AN INVESTIGATION OF SCOTTISH SECONDARY SCHOOL PUPILS' LEARNING DIFFICULTIES WITH THE CONCEPTS OF CURRENT, POTENTIAL DIFFERENCE AND RESISTANCE

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SUMMARY

AN INVESTIGATION OF SCOTTISH SECONDARY SCHOOL PUPILS' LEARNING DIFFICULTIES WITH THE CONCEPTS OF CURRENT, POTENTIAL DIFFERENCE AND RESISTANCE

Electricity is a topic within the Scottish Higher Grade Syllabus in physics which presents difficulty to many pupils. It may also be the topic which deters some pupils from continuing to study physics beyond secondary school.

This study initially set out to investigate pupils' understanding of potential difference, electric current and resistance as found in first and second years of secondary school (age 12 to 14 years) and then in fourth and fifth years (age 16 to 17 years). It later included a short investigation of the knowledge of electricity possessed by primary school pupils who had no formal science teaching aged 11 to 12 years. The concept of potential difference presented the greatest difficulty to puplis at all stages, with the concept of resistance following closely behind.

The method adopted for each of the investigations was an open ended questionnaire. This method was selected in preference to a multiple choice test to avoid restricting pupils' responses to the questions and hence obtain as much information as possible about how well they can explain and use electrical concepts and relationships. From this standpoint it was successful, though, since machine marking was not possible, it did not lend itself to sophisticated item analysis or to use with a large population.

Pupils responses appeared to be affected to some extent by the learning experiences to which they had been exposed. Some limitations were found which might be attributed to teacher experience, for example if a non-physicist had taught electricity in year 1 (though this was not always the case), or to school policy.

Pupils appeared to have difficulty in considering each of

the concepts of potential difference, electric current and resistance on its own. This is particularly true of resistance which tends to be defined in terms of potential difference and current. There would appear to be a need for teaching strategies which separate the three concepts and look at them as far as possible in isolation.

From the investigations recommendations have emerged for a primary school course on electricity; a revision of the syllabus for the Scottish Integrated Science Course, Section 7; and changes in nomenclature to replace the terms e.m.f. and potential difference which might be used in the Scottish Certificate of Education Ordinary and Higher Grade physics course on electricity.

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C H A P T E R   O N E

1. INTRODUCTION

Electricity is widely recognised as a topic which presents difficulty to pupils in school and students in higher education. Most educated laymen admit to an inability to understand it and on the whole lack the confidence to connect up fairly simple circuits. Calculations for electrical circuits tend not to be well done and very often reveal the same misconcepts among pupils from many different schools.

If however, the concepts and relationships have been mastered there is a predictability possible in electrical circuits which is quite attractive. This provides some of the motivation to make this power of prediction available to more pupils and students.

In Scotland, electricity is taught from a relatively early stage in the curriculum. The first exposure is during the first year of secondary education around age 12 years. The second exposure can be in the second year and may be the last for pupils who take no more science. Whether this is a sufficient provision for adult life is debatable, given that much of what we learn at this stage will be forgotten in favour of material studied later.

Pupils who take 'O' grade physics will of course study electrical concepts in third and fourth year and again for many this will be the limit of their contact with them. For those who take 'H' grade physics there will be an opportunity to have more practice in applying the concepts and exposure to additional material which may or may not assist understanding of them.

The motivation for this research came from the writer's own good fortune to have some facility with the concepts required to understand electrical circuits as a school pupil - a facility which led to a career in physics, but also a recognition that this facility was not shared by all pupils and indeed by many scientists in other disciplines. This impression was confirmed by a report (Johnstone and Mughol,1976) (1) which described an investigation to establish which of the concepts taught in school physics were proving troublesome so that further systematic study could be made into the cause of difficulty. The two particular areas of difficulty of interest to the writer which were highlighted were the "idea of resistance" and the"difference between e.m.f. and p.d.".

The concept of resistance is introduced from the first year of secondary education onwards. In spite of this there appears to be a lack of facility in describing what is understood by the resistance of a conductor which is found at all stages.

Potential difference is introduced as voltage in first and second year and again the concept appears to be unclear. It may be that what is taught has much to do with this.

E.M.F. is not introduced until the fifth year as part of the 'H' grade course. It is therefore perhaps inappropriate to consider it in a list presented to pre-O grade pupils. However it is reported as presenting difficulty among more mature students (Page,1977) (2) and graduate engineers.

This work has chiefly been considered in a Scottish context, but as it progressed it appears to have international implications in the English speaking world.

1.1 Curricula and Objectives

Since 1969, curriculum development in science in Scotland has been characterised by attempts to set objectives for various parts of the courses taught. The first such attempt is to be found in Curriculum Paper No.7, "Science for General Education "(S.E.D. 1969) (3) which provided specific objectives for each of the fifteen sections of the science curriculum for years one and two - the Scottish Integrated Science Course.

These objectives have on the whole been retained in later curricula devised for these two years, but on occasions the ability of the pupils who should be able to achieve them has been specified.

In more recent years (S.E.D. 1977)(4) specific objectives for Ordinary Grade physics were published. These provide a useful guide to what is expected nationally and make it possible to assess how well the objectives are being achieved.

The topic of electricity is first introduced in section 7 of the Scottish Integrated Science Course. The objectives which were set down for this section in Curriculum Paper No.7 are given below:

Pupils should acquire,

1. the knowledge that there are only two types of electric charge called positive and negative

2. the knowledge that current is a flow of electrons

3. knowledge of certain basic facts about current, voltage and resistance in simple d.c. circuits

4. ability to apply the above knowledge in new problem situations

5. ability to work with multiple variables in these experiments

6. ability to generalise from particular observations in simple electrical circuits

7. ability to form a theory relating current to voltage using observed phenomena

8. awareness of danger in using mains electricity

9. skills in simple wiring techniques.

When this section was revised in 1977 by a working party set up by the Scottish Central Committee on Science (S.C.C.S.)(5) the objectives set were very similar. Some were however assigned to all pupils and others assigned to the average and more able pupils. This differentiation was to allow for the use of the syllabus to teach all pupils in comprehensive schools. The revised objectives became:

All pupils should acquire:

1. the knowledge that there are two types of charge called positive and negative

2. the knowledge that current is a flow of charge (electrons)

3. knowledge of certain basic facts about current, voltage, and resistance in simple d.c. circuits

4. ability to apply the above knowledge to everyday situations

5. awareness of danger in using electricity

6. skills in simple wiring techniques

7. ability to form a theory relating current to voltage using observed phenomena.

The average and above average pupils should also acquire:

8. ability to apply the basic knowledge of the section in new problem situations

9. ability to work with multiple variables in such situations

10. ability to generalise from particular observations in simple electric circuits.

Along with these objectives the basic concepts to be acquired in this section are given as charge, current, resistance, voltage, conductors and insulators, and electrical circuit.

Within this section, lesson objectives are also given. For the lesson introducing the concept of resistance, "Opposing the current", the objectives are:

Pupils should be able to:-

1. define resistance in terms of the ability of a solid to reduce the current in a series circuit

2. identify a resistor as an object which has resistance

3. state that the resistance of a wire depends directly on its length

4. state that the current in a series circuit depends on the circuit resistance.

5. identify a variable resistor

6. identify a variable resistor as a wire with a sliding contact

7. give simple applications of a variable resistor

8. connect a variable resistor into a series circuit to control the brightness of a bulb

The first two objectives in this list are the key ones in any test of mastery of the concept. For pupils at this stage however they demand a level of thought and language for which many may not be ready

The lesson on voltage, "Pushing the current", has the objectives Pupils should be able to:-

1. state that increasing the number of batteries in a series circuit increases the current

2. define voltage as 'electrical push'

3. state that an increase in the number of batteries in a circuit leads to an increase in the voltage

4. state that the voltages of batteries connected in opposition 'cancel'

5. connect a voltmeter correctly across a d.c. power source

6. measure the voltages of batteries with a voltmeter.

The key objective as far as the concept of voltage is the second one in the list. Unfortunately as stated, this could lead to a misconception. If we describe voltage as an 'electrical push' we are leading pupils to see it as a force to be measured in newtons. In fact voltage is the energy given to unit charge and can be measured in joules per coulomb.

Fortunately this misconcept has been remedied in Memorandum No.42, Science in S1 and S2 (S.C.D.S. 1980) (6) in which voltage is referred to as 'pressure'. This is the true mechanical analogue for voltage as it can be considered to be measured in joules per cubic metre. This analogue will be discussed later.

It must be conceded however that pressure is in turn a difficult concept. It would therefore be better to teach voltage from an energy standpoint to begin with using the background and language established in section 3 of the Integrated Science Course. A suitable analogue has been developed (Jeffrey 1979)(7) which allows a logical discussion of voltage to be carried out at all stages in terms of energy. This will be discussed in more detail later.

Many teachers find that pupils have difficulty in differentiating between series and parallel circuits. There appears to be a possible source of this difficulty in our use of identical bulbs when teaching both types of circuit. This possible confusion is highlighted in the given lesson objectives.

In the lesson to introduce the characteristics of series circuits the objectives are given as:

After these activities pupils should be able to:

1. identify a series circuit
2. state that similar bulbs connected in series are equally bright
3. state that the current in a series circuit is the same at all points
4. state that an increase in the number of bulbs in a series circuit leads to a decrease in bulb brightness and current
5. demonstrate, experimentally, that similar bulbs in series are equally bright
6. connect an ammeter correctly into a series circuit.

The second and third objectives in the list indicate the main ways in which pupils would describe a series circuit. There is a danger however that they will expect all bulbs in series to be equally bright.

If we now compare this list with the one for the lesson introducing parallel circuits we find the objectives:

After these activities pupils should be able to:

1. identify a simple parallel circuit
2. state that similar bulbs in parallel are equally bright

3. state that the current from a battery increases as bulbs are added in parallel

4. demonstrate, experimentally, that similar bulbs in parallel are equally bright.

Comparing the second objectives in each list we find that in one lesson the pupils have been taught that similar bulbs connected in series are equally bright and in the one which probably follows it that similar bulbs connected in parallel are equally bright. Both of which are perfectly correct but obviously very confusing.

Further characteristics are investigated by the average and more able pupils but still the important difference between series and parallel circuits is not brought out as we find:

After these activities the average and above average pupils should be able to:

1. state that the current divides between the branches of a parallel circuit

2. state that the current is the same in two branches of a parallel circuit containing similar bulbs

3. measure current with an ammeter

4. connect an ammeter correctly into each part of a parallel circuit containing two batteries and two bulbs.

The basic problem appears to be that up to this stage in the section all teaching has been done in terms of the current or currents in the circuits. We therefore do not identify that the voltage is the same across all the bulbs which are connected in parallel and that each lamp will have the brightness it would have if it alone were connected to the battery. Parallel circuits should therefore be taught using non-identical bulbs to highlight this.

It would appear that a re-ordering of this section could be useful and we shall consider this in more detail later.

Specific objectives for Ordinary Grade physics were published in Memorandum 31 by the Scottish Curriculum Development Service in 1977(4). Some of the cognitive objectives given in Memorandum 31 most relevant to this study are given below:

Pupils should acquire the ability to:

a. recall that the potential difference (p.d.) between two points is a measure of the work that has to be done to move one coulomb of charge from one point to another

b. recall that if 1 joule of work has to be done to move 1 coulomb of charge from one point to another the p.d. between the points is 1 volt

c. recall that 1 coulomb is the charge that passes when 1 ampere flows for 1 second

d. recall that the ampere can be defined in terms of the forces that current carrying conductors exert on each other

e. recall that for most conductors at constant temperature the current through the conductor varies directly as the p.d. across it (Ohm's Law)

f. calculate the equivalent resistance of a number of resistors in series

g. calculate the equivalent resistance of not more than three resistors in parallel

h. solve problems involving currents, voltages (p.d.'s) and resistance in simple d.c. circuits

i. use the following terms correctly in context: charge, electric field, potential, potential difference, voltage, volt, coulomb, current, ampere, resistance, ohm, series, parallel, resistor, conductor.

The success of pupils in meeting these objectives apears to be variable and certainly merits further study.

1.2 PROBLEMS OF INTELLECTUAL DEVELOPMENT

The concepts associated with the study of electricity include charge, current, resistance, voltage, conductors and insulators, electrical circuit, energy and power. Most of these are built up on the basis of indirect observation which involves ability to make abstractions and evolve appropriate descriptions and relationships. We must therefore consider whether many pupils are in fact ready to make the necessary abstractions and connections when we try to teach the topic.

The work of Piaget gives us some pointers which are very useful. In the age group which concerns us, he identifies two main stages of thinking - concrete, which is the principal mode of thinking for upper primary pupils, and abstract (or formal) which is a possible mode of thinking for upper secondary pupils.

In the concrete stage reasoning depends on operating on actual objects and in the scientific context, experiments giving readily identifiable data. In the abstract or formal stage, hypotheses can be evaluated and discussed without reference to actual objects or data.

Renner (1976) (8) has shown that pupils who are not capable of formal thought performed badly in mathematical questions involving ratios and percentages. In teaching electricity, we have the problem that one of the key concepts, potential difference, involves a ratio - potential difference is energy per unit charge.

The writer has observed that student teachers are often guilty of discussing concepts and problems at formal level with pupils who are still operating at the concrete level with a resultant failure in communication. If more concrete examples are provided and conceptual models are built up in small steps, the pupils are found to cope.

Rosalind Driver (1981) (9) draws our attention to the idea that "pupils bring to their school learning in science, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. These alternate frameworks, in some cases strongly held and resistant to change, in others flexible and with many internal inconsistencies, have their influence on the effectiveness of formal school science programmes." While examples given of "alternate frameworks" ate from topics other than electricity, we can visualise uses of language and concepts of electric circuits which could affect pupils' ability to build electrical concepts such as voltage, current and resistance from the observations they have made.

From her analysis of the selected examples of alternate frameworks, Driver identifies four possible implications for classroom practice.

1. Curriculum development in science needs to pay as much attention to the structure of thought of the child as it has recently paid to the structure of the disciplines in organising learning experiences.
2. Teaching programmes may need to be structured so as to be more in keeping with the developmental path in understanding important scientific ideas. The logical order of teaching a topic may not correspond to the psychological order in learning.
3. Activities in science need to include those which enable pupils to disprove alternate interpretations as well as affirm accepted ones.
4. We need to include opportunities for pupils to think through the implications of observations and measurements made in science lessons. We must realise that our explanations do not spring clearly from the data.

Any one of these four points may be applied to the teaching of electricity, and in particular with reference to 3 and 4, lessons can be designed to test preconceived ideas which may be wrong and show them to be so, before building up the correct interpretations of electrical circuits, and to give time to build up the difficult concepts like voltage and resistance.

Marcia Linn (10) has shown that logical reasoning can be frustrated by a number of factors. These were the ability to identify the relevant variables to consider in an investigation; the perceived goal of the investigation; and finally how perceptually obvious the variables were. Electrical experiments depend very much on logical reasoning and in particular in investigations and interpretation of the interaction of variables. We therefore have to ensure in our teaching that the effects of these pitfalls is understood. For example investigation of resistance requires the isolation of an appropriate pair of variables for inspection while others are held constant. Some of these latter variables, such as dimensions of conductors are not immediately obvious. In addition, as the investigation proceeds the pupil must begin to recognise where it is heading if the outcome is to be really successful.

1.3 OTHER STUDIES ON ELECTRICAL CONCEPTS.

Johnstone and Mughol (1978) (11) report on an investigation into pupils' understanding of resistance. The test used was a multiple choice one with distracters based on pupils' responses to interview questions. The results reported from this test were : -

1. Pupils at all levels are familiar with the basic symbols of electrical circuits.
2. All are aware of the necessity for a closed circuit if current is to flow.
3. There is confusion at all levels between voltage and power.
4. About half of the junior pupils and three-quarters of the seniors are aware that there is a practical difference between e.m.f and p.d.

but there is little understanding at any level of why this should be so.

5. Between 80 - 90 % of pupils know that increasing the voltage across a given circuit will increase the current in it.

6. About 70% of the juniors and 90% of the seniors relate the length of a resistance wire and its resistance correctly (direct proportion).

7. About 25% of juniors and 70% of seniors relate the cross-sectional area correctly (inverse proprtion).

8. At second-, third-, and fourth-year levels pupils seem to equate resistance with 'amount of material', i.e. short, thin wire has least resistance. Only at fifth year is the effect of cross-sectional area correctly interpreted by the majority of pupils.

Johnstone and Mughol go on to speculate whether the concept of resistance is introduced too soon suggesting that perhaps conductance should be the concept introduced in the early stages. While a case could probably be made on both sides with regard to the general concepts, it is almost certainly too soon for most pupils to worry about factors affecting resistance in first year.

Prompted by Johnstone and Mughol's report, O'Sullivan (1980) (12) comments on problems with Ohm's law found by students in introductory courses at university level. He points out that Ohm's law is often stated as a mathematical relationship such as

$$E = R\,I$$

or

$$P = R\,I^2$$

where, E, I and P are the sum of all the e.m.f.s, the electric current flowing and the total (thermal) power being generated in the circuit respectively.

The problem may then begin to appear when the student looks for a definition of the resistance R and finds that this has been defined as E/I or P/I^2. He suggests that it is not therefore surprising that students find themselves forced to conclude that Ohm's law is nothing more than a definition of resistance, while being aware at the same time that it describes well the observed behaviour of electrical circuits. He sees this as just one example of the many cases in introductory physics where definitions and physical law seem to coalesce, , and concludes that it would appear that much pedagogical clarity is to be gained if distinctions are made between definitions of physical quantities on the one hand and the relationships between quantities ('laws') on the other.

Evans (1978) (13) describes a course on electricity suitable for American high school in which simple circuits using batteries and bulbs are used to assist the formation of electrical concepts in a qualitative way before formal definitions are introduced. This course is an attempt to move away from the normally abstract treatment given in high school courses. Concepts such as resistance, current and potential difference are only introduced as students find a need for them to form a model for their observations. One problem with a program of this nature is that it possible uses apparatus used by the students at a more elementary stage. They may therefore feel that they know all about it. However, very often simple circuits with easily made observations can help more mature pupils or students to make sense of problems presented in a more formal manner.

Fredette and Lochead (1980) (14) describe student (pupil) conceptions of simple circuits. They find that many school pupils find difficulty in forming a simple circuit to light a torch bulb which is not mounted in a holder. They also found that even more mature students have this difficulty. The basic difficulty would appear to be that pupils do not know how the path through the bulb is formed and therefore do not know where to connect wires to the bulb. Many students make only one contact with the bulb, and short circuit the battery into the bargain! Similar difficulties have been observed by the writer where Scottish pupils in second year who have completed Integrated Science section 7 are unable to form a circuit from a battery and a lamp if presented with only one wire. The fact that all the components have been mounted on boards etc. for the previous work makes it difficult to improvise.

The use of models to teach elementary physics and in particular the use of the water model in teaching electricity is discussed by Bullock (1979) (15). He makes the important point that for the water model to be successful the pupil needs to understand the model as a physical system in its own right. He must then be able to see the analogies between elements of the model and the phenomena under consideration and be able to generalise from relevant properties of the model to properties of the system which is to be interpreted and understood. He must, at the same time, ignore or not be misled by those aspects of the model which do not generalise to the phenomena considered. Given all this, the generalisations which are appropriate are thought to aid understanding.

Bullock quotes a small scale investigation by Wilkinson (1973) (16) of pupils' understanding of the concept of fluid flow and its analogous relation to current flow. Wilkinson found that relatively few secondary school second-year pupils (12 years) understood all the relevant properties of fluid flow in pipes and a mere 6% (two pupils) correctly used the analogy in their explanations of simple d.c. electrical circuits.

The central part of the article describes Bullock's own investigation of the efficacy of the water model for pupils in years three to five in English schools. He used a questionnaire which contained questions designed to elicit pupils' understanding of : relevant terminolgy (e.g. electric current, voltage, resistance); essential attributes and relations (e.g. the vector additive property of series sources of e.m.f., use of a voltmeter, Ohm's law); the elements of the water model (e.g. voltage - pressure analogy); the elements of an alternative model not previously taught to subjects, in which energy in a d.c. circuit is likened to the coal carried by a train.

The results seemed to suggest that use of the water model does not, of itself, lead to enhanced understanding of concepts associated with voltage - at least in the situation represented by the test used with the particular pupils. Questions in the test concerned with electric current (including the analogies) were on the whole, answered much better than questions dealing with much less tangible voltage. Bullock concludes that a much simpler model - even an electron flow model- with rather more restricted objectives and fewer inappropriate features would be more effective for the majority of this range of pupil. In addition it could be that a variety of models to emphasise the crucial attributes of the system could be more effective.

The writer is inclined to agree with these sentiments and suggests some models for consideration in chapter 3.

Osborne and Gilbert (1980) (17) in a report of an 'Interview about instances' technique for the investigation of students' concept understanding in science, describe some of the results obtained from an interview given to thirty pupils varying in age from seven to 18 years about the concept of electric current. They found that although some 17- and 18- year old physics students displayed an understanding of electric current similar to that of trained physicists, others showed understandings very similar to those of 7 - 13-year-old pupils who had received no formal teaching about electric current.

So far all references have been written in English. We would mention however two references not written in English which contain attractive features which might usefully be incorporated into Scottish syllabi. The first of these is the syllabus suggested for the Orientation Stage (Orientierungstufe) in West German Schools (18) by IPN (Institut fur die Padagogik der Naturwissenschaften) in Kiel University, where electricity is the first topic introduced to pupils aged about 10-yerars, in grade 5. The emphasis is placed here on the electric circuit as represented by simple laboratory circuits, the cycle dynamo lighting circuit and the model railway. Electric current is introduced in grade 6 at age 11-years. The second of these is the syllabus produced for Danish Schools (19) which has attractively prepared material for use by pupils as they explore electrical concepts. Thomsen (1977) (20), one of the co-authors of the Danish course describes the development of it, fortunately in English !

Finally we might mention the IPN Physics Curriculum for the 9th and 10th grades, age 15- to 16-years (21) which contains a section with the title "Models of Electric Circuits". This looks at the water model and other ideas in some detail. It describes apparatus designed to model the behaviour of electric circuits hydraulically. Water "resistors" show the pressure drop to be observed when a current of water passes through.

