REVISED

NUFFIELD ADVANCED SCIENCE

PHYSICS

EXAMINATIONS AND INVESTIGATIONS

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Revised Nu

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REVISED NUFFIELD ADVANCED SCIENCE

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CHAPTER 1
THE PRINCIPLES

The original authors of the Nuffield Advanced Physics course were keenly aware of the need to design an end-of-course examination that was not only technically 'reliable' but was also 'valid', in that it tested the stated aims of the course. As all teachers know, and candidates learn, whatever the declared intentions of a course, what counts in the end is the range of skills and knowledge demanded by the actual examination papers. Styles of teaching and modes of learning, perhaps, are determined as much by the hard 'case law' of examination questions as by the hopes expressed in teachers' guides. So those who set the papers have to ensure that the match between the course and its testing is as close as humanly possible. Over the years the examination has changed in details, largely in response to the feedback from teachers – for example the significant restructuring of the 'Long Answer and Comprehension' package in 1985.

The examination is meant to test a candidate's knowledge of physics. But 'knowing' physics can mean many things: remembering some physics, understanding physics, being able to explain some physics, using or doing physics, and clearly these are not at all the same. In any case there is a distinction between the ability to do any of these and the ability to convince other people of one's level of skill in these areas. The Nuffield A-level examination uses a variety of testing methods so that various ways of being 'good at physics' may be displayed by a candidate. Accordingly, the examination has six elements, weighted as shown:

1 Coded Answers (60 marks, 22%); 1¼ hours:
  40 questions covering all Units of the course.

2 Short Answers (60 marks, 22%); 1½ hours:
  7 or 8 questions, answered in spaces provided on the question paper.

3 and 4 Comprehension together with Long Answers (total 80 marks, 29%); 3 hours (candidates are advised to spend about 1½ hours on each paper):

  3 Comprehension – Section A: a passage with 4 to 6 questions based on it; Section B: a set of situations or effects requiring short explanations.

  4 Long Answers – Section A: one structured data-analysis question; Section B: a choice of one from three essay-type questions.

5 Practical Problems (45 marks, 16%); 1½ hours:
  8 short questions testing physics in a practical context.

6 Investigation (30 marks, 11%):

about two weeks of 'school physics time' in which the candidate selects and carries out an original practical investigation in physics (internally assessed by the teacher).

In addition, candidates may choose to sit a Special Paper of 3 hours, the format of which varies but which is designed to be a searching test of any of the skills and topics covered by the course. A separate grade for the Special Paper is awarded.

Clearly it is impossible to reflect the content of every one of the twelve Units of the course in each of the papers. The examiners do, of course, review the papers as a whole to avoid serious gaps or an over-emphasis of a particular topic.

Chapter 2 gives full details of these examination elements, with examples of the kinds of questions set. The detailed discussion of each paper should be read bearing in mind the examination's purpose, which is to **reinforce** the aims set out in the *Teachers' guide 1* of Revised Nuffield Advanced Physics (Longman, 1985) as well as to test them. For example, an important component of doing physics is the ability to combine practical and theoretical skills in the creative perseverance that leads to the discovery of new effects, laws, or explanations. If this complex of skills is considered important, then it is worth encouraging students to develop their abilities in this field, and accordingly to reward them in the final examination. Thus the 'Investigation' is recognized as a very important element of the total assessment. Its presence should ensure that students spend some time in the first year of the course practising this activity and discussing amongst themselves, and with their teachers, the strategies and tactics likely to achieve success in any kind of research. The time and effort spent on this can be seen to be rewarded – it becomes more than a mere hope of syllabus planners.

Another example of the relationship between the examination and the aims of the course concerns the use of formulae in physics. Some examinations emphasize the learning of formulae by heart. It is considered in this course that this could obscure the more important aim of testing candidates' **understanding** of physics, and also devalue the important ability to look up and **select** relationships. Thus a sheet of 'Formulae and relationships' is issued by the Examination Board for each candidate to use in the examination, and it is expected that this will also be used throughout the course as a sensible, practical aid in everyday work.

One consequence of an emphasis on the skills of using and applying knowledge, rather than simply recalling it, is that questions may be set about topics that are not in the course content listed in the *Teachers' guides* (or in the *Syllabus statement* obtainable from the Examination Board). Questions have been set about icebergs, sea waves, thunderstorms, battery-powered cars, and the energy output of the Sun, but this does not mean that such topics have suddenly been added to the course content. The whole purpose in choosing such topics is to test students' ability to apply basic A-level physics to situations which are new to them.

CHAPTER 2

THE COMPONENTS OF THE A-LEVEL EXAMINATION

The A-level examination based on the course is set by the Oxford and Cambridge Schools Examination Board, on behalf of all GCE examination boards, as an Inter-board Examination. Further details about examination entries and past papers may be obtained from the Secretary of the Board at 10 Trumpington Street, Cambridge CB2 1QB. The Board will also provide a *Syllabus statement*, which gives a synopsis of the course and its examination. It should be emphasized that although *Examinations and investigations* is accurate at its date of publication, the examination procedures and structure are liable to change. The Board's own publications are the only definitive formal statements and should be studied carefully.

Nuffield A-level physics candidates undergo about $7\frac{1}{2}$ hours of written examination, plus the Investigation (occupying about two weeks of 'school physics time'), as briefly outlined in Chapter 1. The examination is broken down into three sessions:

Session 1: Paper 1 Coded Answers ($1\frac{1}{4}$ hours) plus Paper 2 Short Answers ($1\frac{1}{2}$ hours).
Session 2: Papers 3 Comprehension and 4 Long Answers (3 hours).
Session 3: Paper 5 Practical Problems ($1\frac{1}{2}$ hours).

PAPER 1: CODED ANSWERS

In 'coded answer' questions the candidate is not expected to explain how the answer is arrived at, or indeed to write anything at all, but only to mark the letter-code of the correct answer. The advantage of such questions is that the understanding of a large part of the course content may be tested quickly. They are sometimes called 'objective' questions, but the objectivity lies in the machine that marks them: the writing and selection of such questions is still a matter of fallible human judgments. Writing such questions takes skill and experience; even so, they are unlikely to work in their 'raw' state: they have to be revised and edited by an equally experienced eye and then submitted to a 'pre-test'. This involves setting groups of questions to a large number of students who are taking the course, under conditions of strict confidentiality, early in their sixth term. The answers, right and wrong, are then analysed statistically to produce the two most important measures of the value of each question, its *facility* and its *discrimination*. The pre-test values are treated with some caution, being based on a sample of hundreds rather than the thousands who ultimately sit the paper. After each year's examination the Board supplies to participating schools the correct answer, the item statistics, and the most popular wrong answers to each question in the Coded Answer paper.

In general terms, the coded answer questions may be chosen to test the candidate's ability to:

recall basic facts or ideas;
interpret a formula, graph, or a set of data;
understand a concept or the relationship between events or effects;
analyse a complex situation and identify the significant factors.

A given question may involve more than one of the above – and could thus prove to be 'hard'. A question can also be hard because it is set on an area that students happen to find difficult anyway (for example electromagnetic induction).

Three types of question are set, in approximately equal numbers.

Situation sets

In 'Situation sets' (Section A) two or three questions are set on a linked theme or physical situation. The following example is taken from the 1982 paper.

Example

1, 12, 13 A battery of e.m.f. V and negligible internal resistance is connected to the arrangement of resistors shown (figure 1). All the resistors have the same resistance, R.

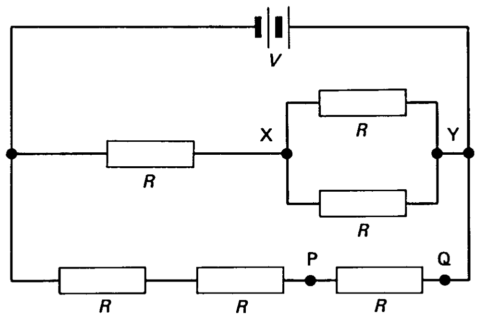

Figure 1

Here are five possible values for potential differences across parts of the circuit.

A zero **B** $V/2$ **C** $V/3$ **D** $2V/3$ **E** V

Which of **A** to **E** above is the potential difference

11 between points X and Y?
12 between points P and Q?
13 between points X and P?

The statistics for these questions were as follows:

Question	Key	Facility	Discrimination	Popular distractors
11	C	56%	0.59	B, D
12	C	77%	0.43	–
13	A	60%	0.52	–

Five-choice answers
'Five-choice' questions are similar to the above examples, but stand on their own. The following example is also from the 1982 paper.

Example

A light car with very soft springs bounces up and down on its springs, after hitting a bump, with a period of roughly $\sqrt{2}$ s. The mass of car and driver is 300 kg.

If the driver now packs in several friends, so that the mass of car and occupants is 600 kg, which one of the following is the best estimate of the new period of oscillation of the car on its springs?

A $2\sqrt{2}$ s **B** 2 s **C** $\sqrt{2}$ s **D** 1 s **E** $1/\sqrt{2}$ s

This is perhaps a typical example of a question in which the examiner can test the understanding of a physical effect and the factors that are involved without the result being distorted by the fact that a number of candidates may have 'forgotten the formula' that applies. Of course, a candidate still has to *choose* the formula, and then *use* it correctly: it is these qualities that the examination tests.

This question (key **B**) had a facility of 48 per cent (so it was not easy) but a discrimination of 0.46, showing that it did indeed reward the better candidates. (**A** was the popular wrong answer.)

The following is an example of a question requiring some basic knowledge to be remembered and then applied to a situation which need not be remembered.

Example

The four inputs, 1 = high and 0 = low, to a pair of two-input NOR gates are as shown (figure 2).

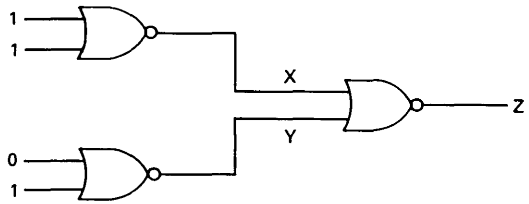

Figure 2

Which of **A** to **E** is the correct combination of the values X and Y at the input to the third NOR gate, together with the output Z of the third gate?

	X	Y	Z
A	0	0	0
B	0	0	1
C	0	1	0
D	0	1	1
E	1	0	1

(Specimen question from *Students' guide 1*)

Questions of this general type are set in Section B of the Coded Answer paper.

