier years can be given and a tradition of such work grows in the school, explaining these matters will become easier. But it will need to be said often that while the investigations can show what doing physics is like, they cannot aspire to being completed tasks. The essential ingredients are involvement, persistence, imagination, ingenuity, 'know-how', and thoughtfulness. Most students in the trials seem to have found the experience rewarding and memorable, and all teachers in the trials have been in favour of retaining investigations in the course, despite the many difficulties they pose for the teacher.

Problems of timing

There are two problems; how to spread the two or so weeks available for each investigation, and when to run the investigations.

Spreading the time available

Any pattern, ranging from setting aside one double period a week for seven or eight weeks to setting aside all lesson time for two weeks or so, is acceptable. The vast majority of teachers in the trials have so far chosen something nearer the latter arrangement, which at least restricts the time for which apparatus is tied up in an investigation. Not all students need do their investigations at the same time, though if they do there are obvious advantages in keeping them together in other work. The important thing is that the time should be taken from time normally allocated to physics, so that the investigations do not encroach upon other subjects or activities.

Choosing the time

The best way, but not always the most practical one, is for the teacher to decide when the time is ripe. The first investigation needs to come after the class has done a fair amount of physics, so that students have a good background and may also, perhaps, have had problems suggested to them in that work; it should not, however, come so late as to leave little time for the lessons gained from the first investigation to be digested before the second, assessed investigation.

Many teachers in the trials chose a fortnight near the end of the summer term for the first investigation, because laboratories were then less in demand. This turned out not always to be a very good time, because the other end-of-year activities that helped to free the laboratories also disrupted the work on investigations.

A time around the last part of the second term seems to offer some advantages. It might follow basic work on electricity and on waves, but come before Unit 5, *Atomic structure*, in which individual working of a different kind is suggested.

The time for the second, assessed investigation in the second year is inevitably constrained by the need to submit assessments and reports for moderation to the examiners before the written papers are taken. In practice, allowing for the time needed to make the assessments, this leads to a time not later than the first half of April.

Problems of choosing topics

There are no safe rules for choosing topics for investigations that will be certain to succeed. But some general guidelines can be given.

The physics of the problem should involve ideas the student already knows, or can soon find and grasp. This need not exclude, say, flow problems on the grounds that hydrodynamics is not part of the course, because the basic physical ideas are those of dynamics. Certainly a flow problem may turn up phenomena that an expert would find hard to explain, but this is a valuable feature. Indeed, the topic should be one that is *likely* to produce something unexpected. This is easier to arrange than it sounds, as anyone who has tried to make a piece of apparatus to demonstrate even the most basic principle knows, to his cost. The unexpected is to be expected, even in the simplest situations.

But a problem like, 'investigate the behaviour of a blocking oscillator', would not be very suitable for a student with little knowledge of this or similar electronic circuits, as he or she would spend most of the time finding out what a blocking oscillator is.

The problem should not be too ambitious. It was noticeable in trials how teachers and students chose more modest problems for their second investigations than for their first.

The topic should not be described so definitely that it leads only along some well worn path. Thus, 'Measure the resistivities of the metal wires available in the laboratory' would be a bad topic, but, 'Investigate the effect of alloying metals on their resistivity', or 'How does the electrical conduction of glass change when it is hot?' might be better. Both would probably end up as investigations either of part of the problem, or as investigations into something different. The first might become a study of the problems of making two metals alloy, while the second might turn into an investigation of surface conduction due to moisture. Both such outcomes would be happy ones.

The apparatus or materials needed to make a start must obviously be available. We have found it useful in choosing topics to ask, 'Could I, working in the school laboratory with the apparatus and material available, produce in an hour either a first set of rough measurements, or a first rough trial piece of apparatus, as a basis for thinking further about what to do next?'.

The investigation should be a practical one, and it should be an investigation, not a constructional exercise. Making a linear motor, an audio amplifier, or an oscilloscope from a recipe in a book is a fine thing to do, but is not something we believe we can justify as a part of the Advanced Physics course. A reading investigation, or the collection and presentation of information from outside the school should also be ruled out, not because they are bad things to do (they are not), but because they do not serve the same aims as an experimental investigation.

The topic should raise the immediate question, 'How could I start on that?' An attempt to make the problem easier by specifying how to do it may end up by making it very dull to do, and spoil it by suggesting – quite wrongly – that there is only one way to tackle it.

Problems of preparation

Clearly, the class needs some explanation of what is to come, what its purpose is, and the practical limitations that will have to be imposed. They need some guidance about prior planning, and about how to tackle an investigation.

This can all happen in the month before investigations start. During that time, a list of possible topics can be posted up, and students can be asked to choose a topic, or to suggest one of their own. The topics chosen can usefully be discussed with students before they start, and it may be helpful to ask each to produce a plan for a way of starting off. Most teachers will want to have a list of apparatus needs from each student, and will have to steer those making impracticable or extravagant demands into more modest paths.

Special materials needed will have to be obtained. It is helpful to set a limit, say £10, on the total that may be spent, and to require students to limit their demands so that the class as a whole spends no more than the total sum.

If two or more topics require the same apparatus, and the school does not have sufficient sets of it, some students will have to choose other topics. It is often necessary to explain which apparatus, like lumps of metal or springs, they may keep throughout the investigation, and which they must return after each working session.

Guidance before the investigation starts

Cases will arise where the teacher wonders whether to discourage a student from tackling a particular topic, or from tackling one in a particular way. Apart from the practical reservations above, it is often best not to interfere, even with quite outlandish suggestions. Sometimes the strangest ideas work; more often a crazy idea suggests, when it is tried, something else to investigate. The situation to watch out for is the one where the student has no ideas at all.

Practical help beforehand

If it is clear that a student's proposed method is going to involve some construction, or some skill such as soldering or glass working, it may be possible to arrange for a short previous course in this skill. Such courses relieve the anxieties of teachers responsible for tools and for safety, but they take up time. If the time is not available, it may be best to look for a way round the difficulty, perhaps by suggesting another method. On the other hand, if supplies of wood and steel rod and strip, and of Dexion or Handy angle can be set aside, the demand for retort stands can be reduced. Students often find that a limited amount of constructional work is satisfying.

Supplies of materials

Plenty of common laboratory materials need to be available, including such simple items as string, rubber bands, Plasticine, and adhesive tape, as well as springs, stands, beakers, burners, electrical supplies, and pieces of wood and metal.

Some simple items offer wide scope for investigations. The length of plastic gutter pipe (under item 1053 – see Chapter 8, 'Guide to apparatus') can be used as a towing tank, for studies of the wakes of boats, for studies of waves in deep and shallow water, and for investigations of waves in moving water, as well as for investigations of water flow in channels, for example.

Some materials are needed quite often. Photographic paper and film are examples, and it may be worth buying them in bulk. If one or two extra cameras can be borrowed for the period of the investigations, so much the better.

Problems of working in groups or individually

It is not easy to see how the second investigation can be assessed individually unless each student has a definite, unique task. The simplest way is to ask students to work individually, but if for any reason working in pairs or groups seems desirable, it is essential that the teacher is sure beforehand that it will be possible to make an individual assessment for each student, and that the agreement of the Board is secured in advance.

The first investigation can, of course, be done in groups. This may have *educational advantages and may also reduce the load on the teacher.* Of course, the first investigation could be omitted, but it is fair to say that those few schools who omitted it in the trials regretted it.

Problems of guidance during the investigations

As the investigations progress, many problems will arise, which will not have easy or obvious solutions. Again, there are no rules which guarantee success, but only a few general guidelines.

Getting started

Without adequate preparation, the initial stages will usually be impossibly chaotic. Even with preparation, there will be a constant flow of requests for odd items, and it is a great help if all available staff, including any technicians, can be on hand for the first session.

Soon after they begin, some students will get stuck, when things do not work as they expected. It seems better to offer a hint, or a suggestion of something else to try, or a book to look at, than to try to provide an answer in such situations. But it is also necessary to be aware of the danger that the student will go on getting nowhere for a long time, and a good guiding rule is to give enough help for him or her to get *something* done quite soon.

Some students seem to be getting along well, but are in fact playing very safe and keeping to a line they know very well. Once they have something working, there is nearly always some odd or interesting feature to which their attention can be drawn, which will repay investigation.

Despite the need for occasional help, the general rule should be to let well alone. Students will soon discover whether the statement that these are their own individual experiments is a genuine one or not and, knowing that not all things said in school are meant literally, some will use the experimental method to find out whether this one is.

Keeping going

Many students become a little disappointed with their investigations, either because of the many unexpected difficulties, or because their achievements seem modest. Plenty of praise for even quite small achievements seems to be at least a partial answer, particularly praise for recognizing and trying to meet a difficulty. Often, students do good things without knowing it, especially if their minds are firmly fixed on some rapidly receding goal.

Many students can be helped by a suggestion that they limit an inquiry that is proving too large. For example, one student set out to produce and study moiré fringes; producing the necessary regular grids proved hard, and the investigation turned into a study of means of making good photographs of large scale drawings, as this seemed to be a necessary technique.

Problems of making written reports

So far as the student is concerned, the written record need only be useful to him or her, having enough in it for use at later stages.

The assessment of the investigation makes a further demand: that an outsider should be able to find out what happened, and why. This would be a very severe and artificial demand, and could lead to reports whose main purpose was to conceal problems from the reader, if the teacher were not involved in the assessment.

Bearing in mind that the assessment is of the ways in which the work was done, difficulties were seen and met, and ideas were formed, criticized, and often rejected, a diary form seems a good form to recommend. It is worth pointing out to students that if they conceal their difficulties, it will not be easy to give them credit for trying to overcome them. It is necessary to say that having ideas – right or wrong – will be rewarded, and that a low grade will be earned much more surely by having no ideas than by having not very good ones. Nobody can be right all the time, and most research workers are wrong much of the time. Those who succeed do so by testing and criticizing their ideas to find out where they are wrong.

The record should be an honest record of what happened, of the student's changing thoughts and ideas, of the information that was found, and of the attempts which were made to understand it. If the student does not understand something he meets, he should say so, as it should count in his favour that he is thinking clearly enough to know when he does not understand. If he has a bad idea it should count in his favour that he has had an idea at all, and there should be further credit for recognizing its failings later on.

Problems of assessment

Much has already been said, indirectly, about assessment in the previous discussion. The method of assessment for the Advanced level examination will be announced from year to year by the Examining Board, but is likely to continue to be based on an assessment by the teacher, moderated by the Board. Only by using teacher assessment is it possible to ensure that the unique features of particular investigations are taken into account; only the teacher can know what really happened, and be able to read below the surface of an apparently undistinguished report.

The method developed in trials, which does not, of course, commit the Examining Board for the future, was to ask each teacher to give the investigations one of the four grades 1, 2, 3, or 4. Where the teacher is in doubt as to whether the grade should be one higher or lower, the grade is given a plus or a minus sign. Work of remarkable quality may be distinguished from other work with grade 1 by a special endorsement.

Samples from each of the grades were then taken by the moderators, and used to try to bring schools onto a common scale. In general, the principle was to keep to the teacher's rank order always, and to interfere as little as possible with his overall assessment.

The significance of each grade was described, together with an indication of the proportions of students to be expected in each grade over a period of years in any one school.

Grade 1 was not reserved for one or two exceptional students, but was to be given for work that showed a serious and effective attack on a problem (not necessarily a successful conclusion), and which seemed to the teacher, as a physicist, to reflect sensible scientific behaviour in the face of difficulties. There are bound to be minor flaws in such work by young people, and grade 1 should not be reserved for perfection, but for competent, thoughtful work of the kind that may be hoped for from a sixth form student in the time available.

Over the years, perhaps 5 out of every 20 students would gain grade 1 – but this is only a suggestion of an average figure and in any one year there may be more or less than this number.

Grade 2 was expected to be the commonest grade, with perhaps an average of 10 out of every 20 students having this grade. It should be awarded for work which, although open to substantial objections according to the criteria above, shows evidence of thought and sensible behaviour.

Grade 3 was expected to be given to perhaps 4 students out of 20 on average, and would represent work that, although failing to match up to the criteria above, nevertheless contains some actual achievement, in the form of results obtained or apparatus made. Roughly, a student who has made any real effort, obtained any definite results, or made any but the most trivial apparatus work should have at least grade 3.

Grade 4 was reserved for worthless, or nearly worthless investigations, reflecting little or no serious work or thought. We would hope that many schools would have no students in this category, and that the average over all schools might be less than 1 in every 20. It is likely that work which deserves this grade will stand out all too clearly to the teacher.

Standards and criteria

It was felt that no scheme of qualities to be looked for – planning, accuracy, initiative, and so on – would do justice to the very varied kinds of merit that investigational work can have. While such schemes deserve further study, and have been tried by other Nuffield projects, we have tried a slightly different approach, as a way of gaining more experience.

The central criterion suggested was the notion of *sensible scientific behaviour*. The notion is hard to define, but not hard to exemplify. In many cases it is sensible to put together some rough apparatus and to try some rough measurements at first, so as to discover the main problems at an early stage. It is often foolish to design and build elaborate apparatus, or to spend time taking accurate measurements too soon, as the principle may turn out to be wrong or the measurements to be irrelevant.

It is sensible to have some plan or purpose in mind, though not so sensible to plan far ahead, in ignorance of the pitfalls that may arise. It is foolish to have no plan or purpose at all, though sensible to try something out quickly to see if it is worth going on with.

When one meets a difficulty it is sensible to think hard about it, and maybe to switch all one's effort to solving it, even if this means abandoning the original line of inquiry. It may be sensible to try to find a way round the difficulty, but it is foolish to ignore the problem, to hope that it may go away by itself, to refuse to think about it, or always to abandon a line of attack whenever a difficulty crops up.

It is sensible to be flexible, in a situation where no one knows the answer, and foolish to stick obstinately to a problem that cannot be tackled in the time.

It is sensible to think hard and critically, as that is the only way to detect flaws in reasoning. It is sensible to test ideas experimentally, as that is the way to find out if they are wrong or inappropriate or inexact. It is foolish to hope that if one keeps on mindlessly trying things, 'something will turn up'. It is foolish to suppose that because you *think* an idea is right, it really is, or that because you 'understand' it, it must be true.

It is sensible to try to take the initiative, and to find ways of doing things. It is foolish to suppose that if there is no obvious solution, there is no solution at all.

It is sensible to use whatever information one can get from books or other people. It is also sensible not to rely on it too much, but to maintain a reasonable standard of scepticism and open-mindedness, as such information is not always exactly relevant to the problem in hand, even if it is reliable. If one gets help, from a teacher or a book, it is sensible to try to use it, and foolish to ignore it.

It is sensible to keep adequate records, which are good enough for one to see what one did some time ago, and why.

If one meets an especially severe problem, it is sensible to get what help one can, and then to try to do something about it.

None of this description focuses concern on the outcome, and we think that to be perfectly proper. Schools and students differ in the resources they have, and the test should be what students made of those resources. If credit goes for the outcome, then good or bad luck will be an important factor. It will always be a factor, but will not be so important if difficulties are treated as occasions for the student to show his or her mettle.

Possible topics for investigation

The list that follows is intended mainly to suggest ideas, and to indicate the sort of investigation we have in mind. Many of them could become several separate investigations, and if the scope of several topics looks too large, that is because they are meant as starting points, not as goals.

Many of the suggestions have come from schools that took part in the trials, often from students. As time goes by it will be possible to use previous investigations as starting points for new ones, especially if records are preserved.

List of topics for investigation

The shutter speeds of a camera

The accuracy of aim of an air rifle, catapult, or improvised gun

The true path of a ball thrown in air

Water drops falling on water (flash pictures?)

Splashing of moving drops hitting solids

A narrow water trough as an accelerometer

The profile of a rotating water surface

The precession of a gyroscope

Comparisons of human reaction times (between individuals; for different stimuli)

Time taken by a switch to make or break contact

Bouncing of relay contacts

How much does the air pressure in a football matter?

The performance of a firework rocket

The bounce-time of a ball

Factors affecting the friction of steel on ice

The effect of oil films between sliding metal surfaces

Does water absorb ultra-violet light?

How long does the flash from a flash bulb last?

How long does the flash from a xenon stroboscope last?

How does the light coming through a slotted wheel stroboscope vary with time?

Study the motion of a ball rolling on a turntable

What does an air track collision look like from a moving point of view? (Moving camera)

The distribution of speed, or of energy, among balls rolling randomly in a shaking tray

The possible orbits of a pendulum bob

The motion of the tip of a vibrating wire

The performance of a water pump

The performance of a fan

The thrust of a propeller (in air, or in water)

The energy delivered by a catapult

Load and speed variations of a model aero-engine

The fuel consumption of a model aero-engine

The temperature changes and cooling of a model aero-engine

The air supply to a model aero-engine

Reduction of noise from a model aero-engine

Factors affecting beam bending

Factors affecting the buckling of a beam under compression

Factors affecting the flexing of a rotating shaft

The strength of girders of different construction (use balsa wood)

The energy stored in a spiral clock spring

Factors affecting the design of a good paddle wheel

Making strong concrete bars

The fracture of concrete by impact forces

Effects of reinforcement on concrete

The strength of fibreglass repairs (commercial fibreglass kits)

Ice is said to be made less brittle by freezing sawdust into it. Is it?

Variation of flow behaviour with rate of strain (silicone putty)

Effects of heat-treating razor blades

Heat-treatment of steel

Heat-treatment of copper

Heat-treatment of glass

Perspex is said to 'remember' that it has been deformed, for a while. Does it?

The strength of human hair

The strength of paper

The properties of glued joints

Making long lasting soap films

Adhesion of glues to metals, fabrics, etc.

How finely woven must umbrella material be?

The changes in melting point of a solder with composition

What is necessary for solder to flow?

The strength of a soldered joint

The bouncing of steel balls on glass

Impact cracks when steel balls are dropped on glass

Dents made in metals by balls pressed on them (Brinel hardness test)

The heating and cooling of stretched rubber

The creep of stretched rubber

The strength and fracture of taut rubber bands

The effect of temperature on stretched rubber

Changes of length of hair with moisture content

Factors affecting the growth of crystals

The sagging of taut wires loaded in the middle

The shape of a suspended loose chain

Will a hole at the end of a crack help to stop the crack from spreading?

What factors influence the production of good, uniform bubble rafts?

The effect of various sorts of perforations on tearing paper

The pressure–volume relation for a rubber balloon

The effect of temperature changes on the flow of motor oils

The design of a flow meter

Reduction in pressure with fast flow (Bernouilli effect)

Calibration of a V-slot flow meter (rate of flow from height of water in a V-shaped slot)

Flow patterns in glycerine (see Shapiro, A. H. Science Study Series, *Shape and flow*, Heinemann)

The drag on spheres and other shapes in an airstream

The resistance to water flow of various plumbers' fittings (pipe, bends, etc.)

The drag on objects towed in water (changes with length, depth of water, and many other factors)

When does water flow in a tube become turbulent?

The effect of changing the size or shape of the wings of a glider

The penetration of projectiles into soft materials

Load and speed variations for a parachute

A water-driven rocket

Measuring the viscosity of air

Factors affecting the performance of an air track vehicle

Making very big drops (oil in water and alcohol mixtures)

How do Plateau spherules form?

Soap films formed on spirals and other wire shapes

The behaviour of bubbles rising in liquids

The noise made by a kettle just before it boils (singing)

The airflow in a room with a heater

Smoke rings (a box with a hole at one end, and a flexible diaphragm at the other)

Vortex rings in water (drop coloured water drops onto clear water)

How much can a container be overfilled with water?

How does water drip from a narrow jet?

Variations in damping of a pendulum in air

Water from a tap running into a flat basin sometimes forms a smooth ring of water, with a circular edge beyond which the flow is rougher. What decides the size of the ring?

Where does dust collect? Why?

Stiff standing rods will oscillate in an airflow. Investigate.

The supporting of a ball on a jet of air, or of water

The behaviour of coupled oscillators

How much damping is needed to stop oscillations?

Variable damping of a galvanometer

Oscillations of drops

Oscillations of rubber sheets

Oscillations of soap films

Oscillations of metal discs

Oscillations of thin panels (e.g. doors, sheets of hardboard, sheets of metal)

Oscillations of wire rings

Oscillations of solid bars (notes from a xylophone)

The factors affecting the performance of a sensitive flame

How long does a sound last in a large hall?

The propagation of sound at low pressures

Can the motion of air in a sound wave be made visible?

Slopping modes of oscillation in tanks of water

How to isolate laboratory apparatus from vibrations

'Pearls in air' – what makes them form easily? (See Nuffield O-level Physics, *Guide to experiments IV,* experiment 21b)

The resonance of a 'ticker timer'

The frequency characteristics of a cheap gramophone pick-up

The frequency response of a one-transistor amplifier with feedback

Photographing waves on strings or springs

The wakes of boats

Waves in moving water

Speed of waves in shallow water

Breaking of waves

The speed of ripples on water

What are the shadows of waves on a ripple tank shadows of?

The directional properties of a television aerial

Variation in response of a dipole with length of the dipole

Frequency range of a microphone

Audible range of humans and animals

The diffraction of sound waves

Producing and detecting ultrasonic waves

The pressure changes in the sound from an explosion

Reflection or absorption properties of materials for microwaves

Reflection or absorption properties of materials for sound waves

Sound-absorbing tiles sometimes have perforated hardboard over an absorbent layer. Does the hole size matter?

The behaviour of a loudspeaker cabinet at low frequencies

The penetration of sound through double glazed panels

Waves in circular dishes

How good is a wax lens for microwaves?

The colours of thin films of oil on water

'Shadows' of hot air from flames or heated objects

The field of view of a simple telescope

The depth of focus of a simple telescope

The depth of focus of a microscope

The resolution of a microscope

Depth of focus of a camera

Photography through a microscope

Patterns in stressed materials between crossed polaroids

Moiré fringes (patterns from overlapped regular grids)

Detection of small motions by interference methods (thermal expansion, compressibility)

How much light is reflected at various angles by glass?

The sensitivity of Kodak P153 paper at various wavelengths

The adaptation to dark of the human eye

The resolution of close-spaced objects by the eye

Does photographic film fog equally if the light is bright and the exposure short, or if the light is dim and the exposure long?

How big are the grains in a photograph?

How fast must a flicker be before it stops being observable?

Make a diffraction grating by photographic reduction, and test it

Do people vary in the range of wavelengths they can see?

How quickly does the iris of the eye contract when the light is made brighter?

Does the resolution of the eye depend on the illumination?

The performance of a pin hole camera

How much is scattered light polarized?

A dynamo as a speedometer (conversion to accelerometer?)

The efficiency of a dynamo

The efficiency of an electric motor

Load and speed variations of an electric motor

Efficiency of a transformer

Saturation effects in a transformer

Effect of air gaps in transformers or electromagnets

Eddy current losses in transformers (solid core)

Stray fields around transformers

The time taken for a fuse to blow

The conduction of electricity by pencil lines on paper

Conducting paper as a model for electric potential variations

Potential variations in a tank of conducting liquid

The time taken for ions to recombine (e.g. blown down-wind of a flame)

How good are 10 per cent radio resistors?

How good are 20 per cent radio capacitors?

Torque-speed variations of a gramophone motor

Energy emitted by a lamp bulb

Lifetime of torch bulbs

Does a photo-transistor respond instantly?

Variations of resistance with strain

How sensitive can a Wheatstone bridge be made?

Resistance changes of human beings with variations in emotional state

The running down and recovery of a dry cell

How much charge can a home-made accumulator store?

Electrolytic capacitors are said not to lose all their charge if short-circuited after being charged for some time. Is it so?

An electroscope as a voltmeter

The sensitivity of an electroscope as a charge measuring device

Moving coil milliammeters as ballistic galvanometers

Make a capacitor microphone

The variation of the field of a small coil with angle

The contraction of a spiral carrying a current

The effect of thickness of metal on eddy current forces

How high will a 'jumping ring' jump? (A ring over an iron core with a coil carrying a.c. on the core)

Frequency dependence of the impedance of an iron-cored inductor

The dependence of the speed of a d.c. motor on field current

Change in length of a nickel rod in a magnetic field

The voltage from a thermocouple

Temperature variations of transistor currents

Is it true that a dry cell is the most expensive way to buy electricity?

The design of an alternating current ammeter

Behaviour of two *LC* circuits coupled together

The design of an electronic exposure timer

The energy balance of a photocell

Electrical noise in a hot resistor

Does a flame conduct electricity?

Does hot air conduct electricity?

What factors make for good deposits of copper in electrolysis?

What factors affect heating by eddy currents?

How does the resistance between two points on a conducting sheet vary with distance?

How does the resistance between two flat plates in a tank of conducting liquid vary with their spacing?

Make an electrostatic dust collector

Magnesium oxide smoke collects in long fibres on electrodes at high potentials. Investigate. (Exclude draughts.)

How does the resistance in an LC circuit affect the resonance?

How does the electron current in a radio valve vary with filament temperature?

Temperature variations with depth in soil

Temperature variations in air up to the top of a building

Wind speed variations with height

Temperature distribution in a room

Temperature variation on the surface of an iron

Heat losses from thermos flasks

Does anti-freeze freeze?

The temperatures in a flame

Making a thermistor into a thermometer

Absorption of thermal radiation by different surfaces (colours)

Emission of thermal radiation by different surfaces (colours)

Compare glass and polythene as greenhouse materials

How much thermal radiation does water absorb?

The formation of dew

The value of insulating materials (tea cosies, hot-water-tank lagging)

The behaviour of a thermo-electric heat pump (see item 1072)

The cooling of a cup of tea

Temperature distribution along a metal bar heated at one end

How fast does gas burn?

Make an air flow meter using a hot wire (resistance change)

Small drops of water dance about on very hot metal surfaces, without evaporating (the Leidenfrost phenomenon). How hot must the metal be, and how small the drop?

The flow of heat through double glazed panels

The effect of pressure changes on the behaviour of a spark plug

The value of fins for cooling purposes

The growth of frost on cold surfaces

Variation in range of alpha particles with air pressure

Variation in range of beta particles in different metals

How many beta particles are scattered back from various substances?

The natural radioactivity of potassium salts

Can the background radiation be reduced by screening?

Chapter 8

Guide to apparatus

This chapter contains two lists of apparatus. Together, these lists cover all the apparatus required for the experiments suggested in the *Teachers' guides* for the Advanced Physics course.

The first list is of items taken from the Nuffield O-level Physics course. These items have reference numbers less than 1000, and descriptions of them may be found in the Nuffield O-level Physics book, *Guide to apparatus*. Only those items used in the Advanced course are listed. The quantity required for the Advanced course is given, with the quantity suggested for the O-level course in italics after it. There are a few items which are required for the Advanced course in greater quantity than at O-level, and there are some items needed for the Advanced course which are optional at O-level. See items 14, 52B, 59, 65, 101, 181, 183, 184, 196, 197, 517, each distinguished by an asterisk*.

The second list, with reference numbers above 1000, contains items required only for the Advanced course. Each of these items is described briefly, though these descriptions should not be taken as complete specifications.

In both lists, the quantities recommended for Advanced work are for a school with a single class of 16 students. Larger schools require more apparatus, to enable different classes to be taught at the same time, but the extra apparatus need not be proportional to the number of extra classes. Smaller schools require less of such items as electrical meters and electronics kits, which are used by all members of the class at the same time, but again the difference may not be a proportional one.

In both lists, the experiments for which each item is needed are given. Teachers are advised to consult the details given for experiments in the *Teachers' guides* if they are in doubt as to the need for an item, the use to which it would be put, or the quantities they require. In the lists of apparatus given with each experiment in the *Teachers' guides*, the quantities are those needed to set up one version of the experiment. The quantity needed by the class may therefore be a multiple of these quantities. Such multiples have been taken where necessary in arriving at the quantities for a class of 16 in the two lists in this chapter.