The recurrent theme would appear to be the need for appropriate learning experiences to build up concepts, and having built them up, to separate their formal definitions from the corresponding laws which describe the behaviour of, for example, electrical circuits.

C H A P T E R   T W O

2. THE INVESTIGATION

2.1 THE OVERALL STRATEGY.

Although the prompt for this particular investigation was the difficulty with the concept of resistance found by pupils taking Scottish Certificate of Education Ordinary and Higher Grade examinations in physics, it appeared to be sensible to investigate the concepts of electric current and potential difference and the relationships between the three at the same time. In addition, since the the topic of electricity is taught from the first year of secondary education onwards, it appeared to be appropriate to begin with pupils who had completed at least the work of the first year (S.1) and try to find a measure of their grasp of concepts at this stage.

So as not to place limitations on pupils' responses, multiple choice tests were avoided in favour of more open ended questionnaires. Admittedly this produced a greater marking load, but provided the writer with a better grasp of what pupils were thinking and how they set down their responses.

A list of learning outcomes was prepared for the electricity course incorporated in the Scottish Integrated Science Course for years one and two, and based on the expectations represented by this list, a set of questions was prepared. Initially the questions were given orally to groups of four pupils who wrote down their responses. When the questions were found to be appropriate, the same procedure was used taking a class of 18 second year pupils (aged around 13-years) at a time. In this way 80 pupils were interviewed in three different schools.

The next stage of the investigation was carried out with pupils in fourth and fifth year who were either about to sit Ordinary Grade physics or Higher Grade physics. They could therefore be considered to have completed the syllabus for their appropriate grade. It should be noted that the Scottish fourth year corresponds to the English fifth form in age group and approximate standard.

A set of questions was prepared appropriate to pupils who had taken the 'O' Grade physics course to test their understanding of the concepts of electric current, potential difference and resistance, and the relationships between them. An initial test was carried out with a group of pupils in fifth year (S.5) who had completed the 'O' Grade physics course but had still to commence the 'H' Grade course. On the basis of the experience gained from this, a questionnaire was prepared which was given to pupils fourth year (S.4) and fifth year (S.5) in four different schools.

Once again multiple choice questions were avoided and space was provided for extended answers where this was appropriate. The questionnaire was administered to 179 'O' Grade pupils and 93 'H' Grade pupils.

Finally, it was decided to investigate the knowledge of electricity possessed by primary school pupils just before they enter secondary school. A questionnaire with open questions was given to 145 pupils in primary seven (P.7) aged between 11 to 12 years in five different classes of three primary schools. All these schools are feeder primaries to the same comprehensive school. There is no significant teaching of science in these primary schools and we must therefore surmise that what electrical knowledge there is comes from experiences in the home. The questions were based on anticipated experiences in the home of battery operated toys, radios and domestic appliances.

2.2 SCOTTISH INTEGRATED SCIENCE COURSE - SECTIONS 7 & 15 ANTICIPATED LEARNING OUTCOMES FOR ELECTRIC CIRCUITS

The list which follows represents the knowledge which should be acquired in sections 7 and 15. Clearly the statements are more formal than most pupils will give, but these provide the criteria against which the responses from pupils were assessed.

1. An electric current is a flow of electric charges.

2. An electric current requires a complete circuit.

3. The unit of electric current is the ampere.

4. The size of the electric current in two conductors in series is the same.

5. Voltage is an electrical pressure which can cause an electric current in a conductor.

6. Voltage gives energy to the electric charges.

7. The unit of voltage is the volt.

8. The voltage is the same across conductors in parallel.

9. The total current in a set of parallel conductors is the sum of the currents in each individual conductor.

10 The total voltage across a set of conductors in series is the sum of the voltages across each individual conductor.

11. A perfect conductor passes an electric current without loss of voltage.

12. A conductor which requires a voltage to pass a current is said to have resistance.

13. A conductor with significant resistance is called a resistor.

14. The resistance of a conductor measures the difficulty with which a current will pass through it.

15. If a conductor is added in parallel with another one, the current in the first conductor is the same as before. The second conductor has no effect on the first.

16. If a conductor is removed from a parallel circuit, the remaining conductors are not affected.

17. A voltage source, e.g. a battery, will supply the current required by a conductor. If the conductor is replaced by a different one, the current supplied by the battery will be what is required by the new one.

18. A battery is an energy source; a resistor e.g. a lamp, is an energy consumer. The electric current carries the energy from the source to the consumer.

19. An electric current passes through the external circuit and also the battery.

20. The size of an electric current is measured with an ammeter. An ammeter is placed in the circuit in series with the conductors.

21. The size of a voltage is measured with a voltmeter. A voltmeter is connected across a battery or a conductor, in parallel with it.

2.3 SCOTTISH CERTIFICATE OF EDUCATION ORDINARY GRADE PHYSICS COURSE (22) ANTICIPATED LEARNING OUTCOMES FOR SECTION L.2 - ELECTRIC CIRCUITS.

In addition to the learning outcomes for Scottish Integrated Science Course electricity the following, based on the objectives written for the Ordinary Grade physics course in Memorandum No 31 (4), may be added for pupils in year 4.

1. The potential difference (p.d.) between two points is a measure of the work that has to be done to move one coulomb of charge from one point to the other.

2. If 1 joule of work has to be done to move 1 coulomb of charge from one point to another, the p.d. between the points is 1 volt.

3. A charge of 1 coulomb passes when a current of 1 ampere flows for 1 second.

4. For most conductors, at constant temperature, the current through the conductor varies directly as the p.d. across it. (Ohm's Law).

$$\text{i.e.} \quad V \propto I$$

$$V = R\,I$$

5. The equivalent resistance of three conductors in series is given by

$$R = R_1 + R_2 + R_3$$

6. The equivalent resistance of three conductors in parallel is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

7. The power given out by a conductor in an electric circuit is given by

$$P = V\,I$$

$$\text{or} \quad P = I^2R \qquad \text{or} \quad P = \frac{V^2}{R}$$

2.4 QUESTIONNAIRE ON ELECTRIC CIRCUITS - YEARS ONE AND TWO (S.1 & S.2)

The questionnaire which follows was given by interview to 80 pupils in the second year of three different comprehensive schools. Although the questionnaire is laid out to take the responses, the pupils used lined paper for their answers. The questions were designed to check whether the key ideas listed in the anticipated learning outcomes had been mastered, or whether there were some misconceptions which were common to many of the pupils.

The questions moved systematically from the simple circuit and the requirements for a flow of electricity to conductors and insulators, measurement of current and finally the series circuit. They were then used to test ideas about parallel circuits, with particular reference to the currents in a parallel circuit. Finally voltage in parallel and series circuits was investigated before allowing pupils to explain in their own words electric current, voltage and resistance.

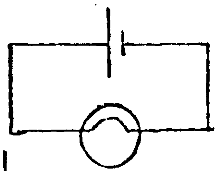
Where descriptive and explanatory answers were appropriate it was considered better to allow the pupils to use their own words rather than offer a list of suggestions from which the answer might be selected. Clearly some responses could be considered to be "correct responses". However it seems useful to record in our discussion some of the others received.

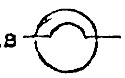
The item analysis for this questionnaire was carried out by hand.

Questionnaire on Electric Circuits.

Years S.1 and S.2.

This is an electric circuit.



The symbol for the battery is  , and for the lamp is  .

1. What flows round the electric circuit? [ ]

2. What makes it flow? [ ]

3. What name is given to a material which allows electricity to flow through it easily ? [ ]

4. What name is given to a material which does not allow electricity to flow through it easily ? [ ]

5. Name two materials which allow electricity to flow through them.
   a. [ ]
   b. [ ]

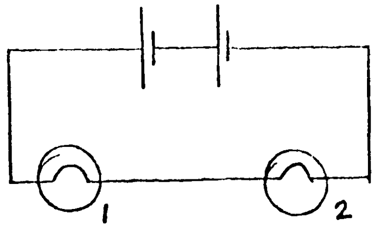
6. Name two materials which do not allow electricity to flow through them.
   a. [ ]
   b. [ ]

7. What instrument is used to measure the size of an electric current? [ ]

8. Draw a diagram to show the instrument connected correctly in an electric circuit.

9. What name is given to the unit of electric current. [ ]

10. In the circuit below



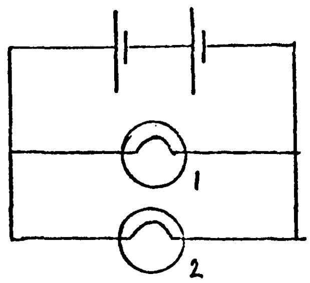
what is the name given to the way in which the lamps are connected?

11. The current through lamp 1 is 0.2 A. Is the current through lamp 2 greater, equal or less than 0.2 A?

12. Does this current flow through the batteries?

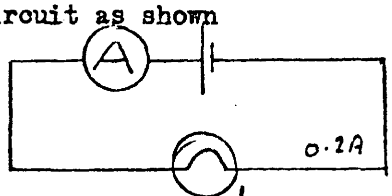
13. Why do you think so?

14. In the circuit below



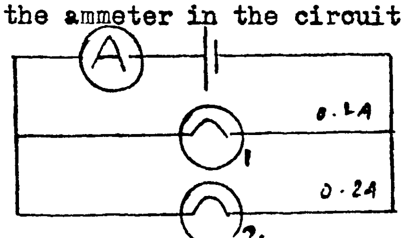
what is the name given to the way in which the lamps are connected?

15 With one lamp in the circuit as shown

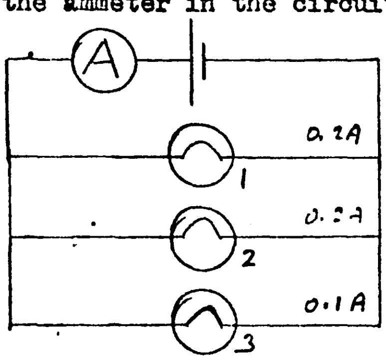


the reading on the ammeter is 0.2 A.

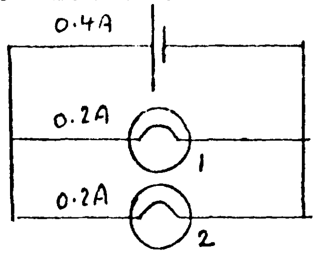
What is the reading on the ammeter in the circuit shown below?



6. What is the reading on the ammeter in the circuit shown below?

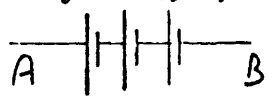


17. In the circuit below the currents are as shown.

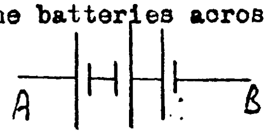


If lamp 1 is removed, what will be the current in lamp 2 ?

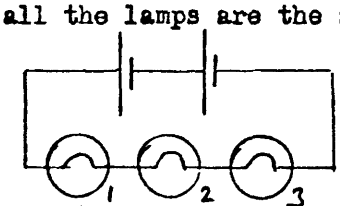
18 If the voltage of one battery is 1.5 V, what is the voltage across AB ?



19 What is the voltage of the batteries across AB with this arrangement?

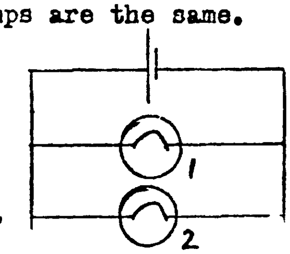


20. In the circuit below, all the lamps are the same.



What is the voltage across lamp 2 ?

21. In the circuit below, both the lamps are the same.



What is the voltage across lamp 2?

22 What is an electric current?

23. What is voltage?

24. What is resistance?

2.5 SUMMARY OF PUPILS' RESPONSES TO QUESTIONNAIRE ON ELECTRIC CIRCUITS - YEARS S1 AND S2

1. In questions which involved explanation or description pupils tended to show a lack of precision in their language.

2. "What flows in an electric circuit?" elicited a satisfactory response from most pupils. (80%)

   "What makes it flow?" however, produced more variable answwers.

3. 65% of pupils knew the term conductor while 58% knew the term insulator. Most could give examples of each.

4. 43% knew that an ammeter was used to measure the size of an electric current; though 76% could show its position correctly in a circuit diagram. 60% could name the unit of current.

5. 36% could identify a'series' circuit.

   78% recognised that the current through two components in series was the same.

   62% stated that the current flowed through the batteries.
   However, reasons given in support, were on the whole not too convincing.

6. 25% could identify a 'parallel' circuit.

7. 70% correctly added the currents in a parallel circuit.

   However 34% believed that if a circuit element is removed the current which flowed through it, flows through the remaining circuit.

8. 85% correctly added the voltages of three batteries in series.

   8% added them correctly if one battery is reversed.

9. The summing of voltages across components presented problems.

   This may not be explicitly taught.

10. Only 22% recognised that the voltage across two components in parallel is the same.

11. Confusion was observed in application of concepts of current and voltage.

12. 53% of pupils could explain satisfactorily what an electric current is.

10% of pupils could explain satisfactorily what is meant by voltage.

11% of pupils could explain satisfactorily what electrical resistance is.

2.6 RESULTS OF QUESTIONNAIRE ON ELECTRIC CIRCUITS - YEARS S.1 AND S.2.

The pupils responses to the questionnaire are given below. The number beside the response indicates the actual number who gave it, and where it is considered helpful in making comparisons this is given as a percentage. . The total number of pupils in the sample was 80.

1. **What flows round the electric circuit?**

electric current 14 (18%); electricity 32 (40%); current 14 (18%); electrons 11 (14%); neutrons 2 ; positive and negative charges 2 ; electric power 3 ; electrical energy 2 ; elternitive 1 ; air 2 ; electric element 1 .

This question was on the whole well answered with about 90% of pupils in the sample giving an acceptable answer.

2. **What makes it flow?**

battery 20 (25%) ;
conductor 5 ; positives attract negatives 11 ; wires 4 ; electrons 2 ; electricity 5 ; volts 10 ; current 4 ; positives 1 ; power from the battery 5 ; power from the electricity 1 ; the power of the charge from the battery 1 ; the force of the electricity trying to get out of the battery 1 ; charge from the battery 2 ; power or energy 4 ; heat 1 ; air 1 ; don't know 3.

The battery was clearly the popular answer. Ideas about the actual mechanism were in the right direction if sometimes not too well expressed.

3. What is the name given to the set of materials which allows electricity to flow through it easily?

conductor 52 (65%); don't know 12 (15%);

metal 5 ; conduction 2 ; circuits 1 ; co-ordinates 3 ;

current 1 ; statics 1 ; wire 1 ; solids 1;

non resistant 1.

This question was reasonably well answered, with some of those who did not give the name of the set having some reasonable alternative ideas.

4. What name is given to the set of materials which does not allow electricity to flow through it easily?

insulator 46 (58%) ; don't know 17 (21%);

non conductors 3 ; rubber 1 ; non conducting 1 ;

plastic 2 ; inconduction 1 ; wood 2 ; resistors 2 ;

resistant 1 ; contractors 4 ; transistant 1.

This question presented a little more difficulty than the previous one, with rather more pupils having no idea to offer.

5. Name two materials which allow electricity to pass through them.

copper 41 ; iron 20 ; steel 13 ; wire 11 ; metal 12 ;

water 9 ; silver 5 ; brass 5; aluminium 2 ; lead 1 ;

tin 2 ;

wood 2 ; cotton 1 ; nylon 1 ; plastic 4 ; sulphur 1 ;

glass 1 ; air 2 ;oil 3 ; electrons 1 ; atoms 1 ;

power and energy 1 .

We note that some insulators crept into the lists. On occasions one conductor and one insulator was given.

6. Name two materials which do not allow electricity to flow through them.

wood 36 ; plastic 31 ; glass 18 ; rubber 23 ;

polystyrene 6 ; asbestos 3 ; water 2 ; stone 2 ;

paper 2 ; wool 1 ; cotton wool 1 ; clothes 1 ;

tin 2 ; steel 2 ; zinc 1 ; iron 1 ; metal 1, brass 3 ;

don't know 9.

We note that some conductors crept into the lists.

7. What instrument is used to measure the size of an electric current ?

don't know 35 (43%)

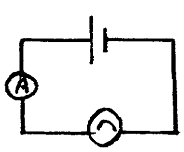
ammeter (ampmeter, ampmuter, ametre) 35 (43%)

meter 3 ; gyder counter 1 ; seismograph 1 ; capacitor 1 ;

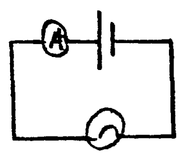
battery 1 ; voltameter 1 ; anemeter 1 ; voltage meter 1 .

The main division in this question was between don't knows and those who identified the meter correctly.

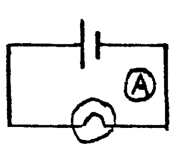
8. Draw a diagram to show the instrument connected correctly in an electric circuit.



59



2 (76%)



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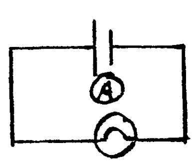

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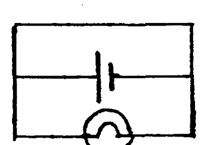
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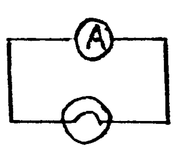

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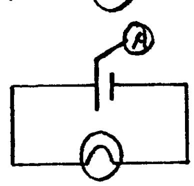

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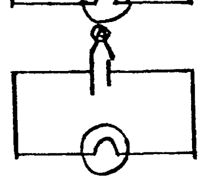
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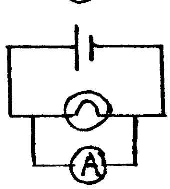

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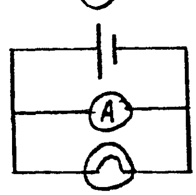

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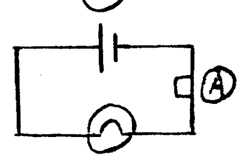


2

It is interesting to note that more pupils could indicate the correct location of the ammeter than could name it.

9 | What is the name given to the unit of electric current? |

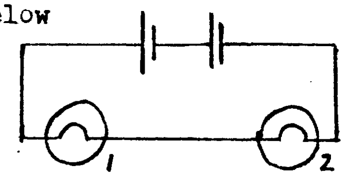
amp 48 (60%) ;

volt 16 (20%) ; watt 5 ; amps watts 1 ; joule 1 ;

voltage 4 ; don't know 7.

There is evidence here of the confusion between current and voltage.

10. In the circuit below



what is the name given to the way in which the lamps are connected?

series 28 (35%) ; don't know 40 (50%) ;

serial 2 ; ceries 1 ; seriouses 3 ; extended 1 ;

positive 1 ; sequence 2 ; joint circuit 2.

The name "series" did not appear to be well known, but may not have been formally taught.

11. The current through lamp 1 is 0.2 A. Is the current through lamp 2 greater, equal or less than 0.2 A ?

equal to 0.2 A 62 (78%)

less than 0.2 A 12 (15%)

greater than 0.2 A 5 (6%)

Most of the pupils appeared to recognise that the current is the same in two lamps in series.

12. Does the current flow through the batteries ?

yes 50 (63%)

no 30 (37%)

Obviuusly the majority thought that the current did flow through the batteries.

13. Why do you think so ?

(yes) complete circuit required - electricity has to go all the way round ;

(yes) because the power goes round the circuit ;

(yes) because it must go through the battery to make the bulbs light ;

(no) because when the current gets to the battery it can't go any further ;

(no) because it is the battery that gives the power ;

(yes) because the wire is connecting both batteries ;

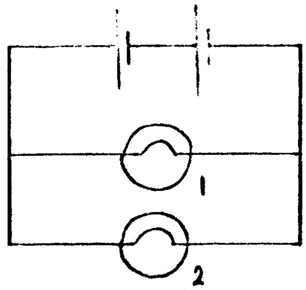
(yes) because the metals at each side of the battery are conductors ;

(no) because the negative part stops it ;

(no) because batteries are pushing current out, if it got through battery would not run down.

The pupil's answer to question 12 is indicated in the brackets. Not all who had answered "yes" had the complete idea. Those who answered "no" revealed fairly familiar misconceptions.

14. In the circuit below



what is the name given to the way in which the lamps are connected ?

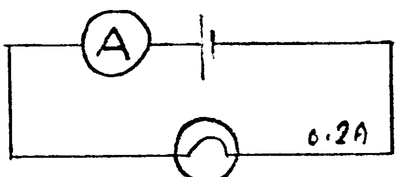
parallel 20 (25%)

don't know 56 (70%)

series 2 ; energy 1 ; telegraphic 1 .

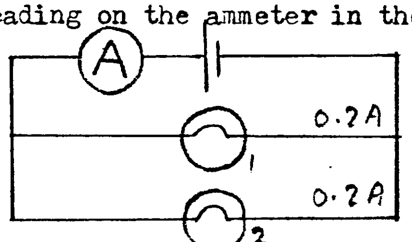
Clearly this was a term which was unfamiliar to most pupils. It may not have been taught in all schools at this stage.

15. With one lamp in the circuit as shown



the reading on the ammeter is 0.2 A.

What is the reading on the ammeter in the circuit shown below ?



Ammeter reading 0.2 A 15 (19%)

Ammeter reading 0.4 A 56 (70%)

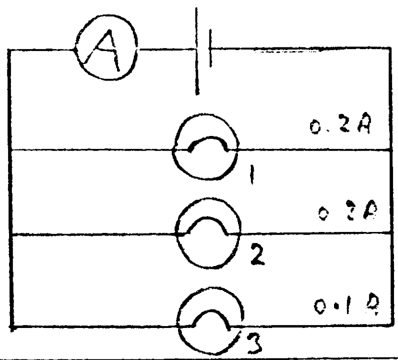
Ammeter reading 0.1 A 5 (6%)

Ammeter reading zero 1

Don't know 2

This question was well answered, although the most likely connection between the currents was a sum.

16. What is the reading on the ammeter in the circuit shown below ?



Ammeter reading 0.05A 1 ; ammeter reading 0.02A 1 ;

Ammeter reading 0.15A 1 ; ammeter reading zero 1 ;

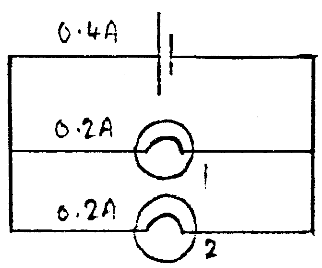
Ammeter reading 0.2 A 5 ; ammeter reading 0.5 A 57 (71%) ;

Ammeter reading 0.3 A 5 ; ammeter reading 0.1 A 2 ;

Don't know 6 .