Multiple selection questions
Section C contains the type of question at which candidates may have to work hardest: the 'multiple selection' type. Three statements are given about a particular situation or effect, some of which or perhaps all of which are correct. The question invites the candidate to select from a list of five choices which *combination* of statements is correct, as in the next example.

Example

The graphs (figure 3) show the (small) changes in density with temperature of a material which is crystalline when solid, and of a glass. Both are solid at 300 °C; both are liquid at 400 °C. The crystalline solid melts at 350 °C; the glass softens over a range of temperatures around 350 °C.

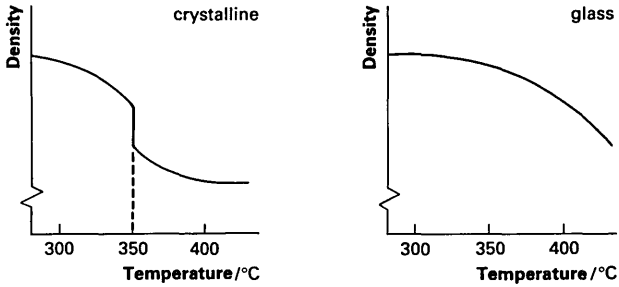

Figure 3

Which of the following statements may be deduced from the shapes of the graphs?

1 The crystalline material contracts abruptly when it melts.

2 The glass expands more per degree temperature rise when molten than when solid.

3 The crystalline material, when *liquid*, expands less and less per degree temperature rise, as the temperature goes up.

A 1 only **B** 2 only **C** 1 and 3 only

D 2 and 3 only **E** 1, 2 and 3

(Coded Answer paper 1982)

The question (key **D**) had a facility of 76 per cent and a discrimination of 0.38. This is an example of a question on a topic not directly taught in the course, but which depends on the candidates' ability to **interpret** information given graphically and draw correct conclusions from it.

PAPER 2: SHORT ANSWERS

In the Short Answer paper the examiners can test particular skills and abilities in a highly selective manner. The paper consists of seven or eight questions and the answers are to be written in spaces provided on the question paper. The questions are 'structured', ensuring that candidates display their reasoning in arriving at a conclusion. The emphasis of the paper is on the testing of skills and understanding, such as:

– *understanding basic ideas and applying them* to novel situations, including the technological;
– *translating information* between verbal, numerical, graphical, and algebraic forms;
– *estimating quantities* and appreciating the degree of approximation and variation involved;
– *understanding the reasons* for basic experimental procedures and the appropriate choice of apparatus;
– *the ability to think quantitatively.*

An example (set in 1982) of a question testing the first of these aims is the following, which involves the application of physics ideas to a novel, technological situation.

Example

A rolling-mill, as indicated in figure 4, is used for compressing slabs of hot steel.

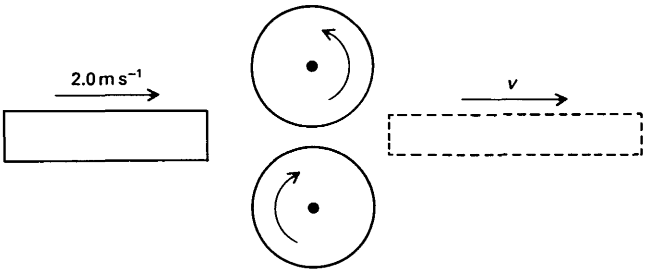

Figure 4

A hot slab of metal 20 mm thick, 0.50 m wide, and 6.0 m long, enters the rolling-mill at 2.0 m s^{-1}, and takes 3.0 s to pass through. In the rolling process its width is not changed but its thickness is reduced to 16 mm.

a Showing how you arrive at your answers, calculate
i the speed, v, at which the slab leaves the rolling-mill.

ii the momentum with which the slab leaves the rolling-mill, given that the density of the steel is 8.0×10^3 kg m^{-3}.

b Calculate the backward force on the rollers. Show the steps in your calculation.

c State what might happen if the material of the rollers lacked
i toughness

ii strength

The interpretation of graphs, both verbally and numerically (as well as an understanding of *RC* circuits and the use of an oscilloscope) was tested in the following example (again from the 1982 Short Answer paper).

Example

A capacitor is charged from a 6 V d.c. supply, and is then discharged through a 10 kΩ resistor using the circuit shown in figure 5. Figure 6 shows a careful drawing of the appearance of the resulting cathode-ray oscilloscope trace. The sensitivity of the C.R.O. was 1 V cm^{-1} and its time-base was set to 0.1 s cm^{-1}.

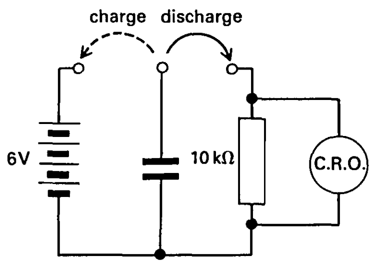

Figure 5

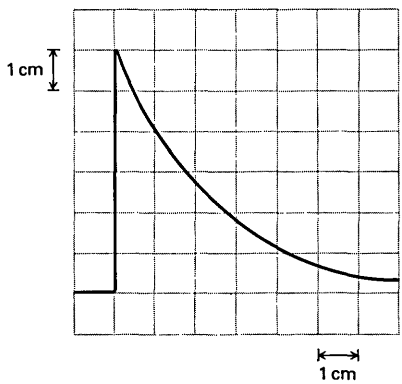

Figure 6

a Showing your working, calculate the initial value of the discharge current.

b *i* Use the drawing of the C.R.O. trace to estimate a value for the charge which flowed through the resistor during one discharge.

ii Use your answer to part **b***i* to calculate a value for the capacitance.

c This capacitor is now replaced by one of half its capacitance. On the diagram of the C.R.O. screen above draw the trace as it would now appear.

Questions requiring the candidate to make reasonable estimates about the magnitudes of common effects or quantities and then use them to make predictions are set quite frequently. The following is from the 1983 paper.

Example

In answering the questions below you will have to estimate various quantities and then use your estimates in order to obtain the required answers. Show clearly your estimates and all the steps in your calculations. Always include the units in estimates as well as in answers.

The men's World high jump record is about 2.3 m.

a How much gravitational potential energy would an athlete have to supply in order to jump this height?

Estimates	*Calculations*

b State two other factors that must be taken into account in order to obtain a more accurate value for the total energy required.

c Accepting the answer in **a**,
i What would be his vertical take-off speed?

ii What would be the average vertical force he exerted on the ground during take-off?

Estimates	*Calculations*

This question required the candidate to apply some knowledge of physics to a situation in which few quantities would be accurately known, but the process of arriving at an answer exposes the particular needs for further information while at the same time exemplifying how much can be deduced from imprecise information.

Obviously, the subject matter tested in any one paper can only be a small fraction of what is covered by the course, and questions are chosen to test and encourage the development of the skills described on page 10, rather than to 'cover' the syllabus.

It is hardly possible even to cover all the skills in a given year, and certainly questions are not set in order to test any one skill in isolation. Some basic skills are tested in every paper, such as the ability to draw and interpret electrical circuit diagrams and to carry out straightforward calculations, but routine questioning is avoided. But however basic the physics, questions tend to test it in unusual contexts, to discourage the mere reproduction of some learned – or worse, half-learned – drilled response. There is, however, a danger that if the context is too unusual the candidate may not recognize the simplicity of the physics involved. Examiners try to avoid this by pre-testing such questions.

Candidates tend to find this a 'hard' paper, the facility being about 45 per cent on average, and it is to be expected that only the better candidates will be able to display the fairly high-level skills required across the range of subject matter tested in a particular year. With the structured format, it is usually clear to candidates when they are getting things right or wrong, but it should of course be possible to do well on a later part of a question even though failing on the earlier part. So a wrong result once penalized will not be penalized again if it has to be fed into a subsequent calculation. Arithmetical errors are not ignored but neither are they allowed to unbalance the assessment by carrying too heavy a penalty. Mathematical skills – particularly in algebra – may be quite searchingly tested on this paper, but questions whose main interest is mathematical are not set.

Quite often, the question structure is designed to aid the candidates by hinting at the most efficient solution to the problem, but the examiners are aware of the danger of limiting the variety of correct thinking possible. The spaces for answers are another means of suggesting the depth of answer required, as are instructions such as 'say why' or 'justify your answer'. Experience has shown that such phrases are more likely to provoke a sensible level of response than simply asking candidates to 'explain'. It is a perennial problem to find a balance between being obscurely brief and being so very precise that short answers are preceded by excessively long questions.

PAPERS 3 AND 4: COMPREHENSION AND LONG ANSWERS

The format of the Paper 3/Paper 4 combination was changed in 1985, with the aim of making more explicit to teachers and candidates the kinds of skill and ability being tested. Also, a substantial element of question choice, as in the pre-1985 'Long Answer' paper, inevitably introduces an element of chance. The change to the new format with its combination of compulsory and free-choice questions should help to ensure that all candidates are given equal opportunities to deploy the variety of skills that the course is designed to encourage. The compulsory element tests physics in the context of comprehension, explanation, and analysis of data. Free-choice questions will tend to test the candidates' understanding of the nature of physics, the planning of investigations, choice of experimental techniques, the control of variables, the role of physics in the world, and the consequent human and technological implications (aims C, D, and E of the *Syllabus statement*).

Paper 3

Paper 3 carries a total of 40 marks, and consists of two sections.

Section A

This consists of four to six short questions based on a piece of scientific prose and is essentially a 'comprehension' exercise. But just as the Practical Problems paper (Paper 5) requires more than the ability to manipulate apparatus and take measurements, so this paper tests more than the basic ability to translate or summarize a form of words, a diagram, or a graph.

The aims of the questions set on the comprehension passage may be described briefly as:

Basic comprehension – can the candidate make sense of what the author has written?
Not-so-basic comprehension (or *reading critically*) – does what the author wrote actually make sense?
The physics of it – does the candidate know enough physics to follow the author's ideas?
Implications and applications – having followed the author so far, can the candidate deduce some consequences of the ideas presented (scientific, social, technological)?
Creative thinking – 'that was all very interesting! Can you think of a better/different way of doing it?'

As a general rule, the questions start with what is intended to be an easy question in basic comprehension (often treated with undue suspicion by candidates who look for deeper meaning). For example, a passage used in the 1982 Comprehension paper on the use of sound waves to form images in 'acoustic microscopes' explained how such microscopes work and are designed, and compared this method with the use of light in optical microscopes. The first question asked candidates to:

Example

Give (*i*) two advantages, (*ii*) two disadvantages, that acoustic microscopes have compared with optical microscopes.