Both lists include minor items such as drinking straws and rubber bands. Those used at O-level are included in the first list, while extra small items needed for the Advanced course are collected in the second, Advanced Physics list, under the reference numbers 1051 *Small electrical items,* 1053 *Local purchase items,* 1054 *Expendable items,* 1055 *Small laboratory items,* and 1056 *Chemicals.* While these lists should cover the immediate needs for the performance of all the experiments suggested, it should be remembered that the class may make suggestions which require further materials. A good stock of materials of many kinds should be available so that experiments can be experiments, not performances.

The individual investigations which also form part of the course will produce demands for materials such as wood, metal, glues, and glassware which cannot be foreseen, and a stock of miscellaneous material will help to ease this problem.

Apparatus also required for the Nuffield O-level Physics course

See the Nuffield O-level Physics *Guide to apparatus* for descriptions.

1 materials kit

The Advanced course uses

1M lead block

Experiment 5.1

Quantity 1 *O-level 8*

2 elastic materials kit

The Advanced course uses

2A expendable steel spring

Experiments
2.22
4.5 4.11 4.12

Quantity 50 *O-level 100*

2B reel of 32 s.w.g. bare copper wire

Experiments
1.1 1.7
2.20
9.6 9.10 9.14

Quantity 2 reels *O-level 4 reels*

3 crystals kit

The Advanced course uses

3G microscope slides

Experiments
2.5
5.18
10.4

Quantity 1 packet *O-level 1 packet*

3N copper sulphate

Experiment 5.2

Quantity 10 g *O-level 500 g*

4 microbalance kit

The Advanced course uses

4A drinking straws

Experiments

1.7
2.21 2.27
4.5

Quantity 100 *O-level 240*

7 oil film kit

The Advanced course uses

7L lycopodium powder

Experiment 5.14

Quantity 100 g bottle *O-level 100 g bottle*

8 bromine diffusion kit

The Advanced course uses

8H spare rubber bung

Experiment 5.13

Quantity 1 *O-level 6*

9 Malvern energy conversion kit

The Advanced course uses

9A motor generator unit

Experiments

2.10
6.18
9.1

Quantity 1 *O-level 1*

9B small motor generator unit

Experiments

2.10 2.18
9.1

Quantity 1 *O-level 1*

9C switch unit

Experiments

2.20
4.3
9.1

Quantity 1 *O-level 1*

9D lamp unit

Experiment 9.1

Quantity 1 *O-level 1*

9F lineshaft unit

Experiments

2.10
4.10
9.1

Quantity 1 *O-level 1*

9L storage battery unit

Experiment 9.1

Quantity 1 *O-level 1*

9M driving belt

Experiments

2.10
6.18
9.1

Quantity 2 *O-level 6*

10 Year I general kit

The Advanced course uses

10A ball of cord

Experiment 7.7

Quantity 1 *O-level 1*

10F set of parts for heavy pendulum

Experiment 4.9

Quantity 1 *O-level 1*

10Y Aquadag

Experiments
2.4
3.11 3.13

Quantity 1 bottle *O-level 1 bottle*

12 **two-dimensional kinetic model kit**

Experiment 9.2

Quantity 1/8 kit *O-level 1 kit*

13 **vacuum pump**

Experiment 5.13

Quantity 1 *O-level 1*

*14 **e.h.t. power supply**

Experiments
2.13 2.16 2.23 2.24
3.1 3.2 3.3 3.5 3.8 3.11 3.13
5.2
7.6
8.9
10.5 10.7

Quantity 2 *O-level 1*

15 **h.t. power supply**

Experiments
2.5 2.23
3.4 3.7
4.9
7.1 7.6

Quantity 1 *O-level 1*

16 **radium source**

Experiments

2.25

5.5 5.12 5.13

Quantity 1 *O-level 1*

19/1 **CO_2 cylinder**

Experiments

5.3 5.6 5.7 5.8 5.15

Quantity 1 *O-level 1 plus spare*

19/2 **dry ice attachment**

Experiments

5.3 5.6 5.7 5.8 5.15

Quantity 1 *O-level 1*

20 **domestic balance (5 kg)**

Experiment 4.8

Quantity 1 *O-level 1*

21 **compact light source**

Experiment 4.3

Quantity 1 *O-level 1*

23 **microscope**

Experiments

1.7 (possibly also 2.24)

8.8

Quantity 2 *O-level 8*

24 **hand lens**

Experiment 4.1

Quantity 4 *O-level 36*

27 transformer

Experiments

2.9 2.13 2.22 2.23 2.26 2.28 2.29
3.6 3.8 3.11 3.13
4.3 4.12
5.3 5.6 5.8 5.15
6.2 6.4 6.7 6.13 6.19
7.10 7.11. 7.13 7.15 7.17
8.1 8.3 8.15
9.7
10.7

Quantity 8 *O-level 8*

28 diffusion cloud chamber (Taylor pattern)

Experiments

5.3 5.6 5.8 5.15

Quantity 8 *O-level 8*

30 slotted base

Experiments

3.2 3.8
6.18
7.6 7.13

Quantity 8 *O-level 16*

31/1 weight hangers with slotted weights (10 g)

Experiment 2.21

Quantity 4 *O-level 16*

31/2 weight hangers with slotted weights (100 g)

Experiments

1.7 1.8
4.11

Quantity 8 *O-level 16*

32 1 kg weights

Experiments

1.7 1.8
3.4
4.5 4.6 4.10

Quantity 16 *O-level 16*

35 S-hooks

Experiment 1.7

Quantity 8 *O-level 16*

40 single pulley on clamp

Experiments

1.7 1.8
4.3

Quantity 8 *O-level 16*

42 lever arm balance

Experiments

2.21 2.22
9.9 9.10

Quantity 1 *O-level 8*

43 spring balance (1 kg force)

Experiments

4.6 4.12

Quantity 8 *O-level 16*

44/1 G-clamp (large)

Experiments

2.22
4.10 4.12 4.13
9.10

Quantity 8 *O-level 16*

44/2 G-clamp (small)

Experiments

1.7
2.22
4.11 4.15
6.18
9.1
10.8

Quantity 8 *O-level 16*

46/1 translucent screen

Experiments

8.5 8.8

Quantity 1 *O-level 1*

47 illuminant

Experiments

5.3 5.6 5.8 5.15
8.2

Quantity 8 *O-level 8*

50/1 pairs of cylindrical magnets

Experiments

3.9
4.10
7.1
10.7

Quantity 8 *O-level 32*

50/2 horseshoe magnets

Experiment 4.10

Quantity 2 *O-level 2*

50/3 magnet Eclipse Major

Experiments

5.1 5.13

7.1 7.9 7.16

Quantity 1 *O-level 1*

51 Malvern electrostatics kit

The Advanced course uses

51A electroscope boxes

Experiments

2.23

3.8 3.11

Quantity 1 *O-level 16*

51B plates

Experiment 2.23

Quantity 1 *O-level 16*

51C gold leaf (As needed for 51A)

51D metallized polystyrene balls

Experiment 3.13

Quantity 16 *O-level 64*

51E reel of nylon suspension

Experiments

3.1 3.13

Quantity 8 *O-level 16*

51G polythene strip

Experiments

3.1 3.2 3.8 3.13

Quantity 8 *O-level 16*

51I 'rubber'

Experiment 3.13

Quantity 8 *O-level 16*

51J hook

Experiments

3.8 3.11

Quantity 1 *O-level 16*

51K electrophorus plate

Experiment 3.13

Quantity 8 *O-level 16*

51L proof plane

Experiments

2.16
3.13

Quantity 8 *O-level 16*

51M square polythene tile

Experiments

3.2 3.8 3.13

Quantity 8 *O-level 32*

52 Worcester circuit board kit

Experiments

2.9 2.12 2.19
4.1
6.15
8.11
10.6

Quantity 1/8 kit *O-level 1 kit*

The Advanced course also uses the following item in greater quantity:

*52B U2 cells

Experiments

2.1 2.3 2.4 2.6 2.7 2.8 2.9 2.14 2.15 2.16 2.17 2.18 2.25 2.28 2.29
3.5 3.6 3.12
4.2 4.4 4.9
5.10 5.16 5.17
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 6.13 6.14 6.16 6.19
7.4 7.11 7.12
8.2 8.11 8.13
9.1 9.13 9.15

10.1 10.2

Quantity 150 in addition to any O-level provision.

See the note under item 1033, cell holder, on other ways of providing low voltage direct current supplies.

52K crocodile clips

Experiments

2.5 2.25
3.8 3.11
4.6 4.7
5.16
7.13
9.13 9.15
10.1

Quantity 16 *O-level kit 32*

52L mounted bell push

Experiment 6.10

Quantity 1 *O-level kit 32*

55 friction kit

Experiment 4.10

Quantity 1 *O-level 1*

57 Year II general kit

The Advanced course uses

57L table tennis ball coated with Aquadag

Experiment 3.1

Quantity 1 *O-level 2*

*59 l.t. variable voltage supply

Experiments

1.4 1.6
2.2 2.3 2.13 2.20 2.25 2.26 2.28 2.29
3.4 3.7
4.2 4.9 4.10
5.17
6.18

7.1 7.3 7.4 7.8 7.9 7.10 7.12 7.17
8.5 8.8 8.12
9.9 9.10
10.2

Quantity 2 *O-level 1*

60/1 Van de Graaff generator

Experiments
3.3 3.13

Quantity 1 *O-level 1*

This item is an alternative to item 14, e.h.t. supply, and is not essential.

61 fine beam tube

Experiments
2.23
7.1 7.6

Quantity 1 *O-level 1*

62 fine beam tube base

As for item 61.

64 oscilloscope

Experiments
1.4
2.15
4.7 4.9 4.16
6.1 6.6 6.8 6.11 6.12 6.17 6.18
7.7 7.14
8.7 8.12

Quantity 1 *O-level 1*

***65 metal plates with insulating handles**

Experiments
2.25
3.1 3.5

Quantity 4 pairs *O-level 1 pair*

67 Bourdon gauge

Experiment 9.11

Quantity 2 *O-level 8*

68 phototransistor

Experiment 4.2

Quantity 1 *O-level 1*

69 high dispersion prism

Experiments

4.2
5.17
10.2

Quantity 1 *O-level 1*

70 demonstration meters

Experiments

2.10 2.13 2.23
6.8
7.3 7.8 7.9 7.12
9.10

Quantity 2 *O-level 2*

71 dials for demonstration meters

71/1 d.c. dial: 1 A

Experiments

2.10
7.3 7.8 7.12

Quantity 1 *O-level 1*

71/2 d.c. dial: 5 A

Experiments

7.3 7.8 7.9 7.10
9.10

Quantity 1 *O-level 2*

71/3 d.c. dial: 5 V

Experiments

6.8
7.8 7.12

Quantity 1 *O-level 1*

71/4 d.c. dial: 2.5–0–2.5 mA

Experiment 6.8

Quantity 1 *O-level 2*

71/6 a.c. dial: 15 V

Experiment 2.13

Quantity 1 *O-level 1*

71/8 a.c. dial: 1 A

Experiment 7.12

Quantity 1 *O-level 1*

71/10 d.c. dial: 15 V

Experiment 9.10

Quantity 1 *O-level 1*

71/12 d.c. dial: 100 mA

Experiment 2.23

Quantity 1 *O-level 1*

73 lamp (12 V, 36 W)

Experiment 2.13

Quantity 1 *O-level 8*

74 lampholder s.b.c. on base

Experiments

2.13
7.8 7.11

Quantity 16 *O-level 16*

75 **immersion heater**

Experiments

9.9 9.10 9.11

Quantity 2 *O-level 8*

77 **aluminium block**

Experiments

2.20
4.6
9.6 9.10 9.14

Quantity 2 *O-level 8*

78 **variable a.c. supply (Variac type)**

Experiment 7.17

Quantity 1 *O-level 1*

79 **d.c. ammeter (0–1 A)**

See item 1003/4.

80 **d.c. voltmeter (0–5 V)**

Experiments

2.6 2.7

Quantity 8 *O-level 16*

81 **newton spring balances (10 N)**

Experiments

1.7 1.8
2.22
4.6 4.8 4.12
7.7

Quantity 8 *O-level 8*

84 **wire strippers**

Experiments

7.2 7.9 7.11

Quantity 8 *O-level 16*

90 ripple tank kit

Experiments
1.2
4.8
8.2

Quantity 1/4 kit *O-level 1 kit*

92 Westminster electromagnetic kit

The Advanced course uses

92B Magnadur magnets

Experiments
2.23
5.1
7.2 7.3 7.4 7.9 7.16
8.13

Quantity 32 *O-level 32*

92C reel of cotton

Experiment 7.16

Quantity 1 *O-level 16*

92G double C-core and clip

Experiments
6.12 6.13 6.14 6.16 6.17 6.19
7.11 7.12 7.17
8.11

Quantity 16 *O-level 16*

92I mild steel yoke

Experiments
5.1
7.3 7.9 7.16
8.13

Quantity 8 *O-level 16*

92P aluminium ring

Experiments
7.1 7.16

Quantity 8 *O-level 16*

92Q aluminium ring (split)

Experiments

7.1 7.16

Quantity 8 *O-level 16*

92R m.e.s. bulbs (2.5 V, 0.3 A)

Experiments

2.19
6.10 6.12
7.12

Quantity 16 *O-level 32*

92S neon lamp

Experiments

4.9
6.12
7.12

Quantity 1 *O-level 18*

92T m.e.s. holder

Experiments

2.19
4.9
6.10 6.12
7.12

Quantity 16 *O-level 32*

92X reel of 26 s.w.g. PVC covered copper wire

Experiments

3.8 3.11
4.6
6.1 6.18
7.1 7.9 7.10 7.11 7.13 7.15

Quantity 8 *O-level 16*

94 kit for ray optics

The Advanced course uses

94A lamp, holder, and stand

Experiments
3.8 3.9 3.11 3.13
8.1 8.3 8.5 8.8 8.15
9.7

Quantity 8 *O-level 16*

94B housing shields

As for 94A.

94G barrier

Experiment 8.15

Quantity 16 *O-level 32*

94H plano-cylindrical lens+7D

Experiment 8.15

Quantity 8 *O-level 32*

95 Edinburgh CO_2 pucks kit

Experiment 5.7

Quantity 1 *O-level 1*

100/1 rectangular plastic tank

Experiments
1.1 1.2
8.15

Quantity 8 *O-level 8*

100/2 large rectangular transparent tank

Experiment 4.16

Quantity 1 *O-level 1*

*101 large Slinky

Experiments

4.5 4.15
7.13

Quantity 4 *O-level 1*

104 low voltage power unit

Experiments

6.2 6.4 6.5 6.7 6.10 6.13 6.14 6.19
7.2

Quantity 8 *O-level 16*

106/1 dynamics trolleys

Experiments

2.22
4.5 4.6 4.11 4.12
7.9
8.13

Quantity 16 *O-level 32*

106/2 elastic cords for accelerating trolleys

Experiment 2.22

Quantity 8 *O-level 96*

107 runways

Experiments

2.22
4.11 4.12

Quantity 8 *O-level 16*

108/1 tickertape vibrators

Experiments

2.22
4.12

Quantity 8 *O-level 16*

108/2 **carbon paper discs**

As for item 108/1.

108/3 **rolls of tickertape** (plain)

Experiments

2.22
4.12
7.3 7.6

Quantity 1 roll

116 **plane mirror**

Experiment 8.1

Quantity 8 *O-level 16*

121 **50 mm metal strips as jaws**

Experiments

4.15
10.8

Quantity 2 pairs *O-level 32*

130/1 **scaler**

Experiments

2.21 2.22
4.6 4.9
5.1 5.2 5.4 5.9 5.12 5.13
10.3 10.10

Quantity 1 *O-level 1*

One extra scaler would be a great advantage.

130/2 **photodiode assembly with light source**

Experiments

2.21 2.22
7.7

Quantity 1 *O-level 1*

130/3 GM tube holder

Experiments
4.9
5.1 5.4 5.9 5.12
10.3 10.10

Quantity 1 *O-level 1*

One extra GM tube holder would be a great advantage.

130/4 solid state detector and pre-amplifier

Experiments
5.2 5.4 5.13

Quantity 1 *O-level 1*

130/5 thin window GM tube

Experiments
4.9
5.1 5.4 5.9 5.12

Quantity 1 *O-level 1*

130/6 gamma GM tube

Experiments
5.4
10.3 10.10

Quantity 1 *O-level 1*

131 Year IV general kit

The Advanced course uses

131B steel ball with hook (50 mm diameter)

Experiment 2.30

Quantity 1 *O-level 2*

131D steel ball with hook (10 mm diameter)

Experiment 2.30

Quantity 1 *O-level 1*

132 Year IV electrical general kit

The Advanced course uses

132N thermistor (Radiospares TH3, cold 400 Ω, hot 28 Ω)

Experiments

2.3
6.4
9.13

Quantity 1 *O-level 1*

133 camera

Experiments

2.21 2.22 2.27 2.30
3.10
4.5 4.12 4.14
5.3 5.7
9.2

Quantity 1 *O-level 1*

134/1 motor-driven stroboscope

Experiments

2.21 2.22 2.27 2.30
4.5 4.9 4.12
5.7

Quantity 1 *O-level 1*

134/2 xenon flasher (optional)

Experiments

2.27 2.30
3.10
4.15 4.16
7.7
10.8 10.9

Quantity 1 *O-level, 1 optional*

138 deflection tube

Experiments

2.23
7.6

Quantity 1 *O-level 1*

139 **set of coils and supports**

As for item 138.

140 **stand for tubes**

As for item 138.

147 **demountable transformer kit**

Experiments
6.15
7.9 7.17

Quantity 1 *O-level 1*

149 **electric field apparatus**

Experiment 3.3

Quantity 1 *O-level 1*

150 **fractional horse power motor**

Experiments
4.9 4.10
7.7 7.8 7.9

Quantity 1 *O-level 1*

154/1 **turntable**

Experiments
4.9
7.9 7.16 7.17

Quantity 1 *O-level 1*

157 **microphone**

Experiments
4.1 4.9 4.16
6.4 6.6 6.19
8.7

Quantity 4 *O-level 8*

158 class oscilloscope

Experiments
2.14
3.4 3.6
4.1
6.2 6.4 6.7 6.9 6.11 6.14 6.16 6.19
7.11 7.13
8.11

Quantity 8 *O-level 8*

161 gantry for CO_2 pucks kit

Experiment 5.7

Quantity 1 *O-level 1*

170 low frequency a.c. generator

Experiments
6.8 6.18

Quantity 1 *O-level 8*

171 photographic accessories kit

Experiments
2.21 2.22 2.27 2.30
3.10
4.5 4.12 4.14
5.3 5.7
9.2

Quantity 1 *O-level 1*

173 Malvern current balance kit

Experiment 7.6

Quantity 1 *O-level 1*

176 12 volt battery

Experiments
2.2 2.10 2.11 2.20 2.23
4.3
7.3 7.5 7.7 7.8 7.13 7.15
9.1 9.6 9.9 9.11 9.14

Quantity 2 *O-level 4*

177 **lamp (12 V, 6 W)**

Experiments

7.8 7.11

Quantity 16 *O-level 16*

178 **d.c. ammeter (0–1 A, 0–5 A)**

See item 1003/4.

179 **d.c. voltmeter (0–5 V, 0–15 V)**

As for item 80.

180 **galvanometer**

Experiments

2.9 2.14

Quantity 8 *O-level 16*

*181 **general purpose amplifier**

Experiments

1.4 1.5 1.6
4.1 4.4 4.9
6.1 6.5 6.15 6.18 6.19
7.10 7.14
8.4 8.6 8.14 8.16 8.18

Quantity 1 *O-level 1 optional*

182 **l.f. signal generator**

See item 1009.

*183 **loudspeaker**

Experiments

4.7
8.7

The loudspeaker is also needed for the experiments listed under item 181, if the amplifier has no loudspeaker.

Quantity 2 *O-level optional*

***184/1 3 cm wave transmitter**

Experiments
1.4 1.5 1.6
4.1 4.4
8.1 8.4 8.6 8.14 8.16 8.18

Quantity 1 *O-level optional*

***184/2 3 cm wave receiver**

Experiments
1.4 1.5 1.6
4.1 4.4
8.6 8.14 8.16 8.18

Quantity 1 *O-level optional*

189 ultra-violet lamp

Experiments
5.16
10.1

Quantity 1 *O-level 1*

191/1 coarse grating

Experiments
8.8
10.6

Quantity 8 *O-level 16*

191/2 fine grating

Experiments
9.7
10.4 10.5

Quantity 8 *O-level 16*

192/1 red filters

Experiment 4.1

Quantity 4 *O-level 16*

192/2 **green filters**

As for 192/1.

Item 1067/3 R can include filters such as item 192.

193/2 **hydrogen spectrum tube**

Experiment 10.5

Quantity 1 *O-level 1*

194 **holder for spectrum tubes**

Experiment 10.5

Quantity 1 *O-level 1*

195/1 **pure gamma source**

Experiments

5.3 5.4
10.3 10.10

Quantity 1 *O-level 1*

195/2 **pure beta source**

Experiments

5.1 5.4

Quantity 1 *O-level 1*

195/3 **pure alpha source**

Experiments

5.2 5.4 5.8

Quantity 1 *O-level 1*

*196 **source holder**

Experiments

5.1 5.2 5.3 5.4 5.12

Quantity 4 *O-level 1*

*197 **electron diffraction tube**

Experiment 10.7

Quantity 1 *O-level optional*

The 500 series

The items with reference numbers from 501 onwards are basic laboratory items, likely to be available already in many schools.

501	metre rules	Quantity 8	*O-level 16*
503	retort stand bases	Quantity 16	*O-level 32*
504	retort stand rods	Quantity 32	*O-level 32*

It is convenient to have rods of 0.2 m, 0.5 m, and 1.0 m. Some of the rods of each length must be of mild steel, for magnetic induction experiments (experiments 7.1, 7.10, 7.11). A 1.0 m steel rod is also used for a measurement of the speed of sound in steel (experiment 4.7).

505	bosses	Quantity 16	*O-level 32*
506	clamps	Quantity 16	*O-level 24*
507	stop watches or stop clocks	Quantity 8	*O-level 16*
508	Bunsen burners	Quantity 4	*O-level 16*
510	gauzes	Quantity 2	*O-level 16*
511	tripod	Quantity 2	*O-level 16*
512/1	beaker, 250 cm³	Quantity 4	*O-level 16*
512/2	beaker, 400 cm³	Quantity 4	*O-level 32*
*517	volumetric flask, 1 dm³ (1 litre)	Quantity 2	*O-level 1*
522	Hoffmann clips	Quantity 8	*O-level 8*
524	mercury tray	Quantity 1	*O-level 1*
529	scissors	Quantity 8	*O-level 8*
530	pliers	Quantity 1	*O-level 1*
533	buckets	Quantity 4	*O-level 8*
535	bottle of mercury, 2 kg	Quantity 1	*O-level 1*
541/1	rheostats (10–15 ohms)	Quantity 8	*O-level 8*
541/2	rheostats (330 ohms)	Quantity 1	*O-level 1*

542	thermometer ($-10°C$ to $110°C$)	Quantity 8	*O-level 24*
543	chinagraph pencils	Quantity 2	*O-level 16*
548	round bottomed flask, 250 cm^3	Quantity 2	*O-level 8*

Apparatus required only for the Advanced course

1000 leads

Insulated flexible leads with 4 mm stackable plugs at each end. (A stackable plug is also a socket into which another plug can be put.) Some of the leads should be at least half a metre long, and able to carry 5–10 amperes without overheating. About half of the leads would be used principally with the electronics kits, and should be shorter and thinner if the kits are fairly compact.

Leads with plugs which do not stack are cheaper, and they can be stacked into additional plugs with two sockets where necessary. But they generally increase the time taken to connect up a circuit, and they are not recommended where they would be used frequently.

Leads are used in most experiments, but the full number, particularly of the smaller leads, is not needed until Unit 6.

Quantity 150

Note on sockets, terminals, and plugs

As for the Nuffield O-level Physics apparatus, it is recommended that all electrical apparatus (except for coaxial connections) should be provided with 4 mm sockets, connections being made with leads carrying stackable 4 mm plugs.

A choice has to be made for each item between cheap, simple sockets and more expensive socket terminals which will accept a bare wire as well as a 4 mm plug. The socket terminals are more appropriate for relatively expensive items which are likely to be used in many different ways, such as meters, or power supplies. Smaller items, with a single use within the course, such as two- or four-terminal boxes (items 1047 and 1048), should have the cheap sockets.

Items such as the parallel beam projector (1068), large loudspeaker (1044), or solar motor (item 1023), which will have to be connected to a source of power but to nothing else, may conveniently have captive leads ending in 4 mm plugs, if this is cheaper.

1001 galvanometer (internal light beam)

A taut-suspension meter with these features:

1 sensitivity of 1 or 2 mm μV^{-1}

2 coil resistance about 20 Ω or more

3 scale about 150 mm long

4 a switched set of shunts and series resistors so that sensitivity can be reduced, preferably in steps of a factor 10 or less, while the resistance between the terminals remains constant

5 terminals which can be switched direct to the moving coil.

The instrument required is one which is sensitive to small voltages rather than to small currents, as it is usually used to detect or measure potential differences. The resistance should be as high as possible, so that the meter shall not reduce the potential difference it measures, but this requirement conflicts with design for high voltage sensitivity, and a compromise is needed.

The instrument should be robust enough to withstand heavy electrical overload (galvanometers may be made to withstand voltages of more than 10^6 times what will give full scale deflection) and considerable mechanical ill-treatment.

Cheaper electronic amplifying devices are increasingly able to do the work of sensitive galvanometers. They are already more current-sensitive, and greater voltage sensitivity may only be a matter of time. Nothing in the Advanced course precludes their use and schools are advised to consider them.

Quantity 2

Experiments

2.1 2.4 2.20 2.28 2.29
3.1 3.4 3.7
4.1
7.4 7.5 7.9 7.10 7.13
8.9 8.13 8.14
9.6 9.10 9.14 9.15

1002 microammeter

A moving coil meter for class use with a scale at least 60 mm long, giving full scale deflection for 100 μA. A scale 20–0–100 μA is to be preferred to a scale of 0–100 μA. A coil of resistance 1000 ohms is convenient, so that 100 mV gives a full scale deflection. The microammeter is the basic movement from which ammeters and voltmeters can be built up by means of accessories. See items 1003 and 1004.

There is a need for many meter ranges. Some ranges will only be used occasionally and by single groups of students. It will never be necessary to use more than eight meters on any one range simultaneously.

One way to meet the need is to base all meters for the Advanced Physics course on the 100 μA instrument, item 1002. Modern instruments of this sensitivity are robust enough for this to be a practicable arrangement. The quantities suggested for items 1002, 1003, 1004, and 1057 assume that this method is chosen.

Two other possible ways of providing many meter ranges are worth considering. The first is to use more than one basic meter movement. The second is to use small multi-range meters.

A school already possessing a set of 1 mA or 10 mA meters with accessories to enable them to measure larger currents, could use them as eight of the sixteen meters needed for the Advanced course. The other eight meters, each of 100 μA full scale deflection, would be used to measure voltages and smaller currents. The disadvantage of this method is loss of simplicity: all accessories do not go with all meters. The advantage might be economy of initial outlay. The bigger the school, the less the economy of this method would be worth the loss of simplicity.

Small multi-range meters (that is, ones with fewer ranges than item 1005) with 100 μA movements are cheap enough for sixteen of them to be bought instead of microammeters and accessories. They have disadvantages, but none are likely to be decisive. Personal preference, costs at the time of purchase, and other circumstances must guide the choice.

Two more possible ways of providing meters are so expensive as not to be considered seriously. They are the use of a separate instrument for each range, and the use of sixteen multi-range meters such as item 1005.

Quantity 16 (of which 8 may be 10 mA movements)
Experiments (for which item 1002 is used without shunts or multipliers)
2.1 2.14 2.15 2.17 2.28 2.29
3.6
4.1
6.3 6.9
See also experiments under items 1003/1 to 5 and 1004/1 to 3 if item 1002 is used as the basis of these instruments.