This question was also well answered.

17. In the circuit below the currents are as shown.



If lamp 1 is removed, what will be the current in lamp 2.

Current in lamp 2 0.2 A 46 (58%)

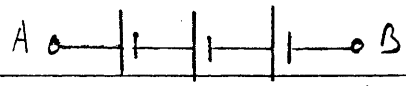
Current in lamp 2 0.4 A 27 (34%)

Current in lamp 2 0.6 A 5 (6%)

Current in lamp 2 0.3 A 2

This is a question which will even cause graduates to make a mistake. The performance of these pupils is therefore commendable. When the same question was presented to pupils in S.4 and S.5 only 17% were correct in S.4 and 10% were correct in S.5. It would appear that the pupils in this test were assisted by building up a rule from experience of questions 15 and 16 that as additional circuits are added in parallel the currents add up. They therefore recognised that when one was removed, the current remained the same in the remaining circuit and the battery supplied less.

This sequence has clear implications for what must be taught about currents in parallel circuits.

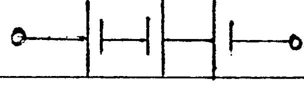
18. If the voltage of one battery is 1.5 V, what is the voltage across AB ? 

Voltage across AB 4.5 V 68 (85%)

Voltage across AB 1.5 V 2

Voltage across AB 4.5 A 7

Clearly the majority gave the correct answer. There was some evidence of a mix-up with units.

19. What is the voltage of the batteries across AB with this arrangement ? 

Voltage across AB 1.5 V 6 (8%)

Voltage across AB 4.5 V 18 (22%)

Voltage across AB 3 V 16 (20%)

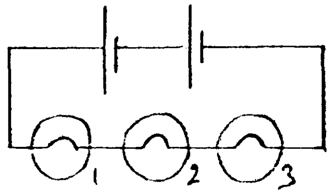
Voltage across AB zero 16 (20%)

It would not work 4

Don't know 9

This question obviously presented a problem. It probably tested something outwith the experience of most of the pupils.

20 In the circuit below, all the lamps are the same.



What is the voltage across lamp 2 ?

Voltage across lamp 2 1 V 33 (41%)

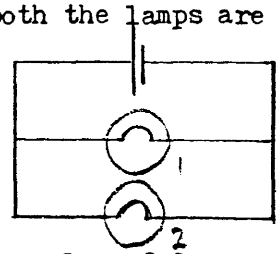
Voltage across lamp 2 2V 11 (14%)

Voltage across lamp 2 3V 17 (21%)

Don't know 11 (14%)

Less than half the pupils gave the correct response. This is a result which has to be taught experimentally, as it is not immediately obvious.

21. In the circuit below, both the lamps are the same.



What is the voltage across lamp 2 ?

Voltage across lamp 2 0.75 V 30 (38%)

Voltage across lamp 2 1.5 V 18 (22%)

Voltage across lamp 2 3 V 6 (8%)

Don't know 17 (21%)

The fact that only 22% gave the correct response seems to indicate that the wrong emphasis is placed on parallel circuits at this stage. The important link is that the voltage is the same. The summation of currents is secondary.

22. What is an electric current ?

An electric current is

electricity passed through a substance

energy used as power

flow of electricity

force of energy

hundreds of electrons

a current with electricity in it

passed through the battery to the lamp and makes it go on

electricity flowing the same way

electrons moving round a wire i.e. + attracts -

what goes through the batteries.

23. What is voltage ?

Voltage is

the amount of stuff in a substance

power that is pushing the electric current through

power of the battery

force of energy that pushes the current

an electric charge

what pushes an electric current

is an electric current

is an electric shock

amount of power that a battery has

the potential amount of power that a battery has and the work it can do

what electricity is measured

what current is in the battery.

24. What is resistance ?

Resistance is

something that electricity cannot pass

force which pushes against another force e.g a light switch when the power is on or not

something that pushes the electricity

force that keeps another force from pushing it

where a current has trouble in getting through or not at all

force that stops power getting through

force which can cut down the amount of current passing and even stop it e.g. a rheostat

a thing which stops electricity going through to the battery

what the wire can take through it (electricity)

the amount of units in a coil

the power you get.

Taking 22, 23 and 24 together, there was evidence that the concepts were not formed in depth. A fair number of pupils recognised an electric current to be a flow of electricity or even electrons. Many others saw it as a flow of power or energy. Others were more confused.

Very few thought of voltage in energy terms. However this idea is not built in to the objectives of the Integrated Science Course.

A number of pupils appeared to think of resistance in terms of forces. A number of others thought of it as stopping the current.

2.7 QUESTIONNAIRE ON ELECTRIC CIRCUITS BASED ON SCOTTISH CERTIFICATE OF EDUCATION SYLLABUS FOR YEARS THREE AND FOUR (S.3 & S.4)

Following on from the questionnaire based on the work of the first and second year, a further questionnaire to test similar ideas and concepts was prepared from the S.C.E. syllabus for section L - Electron Physics (22). The learning outcomes being investigated embrace all those given in sections 2.2 and 2.3 of this chapter.

In this case the questionnaire was designed to be used as a written test without comment from the administrator. Provision was made for pupils to record their responses on the questionnaire itself. All the questionnaires were marked by the writer. With the exception of questions 14 and 15 all responses were marked as acceptable or unacceptable in terms of the anticipated learning outcomes. One mark was given to answers which were acceptable and zero to those which were unacceptable. Questions 14 and 15 were marked on the basis of two marks for a completely acceptable answer, one mark for a partially acceptable answer and zero for an answer which was unacceptable. The criteria applied are discussed in more detail on page 72.

The questionnaire was presented just before the S.C.E. examinations when the Ordinary Grade syllabus had been completed by fourth year pupils aged around sixteen years. It was given in four comprehensive schools to all those pupils being presented for the S.C.E. Ordinary Grade examination in physics. At the same time it was given to candidates for the Higher Grade examination in physics, most of whom were in fifth year (S.5) but also to a few who were in sixth year (S.6).

Altogether the questionnaire was given to 179 pupils in S.4 taking the Ordinary Grade examination, and 93 pupils in S.5 and S.6 taking the higher grade examination.

As an aid to processing the results of the questionnaire the computer program produced in Jordanhill College of Education for processing multiple choice tests was used. The data from each questionnaire was transferred to a mark sense card normally used by pupils in such tests. If one mark had been given the response box A was marked, if a zero mark had been given response box B was marked. Where a question had several parts the appropriate number of lines on the card were given. For example question 4 has three parts. These are denoted 4(a), (b) and (c) in the tables and graphs, and three lines were given on the card. The computer was informed that 'A' was the key for all the items and on this basis a facility value, given as a percentage, and criterion score (the average score of those having the correct answer) could be obtained for each question and part question in the questionnaire.

Questions 14 and 15 were again the exceptions. For them a mark of 2 was recorded as 'A', a mark of 1 was recoded as 'B' and a mark of zero recorded as 'C'. This data was recorded on two lines for each of these questions. For the first line the key was given as 'A'. This allowed the calculation of the percentage of the group who scored two marks. For the second line the key was given as 'B'. This allowed the calculation of the percentage of the group who scored one. Criterion scores were also obtained.

The data was processed for each school and also for the whole year group taken together. The results are summarised in the tables and graphs which follow in section 2.8.

The copy of the questionnaire which follows has been annoted to correspond to the tables and graphs.

QUESTIONNAIRE ON ELECTRIC CIRCUITS

based on

S.C.E. SYLLABUS FOR YEARS S.3 and S.4.

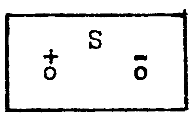
Pupil's Name ....

This is not an examination, but is an attempt to identify those parts of the topic of electricity which present difficulty to most people.

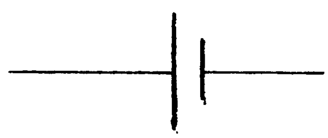
Thank you for helping.

The following symbols are used:

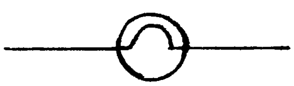
Voltage Source



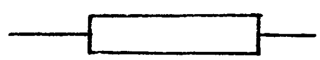
Cell



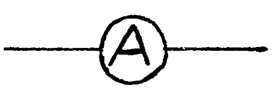
Lamp



Resistor



Ammeter



J.B. Muir 1977

1. What is an electric current?

2. What is electrical potential difference?

3. What is electrical resistance?

4. To answer this question you should select from the following expressions:

CJ^{-1} CV Js Cs^{-1} VA

Js^{-1} JC^{-1} VA^{-1} JV^{-1} AV^{-1}

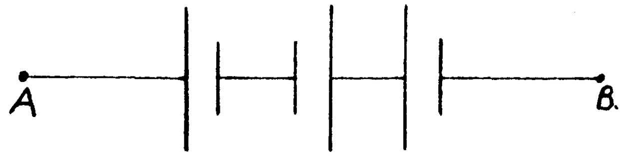
Which expression can be used to define

(a) the ampere

(b) the volt

(c) the ohm

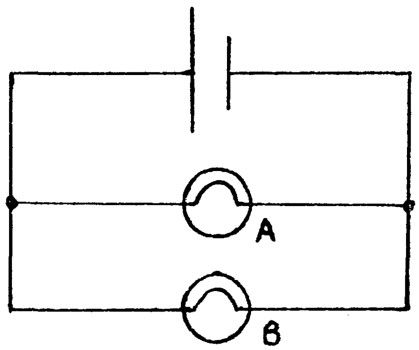
5. Each cell is the same. If the potential difference of each one is 1.5V



what is the potential difference across AB?

[ ] V

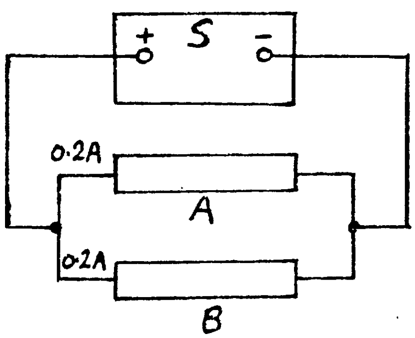
6. In the circuit below, the potential difference of the cell is 1.5V, and both lamps are the same



What is the potential difference across lamp B?

[ ] V

7. In the circuit below



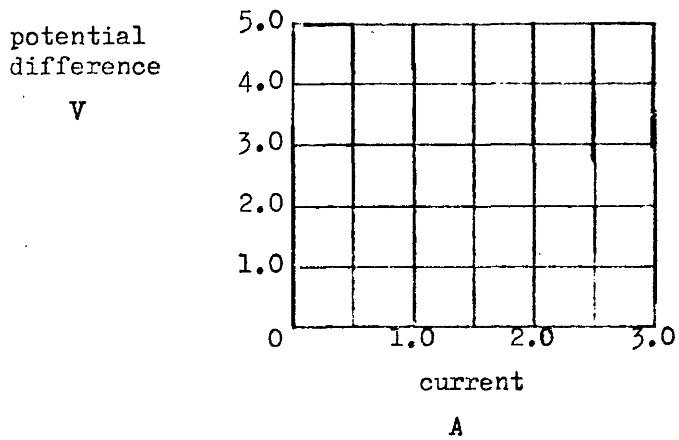
if resistor B is removed what will be the size of the current through resistor A?

[ ] A

8. Complete the following table of measurements made on an electrical conductor

Potential Difference	Current
0	
1.0 V	0.6 A
2.0 V	1.2 A
3.0 V	
	3.0A

9. Draw the graph of potential difference versus current from the table above



10. Calculate the resistance of the conductor in question 8

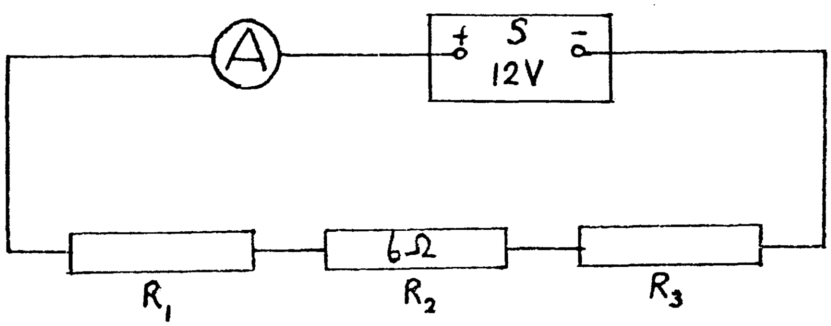
ohm

11. Using the grid in question 9, draw the graph of voltage versus current for a conductor of twice the resistance.

Mark the graph X

12. Draw a diagram for the circuit used to measure resistance

13. For the electric circuit shown below



the following information is given

V_s = 12 V	V_1 = 5 V	V_2 = 3 V	V_3 = ?
I_s = 0.5 A	I_1 = ?	I_2 = ?	I_3 = ?
R_{tot} =	R_1 = ?	R_2 = 6 Ω	R_3 = ?

What is the potential difference across R_3 ? V

What is the current through R_1 ? A

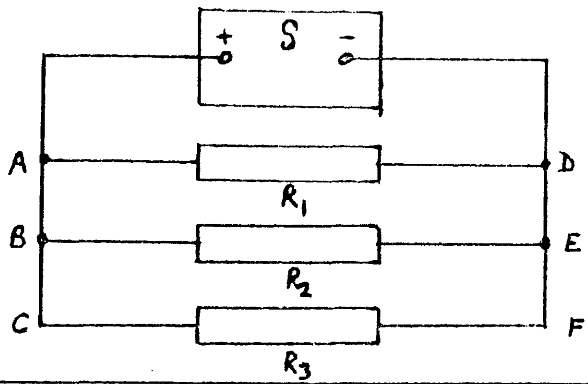
What is the current through R_3 ? A

What is the resistance of R_1 ? ohm

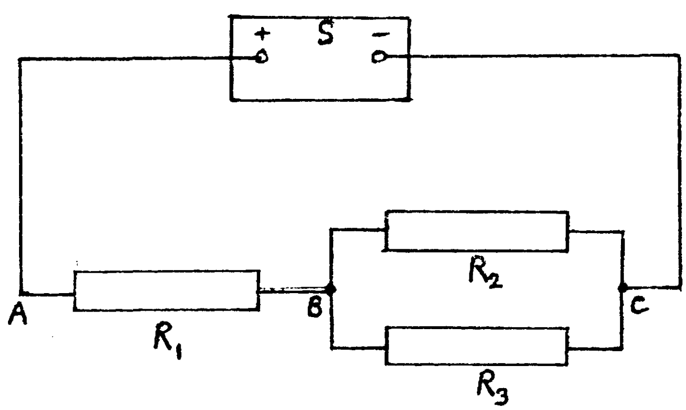
What is the resistance of R_3 ? ohm

What is the total resistance of the three conductors ? ohm

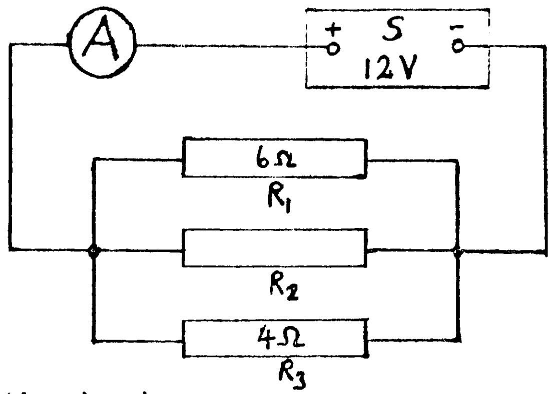
Describe the flow of currents through this circuit



Describe the flow of currents through the circuit below



16. For the circuit shown below



the following information is given

V_s = 12 V	V_1 = ?	V_2 = ?	V_3 = 12 V
I_s = ?	I_1 =	I_2 = 1 A	I_3 = ?
R_{tot} = ?	R_1 = 6 Ω	R_2 = ?	R_3 = 4 Ω

What is the potential difference across R_1 ? [ ] V [ ]

What is the potential difference across R_2 ? [ ] V [ ]

What is the current through R_1 ? [ ] A [ ]

What is the current through R_3 ? [ ] A [ ]

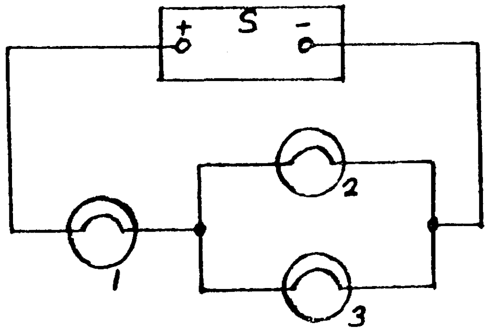
What is the current drawn from the voltage source ? [ ] A [ ]

What is the resistance of R_2 ? [ ] ohm [ ]

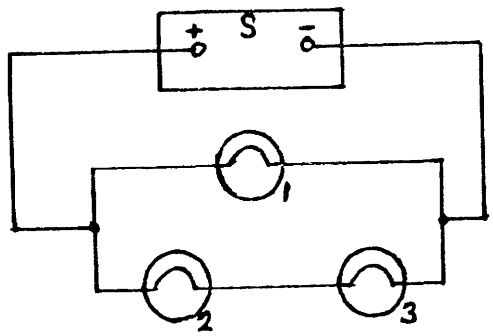
What is the total resistance of the three conductors? [ ] ohm [ ]

7\. The lamps in the circuits below are identical. Name the brightest in each case.

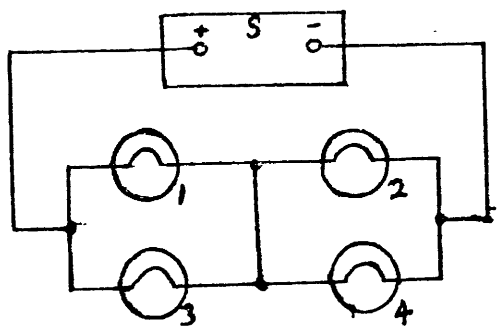
A



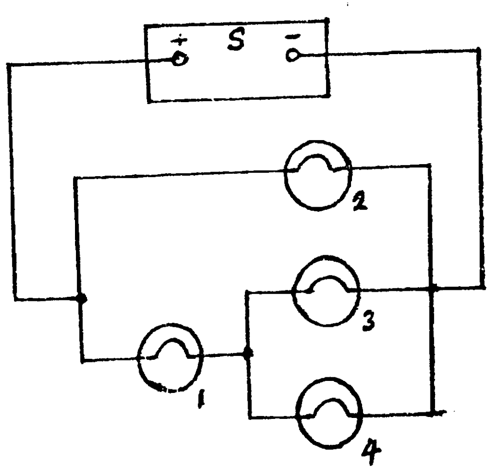
B



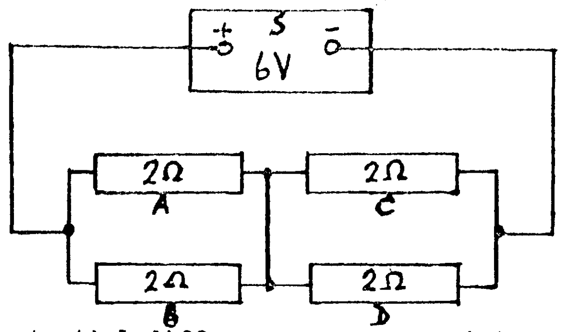
C



D



In the circuit below



(a) What is the potential difference across resistor A? V

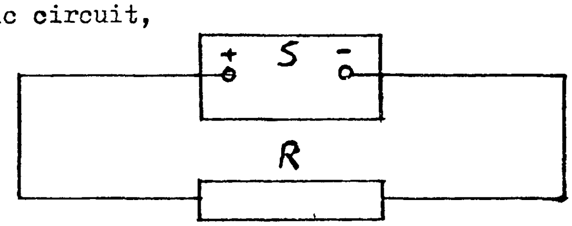
(b) What is the size of the current through resistor D? A

If the resistor B is now removed,

(c) What is the potential difference across resistor A? V

(d) What is the size of the current through resistor D? A

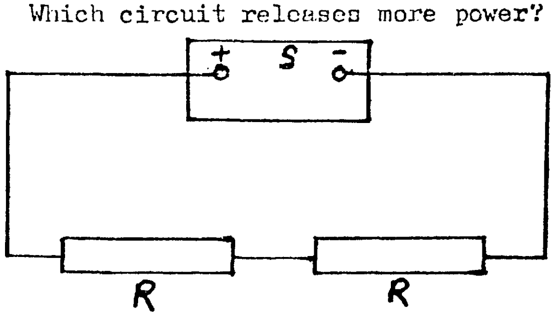
In this electric circuit,



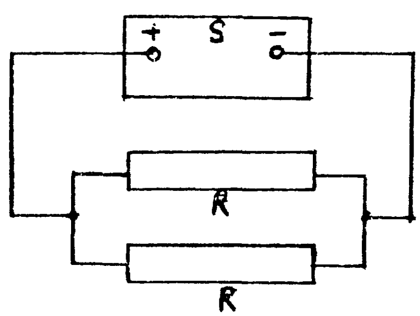
if the power released in the resistor R is 50W and the size of the current through it is 2A, what is the potential difference between the terminals of the voltage source?

V

Which circuit releases more power?



A



B

2.8 SUMMARY OF PUPILS' RESPONSES TO QUESTIONNAIRE ON ELECTRIC CIRCUITS YEARS FOUR AND FIVE (S.4 & S.5).

Inspection of the tables of results and graphical data together with the pupils' scripts revealed the following points:-

1. Most pupils could give an adequate definition to convey their concept of an electric current.
2. 52% of pupils in S.4 could not give an alternative statement in symbolic form for the ampere.
3. 52% of pupils in S.4 did not recognise that the current through two conductors in series was the same.
4. Only 14% of pupils in S.4 and 33% of pupils in S.5 were able to give a reasonable definition of potential difference.
   Many pupils simply described it as 'voltage'.
5. Pupils in S.4 were relatively unsuccessful in giving an alternative statement for the volt in symbolic form.
6. 58% of pupils in S.4 did not recognise that the p.d. across resistors in parallel is the same.
   This was a factor later in their failure to solve a problem on a parallel circuit.
7. Only 34% of pupils in S.4 drew the diagram for a circuit which could successfully be used to measure the resistance of a conductor. The voltage measurement required, was often not indicated.
8. In item 13, only about 36% of pupils in S.4 could isolate the data to allow them to calculate the values of the resistors in the series circuit.
   More than 80% of pupils in S.5 were successful.