As the information necessary to answer this was spread across several paragraphs in the passage, this required candidates to read quite carefully and to make a selection from the information presented, but it was by no means a difficult question. A more searching question of this kind was set as part of question 5:

Example

The passage refers to the waves being 'attenuated' at high frequencies in certain media. Give one other example you know of in which waves are attenuated, and give the reason for the attenuation occurring.

Here, the examiners assumed that few candidates would have come across the word 'attenuated' previously, so that they would have to deduce the meaning from the context in which the word was used. To ask simply 'What does attenuation mean?' would have been too direct a question for candidates who knew that they didn't 'know' the word's meaning, and likely to lead to many not attempting the question. Sensible answers based on the context gained full marks.

Journalism being at best an inexact activity, 'raw' passages culled from scientific magazines or newspapers contain a surprising number of errors of logic or calculation, or are simply too obscure in their explanations. These deficiencies are generally edited out in preparing the passage for use in the examination: this in itself is a very educational activity, but would probably be too difficult for candidates under examination conditions. However, a test of 'not-so-basic comprehension' is usually present, not only to check an author's calculations, but also to draw attention to seemingly contradictory statements. For example, one question asked candidates to use their knowledge of physics, together with ideas from a passage on thunderstorms, to calculate the acceleration of an atmospheric ion in the electric field of a thundercloud. The candidates were then expected to reconcile the very high value of this with the author's statement that '... ions move at only a few metres per second under the influence of the field'. The training value of such questions is to encourage students to read critically.

Nearly every question tests candidates' understanding and application of physics, and as many comprehension passages are about the applications of physics, the technological implications of physical principles are frequently emphasized. For example, a passage entitled 'Power from the Sun' (used in 1981) generated a question involving most of the aims outlined above:

Example

3a Two of the problems involved in using solar energy effectively are
i 'the fact of night time' (line 34)
ii 'the absence of an efficient storage system for solar energy' (line 35).

Suggest, briefly, a possible solution for each of these problems.

This calls for creative thinking, based on an understanding of the physics and assuming the candidates' comprehension of the lines referred to. The question continued:

Example

b The output of a power station in Canada 'is precisely equal to the solar thermal energy falling upon it' (line 39). Use the information given in the passage to show that the author's statement is in fact justified.

This calls for critical reading, based on the ability to carry out a simple calculation having searched the passage for the relevant information.

Example

c Apart from the problems mentioned in **a** above, suggest two reasons why the power stations due to be built in the United Kingdom during the next few years are unlikely to be solar-powered.

Again, this required creative thinking based on general knowledge of technological and social issues as well as the direct implications of the passage.

Section B

This section of Paper 3 is about explaining an effect or a situation in physics. It consists of five or six short passages from which candidates select three to explain. Some passages describe a situation in which the significant feature that needs explaining requires an understanding of physical principles and concepts. Others are more to do with the nature of physics itself – the role of experiment and theory, the use of models and analogies, the strategies for solving problems in physics.

The following example is taken from the specimen questions sent to schools in 1985.

Example

5 Choose THREE of the statements **a** to **e** below. Write a paragraph or two about each of the three statements.

For each statement you select, state the physical principles which are relevant, and show how they apply to the situation described. Make calculations and give equations wherever possible to show the relationships between the quantities involved. You should not spend more than about 10 minutes on each of the three.

a Electromagnetic waves in the infra-red are strongly absorbed by ionic crystals, such as sodium chloride, which are fairly transparent to waves of higher or lower frequency. (5)

b The circuit (figure 7) shows an a.c. generator G of variable frequency. Ammeter A_1 measures the current drawn from G by the load; A_2 measures the current flowing through the inductor L, and A_3 measures the current through the capacitor C.

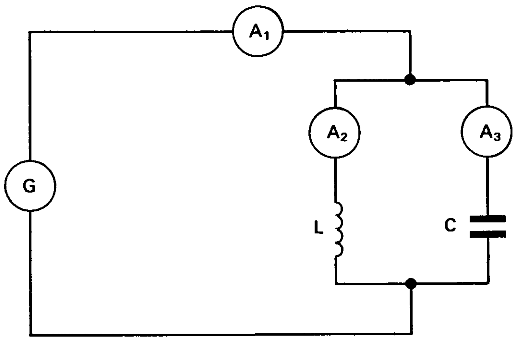

Figure 7

It found that at one particular frequency, the reading of A_1 is very small, even though A_2 and A_3 show substantial readings. (5)

c A puzzled student comments:
'I can't see how anyone can say that a few bits of radioactivity, alpha-particles, being scattered backwards very occasionally, proves that most of an atom is empty space, and that all the mass and the positive charges are contained in one entity about 10^{-14} m in diameter.' (5)

d When an electron collides with an atom:
– we might expect the electron to lose very little energy, since we can regard the collision as rather like a small marble hitting a big one;
– in practice, some such collisions give a big energy loss;
– ionization may occur. (5)

e The human eye is not capable of resolving a pair of car headlamps 1 m apart at a distance of 10 km, even though they are clearly visible, whereas a telescope can resolve them successfully. The wavelength of visible light is about 6×10^{-7} m. (5)

Paper 4

Paper 4, like Paper 3, carries 40 marks, and also consists of two sections.

Section A

Section A consists of one compulsory question, which is likely to be a test of the candidates' ability to interpret data – to analyse data in the form of graphs or tables, to recognize and describe patterns, to draw conclusions and make predictions based on the information presented. The following example is from the 1985 specimen questions.

Example

1 This question is about the use of windmills as a source of energy.

It is proposed that a cluster of these built out to sea could make a substantial contribution to our needs. Answer the following questions which are about the physics and economics of this idea. The data given at the end of the question will be useful. Wherever appropriate, you should make quantitative estimates to support your arguments.

a If a blade of area A intercepts a wind of speed v, it can generate power given by $\frac{1}{2}\rho A v^3 = \frac{1}{2}\rho v^2(Av)$, where ρ is the density of air. What physical quantities do $\frac{1}{2}\rho v^2$ and Av each represent? Explain why they are multiplied to give the power. (2)

b The wind speed (v) actually varies a lot. As a result the mean power is given by $K(\frac{1}{2}\rho A v_m^3)$, where K is a constant with approximate value 2.4 and v_m is the mean speed over the whole year.

The data below show the wind velocity distribution for an average year.

Fraction of year	0.34	0.31	0.23	0.08	0.04
Mean wind speed v_m/m s^{-2}	0.3	0.9	1.5	2.1	2.7

Using these data and the equations given in **a** and **b**, show that the value for K is about 2.4. (4)

c The speed of the wind over the sea varies with height according to $v_H = CH^{0.14}$, where H is the height and C is a constant. By considering the power developed by windmills of heights 10 m and 50 m above sea level, show why there is some advantage in building a high structure for a windmill. What other factors would you need to take into consideration in deciding the best height to build a windmill? (3)

d How big would the total blade area of the windmill need to be, given that:
- v_m for the region was 9.0 m s^{-1} at 50 m height
- the windmill is to be 50 m high
- the windmill is to be designed to operate at about $1.5v_m$
- the power generated is to be 2.5 MW at the design speed?

Say, with reasons, whether you would expect your design to be practicable. (4)

e The windmills in a cluster cannot be too close behind one another; they must be set apart with a spacing of between 7 and 10 times the largest blade dimension. Suggest one reason for this. (2)

f Make a rough estimate of the cost of electrical energy generated by a cluster of 400 such windmills designed to produce a mean power of 100 MW. Assume that the capital cost is to be met by a loan on which interest has to be paid at 15% per year. (5)

Data
Density of air ≈ 1 kg m^{-3};
Area off east coast of England at suitable depth near the Wash is 4000 km^2;
Cost of one off-shore windmill to generate 2.5 MW is about £600 per kW of which 40% is cost of the tower;
Windmill designed for $1.5v_m$ will operate for effectively 40% of the time;
Cost of cables for transmission over 30 km out to sea is about £50 per kW;
Number of seconds in a year $\approx 3 \times 10^7$.

Section B

In Section B, candidates choose one of three questions. These are likely to be open-ended questions giving a great deal of initiative to candidates to formulate their own ideas and communicate clearly and effectively. The following examples are from the 1985 specimen questions.

Example

2 This question is about the simplifying assumptions that are made when theories in physics are invented.

From the list below, choose *two* examples of theoretical arguments in physics, and discuss the ideas involved.

In your discussion of each example you should:
- give an account of aspects of the situation which are being simplified or selected.
- describe ways in which the argument might give wrong results in a real situation because of simplifying assumptions it makes.

Examples (choose TWO)

i The argument in the kinetic theory of gases which shows that the pressure p of a gas having n molecules per unit volume, which have mean square speed $\overline{c^2}$, and mass m, is given by $p = \frac{1}{3}nm\overline{c^2}$.

ii The argument which shows that the speed v of sound in a crystalline solid is given by $v = \sqrt{E/\rho}$ (where E is the Young modulus and ρ is the density), and links this with the speed $v = x\sqrt{k/m}$ for a wave along a set of masses m, with spacing x, joined by springs with spring constant k.

iii The argument using $\frac{1}{2}mv^2 = Ve$, to find the velocity v of electrons (mass m, charge e) fired from a gun, with a heated cathode, and a p.d. of V between anode and cathode, when they travel down the tube of a television set and arrive at the screen.

iv The arguments which use the rate of change of flux to show that the ratio V_s/V_p of the amplitudes of the voltages across the secondary and primary coils of an iron-cored transformer will be equal to N_s/N_p, the ratio of the numbers of turns in each, while the ratio of the currents I_s/I_p will be N_p/N_s. (10) + (10)

3 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 weakness can be avoided, composite materials such as plywood, reinforced concrete and fibreglass, and the new technology of composite materials. (20)

4 Faraday wrote a whole book about the science involved in the burning of a candle; this question asks you to explain the physics involved in some other everyday phenomena.

Choose TWO out of the following list of everyday events. For each of your choices write a short article to explain how they illustrate or involve AS MANY fundamental physics ideas as possible.

List

a Making a telephone call

b Watching television

c Boiling a kettle of water and making tea. (10) + (10)

As these examples show, the kinds of question set in the format introduced in 1985 are not significantly different from those set in previous years, and test the same range of skills and abilities.