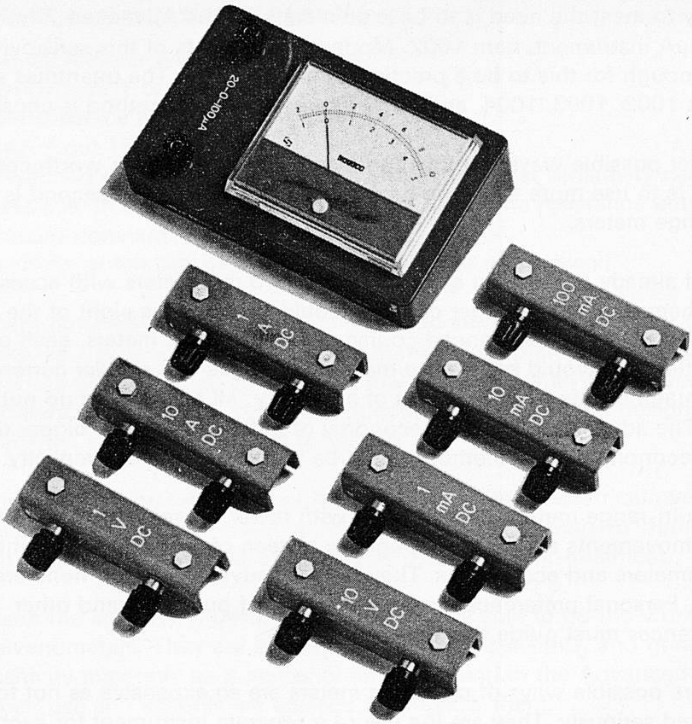


Figure 43
Items 1002, 1003, and 1004, Basic 100 μA meter with shunts and multipliers.
Photograph, Michael Plomer.

1003 range of direct current ammeters

The following ranges, 1003/1 to 1003/5, are required. As indicated under item 1002, these ranges can be provided using shunts with item 1002. Thus item 1003/1, for example, may be interpreted either as a requirement for four 1 mA shunts for a 100 μA meter, or as a requirement for four 1 mA meters to be provided in some other way.

1003/1 *milliammeter (1 mA)*
Quantity 4

Experiments
2.1 2.9 2.16 2.25
3.5 3.6 3.12 3.13
4.2
5.2 5.10 5.16 5.17
6.3 6.19
9.15
10.1 10.2

In a number of these experiments, this instrument is listed as the display meter for the electrometer, item 1006. It may not be suitable for this purpose for all types of electrometer. Items 1001 or 1002 may serve instead.

1003/2 *milliammeter (10 mA)*

Quantity 4

Experiments

2.1 2.3 2.13 2.14 2.26
8.11
9.13

1003/3 *milliammeter (100 mA)*

Quantity 8

Experiments

2.1 2.6 2.26
7.4
9.13

1003/4 *ammeter (1 A)*

Items 79 or 178 can be used.

Quantity 8

Experiments

2.2 2.3 2.11 2.26
7.5 7.6 7.7 7.15

1003/5 *ammeter (10 A)*

Quantity 2

Experiments

7.4 7.5 7.6 7.7 7.13 7.15
9.9 9.11

1004 range of direct current voltmeters

The following ranges, 1004/1 to 1004/3, are required. As indicated under item 1002, these ranges can be provided using multipliers with item 1002. Thus item 1004/1, for example, may be interpreted either as a requirement for four 1 V multipliers for a 100 μA meter, or as a requirement for four 1 V meters to be provided in some other way.

Voltmeters based on movements less sensitive than 100 μA will *not* be suitable for a number of the experiments in the Advanced course.

1004/1 *voltmeter (1 V)*

Quantity 4

Experiments

2.2 2.9 2.16
8.11
9.6

1004/2 *voltmeter (10 V)*

Quantity 8

Experiments

2.1 2.6 2.7 2.8 2.12 2.17
3.4 3.6
6.2 6.19
7.7
9.11

1004/3 *voltmeter (100 V)*

Quantity 2

Experiments

2.26 2.28 2.29
3.4 3.7
9.9

1005 multi-range meter

A meter with a scale 100 mm long or more, having direct and alternating current and voltage ranges and resistance ranges, including:

d.c. down to full scale deflection for 50 μA
d.c. up to full scale deflection for 10 A
a.c. down to full scale deflection for 100 mA
a.c. up to full scale deflection for 10 A
alternating voltages down to full scale deflection for 2.5 V

Quantity 1 (see the note under item 1002)

Experiments

2.20 2.24 2.26 2.28 2.29
3.5 3.12
6.10 6.15 6.19
7.1
9.9

1006 electrometer

An amplifier whose last stage operates a meter which indicates the potential difference applied to the first stage. The input impedance is of the order of 10^{12} ohms or more, so the instrument is effectively a voltmeter of this resistance, but it may also be regarded as a d.c. amplifier of uncertain gain.

When placed across known resistors the electrometer measures current, and when placed across known capacitors the electrometer measures quantity of electricity. The resistors and capacitors for these measurements may be built in and switched, or may be plug-in accessories. They need good insulation and some values are expensive. Full scale deflection for 10^{-9} A, 10^{-10} A, 10^{-11} A, 10^{-8} C, and 10^{-9} C are useful and accessories for these ranges should be regarded as necessary items when they are not built in. But a school does not need an accessory of each value with every electrometer. One of each of the more expensive accessories is enough.

Electrometers may be mains or battery powered.

Electrometers may have built-in meters, or may require external meters. For each experiment in which an electrometer is required, a milliammeter 1003/1 has been listed for this purpose, but schools may not find that 1003/1 is either necessary or suitable. Items 1001 or 1002 may be suitable, or the electrometer may have a built-in meter.

Full scale deflection is for about 1 volt. The ability to change this figure somewhat without altering the input impedance is an advantage.

Screened cable is often necessary for input connections. The input should be to a UHF socket with P.T.F.E. insulation.

Desirable qualities in the instrument are linearity and stability of zero.

Quantity 4

Experiments

2.9 2.16 2.25
3.5 3.12 3.13
5.2 5.10 5.16 5.17
9.15
10.1 10.2

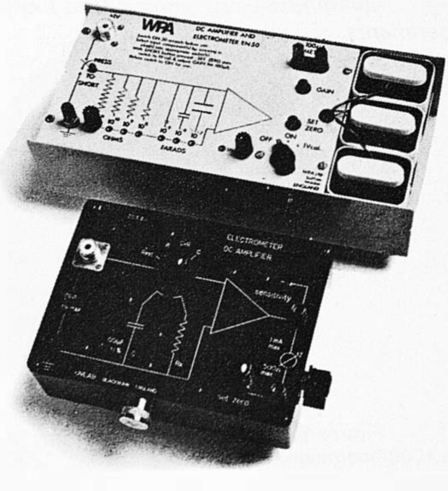


Figure 44
Item 1006. Two forms of electrometer.
Photograph, Michael Plomer.

1007 double-beam oscilloscope

An oscilloscope differing from O-level item 64 in that it has two Y-inputs, two Y-amplifiers, and two traces, but in other respects fulfilling the same requirements as item 64. It is an advantage if one amplifier has a wider band width (−3 dB up to 6 MHz) and a greater maximum sensitivity (10 mV cm^{-1}).

Various time base systems are used in double-beam oscilloscopes. The most desirable are those in which the time base operates simultaneously on two separate beams, each of which has an independent pair of Y-plates in the tube, but such instruments are fairly expensive. An arrangement which is less desirable, but is satisfactory for many purposes, uses a tube with one pair of Y-plates which are switched alternately to one amplifier and the other.

It is particularly convenient to be able to trigger the time base from either input.

Quantity 1

Experiments

4.4
6.5 6.9 6.11 6.12 6.14 6.15 6.18
7.9 7.10 7.12 7.15 7.17
8.10 8.11

1008 ionization chamber

A container with a well-insulated central electrode, in which the electrical conduction of air, ionized by alpha radiation, can be measured. The ionization chamber is used with the electrometer (item 1006) and the 'thoron' generator (item 1066) and should be compatible with them. The chamber should not be open to the atmosphere, through a gauze, for example.

Quantity 1

Experiments

5.2 5.10

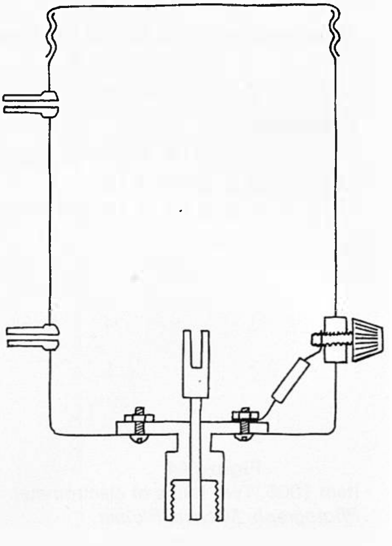


Figure 45
Item 1008. Ionization chamber

1009 signal generator

A sine wave generator up to 5 V r.m.s. covering the range 10 Hz to 100 kHz with fairly constant output into a high impedance load over the whole range. Accuracy of frequency calibration may be useful but it is not essential. The generator must also have a low impedance output (such as 5 Ω), to deliver at least 1 W, for use with a loudspeaker or mechanical vibrator. At the extreme ends of the frequency range the output may fall off more than is acceptable for the high impedance output.

The generator should also be able to produce a 'square' waveform over most of the frequency range at the high impedance output. A switched attenuator should be provided.

A signal generator bought for the O-level course (item 182) may fulfil all these requirements.

Quantity 4

Experiments

3.4 3.6 3.7
4.1 4.7 4.8 4.9 4.15 4.16
6.4 6.6 6.7 6.13 6.15 6.17 6.18 6.19
7.10 7.13 7.14
8.7
10.8 10.9

1010 reed switch

A switch for connecting a capacitor plate alternately to a source of p.d. and to a meter. The contacts should be able to withstand a p.d. of up to 25 volts and current up to 50 mA at least. The switch should be capable of being operated at frequencies up to 400 Hz from the output of the signal generator 1009.

Quantity 4

Experiments

3.4 3.6 3.7

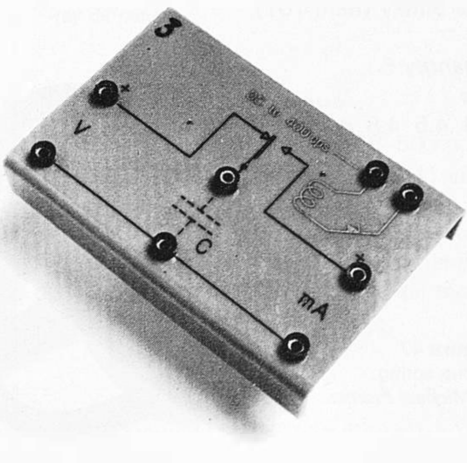


Figure 46
Item 1010. Reed switch.
Photograph, Michael Plomer.

1011 apparatus for measuring joules per coulomb

A metal block which can be warmed by energy transferred by friction and measured as work, and also by an electrical heating coil inside it. The apparatus includes any handle, stand, and cord which are needed to transfer mechanical energy to the block, and may also include a device for making electrical contact with the ends of a heating coil embedded in the block. The apparatus need not include the electrical meters which are needed for use with it.

The experiment is very like a traditional measurement of the mechanical equivalent of heat, and much of the apparatus may be the same, but the metal block, which can be warmed by friction and can also be heated electrically, may be a special item.

Quantity 1
Experiment 2.11

1012 semiconductor Hall effect demonstration

Mounted wafers of doped semiconductor (e.g. germanium), both *p*- and *n*-type, each with connections for passing current and connections for measuring the Hall voltage. It must be possible to reduce any misalignment potential difference to a small proportion of a typical Hall voltage, and this would normally be achieved using a compensating potentiometer mounted with the wafer.

Quantity 1 *p*-type; 1 *n*-type
Experiment 7.4

1013 long spring

A spiral spring about 20 mm in diameter, and about 3 m long unstretched, for showing transverse waves. A spring wound of wire with circular cross-section is better than a Slinky (item 101).

Quantity 6
Experiments
4.4 4.5 4.8 4.15 4.16

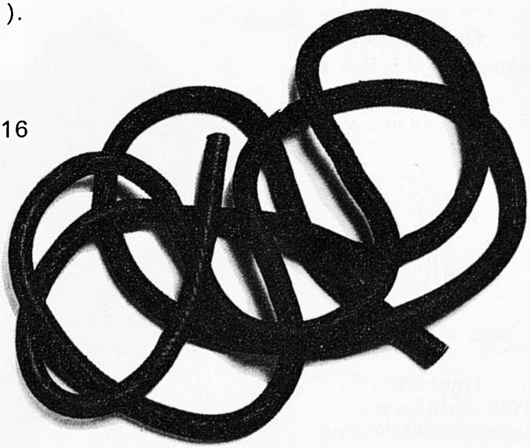


Figure 47
Item 1013. Long spring.
Photograph, Michael Plomer.

1014 wax lens

The lens is of wax or other material and is designed to make 3 cm radiation converge. A diameter of 0.3 m and a focal length of 0.6 m are suitable. Dimensions are not critical.

A simple block may be needed to hold the 3 cm transmitter or receiver at the level of the lens centre, and a rod may be useful to join the lens to the block and also to prevent the lens from falling over. Manufacturers will probably be willing to supply such a block and rod for each lens.

Quantity 2

Experiments

1.4 1.5 1.6

8.4 8.6

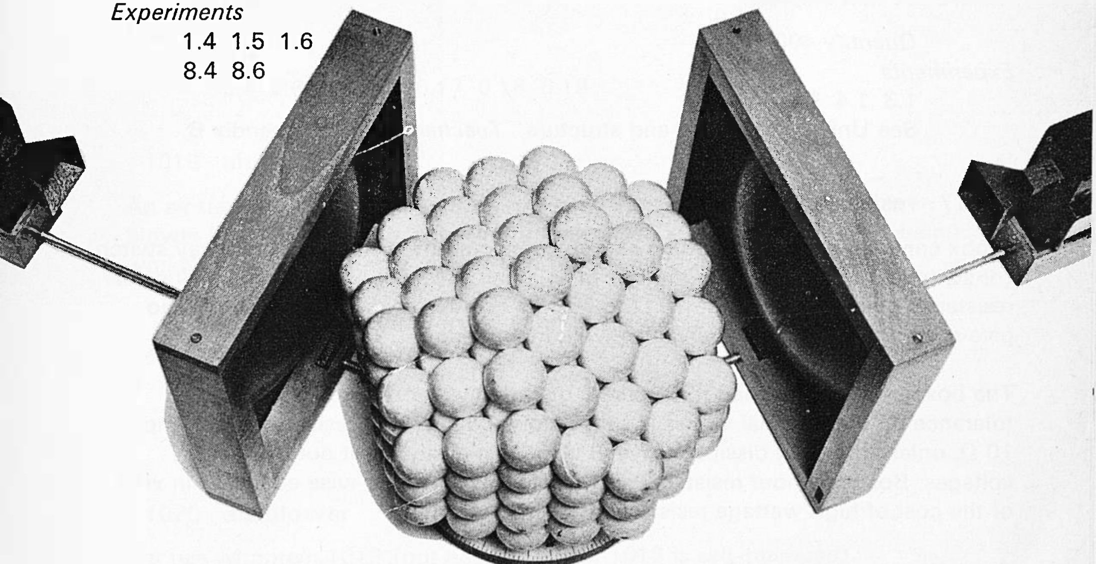


Figure 48

Items 1014, 1015, 1016. Analogue of X-ray diffraction.

Photograph, Michael Plomer.

1015 turntable for 3 cm X-ray diffraction analogue

A motor-driven turntable which will rotate a crystal model at 30–50 r.p.m. in a beam of 3 cm radiation produced by a 3 cm transmitter (item 184/1) and a wax lens (item 1014), enabling angles to be measured which correspond to the Bragg angle for diffraction of X-rays. The base of the turntable can be made to accept connecting rods (see item 1014) and can be marked so that the angle by which the crystal model deflects the beam can be measured. The crystal model may be about 0.3 m across and may weigh 2 or 3 kg.

Quantity 1

Experiments

1.4 1.6

1016 **expanded polystyrene spheres**

Spheres for making crystal models. They can usually be bought by the hundred. Such spheres are sometimes sold under registered names.

1016/1 *25 mm diameter*

Quantity 100

Experiments

See Unit 1, 'Materials and structure', *Teachers' guide*, Appendix B.

1016/2 *50 mm diameter*

Quantity 400

Experiments

1.3 1.4 1.6

See Unit 1, 'Materials and structure', *Teachers' guide*, Appendix B.

1017 **resistance substitution box**

A box containing resistors, which can be connected by means of a multiway switch (or switches) to terminals on the box or to a pair of leads. About twenty values of resistance covering the range 10 Ω to 10 MΩ in steps of roughly constant ratio give a useful box, but twelve values would be enough.

The boxes will not be used for accurate quantitative work, and 10 per cent tolerance on the nominal values is satisfactory. Low-valued resistors, for example 10 Ω, unless they can dissipate several watts, are easily burnt out by low voltages. Boxes without resistors less than 100 Ω may be a wise economy in view of the cost of high wattage resistors.

A resistance substitution box may be used with a capacitance substitution box (item 1018) to show the effect of constant RC. For this purpose it is convenient if the two boxes have the same ratio steps. Then, when R is increased, C can be simultaneously decreased and the time constant RC can be kept about the same.

Quantity 8

Experiments

2.26
3.4 3.6 3.7
4.9
6.2 6.4 6.5 6.7 6.9 6.11 6.12 6.13 6.14 6.17 6.18 6.19
7.5 7.10 7.12

1018 capacitance substitution box

A box containing capacitors, which can be connected by means of a multiway switch (or switches) to terminals on the box or to a pair of leads. Eight values of capacitance, covering the range 1000 pF to 0.22 μF in steps of roughly constant ratio give a useful box. More values would be an advantage.

The boxes will not be used for accurate quantitative work, and 20 per cent tolerance on the nominal values is satisfactory.

See also resistance substitution box (item 1017).

Quantity 4

Experiments

3.6

6.4 6.6 6.7 6.9 6.17 6.18 6.19

1019 air track

An air track about 2 m long, not necessarily incorporating its own blower. (The blower is needed for only a small proportion of the time an air track is being worked with, and a single blower can service more than one air track.)

Quantity 2 (1 will serve if economy is necessary)

Experiments

2.21 2.27

4.10

7.16

1020 air blower

For use with item 1019 (not needed if item 1019 is self-powered).

Quantity 1

Experiments

2.21 2.27

4.10

7.16

1021 freezer

A means of reducing the temperature of an object, for example by the rapid evaporation of a liquid which is sprayed on it from an aerosol. Such freezers are sold for transistor testing.

Quantity 3

Experiments

1.7
2.3
6.4

1022 jig for making sodium chloride lattice model

This model is made from expanded polystyrene spheres which are 25 mm and 50 mm in diameter (item 1016). The jig is needed to hold the spheres in position while they are being glued, and should be big enough to enable a model to be made whose edges contain three large balls and two small ones.

Quantity 1 (see Unit 1, *Teachers' guide*, Appendix B)

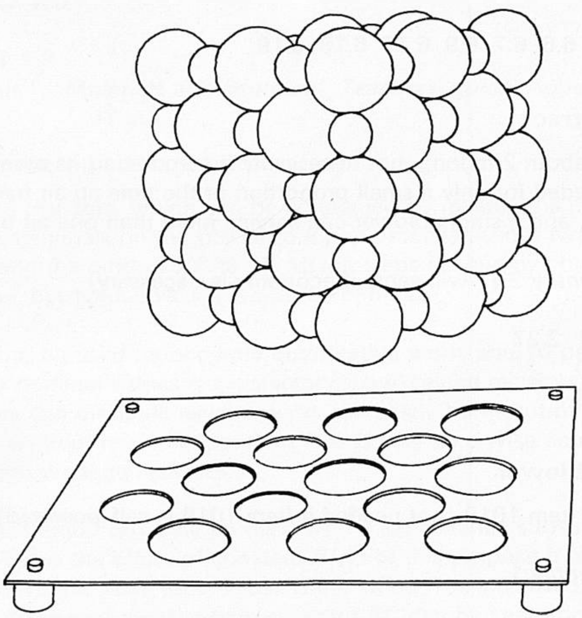


Figure 49
Item 1022. Jig for making sodium chloride lattice model. Completed model of sodium chloride.

1023 solar motor

An electric motor requiring very little input power. The motor need not be able to drive appreciable mechanical loads, but is used to show that electrical energy is available from small sources such as solar cells, thermopiles, and charged capacitors. It would be wise to buy the motor from the same manufacturer as the semiconductor thermopile unit (item 1072) so as to be sure that the motor can be driven by the thermopile. Such a motor will run on a small current at a low voltage, and could be damaged by connecting it to a voltage as large as that from a dry cell, or by connecting it to too big a charge stored on a capacitor. (See figure 78, p. 207.)

Quantity 1
Experiments
2.18
9.6 9.14

1024 hacksaw blade oscillator

A simple arrangement for students to use by themselves in investigations of forced vibrations. A suitable oscillator is a loaded hacksaw blade, coupled by a rubber band either to a massive pendulum of variable length or to a hand-driven crank. A simple means of varying the damping of the oscillator should be provided, such as a card which may be attached to the blade and be turned into at least two different positions. Cheap and simple forms of the apparatus, perhaps employing components, such as Meccano strips, from other sources, are to be preferred to more elaborate forms.

Quantity 8
Experiment 4.13

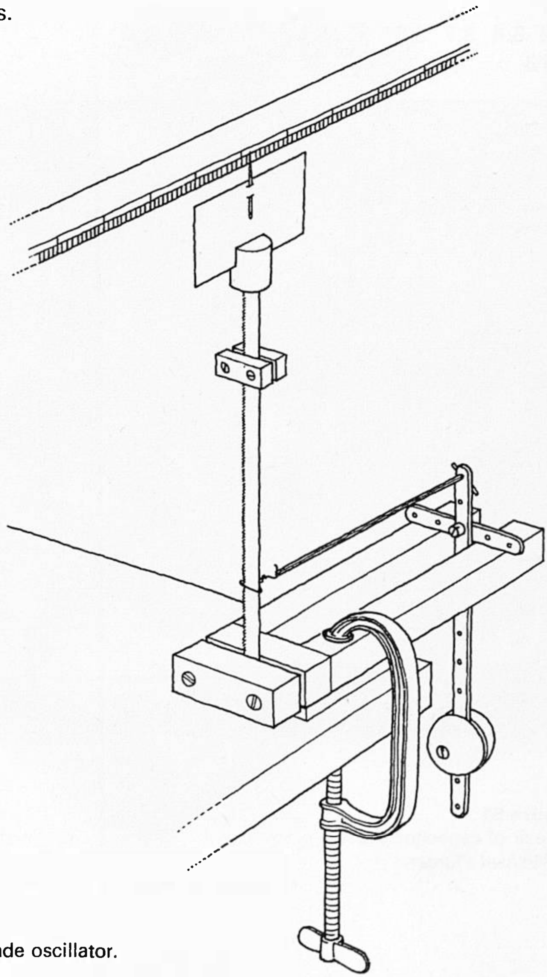


Figure 50
Item 1024. Hacksaw blade oscillator.

1025 pair of capacitor plates

A pair of conducting plates 0.25 m square (or with roughly that area), each plate having a 4 mm socket. The plates must be flat and rigid enough to give nearly constant separation when used with spacers 1 mm thick. A sheet of thin flexible dielectric (polythene, 1 to 2 mm thick) should be supplied, together with extra insulating sheet from which spacers can be cut.

Square plates have the advantage of enabling change of capacitance with area to be roughly investigated easily. This advantage does not preclude the use of circular plates, which it may perhaps be possible to manufacture so as to maintain their flatness more perfectly.

Quantity 2 pairs

Experiments

3.2 3.4 3.7 3.8
8.13

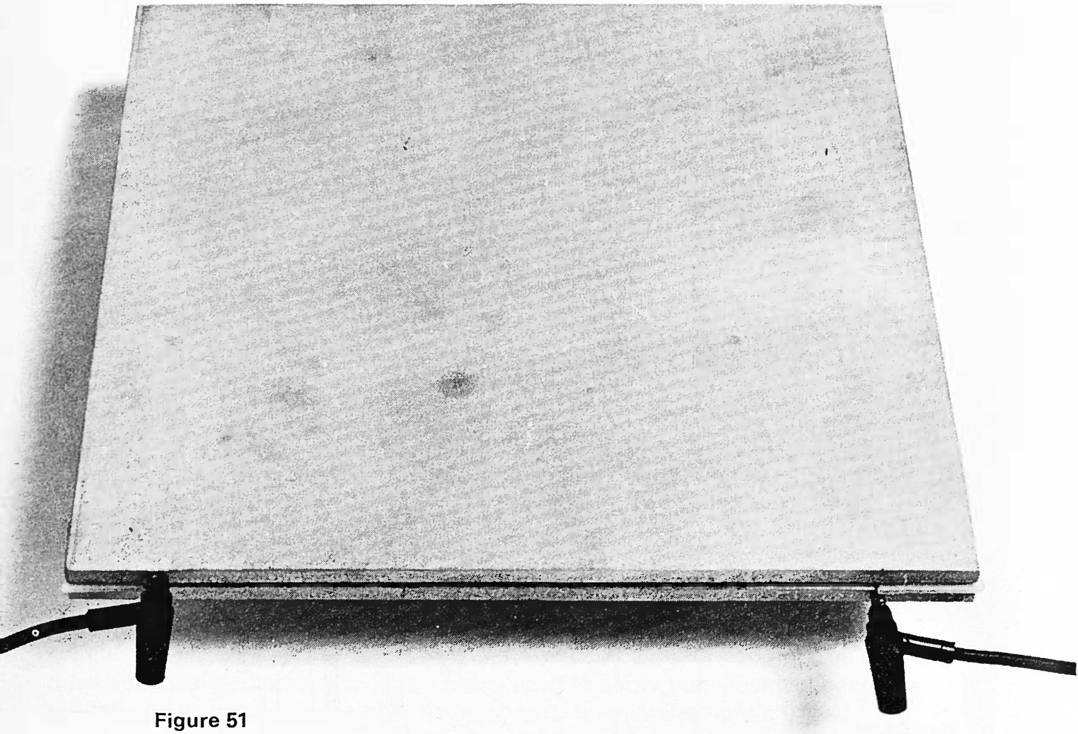


Figure 51
Item 1025. A pair of capacitor plates.
Photograph, Michael Plomer.

1026 kit to make gravitational constant apparatus

A small torsion balance, based on Cavendish's, with which the gravitational constant can be estimated. The apparatus as supplied by a manufacturer need not include a lamp and scale to measure the deflection. If the large attracting masses are made of mercury, the manufacturer should supply flasks to contain the mercury as part of the apparatus, but not the mercury itself. The gravitational effect is so small that the apparatus must be delicate and fragile. Manufacturers are not invited to supply apparatus with a permanent torsional suspension ready for immediate use, but plenty of material (e.g. tungsten wire) from which the suspensions are made should be provided. It is intended that only the more patient and skilful pupils should take measurements, having first completed the suspension and set up the apparatus themselves. Consequently a simple design of balance is important.