9. In item 16, only 48% of pupils in S.4 correctly stated the values of the potential difference across the parallel conductors. 35% of pupils in S.4 recognised that the current drawn from a voltage source was the sum of the currents in the conductors connected in parallel to it. Performance of S.4 pupils deteriorated as they worked through this item.

   Performance of S.5 pupils was better and reasonably consistent.

10. Performance in item 18 was poor for pupils in S.4 and S.5. There was a failure to notice the change in currents and p.d.s brought about by the removal of a conductor. This tendency was also noted in item 7 which was also badly done, especially by pupils in S.5.

    This problem has been observed by the writer in other examinations and tests given to other groups of pupils.

11. Pupils in S.4 and S.5 were not particularly good at describing the distribution of currents in a parallel circuit where it was shown in "ladder" form. There was some improvement where the parallel conductors were joined to a common point.

12. Pupils in S.4 and S.5 were not very proficient at considering power dissipation in circuits in abstract terms.

In comparing the results of pupils in fourth year with those in fifth year it is important to keep in mind that the fifth year population is a much more selective one than the fourth year one. If it had been possible to compare theresults of only those pupils in fourth year who passed the Ordinary Grade examination with say grades A to C, with the fifth year group we might have found a smaller difference in performance between them.

TABLE OF RESULTS OBTAINED FROM QUESTIONNAIRE GIVEN TO PUPILS IN S.4.

Question No.	Total Group F.V.	Total Group C.S.	School 1 F.V.	School 1 C.S.	School 2 F.V.	School 2 C.S.	School 3 F.V.	School 3 C.S.	School 4 F.V.	School 4 C.S.
1	80	22	80	22	80	19	93	25	70	22
2	15	27	25	29	3	12	14	24	17	27
3	35	25	25	29	34	21	66	25	27	25
4(a)	46	25	39	27	36	24	90	26	40	23
4(b)	41	26	37	27	31	24	72	28	40	26
4(c)	37	26	29	28	30	25	69	28	40	21
5	44	23	42	22	41	22	90	26	7	16
6	45	23	46	26	38	20	41	26	60	20
7	18	24	7	29	20	25	34	24	20	21
8(a)	94	21	97	21	89	19	97	26	97	20
8(b)	88	21	83	22	85	19	93	26	100	20
8(c)	85	22	86	22	77	19	93	26	93	21
9	82	22	85	22	72	20	90	26	87	21
10	67	24	71	24	52	23	90	27	67	22
11	46	25	47	25	46	23	45	33	47	24
12	35	27	25	32	28	26	62	27	40	23
13(a)	51	25	54	26	43	24	66	26	50	23
13(b)	51	26	47	28	38	26	72	28	63	22
13(c)	49	27	46	28	36	26	72	28	57	23
13(d)	38	29	39	29	28	28	52	32	43	26
13(e)	36	29	36	29	28	28	48	33	43	26
13(f)	42	27	47	26	31	27	52	31	47	25

Question No.	Total Group F.V.	Total Group C.S.	School 1 F.V.	School 1 C.S.	School 2 F.V.	School 2 C.S.	School 3 F.V.	School 3 C.S.	School 4 F.V.	School 4 C.S.
16(a)	50	27	51	27	34	26	72	29	60	24
16(b)	50	27	49	27	39	26	66	29	57	24
16(c)	51	26	54	25	46	23	59	31	47	25
16(d)	56	25	56	25	48	23	72	28	60	24
16(e)	37	29	39	29	26	28	45	33	47	25
16(f)	38	28	46	27	21	28	52	32	43	26
16(g)	23	30	25	30	15	32	38	31	20	26
17(a)	85	21	88	22	82	19	79	28	90	20
17(b)	83	22	95	21	80	20	72	29	73	20
17(c)	40	24	42	22	41	22	55	30	20	26
17(d)	63	22	61	22	62	20	66	29	67	19
18(a)	37	24	51	22	33	24	24	31	30	23
18(b)	24	27	34	25	13	25	28	34	23	26
18(c)	13	23	24	24	8	22	10	25	3	13
18(d)	5	27	8	27	3	33	3	35	3	10
19	56	23	61	23	52	21	66	28	47	19
20	41	23	39	23	36	19	52	29	47	20

Note: F.V. = Facility Value = percentage of population who had correct answer in an item.

C.S. = Criterion Score = mean score of those who had item correct.

TABLE OF RESULTS OBTAINED FROM QUESTIONNAIRE GIVEN TO PUPILS IN S.5/S.6.

	Total Group		School 1		School 2		School 3		School 4	
Question No.	F.V.	C.S.	F.V.	C.S.	F.V.	C.S.	F.V.	C.S.	F.V.	C.S.
1	94	29	92	30	96	31	93	31	94	25
2	22	34	26	34	9	38	43	34	11	28
3	66	30	50	31	100	31	64	31	56	28
4(a)	76	31	76	31	91	31	86	32	50	28
4(b)	61	31	68	31	61	33	79	32	33	29
4(c)	82	31	82	31	87	31	93	31	67	28
5	75	31	63	31	96	32	93	32	61	27
6	66	32	76	31	74	32	71	32	28	31
7	15	32	18	31	22	33	0	0	11	29
8(a)	96	29	92	29	96	31	100	31	100	25
8(b)	91	30	92	30	100	31	79	31	89	26
8(c)	90	30	92	30	91	32	86	31	89	26
9	92	29	97	30	91	31	86	31	89	26
10	94	30	87	30	96	31	100	31	100	25
11	69	31	63	32	74	31	64	31	78	27
12	58	31	53	33	57	31	79	31	56	28
13(a)	88	31	84	31	96	32	100	31	78	27
13(b)	86	31	89	31	83	33	100	31	72	27
13(c)	88	30	89	31	83	33	100	31	83	27
13(d)	87	30	84	31	87	32	93	32	89	26
13(e)	81	31	79	32	83	32	86	32	78	27
13(f)	84	30	87	31	74	33	86	32	89	26

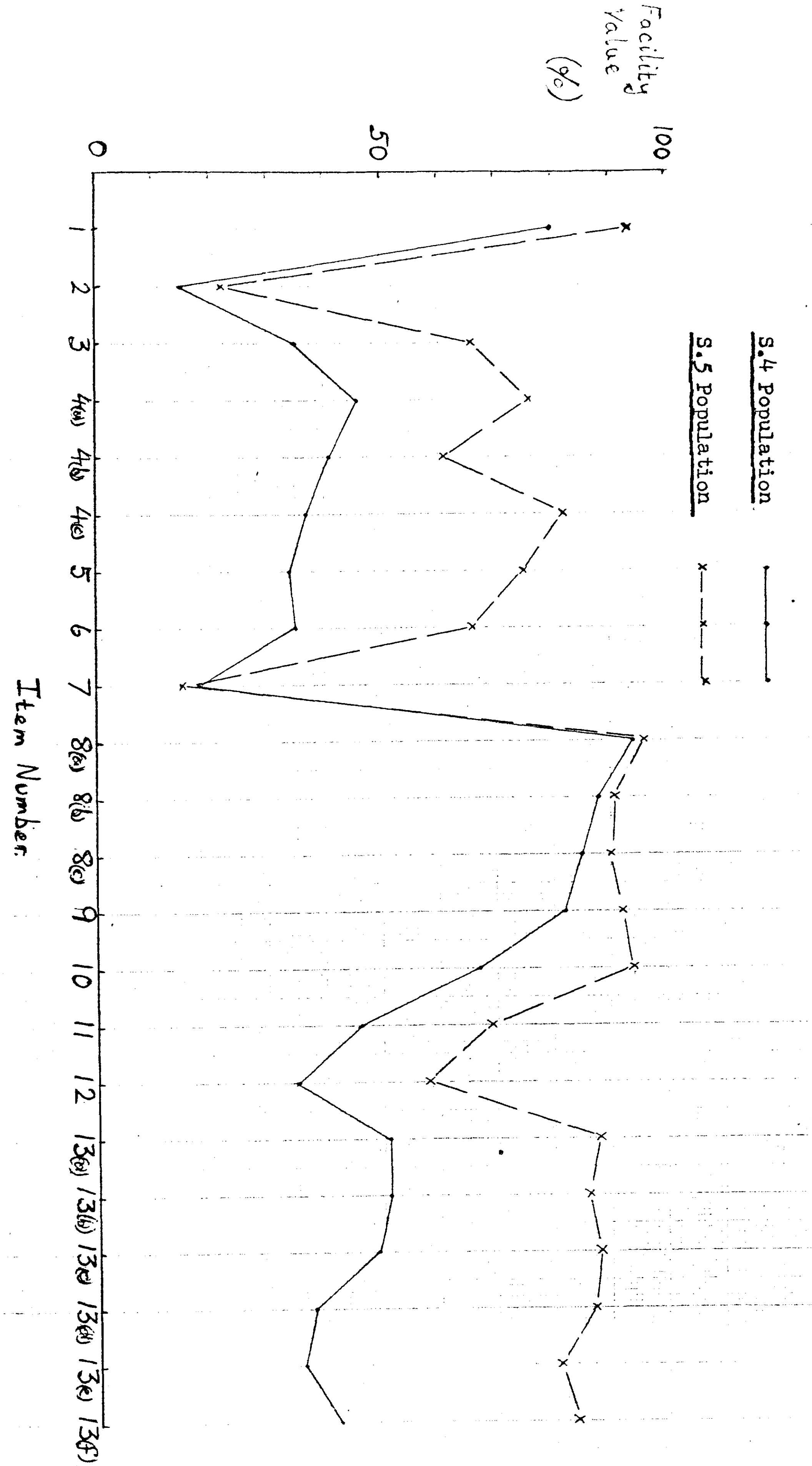
Question No.	Total Group F.V.	Total Group C.S.	School 1 F.V.	School 1 C.S.	School 2 F.V.	School 2 C.S.	School 3 F.V.	School 3 C.S.	School 4 F.V.	School 4 C.S.
16(a)	80	31	87	31	87	32	93	31	44	30
16(b)	80	31	87	31	87	32	93	31	44	30
16(c)	81	31	82	31	96	32	93	31	50	29
16(d)	82	31	79	31	96	32	79	31	72	28
16(e)	72	32	74	31	78	33	86	32	50	29
16(f)	75	31	84	31	78	32	79	32	50	29
16(g)	65	32	68	32	61	33	93	31	39	31
17(a)	91	29	89	20	91	32	100	31	89	24
17(b)	86	30	89	30	74	32	93	32	89	25
17(c)	49	32	37	33	65	34	71	32	39	27
17(d)	79	30	79	30	74	33	71	31	89	26
18(a)	47	32	53	33	52	33	14	34	56	26
18(b)	45	32	47	33	61	34	21	34	39	26
18(c)	23	32	18	36	26	35	21	28	28	27
18(d)	20	33	21	32	22	37	29	34	11	25
19	82	30	89	30	78	31	93	31	61	27
20	57	30	61	30	65	31	36	33	56	25

TEST ANALYSES - PUPILS IN S.4.

Population	Highest Score	Lowest Score	Median	Arithmetic Mean	Standard Deviation
Total Group (179)	41	1	19	20.1	8.93
School 1 (59)	41	7	19	20.7	8.63
School 2 (61)	39	1	16	17.3	9.08
School 3 (29)	37	8	25	24.9	8.82
School 4 (30)	35	6	19	19.8	6.89

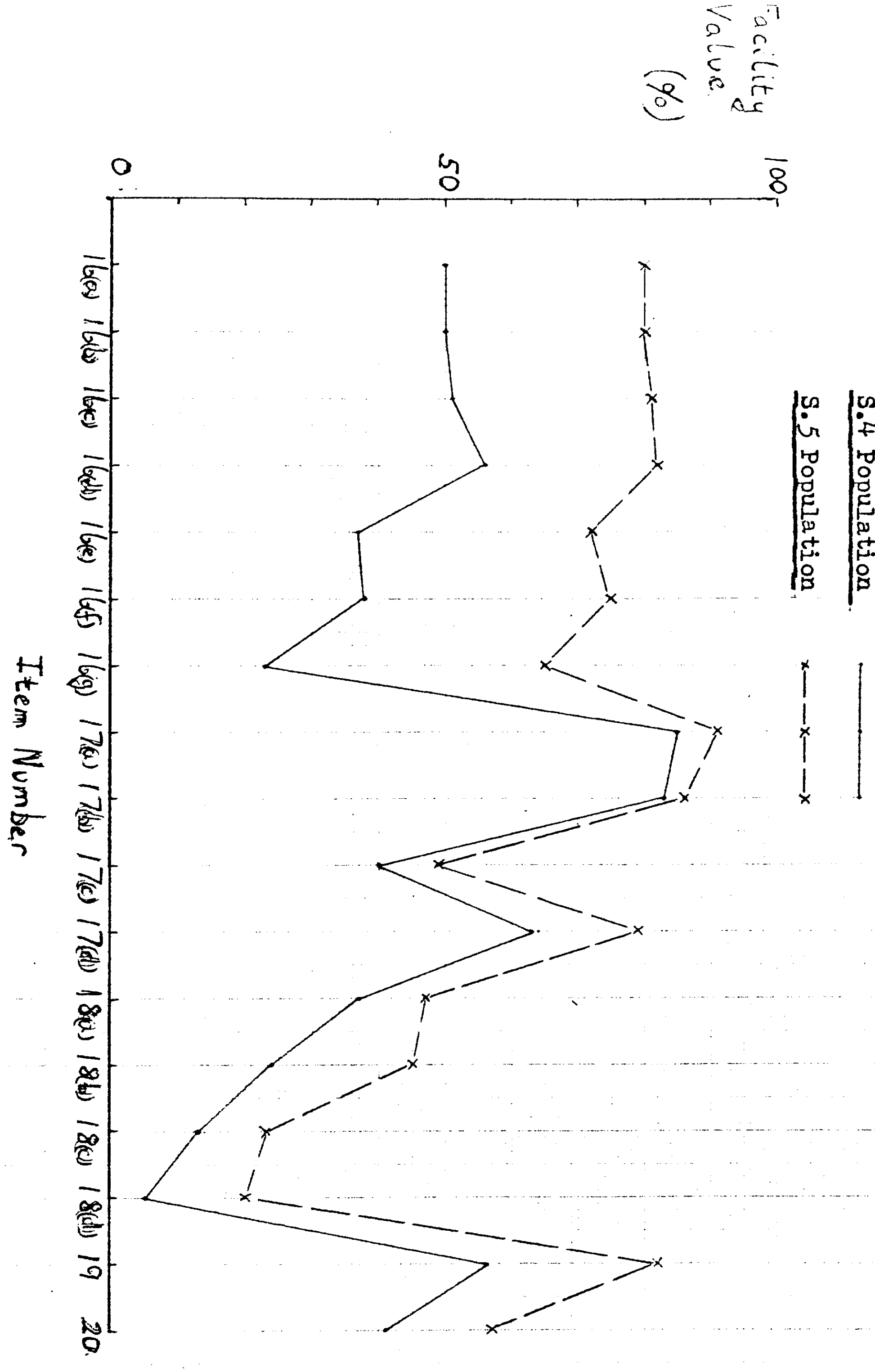
TEST ANALYSES - PUPILS IN S.5 & S.6

Population	Highest Score	Lowest Score	Median	Arithmetic Mean	Standard Deviation
Total Group (93)	39	13	30	29.2	6.07
School 1 (38)	39	15	33	30.7	6.07
School 2 (23)	39	15	33	30.7	5.85
School 3 (14)	36	23	31	30.9	3.61
School 4 (18)	35	13	26	25.3	6.19

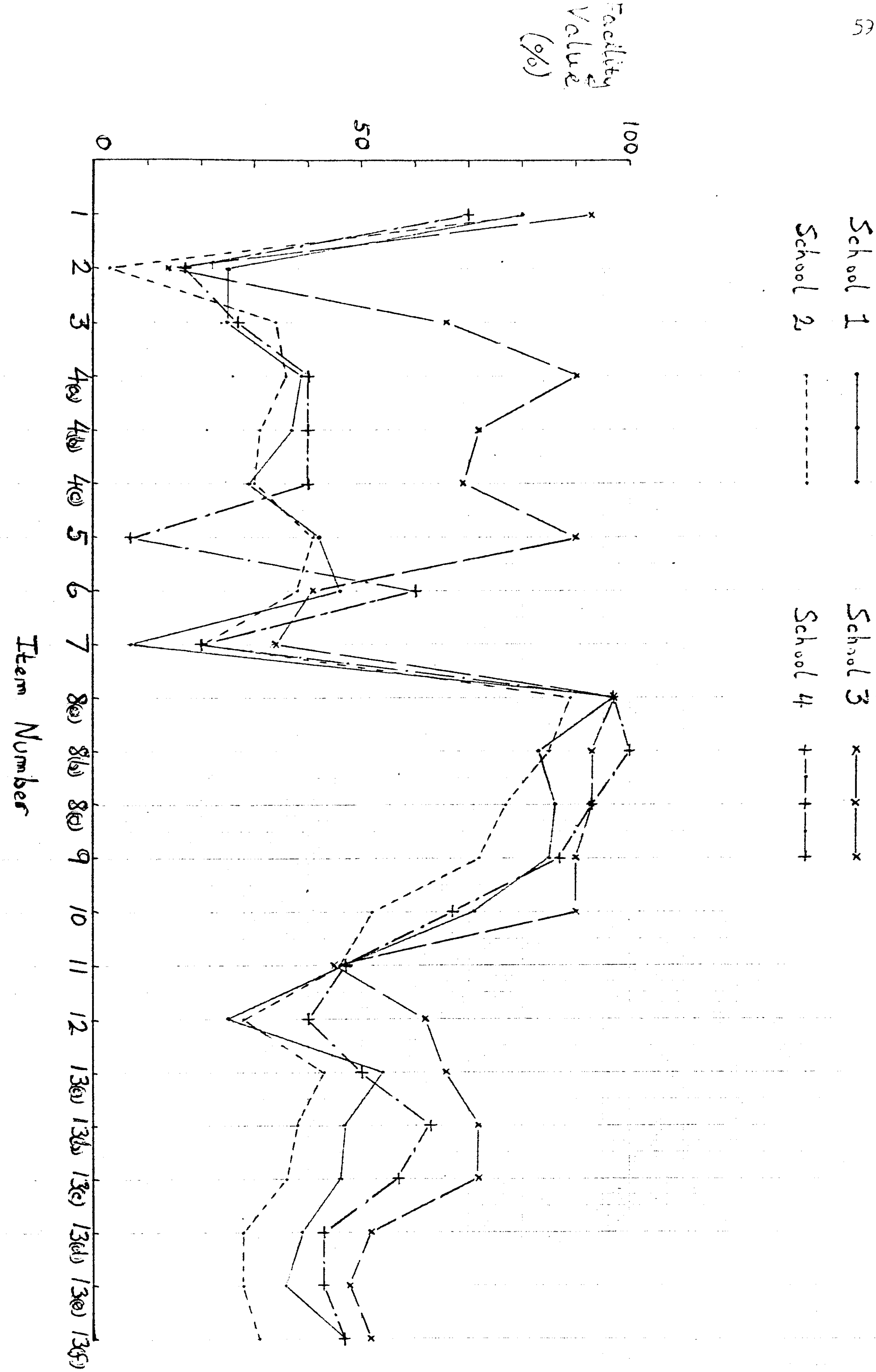


Plot of Facility Value versus Item Number for Total S.4 Population and Total S.5 Population (Items 1 to 13(f))