PAPER 5: PRACTICAL PROBLEMS

The purpose of the Practical Problems paper is to pose problems involving apparatus. The aim is not just to test whether or not candidates can manipulate apparatus, but also to act as a stimulus, a firm context of reality in which to produce an answer.

Sometimes candidates are faced with a surprising effect, to tap originality; at others a straightforward laboratory situation that should have been met before. In a given paper, candidates are likely to have to observe, describe, explain, calculate, estimate, measure, plot graphs, make deductions, frame hypotheses, test hypotheses, and so on.

In one paper of 90 minutes, candidates may be asked to answer 8 questions. At 11 minutes per question, it is clearly impossible to test all skills, in all areas of the course, using every piece of apparatus. The paper has to be a sampling of what students have learned. Several questions may ask for a calculation to be done, but with the aid of a calculator and, of course, the sheet of 'Formulae and relationships' provided. All Practical Problems questions should test the ability to apply physics principles to solve problems and to use physics terminology to communicate. The principles involved tend to be fairly simple: the laws describing currents in circuits, the laws obeyed by moving or falling objects, the wave nature of light, and so on. The practical tasks are equally straightforward and most candidates have little difficulty in actually performing the experiments. Communication is not so easy, partly because it is a hard-won skill and partly, of course, because the candidates may not understand the principles in relation to, or in the puzzling context of, the real situation that confronts them.

Accuracy

Good experimental physics doesn't always require accurate measurements. There is a place for precisiȯn, but there is also a place for the ability to detect a trend from a few quick, rough measurements. Both kinds of measuring are part of the course: in a short practical examination the latter is more likely to occur. But this is no excuse for sloppiness. Measurements should be made as carefully and accurately as the time and instrumentation permit: the important thing is that physicists should know the limits of accuracy to which they are working. Markers check candidates' results against the school's values as recorded in the 'Information Required by Examiners', and deduct marks for serious errors. There are three ways in which candidates can offend against the principle of 'appropriate accuracy'. One is the straightforward failure to measure the right thing or to read the appropriate scale on an instrument. Another is to read a scale to a degree of accuracy far less than is expected and possible, for example to measure to the nearest centimetre instead of millimetre. The third, increasingly common in the age of the calculator, is the presentation of a result to an excessive number of significant figures. Particularly in the context of this paper, candidates are likely to be penalized for not realizing that a quantity written down as, say, 7.6437 implies an accuracy of 1 part in nearly 80 000: this is a bold claim to make after 9 minutes or less of experimenting!

Answers are written in spaces on the question paper. The size of these spaces, together with careful wording of questions, indicate how much the candidate is expected to write, without being too prescriptive.

Question types

Although papers vary from year to year – and examiners may invent new styles of problem – most of the questions set tend to be of the following types.

The investigation type: these are reasonably open-ended, given the limitation of time, and it is up to the candidate to decide upon procedures and perhaps to choose which of several given pieces of apparatus are best to use. For example:

Example

'Stays strong when wet,' says the advertisement about a particular brand of paper towels.

a Explain what you think is meant by 'strong'.

b Do simple tests on the samples of paper provided to find out how true the statement is. Describe your tests and the results clearly.

The faults type: candidates are expected to identify a fault and put it right – questions based on electric circuits are particularly appropriate.

The skills type: these are questions set to test those skills particularly relevant to practical work, such as graph-plotting; careful observation and description; measuring to the limit of resolution of the given instruments; assessing the reliability of a test; and making appropriate deductions from necessarily limited evidence.

Graph-plotting may be based on careful measurements requiring precise plotting or on quick observations resulting in a sketch of the general trend of how one variable depends upon another – both are essential skills for a physicist. The following is an example of this type of question:

Example

A coil and a milliammeter are connected together on the bench. The total resistance of the circuit is indicated on a notice nearby, and the number of turns on the coil should be clear to you.

Position the magnet inside the coil.

Slide the magnet out of the coil so that the coil is well outside the magnetic field in about 2 seconds (count '0 is a second, 1 is a second, 2'). Notice the reading of the meter while the magnet is being removed.

a Sketch the way in which the induced current varies with time, and explain the shape of the curve.

(Part question, 1981)

The candidates were expected to put in their own axes and labels and decide upon a scale on graph paper provided in the answer space on the question paper.

The observe and describe type: while many questions ask candidates to observe, the emphasis may be on interpretation and explanation rather than on the observations themselves. A question that is almost pure 'observe and describe' was set in 1971:

Example

Assume that the pieces of expanded polystyrene you have been given are samples of a 'new material'. Try a few simple tests on the material and then write a concise description of its characteristics based only on these tests, using the technical words and phrases which materials scientists would employ.

The suggesting and testing of hypotheses type: these are like the investigation type, but rather less open-ended. In one such question (set in 1982) candidates were asked to explore and describe the behaviour of a ball floating on a dish of water, the dish being tilted so that the ball was attracted to the side of the dish in one place but not in another. The final two parts of the question were:

Example

c *i* Suggest a hypothesis which might explain the behaviour which you have just described in **a** and **b** above.
ii Suggest a test, using this or any other apparatus, which you could do to check your hypothesis.

The understanding and application of physics principles type: most of the questions set are of this type, and obviously all the questions test this to some degree, even if their main aim is to test other factors. Thus the basic principles of how current, potential difference, and power are related in a series circuit were tested as follows:

Example

Two wires A and B are connected in series to a power supply. (CAUTION: both wires will cause a burn if touched.) The wires are made of the same material but B is longer than A and has a greater diameter.

a Switch on the current and measure the potential difference across each wire.
p.d. across A = ...
p.d. across B = ...

b What is the resistance of A compared with that of B?
Give your reasoning.

c What is the rate of dissipation of energy in A compared with that of B?
Give your reasoning.

d Explain why A glows red hot and B does not.

(Practical problems paper, 1977)

Organizing a Practical Problems examination

Instructions to supervisors for setting up the Practical Problems examination are sent to examining centres a minimum of one month before the date of the examination, with advance warning in January of any unusual or expensive items that are needed. The teacher responsible for setting up the examination should try out the experiments as soon as possible and report any local difficulties to the Oxford and Cambridge Board. As a general rule, minor variations in the arrangements or apparatus for a particular question will be acceptable, provided they do not change the nature of the question. Obviously this may affect the actual quantities recorded by the candidates and so a note of any changes *must* be reported on the special Report Form, so that the variations may be allowed for in the marking.

Some questions require supervisors to provide accurate results or precise information about the measuring instruments used: this should be done with great care to avoid penalizing candidates unfairly.

Confidentiality

A copy of the examination paper accompanies the instructions to supervisors. Care must be taken to ensure that no details of questions or of likely apparatus reach the candidates.

Disasters

Even in the best-regulated establishments things go wrong now and again. Practical examinations are particularly prone to 'Murphy's Law': oscilloscopes break down, fuses blow repeatedly, hot-water systems leak and turn laboratories into midsummer saunas, etc. So teachers are advised:

1 To have spares (and spares for spares if possible) of anything that might conceivably break down.
2 To make a note on the script if a candidate's work is affected by a

breakdown or a last-minute change in equipment, and if a group of candidates is affected to make sure that the marker knows who they are.
3 To give full details of the incident so that the marker or chief examiner can make an accurate allowance for consequent errors.
4 To let the candidates know that their work will *not* be penalized as a result of circumstances beyond their control.

The success of any practical examination depends very much on the good sense and co-operation of the teachers who set it up and supervise it. With up to 10 000 candidates, each doing 8 experiments, examiners are not surprised to find considerable variation in what actually happens. Add to this the tendency to set the occasional 'interesting and unusual' question and it follows that the marking of scripts needs to be flexible and sympathetic to local variations.

THE SPECIAL PAPER

The aim of the Special Paper is to test excellence in physics. The basic skills that are tested in the other papers tend to be taken for granted: here, the emphasis is on the higher skills. These include the rapid selection of appropriate knowledge and basic skills; the use of analysis and synthesis; speed and accuracy of computation; the fluent deployment of mathematical techniques; the ability to identify and estimate the values of relevant parameters; the consideration of errors, both random and systematic; the production of a good experimental design; the prediction of the likely outcome of events; and a high standard of communication.

Although the physics *content* on which the Special Paper is based is exactly the same as that of the other papers, questions are more likely to be based on novel situations, in a theoretical as well as a practical context. The paper is intended to provide a stimulating and challenging examination for the more able candidates. It is, of course, a voluntary test and is not designed to be used as a means for selection to a university (although some Cambridge colleges may ask for 'S-level' passes as a condition of entry).

Currently the Special Paper has two sections. The first consists of five or so compulsory questions, one longer than the others; the second section contains four long questions, usually of essay type, from which candidates select two. As a matter of policy, new styles of question are continually being tried: it is hoped that there is no such thing as a 'typical' question! For this reason, the questions quoted below are meant simply as samples to indicate the quality of thinking called for by the paper.

Section A

The four short questions carry ten marks each, the longer fifth question twenty marks. In general, the questions set the candidates a clear, specific task – of explanation, of calculation, or a mixture of both. The following is a short question that was set in 1982.

Example

3 Any physicist knows how difficult it is to obtain a precise and reliable measurement. At Zürich, Switzerland, on 15 August 1979 Sebastian Coe ran 1500 m in 3 min 32.1 s and broke the existing world record. If a physicist were consulted about how large a change in the above time would be required before the record could be considered to be broken, what effects would he need to think about? You should mention as many effects as possible, including problems of defining starting and finishing times, and, wherever you can, indicate the size, or importance, of the difficulty in making the measurement. [*You are not asked to discuss factors affecting the performance of the runners but only to consider methods of making the physical measurement.*]

The next example is from the 1983 paper.

Example

4 There are a number of physical processes which depend on the ratio of numbers of particles having energies differing by E being given, at least approximately, by the Boltzmann factor $\exp(-E/kT)$.

a Give an example (other than that in **c** below) of such a process, explaining the significance of the factor $\exp(-E/kT)$ in that case, including the nature of the energy difference E.

b What is the connection between the Boltzmann factor and the manner in which energy is shared amongst particles?

c Viscosity, that is the resistance to flow of a fluid, can be an example of such a process, if flow occurs by molecules needing extra energy E to push between their neighbours.
i If viscosity was thought to be inversely proportional to the number of molecules with the extra energy E needed to push between neighbours, what straight-line graph derived from measurements of viscosity and temperature could you plot to test the theory?
ii Suppose the theory is correct for a given motor oil. If its viscosity

falls by a factor e (=2.718) when the temperature rises from 27 °C to 77 °C, what is the energy E?