Quantity 1
Experiment 3.9

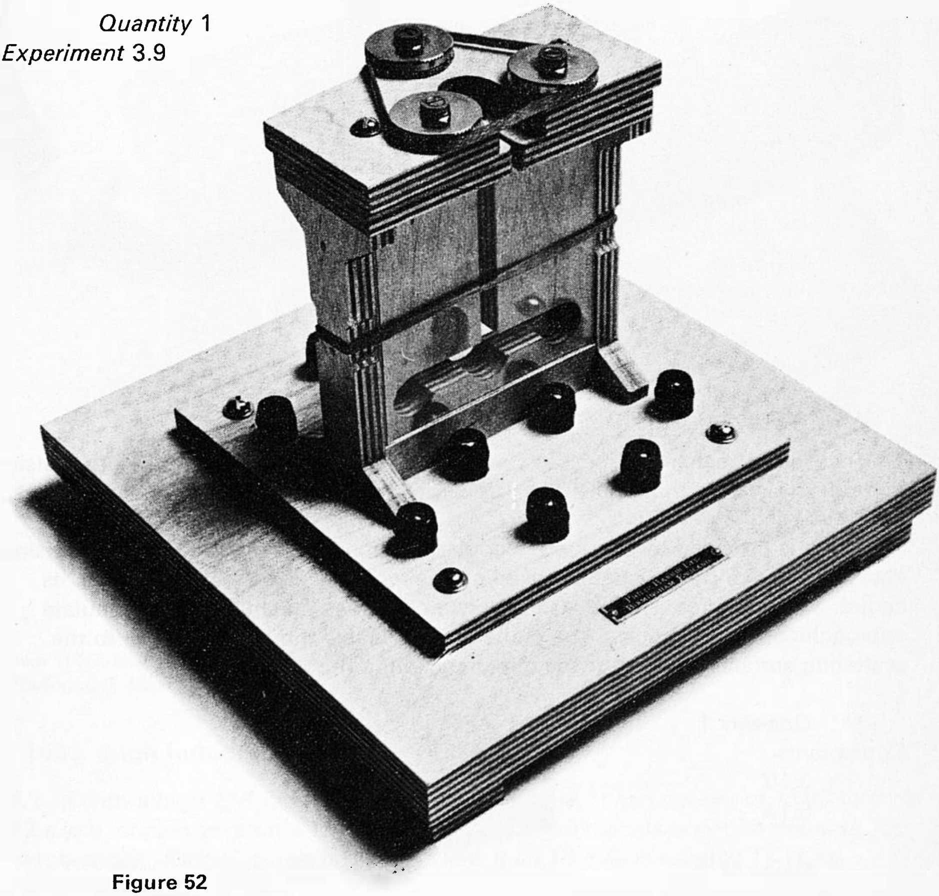


Figure 52
Item 1026. Kit to make gravitational constant apparatus.
Photograph, Michael Plomer.

1027 **Rogowski spiral**

A flexible spiral coil for estimating $\int B\,dl$. Suitable dimensions are about 1 metre long at 5 turns per mm (or more), and about 500 mm² area of cross-section. A resistance of about 100 Ω makes the spiral suitable for use with a low resistance galvanometer, such as item 1001 but a higher resistance is no disadvantage for use with a.c. It should be possible to loop the spiral at least twice around a conductor.

Quantity 1
Experiment 7.14

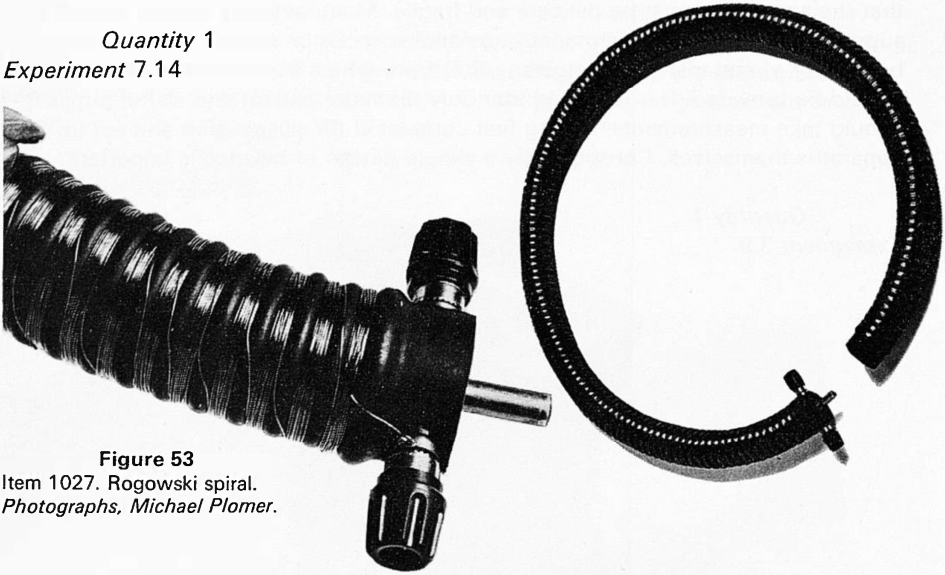


Figure 53
Item 1027. Rogowski spiral.
Photographs, Michael Plomer.

1028 **alpha scattering analogue**

This is used to scatter ball-bearings according to an inverse square law of repulsion, in order to simulate the repulsion of alpha particles from an atomic nucleus.

The force is provided by a smooth, circular hill, about 0.3 m in diameter, and rising above the bench by an amount based on the reciprocal of the distance from its centre. Manufacturers should also supply a chute and suitable balls to simulate approaching alpha particles. The chute should enable the balls to get onto the scattering surface in reproducible directions without bouncing.

Quantity 1
Experiments
3.10
5.14

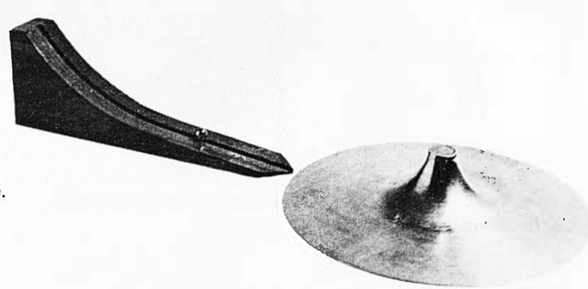


Figure 54
Item 1028. Alpha scattering analogue.
Photograph, Michael Plomer.

1029 **Hall voltage apparatus for metals**

A stand for holding a piece of metal foil, and making current and voltage connections to it, including a pair of voltage connections on the same side of the specimen to enable misalignment to be compensated. A means of holding a C-core and magnetizing coil in position, and a potentiometer for misalignment compensation are useful. The apparatus is required only for one experiment, which is complicated and will be done by few students at the most.

Quantity 1
Experiment 7.5

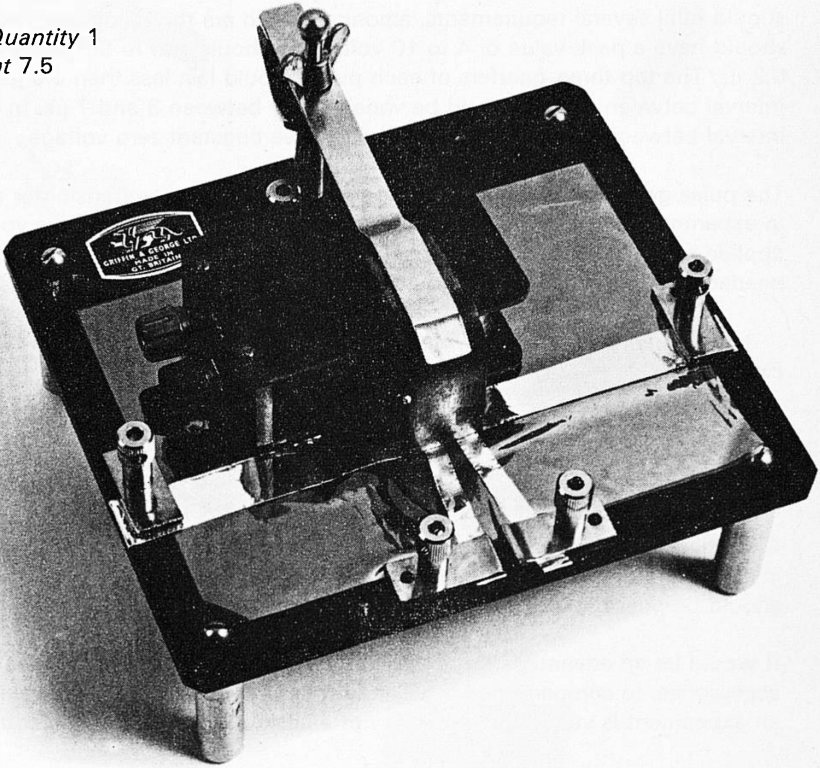


Figure 55
Item 1029. Hall voltage apparatus for metals.
Photograph, Michael Plomer.

1030 **high inductance coil**

A coil with a high L/R ratio when used on a C-core. It can consist of 1100 turns of 22 s.w.g. copper wire on a former occupying the whole space within the core. Its inductance, on the C-core, for currents less than 15 mA, is roughly 15 H. Its resistance is about 6 Ω.

Quantity 12

Experiments

6.12 6.13 6.14 6.16 6.17 6.19
7.3 7.12 7.13
8.11

1031 200 kHz pulse generator

A battery-operated circuit giving a very sharp pulse at about 200 kHz. The circuit should fulfil several requirements, amongst which are the following. The pulse should have a peak value of 4 to 10 volts, and should rise to this value within 0.2 μs. The top three-quarters of each pulse should last less than 0.5 μs. The interval between pulses should be variable, say between 3 and 7 μs. In the interval between pulses, the circuit should give constant zero voltage.

The pulse generator is required to modulate the 3 cm wave transmitter (item 184/1) in experiment 4.4. For this purpose, some smoothing of the negative voltage applied to the reflector in the transmitter (if it contains a klystron) may be needed. The pulse generator should contain a suitable capacitor for this purpose.

Quantity 1

Experiments

4.4
8.10

1032 speed of light apparatus

A rotating mirror apparatus for estimating the speed of light over a short distance in the laboratory. A simple method is more desirable than an accurate result. It should be possible to set up and use the apparatus in subdued daylight.

It would be an advantage if the apparatus could be adapted, by means of optional accessories, to compare the speed of light in air with the speed in water, but such an experiment is very difficult and is not a basic requirement of the course.

Quantity 1

Experiment 4.3

1033 cell holder

A holder for up to four U2 cells, so as to deliver 1.5, 3.0, 4.5, and 6.0 volts at 4 mm sockets. It should be easy to change the voltage quickly.

The great majority of experiments with low voltage direct current require only small currents, such as dry cells can supply. A well smoothed, multi-tapped mains-operated supply could replace this item, and eliminate the running cost of dry cells, which is considerable (£5 to £10 per annum). If the capital cost of such supplies is not too large, they may have the economic advantage over dry cells.

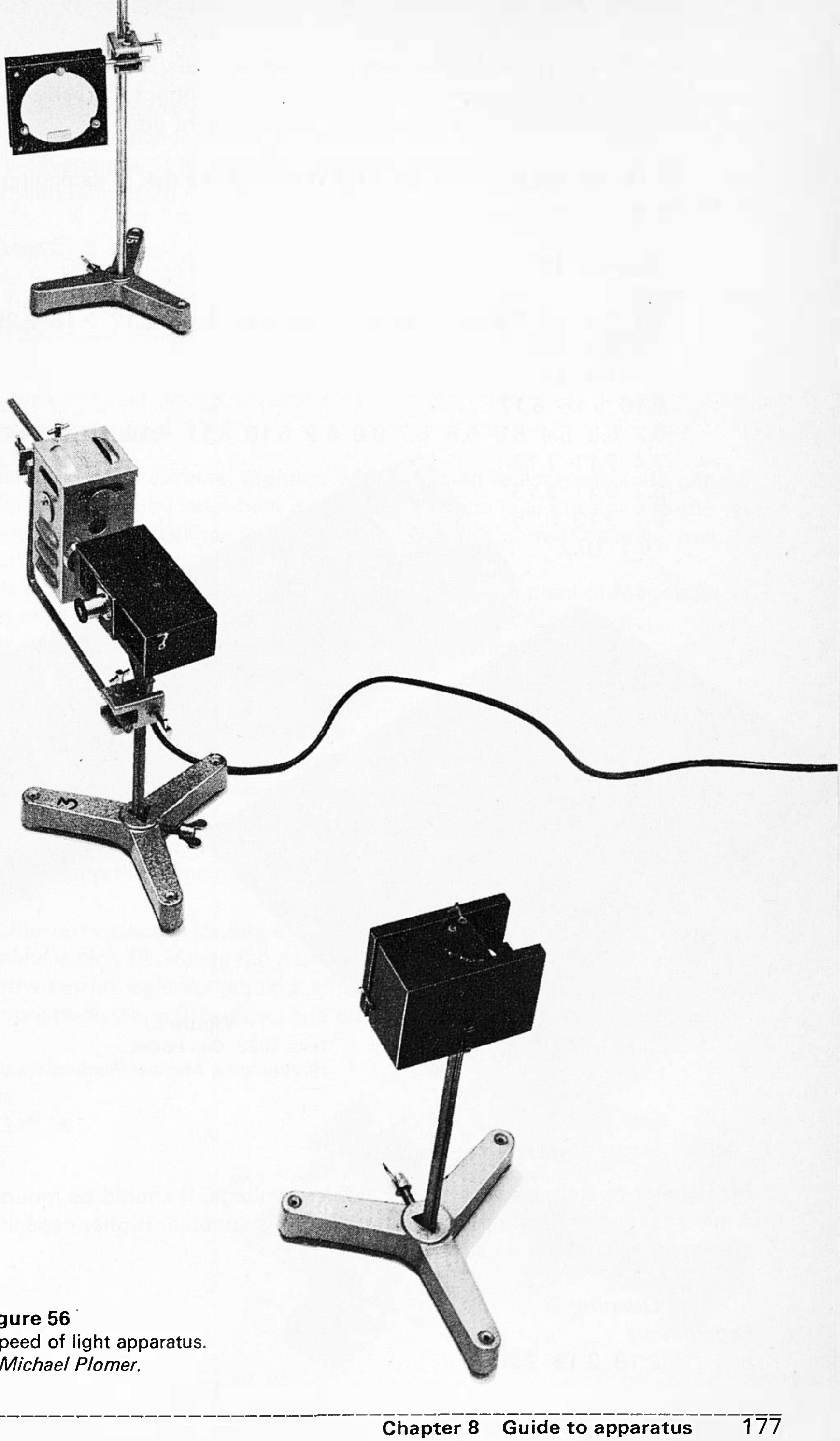


Figure 56
Item 1032. Speed of light apparatus.
Photograph, Michael Plomer.

The important considerations are very good smoothness, simplicity, ease with which the voltage can be changed in roughly equal steps without the use of a voltmeter, and reasonable steadiness of the voltage at low current drain.

Item 176, 12 volt batteries, can be used, but there is a risk of damaging them by accidental short circuit.

Quantity 16

Experiments

2.1 2.3 2.4 2.6 2.7 2.8 2.9 2.14 2.15 2.16 2.17 2.18 2.25 2.28 2.29
3.5 3.6 3.12
4.2 4.4 4.9
5.10 5.16 5.17
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10 6.11 6.12 6.13 6.14 6.16 6.19
7.4 7.11 7.12
8.2 8.11 8.13
9.1 9.13 9.15
10.1 10.2

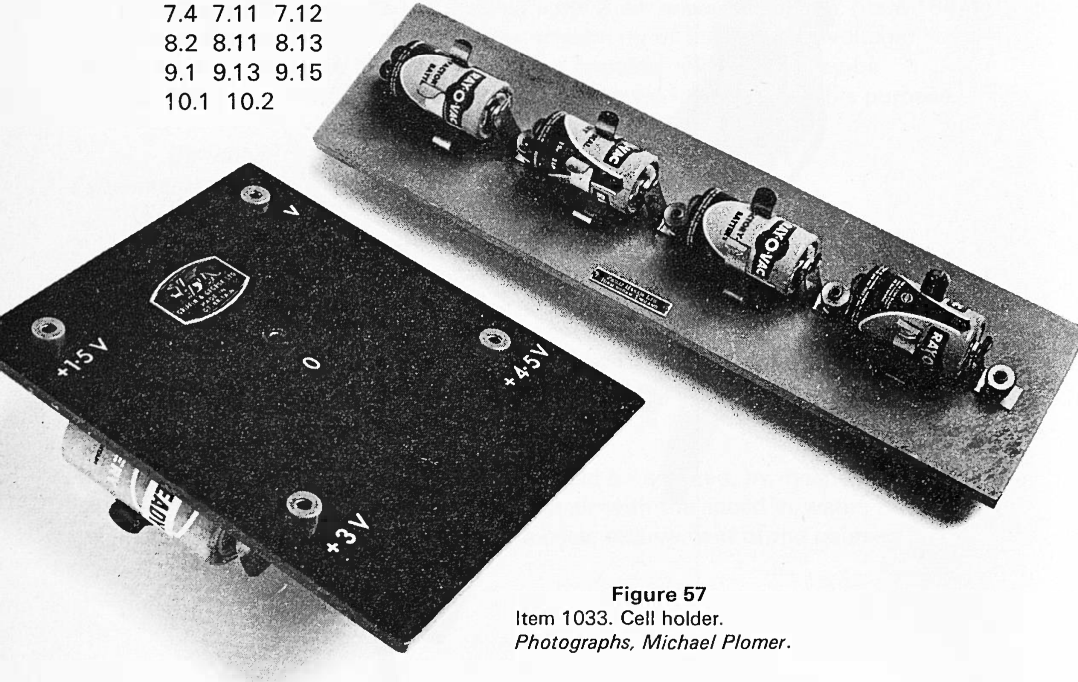


Figure 57
Item 1033. Cell holder.
Photographs, Michael Plomer.

1034 large electrolytic capacitor

A capacitor to store a lot of energy at a low voltage. It should be mounted with 4 mm sockets. A 10000 μF 30 volt capacitor is suitable. Higher capacitance and maximum voltage are an advantage.

Quantity 2

Experiments

2.18 2.19 2.20

1035 pre-amplifier

A battery-operated oscilloscope pre-amplifier with a gain of about 40 dB up to about 10 MHz. An amplifier which can also be used for low frequencies and d.c. would have advantages. It is possible that such an amplifier could be made compatible with item 1075.

Quantity 2

Experiments

4.1 4.4 4.16
6.19
8.7

1036 current balance

A simple rectangular wire frame, together with mounted replaceable knife edges (razor blades, for example) on which it pivots and which lead current into the wire. Except for its width, the balance is similar to the Malvern current balance, item 173.

The balance should be wide enough to accommodate three pairs of Magnadur magnets on mild steel yokes (item 92), but should also fit inside the flat solenoid, item 1079, so as to measure the field in this solenoid.

The wire frame of the current balance is expendable, and can be made in the laboratory from a stretched length of 16 s.w.g. bare copper wire. The support on which the frame rests, carrying knife edges and 4 mm sockets connected to the knife edges, is a manufactured item. It should support the frame at such a height that the frame conveniently enters the flat solenoid, and can rest in the middle of a magnet made from the mild steel yokes. It is best to buy the flat solenoid and the current balance from the same manufacturer.

It is useful, but not essential for any experiment in the course, to have a narrower current balance which fits inside the narrowest of the set of solenoids, item 1037. Such a narrow current balance requires a further knife edge on the support, placed at the appropriate distance from one knife edge provided for the wider balance.

Quantity 2

Experiments

7.3 7.15

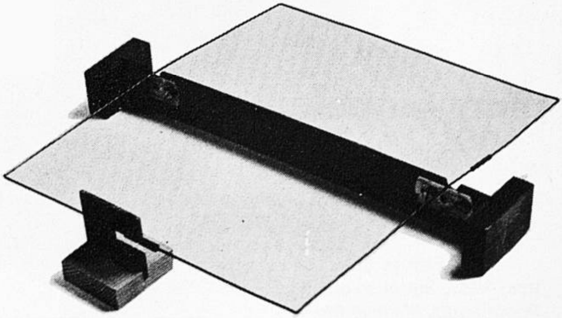


Figure 58
Item 1036. Current balance.
Photograph, Michael Plomer.

1037 set of solenoids

Four single-layer solenoids of equal length. In the set two solenoids are narrow, having half the area of cross-section of the other two. One narrow and one wide solenoid each have twice as many turns as the other two.

The solenoids should:

be long enough for the field at the centre to be not much less than if the solenoid were infinitely long

allow the narrow solenoids to be slid inside the wide ones

be open and without obstruction at either end

end in 4 mm sockets.

Square cross-section and the following dimensions give satisfactory results. Length 0.3 m; wide solenoids 70 mm × 70 mm; narrow solenoids 50 mm × 50 mm; one wide and one narrow solenoid to have 380 turns; one wide and one narrow solenoid to have 190 turns. 22 s.w.g. insulated copper wire is suitable for all windings.

Quantity 2 sets

Experiments

6.1 6.15 6.18
7.10 7.13 7.14 7.15
8.12

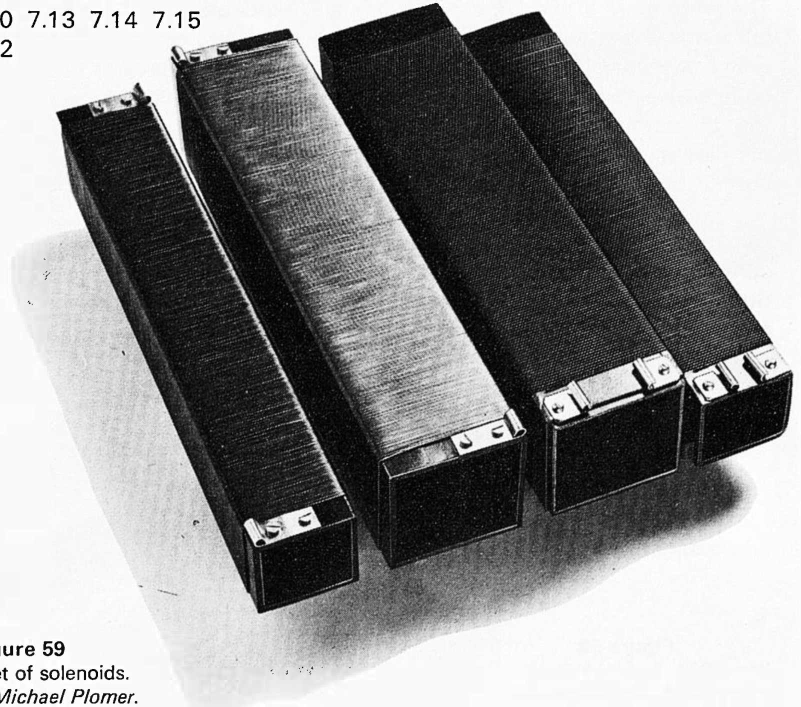


Figure 59
Item 1037. Set of solenoids.
Photograph, Michael Plomer.

1038 Hall probe and circuit box

A small Hall probe for measuring magnetic field. Satisfactory Hall probes may be very thin wafers mounted on metal backing plates. Thinner material reduces current and heating for a given Hall voltage, and a metal backing plate reduces temperature differences. With a sensitivity of 0.2–0.5 volts per tesla at a current of 200 mA, it is possible to estimate fields of the order of 10^{-4} tesla using direct current. The mounting of the Hall probe should restrict its use as little as possible. It must be possible to measure the field well inside a solenoid.

The probe needs a circuit to link it with a meter. It is convenient to use a special small box containing a cell, a switch, a series resistor which may be a torch bulb, and a potentiometer for compensating for misalignment voltage. It should be possible, if desired, to put an ammeter in the circuit to measure the current through the probe.

Quantity 2

Experiments

7.4 7.13

8.13

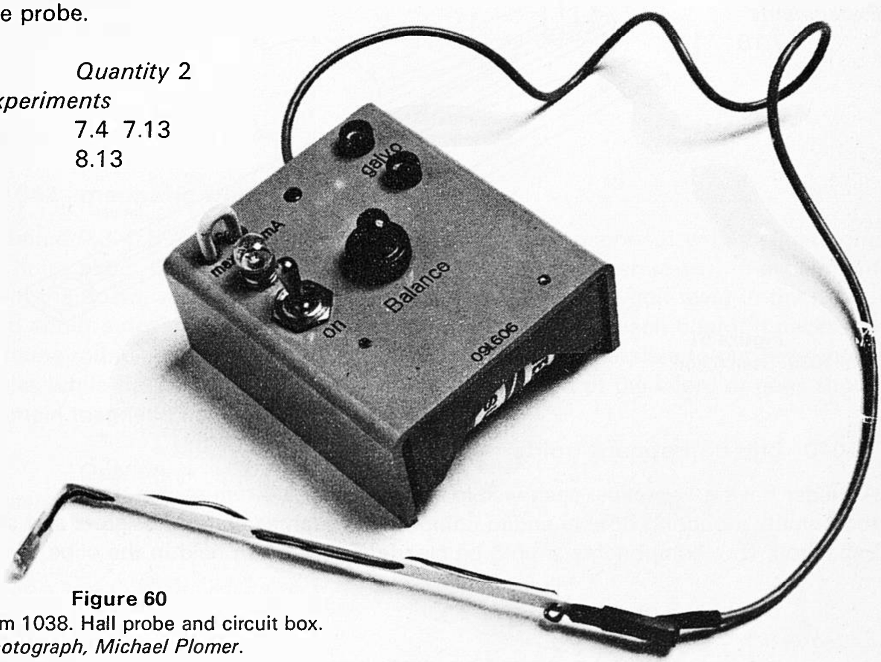


Figure 60

Item 1038. Hall probe and circuit box.

Photograph, Michael Plomer.

1039 search coil

A search coil of many turns of fine wire, suitable for measuring alternating fields with an oscilloscope. 5000 turns of 48 s.w.g. with a mean diameter of about 10 mm have been found to be satisfactory. The former on which the coil is wound should be transparent so that the wire can be seen. Consequently, manufacturers need not supply information about dimensions or area, but the number of turns should be marked on the device.

Mountings for the coil

1039/1 Axial: with the coil mounted coaxially with a rod, so that it can be used in the middle of a solenoid. The rod should be at least 0.2 m long.

Quantity 4
Experiments
7.10 7.11 7.13 7.17
8.12

1039/2 Lateral: with the coil mounted in a strip of insulator whose length is perpendicular to the coil's axis. The strip should be at least 0.2 m long.

Quantity 4
Experiments
7.10 7.13

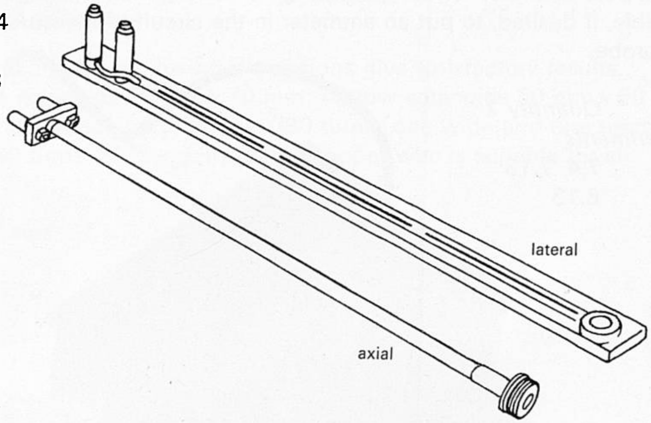


Figure 61
Item 1039. Search coil.

1040 clip component holder

A holder having two clips, each visibly connected to a 4 mm socket, for temporarily mounting double ended components such as carbon resistors and small capacitors. The components should be clearly visible when held in the clips.

Quantity 8 or more
Experiments
2.3 2.4 2.14 2.15 2.17 2.26 2.28 2.29
3.6
4.9
6.2 6.4 6.7 6.8 6.19
7.1 7.9 7.17
8.10 8.11 8.13

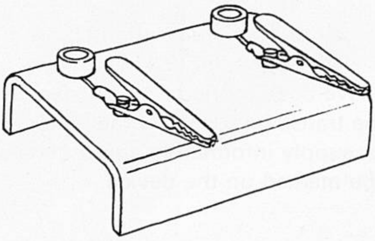


Figure 62
Item 1040. Clip component holder.

1041 potentiometer holder

A holder with 4 mm sockets and holes to enable a potentiometer to be mounted. Commercial preset controls cover a wide range of values, and holes to fit them are recommended. The holder should be supplied empty. A 5 kΩ potentiometer is used more often than any other, and could form part of item 1075, reducing the numbers of item 1041 needed.