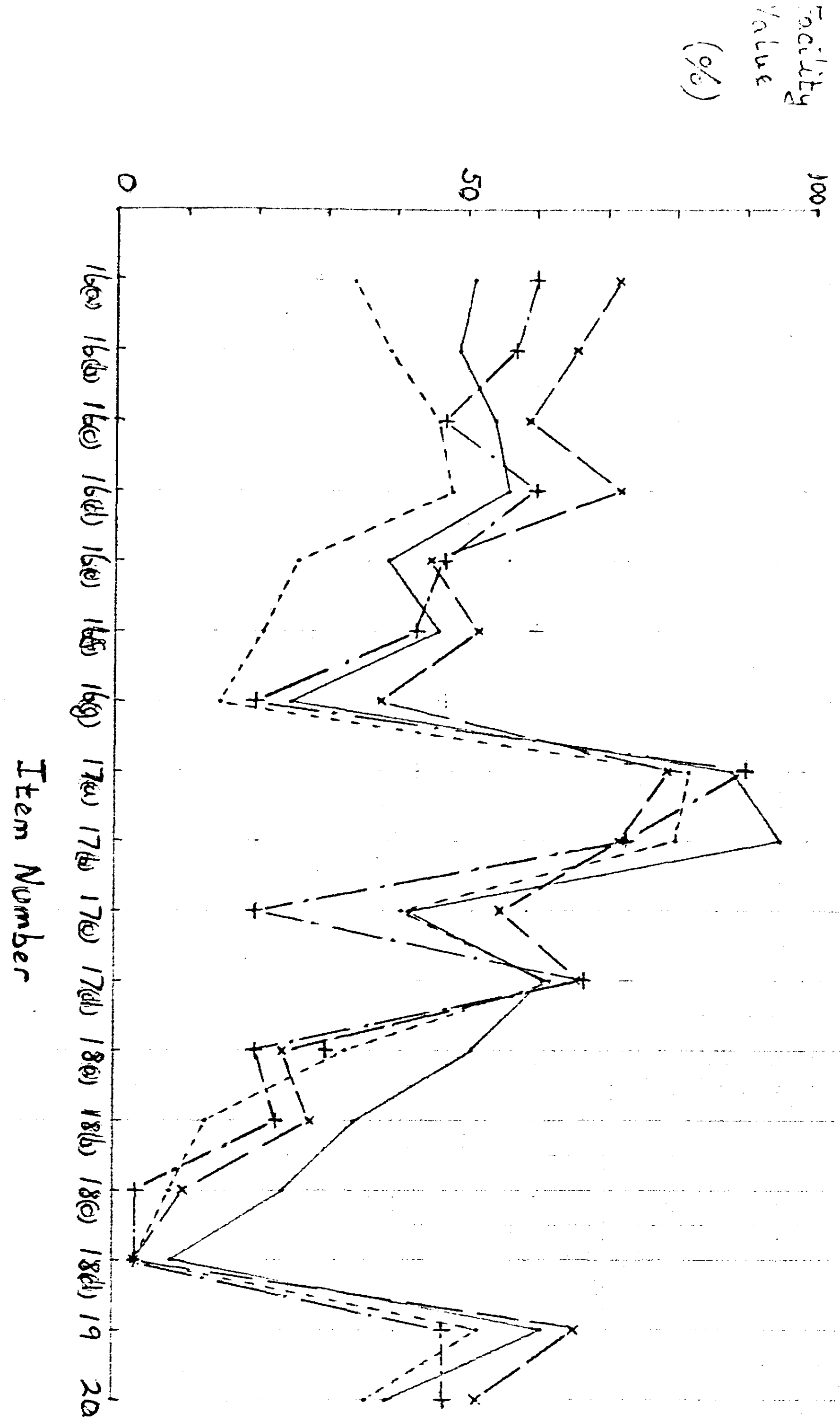
53



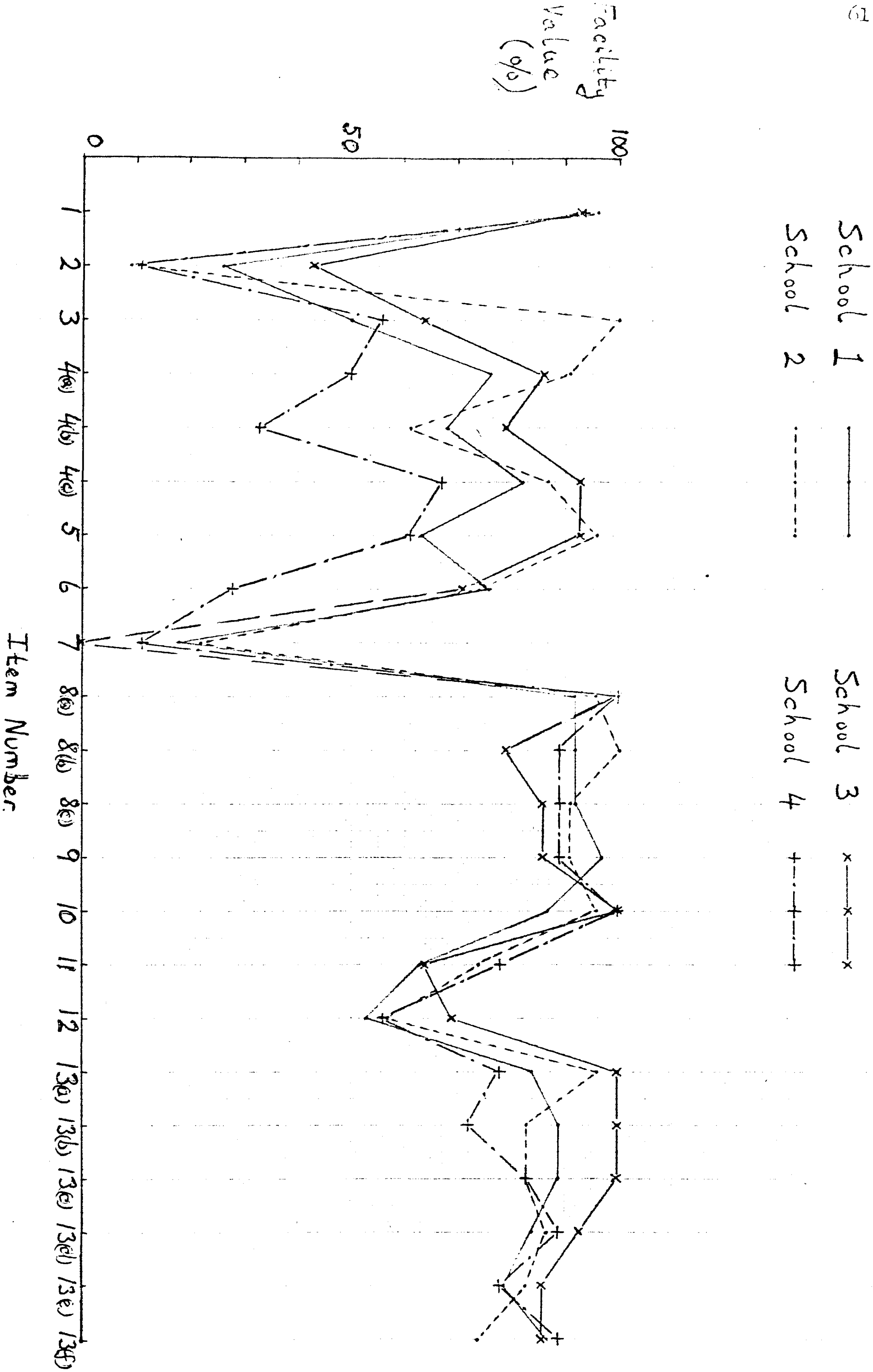
<u>Plot of Facility Value versus Item Number for Total S.4 Population and Total S.5 Population (Items 16(a) to 20)</u>



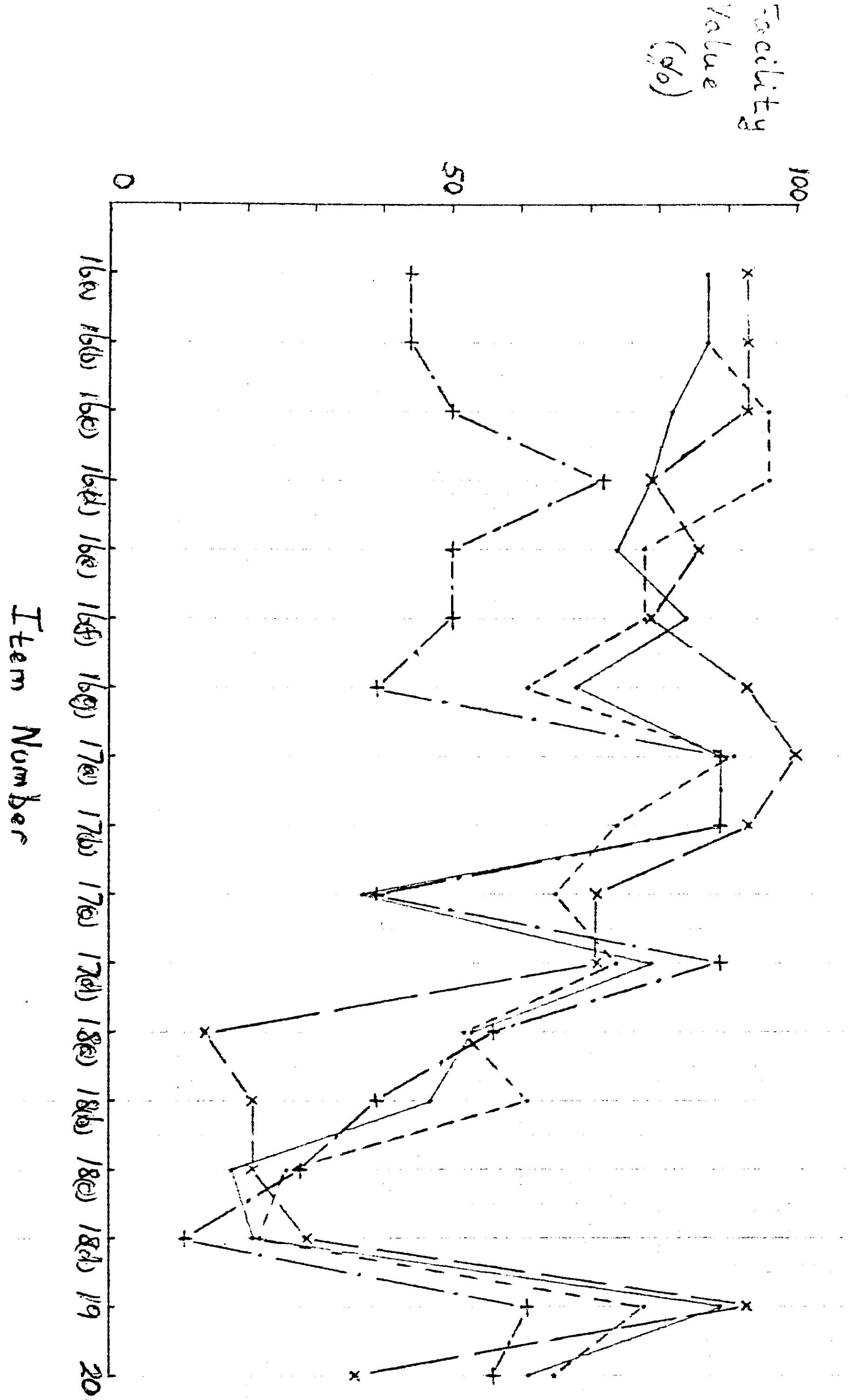
Plot of Facility Value versus Item Number, by School, for S.4 Population (Items 1 to 13(f))



Plot of Facility Value versus Item Number, by School, for S.4 Population (Items 16(a) to 20)



Plot of Facility Value versus Item Number, by School, for S.5 & S.6 Population (Items 1 to 13(f))



Plot of Facility Value versus Item Number, by School, for S.5 & S.6 Population (Items 16(a) to 20)

2.9 DISCUSSION OF RESULTS OBTAINED FROM QUESTIONNAIRE ON ELECTRIC CIRCUITS YEARS FOUR AND FIVE (S.4 AND S.5)

1. What is an electric current ?

This question was designed to allow pupils to state without imposed constraints their concept of an electric current. Acceptable answers had to indicate the idea of flow of electricity, or charge or charged particles.

This question was well answered.

Facility Value S.4 83

Facility Value S.5 94

2. What is electrical potential difference ?

This question was designed to allow pupils to state without imposed constraints their concept of electrical potential difference. Acceptable answers had to indicate the idea of the energy available to cause an electric current or the movement of charge.

In one school many pupils simply called it "voltage" but did not attempt to explain what it was. For this exercise, "voltage" was rejected.

This question was not well answered.

Facility Value S.4 14

Facility Value S.5 33

3. What is electrical resistance ?

This question was designed to allow pupils to state without imposed constraints their concept of electrical resistance. Acceptable answers had to indicate the idea of opposition to the flow of charges. Many pupils did not attempt to answer this question particularly in S.4. On the whole those that did answer were not very successful. A fairly large improvement in performance between S.4 and S.5 was noted.

One particular difficulty appears to come from the fact that one would wish to talk of "resisting the current", but it is difficult to find suitable synonyms for "resist" to avoid a circular description.

In addition many pupils may have resistance defined as $\frac{V}{I}$ and have not had to verbalise the concept before.

Facility Value S.4 37

Facility Value S.5 59

4. ~~To~~ answer this question you should select from the following expressions:

$C\ J^{-1}$	$C\ V$	$J\ s$	$C\ s^{-1}$	$V\ A$
$J\ s^{-1}$	$J\ C^{-1}$	$V\ A^{-1}$	$J\ V^{-1}$	$A\ V^{-1}$

Which expression can be used to define

(a) the ampere

(b) the volt

(c) the ohm

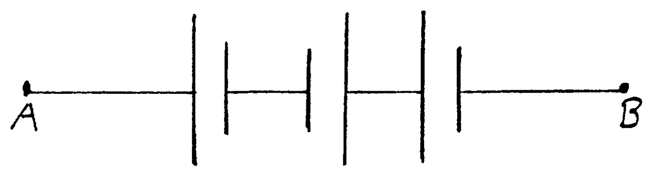
This question was designed to test whether pupils had a reasonable understanding of the units of current, potential difference and resistance and how they were interconnected.

There is a danger that some pupils were unable to cope with the symbols used, however there was significant evidence that many pupils in S.4 were uncertain of the definitions of all three units.

4. A marked improvement was noted between S.4 and S.5 particularly in the the unit of resistance

		(a)	(b)	(c)
Facility Values	S.4	48	42	37
Facility Values	S.5	75	63	84

5. Each cell is the same. If the potential difference of each one is 1.5 V



what is the potential difference across AB ?

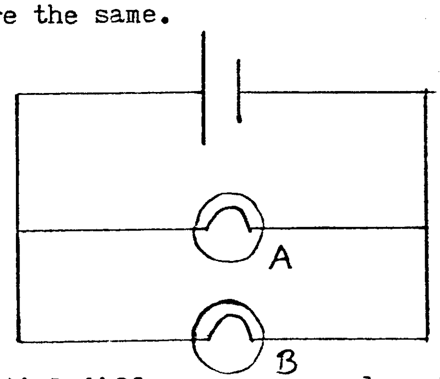
This question was designed to test pupils' ability to read a simple diagram and deduce correctly the potential difference produced by the arrangement of cells.

A number of pupils did not notice the reversed cell and gave 4.5 V as their response. A significant number gave 0 V as their response.

Once again a significant improvement was found between S.4 and S.5.

Facility Value	S.4	51
Facility Value	S.5	78

6. In the circuit below, the potential difference of the cell is 1.5 V , and both lamps are the same.



What is the potential difference across lamp B ?

6. The question was selected to test recognition of a parallel circuit and recall that the potential difference across conductors in parallel is the same. It was also necessary to recognise that although B is not shown connected directly to the cell it behaves as though it were.

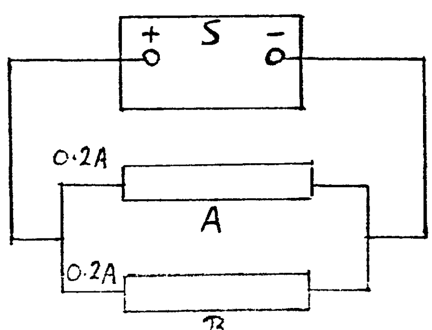
Many pupils gave 0.75 V as their answer so had obviously not recognised this.

The difficulties found with this question may go back to the early work done on parallel circuits which does not give sufficient emphasis to the fact that the parallel circuit shown is equivalent to having all the conductors connected directly to the cell, giving each a potential difference of 1.5 V.

The performance of pupils in S.5 was not particularly outstanding in this item, although it was better than those in S.4 .

Facility Value	S.4	42
Facility Value	S.5	63

7. In the circuit below



if resistor B is removed what will be the size of the current through resistor A ?

This is a question which catches out many people including science graduates. The most popular answer was 0.4 A, indicating the belief that the current now unable to flow through B must now flow through A. This is a very popular misconcept, and specific action must be taken to eradicate it in our teaching.

7. Very poor performances were found with this item, and those of S.5 were even worse than S.4 !

Facility Value S.4 17

Facility Value S.5 10

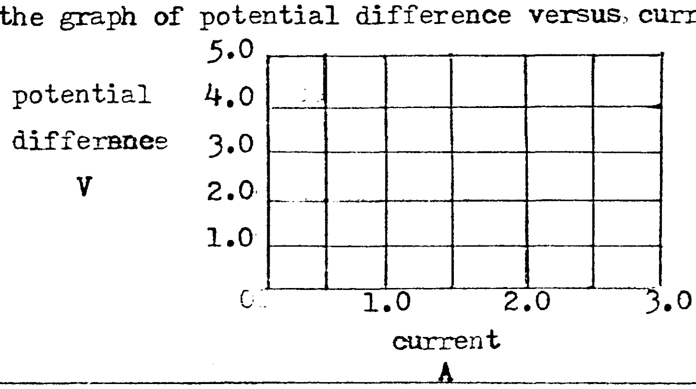
8, 9, 10, 11. These items form a set which was designed to test pupils' knowledge of Ohm's Law by correct manipulation of data and graphical display. It was also hoped to test the pupils' ability to relate the gradient of the graph to the value of the resistor.

The questions are as follows:-

8. Complete the following table of measurements made on an electrical conductor.

	Potential Difference	Current
(a)	0	
	1.0 V	0.6 A
	2.0 V	1.2 A
(b)	3.0 V	
(c)		3.0 A

9. Draw the graph of potential difference versus current from the table above



10. Calculate the resistance of the conductor in question 8

11. Using the grid in question 9, draw the graph of voltage versus current for a conductor of twice the resistance.

Mark the graph X.

8 Responses to this item were on the whole satisfactory. Most pupils appeared to recognise the relationships involved in deciding the numbers to place in the table. Errors appeared to be chiefly arithmetical.

	(a)	(b)	(c)
Facility Value S.4	93	86	84
Facility Value S.5	96	88	92

9 Both year groups performed reasonably well in this item. Some pupils omitted to draw the graph and some transferred the data inaccurately, but most were correct.

Facility Value S.4 81

Facility Value S.5 90

10 The performance of pupils in S.4 was disappointing in this item. A fair number omitted the calculation, while others did it wrongly. There was considerable improvement between S.4 and S.5.

Facility Value S.4 67

Facility Value S.5 98

11 The performance of pupils in S.4 was disappointing in this item. Many pupils omitted this one while many others gave the wrong line, usually for a conductor of half the resistance of the first one, or for a decidedly non-ohmic conductor.
There was a marked improvement between S.4 and S.5.
It may be that many pupils had not used graphs to any great extent in studying resistance of conductors.

Facility Value S.4 46

Facility Value S.5 75

12 Draw a diagram for the circuit used to measure resistance.

This item was not well handled by pupils in S.4.

On the whole most pupils failed to show adequately how they would measure current and voltage in the circuit.

Many showed the ammeter only and made no statement about whether the potential difference of the source was known.

Many placed the voltmeter in series with the conductor or in some other part of the circuit where it was useless.

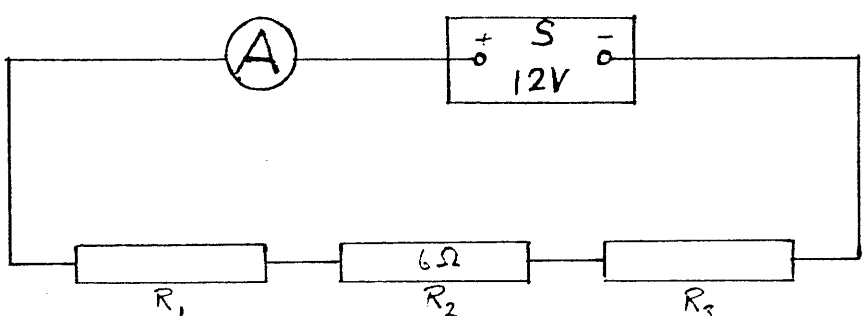
There was considerable improvement in performance between S.4 and S.5.

It would appear that this is an area requiring attention at the teaching stage in S.4.

Facility Value S.4 34

Facility Value S.5 65

13 For the electric circuit shown below



the following information is given

V_s = 12 V	V_1 = 5 V	V_2 = 3 V	V_3 = ?
I_s = 0.5 A	I_1 = ?	I_2 = ?	I_3 = ?
R_{tot} = ?	R_1 = ?	R_2 = 6 Ω	R_3 = ?

What is /

13 What is the potential difference across R_3 ?

This item was set to test knowledge that the total potential difference across conductors in series was the sum of the individual potential differences.

Performance of pupils in S.4 was disappointing.

12 V was a common response. Many pupils failed to give anything.

There was a considerable improvement in performance between S.4 and S.5.

Facility Value	S.4	52
Facility Value	S.5	88

What is the current through R_1 ? (a)

What is the current through R_3 ? (b)

These two items together were set to test the knowledge that the current in the source and the current in the conductors connected in series with it was the same.

Once again performance in S.4 was disappointing. It would appear that many pupils did not understand this basic concept.

A considerable improvement was noted in S.5

		(a)	(b)
Facility Values	S.4	48	47
Facility Values	S.5	88	92

What is the resistance of R_1 ? (c)

What is the resistance of R_3 ? (d)

These two items together were set to test ability in calculating resistance values from knowledge of potential difference and current associated with a conductor.

This depended on having the correct values for the current in R_1 and R_3, and also the correct value for V_3.

This was not well done by pupils in S.4 but was well done by pupils in S.5.

/in S.5.

		(c)	(d)
Facility Values:	S.4	37	35
Facility Values:	S.5	90	82

What is the total resistance of the three conductors ?

This item could have been answered by two routes.

Firstly the ratio of V_s over I_s could be used since these represent the total potential difference and current in the equivalent conductor.

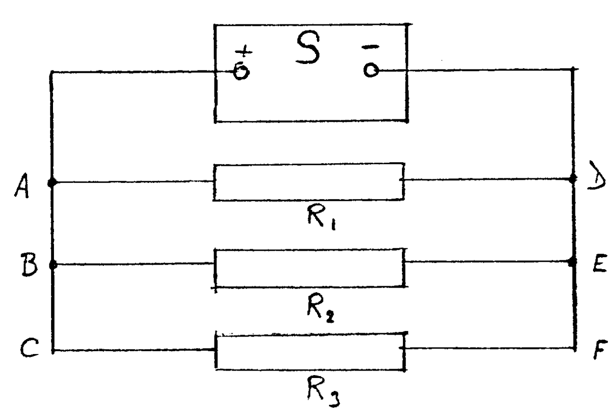
Alternatively, the sum of the values for R_1 , R_2 and R_3 could be taken.

Once again performance in S.4 was poor.

Facility Value	S.4	42
Facility Value	S.5	88

This set of items taken together revealed an inability of many pupils in S.4 to deal with the various parts of a series circuit. The basic concepts required seemed to be inadequately mastered.

14 Describe the flow of currents through this circuit



This item was marked on a three point scale of 2, 1, 0. The criteria applied were as follows: -

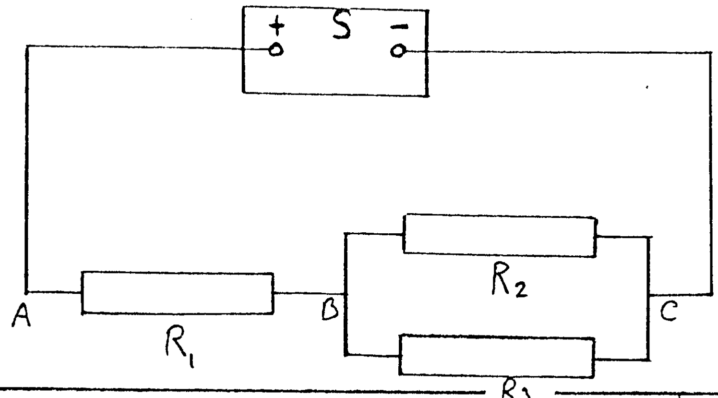
Rating	Criteria
2	Full answer showing good conceptual understanding. No significant errors.
1	Incomplete answer. Some errors, but about 50% of material correct.
0	No answer, answer insufficient to judge, obviously wrong.