The two questions just quoted are apparently very different, but both require a high level of skill. The first question controls the candidates' thinking quite closely, the second poses difficult problems of selection of relevant physics. The answers to such questions have to be written in less than 20 minutes, so thinking has to be quick and presentation rapid. Note form is acceptable, as are quick, 'back of the envelope' calculations. Key words such as 'estimate' or 'indicate' should trigger off this kind of brevity; 'calculate' or 'show that' signal the need for more detail or precision.

The longer question in Section A is often numerical and usually structured, and hence is lengthy. The context is of a real physical situation (perhaps grossly simplified) or, on occasion, of one of the more complex experiments from the course. Such questions are too long to exemplify here, but have involved such topics as the study of the standing wave pattern in a water-filled microwave guide, the critical dimensions of a Cavendish 'G' apparatus, and the effect of drift and Brownian motion on the oil-drop in a Millikan experiment. Experience has shown that candidates find questions involving experimental design to be difficult. Maybe this is because experimental design *is* difficult, but it is perhaps not discussed as often and as fully as it should be.

Section B

Each question carries 20 marks and candidates have to choose two from the four set. The questions are more extensive and tend to be similar to the reflective type of question found in the Long Answer paper. They are usually less structured and so offer more scope for individual development. Coherent, relevant writing is expected and candidates must have the skills to communicate fluently. It is totally unacceptable if a candidate answers in note form when the question says 'Write an essay ...' or 'Explain to a fellow student who is puzzled about ...'.

It is likely that in the future this section will include a question of a more mathematically analytical nature, at a level beyond that specified in the mathematical requirements of the common core syllabus. This is to allow candidates with highly developed mathematical skills the opportunity to deploy them. Question choice in this section means that the less mathematical students, or those who do not study mathematics at A-level, will not be penalized unduly.

THE INVESTIGATION

The ability to explore and investigate, to frame and test hypotheses, to recognize and solve problems, to overcome or outflank the snags presented by awkward reality is highly prized – and not only in the limited field of physics. To devote only four weeks of a two-year course to this kind of activity may seem rather inadequate, but it is hoped that the training and gradual development of investigatory skills will be a significant feature throughout the course: the Investigation itself is merely the opportunity for students to display and to be rewarded for the skills that they have developed.

Students do one such Investigation in each year of the course, spending two weeks of 'physics teaching and working time' on each occasion. The second Investigation carries about 10 per cent of the total marks assigned to the A-level examination and is assessed by the physics teacher. As will be clear from the criteria used to make the assessment, the successful student has to do more than build a piece of apparatus, or collate and present information: hence the title 'Investigation' rather than 'Project'. The assessment criteria are related to the following:

1 Applying knowledge and understanding of physics of an appropriate standard at all stages of the Investigation.
2 Showing sensible scientific behaviour.
3 Devising and carrying out simple, effective experiments.
4 Incorporating a variety of worthwhile ideas – even if they are not always successful.
5 Appreciating the meaning of observations and being able to evaluate them critically.

The Examination Board issues a pamphlet ('Investigations: Notes and instructions for assessment') which expands on these criteria and explains how they should be used by the teacher in judging the quality of a candidate's work. Each centre submits a sample of its assessed Investigations, each year, for checking by external moderators appointed by the Board. This is to ensure uniform standards between centres.

Helping the student

Like other components of the A-level examination, the Investigation exists not only to test students' abilities but also to encourage their development. The professional task of the teacher is to assist and assess at the same time, and to do so in such a way that both teacher and student are clear as to which is which.

Teachers must keep up the momentum of the Investigation by asking questions and encouraging the student to talk about it. This helps to clarify the student's ideas, without necessarily giving any prompting. But if the work has ground to a halt it is better to offer advice to get it going again: this can be allowed for in the assessment, of course. Students should be encouraged to ask for advice, but not to become too dependent. The use of reference books is sensible and should be recorded. The 'ability to apply knowledge and understanding of physics' refers to A-level physics, not to more advanced knowledge outside the candidate's experience, and assessment and advice should bear this in mind.

Some schools produce their own 'Guide to Investigations' which summarizes the advice from other publications, gives the criteria by which the Investigation will be judged, and adds any particular hints or tips experienced teachers may think useful. This is likely to be advice on care and accuracy, expressing results to an appropriate number of significant figures, and presenting information clearly in graphical form.

Choosing a topic

Often the biggest hurdle perceived by students is choosing a topic. The Investigation is essentially the students' own work, and they must be encouraged to be imaginative: the evidence is that the best investigations develop from the personal interests of each student. Nevertheless, when imagination fails, a topic may be selected from the list of previous Investigations obtainable from the Examination Board, or suggested by the physics teacher. A more difficult task, perhaps, for the teacher is to nip unsuitable investigations in the bud, before a student has wasted too much time. Each student should discuss the proposed topic with the teacher well in advance, and critical questions to ask include:

'Does it include physics measuring techniques?'
'Could you produce a first set of rough measurements, from materials readily available in the laboratory, in an hour or so?'
'Are you likely to be spending much of your time sitting in front of apparatus taking masses of measurements, i.e., *do you behave as a data-recording device rather than a thinker?'*
'Do you hope to produce some useful conclusions?'

Unfavourable responses *must result in rejection of the topic.*

Students should be encouraged to use simple equipment that they themselves can adapt or modify as needed – basing the whole Investigation on the school's only laser can be disastrous if the device breaks down half-way through. Students do better when they have chosen a topic that generates several small, soluble problems than one with the likelihood of a large, insoluble one. Thus good thinking is more likely to occur with simple apparatus, and it is good thinking that is rewarded rather than a successful 'result'.

Students should be warned about the use of computers in investigations: while a computer might be useful in exploring theoretical models of a phenomenon, or suggesting a phenomenon to investigate, it must be only a part of the Investigation. An exercise that is purely theoretical is not acceptable: computers should be servants, not masters. A similar caution is needed with regard to electronics. While it would be appropriate to *use* electronics to measure or control something as *part* of the Investigation, an Investigation which consisted solely of building an electronic circuit or system for its own sake would not be acceptable.

Every year the range of topics chosen varies enormously, from the apparently trivial ('The friction between shoe soles and various materials', 'The effect of electric fields on water drops', 'The time taken for fuses to blow') to the unexpected and imaginative ('Why do flags flap?', 'Investigation of cling wrapping: why does it cling?'). While a novel Investigation is certainly more interesting from the teacher's point of view, even an often repeated topic such as the electrical properties of pencil lines on paper, or the mechanical properties of a fishing line, may be novel to the student and can stimulate first-class work. The prime basis for choice should be the criteria suggested above rather than the originality of the topic. Some idea of the range of topics which have been investigated in the past is given in the Appendix (page 49).

It may be instructive to compare two Investigations submitted in the same year on the same topic: the conduction of electricity by pencil lines drawn on paper. Both candidates started their reports with a brief account of the manufacture of pencil lead. One went on to do some rough calculations, based on the assumption that pencil lead has the same resistivity as graphite, of the likely resistance of a typical pencil line. This value was then used as a guide to choosing the power supply and meters to be used in the first experiment. Both students concerned themselves with the problem of making electrical contact with the pencil line, but whereas one was satisfied with an arrangement which gave reproducible results, the other went on, later in the Investigation, to estimate the extra resistance due to the contacts.

The first candidate took trouble to devise a way of drawing the lines in a consistent fashion, and went on to take many measurements (varying p.d., line width, length, and thickness, for different grades of pencil and of paper). But the physics involved was quite small, being little more than showing that the results were consistent with the formula $R = \rho L/A$.

The second candidate used the known value of the resistivity of graphite to estimate the thickness of a pencil line from its length, width, and resistance. It was seen to be unrealistically low and the candidate went on to measure the resistance of a pencil lead and so obtain the resistivity of the material. This (higher) value gave a new estimate of the thickness, and in an attempt to confirm this the candidate was able to measure the increase in mass when a very long line was drawn on a piece of card. The density of lead taken from a pencil was measured and used to calculate the thickness of the line on the card. Using this value of thickness, the candidate re-estimated the resistivity and found it to be higher than that of pencil lead itself. Allowance was made for contact resistance by comparing the current passed by two otherwise similar lines of different length.

This second Investigation was by no means an 'ideal' one and is not presented here as a model to be copied. Nevertheless, it shows how sensible scientific behaviour, variety of ideas, and simple, effective experiments can arise in an apparently mundane Investigation.

The report

It is expected that the candidate's report will consist largely of the record of day-to-day measuring and thinking, written as a diary, with the emphasis on clarity and communication rather than on formal presentation. 'Tidied-up' accounts tend to leave out the very qualities that the assessors are looking to reward, such as the variety of ideas incorporated even if unsuccessful. The account should be brief and to the point, and the final summary or conclusions should draw the reader's attention to the significant discoveries or processes involved in the Investigation.

An Investigation that begins with something simple and then becomes more and more complicated is by no means a 'failure', even if few of the questions raised are answered. This, after all, is the way physics tends to happen! An Investigation can be a good one even if it produces no answer other than that a certain line of inquiry looks promising, or even that no answer is at all possible with the resources available. In a couple of weeks it is a success if one or two variables have been sorted out, one or two have been got under control, and one or two problems arising from the measurements have been clearly defined.

Timing and organization

The school's assessment of the second-year Investigation, together with the sample reports, must be submitted to the Board by 1 May. This means that the Investigations themselves are usually done in the fifth term of the course. Many schools and colleges find that the most convenient time for the first-year 'practice investigation' is towards the end of the third term. Potential clashes of equipment use may be resolved by requiring students to submit a list of their expected needs about two weeks before the start of the Investigations themselves. Leaving apparatus set up, ensuring that a standard piece of equipment such as an oscilloscope will be available when a student needs it – these are some of the organizational problems that need to be thought through in advance. Clearly the ideal is a laboratory that can be entirely devoted to Investigations for a fortnight twice a year. Of course, this is not always possible and individual schools and colleges evolve their own strategies for coping with such problems.

CHAPTER 3
PREPARING FOR THE EXAMINATION

It should be clear by now that whereas straightforward *knowledge* of physics is by no means undervalued in the A-level examination, there is at least an equal emphasis on *skills* and on *understanding*. It is important that candidates realize this from the beginning of the course, so that they do not labour ineffectively, under the false impression that success can be obtained either by the last-minute burning of midnight oil or the monotonous copying up of folios of 'notes' in impeccable handwriting. As a general rule, the student who works steadily and with interest throughout the course, and who insists on understanding the material as it appears, week by week, is going to do well in this A-level. The many questions in the *Students' guides* may not only be used to assist learning but also to test (and self-test) basic understanding of the ideas.