Quantity 16

Experiments

2.8 2.9 2.14 2.15 2.16
3.5 3.12
6.3 6.4 6.6 6.19
7.5
8.11
9.15

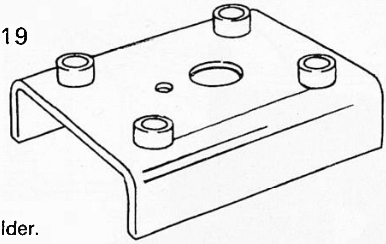


Figure 63
Item 1041. Potentiometer holder.

1042 magnetic field board

A board 0.3–0.5 m square with many holes in it (e.g. pegboard with a square grid of holes about 4 mm in diameter and about 20 mm between rows). In experiments with the board, wire will be wrapped round pegs (such as golf tees) in the holes, and about a dozen suitable pegs should be supplied with each board. If necessary, a frame round the board should be provided to make it possible to put pegs into the holes while the board is resting on the bench. No part of the board or pegs should contain magnetic material.

Quantity 4

Experiments

7.10 7.13

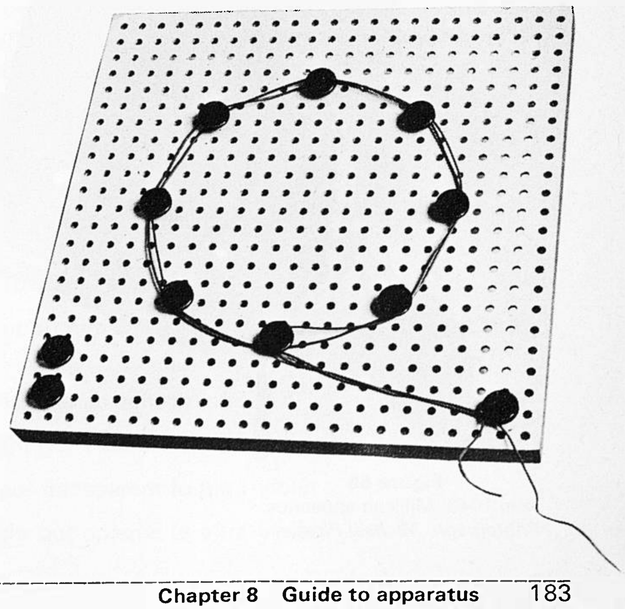


Figure 64
Item 1042. Magnetic field board.
Photograph, Michael Plomer.

1043 Millikan apparatus

An apparatus for measuring the charge on small oil drops or plastic spheres. From several such measurements it must be possible to deduce that the charges are small whole number multiples of a particular value, and also the magnitude of that value.

It is best if the apparatus is suitable for use with both oil drops and plastic spheres. It need not include any power supply or meter already specified for the O-level or Advanced course. Simplicity of design and ease of use are important. A version which consists of a cell which fits the microscope, item 23, may be convenient where the microscope is already available.

Quantity 1
Experiment 2.24

Figure 65
Item 1043. Millikan apparatus.
Photograph, Michael Plomer.

1044 large loudspeaker

A loudspeaker used at low frequencies to drive a rubber diaphragm into oscillation. It should be capable of handling at least 3 W at 100 Hz. A suitable loudspeaker can be bought from suppliers of components or of audio reproduction equipment. See item 1076.

Quantity 1
Experiments
4.16
10.8

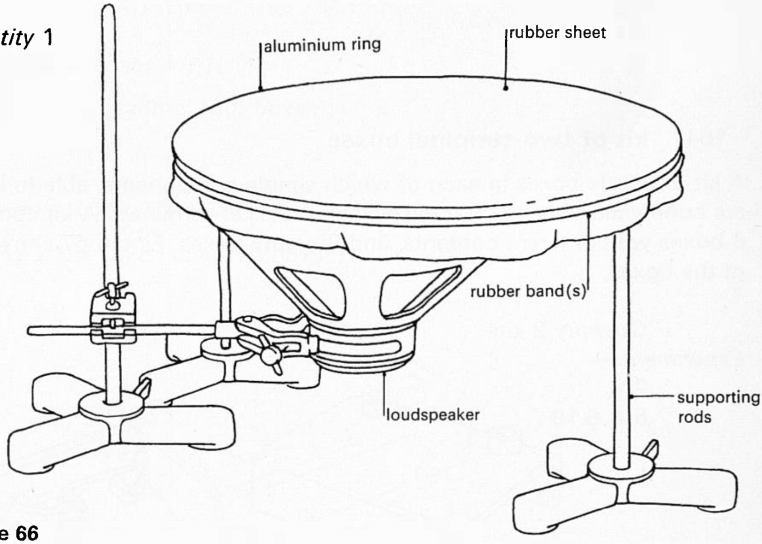


Figure 66
Items 1044 and 1076. Loudspeaker and ring used to generate standing waves on a rubber sheet.

1045 diode probe for microwave experiments

A diode probe for use with 3 cm wave equipment, using item 184/1. It replaces the horn receiver (item 184/2) for some purposes, being able to receive over a wider angle, though also being less sensitive.

Quantity 1
Experiments
4.1
8.4

1046 infra-red and ultra-violet filters

A set of four different filters about 50 mm square having as nearly as possible the following properties:

opaque to visible light but transparent to infra-red

transparent to visible light but opaque to infra-red

opaque to visible light but transparent to ultra-violet

transparent to visible light but opaque to ultra-violet

Thick filters of materials like glass or Perspex are more durable than gelatine filters. The optical quality of the filters should be such as will not impair the image produced by a parallel beam projector (item 1068).

Quantity 1

Experiments

4.2
5.17
10.2

1047 kit of two-terminal boxes

A kit of puzzle boxes in each of which simple components, able to be concealed, are connected between 4 mm sockets or socket-terminals. A kit consists of about 6 boxes with different contents, and 2 empty boxes. Figure 67 shows the contents of the boxes.

Quantity 2 kits

Experiments

2.1
6.4 6.19

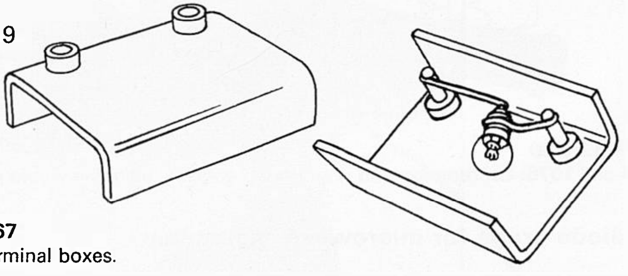


Figure 67
Item 1047. Two-terminal boxes.

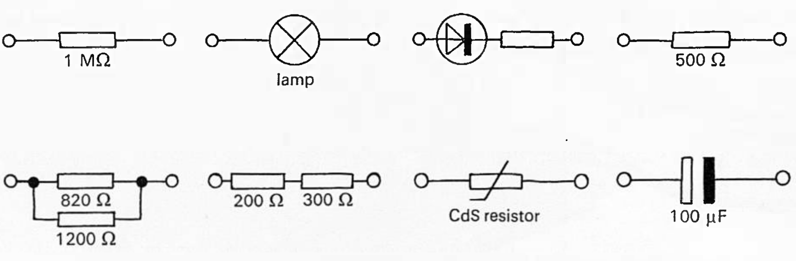


Figure 68
Item 1047. Possible contents of two-terminal boxes.

1048 four-terminal boxes

Two kits of puzzle boxes, like item 1047, but each having four terminals. One pair of terminals is permanently connected together. Various resistors and passive components are connected to the other terminals. The boxes should be such that the contents are invisible in use, but can be inspected if necessary.

Kit 1 consists of four different boxes, containing rather simple circuits. Kit 2 consists of seven different boxes, containing more complicated circuits. Details are given in *Teachers' guide*, Unit 2.

It may be convenient for a manufacturer to sell, and for a school to buy the boxes without components in them.

1048/1 *Four-terminal boxes, kit 1*

Quantity 2 kits (each of four boxes)
Experiment 2.6

1048/2 *Four-terminal boxes, kit 2*

Quantity 2 kits (each of seven boxes)
Experiments
2.6 2.7 2.8

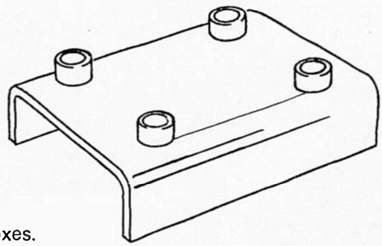


Figure 69
Item 1048. Four-terminal boxes.

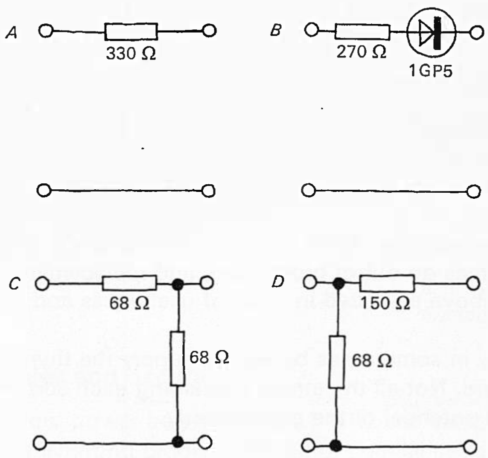


Figure 70
Item 1048/1. Four-terminal boxes, kit 1. (Possible contents of boxes.)

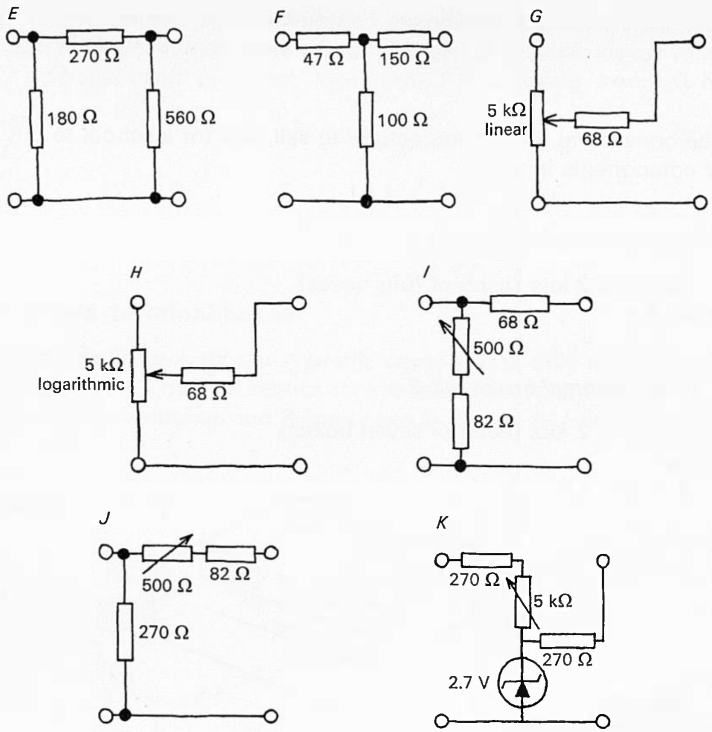


Figure 71
Item 1048/2. Four-terminal boxes, kit 2. Possible contents of boxes.

1049 thyratrons and thyratron base

A board carrying international octal and B7G valve bases wired in parallel to 4 mm sockets, so that the behaviour of a thyratron plugged into either base may be investigated.

Three thyratrons are suitable: EN91 (xenon); 884 (argon); and 6K25 (helium). Such tubes sometimes go out of production, and replacements may have to be found. The tubes above are listed in order of usefulness and of convenience of use.

Manufacturers may in some cases be able to supply the thyratrons with the thyratron base board. Not all thyratrons containing each sort of gas will appear to give the ionization potential of the gas correctly.

Quantity 2

Experiments

2.26 2.28 2.29

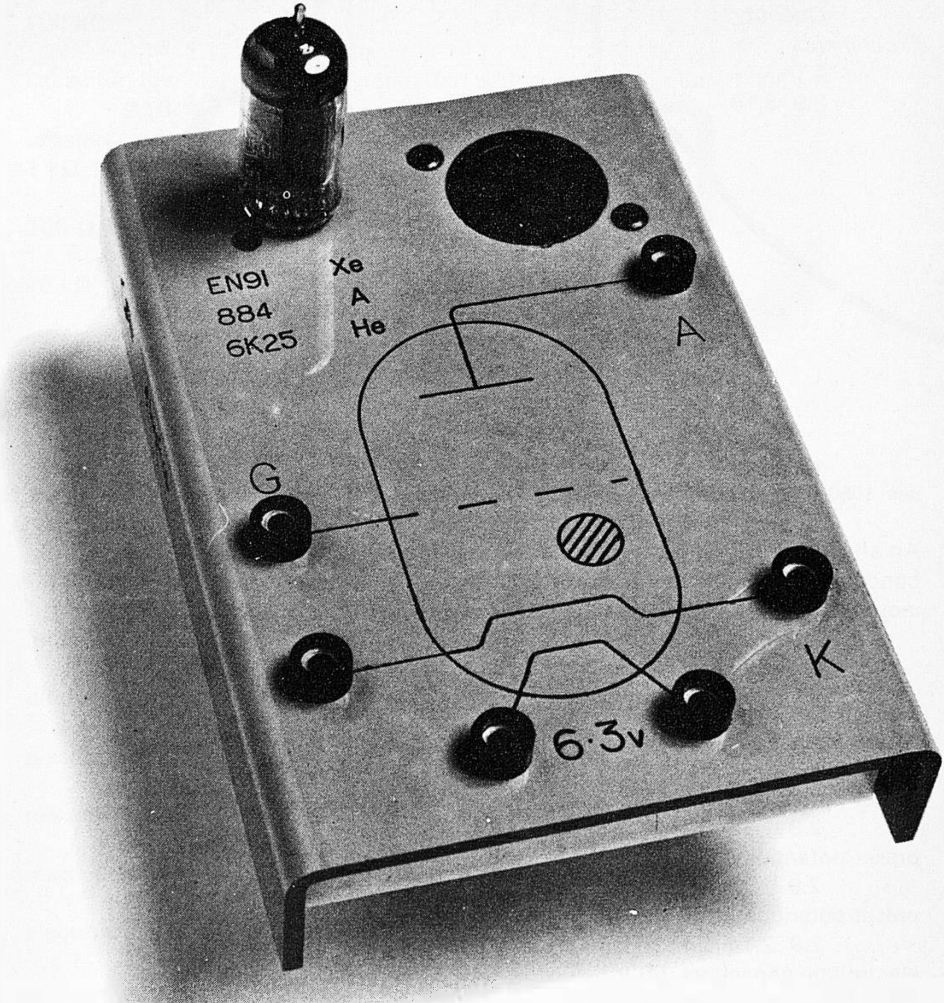


Figure 72
Item 1049. Thyratron base.
Photograph, Michael Plomer.

1050 15 cm dipoles and oscillator

A kit consisting of a low power battery-driven 1 GHz oscillator, modulated at an audio frequency, a transmitting dipole, a length of coaxial cable to join the oscillator to the transmitting dipole, and a receiving dipole carrying a rectifier.

The transmitting dipole should also be usable with a 0–5 kV supply (item 14) as a spark transmitter; if not, a separate transmitting dipole should be provided for this purpose.

Quantity 2
Experiments
4.1
8.9 8.14

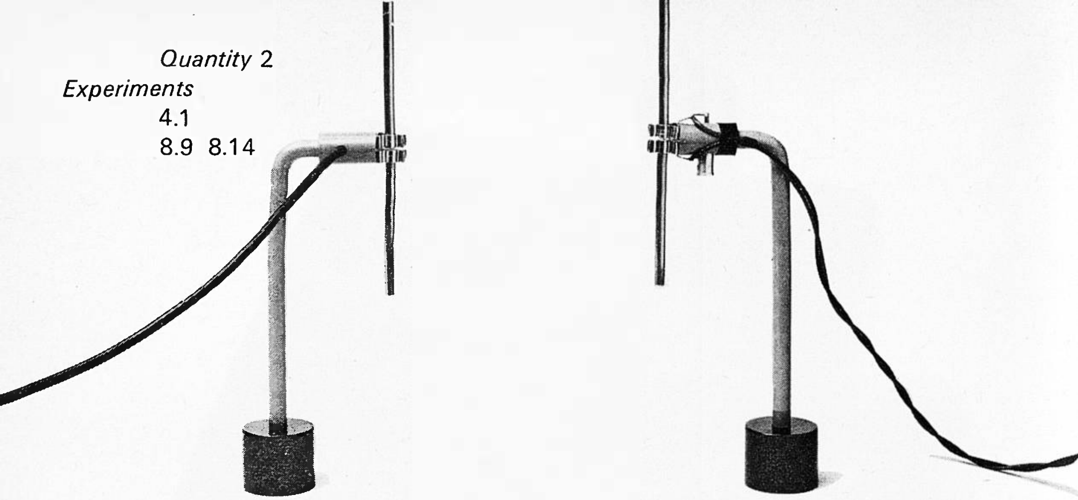


Figure 73
Item 1050. 15 cm dipoles. *Photograph, Michael Plomer.*

An effective design for these items requires the dimensions of high frequency conductors to be chosen so that they are properly matched. The dipoles should be mounted so as not to restrict the use of reflecting conductors near them.

1051 **small electrical items** listed in order of teaching

The relevant experiments are listed under each item.
carbon resistor, $\frac{1}{8}$ W, 150 Ω
2.3
preset potentiometer 5 kΩ (up to 16 required). See items 1041 and 1075.
2.8 2.16 3.5 3.12 6.2 6.3 6.4 6.6 6.19 8.11 9.15
preset potentiometer 1 kΩ
2.9
preset potentiometer 100 kΩ
2.9 2.14 2.15 6.6
electrolytic capacitors, 50 V:
500 μF (up to 16 required)
2.14 2.15 2.17 6.8 6.16 7.17
250 μF
2.14 6.16
100 μF
2.14 6.16
50 μF
2.14 6.16
resistors (any wattage):
100 Ω
2.14
350 Ω
2.14

100 kΩ

2.14 2.17

capacitor, low leakage, polystyrene, 0.01 μF (accessory for item 1006)

2.16 3.5 3.12 3.13

resistors:

1 kΩ, 1 W

2.26

100 Ω, 5 W

2.26

10 kΩ

2.28

220 Ω

3.6

2 kΩ

3.6

capacitor, paper, 2 μF

3.6

resistor, 1 MΩ, $\frac{1}{4}$ W

4.9

small loudspeaker (50 mm diameter)

4.16

tuning capacitor, 365 pF or 500 pF

6.1 6.18

diode, 0A81 or 1 GP 5

6.1 6.18

preset potentiometer 1.5 Ω

7.5

resistor 68 Ω

8.10

resistor 120 Ω

8.11

electrolytic capacitor 1000 μF, 15 V (10 required)

8.11

germanium transistor (OC 71, for example)

9.13

1052 absorbers for alpha, beta, and gamma rays

For the study of absorption of radiation from radioactive sources. Some manufacturers supply a suitable kit with their radiation detecting instruments. Absorbers, about 50 mm square, can be obtained locally, cheaply. For alpha particles, cigarette paper, ordinary paper, and aluminium foil are suitable. Beta particles need pieces of aluminium sheet ranging in thickness, or stackable to achieve a range of thickness, from 1–5 mm. Gamma rays need lead from 5–20 mm thick. Lead obtained from a plumber or builder is suitable.

Quantity 1 kit

Experiment 5.4

1053 **local purchase items** listed in order of teaching

The relevant experiments are listed under each item.

glass wool
1.1

glass fabric
1.1

nylon fishing line
1.1 3.13 4.10 4.14

rubber bands
1.1 1.7 2.21 3.9 4.7 4.11 4.12 4.13

plywood (3 ply)
1.1 1.12

plywood (5 ply)
1.1 1.12

fibreglass
1.1 1.12

polythene food bags
1.1 2.4 3.9 5.8

polythene, heavy gauge sheet
1.1 1.7 1.11

plastic roofing material
1.1

mixed cement and aggregate
1.1 1.12

hardwood
1.1

softwood
1.1

corrugated paper
1.1

metal screen about 0.3 m square
1.4 1.5 1.6 4.1 4.4 8.4 8.6 8.16 8.18

hardboard screen about 0.3 m square
1.5 8.16 8.18

expanded polystyrene ceiling tiles
1.6 5.8

glue, e.g. Evo-stik 863
1.6 Unit 1 Appendix B

PVC insulating tape
1.7

thin string (or use item 10A)
1.7 2.30 4.14

razor blades
1.7 3.2 3.8 3.9 3.11 5.13 5.16 10.1

potatoes
1.7

sewing needles
1.7 4.13
Sellotape
1.8 2.21 3.2 3.8 3.9 3.11 3.13 4.7 4.9 9.10 9.11
toy balloons
1.9
pins
1.9 5.8
matches
1.11 2.25
steel knitting needles
1.12
glass fibre and resin repair kit
1.12
paint brush (for Aquadag)
2.4
cotton thread
2.18
Plasticine
2.18 4.1 4.12 7.9 7.16 8.13
card
2.21 4.9 4.13 5.17 5.18 7.11 8.1 10.2
candle
2.25
castor oil
3.3
semolina
3.3
aluminium foil (e.g. cooking foil)
3.9 7.1 8.1 8.8
quick-drying glue (e.g. Durafix)
3.9 3.13
plastic football
3.11 3.13
fluorescent paper
4.2 5.18 10.4
plastic guttering, with two end stops (2 m long, roughly rectangular section)
4.5
rubber ball (Supaball)
4.9
long lath
4.10
cork
4.13 5.14 9.13
hacksaw blades
4.13

Meccano strips (Nos. 1 and 2a)
4.13
plastic curtain rings
4.14
wooden rod
4.14
screw eyes
4.14
sheet of rubber
4.16 10.8 10.9
wooden strips
7.13
length of thick insulated wire (e.g. wire for domestic electrical wiring)
7.14
aluminium plate, 0.2 m by 40 mm, 2 mm thick
7.16
aluminium plate, 50 mm square, at least 3 mm thick (item 1052 may serve)
7.17
empty 35 mm film can
7.17
cardboard 35 mm slide mounts
8.1 8.8 10.6
transparent ruler with millimetre graduations
8.1 8.5
bent metal plate
8.6
slab of expanded polystyrene
9.6 9.10 9.11
Vaseline
9.13
Polyfilla
9.15
fogged photographic film
10.6

1054 **expendable items** listed in order of teaching

The relevant experiments are listed under each item.
stainless steel wire, 44 s.w.g. bare (item 7A may serve)
1.1 1.7
soda glass rod, diameter 3 mm
1.1 1.7 1.11
soda glass tube, 4–5 mm diameter
1.2 1.10
copper wire, 14 s.w.g. bare
1.10 3.3 7.3 7.9 9.15

graph paper
2.1 2.17 3.9 3.13 5.11 5.14 9.3 9.4 9.8
constantan wire, 24 s.w.g. bare
2.2
constantan wire, 32 s.w.g. bare
2.2
copper wire, 36 s.w.g. enamelled
2.3 8.1 8.13
filter paper
2.5
constantan wire, 28 s.w.g. insulated
2.20
photographic developer, fixer, P153 daylight printing paper
2.21 2.22 2.27 2.30 3.10 4.2 4.5 4.12 4.14 5.5 5.7
film and monobath developer
2.21 2.22 2.27 2.30 3.10 4.5 4.12 4.14 5.3 5.7 9.2
nichrome wire, 28 s.w.g.
2.25
aluminized plastic film, 25 gauge
3.2
copper wire, bare, 22 s.w.g.
3.8 7.15
dental X-ray film
5.5
fast bromide paper
5.5
steel rod, 5 mm diameter, 50 mm long
7.7 7.8
rubber pressure tubing
7.7 7.8 9.11
constantan wire, 32 s.w.g., covered
9.6 9.10 9.14
glass tube, 10 mm bore
9.15
piece of porous pot
9.11

1055 **small laboratory items** listed in order of teaching

The relevant experiment numbers are listed under each item.
gas tubing
1.2 1.10 8.17
hypodermic needle, 25 gauge
1.2 1.10 3.8 3.11
micrometer screw gauge
1.7 1.8 3.7 7.5

Vernier callipers
1.7 3.7 5.4
silicone putty (known as Potty putty, Crazy putty, and by other trade names)
1.7
hammer
1.7 4.7
Petri dishes
1.10
file, small triangular
1.11
Perspex safety screen
1.11
0.5 kg mass
2.10
hypodermic syringe, 1 cm^3
3.8 3.11
Perspex rod, 10 mm diameter
3.8 3.11
PVC tubing, 6.5 mm bore
3.8 3.11
polythene beaker, 250 cm^3
3.9
wooden rod 0.5 m long, 10 mm diameter
4.1
burette
4.9 9.11
measuring cylinder, 100 cm^3
4.16 9.10 9.12
rubber cord, 0.5 m long, 3 mm square cross-section
4.15 10.8 10.9
gold foil
5.6
cork borer
5.8
polythene bottle, 50 cm^3
5.9 5.18
dice
5.11 9.3 9.4 9.5 9.8
glass T-piece
5.13 9.11
PVC tubing, 8 mm bore
5.13
PVC tubing, 5 mm bore
5.13
glass tubing, 8 mm outside diameter
5.13

drawing board
5.14
spirit level
5.14
wire gauze, 20 mesh copper
5.16 10.1
glass plate
5.16 10.1
geared hand drill
7.7 7.8
whistle
8.17
test-tube, hard glass, 150 mm by 25 mm
9.7 9.11 9.15
flat-bottomed flask, 1 dm^3 (1 litre)
9.12
specimen tube
9.15
teat pipette
9.15
light chain, 1 m long (bath plug chain, for example)
10.9
dressmaker's elastic, 1 m
10.9

1056 **chemicals** listed in order of teaching

The relevant experiment numbers are listed under each item.
Teepol or washing-up liquid
1.2 1.10
glycerol
1.2 1.10
potassium permanganate (solid)
2.5
ammonium hydroxide (strong solution)
2.5
carbon tetrachloride
3.3
methylated spirit
5.3 5.6 5.8 5.15 9.14
amyl acetate or iso butyl methyl ketone (2-methyl butan-3-one)
5.9
concentrated hydrochloric acid
5.9
uranyl nitrate (solid)
5.9

magnesium ribbon
5.16 10.1
iodine (solid)
9.7
sodium metabisulphite (solid)
9.12
sodium sulphite (anhydrous solid)
9.12
formaldehyde
9.12
phenolphthalein
9.12
sodium hydroxide (solid)
9.12
dextrose (glucose)
9.12
methylene blue, 1 per cent in ethanol
9.12
*0.1 M potassium iodide solution
9.12
*0.5M sulphuric acid
9.12
*0.1 M hydrogen peroxide solution
9.12
*0.01 M sodium thiosulphate solution
9.12
*0.2 per cent starch solution
9.12
1 M copper sulphate solution
9.15
zinc dust
9.15
0.1 M silver nitrate solution
9.15
saturated potassium nitrate solution
9.15
silver wire (100 mm length)
9.15

* Only required for an alternative version of experiment 9.12.

1057 alternating current ammeter

A dual or multirange meter giving full scale deflection for 1 A and for 5 A or 10 A. An instrument using a transformer, rectifier, and moving-coil movement is best because it has a linear scale and is not very dependent on frequency. It is economical to use a transformer–rectifier attachment on a microammeter (item 1002), or on a meter with a 10 mA movement.

Quantity 8 transformer–rectifier attachments

Experiments

6.15
7.11 7.13 7.15 7.17
8.12

1058 coil with 120+120 turns

A coil with 240 turns, centre tapped. Two such coils should fit onto the double C-cores and clip, item 92G. The coil should carry 2 A without overheating.

Quantity 16

Experiments

6.15
7.1 7.10 7.11 7.13 7.17

1059 earpiece

An earpiece or earphone or pair of earphones with impedance of not less than 1000 Ω. 4 mm plugs are convenient as the earpiece will be used with the electronics kit (item 1075). Satisfactory cheap earpieces or pairs of high impedance headphones can often be bought from radio suppliers. A pair of headphones can be separated to make two earpieces.