This item was set to illustrate the difficulty which pupils have in verbalising the distribution of currents in complicated circuits. It was also designed to illustrate specifically the difficulty presented by the diagram used.for the parallel circuit. A diagram which is used in material presented to pupils from S.1 onwards. The scores obtained by pupils both in S.4 and S.5 confirmed the hypothesis. No significant improvement was found between S.4 and S.5.

The distribution of scores is shown below.

Score	2	1	0
% 0fpupils in S.4	22	40	38
% of pupils in S.5	29	41	30

15 Describe the flow of currents through the circuit below.



This item was marked on the same basis as item 14 above.

It was designed to show that the parallel circuit shown in the above diagram is easier to handle when visualising the distribution of currents than the diagram of question 14.

It was noted that while many pupils gave essentially a correct description of the distribution of currents, they said that the greater current was to be found in the larger resistance between R_2 and R_3.

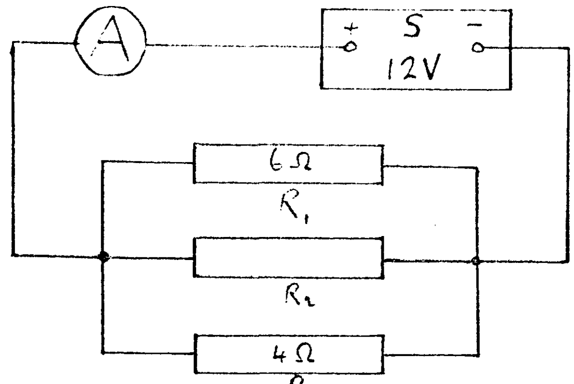
The performances in this item were much better than those in item 14.

The scores obtained were as follows: -

Score	2	1	0
% of pupils in S.4	44	28	28
% of pupils in S.5	41	43	16

16 For the circuit shown below/

16. For the circuit shown below



the following information is given

V_s = 12 V	V_1 = ?	V_2 = ?	V_3 = 12 V
I_s = ?	I_1 = ?	I_2 = 1 A	I_3 = ?
R_{tot} = ?	R_1 = 6 Ω	R_2 = ?	R_3 = 4 Ω

What is the potential difference across R_1 ? (a)

What is the potential difference across R_2 ? (b)

These two questions taken together were designed to test knowledge that the potential difference across conductors in parallel is the same.

Performance by S.4 pupils in this item is poor in comparison to those in S.5. Mainly because a fair number of S.4 pupils did not attempt it. In addition a fair number came up with wrong answers. Many of those giving wrong answers did not treat the circuit as a parallel one.

	(a)	(b)
Facility Value S.4	48	48
Facility Value S.5	76	76

What is the current through R_1 ? (c)

What is the current through R_3 ? (d)

These two questions taken together were set to test knowledge of the distribution of currents in a parallel circuit and ability to calculate their magnitude from data given.

Once again a distinct improvement in performance was noted between S.4 and S.5.

	(c)	(d)
Facility Value S.4	52	56
Facility Value S.5	78	80

What is the current drawn from the voltage source ?

This item was set to test recognition that the total current in the voltage source would be equal to the total current of the parallel circuit.

This item was not well done by pupils in S.4 but was well done by those in S.5.

In marking this item, only the stated correct answer was taken as correct.

Many pupils in S.4 did not attempt this part.

Facility Value S.4	35
Facility Value S.5	71

What is the resistance of R_2 ?

This item was set to test ability to isolate the correct data and hence calculate the value of the resistance.

Many pupils in S.4 did not attempt this part.

Facility Value S.4	37
Facility Value S.5	75

What is the total resistance of the three conductors ?

This item was set to test ability to recognise that the potential difference of the voltage source taken with the current through it could give the desired result.

Alternatively, as many pupils appeared in fact to do, the formula for resistors in parallel could be used.

Once again performance in S.4 was poor, either because it was not attempted or because wrong data was used.

Facility Value S.4 23

Facility Value S.5 69

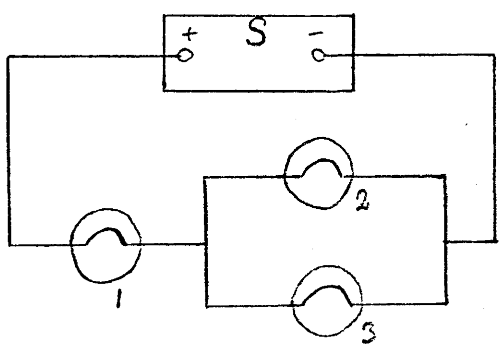
Overall the performance of S.5 pupils in this series of questions was consistent with little variation of facility value.

Performance of S.4 pupils deteriorated as they worked through the set of questions.

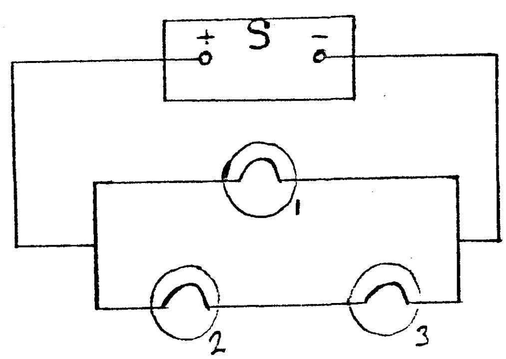
There was quite clear evidence of a lack of knowledge of the basic rules for series and parallel circuits in evidence in question 13 and in this one.

17 The lamps in the circuits below are identical. Name the brightest in each case.

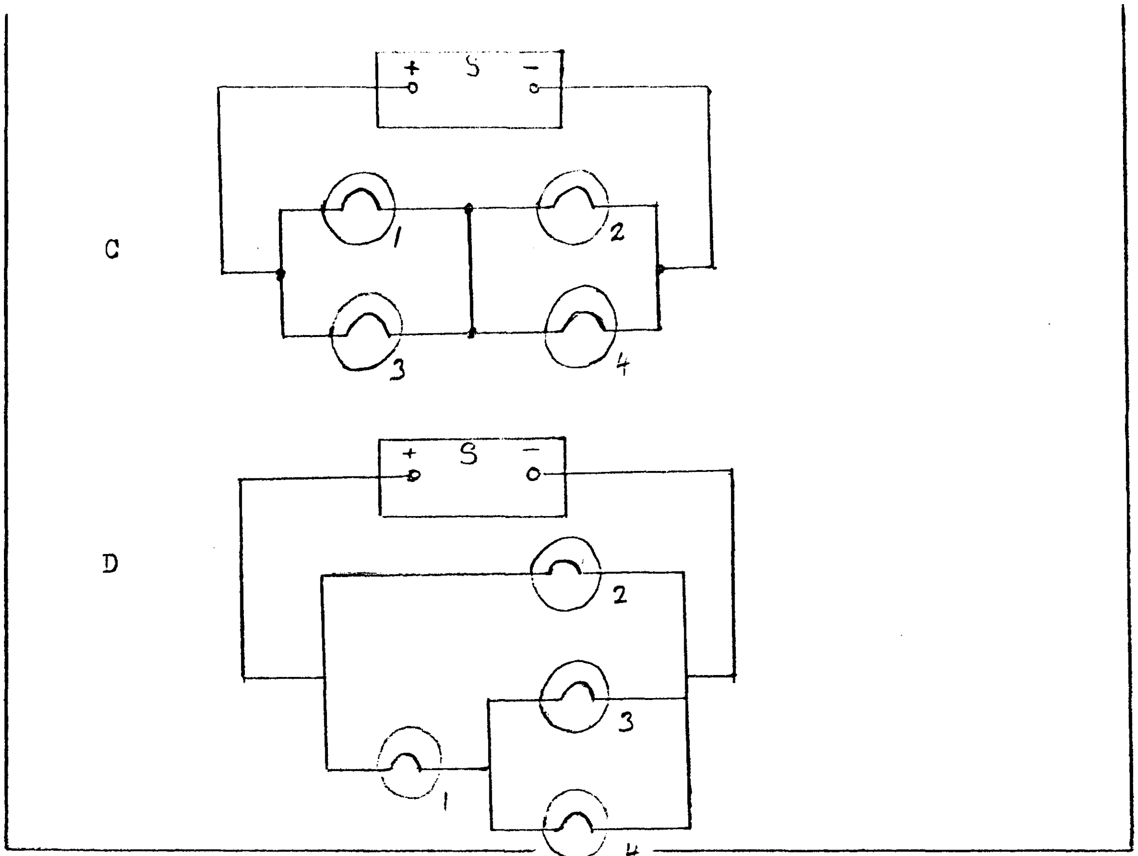
A



B



17



The various parts of this item were set to test pupils' ablity to work out the relative potential differences in a circuit without use of numbers.

Parts A and B were performed well by both year groups.

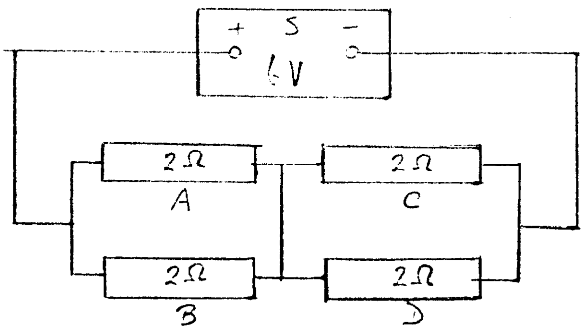
Part C presented problems to both year groups. Many pupils did not recognise that the lamps would be equally bright.

Part D was performed better by pupils in S.5 than those in S.4.

	A	B	C	D
Facility Values S.4	84	85	44	62
Facility Values S.5	92	94	49	80

It is interesting to note the relatively poor performance of pupils in S.5 in part C, in spite of the fact that they will have studied potentiometer and Wheatstone bridge circuits.

18 In the circuit below



(a) What is the potential difference across resistor A ?

(b) What is the size of the current through resistor D ?

If the resistor B is now removed,

(c) What is the potential difference across resistor A ?

(d) What is the size of the current through resistor D ?

It was anticipated that this set of questions would present problems to pupils in S.4. This was confirmed.

Many pupils gave the answer to part (a) as 6 V and calculated the size of the current accordingly

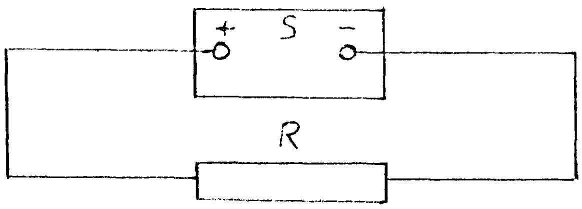
Many S.4 pupils did not attempt parts (c) and (d).

Many of those who did attempt part (c) gave the answer to be 3 V, and had obviously not recognised the new set of potential differences which had resulted from the removal of resistor B.

The current which was calculated for part (d) was usually wrong. Either it was based on the potential difference calculated in part (c) or was based on no obvious data.

	(a)	(b)	(c)	(d)
Facility Value S.4.	37	24	13	5
Facility Value S.5.	47	45	23	20

19 In this electric circuit,



if the power released in the resistor R is 50 W and the size of the current through it is 2 A, what is the potential difference between the terminals of the voltage source ?

This item was set to test ability to use the relationship

power = potential difference X current

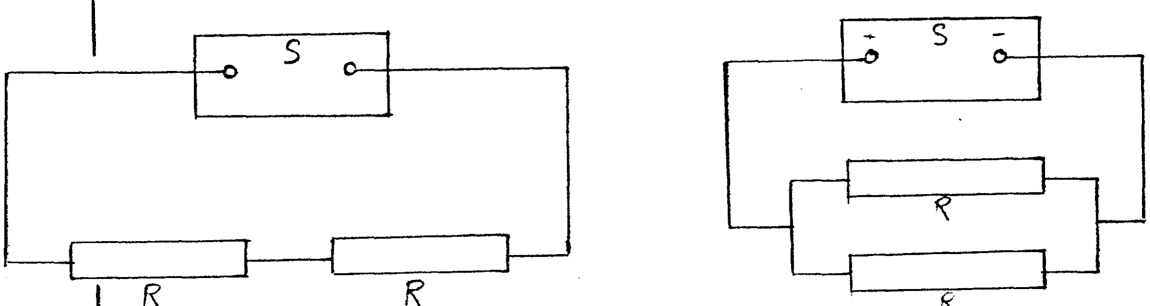
and apply it at the Bloom comprehension level.

Relatively speaking, this item was reasonably well done, though there was a fairly large difference in performance between S.4 and S.5

Facility Value S.4 56

Facility Value S.5 82

20 Which circuit releases more power ?



This item was set to test pupils ability to consider this problem in general terms. On the whole it presented problems to both groups of pupils. This was in spite of a fair amount of experimental help from S.1 onwards.

Facility Value S.4 41

Facility Value S.5 57

2.10 INVESTIGATION OF ELECTRICAL KNOWLEDGE POSSESSED BY PRIMARY SCHOOL PUPILS (P.7) IMMEDIATELY BEFORE TRANSFER TO SECONDARY SCHOOL

This investigation was the final one in the sequence. It was prompted by Rosalind Driver's article (1981)[9] "Pupils' Alternative Frameworks in Science" in which she describes how ideas, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experience can affect their response to what is taught in the science class later on. It seemed sensible in this context to try to gauge the knowledge of electricity with which pupils arrived in secondary school as they met what was probably their first formal science teaching. Assuming no formal teaching, we were therefore testing what might be termed general knowledge gained in the home and through hobbies. It was possible that this was the first occasion on which the pupils had been made to think about electricity.

A questionnaire was prepared which sought to test this "general knowledge". It was designed to be presented orally to a whole primary class using apparatus and electrical appliances where appropriate. The pupils made their responses on the question papers which were later marked by the writer. When the questionnaire had been completed a discussion took place of the pupils responses, and misconceptions were corrected.

The questionnaire was presented in three primary schools all of which fed the same comprehensive school. A total of 145 pupils were involved which was about 50% of the intake to S.1 of that school. The largest group of pupils was in School 1 which had three primary 7 classes giving a total of 44 boys and 33 girls. School 2 provided one class with 16 boys and 16 girls, while School 3 provided one class in primary 7 and primary 7 pupils from a composite class to give 19 boys and 17 girls. None of the primary schools taught science in a formal way, nor electricity in particular.

To aid later discussion the results of the questionnaire have been analysed by school and by sex. Facility values have been calculated to give a basis of comparison. Where the sample is small however these must be treated with great caution.

In preparing the questionnaire the following outcomes were set as criteria for success in answering the questions:-

1. Identifies common use for batteries exhibited.
2. Identifies voltage obtained from batteries in item 1 and 13 A socket.
3. Completes circuit diagram of simple circuit made from battery and bulb.
4. Completes circuit diagram to show that bulbs are connected in series on a Christmas tree.
5. States that each bulb in circuit for item 4 cannot be switched off on its own.
6. Completes circuit diagram to show that bulbs which are to be switched off separately are connected in parallel.
7. Completes circuit diagram to show switch included in simple circuit.
8. Identifies conductors from a list of conductors and insulators.
9. Gives the name 'conductor' to set of items which pass electricity.
10. Explains what is meant by "13 amp socket", including idea of maximum current to be given out.
11. Item omitted.
12. States that current supplied to electric adaptor is sum of currents taken by appliances connected to it.

13. States that voltage supplied to electric adaptor is equal to voltage supplied at outlets.
14. States that voltage needed by model railway is 12 volts.
15. Identifies from list lowest voltage that can kill.
16. Lists wiring colour code for 13 amp plug.
17. Lists names of pins in 13 amp plug.
18. Identifies fuse.
19. States function of a fuse.
20. Identifies function of battery, bulb and switch in simple circuit.
21. Identifies battery as source of energy.
22. Identifies as "true" or "false" three sentences about electricity.

In the questionnaire there is a danger that later items may give a clue to responses needed for earlier ones. Because of this it was presented page by page in order, one question at a time. Pupils were given clear instructions not to read ahead and none were observed to do so.

The questionnaire and tables of results are shown on the following pages.

JORDANHILL COLLEGE OF EDUCATION

HOW MUCH DO YOU KNOW ABOUT ELECTRICITY ?

These questions are to help find out how much you already know about electricity before you take Science in the secondary school. It is not a test and nobody fails.

If you know the answer to a question answer it as fully as you can.
If you do not know the answer put "I do not know".

Thanks for your help.

J.B.Muir.

NAME

WRITE YOUR ANSWERS IN THE BOXES

Where would you use these batteries

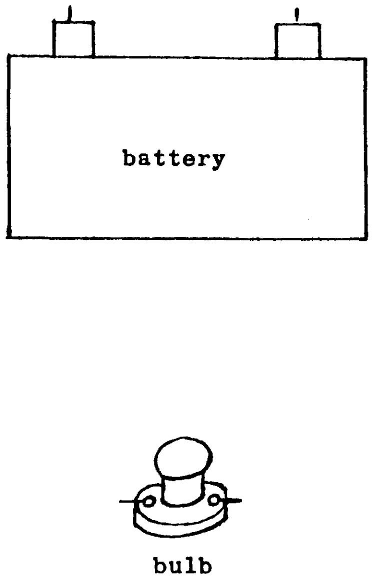
A.
B.
C.

What voltage do we get from these supplies.

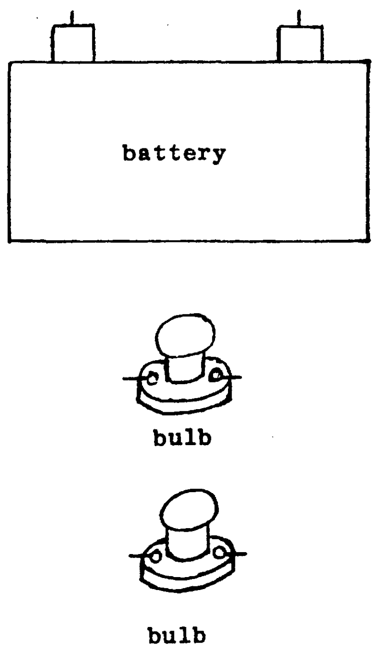
A.	volts
B.	volts
C.	volts
D.	volts

3/over

Draw the wires to join the battery to the bulb to make it light up.

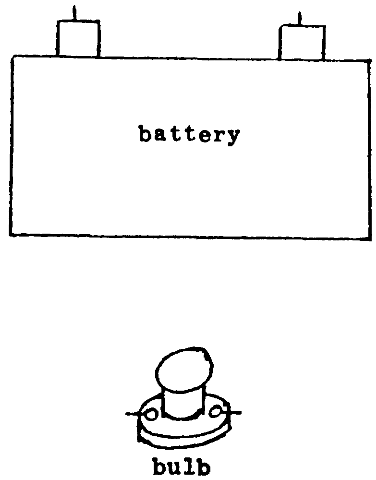


Draw the wires to join the battery to the bulbs so that they are connected like lights on a Christmas tree.

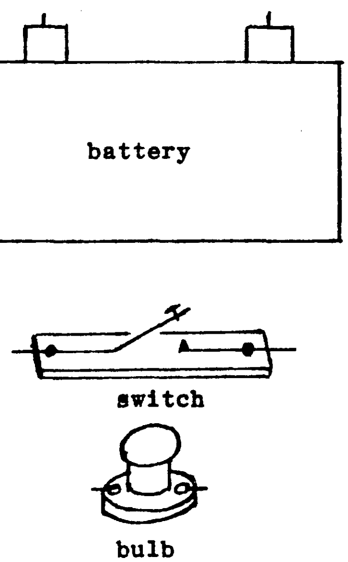


Can we switch off each bulb on its own?

Draw the wires to join the battery to the bulbs so that they can be switched off separately.



Draw the wires to join up the battery, switch and bulb.



Read this list:

key, rubber, paper clip, wool, wood, plastic, coin, paper.

Write down the set of things which pass electricity.

What is the special name we give to things which pass electricity?

What do we mean by "13 amp socket" ?

If we have a T.V. which needs 1 amp and an electric fire which needs 4 amps plugged into an adaptor? How many amps pass through the adaptor?

amps

If the T.V. needs 250 volts and the electric fire needs 250 volts, how many volts must the adaptor supply?

volts

What is the voltage needed for a model railway?

volts

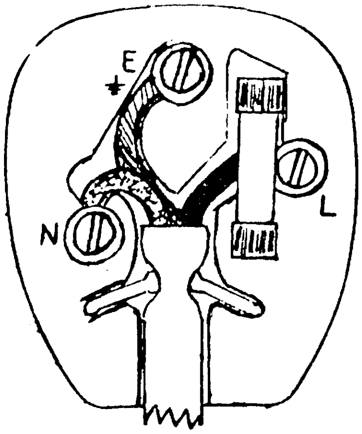
Put a ring round the lowest voltage that could kill.

3 volts; 12 volts; 50 volts; 100 volts; 250 volts.