UNIT TESTS

It is wise to set a test at the end of each Unit of the course: such a test has several functions, which may include:

informing students of their progress;
allowing teachers to check on students' progress;
diagnosing particular difficulties and areas of weakness in either learning or teaching;
practising examination techniques;
assuring students that the aims of the course are also reflected in the kinds of examination papers set.

Of course, no single test will be able to do all these jobs, but it is worth the time and trouble to ensure that over a series of tests, all are catered for. The first two functions are always present in a test, more or less reliably; the others may need a special effort to build them in. It takes at least two people to set an exam question: one to set it, and a critical 'shredder' who can usually see defects and ambiguities not obvious to the setter.

An end-of-Unit test will be only about two periods (say just over an hour) long. It is idealistic to expect a school-based test to be original, reliable, and valid. But the teacher has the advantage of knowing the students well enough to be able to gauge the significance of the raw test marks in ways denied to distant examiners. Different groups may need different tests: a high-flying set may be stimulated and suitably chastened by questions that could irremediably traumatize a group of worthy plodders. Thus the aim is to produce a bank of questions for each Unit that cover a range of content, expose common errors, have a range of difficulty, and exemplify the main modes of the examination: practical problems, coded answers, short answers, comprehension, analysis, explanation. From these, a suitable test for a particular group may be assembled – an easy task if the bank is stored in a word-processor file.

It is worth emphasizing one very important point at this stage: although past examination papers are valuable as quarries from which questions may be mined, students in the first year of the course rarely have the maturity to be able to tackle such questions with confidence, even if the *content* of the question is based on a 'first-year' Unit. There may be subtleties of phrasing in the question, or skills of analysis and evaluation required that are outside their experience and preparation. This is particularly true of Long Answer or Comprehension questions. So the experienced teacher will sculpt the raw material of such questions to match his or her expectation of the students' performance.

Examples of test questions

Coded Answer questions

The Board does not keep these questions secret and each year schools are supplied with the keys to the previous year's questions, together with the 'facility' quotient (a measure of how easy the question is). Those with a high facility are suitable for an end-of-Unit test in the first year, but, statistically, it is hardly worth setting less than ten such questions for any particular test. One value they do have is that, if well chosen, they may diagnose common errors and so provide a useful basis of post-test discussion. Examples of this kind of question are given in Chapter 2.

Short Answer questions

These questions are able to test a small section of a Unit just as a Coded Answer question might. In many respects they may test similar abilities: to interpret a graph or a formula; to make a rational judgment; to perform a calculation or algebraic manipulation, etc. But they do so in different ways and allow a freer response: students may have to draw graphs, explain in their own words, justify a choice. Thus the teacher-as-examiner can assess the level of skills and thinking with more evidence available to him. (See, for example, the questions from 1982 used to illustrate the Short Answer paper in Chapter 2.)

Paper 3/4 questions

These papers test the following four kinds of skill:

Comprehension – the ability to read with understanding both text and graphs.
Analysis – the ability to recognize and identify the elements of a complex situation and the relationships between them.
Reflection – the ability to bring together disparate ideas into a meaningful whole and present them in a logical way (which may also include some analysis).
Explanation – the ability to recognize the basic physical reasons for observed effects and then state them in a logical and coherent manner.

Obviously, other skills may be required and any given question may well include elements of all four main abilities. However, it should be possible to recognize the *main* purpose of a question, if only by its style.

A full comprehension question may be too long (45 minutes) for a Unit test, and may cover more than one Unit, but it is fairly easy to find a few paragraphs in a book or magazine – perhaps from the reading matter in the *Students' guides* or the Background Readers – on which appropriately searching questions may be set. The following sample comprehension question, 'Tough engineering materials', is based on an article by J. G. Morley in *Physics and the Engineer* (Longman, 1973).

Example

Summarizing the present position, there are two alternative routes to tough engineering materials. In the first group crack stopping is brought about by changes in material properties taking place on a very small scale around the tips of stress-raising cracks or flaws. The only practical examples of this group are metals. In the second group cracks are initially allowed to grow but are then prevented from propagating further by the material's macroscopic structure. Practical examples of this group are glass-fibre-reinforced plastics and biological materials such as bamboo.

Both types of material have their advantages and disadvantages. Metals are very efficient in that the crack-stopping component is generated in microscopic quantities just when and where it is needed, while the rest of the material continues to behave elastically and carry the applied load. Generally the properties of metals are the same in all directions and this assists the construction of three-dimensional engineering components. The major limitation of metals is that, relatively speaking, they are heavy, not very stiff, and suffer from fatigue failure.

The great advantage of a fibre-reinforced system is that the fibres can be chosen purely on properties such as low density and high stiffness; their brittleness can be ignored. But these materials are inefficient in that the second, crack-stopping component (the matrix) has to surround all the fibres, extend throughout the bulk of the material, and of course be present all the time. A further limitation of such materials is their anisotropic nature. This is no handicap when good properties are needed only in one direction, as in the case of a fishing rod. But when isotropic sheets are required the properties are reduced to about one-third of the unidirectional strength and stiffness. A three-dimensional material of this type, able to bear loads equally in all directions, is not likely to be a practical possibility.

a Explain how cracks originally present in a material propagate through it when it is under stress.

b *i* What 'changes taking place on a very small scale' in a metal may stop a crack propagating?
ii How do these changes actually stop the crack propagating?

c Explain how the structure of **either** glass-reinforced plastics **or** bamboo may stop cracks propagating too far.

d What is the meaning of each of the following words or phrases used in the passage:
i macroscopic
ii behave elastically
iii fatigue failure
iv anisotropic
v stiffness

e Explain why 'brittleness can be ignored' in choosing fibres for reinforcement of a material.

The skills and knowledge expected here are fairly obvious and are of about the level expected from a student in the first few months of an A-level course. It would be possible to find both easier and more difficult questions based on the passage, and also to use it to generate some mathematical or graphical work.

It is helpful to make a check list (or better an analysis grid) of the main skills in physics and in tackling question-types plotted across the course content. This will ensure that neither major topics nor significant skills are missing from, say, a year's Unit tests seen as a whole.

Practical problems

Many teachers set a complete Practical Problems paper as a trial examination late in the second year of the course, mainly to give practice before the real thing, but there is a case for using these problems earlier in the course as part of a Unit test. As explained earlier, the Practical Problems paper is as much a test of understanding of theory as of practical skills. In so far as we may use assessment to *help* learning, the Practical Problems paper is perhaps closest to one of the ways in which students learn their physics on the course by an intimate mixture of doing and thinking. The bank of past questions is large enough for a whole test to be set on the topics in one Unit. Of course, giving such a test involves more preparatory work in setting up experiments, but questions can be chosen which are straightforward enough to make it worth while. To make things easier in this regard, a mixed test might be set in which half the time is used for written questions (Short and Coded Answer, say) and the rest for practical problems – the class may be split in two, with one half tackling the practical problems first, and then the other half.

The Investigation

The Investigation has been discussed at some length in Chapter 2, but it is worth emphasizing here, again, how much students benefit from the 'practice investigation' in the first year, and also from the mini-investigations and report-back opportunities that the course provides. Students begin the course very much as novice physicists; by the end of it they should be able to operate effectively and independently as worthy apprentices.

CHAPTER 4

AN ACCEPTABLE STANDARD

A question of standards

Students, parents, and teachers want to be assured that a Nuffield Physics A-level is as good as any other Physics A-level. Can such an assurance be given?

The short and formally correct answer to this question is 'yes'. The syllabus and examination policy has been scrutinized and approved by the Secondary Examinations Council, the inter-board examination is attested by one of the main GCE Boards on behalf of all of them, the syllabus incorporates the core-syllabus in physics recommended jointly by the Boards, and successful pupils will have their grade recorded on their GCE certificates in the normal way. Moreover, the examination has been in existence since 1970 and is now taken by about 20 per cent of the country's total A-level physics entry, so it is hardly a novelty or minority phenomenon to be matched against some yard-stick set by others. Rather, it is one of the major national elements between which standards are defined and accepted, and, as this chapter will show, standards at A-level in physics do not vary significantly between one board and another.

The Boards, and the examiners for the Nuffield A-level examination itself have always been anxious to satisfy themselves that Nuffield Physics A-level is as valuable and as valued a qualification as any other physics A-level. There are two ways of doing this: internally by comparing the examination performances and grades with those in other A-levels, and externally by exploring what the customers, those who use the results, think about their value. These two approaches will be discussed below.

Internal comparisons

Four main methods have been used to compare Nuffield with other A-levels in physics. The first, used mainly in the first few years of the examination, was to rely on the judgment of individuals. The Oxford and Cambridge Board appointed the Chairman of Examiners for its own physics examination to take part in external scrutiny of examination papers and to spend time with the Nuffield examiners looking at individual scripts when grade boundaries were being determined.

Decisions were reached with his advice and agreement. This helped the examiners in the first years of the new examination to build up their judgment of appropriate standards. It helped the Board to fulfil its responsibility to itself and to the other boards for public attestation of the standards achieved.

The second method was used by the Schools Council as part of its work, now carried out by the Secondary Examinations Council, of scrutinizing A-level procedures and standards. A group of about four experts not themselves involved in setting or marking this particular examination conducts a thorough scrutiny of all phases of a selected A-level. This involves study of syllabus materials, examination papers, mark schemes, samples of marked scripts, statistical data on mark distributions, borderline levels, and so on. The Nuffield Physics A-level was scrutinized in this way on two occasions, in 1970 (the first year of operation) and in 1979. On both occasions the standards were pronounced satisfactory. The 1979 report recommended that the examiners be rather more generous in awarding grade C; the Board acted on this recommendation and the effect can be seen if the 1980 and 1979 results are compared.

The third method is to set the same questions in both the Nuffield and other examinations and check the performance on these of the different sets of candidates. This was done in 1978 when 15 multiple-choice items were set in the Nuffield and in two other physics A-level papers. The method of analysis used was to take candidates who had been awarded equal grades by the three boards and compare their performance on the common questions. The items themselves were set by the different examiners, but agreed by all as suitable. While Nuffield candidates, for example, looked better on items of Nuffield origin and less competent on those from other examiners, the overall result was that differences between the three boards were very slight: changes in total marks of less than 1 per cent would have eliminated all the inter-board differences. The differences indicated that in order of leniency the Nuffield examination came between the other two. This method may appear to be more objective than the first two, but it did still depend on the judgment of examiners that the questions selected would be equally fair for candidates entered for all three A-levels.