Quantity 8

Experiments

6.1 6.6 6.18 6.19

1060 vibrator

For producing mechanical vibrations at low and audio frequencies corresponding to the frequencies of a.c. supplied. The vibrator's impedance should be suited to the low impedance output of the signal generator (item 1009). A form of construction derived from that of a moving coil loudspeaker is suitable.

Quantity 1

Experiments

4.8 4.15 4.16
10.8 10.9

1061 aluminium disc

A thick aluminium disc to fit onto the turntable, item 154/1. The disc should be thick enough to show a marked effect due to eddy currents induced in the disc by a large magnet, item 50/3, held so that the disc passes between its poles. It is advisable to buy the disc and the turntable from the same supplier.

Quantity 1
Experiments
7.9 7.16 7.17

1062 drum of coaxial cable

About 200 metres of coaxial cable wound on a drum. Both ends of the cable should be accessible and may be fitted with 4 mm plugs. Capacitance, attentuation per unit length, and impedance are not critical.

Quantity 200 metres (1 drum)
Experiments
4.1
8.10

1063 multiple light source

Several lamps with straight filaments set parallel which, when seen from a distance or through a slit, may or may not be resolved as separate objects. Five festoon lamps, their centres about 10 mm apart, are suitable.

Quantity 1
Experiment 8.1

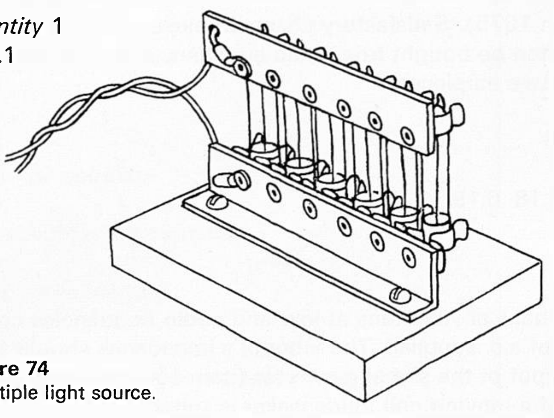


Figure 74
Item 1063. Multiple light source.

1064 low voltage smoothing unit

A unit for smoothing the output from a variable low voltage supply unit (item 59).

Quantity 1
Experiments
2.20 2.26 2.28 2.29
3.4 3.7
7.1 7.3 7.4 7.9 7.10 7.12
9.9 9.10

1065 big mirror

A flat mirror to reflect 3 cm electromagnetic radiation, about 1 m by 0.7 m. Metallized plastic stretched on stiffened plywood is suitable. Aluminium foil on wood is less satisfactory, but is more easily improvised. Schools are best advised to make their own mirrors, as larger sizes may sometimes be convenient.

It is best if the mirror reflects visible light well enough to form an image that can be used in aligning the mirror. The mirror is required for only one experiment, which is difficult and optional, but it would find other uses (for example with 1 GHz radiation) if it were available.

Quantity 1
Experiment 4.4

1066 'thoron' generator

A flexible bottle containing a solid thorium compound, fitted with tubes, filter, valves, etc. The radon 220 (or 'thoron'), which has recently emanated from the thorium and has not yet decayed, can be injected, by squeezing the bottle, into the apparatus (items 1008 or 28) where its decay is to be observed. The generator must not allow solid radioactive material to be released.

Quantity 1
Experiments
5.10 5.15

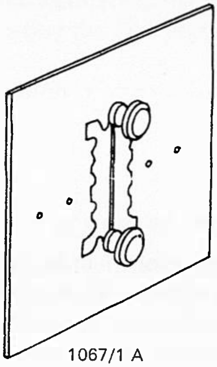
1067 physical optics kit

A kit of items, listed below, for class experiments. The items should be designed to be compatible with one another, and to be easy to align. The kit is used with item 94A (lamp, holder, and stand), and eight of these are required.

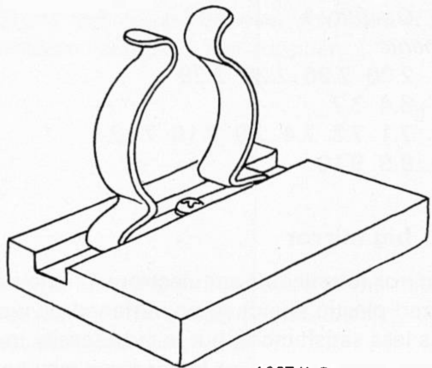
Because some of the parts needed may already be available in a school, because some may be easy and cheap to make, and because not all are economic for a manufacturer to supply, the list of parts below is divided into three groups.

1067/1

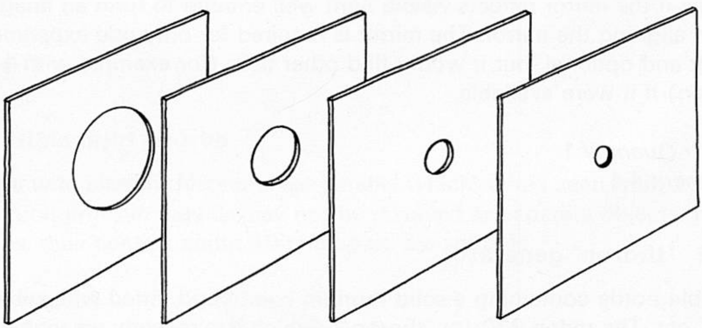
A manufacturer should be able to supply these parts as one transaction; it may not be economic for them to be supplied as separate items. These items are shown in figure 75 *a*.



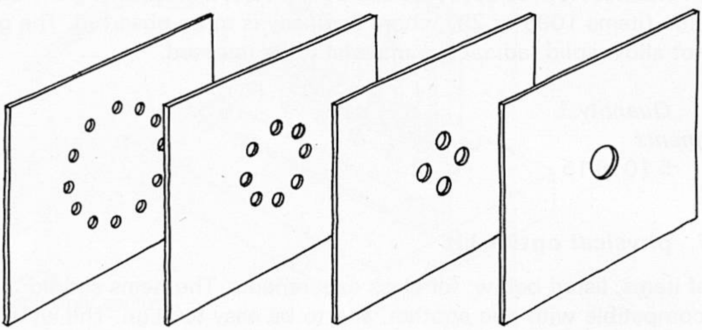
1067/1 A



1067/1 B



1067/1 E



1067/1 F

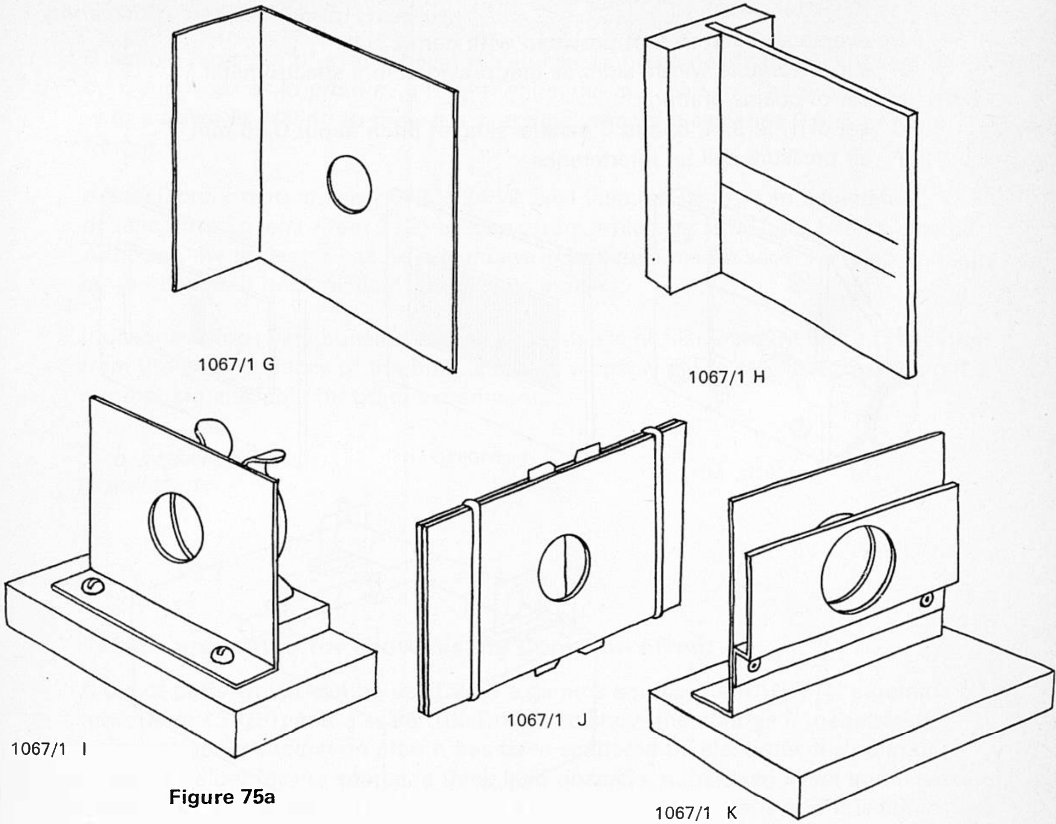
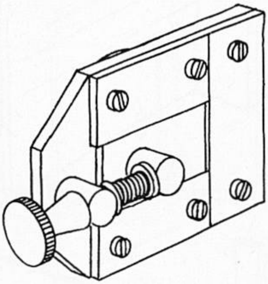


Figure 75a

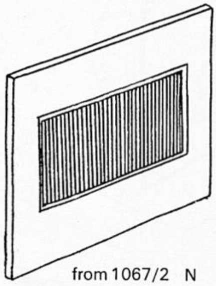
		Quantity
A	sheet with slit and holes	4
B	holder for lens of diameter 37 mm	8
C	plano-convex lens, diameter 37 mm, focal length 0.5 m (+2D)	8
D	plano-convex lens, diameter 37 mm, focal length 0.15 m (+7D)	1
E	set of stops for lens in holder	1
F	set of masks with holes at different zone radii	1
G	big stop to stand on bench	4
H	small translucent screen	6
I	holder for eyepiece or adjustable slit	5
J	holder for two halves of a razor blade to be used as a single slit	16
K	support for a set of slits	1

1067/2
A school may have some of these parts. They should be available as separate items. See figure 75 *b*.

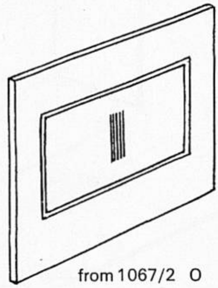
		Quantity
L	eyepiece (such as that provided with item 23)	4
M	slit of variable width, such as that provided in a spectrometer	1
N	set of coarse gratings	1
O	set of 1, 2, 3, 4, 5, and 6 parallel slits, of pitch about 0.25 mm	1
P	air pressure cell for interference	1



1067/2 M



from 1067/2 N



from 1067/2 O

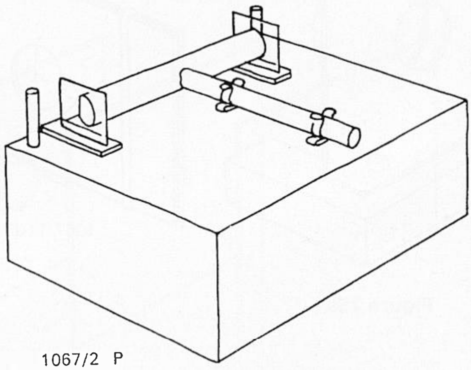


Figure 75b

1067/2 P

1067/3
A school should easily be able to make or provide all these items, but manufacturers may be willing to supply them. See figure 75 *c*.

		Quantity
Q	matt white reflecting screen (postcard)	8
R	set of three colour filters (red, blue, green)	6
S	small piece of fine black chiffon	1
T	card with slits for air pressure cell	1

Quantity 1 kit

Experiments
5.17
8.1 8.3 8.5 8.8
10.2

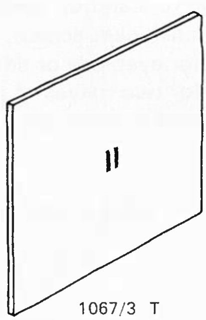


Figure 75c

1067/3 T

1068 parallel beam projector

A simple projector of a light beam which can be made nearly parallel or slightly converging so as to produce a bright white line on a screen. The projector is used with a prism or grating to project a spectrum when the screen is 0.5 m or more from it.

A satisfactory pattern uses a 12 V 24 W axial filament lamp at an adjustable distance from a lens (item 112) in a box from which no stray light beams emerge. Although the projector has no advantage in principle over a separate lamp and lens on the bench, it has practical advantages in use.

Individual lamps vary considerably in straightness of filament and lack of reflection from the back surfaces of the bulb, and it is worth while to select a good lamp if a number are available for other experiments.

Quantity 1
Experiments
4.2
5.17
10.2

1069 apparatus for showing the Compton effect

A set of parts which can be used with a gamma source (item 195/1), a gamma GM tube (item 130/6), and a scaler (item 130) to show the change in penetrating power of gamma radiation after it has been scattered by electrons in a solid or liquid. A holder for the source, a thick lead obstacle, a thin lead sheet and a piece of material for scattering the radiation (or a container for the material if it is liquid) are the important parts. The apparatus can be improvised without much difficulty.

Quantity 1
Experiment 10.10 (optional)

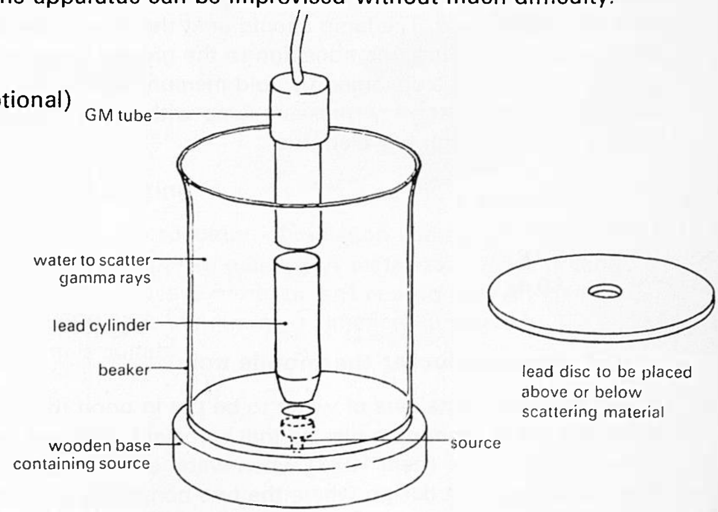


Figure 76
Item 1069. Apparatus for showing the Compton effect.

1070 **gas energy transfer apparatus**

An apparatus for estimating the thermal transfer of energy when the volume of a gas is changed. It may consist of a light clamped bicycle pump, with its outlet blocked, against which one junction of a thermocouple can be held. The change in temperature of the pump casing is compared with that of a larger mass of the same material, so that it is convenient to use an aluminium alloy pump with an aluminium block (item 77). The experiment can be regarded as a measurement of Boltzmann's constant. The gas energy transfer apparatus consists only of the pump, with suitable modification of the piston and outlet, mounted on a base so that it can be clamped to the bench together with thermal insulation to surround the pump. The apparatus can be improvised if an aluminium alloy pump whose casing has a heat capacity not exceeding 50 J K^{-1} can be obtained.

Quantity 1
Experiment 9.10

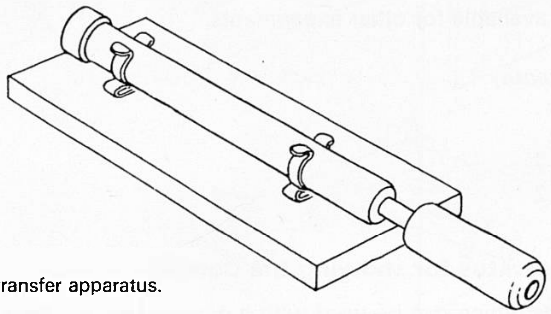


Figure 77
Item 1070. Gas energy transfer apparatus.

1071 **mercury discharge lamp**

A lamp emitting the principal visible and ultra-violet lines of the mercury spectrum down to a wavelength of 200 nm. High intensity is desirable within the limits imposed by danger and discomfort. Item 189 is too dim to be satisfactory except for a very small class. The lamp should emit the ultra-violet line of wavelength 254 nm corresponding to a transition to the ground state, and the line should be narrow enough to be absorbed by cold mercury vapour outside the lamp. These requirements suggest a low pressure lamp with a quartz envelope. Glass does not transmit short enough wavelengths.

Quantity 1
Experiments
5.18
10.4

1072 **semiconductor thermopile unit**

A unit enabling containers of water to be put in good thermal contact with the two sides of a set of thermocouples so that sufficient electrical power may be generated to run a solar motor (item 1023) when water at different temperatures is put into the two containers. In a design where the two containers are specially made they should be regarded as part of the unit with the thermopile. It should be possible to fill the two containers with water at the same temperature and observe the rise in temperature of one and the fall in temperature of the other when a current is driven through the thermopile. For this, a current of several amperes may be needed.

Quantity 1
Experiments
9.6 9.14

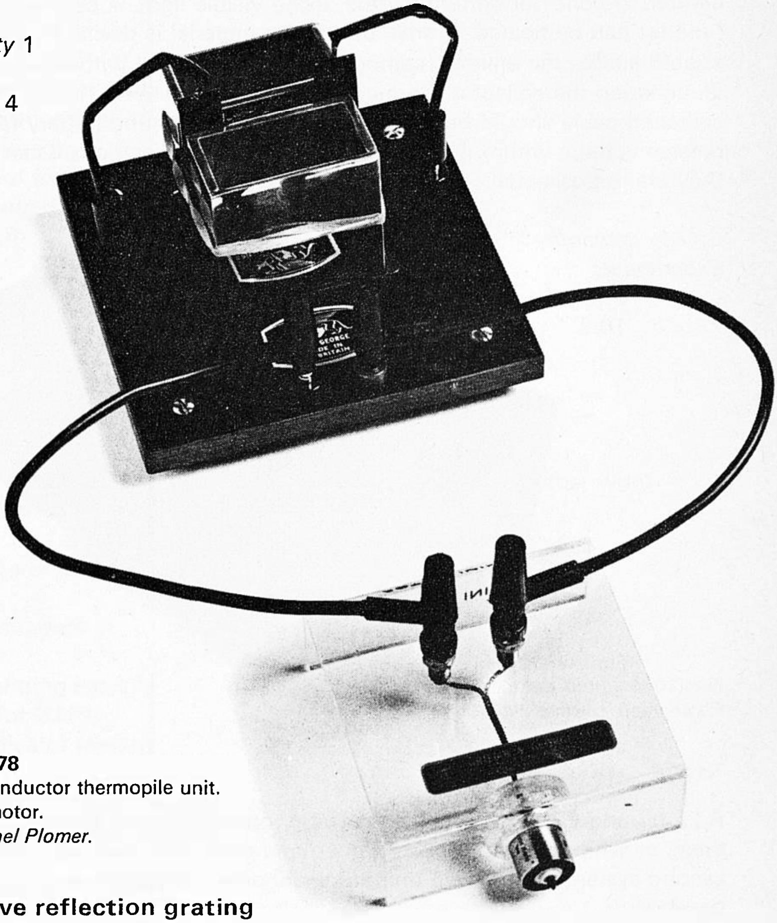


Figure 78
Item 1072. Semiconductor thermopile unit.
Item 1023. Solar motor.
Photograph, Michael Plomer.

1073 concave reflection grating

A grating capable of projecting the spectrum of radiation without the need for the radiation to pass through any transparent material. A metallized replica grating cemented onto the surface of a concave mirror or lens is adequate. An area 1000 mm² of grating with 600 lines per mm on a spherical surface with a radius of curvature of 0.5 m is suitable.

Quantity 1
Experiments
5.18
8.8
10.4

1074 photo-electric cell

A good photo-electric cell with which a fairly precise evaluation of Planck's constant is possible by measuring the least voltage which reduces the emitter-to-collector current to zero, using visible light. A cell whose collector (anode) can be heated to drive off emitter material is desirable. The mounting should enable the emitter (cathode) to be illuminated without at the same time illuminating the collector. Connection to an electrometer (item 1006) by means of a screened cable should be possible. A potentiometer and battery for providing reverse voltage within the mounting of the photo-electric cell can be useful, but they are not essential.

Quantity 1

Experiments

5.17

10.2

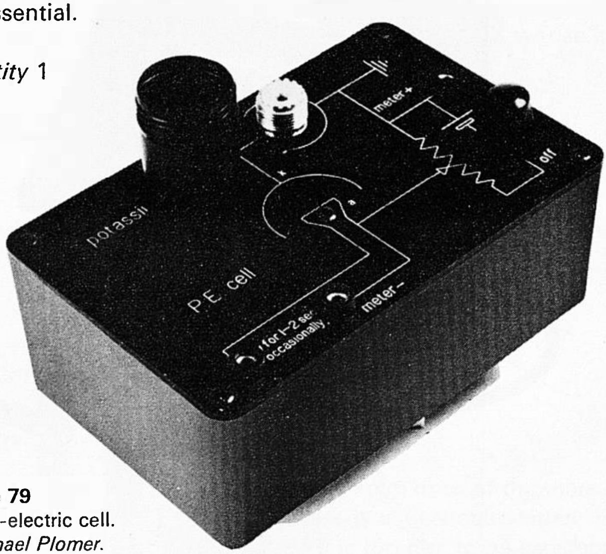


Figure 79
Item 1074. Photo-electric cell.
Photograph, Michael Plomer.

1075 electronics kit

A kit of modular units which either plug into baseboards carrying connections to them, or which plug into one another, and carry their own connections. The second system makes each unit more elaborate, but eliminates the cost of baseboards.

Each module, and baseboards if required, should be available as separate items, as well as in kit form as suggested below. Three kits are suggested. The *starting kit* contains enough modules for a pair of students to do many of the suggested experiments. In principle, nearly all the experiments can be done with this kit, but any attempt to do so would require so many of the basic units (item C) as to be very inconvenient indeed.

The *working kit* consists of a starting kit and some further modules, some of which contain, in effect, several of the basic units in varying combinations. The working kit is adequate for all the experiments suggested.

The *extension kit* may contain some of the items listed, and others which may become available in the future. It is not needed for the course, but it is hoped that the modular system will be developed in the future, adding items which either make the kit more convenient, or which add to its interest.

starting kit

Quantity in a kit is shown under each entry.

A baseboard for three modules
1 (if required)

B baseboard for one module
1 (if required)

C basic unit
3

D lamp indicator module
1

E switch module
1 (not required if baseboards having a switch are used)

working kit

Quantity is shown under each entry. Items are the *starting kit,* together with:

F *and*-gate module
1

G multivibrator module
1

H bistable module
1

I beam splitting module
1 (or 1 for 2 kits)

D lamp indicator module
1 more

A baseboard for three modules
(extra one for every two kits, if baseboards are required)

extension kit

Items such as:
resistance module (replacing item 1017, resistance substitution box)
capacitance module (replacing item 1018, capacitance substitution box)
potentiometer module (replacing item 1041, potentiometer holder)
battery eliminator
operational amplifier module
sinusoidal oscillator module
binary counter module
power amplifier module
voltage amplifier module
relay module, and many others.

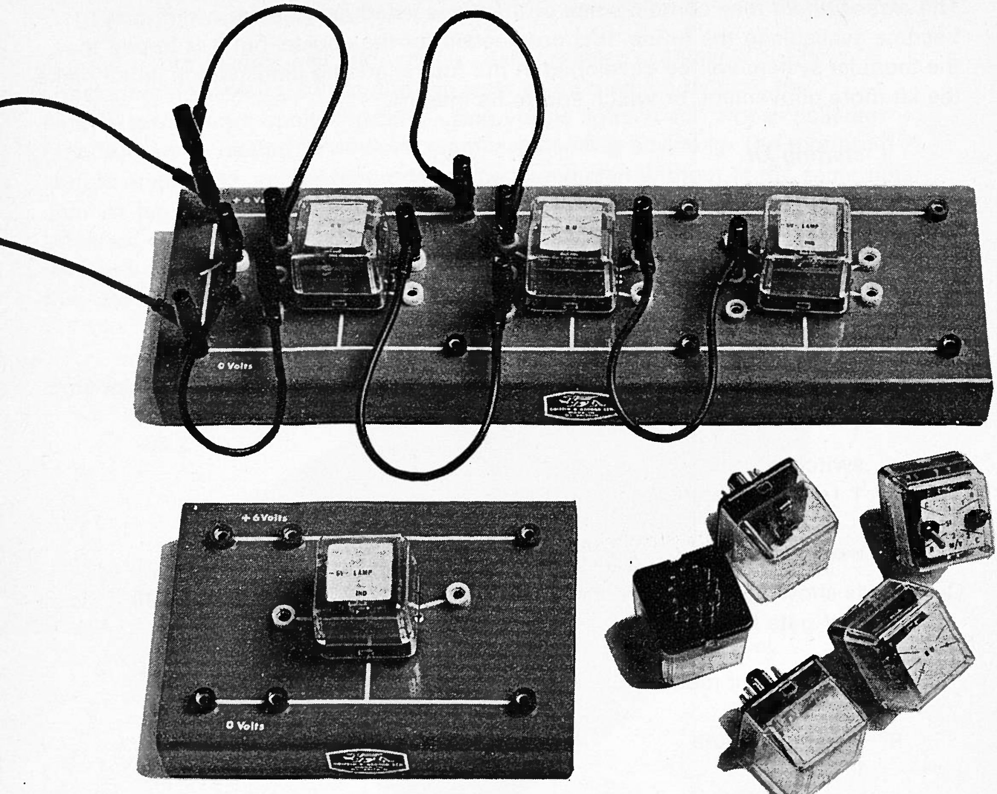


Figure 80
Item 1075. Electronics kit using baseboard and plug-in modules.
Photograph, Michael Plomer.

Item 1075C, the basic unit, may consist of a single silicon transistor in the circuit shown in figure 82. The markings on the unit should distinguish the resistive and capacitative inputs, and the direct and capacitative outputs. The baseboards should have their circuits marked on them.

There is no need for the markings on items 1075D to I to show their circuits, but the markings should identify the modules, and distinguish their various inputs and outputs. Figures 83 to 88 show suitable circuits. Every circuit can be built in a school. Figures 80 and 81 show two forms the kit can take.

It may well be that the most economical and effective contents of the modules will change in time, with, perhaps, the replacement of the contents of the basic unit by some form of integrated circuit amplifier. Manufacturers are encouraged to consider alternative devices, and to develop additional items for the extension kit.

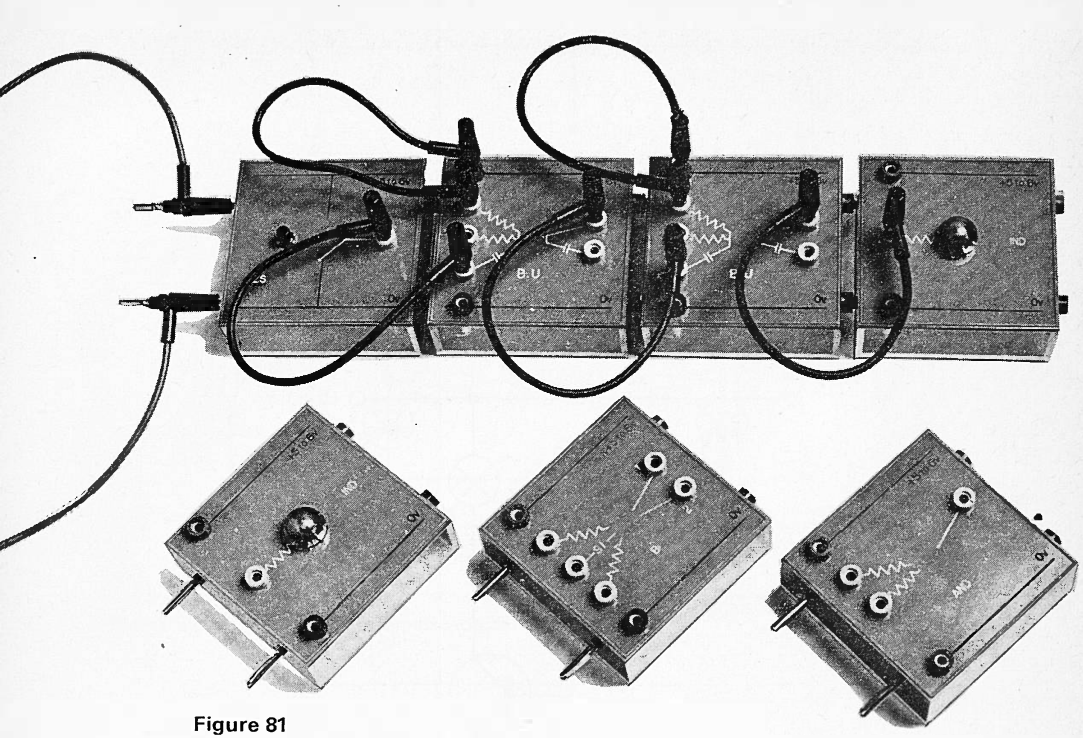


Figure 81
Item 1075. Electronics kit using plug-together modules.
Photograph, Michael Plomer.