16. Write down the colours of the wires to go on the pins of the 13 amp plug.

E

N

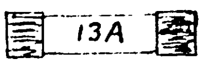


L

17. **What are the full names of the three pins?**

L	
N	
E	

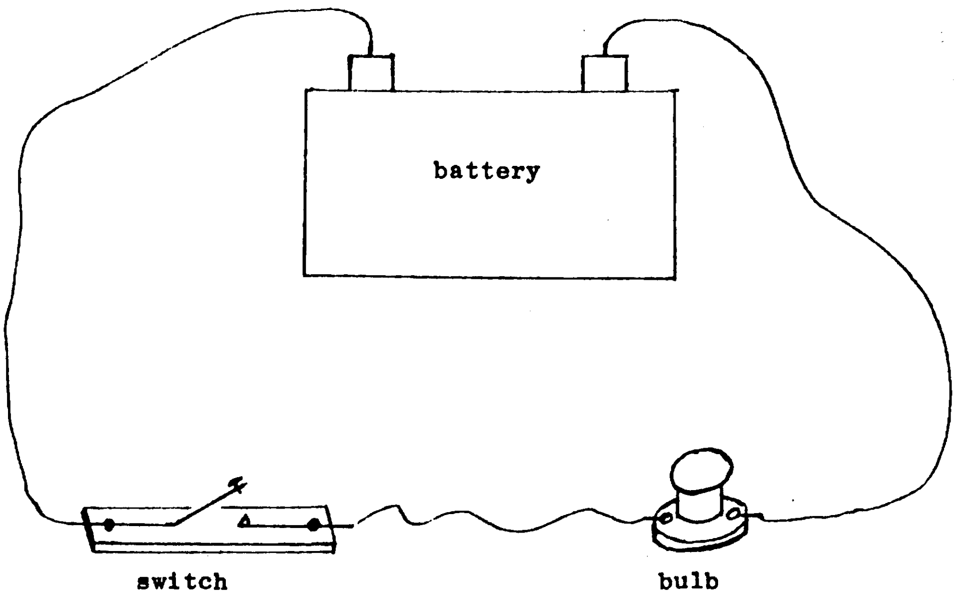
18. **What is this device?**



19. **What does it do?**

20/

20. In this simple circuit



What does the battery do to the electricity?

What does the bulb do to the electricity?

What does the switch do to the electricity?

21. Energy is given out. Where does it come from?

22 The sentences below might appear in a newspaper or book.

Write "true" in the box beside the sentence if the words used look reasonable.

Write "false" in the box beside the sentence if the words used do not look reasonable.

"A voltage of 30,000 volts passed through the man and killed him."

"A current of 4 amps is passed through a head lamp on a car."

"There is electricity in the wires of an electric circuit before the battery is connected to it".

Investigation of Electrical Knowledge possessed by Primary School Pupils - Test Facility Values

Population	Test F.V. Boys (n_b)	Test F.V. Girls (n_g)	Test F.V. Boys + Girls (n_t)
School 1	42 (44)	37 (33)	40 (77)
School 2	40 (16)	38 (16)	39(32)
School 3	34 (19)	34 (17)	34 (36)
Total Group	41 (79)	36 (66)	38 (145)

(The numbers in brackets in the table show the number of pupils in the sample.)

Investigation of Electrical Knowledge possessed by Primary School Pupils - Item Analysis for All Pupils

Item No.	No. of boys (n_b)	F.V.	No. of girls (n_g)	F.V.	No. of Pupils (n_t)	F.V.
1 A	77	97	64	97	141	97
B	26	33	13	20	39	27
C	78	99	64	97	142	98
2 A	7	9	6	9	13	9
B	10	13	5	8	15	10
C	7	9	0	0	7	5
D	9	11	5	8	14	10
3	75	95	62	94	137	94
4	1	1.3	1	1.5	2	1.3
5	40	51	37	56	77	53
6	50	63	31	47	81	56
7	7	9	2	3	9	6
8	33	42	26	42	61	42
9	18	23	10	15	28	19
10	10	13	8	12	18	12
12	60	76	54	82	114	79
13	1	1.3	2	3	3	2
14	18	23	5	8	23	16
15	59	75	49	74	108	74
16 E	47	59	33	50	80	55
L	28	35	27	41	55	38
N	24	30	19	29	43	30
ALL	21	27	18	27	39	27
17 L	47	59	27	41	74	51
N	30	38	17	26	47	32
E	37	47	19	29	56	39
18	69	87	53	80	122	84
19	9	11	6	9	15	10
20	32	41	24	36	56	39
	8	10	3	5	11	8
	56	71	40	61	96	66
21	41	52	44	67	85	59
22	13	16	10	15	23	16
	39	49	27	41	66	46
	14	18	21	32	35	24

Investigation of Electrical Knowledge possessed by Primary School Pupils - Item Analysis by School and Total Group

	School 1			School 2			School 3			Total Group		
Item	FV_b	FV_g	FV_t	FV_b	FV_g	FV_t	FV_b	FV_g	FV_t	FV_b	FV_g	FV_t
1 A	97	100	99	100	94	97	95	94	94	97	97	97
B	43	30	38	13	13	13	26	6	17	33	20	27
C	100	97	99	100	100	100	95	94	94	99	97	98
2 A	5	6	5	6	0	3	21	23	22	9	9	9
B	11	6	9	6	0	3	21	18	19	13	8	10
C	16	0	9	0	0	0	0	0	0	9	0	5
D	9	6	8	31	3	19	0	12	6	11	8	10
3	93	91	92	100	100	100	95	94	94	95	94	94
4	0	3	1	6	0	3	0	0	0	1.3	1.5	1.3
5	57	64	60	56	50	53	32	47	39	51	56	53
6	61	42	53	63	63	63	68	41	55	63	47	56
7	9	0	5	6	0	3	11	12	11	9	3	6
8	46	52	49	31	38	34	37	29	33	42	42	42
9	30	12	22	19	19	19	11	18	14	23	15	19
10	14	15	14	6	6	6	16	12	14	13	12	12
12	91	85	88	69	94	81	47	65	55	76	82	79
13	2	6	4	0	0	0	0	0	0	1	3	2
14	25	3	16	25	0	13	16	24	19	23	8	16
15	77	76	77	56	69	63	84	76	81	75	74	74
16 E	59	36	49	75	81	78	47	47	47	59	50	55
L	41	42	42	19	38	28	37	41	39	35	41	38
N	34	30	32	25	38	31	26	18	22	30	29	30
ALL	30	27	29	19	38	28	26	18	22	27	27	27
17 L	69	39	52	63	56	59	53	29	42	59	41	51
N	39	21	31	56	38	47	21	24	22	38	26	32
E	43	27	36	69	50	59	37	12	25	47	29	39
18	89	85	87	94	69	81	79	82	81	87	80	84
19	9	15	11	25	6	16	5	0	3	11	9	10
20	41	30	36	50	31	41	32	53	42	41	36	39
	14	9	12	0	0	0	11	0	6	10	5	8
	73	64	69	81	56	69	58	59	58	71	61	66
21	57	70	62	50	75	63	42	53	47	52	67	59
22	16	15	16	25	6	16	11	24	17	16	15	16
	57	42	51	44	38	41	37	41	39	49	41	46
	18	33	25	25	44	34	11	18	14	18	32	24

2.11 SUMMARY OF RESULTS OF QUESTIONNAIRE ABOUT ELECTRICITY - PRIMARY 7

Inspection of the tables of results together with the pupils' scripts revealed the following points:-

1. The overall performance in the questionnaire in all three schools was similar.
2. The overall performance of the boys was better than that of the girls.
3. The same items presented difficulty in all three schools.
4. Terms like voltage, current, power are used fairly loosely, which could present difficulty when trying to explain electric circuits in S.1.
5. There is a tendency to mix up terms like voltage and current and the volt and the amp.
6. There has been little need up to this stage to identify the voltages of various supplies. They are therefore not well known.
7. Pupils tend to accept wrong statements about electricity.
8. There is a lack of understanding of the principles of common simple electrical apparatus.
9. There is little evidence to suggest that the Integrated Science Course Section 7 would be irrelevant for this group of pupils.
10. There was evidence that perhaps more observations should be made and practice given than is built into Integrated Science Course Section 7.

2.12 DISCUSSION OF RESULTS OF QUESTIONNAIRE ABOUT ELECTRICITY - PRIMARY 7

The pupils responses to the questionnaire are given below. The most appropriate way of indicating the pupils' success or failure is selected.

1. Where would you use these batteries?

Three batteries were used;

(A) a single cell type U2 or equivalent,

(B) a PP9 battery,

(C) a car battery.

Very little trouble was found in identifying suitable uses for the type U2 battery. Tape recorders, electronic games and torches were among the favourites.

Only 27% correctly associated the PP9 battery with radios or similar electronic apparatus. Many wanted to use it in large torches.

Pupils in school 1 appeared to do best in this item.

Almost everyone correctly identified the car battery.

2. What voltage do we get from these supplies?

The batteries used in question 1 were presented in sequence.

Only 9% correctly identified the voltage of the U2 battery as 1.5 V ; 10% correctly identified the voltage of the PP9 battery as 9 V and only 5% correctly identified the voltage of the car battery as 12 V.

10% correctly identified the voltage of the 13 A mains socket. Answers in the range 200 to 250 V were taken as correct.

It is interesting to note that many pupils attributed quite a high voltage to the batteries. The U2 cell was given anything from about 20 V up to about 200 V. In addition the values attributed to the batteries went up with their physical size, so that some pupils suggested that the car battery gave out over 1000 V. Most pupils were quite surprised to discover that its voltage was only 12 V. Conversely the voltage attributed to the 13 A socket was on the whole remarkably low. Typical values lay in the region 15 to 50 V.

This is a little surprising given that "safety" and hence low voltage is usually attributed to batteries while "danger" and hence high voltage is usually attributed to the mains electricity. However on reflection, we have to recognise that voltage seldom has to be specified when buying a battery or domestic appliance.

3. Draw the wires to join the battery to the bulb to make it light up.

Only 8 pupils altogether failed to answer this item successfully. Most pupils made the most obvious connections.

4. Draw the wires to join the battery to the bulbs so that they are connected like lights on a Christmas tree.

Only 2 pupils succeeded in answering this item correctly. Most pupils connected the bulbs in parallel.

It may be that the relative positions of the battery and the two bulbs forced the pupils into this line of thought.

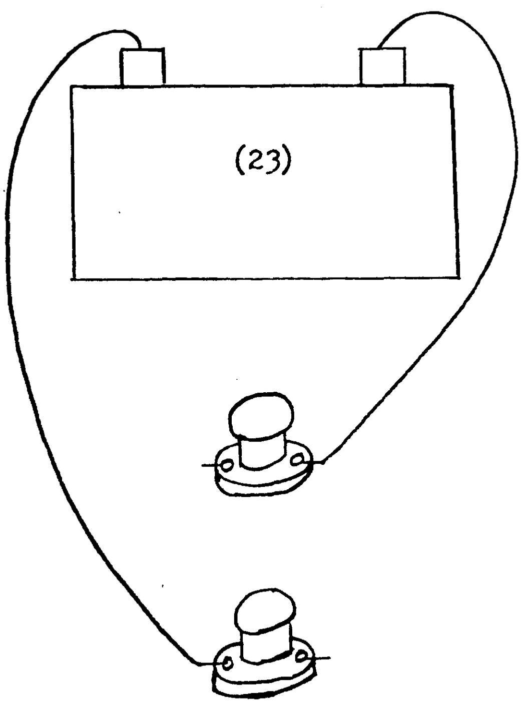
5. Can we switch off each bulb on its own ?

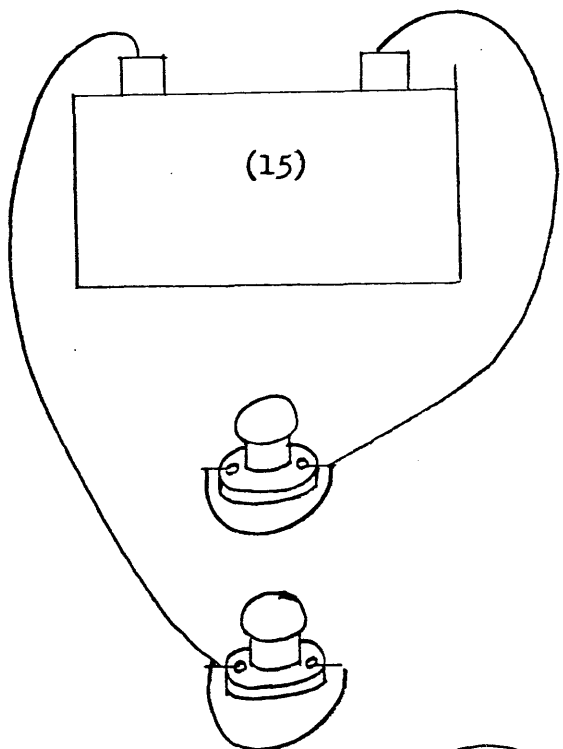
This item was related to the previous one. 42% answered it correctly. Some may have given the wrong response because of the diagram they had drawn in item 4. However no attempt was made to allow for this.

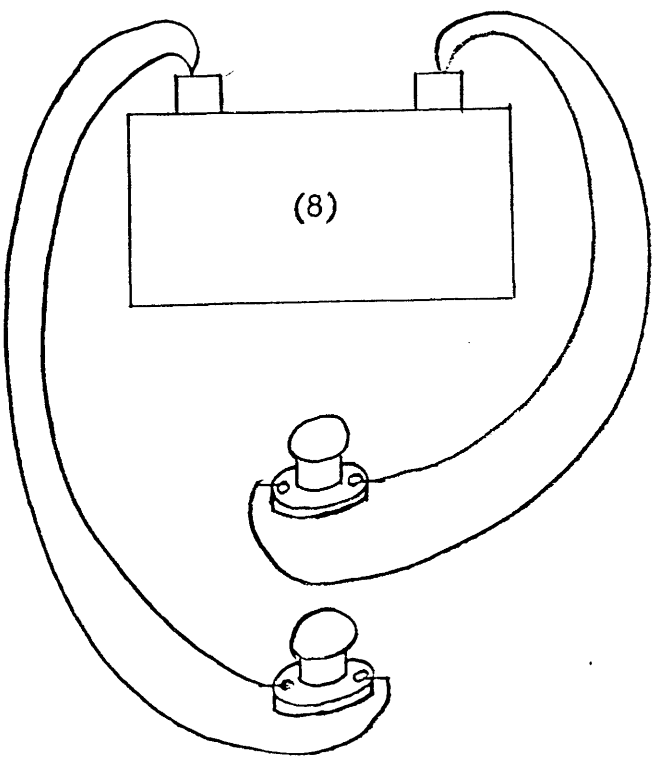
6. | Draw the wires to join the battery to the bulbs so that they can be switched off separately.

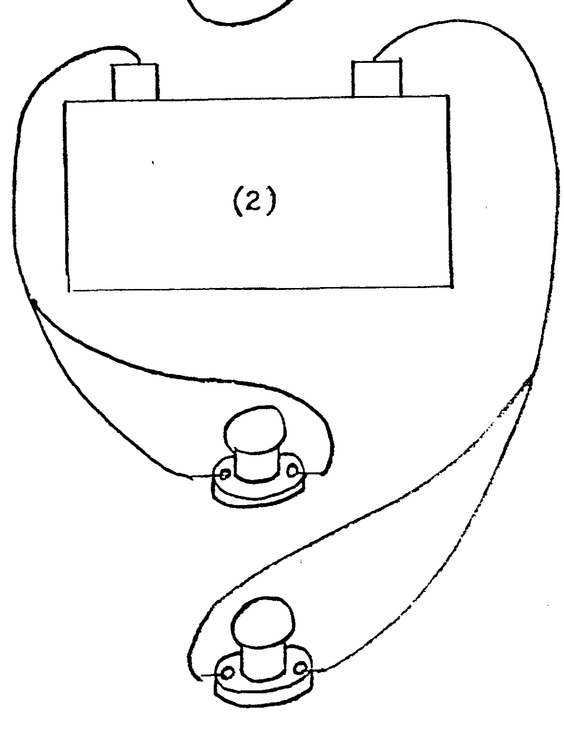
56% answered this correctly. The boys appeared to do better here with 67% of the boys being correct campared with 47% of the girls.

Some interesting diagrams were produced, some of which are shown below:-









7. Draw the wires to join up the battery, switch and bulb.

Only 9 pupils were successful in this item, 7 boys and 2 girls.

Most pupils made a parallel connection so that the switch was connected across the battery and the lamp.

8. Read the list;

key, rubber, paper clip, wool, wood, plastic, coin, paper.

Write down the set of things which will pass electricity.

42% answered this item correctly. Some pupils would give the three conductors and then add one or more insulators. Others would omit one or other of the conductors.

9. What is the special name we give to things which pass electricity ?

19% gave a correct response to thic item.

23% of the boys were successful but only 15% of the girls.

Most pupils indicated that they did not know the answer and a few gave wrong answers, some predictable like "metals".

10. What do we mean by " 13 amp socket " ?

It was hoped that the response to this item would include the ideas that the socket could provide a <u>current</u> of <u>up to</u> 13 amps.

12% gave an answer along these lines.

This item showed the beginnings of the confusion between current and voltage and amps and volts.

A number of pupils thought it would "give out 13 volts".

Others thought it had a 13 amp fuse in it - perhaps not too unreasonable.

12. If we have a T.V. which needs 1 amp and an electric fire which needs 4 amps plugged into an adapter. How many amps pass through the adaptor ?

79% were successful in this item. Most pupils made the obvious sum to come up with the correct response. However some pupils came up with figures which bore no relationship to the original numbers.

13. If the T.V. needs 250 volts and the electric fire needs 250 volts how many volts must the adaptor supply ?

Once again the pupils made the obvious addition and came up with the wrong answer. Only one boy and two girls gave the correct response.
Clearly the pupils had forgotten that the adaptor or the individual appliances could equally be plugged into a socket. There was no real concept of voltage in this context.

14. What is the voltage needed for a model railway ?

This item might be expected to favour the boys which it did. 23% of the boys were successful and only 8% of the girls. 16% of the whole group were therefore successful.
Many pupils offered remarkably high values; much higher than they estimated in the next question might be lethal !!

15. Put a ring round the lowest voltage that could kill.
3 volts; 12 volts; 50 volts; 100 volts; 250 volts.

Since the actual value may depend on circumstances either 50 volts or 100 volts was accepted.
On this basis 74% were correct, boys and girls being equally successful.

16. Write down the colours of the wires to go on the pins of the 13 amp plug.

55% correctly identified the colour of the earth wire (59% of the boys and 50% of the girls).

27% would have wired up the plug correctly, and in this the boys and girls were equally successful.

17. What are the full names of the three pins?

The "live" pin was correctly identified by 51% of the pupils. The neutral pin presented more of a problem was only identified by 32%. Some pupils called it "negative" but most did not attempt to answer. The"earth" pin was identified by 39%. In each case the boys performed better than the girls.

18. What is this device ?

84% correctly identified the fuse.

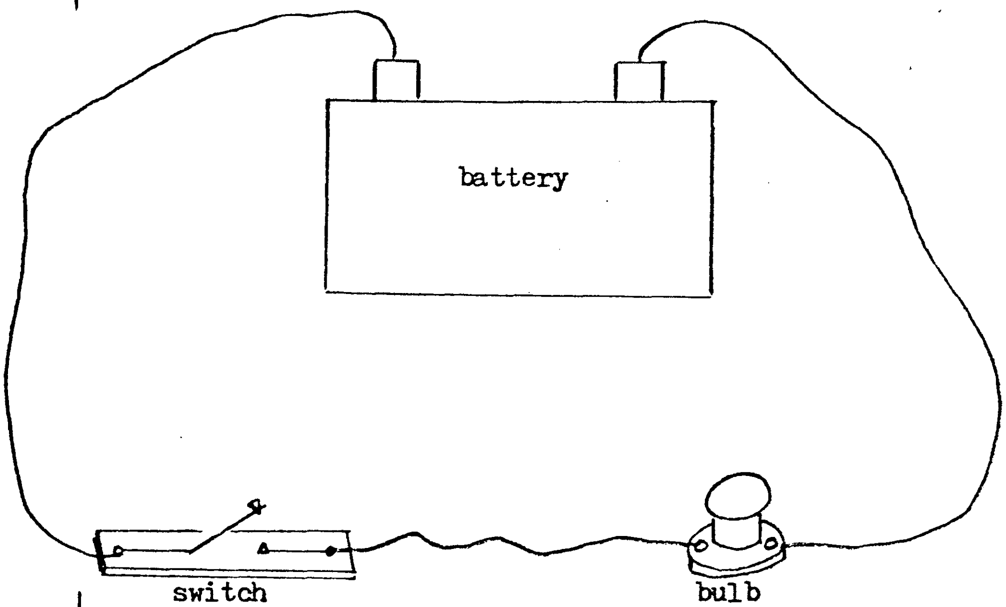
19. What does it do ?

The function of a fuse presented a problem. Only 10% recognised that it gave protection and would "blow" if necessary to give it.

A substantial number thought of it as"giving power" like a little battery.

Others described it as being needed to" make the plug work".

20. In this simple circuit



What does the battery do to the electricity ?

39% gave an acceptable account of this. A few considered it to be a store of electricity, others saw it as giving power or energy to the electricity.

What does the bulb do to the electricity ?

8% saw the bulb as an energy converter . Most responses did not answer the question.

What does the switch do to the electricity ?

66% were successful with this and recognised its on-off control function. The boys were better than the girls in explaining this.

21. Energy is given out. Where does it come from ?

59% overall were successful here. In this case the girls were better than the boys. In spite of being told to focus on the circuit shown in Q.20 a number of pupils wanted to mention the sun or pylons as being the source of energy.

22. The sentences below might appear in a newspaper or book.

Write "true" in the box beside the sentence if the words used look reasonable.

Write "false" in the box beside the sentence if the words used do not look reasonable.

"A voltage of 30 000 volts passed through the man and killed him."

16% recognised this statement to be false.

Boys and girls performed equally in this.

"Acurrent of 4 amps is passed through a headlamp on a car"..

46% recognised this statement to be true.

The boys performed better here.

"There is electricity in the wires of an electric circuit before the battery is connected to it."

24% recognised this statement to be true. The girls gave the better performance here.

When they were told the correct answer after the test, most pupils were openly surprised.

CHAPTER THREE

3 DIFFICULTIES AND SOLUTIONS

3.1 PROBLEMS WITH E.M.F., POTENTIAL DIFFERENCE AND VOLTAGE.

The investigations which have been carried out have confirmed Mughol's conclusion[23] that the concept of resistance presents difficulty to many secondary school pupils. However it has become clear that the concept of potential difference presents even more difficulty and probably is the cause of much of the difficulty with the concept of resistance.

The difficulty with the concept of potential difference was observed at all the levels investigated. In the primary school its use was vague and "voltage", the term used at this stage, was interchanged with current, and the volt with the ampere quite happily. In S.1 and S.2 difficulty was still found, though more pupils made an attempt to explain voltage than made an attempt to explain resistance. In S.4 the pupils were asked to discuss potential difference. Very few thought of it in energy terms although they recognised that the volt is a joule per coulomb. One must assume, therefore, that the term potential difference in itself provides no prompt to think in energy terms and there is a lack of facility in jumping from a unit and its derivatives to a discussion of the concept. Pupils in S.5 performed a little better but many were still unable to discuss potential difference adequately.