The fourth method is again objective and statistical. It involves 'subject-pairs' comparisons. The figures in table 1 illustrate its use: they are taken from analysis of the 1982 A-level examinations of the Joint Matriculation Board.

The first line indicates that 5141 candidates took both the most popular JMB Physics syllabus and the JMB General Studies examination. The mean A-level scores of this group, calculated by reckoning grade A as 7 points, B as 6, and so on, were 4.0 in Physics and 4.3 in General Studies, so that students were finding General Studies easier by about 0.3 of a grade. The correlation between the two sets of grades was almost 0.6, on a scale where zero would indicate no tendency for the two grades of an individual to be the same and 1.0 would indicate perfect matching of the two grades for every individual.

Reference subject (R)	Comparison subject (C)	Number in overlap sample	Mean grade in R	Mean grade in C	Correlation coefficient
JMB Physics	JMB General Studies	5141	4.0	4.3	0.57
(Practical A)	JMB Maths Syllabus A	3938	4.3	4.0	0.80
Nuffield Physics	JMB General Studies	1327	4.0	4.4	0.58
(JMB entry)	JMB Maths Syllabus A	723	4.3	3.9	0.71

Table 1
Subject-pairs comparisons, JMB 1982.

The second line of the table shows that the comparison with Mathematics is different. Here, the 'overlap' candidates found Mathematics more difficult by about 0.3 of a grade, and the correlation between the two sets of results was higher. Differences of less than 0.5 of a grade are not generally regarded as significant. Correlations higher than 0.6 are generally found only between subjects similar in character (for example different foreign languages, or the physical sciences and mathematics).

The third and fourth lines show the results obtained when Nuffield entrants are analysed for comparison with the same two subjects in JMB. The results show a remarkably similar pattern. The only difference that might possibly be significant is that the correlation between Physics and Mathematics was lower for Nuffield.

Several of the GCE Boards have carried out studies of this kind, and analyses which include data about Nuffield A-level Physics have been published (see references *1* and *2* on page 47). No single comparison can give unambiguous evidence: for example, if one particular physics A-level attracts schools or pupils who are good at General Studies, or by its broader scope gives such candidates an advantage in General Studies, then it could be quite wrong to change the standards of that physics examination to correct a subject-pairs aberration with General Studies. Similarly, the data in table 1 only show alignment between Nuffield and JMB standards in physics: it could be that both are out of line with other boards. So comparison studies should involve careful scrutiny over a wide range, and evaluation of assumptions underlying any interpretation. For example, a detailed paper from one GCE research unit, which used 'subject-triples' evidence to cast doubt on the 'subject-pairs' method, concluded that on one set of assumptions 'there does not appear to be any case, one way or the other, for arguing about the standards in Nuffield Physics' but that when other data are examined from a different point of view 'a difference in grading standards between the Board's own Physics and Nuffield Physics would seem to be likely. The evidence here would tend towards the conclusion that the former was too difficult.' (Reference *3*.)

The overall conclusion from all such studies is that the standards are correct. Neither the examiners nor the Board have any motive for making the examination either hard or easy by comparison with others, and justice to the candidates demands that standards be in line.

Of course, merely looking at percentage pass rates can be misleading. To illustrate the need for caution, table 2 shows the cumulative data for percentages of candidates in the grades of Nuffield A-level and the A-level Physics of the London Board, both for 1982.

Grade	A	B	C	D	E	O
Nuffield	13.4	27.7	42.4	56.7	78.0	95.0
London Board (total entry)	7.8	22.2	34.6	46.5	67.2	82.8
London Board (schools only)	10.4	27.6	41.3	54.0	74.4	88.2

Table 2
Cumulative grade percentages, Physics 1982.

However for this Board, only 63 per cent of the entrants are from schools; if only school entries are taken, the result is different, as the third row of figures shows. Adding to the complexity, the Nuffield entry comes from nine different Boards and the standard of entry differs with board of origin. Table 3 shows, again for 1982, data for the six boards that enter over 500 candidates for the Nuffield examination. Each pair of numbers compares the cumulative percentage at grade B (*i.e.* all those with grades A or B) for the board's own physics examination with the corresponding figure for the Nuffield candidates entered from that board.

Board Number	1	2	3	4	5	6
Board's own physics	30.1	23.8	27.9	22.2	14.8	32.3
Board's entry to Nuffield	28.5	24.5	28.7	24.9	19.2	35.5

Table 3
(A + B) grade percentage for entries from different boards.

There is no reason why the Nuffield entry from (say) Board 3 *should* have the same success rate as the other candidates with that Board who enter its own examination. Nevertheless it is evident that, for each board, the pattern of success is much the same for Nuffield as it is for the board's own Physics examination.

Tables 2 and 3 illustrate the need to exercise care in interpreting any particular sets of figures. Comparisons between particular pairs of boards, or between particular pairs of subjects (for example physics grades with mathematics grades) cannot tell us which of the pair is responsible for any apparent discrepancy. Comparisons between overall results of different groups of candidates cannot be interpreted unless we assume that the two groups have the same ability in physics: only then can any differences be taken as evidence of inconsistent standards.

External comparisons

A-level grades are used as selection criteria for future study or employment. We might ask whether teachers or employers who have relied on grades in this way are satisfied. For employers, it is not possible to say, as not enough employers have made comments one way or the other.

The same is true for higher education, but it has been practicable to make systematic enquiries. One such enquiry was conducted in 1972 (see reference *4*) using a questionnaire asking ex-Nuffield university students to compare themselves with peers who had followed traditional physics A-levels, and asking their tutors to compare those qualified by Nuffield A-level Physics with the rest. The results for students showed that they thought they were much better equipped for practical work, for ability to think across subject boundaries, and in ability to handle relevant mathematics. The tutors agreed with the first two of these judgments, but disagreed with the third. They also thought Nuffield students less well equipped in factual knowledge, but appreciably better in participation in tutorial discussion and in showing a questioning attitude.

Again, in 1980, as part of the preparation for the revision of the course, many university departments in engineering, medicine, and science were asked about Nuffield A-level Physics (reference 5). Of the 181 replies, 77 were from engineering, 19 from medical, and the other 85 from science (including 30 physics) departments. About one-third of the physics departments, two-thirds of the engineers, and three-quarters of those in medicine said that they had very little or no direct knowledge of the Nuffield course books or examination papers. This illustrates one of the main problems in evaluating replies to enquiries of this kind.

Table 4 summarizes responses to questions about differences between Nuffield students and others, and about suitability of Nuffield Physics as a preparation for students in the departments' courses. (There were no particular differences between the patterns of response of the different faculties.)

	Differences between Nuffield students and others	**Suitability of the course as a preparation for their degree studies**
Strong positive comments for Nuffield	5	14
Mixed positive and negative	11	17
Neutral; no opinion or minor positive comments	141	122
Minor negative comments	19	18
Strong negative comments	5	10

Table 4
Replies of 181 departments.

It was clear from this enquiry that the bulk of opinion and practice in universities is to treat Nuffield and traditional physics in the same way. The number of departments with strong opinions, either way, is quite small and very evenly divided. Of course, although students and parents can be assured that there is no overall disadvantage, there will always be a small chance that a student may encounter a lecturer who will express reservations about the Nuffield qualification.

Finally, a small number of university students were asked, in 1980, to write about their views, in retrospect, of their Nuffield A-level

Physics work. Their views were varied, but were on the whole about four main themes. One concerned the style of thinking:

> '... good in developing the student's approach to physics. It encouraged the student to find out for him/herself without accepting a lot of formal proofs.'
>
> 'A very good course from the point of view of making students think rather than just learning facts.'
>
> '... has given me a deeper understanding of the workings of physics and good insight into how to tackle problems of all types, not necessarily physical. The one facet of the course which, in retrospect, could be improved upon, would be the greater use of formalism in mathematics.'

This concern about mathematics came up in several comments. A second theme was the relating of theory to practical work, thus:

> 'I found the course more interesting for the way in which theoretical work was related to practical application, *i.e.* the usefulness of theory in the practical world. This almost certainly prompted me to consider engineering as a career.'
>
> 'Other students who didn't do Nuffield seemed to have seen more formulae than me (for example in optics) but had not done experiments designed to show these phenomena which I had. ... it was very useful to have seen the phenomena in practice at A-level to help me see what the maths meant.'

A third theme reflected concern about the range of topics covered, as exemplified by the following:

> 'I found the course very interesting and enjoyable in itself though after a year of university physics I felt that I was not fully prepared to begin this university's physics course. My knowledge was particularly lacking in optics, particularly geometric optics, and classical mechanics ....'
>
> '... early introduction of such topics as quantization, wave particle duality, entropy, and the wave mechanical description of the atom makes the acceptance of the concepts involved much easier when they are reintroduced in the first or second year of a university course. In my first year at university I found my knowledge of classical physics did not meet the expected standard; however in later years very little of that knowledge has been needed or built upon ....'

It should be borne in mind that only a small minority of those who take A-level physics go on to study physics in higher education, and also that these comments related to the course before revision. Nevertheless, such comments were part of the evidence which helped guide the development of the revised course. For example, the treatment of mechanics has been given greater emphasis – one consequence of the fact that the revised course incorporates the agreed inter-board core syllabus in physics at A-level. There has also been an attempt to make more explicit the need for students to be competent in basic mathematical skills such as changing the subject of an equation.

The fourth theme which emerged from students' responses relates to examinations. Two quotations from second-year and final-year honours physics students respectively, can complete this part of the story.

> 'The A-level seemed to emphasize the use of formulae and laws to solve physical problems (rather than learning and regurgitating formulae, etc.) which is useful because this technique is required and developed as part of the degree course. It is also more interesting.'
> 'I think the greatest strength of the Nuffield Advanced Physics course is the examination at the end. The style certainly encourages thought about the problem rather than remembered facts.'