Quantity 8 working kits

Experiments

4.9

6.2 6.3 6.4 6.5 6.6 6.7 6.9 6.11 6.13 6.14 6.19

7.11

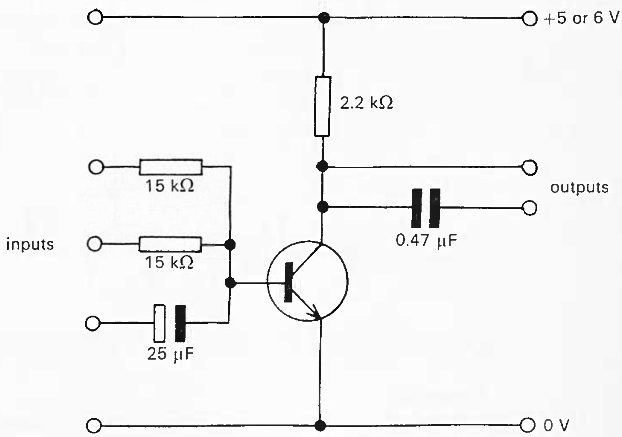


Figure 82
Item 1075. Circuit of basic unit.

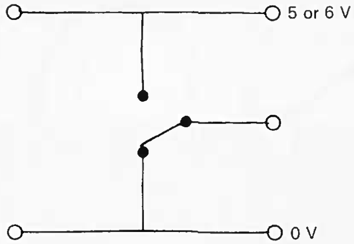


Figure 83
Item 1075E. Circuit of switch module.

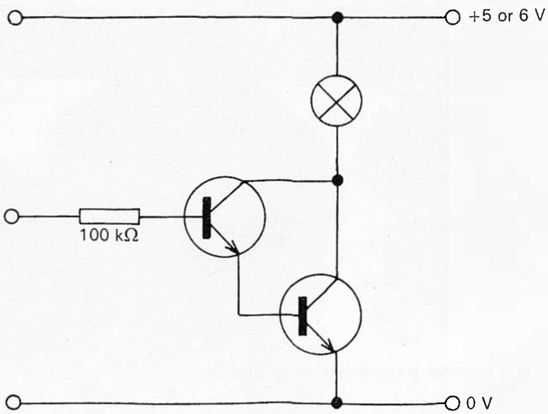


Figure 84
Item 1075D. Circuit of lamp indicator module.

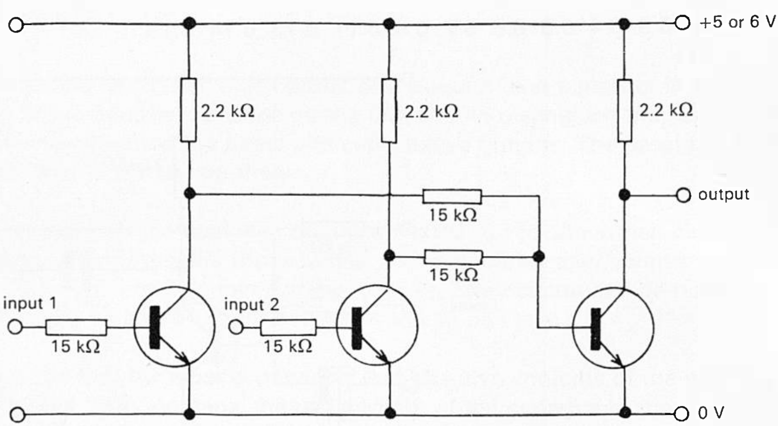


Figure 85
Item 1075F. Circuit of *and*-gate module (other circuits are possible).

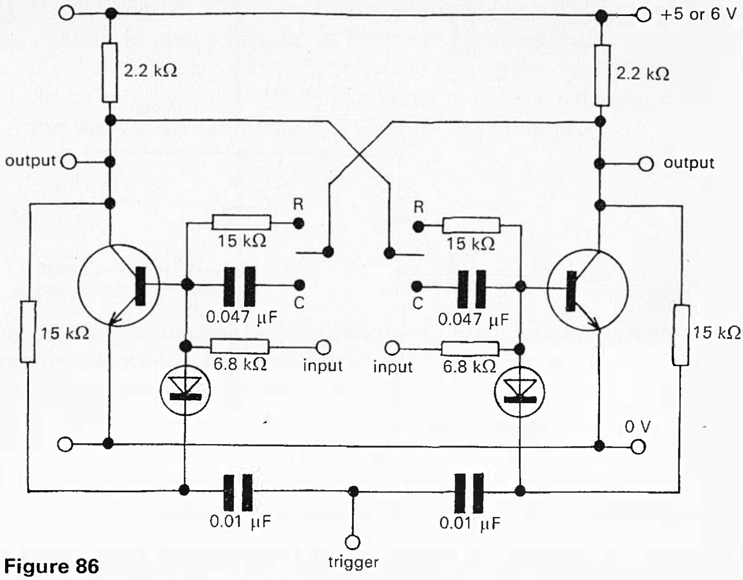


Figure 86
Item 1075G. Circuit of multivibrator module.

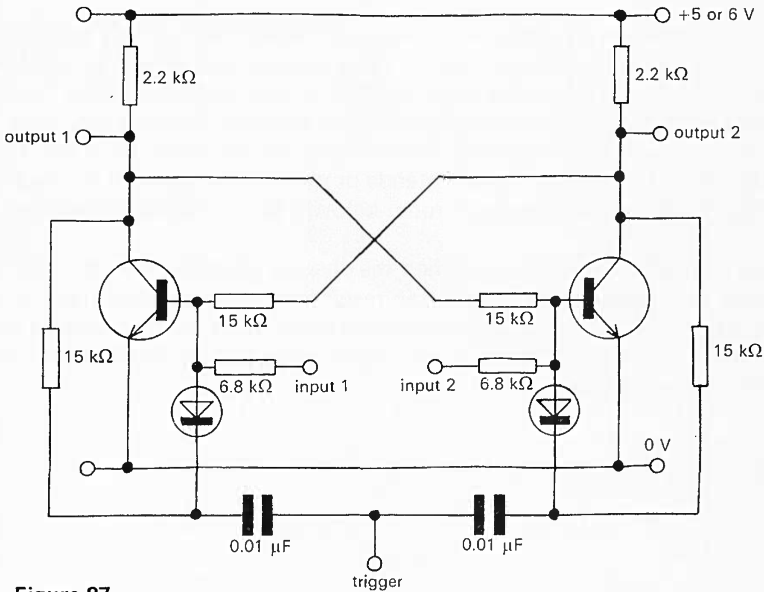


Figure 87
Item 1075H. Circuit of bistable module (same as 1075G, omitting switches and 0.047 μF capacitors).

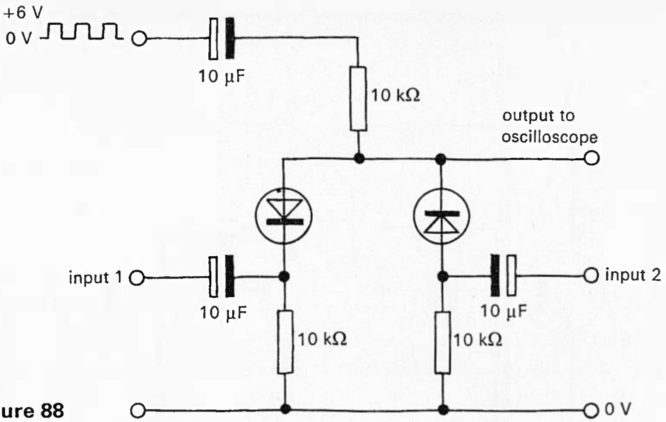


Figure 88
Item 1075I: Circuit of beam splitter module.

1076 large ring

A ring about 0.3 m diameter on which rubber sheet may be stretched as on a drum, so that various modes of vibration may be displayed when the sheet is excited by a loudspeaker held nearby. (See figure 66, page 185.)

Easy replacement of the sheet is essential, as rubber sheet quickly perishes if left stretched in daylight. The ring must be fairly massive and able to be supported rigidly on the bench, so that it does not itself vibrate and take energy from the vibration of the sheet. Aluminium is a suitable material. The ring may have supports of its own so as to be horizontally free standing on the bench, or it may have supports which make use of retort stands or retort stand bases. If the ring is free standing, there should be enough room below it for the loudspeaker (item 1044).

Satisfactory results are obtained when the sheet is stretched over the ring itself, but more even tension in the sheet can result from stretching the sheet on another, larger, frame, and then resting the stretched sheet upon the ring, adding weights to the frame if necessary. Nothing in the construction or support of the ring should prevent this being done.

Quantity 1

Experiments

4.16

10.8

1077 television aerial

A television aerial consisting of a dipole, with the possible addition of a reflector and of directors, of the sort supplied commercially for use with domestic receivers to detect UHF transmissions. The best form of aerial will depend upon the strength of local television signals. There is advantage in having a cheap aerial which is only just good enough to give a picture, as it is used for superposition experiments in which a reflected signal is used to destroy the one going directly to the aerial. The aerial should be fitted with two or three metres of coaxial cable for connection to the television set. The experiments it is used for are optional.

Quantity 1
Experiment 4.1

1078 gramophone motor

A shaded pole motor such as is used for driving gramophone turntables. This may be a demountable motor, perhaps with a coil wound for low voltage alternating current. An alternative, and cheaper, way of meeting the need is to have two commercial motors wound for mains voltage, one of which is dismantled. In either case, it is convenient if the copper shading rings are removed, and replaced by thick lengths of bare copper wire, which can be short circuited by holding their ends together with a pair of pliers. Figure 89 shows one way of achieving this.

Commercial gramophone motors can usually be obtained cheaply from surplus equipment dealers.

Quantity 1 or 2 (see above)
Experiments
7.1 7.17

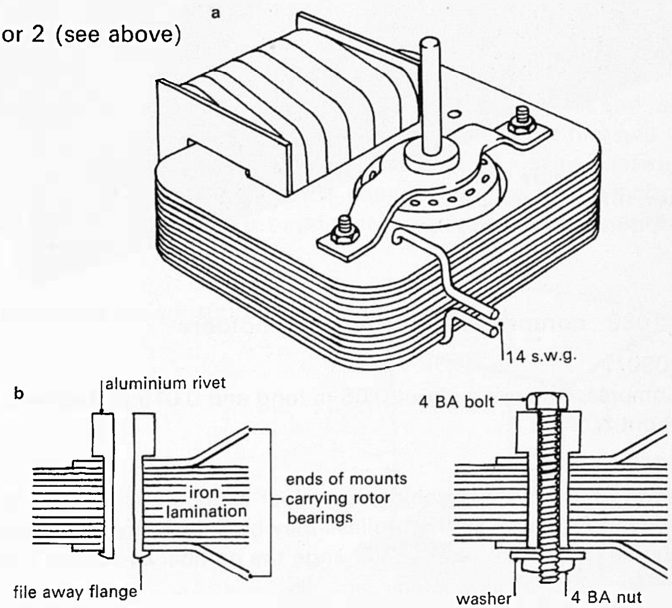


Figure 89
a Item 1078. A shaded pole gramophone motor.
b A small modification makes it possible to remove the rotor for inspection. The rotor bearings are fixed to the iron laminations by an aluminium rivet, widened at one end and turned over to a flange at the other. File away the flange until the rivet is flush with the lower bearing: this can now be lifted off, and the rotor removed.

1079 flat solenoid

A solenoid in which a wide current balance (item 1036/1) can be used to measure the magnetic field at the middle. Suitable dimensions are an end section about 0.03 m by about 0.28 m and a length of about 0.20 m. The smaller the smallest dimension is, the better, provided that there is enough space inside the solenoid to use a wide current balance, a Hall probe (item 1038), and a search coil (item 1039). The solenoid's former should therefore be made of thin material.

It is convenient if the number of turns per unit length of the flat solenoid is the same as for the more closely wound of the set of square solenoids (item 1037), that is: one layer of 22 s.w.g. with the windings touching one another.

Quantity 1
Experiments
7.3 7.4 7.15
8.12

Figure 90
Item 1079. Flat solenoid.
Photograph, Michael Plomer.

1080 compression springs and holders

1080/1
Compression spring about 0.06 m long and 0.015 m diameter, having a stiffness of about 50 N m^{-1}.

1080/2
Spring holders for attaching up to four springs 1080/1 side by side to the ends of dynamics trolleys so that trolleys may be linked together in line by the springs. It should be possible easily to change the number of springs linking each pair of trolleys.

Quantity
2 dozen of 1080/1
1 dozen of 1080/2
Experiment 4.6

1081 decade capacitance unit (1–10 μF)

A switched box of capacitors enabling capacitances in the range 1–10 μF to be connected across a pair of terminals. A high voltage rating for all the capacitors is an advantage. The capacitors will not be used for precision work, and 20 per cent tolerance will do. If the unit is not bought, capacitors of values 1, 2, 5, 8, and 10 μF must be added to the list of small electrical items, item 1051.

Quantity 1

Experiments

6.2 6.9 6.10 6.15 6.18

1082 coils surrounding a space

A number of coils arranged so that each coil is one face of a box. See figure 91. There may be six square coils forming a cube, or four triangular coils forming a pyramid. Each coil is made of thin enamelled wire, the turns are closely spaced, and the edges and corners of the coils are held tightly in contact, so that the wires and the spaces between wires occupy as little as possible of the surface area of the box. Each coil may have about ten turns.

The box is used to show that all the magnetic flux entering a volume of space also leaves that volume. For this purpose, twisted pairs of leads to each coil are brought out to a row of terminals.

Each coil is joined across a pair of terminals, each terminal except the first and last being common to two coils, so that all the coils are in series across the first and last terminals. The coils are connected so that all connections are in the same sense; that is, the righthand terminal (say) for each coil is connected to the lead which becomes positive when a north pole is thrust into that coil from the outside of the box. See figure 92.

The apparatus can fairly easily be constructed in a school.

Quantity 1

Experiment 7.10

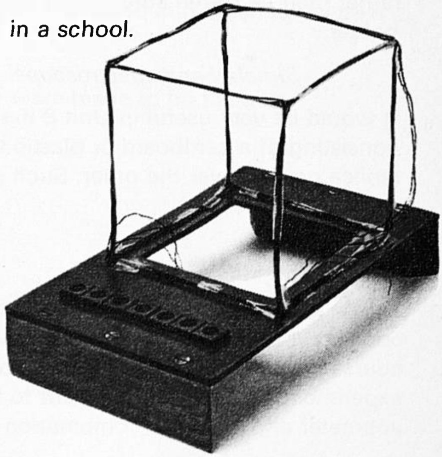


Figure 91
Item 1082. Coils surrounding a space.
Photograph, Michael Plomer.

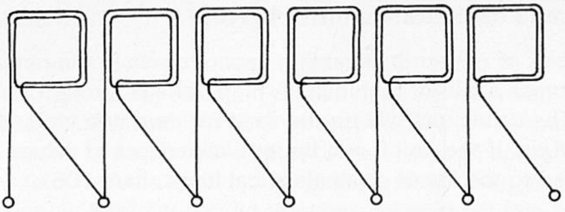


Figure 92
Item 1082. Connections to coils. The coils have been drawn in a row with that face of each which faces out from the box lying uppermost. Each coil has ten turns, but only two are shown here, for clarity.

1083 polarizing filters

Pieces of polaroid material, about 25 mm square. Ideally, they would be supplied mounted in 35 mm slide mounts, but they are easy to mount, and to do this in the school may save expense.

Quantity 16

Experiments

1.11
8.15

Notes on some items not listed

slide projector

A 35 mm slide projector is an essential item, being used for experiments 1.11, 2.21, 2.27, 2.30, 3.2, 3.10, 4.5, 4.12, 4.14, 5.7, 8.5, 8.8, as well as for projecting slides. It should have a 1000 W lamp, and should be a projector of the simple sort which can have small pieces of apparatus placed in the position usually occupied by slides, rather than be of the automatic kind with arrangements for dispensing slides from a holder.

Simple hand spectroscope

It would be very useful in Unit 8 if each student could have a simple spectroscope, consisting of a cardboard or plastic tube with a slit at one end and a piece of replica grating over the other. Such spectroscopes can be bought cheaply or can be made up very easily.

joule-meter

This is a device, like a domestic electricity meter for registering kilowatt-hours consumed, but adapted to operate at 12 volts, and recording joules delivered. The course can be taught without one, but it would be useful to have one for experiment 6.10, and convenient to have one on other occasions, to replace a voltmeter and ammeter combination in demonstration experiments. The use of a joule-meter to replace ammeters and voltmeters for students' measurements of electrical power is not advised.

laser

A low power gas laser would be a convenience in the teaching of physical optics in Unit 8, for the purpose of performing speedy, dramatic and easily visible demonstrations of diffraction and interference effects. Teachers are, however, advised not to replace individual experiments with 'ordinary' light by demonstrations with a laser. They should bear in mind that a laser must be used with care, and should make themselves familiar with the regulations issued by the Department of Education and Science governing the use of a laser in schools. A laser is not a recommended item of apparatus for the course, but teachers may like to consider having one, especially if the cost continues to fall.

X-ray apparatus

The Advanced Physics Project discussed with manufacturers the possibility of having an X-ray apparatus which would produce a beam sufficiently strong and well collimated to make it possible to obtain diffraction peaks from single crystals, detecting the beam with a GM tube. (Photographic detection requires higher intensities.) Such an apparatus should be designed so that it is safe to use, and in particular so that the X-ray beam is automatically cut off if any part of the body is placed in its path, and is absorbed by a suitable screen placed across the forward direction.

At the time of writing, we have not been able to test any apparatus which is of the kind described and which costs a sum schools might afford. Such apparatus as exists is either too simple, allowing only the detection of a feeble beam of X-rays, and simple studies of its absorption, or is too costly and complex. It is to be hoped that development work in this field will continue. Naturally, any such apparatus will have to gain the acceptance of the Department of Education and Science before it can be used in a school.

A series of film loops (see the list on page 232) were made to fill the gap.

Chapter 9

Books, films, film loops, and slides

Textbooks and further reading

This section gives lists of books that may be useful for the course, together with some advice on their relative importance. For convenience, several different sorts of list are given:

Textbooks

Books strongly recommended for reading in the course

Useful books for the library

Reprints strongly recommended for reading in the course

Useful reprints

Books for teachers:
Strongly recommended background books
Useful background books
Nuffield O-level Physics

A selection of the books listed here, or others like them, is an essential part of the equipment needed for the course. Certain Units, notably Unit 5, but also parts of Units 1, 7, and 10, are built around student reading, to help students to develop the skills needed to read with ease and profit.

A range of textbooks is also an essential requirement, though it would be acceptable to begin with a small range and build it up. The aim should be to acquire about as many volumes as there are students, so that each student can usually have access to more or less what he wants. There is no one textbook for the course. Even if there were one which exactly covered it, we would not recommend it alone. We think it better that there should be several books, each with its own strengths and weaknesses, so that students may come to recognize the variety of treatment that exists, and may learn to find those books which suit them best. Several copies of some of these books should be available, while others may be bought in single copies. Suggested numbers are given in the textbook list.

In the long run, the course will have less chance of succeeding in some of its aims if there is not in the school a wide range of background reading available to students. We recognize that building up such a range will take time, but urge that the need to do this should not be forgotten once the selection of textbooks and the other strongly recommended books and reprints has been made.

It is not our intention that these lists be regarded as final, nor have we seen and thought about every book which might be useful. Teachers will want to add favourites of their own, and to keep a watch for new titles in the future. These lists are intended only to ease the initial task of making a selection.

Two lists of reprints are given, both intended for student reading. One list is of reprints suggested for direct use in the teaching of the course, while the other is a list for more general reading by interested students. Teachers are advised to obtain up-to-date catalogues of reprints from W. H. Freeman (*Scientific American* offprints). We have not recommended articles in journals if they have not been reprinted, because of the difficulty of obtaining them. But teachers would do well to ensure that the school takes in magazines such as *Scientific American, New scientist,* and others.

The lists of books for teachers include some more advanced books, some of which come from the various new series of university texts. Teachers all face the problem that they do not understand things which they feel they ought to understand, and we have added to this problem by including in the course simplified treatments of subjects not previously taught in school. As every teacher knows, one must know a subject rather well to present a simplified treatment of it clearly and, in essentials, truthfully. Some teachers will find that these subjects were omitted, or only sketched in, in their own training in physics. The lists of books for teachers may help with these problems.

Schools have varying policies regarding the placing of books in the school. Some prefer all but issued textbooks to go into the central library, while in others, subject departments run extra libraries of their own. We suggest that the textbooks and other reading essential to the course be treated as textbooks usually are, and be under the control of the physics teacher. If possible and if policy allows, it is worth establishing a small physics library, consisting mainly of reprints. Other titles can quite conveniently go into the main school library, where all students can benefit from them.

When making a selection of books from the lists of 'Useful books for the library', and 'Useful reprints', teachers are advised to look with especial care at those listed as being relevant to Units 1, 5, 7, and 10, as a selection of these will be needed for reading references in those Units. Further guidance can be found in the special lists of reading references in the *Teachers' guides* for these Units.

Textbooks

Most of the books in this list are comprehensive textbooks, rather than textbooks specializing in particular parts of physics. This is for economic reasons; it is the cheapest way of obtaining an adequate coverage of subject matter. More specialized books need not be denied a place, especially if the school already has them in stock. Standard Advanced level texts already in the school can be added subject to the cautions that follow about units and other problems.
Most of the books listed below follow broadly the same treatment of electromagnetism as that suggested in the Nuffield Advanced Physics course, restricting the vectors discussed to E and B (excluding D and H), and using rationalized units based on the metre, kilogramme, second, and ampere as primary units. It is convenient, but less essential, if the treatment of B introduces it as related to the force on a current in a conductor or as the force on a moving charge, rather than as related to electromagnetic induced voltage.

Because the comprehensive books listed are rather cursory in their treatment of electromagnetism and of elementary atomic physics, we have listed a few more specialized books covering these areas.

Arons, A. B. (1965) *Development of concepts of physics.* Addison-Wesley.
Units 1, 2, 3, 4, 5, 7, 8.

One copy. (Alternative to Holton and Roller.) It is more humane, and more philosophical than most textbooks. Its electricity and magnetism are based on *B* and *E* only, but are brief.

Baez, A. V. (1967) *The new college physics.* Freeman.
Units 1, 2, 5, 7, 8, 10.

One copy. Not a very detailed book, but a very readable one, and quite comprehensive. Electricity restricted to *E* and *B*.

Bennet, G. A. G. (1968) *Electricity and modern physics.* (MKS edition.) Edward Arnold.
Units 1, 2, 3, 5, 6, 7, 10.

Several copies. It usefully supplements comprehensive books, especially in the treatment of electromagnetism. *B* and *E* are the only vectors used. *B* is introduced as the force on a current.

Caro, D. E., McDonell, J. A., and Spicer, B. M. (1962) *Modern physics.* Edward Arnold.
Units 1, 2, 5, 7, 10.

Several copies. Very useful supplement to comprehensive books, in atomic physics.

Holton, G., and Roller, D. H. D. (1958) *Foundations of modern physical science.* Addison-Wesley.
Units 3, 4, 5.

One copy. (Alternative to Arons.) It is more humane and philosophical than most textbooks. Uses the vectors *E* and *H*.

Nuffield Advanced Chemistry (1972) *Amount of substance: the mole concept and its use in solving problems.* Penguin.
Unit 1 and the later Units.

Two or three copies.

Nuffield Advanced Science (1972) *Book of data.* Penguin.
All Units

Two or three copies in the laboratory will be enough.

PSSC (1968) *College physics.* Raytheon.
Units 1, 2, 3, 4, 5, 7, 8, 9, 10.

Several copies. (Alternative to PSSC *Physics,* 2nd edition.) A very valuable textbook, with useful material not in PSSC *Physics.*

PSSC (1965) *Physics.* 2nd edition. Heath.
Units 1, 2, 3, 4, 5, 7, 8, 10.

Several copies. (Alternative to PSSC *College physics.*) A very valuable textbook.

Rogers, E. M. (1960) *Physics for the inquiring mind.* Oxford University Press.
Units 1, 2, 3, 4, 5, 7, 8, 10.

Several copies. A superb source of ideas and understanding.

Sears, F. W., and Zemansky, M. W. (1964) *College physics.* Addison-Wesley.
Unit 4.

One copy. Useful on wave motion.

Teachers may also wish to consider the following two recent books, among others.
Ruth, P. (1969) *Introduction to field and particle.* Butterworth.
Wenham, E. J., Dorling, G. W., Snell, J. A. N., and Taylor, B. (1972) *Physics.* Addison-Wesley.

Books strongly recommended for reading in the course

These books either contain material, such as original papers, not found in textbooks, or offer reading suggested for use as part of the proposed teaching.

Born, M. (1951) *The restless universe.* Dover.
Units 7, 10.
Classical scientific papers – physics. (1964). Mills & Boon.
Units 5, 7, 10.
Conn, G. K. T., and Turner, H. D. (1965) *The evolution of the nuclear atom.* Iliffe.
Units 5, 10.
Alternative to *Classical scientific papers – physics.*
Gentner, W., Maier-Leibnitz, H., and Bothe, W. (1954) *An atlas of typical expansion chamber photographs.* School edition. Pergamon.
Unit 5.
Gordon, J. E. (1968) *The new science of strong materials.* Penguin.
Unit 1.
Millikan, R. A. (1963) Phoenix Science Series. *The electron.* University of Chicago Press.
Units 2, 3, 5, 10.
Romer, A. (ed.) (1964) *The discovery of radioactivity and transmutation.* Dover.
Unit 5.
Fills the gaps left by *Classical scientific papers – physics.*
Romer, A. (1964) Science Study Series No. 10. *The restless atom.* Heinemann.
Units 5, 7.
Scientific American (1967) *Materials.* A *Scientific American* book. W. H. Freeman.
Unit 1.
Wilson, R. R., and Littauer, R. (1962) Science Study Series No. 15 *Accelerators.* Heinemann.
Unit 7.

Useful books for the library

Each of these books contains material directly linked to some part of the course.

Alexander, W., and Street, A. (1963) *Metals in the service of man.* Penguin.
Unit 1.
Andrade, E. N. da C. (1965) Science Study Series No. 29 *Rutherford and the nature of the atom.* Heinemann.
Unit 5.
Angrist, S. W., and Hepler, L. G. (1967) *Order and chaos.* Basic Books.
Unit 9.
Barber, N. F. (1969) *Water waves.* Wykeham.
Unit 4.
Battan, L. J. (1964) Science Study Series No. 18 *Radar observes the weather.* Heinemann.
Unit 4.
Benrey, R. M. (1965) *Understanding digital computers.* Iliffe.
Unit 6.
Bishop, R. E. D. (1965) *Vibration.* Cambridge.
Unit 4.
Bondi, H. (1961) Science Study Series No. 12 *The universe at large.* Heinemann.
Units 3, 8.
Bronowski, J. (1968) *The common sense of science.* Penguin.
Unit 5.