In spite of all the evidence on equivalence of standards, there is no doubt that the Nuffield examination is distinctive in the way in which it reflects the aims of the course. Comments such as those above confirm this. Independent analyses which compared the Nuffield papers with others came to the same conclusion (see reference *6*). It should also be noted that, just as there is very wide variation in the balance of aims tested between different A-levels (reference *6*), there is equally wide and striking variation between university degree examinations in physics (see reference *7*). We should not be surprised if those in higher education who approach the subject so differently also give different value to the distinctive features of the Nuffield course. We ought to worry only when they cease to see it as distinctive.

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APPENDIX: TOPICS OF INVESTIGATIONS

The following list (reprinted by permission of the Oxford and Cambridge Schools Examination Board) gives the titles of the reports of some Investigations which have been assessed in a high category in past examinations.

While such a list may prove useful to teachers and students it must be interpreted with caution. It would, of course, be wrong to assume that *only* these topics can lead to a successful Investigation. Nor must it be assumed that these topics would be appropriate for any particular future candidate. Before a student starts an Investigation the teacher should ensure that the topic chosen is appropriate to the abilities and interests of the student, and to the local circumstances.

Flow of water over notches and weirs

Contraction of adjacent turns of a coil due to current through them

Load/speed variation of parachutes

Corona discharge

Forced convection

Creep in copper wire

Effect of shelving on breaking of waves

Aerodynamic forces on a motor car

Piezoelectric effect

A wind-powered generator

The formation of a water tornado

Electrostatic particle precipitation

Distribution of air-borne pollution

An electrical analogue for water flow through locks

Pouring – factors making the ideal spout

Construction and use of a variable-interval coincidence counter for study of short-lived isotopes in a radioactive decay

Smoke rings

The effect of different periods of short-circuiting on the rate of recovery of a dry cell

Feasibility of solar energy

Optimum aperture of a pin-hole camera

Absorption of microwaves

A study and analysis of rotational vortices

The control of sound in rooms

The effect of internal pressure on the performance of a football

Absorption of liquids by filter paper

Ionization of air and Van de Graaff generators

Design of an automatically operating burette

Use of a photo-sensitive device as a photometer and application to light emitted from a light bulb

Energy stored in a clock spring

Investigation of cling wrapping: why does it cling?

Magnetic suspension

Temperature in a flame

Absorption of electromagnetic waves by glass

Performance of a fan

Lightening valve rocker arms to improve engine performance

Phase change in an induction motor

Fringes in draining soap films

Hovercraft

Properties of foam plastic

The 'singing' of a kettle

Acoustics of a large room

Relationship between the wavelength and changing concentration in a fluorescent substance

Rotating shafts

Craters

Making an accelerometer

Oscillations of wire rings

Sound frequencies from metal plates

Quantitative transmission of radiant heat

Puncture properties of paper

Plastic properties of leather

Transmission of sound through water

Effect of pressure on a sparking plug

The settling rate of metallic particles

The effect of shape on the efficiency of a rowing blade

Comparison of the thrust of a propeller with its rate of turning

To investigate the streamlining of fish as related to their passage through water

Measurement of capacitance using a monostable circuit

Perfect perforations

Methods of using waves and tides to produce electricity; using models in the laboratory

Harmonics in a guitar

Behaviour of bubbles rising in liquids

Beta particle emission energy spectroscopy

Properties of aerial arrays

Variation in range of α-particles in air at low pressure

An experiment in the synthesis of speech

Three-dimensional waves in jelly

Performance of a model diesel engine

Effect of wavelength on the angle of refraction of water ripples

Dust and static as a problem with gramophone records

Multivibrator used as a motor speed control

A braking system using electromagnetic induction

Properties of a vibrating string using Lissajous' figures

Factors affecting lift of an aerofoil

Magnetic amplifiers

Back-scattering of beta particles

Strength and domain structure of magnets at different temperatures

Hull design

Interference produced by electric switches

Sound damping by polythene

Fishing rod strike times

Path of a ball through air

Absorption spectra of plant pigments

Pitch of xylophone bars

Flight of paper aeroplanes and aerodynamics involved

The catapult, methods of measuring efficiency

To show stress positions in sheets

Visibility of colour in the dark

Use of a search coil to measure magnetic fields at high frequencies

Eddy current heating

Properties of 4-ply wool which make it useful for woollen garments

Some useful properties of nylon fabric

Aeronautics of a fly

Load bearing properties of a spider's web

Minimizing feedback in a microphone system

Design, operation, and uses of spectrum analysis for musical instruments

A water trough as an accelerometer

Factors affecting the suitability of materials for use in umbrellas

Viscosity of fluids in flywheel bearings

How the mass of an air-track vehicle affects its performance

Shapes and oscillations of soap bubbles

Creep in rubber

Support of a ball in a jet

How long does the flash from a bulb last?

Investigation of the behaviour of a commercial radiometer

Contact resistance

Switching speed of a toggle switch

Forces in the skin of a balloon

Schlieren photography

Capacitor microphone

Comparison of three loudspeakers

Electrical impulses in skin

The effect of different pitches on the overall performance of a marine propeller

Efficiency of a 12-volt motor

The spiralling flight paths of various winged seeds

Behaviour of wood under stress; strength and rigidity of different beam and girder constructions

The dashpot method of damping

The electrical characteristics of a solar cell

The behaviour of large waves in a narrow channel

Variation of friction with the relative velocity of two bodies in contact

Variation of speed of a mechanical wave in a wire

Shattering of glass

Noise in a hot resistor

Restitution time of a steel ball on an iron surface

Paddle wheel performance

Effects of detergents on the reflection of light by cotton

Water rise up polymer threads

Photoelectric effect in semiconductors

Effect of load on cells

The bursting of a balloon

Microwave for ranging and detection

Oscillations and deflection of model suspension bridge

Electrical weighing machine

Damping of oscillations in liquids

Efficiency of a fan belt

Venturi principle

Investigation of sails

The thermoelectric effect in metal wire and foils

Why do soap films burst?

The practicality of recharging dry cells.

Effects of revolving black and white disc, why it produces colour

High velocity impacts in sand

Sedimentation

Bumping and boiling

Adhesive properties of 'Blu-tac'

Friction reduction by oil and grease

Rotating liquid surfaces

Measuring forces electrically

Cross linkages in rubber

The physical characteristics of a system which measures distance accurately using light interference

The flight properties of a shuttle cock

Rheological gel strength and other physical properties of solutions of gums used in food industry

Polarization of scattered light

Efficiency of a bow

Soil dispersion by falling water

Origins and forms of waves at interfaces

Construction of an air flow meter

Fresnel lenses for 3-cm waves

Electromagnetic clutch

Dam spillways

Projecting drops from a nozzle

Absorption spectra of plant pigments

To find the best aerial design to give the strongest signal for horizontally polarized radio wave reception

Crystal growth

The bouncing of relay contacts

Friction of shoe soles

The string telephone

Effect of cooling fins

Electronic tuning device for a guitar

Factors affecting the efficiency of infra-red absorption

To study the effect of soaking in water on the tensile strength of cartridge paper

The natural radioactivity of rocks

Factors affecting regelation

Motion of boats through narrow channels

Effect of solvents and papers on performance of chromatograms

Paper strip in an air stream

Absorption of radiation of heat from a surface

Lead cells

Making and testing a graphite strip microphone

Recombination time of ions

Fog lamps

Power transmission efficiency of a cycle chain

Liquid phase secondary coil in a transformer

The frequency response of dielectric materials in capacitors

Penetration effects of air gun pellets on Plasticine and wood

Lubrication of graphite

Efficiency of GM tube

Producing a hologram

Hysteresis in rubber

To investigate the factors affecting the strength of a pillar

Analysis of a Thermos flask

An investigation into the depth of focus of the eye

Factors affecting the bow waves produced by a boat

Factors affecting the playing speeds of a squash ball

Hot wire windspeed meter

The strength of plaster

Corrosion and cathodic protection

Investigation of moiré fringes as of use in measuring

The analysis and synthesis of musical sounds

An investigation of the diffusion of tea through teabags

Torque – r.p.m. curve for a model diesel engine

Linear motor

Forces on fences

Sea anchors

Solders of various composition

Hysteresis in a transformer

The efficiency of cloud chambers

Factors affecting behaviour of sparks

Motion of elastic pendulum

Factors affecting the production of uniform bubble rafts

Measurement of paper thickness

Distribution of velocities of thermo-electrons

The formation of sand dunes

Polarizing effects of transparent adhesive tape

Life history of water drop

Effect of oil on evaporation of liquids

What causes flapping in flags?

Molten metal into water

An investigation into photoelasticity

Resonance of wine glasses

Charge leakage from electroscope

Measurement of speed by Doppler effect

Metals – work hardening and heat treatment
Electrode potentials of Period 4 transition metals
Reverberation time apparatus
Behaviour of ink drops in water
Efficiency of model racing car
Vibrations caused by an electric motor
Electrical resistance welding
Diffraction haloes produced by small particles
Production of diffraction gratings
Refraction of a light beam through unstirred sugar solution
Electrical properties of silver deposited on glass slides
Measurement of the vapour pressure of water at various temperatures using microwaves
Feasibility of comparing abrasive characteristics by light scatter
Application of Bernoulli's principle to design of chimney pots
Variation of light output and temperature of tungsten lamps as a function of power input
Mechanical properties of plastic sulphur
Optimum launching of flying discs
Apparatus to provide a constant force
Self-inductance of metal springs
Acoustic properties of a kettledrum
Velocity of ripples in a ripple tank
An investigation into the optimum helicopter
Erosion of sand from base of piers
Efficiency and energy losses in a small steam engine
Vibration of rubber sheet
Concrete hydration
Slot effect in close hauled sailing
Efficiency of a rudder
Wind induced oscillations in lamina
An electrical method of detecting small movements and vibrations
Characteristics of a loudspeaker inside and outside of an enclosure

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OTHER PUBLICATIONS IN THE REVISED NUFFIELD ADVANCED PHYSICS COURSE

Students' guides 1 and 2

Teachers' guides 1 and 2

Apparatus guide

Energy options

Energy sources: data, references, and readings

Microcomputer circuits and processes

Particles, imaging, and nuclei

Physics in engineering and technology

Dynamic modelling system

Software for Nuffield Advanced Physics

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Examinations and investigations **deals with the assessment of the Revised Nuffield Advanced Physics course. The six elements of the examination – the five papers (Coded Answers, Short Answers, Comprehension, Long Answers, Practical Problems) and the Investigation – are explained. There is also a section on the Special Paper. Questions from past examination papers are used to relate the different types of question to the overall aims of the course. There is a chapter about preparing for the examination.**

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