Brophy, J. J. (1966) *Semiconductor devices.* Allen & Unwin.
Unit 6.
Butler, S. T., and Messel, H. (Eds) (1965) *Time: selected lectures.* Pergamon.
Unit 4.
Carnot, S. (1960) *Reflections on the motive power of fire.* Dover.
Unit 9.
Feather, N. (1961) *Mass, length and time.* Penguin.
Units 2, 3, 4.
Feynman, R. P. (1965) *The character of physical law.* B.B.C. Publications.
Units 3, 5.
Fishlock, D. F. (1967) *The new materials.* Murray.
Unit 1.
Gamow, G. (1962) Science Study Series No. 17 *Gravity.* Heinemann.
Unit 3.
Gouiran, R. (1967) *Particles and accelerators.* Weidenfeld & Nicolson.
Unit 7.
Graham Smith, F. (1966) *Radio astronomy.* Penguin.
Units 4, 8.
Griffin, D. R. (1960) *Echoes of bats and men.* Heinemann.
Unit 4.
Hoffmann, B. (1970) *The strange story of the quantum.* Penguin.
Unit 10.
Holden, A., and Singer, P. (1961) Science Study Series No. 6 *Crystals and crystal growing.* Heinemann.
Unit 1.
Hollingdale, S. H., and Tootill, G. C. (1970) *Electronic computers.* Penguin.
Unit 6.
Hughes, D. J. (1964) Science Study Series No. 1 *The neutron story.* Heinemann.
Unit 5.
Hurley, P. M. (1960) Science Study Series No. 5 *How old is the Earth?* Heinemann.
Units 4, 5.
Laithwaite, E. R. (1966) *Propulsion without wheels.* English Universities Press.
Units 4, 7.
Laithwaite, E. R. (1967) *The engineer in wonderland.* English Universities Press.
Unit 7.
Landau, L. D., and Rumer, G. B. (1960) *What is relativity?* Oliver & Boyd.
Unit 8.
Lewis, J. L., and Wenham, E. J. (1970) Longman Physics Topics *Radioactivity.* Longman.
Unit 5.
Lipson, H. S. (1968) *The great experiments in physics.* Oliver & Boyd.
Unit 3.
Loftas, A. A., and Gwynne, P. (Eds) (1967) *Advances in materials science.* University of London Press.
Unit 1.
Marston, R. M. (1969) *110 semiconductor projects for the home constructor.* Iliffe.
Unit 6.
Marston, R. M. (1969) *20 solid state projects for the home constructor.* Iliffe.
Unit 6.
Moroney, M. J. (1969) *Facts from figures.* Penguin.
Unit 5.
Newton, I. (1962 edition) *Principia, mathematical principles of natural philosophy and system of the world,* Volume 1. Translated by Andrew Motte, 1729. Revised by Florian Cajori. University of California Press.
Unit 3.
Nuffield O-level Chemistry Background Book: Bragg, Sir L. (1967) *The start of X-ray analysis.* Longman/Penguin.
Unit 1.

Nuffield O-level Chemistry Background Book: Platts, C. V. (1967) *The structure of substances.* Longman/Penguin.
Unit 1.
Nuffield O-level Chemistry Background Book: Walker, O. J. (1967) *Plastics*. Longman/Penguin.
Unit 1.
Nuffield O-level Physics Pupils' Guide: Ogborn, J. M. (to be published in 1972) *Molecules and motion.* Longman/Penguin.
Unit 3.
Nuffield O-level Physics Pupils' Guide: Rogers, E. M. (to be published in 1972) *Astronomy*. Longman/Penguin.
Unit 3.
Project Physics* (1971) Reader, Unit 2 *Motion in the Heavens.* Holt, Rinehart & Winston, N.Y.
Unit 3
Project Physics* (1971) Reader, Unit 3 *The triumph of mechanics.* Holt, Rinehart & Winston, N.Y.
Unit 4.
Project Physics* (1971) Reader, Unit 4 *Light and electromagnetism.* Holt, Rinehart & Winston, N.Y.
Unit 3.
Project Physics* (1971) Reader, Unit 5 *Models of the atom.* Holt, Rinehart & Winston, N.Y.
Units 2, 5.
Project Physics* (1971) Text, Unit 5 *Models of the atom.* Holt, Rinehart & Winston, N.Y.
Units 1, 5, 10.
Project Physics* (1971) Reader Unit 6 *The nucleus.* Holt, Rinehart & Winston, N.Y.
Unit 5.

* Project physics books: these are not available in the U.K., but can be obtained in small numbers direct from the American publisher.

Putman, J. L. (1965) *Isotopes.* Penguin.
Unit 5.
Rothman, M. A. (1966) *The laws of physics.* Penguin.
Units 3, 5, 9, 10.
Ryan, P. (1969) *The invasion of the Moon 1969.* Penguin.
Unit 3.
Sanders, J. H. (1965) *The velocity of light.* Pergamon.
Unit 4.
Sandfort, J. F. (1964) Science Study Series No. 22 *Heat engines.* Heinemann.
Unit 9.
Shire, E. S. (1972) Longman Physics Topics: *Rutherford and the nuclear atom.* Longman.
Unit 5.
Sjobbema, D. J. W. (1961) *Using transistors.* Macmillan.
Unit 6.
Smith, A. G. (1967) *Radio exploration of the Sun.* Van Nostrand.
Unit 8.
Solid state hobby circuits manual (1970) R. C. A. Distributor Products.
Unit 6.
Tolansky, S. (1968) *Revolution in optics.* Penguin.
Units 8, 10.
Toulmin, S., and Goodfield, J. (1965) *The architecture of matter.* Penguin.
Unit 10.
Tricker, R. A. R. (1965) *Bores, breakers, waves and wakes.* Mills & Boon.
Unit 4.
Ubbelohde, A. R. (1963) *Man and energy.* Penguin.
Unit 9.
Weaver, W. (1964) Science Study Series No. 24 *Lady Luck.* Heinemann.
Unit 5.

Reprints strongly recommended for reading in the course

The reprints in this list are suggested for direct use in the teaching of parts of the course.

Bragg, Sir L. (1968) 'X-ray crystallography.' *Scientific American* Offprint No. 325.
Unit 1.
Nier, A. O. C. (1953) 'The mass spectrometer.' *Scientific American* Offprint No. 256.
Unit 7.
Wilson, R. R. (1958) 'Particle accelerators.' *Scientific American* Offprint No. 251.
Unit 7.
Morley, J. G. (1966) 'Fibre-reinforced metals.' *Science journal* reprint. Not available at the time of writing, but due to be re-published in Nuffield Advanced Physics (1972) *Physics and the engineer*, Penguin.
Unit 1.

Useful reprints

Each of the reprints in this list contains something relevant to some part of the course.

Scientific American Offprints

Alder, B. J., and Wainwright, T. E. (1959) 'Molecular motions.' Offprint No. 265.
Unit 9.
Allen, J. A. Van (1959) 'Radiation belts around the Earth.' Offprint No. 248.
Unit 7.
Bascom, W. (1959) 'Ocean waves.' Offprint No. 828.
Unit 4.
Bernstein, J. (1954) 'Tsunamis.' Offprint No. 829.
Unit 4.
Bullen, K. E. (1955) 'The interior of the Earth.' Offprint No. 804.
Unit 4.
Burbidge, G., and Hoyle, F. (1966) 'The problem of the quasi-stellar objects.' Offprint No. 305.
Unit 8.
Crow, J. F. (1959) 'Ionizing radiation and evolution.' Offprint No. 55.
Unit 5.
Deevey, E. S., Jr. (1952) 'Radiocarbon dating.' Offprint No. 811.
Units 4, 5.
Dirac, P. A. M. (1963) 'The evolution of the physicist's picture of nature.' Offprint No. 292.
Units 1, 5.
Elsasser, W. M. (1958) 'The Earth as a dynamo.' Offprint No. 825.
Unit 7.
Gamow, G. (1961) 'Gravity.' Offprint No. 273.
Unit 3.
Gell-Mann, M., and Rosenbaum, E. P. (1957) 'Elementary particles.' Offprint No. 213.
Unit 7.
Glaser, D. A. (1955) 'The bubble chamber.' Offprint No. 214.
Unit 7.
Griffin, D. R. (1958) 'More about bat "radar".' Offprint No. 1121.
Unit 4.
Heeschen, D. S. (1962) 'Radio galaxies.' Offprint No. 278.
Unit 4.
Hurley, P. M. (1949) 'Radioactivity and time.' Offprint No. 220.
Unit 5.
Hutchins, C. M. (1962) 'The physics of violins.' Offprint No. 289.
Unit 4.
Lyons, H. (1957) 'Atomic clocks.' Offprint No. 225.
Unit 4.

Oliver, J. (1959) 'Long earthquake waves.' Offprint No. 827.
Unit 4.
Panofsky, W. (1954) 'The linear accelerator.' Offprint No. 234.
Unit 7.
Reynolds, J. H. (1960) 'The age of the elements in the Solar System.' Offprint No. 253.
Units 5, 7.
Sandage, A. R. (1956) 'The red-shift.' Offprint No. 240.
Unit 8.
Segrè, E., and Wiegand, C. C. (1956) 'The anti-proton.' Offprint No. 244.
Unit 7.
Shankland, R. S. (1964) 'The Michelson–Morley experiment.' Offprint No. 321.
Unit 8.
Tustin, A. (1952) 'Feedback.' Offprint No. 327.
Unit 6.
Westerhout, G. (1959) 'The radio galaxy.' Offprint No. 250.
Unit 4.

Science journal Reprints

Science journal reprints can no longer be purchased. The following titles (and Morley, 1966 – see page 228) will, however, be published in 1972 in a bound volume, *Physics and the engineer*, as part of the Nuffield Advanced Physics publications. Penguin.

Felici, N. J. (1965) 'Electrostatic engineering.'
Unit 3.
Frischmann, W. W. (1965) 'Tall buildings.'
Units 1, 4.
Kennedy, A. J. (1965) 'High temperature materials.'
Unit 1.
Laithwaite, E. R. (1966) 'New forms of electric motor.'
Units 4, 7.
McLean, F. C. (1966) 'Colour television.'
Units 6, 7.
Newstead, G. (1967) 'The homopolar generator.'
Unit 7.
Parkinson, D. H. (1966) 'Ultrahigh magnetic fields.'
Unit 7.

Books for teachers

Strongly recommended background books

These books cover areas of physics of special difficulty in a way likely to help many teachers.

Bent, H. A. (1965) *The second law*. Oxford University Press.
Unit 9.
An immensely valuable book for teachers.
Feynman, R. P., Leighton, R. B., and Sands, M. (1963) *The Feynman lectures on physics*, Volume 1. Addison-Wesley.
Units 3, 4, 8, 10.
Sherwin, C. W. (1961) *Basic concepts of physics.* Holt, Rinehart & Winston.
Units 4, 8, 9, 10.

Useful background books

These books each contain something of value for a teacher, but each teacher will have to select from them according to his needs and interests.

Amos, S. W. (1969) *Principles of transistor circuits.* Iliffe.
Unit 6.
Bondi, H. (1964) *Relativity and common sense.* Heinemann.
Unit 8.
Boorse, H. A., and Motz, L. (1966) *The world of the atom* Volume 1. Basic Books.
Units 2, 5, 10.
Reprints and commentary ranging from Greek to present-day science.
Bork, A. M. (1967) *Fortran for physics.* Addison-Wesley.
Unit 4.
Contemporary Physics (1968) *Sources of physics teaching* Part 1. Taylor & Francis.
Units 9, 10.
Contemporary Physics (1968) *Sources of physics teaching* Part 2. Taylor & Francis.
Unit 4.
Crawford, F. S. (1968) Berkeley Physics Course Volume 3 *Waves.* McGraw-Hill.
Units 4, 8.
Cropper, W. H. (1970) *The quantum physicists.* Oxford University Press.
Unit 10.
Delaney, C. F. G. (1970) *Electronics for the physicist.* Penguin.
Unit 6.
Doughty, P., Pearce, J., Thornton, G. (1971) *Language in use.* Edward Arnold.
Einstein, A., Lorentz, H. A., Minkowski, H., and Weyl, H. (1958) *The principle of relativity.* Dover.
Unit 8.
French, A. P. (1968) *Special relativity.* Nelson.
Units 4, 8. (See also other volumes in the same series, French, A. P., Physics, an Introductory Course, published by Nelson.)
Gibson, W. M. (1969) *Basic electricity.* Penguin.
Unit 8.
Gurney, R. W. (1949) *Introduction to statistical mechanics.* McGraw-Hill.
Unit 9.
Hanson, N. R. (1958) *Patterns of discovery.* Cambridge University Press.
Units 5, 10.
Hertz, H. (1962) *Electric waves.* Dover.
Unit 8.
Hesse, M. B. (1961) *Forces and fields.* Nelson.
Unit 3.
Kittel, C. (1956) *Introduction to solid state physics.* 3rd edition. Wiley.
Unit 3.
Kittel, C., Knight, W. D., and Ruderman, M. A. (1965) Berkeley Physics Course Volume 1 *Mechanics.* McGraw-Hill.
Unit 8.
Moffatt, W. G., Pearsall, G. W., and Wulff, J. (1964) *The structure and properties of materials.* Wiley.
Unit 1.
Good source of illustrations.
Nuffield Advanced Biological Science (1970) Laboratory Guide *Organisms and populations.* Penguin.
Unit 5.
Nuffield Advanced Biological Science (1970) Study Guide *Evidence and deduction in biological science,* part two, 'Organisms and populations'. Penguin.
Unit 5.
Nuffield Advanced Chemistry (1970) *Students' book I.* Penguin.
Unit 5.

Orear, J. (1967) *Fundamental physics.* Wiley.
Unit 10.
Peacocke, T. A. H. (1964) 'Nuclear chemistry: some applications of radioisotope techniques in chemistry and biology'. *School science review* **157**, 597–605.
Unit 5.
Popper, K. R. (1963) *Conjectures and refutations.* Routledge & Kegan Paul.
Unit 5.
Purcell, E. M. (1965) Berkeley Physics Course Volume 2 *Electricity and magnetism.* McGraw-Hill.
Unit 8.
Reif, F. (1967) Berkeley Physics Course Volume 5 *Statistical physics.* McGraw-Hill.
Unit 9.
Scroggie, M. G. (1961) *Principles of semiconductors.* Iliffe.
Unit 6.
Scroggie, M. G. (1971) *Radio and electronic laboratory handbook.* Iliffe.
Unit 6.
Toulmin, S. E. (1962) *Quanta and reality.* Hutchinson.
Unit 10.
Tabor, D. (1969) *Gases, liquids and solids.* Penguin.
Unit 3.
Watson, J. D. (1968) *The double helix.* Weidenfeld & Nicholson.
Unit 1.
Wichmann, E. H. (1971) Berkeley Physics Course Volume 4 *Quantum physics.* McGraw-Hill.
Unit 10.

Nuffield O-level Physics

The following are the Nuffield O-level Physics books which contain ideas directly relevant to the Advanced course, and which are referred to in the Advanced level *Teachers' guides.*

Nuffield O-level Physics (1968) *Guide to apparatus.* Longman/Penguin.
Unit 2.
Nuffield O-level Physics (1966) *Guide to experiments I.* Longman/Penguin.
Unit 4.
Nuffield O-level Physics (1967) *Guide to experiments II.* Longman/Penguin.
Unit 4.
Nuffield O-level Physics (1967) *Guide to experiments III.* Longman/Penguin.
Unit 4.
Nuffield O-level Physics (1967) *Guide to experiments IV.* Longman/Penguin.
Units 3, 4.
Nuffield O-level Physics (1968) *Guide to experiments V.* Longman/Penguin.
Units 3, 4.
Nuffield O-level Physics (1966) *Teachers' guide III.* Longman/Penguin.
Unit 4.
Nuffield O-level Physics (1966) *Teachers' guide IV.* Longman/Penguin.
Units 2, 3, 4.
Nuffield O-level Physics (1967) *Teachers' guide V.* Longman/Penguin.
Units 1, 3, 5.

Collected list of films and film loops

All the films or film loops suggested for possible use in each Unit are collected together in the following list. Each *Teachers' guide* contains a list of the films and film loops suggested for that Unit. Where a film may be of use in more than one Unit, it appears here under the earliest of those Units only

Unit 1

Standard 8 mm loop 'The diffraction of X-rays by a crystal.' Longman's Chemistry Loop 582 37206 2.

Standard 8 mm loop 'Bragg reflection of waves.' No. A80-2363/2. Ealing Scientific. Also Super 8 mm loop No. A80-2363/1.

The above two titles are alternatives. They are useful, but not essential.

Standard 8 mm loop 'X-ray diffraction 1 Production of the X-ray beam.' No. XXI 663. Penguin.

Standard 8 mm loop 'X-ray diffraction 2 Diffraction of monochromatic X-rays by a single crystal.' No. XXI 664. Penguin.

Standard 8 mm loop 'X-ray diffraction 3 Diffraction of monochromatic X-rays by a powder specimen.' No. XXI 665. Penguin.

Standard 8 mm loop 'X-ray diffraction 4 Determination of the wavelength of X-rays using a diffraction grating.' No. XXI 666. Penguin.

The above four loops were made in conjunction with the Nuffield Advanced Physics Project. They are intended to fit into the teaching programme for Unit 1, and were made with this Unit specially in mind. The fourth loop could also find a use in Unit 5 or in Unit 10.

16 mm film 'Bubble model of a metal.' 16 minutes, black and white, sound. British Film Institute.

A nice film, but optional.

Unit 2

16 mm film 'The momentum of electrons.' 10 minutes, colour, sound. PSSC Advanced Topics. No. V 661. Central Film Library.

The experiment shown in this film is used in an argument in Unit 2. The film and the argument are interesting, but not absolutely essential.

16 mm film 'Are there electrons? (The Millikan experiment).' 13 minutes, colour, sound. No. 21.7772. Rank Audio Visual Ltd.

Standard 8 mm loop 'Are there Electrons? (The Millikan experiment).' No.
No. 29.0316. Rank Audio Visual Ltd.

The 16 mm film is intended mostly for the Nuffield O-level Physics course, but also includes data from which the charge on an electron is calculated, thus giving it a use at Advanced level. It may make a useful supplement to work with the Millikan apparatus, but does not replace it. The film loop is not an alternative to the film. It merely shows data being obtained, which can be used by students who have handled the apparatus.

Unit 3

A brochure, 'Camera on the Moon', giving details of 8 mm films and 35 mm slides concerning Apollo flights is available from Moon Productions, *Daily Express*, Fleet Street, London E.C.4.

Unit 4

Standard 8 mm loop 'Tacoma Narrows Bridge collapse.' No. A80-2181/2.
Ealing Scientific.
Also Super 8 mm loop, No. A80-2181/1.

Not essential, but well worth having.

Standard 8 mm loop 'Measurement of "G".' No. A80-2124/2. Ealing Scientific.
Also Super 8 mm loop No. A80-2124/1.

This loop is optional. It happens to contain a nice example of damped oscillation.

Super 8 mm loop 'Vibrations of a drum.' No. A80-3924/1. Ealing Scientific.

Standard 8 mm loop 'Soap film oscillations.' No. A80-2660/2. Ealing Scientific.
Also Super 8 mm loop No. A80-2660/1.

The above two loops are optional, and may supplement laboratory demonstrations. They would be of greater value in Unit 10.

Standard 8 mm loop 'Wind-induced oscillations.' No. XXI 671. Penguin.

This loop should be useful in Unit 4. It contains dramatic examples of the effects of wind on structures, to add to the example of the Tacoma Narrows collapse.

16 mm film 'The velocity of gamma rays.' 16 minutes, colour, sound. No. 21.7853.
Rank Audio Visual Ltd.

Worth showing at some point in the course, in Unit 4, Unit 5, or Unit 8. It shows an experiment that is important in principle, but cannot be done in the school laboratory. This film was made in conjunction with the Nuffield Advanced Physics Project.

Unit 5

16 mm film 'The Rutherford model of the atom.' 16 minutes, colour, sound. No. 21.7852. Rank Audio Visual Ltd.

This film should be shown. It was made in conjunction with the Nuffield Advanced Physics Project.

16 mm film 'Random events.' 31 minutes, black and white, sound. No. 900 4116-5. Sound Services.

This film is very interesting and very good, but is not absolutely essential. It could be shown in Unit 5 or in Unit 9.

Unit 8

16 mm film 'Frames of reference.' 26 minutes, black and white, sound. No. 900 4141-9. Sound Services.

16 mm film 'Time dilation.' 36 minutes, black and white, sound. No. 900 4040-3. Sound Services.

16 mm film 'The ultimate speed.' 38 minutes, black and white, sound. No. 900 4039-3. Sound Services.

These three PSSC films are about relativity, which makes a brief appearance in Unit 8. All are good value. The teacher would find it worth aiming to show one in any one year, and to have seen all three himself at some time, so that they may be described briefly.

Unit 9

16 mm film 'Change and chance: a model of thermal equilibrium in a solid.' 13 minutes, black and white, silent. XXI 673. Penguin.

This computer-made film plays an essential part in the teaching of Unit 9, and the school should possess a copy. It was made especially for the Project.

Standard 8 mm loop 'Forward or backwards?' 1. No. XXI 668. Penguin.

Standard 8 mm loop 'Forward or backwards?' 2. No. XXI 669. Penguin.

Standard 8 mm loop 'Forwards or backwards?' 3. No. XXI 670. Penguin.

These three loops play an important part in Unit 9, though they could be substituted for by other suitable film shown backwards.

Unit 10

Standard 8 mm loop 'Solving a standing wave equation for a hydrogen atom.' No. XXI 667. Penguin.

This computer-made film loop is important for those who intend to teach all of Unit 10, and may be of interest to those who stop before the end.

16 mm film 'Photons.' 19 minutes, black and white, sound. No. 900 4173-2. Sound Services.

16 mm film 'Interference of photons.' 14 minutes, black and white, sound. No. 900 4174-9. Sound Services.

16 mm film 'Matter waves.' 28 minutes, black and white, sound. No. 900 4177-0. Sound Services.

The teacher should try to have seen all three of these PSSC films. For showing to students, 'Interference of photons' is the most useful. 'Matter waves' makes a good summary, but is not so essential. 'Photons' could well be omitted.

Collected list of slides

Unit 1

1.1 Diagram to illustrate the arrangement used in an X-ray powder camera
1.2 X-ray powder photograph for copper
1.3 X-ray powder photograph for sodium chloride
1.4 Electron diffraction pattern for unstretched natural rubber
1.5 Electron diffraction pattern for highly stretched natural rubber
1.6 X-ray diffraction pattern for undrawn low density polythene
1.7 X-ray diffraction pattern for drawn low density polythene
1.8 X-ray diffraction pattern for glass
1.9 X-ray diffraction pattern for distilled water
1.10 Von Laue pattern
1.11 X-ray diffraction pattern made from a single crystal of haemoglobin
1.12 The structure of $TlAlF_4$
1.13 The structure of *p*-diphenylbenzene
1.14 Structure of vitreous silica
1.15 The structure of the lysozyme molecule
1.16 Bubble raft showing grain boundaries
1.17 Bubble raft showing dislocation
1.18 Pouring ready-mixed concrete
1.19 Reinforcing rods in a concrete floor
1.20 Reinforcing rods in a concrete pillar
1.21 Manufacture of pre-stressed concrete beams
1.22 Toughened glass windscreens.

Unit 4

4.1 Table. Relative velocity of light and radio waves in space
4.2 Pulses crossing on a rope
4.3 Pulses crossing on a spring
4.4 Infra-red absorption due to a thin layer of sodium chloride

Slides 4.5(1) to 4.5(7) and 4.5(9) all provided by courtesy of the Decca Navigator Company Ltd.

(1) Hyperbolic pattern of constant phase difference lines produced by Master and Red slave transmitters
(2) Overlapping hyperbolae due to Master station and Red slave and Master and Green slave
(3) Complete pattern due to Master station and Red, Green, and Purple slaves superimposed on outline of S.E. England
(4) Two Decometers indicating a 'fix'
(5) Part of an actual map showing Decca lanes
(6) Table showing frequencies, wavelengths, and lane widths
(7) Apparatus used in aircraft
(8) Display unit installed in aircraft cockpit
(9) Block diagram of receiver elements

Unit 9

9.1 World energy production and consumption
9.2 World fuel reserves
9.3 Total world rate of energy consumption
9.4 Cumulative world energy consumption
9.5 Total United Kingdom installed electrical generating power
9.6 Energy production, Africa
9.7 Energy production, North America
9.8 Growth of world population
9.9 Growth of number of cars in Britain
9.10 Energy account for cars
9.11 Power station with cooling towers
9.12 Power station alongside a river
9.13 The iodine molecular absorption spectrum

Index

Schools which took part in the trials

The following schools and colleges took part in the trials of the Nuffield Advanced Physics Project. The Nuffield Foundation wishes to thank the teachers in these schools, their students, the headmasters, governing bodies, and local education authorities for their unstinting help.

Abbey School, Ramsey

Acklam High School, Acklam

Banbury School, Banbury

Bangor Grammar School, Bangor, N. Ireland

Barnard Castle School, Barnard Castle

Batley Grammar School, Batley

Beechen Cliff School, Bath

Bishop's Stortford College, Bishop's Stortford

Blyth Grammar School, Blyth

Brigg Grammar School, Brigg

The Calder High School, Halifax

Camden School for Girls, London NW5

Campbell College, Belfast

Chingford High School, Chingford

Chorlton High School, Manchester

Clifton College, Bristol

Cray Valley School for Boys, Sidcup

Croesyceiliog Grammar School, Croesyceiliog

Cross Green School, Leeds

Dame Allan's (Boys') School, Newcastle-upon-Tyne

East Berkshire College of Further Education, Windsor

Elliott School, Putney, London SW15

Erith School, Erith

Forest Hill School, London SE23

Godolphin and Latymer School, London W6

The Grammar School for Boys, Cambridge

Halesowen Grammar School, Halesowen

The Harvey Grammar School, Folkestone

Highbury Technical College, Cosham

Hillfoot Hey High School, Liverpool

Hinchingbrooke School, Huntingdon

Hinckley Grammar School, Hinckley

Howell's School, Llandaff

Huddersfield New College, Huddersfield

Ilkeston Grammar School, Ilkeston

King Edward's Camp Hill Boys' School, Birmingham

King Edward VII School, Sheffield

Malvern College, Malvern

Mill Mount Grammar School for Girls, York

Monk's Park School, Bristol

North Bromsgrove High School, Bromsgrove

Parliament High School, London NW5

Queen Elizabeth's Grammar School, Gainsborough

Queen's School, Bushey

Repton School, Repton

La Retraite High School, Bristol

Rickmansworth Grammar School, Rickmansworth

Royal Belfast Academic Institution, Belfast

Rugby School, Rugby

St Malachy's College, Belfast

Sale County Grammar School for Boys, Cheshire

The Sir Frederic Osborn School, Welwyn Garden City

Surbiton County Grammar School, Thames Ditton

Teesdale School, Barnard Castle

William Ellis School, London NW5

Woolverstone Hall School, Woolverstone

City of Worcester Grammar School for Girls, Worcester

Worcester Royal Grammar School, Worcester

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This *Teachers' handbook* is intended to be a guide to the teaching of the whole of the Nuffield Advanced Physics course and to provide essential information about it. It is therefore a necessary companion to the *Teachers' guides* for individual Units, and teachers are also urged to study it before beginning the course. Its opening chapters discuss the construction of the course and provide a synopsis of it, set out the general aims, and consider the teaching problems involved. A chapter on examinations follows, with examples of questions used in the Nuffield A-level examination of 1970 and in the trials, and this is supported by a chapter on class tests, also with examples. Then the book considers individual investigations and suggests topics for these. Its latter half includes a list of apparatus required, showing separately items already used at O-level and items required only for the Advanced course, followed by lists of the books, films and film loops, and slides recommended for use in each Unit of the course.

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