In recent interviews of aspiring students for post-graduate training as physics teachers a lack of ability to discuss potential difference was found. Most after reflection could define the volt but many could not go on to discuss potential difference.

The term voltage tends to be used by many pupils and was offered as an explanation for potential difference.

Page (1977)[(2)] considering probably a more advanced level, discusses the use of the terms electromotive force, potential difference and voltage. "The three terms," he states, " are often used interchangeably. Some text books warn about the distiction, but many engineers treat them as synonyms. One reputable technical dictionary deprecates the use of electromotive force, whereas another considers two of the terms synonymous."

There was a tendency in the original version of the revised Scottish Integrated Science Course to refer to voltage as a "push". However if teachers are asked to assign the appropriate unit to "a push" they tend to give the newton, i.e. the unit of force. However potential difference or voltage is not a force as we understand it in the mechanical sense. More recently voltage has been referred to as "an electrical pressure" in teachers' material. This will be shown later to be a more appropriate term. A number of S.4 and S.5 pupils appeared to think of potential difference in force terms as well, possibly falling back on the ideas established early in their learning process.

Derek Carter H.M.I. pointed out in a short discusion paper[(24)] titled "Energy, e.m.f. and potential difference", that we do not exploit sufficiently the work done on exchange of energy in the Scottish Integrated Science Course when we teach topics in the Ordinary and Higher Grade courses later on. He emphasises that more needs to be done to teach e.m.f. and potential difference in energy terms. He also suggests that the term electromotive force should not be used but only its symbolic form "e.m.f.".

In his paper he draws a distinction between potential difference and e.m.f. on the basis of the direction of energy change. "If between any two points in a circuit it is possible to convert from electrical energy into any other form of energy then a potential difference is said to exist between thetwo points, e.g. with electrical into heat in an electric fire, with electrical into mechanical in a loudspeaker or motor. We talk about the potential difference across a loudspeaker, electric fire or electric motor.

"On the other hand, if between any two points in a circuit it is possible to convert from any form of energy into electrical energy, then an e.m.f. is said to exist between the two points,

e.g. heat into electrical in a thermocouple

light into electrical in a photocell

mechanical into electrical in a microphone or dynamo.

We talk about the e.m.f. of a thermocouple, a photocell, a microphone and a dynamo."

These distinctions are however quite subtle and would probably confuse the issue for many pupils.

In a sense agreeing with Carter's distinctions between e.m.f. and potential difference, Page[(2)] says, "The word 'force' is often used in physics in a more general sense than that in classical mechanics, by relating 'force' to energy changes, e.g., exchange forces in quantum mechanics. The mechanical force on a charge in an electric field is qE, but the charge may have work done on it by nonmechanical 'forces', such as chemical or thermal electromotive 'forces'. Defining electromotive force in terms of mechanical force alone is one major source of confusion. For example, Page(25) says 'The electromotive force e.m.f. in a circuit is the work done by the electric field in the transport of a unit charge all the way round the circuit. Therefore the electromotive force is the line integral

$$\text{Emf} = \int_C E \cdot d\lambda$$

taken around the closed curve formed by the circuit.'

In a static field, this line integral vanishes; in a passive network this is the essence of Kirchhoff's voltage law. If however an ideal battery is connected to a resistor, the work done on the charge inside the battery is equal to the work done by the charge passing through the electric field in the resistor; in this case, the e.m.f. is given by the integral along the external path, not the closed path including the battery. The external integral gives the voltage drop in the load; the 'voltage rise' or e.m.f. in the cell is not due to an electric field, but to a change in chemical potential, i.e. a generalised force."

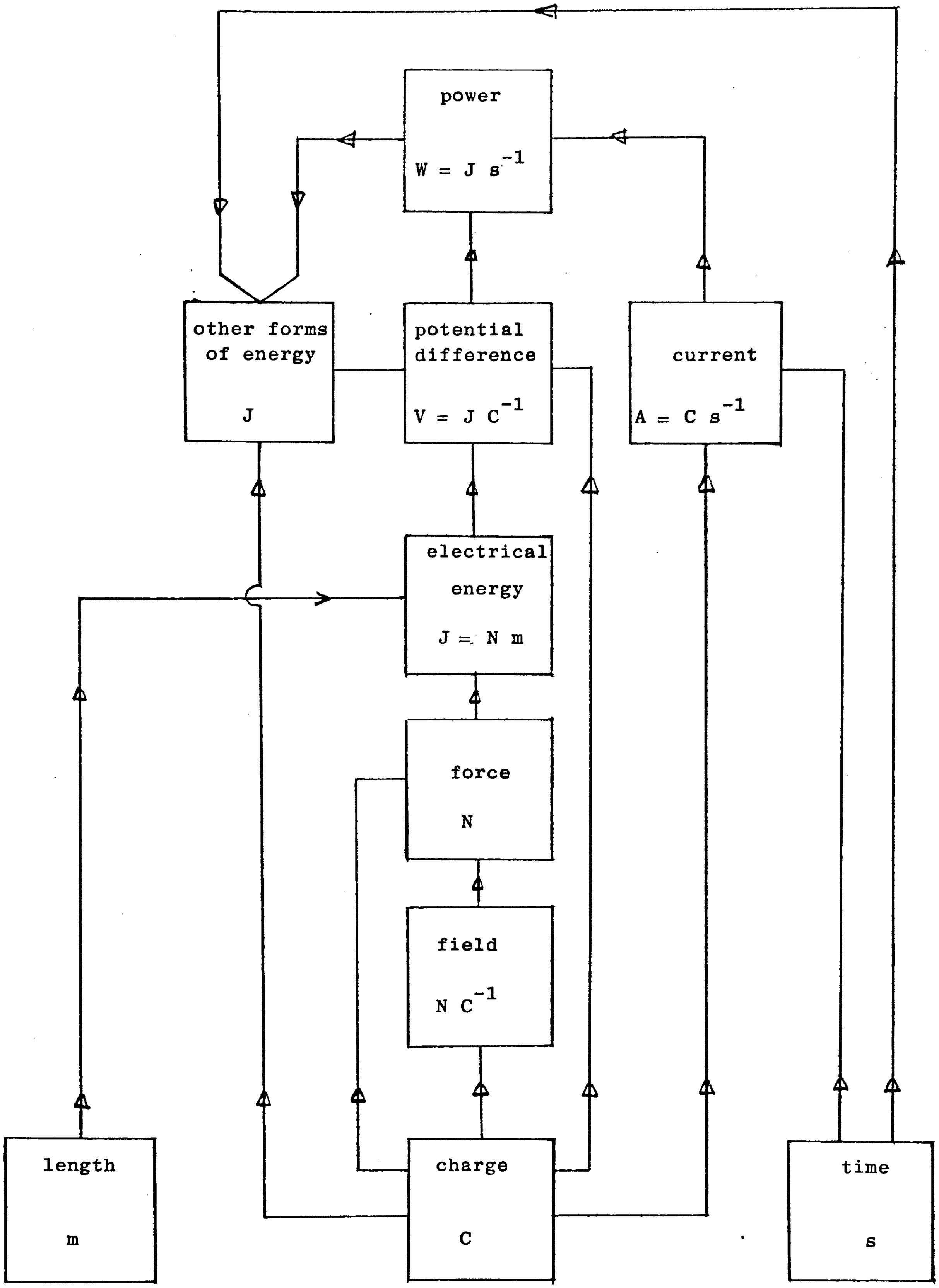
Obviously some of this discussion could be considered to be beyond the scope of even Higher Grade physics. However we must take it into account in evolving a teaching strategy for the various stages.

The basic problem appears to be in separating cause and effect. An electromotive force is required to cause the movement of charges but this "force" is measured in terms of energy. This energy is sometimes said to provide the necessary force but unless the force already existed the energy could not. The difficulty is probably compounded by the fact that the definition for potential difference is essentially based on electrostatics, a topic not too well understood at the best of times, and on essentially mechanical ideas. In practice, potential difference is used in the context of batteries and resistors and is discussed more on the basis of symbols and units with improper understanding of the mechanism of currents and energy transfer. The problem is further aggravated by the order of presentation based on S.I. units which means that we start with current and its unit the ampere and then define the unit of charge, the coulomb. The fundamental quantity is of course, charge, from which we can logically build up a picture of what is happening and also a logical set of units and symbols.

3.2 STEPS TO POTENTIAL DIFFERENCE

We can illustrate in figure 3.1 the relationship between the physical quantities length, charge, and time and the quantities we can derive from them. Alongside the quantities have been written their S.I. unit.

In this discussion charge is taken as the basic quantity.



Relationship between electrical quantities and their units

Figure 3.1

The electron for example, possesses mass and charge. A larger object in the macroscopic context, can also be considered to possess mass and charge. The unit of charge is the coulomb (C) .

Surrounding the charge there is a region in which it can exert a force on another charge. This region is the field of the charge. To use modern parlance we might use the term "force field" which is more descriptive, and which "Star Wars" has made part of the vocabulary of many pupils. The magnitude of the "force field" is measured by the force it would exert on a charge of 1 coulomb placed in it. The logical unit is therefore the newton per coulomb ($N\ C^{-1}$). We are therefore in general measuring the force per unit charge. This unit is rather more descriptive than the normal unit used, the volt per metre, although the latter has its uses later.

Obviously, the actual force exerted on one charge by the other is measured in newtons (N).

When work is done on an electric charge placed in the field of another charge, energy can be stored. The work done is measured in newton metres (N m) and the energy stored is measured in joules (J). The work done is equal to the energy stored.

The energy stored, measured with respect to a zero point is called the called the potential of a point. The position for zero energy in electrostatics is usually taken as being at an infinite distance from a charge. The stored energy is measured as the energy could be given to one coulomb of charge and the unit is therefore the joule per coulomb ($J\ C^{-1}$). This unit is of course given its own name, the volt (V). Hence

1 volt = 1 joule per coulomb.

The energy difference per coulomb between two points in the field is called the potential difference and is measured in volts (V). If the external force is removed which gave the charge its potential, the charge can move and the energy be transformed into other forms, for example heat or kinetic energy.

If we measure the rate at which the energy is released we can measure the power in watts (W).

Alongside this line, we note that the rate at which the charge moves measured in coulombs per second ($C\ s^{-1}$) gives us the current. To this also is assigned the name ampere (A).

1 ampere = 1 coulomb per second.

We shall note for the present that the product of the potential difference and current also gives the power dissipated. However it is more appropriate to consider this in depth later.

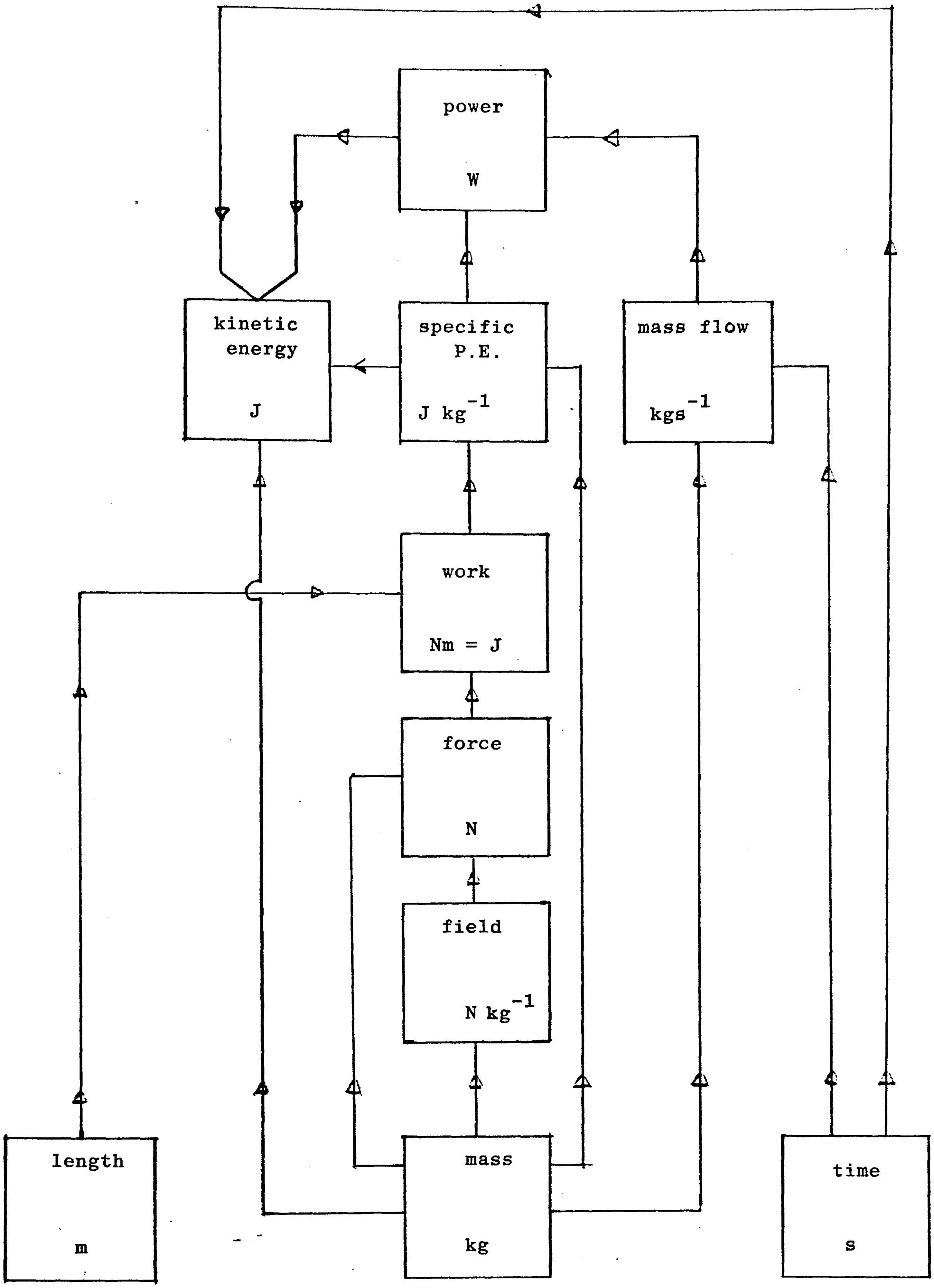
3.3 ANALOGIES BETWEEN ELECTRICAL AND GRAVITATIONAL POTENTIAL.

In figure 3.2 we have a layout identical tothat for the electrical quantities with which we can investigate the quantities length, mass and time and the quantities which are derived from them. Mass is a fundamental property of a body, the size of which we measure in kilograms (kg). Surrounding the body is a "force field" normally referred to as the gravitational field which is measured in newtons per kilogram ($N\ kg^{-1}$). At the surface of the earth the gravitational field strength is "g", 10 $N\ kg^{-1}$.

If another mass is placed in the gravitational field a force acts on it. This force is measured in newtons (N). The force is calculated from the product of the mass with the gravitational field strength. The gravitational force between two masses is an attractive one. If this attractive force is balanced so that one mass is moved away from the other, then work is done. The work is measured in newton metres (N m). The mass stores this work as gravitational potential energy measured in joules (J).

The potential energy stored per kilogram by a mass could be given a a special name specific potential energy . This is more usually referred to as gravitational potential and would have the unit joules per kilogram ($J\ kg^{-1}$).

This is exactly analogous to electrical potential measured in joules per coulomb.



Relationship between mechanical quantities and their units

Fig.3.2

The mass can release its potential energy as kinetic energy measured in joules, and if we measure the rate at which the energy is released then we measure the power in watts.

Analogous to electric current we can identify mass flow which is measured in kilograms per second (kg s^{-1}).

Comparing figures 3.1 and 3.2 we find analogous concepts in each box. Force, energy and power provide clear comparison points where the units are identical. This makes gravitational analogues for electrical phenomena, properly used, very attractive.

3.4 ANALOGIES BETWEEN ELECTRIC AND HYDROSTATIC POTENTIAL.

Setting up a pattern to show the links between the different physical quantities encountered in hydrostatics is a little more difficult than in the electrical and gravitational cases. However figure 3.3 which is one attempt to do this, does show obvious similarities to figures 3.1 and 3.2.

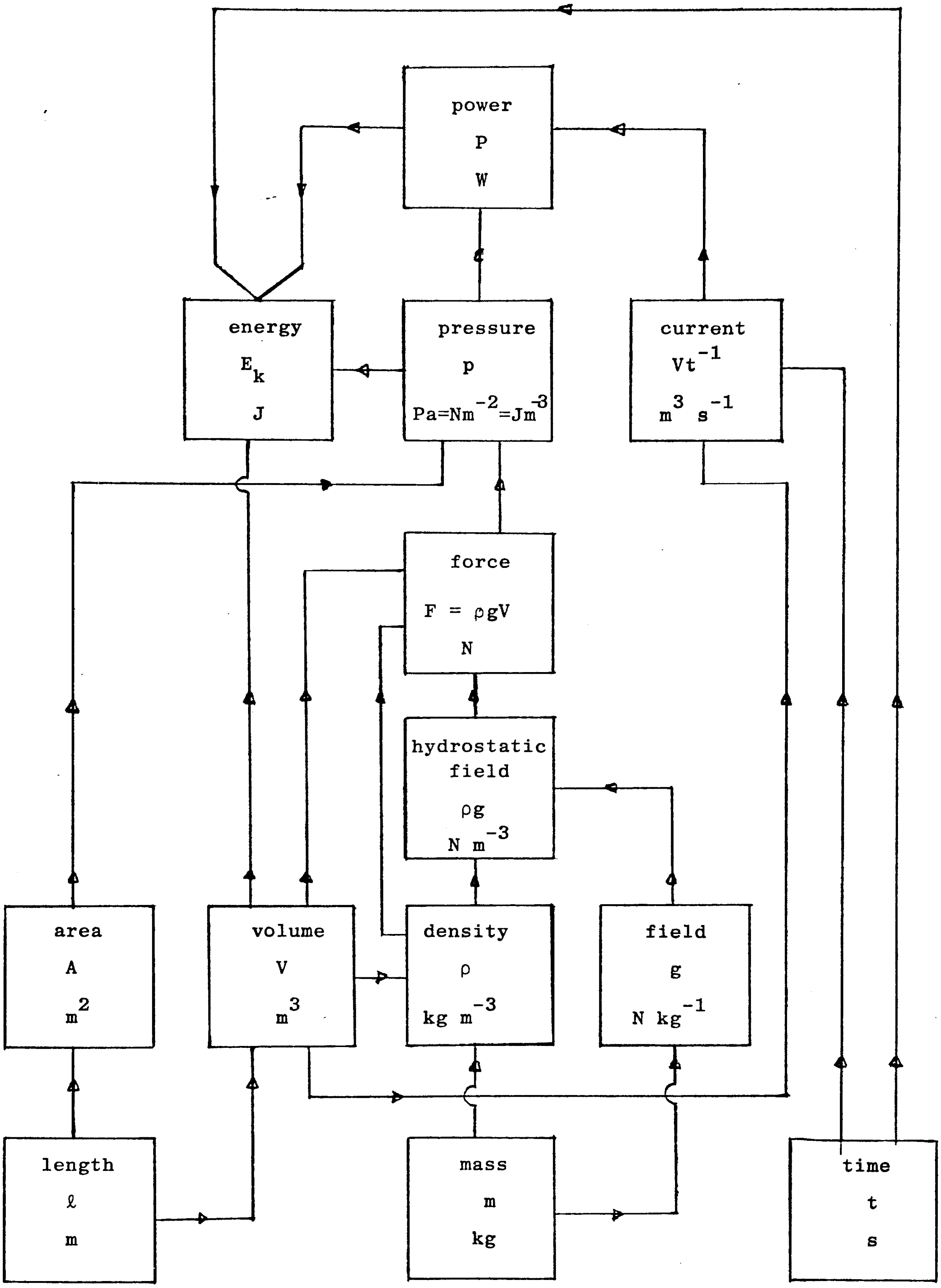
Although we start with the quantities length, mass and time, we have to bring in the additional quantities of area, volume and density to allow us to discuss fluids. In addition, since hydrostatic phenomena are due essentially to the gravitational field, this has to be introduced alongside.

To be consistent with the other two diagrams, we can identify a hydrostatic field which is the force acting on unit volume. This is measured in newtons per cubic metre (N m^{-3}) and is analogous to the electric and gravitational fields.

When the hydrostatic field acts on a volume of liquid then a force is exerted, which of course, is measured in newtons.

In a liquid the force acting can be taken as acting over an area and is called the hydrostatic pressure. This is most obviously measured in newtons per square metre (N m^{-2}), but has the special name pascal (Pa).

The pressure may also be measured in terms of the energy per unit volume, with units, joules per cubic metre, (J m^{-3}) which can easily be seen to



Relationship between hydrostatic quantities and their units

Fig. 3.3

be equivalent to N m^{-2}.

A possible alternative term for pressure is specific energy . Comparing units it is clearly analogous to electrical potential and gravitational potential. This makes pressure a much more acceptable verbal analogue for potential difference or voltage than push.

Finally as with the electrical and gravitational cases we observe analogous links with current, energy and power. This therefore makes a water analogue for electrical phenomena attractive provided it is used with care.

3.5 COMPARISON OF ELECTRICAL, GRAVITATIONAL AND HYDROSTATIC QUANTITIES.

In the previous sections we have shown one way of displaying and explaining the physical quantities associated with electrical, gravitational and hydrostatic phenomena. Since our particular concerns are the concepts of electric potential and potential difference, it would appear to be useful to start with these and operate on them to produce some of the associated physical quantities, and at the same time, perform a similar exercise with the equivalent gravitational and hydrostatic quantities.

The results of this exercise are displayed in table 3.1. We consider the physical quantities potential, field, force, current and power. In each box, where possible, the quantity has been named, its S.I. unit given and the units from which it came.

If we look on gravitational and hydrostatic quantities as possible verbal analogues to explain electrical quantities then we can see very easily from table 3.1 that provided we take specific potential energy and hydrostatic pressure as being analogues for electric potential then a coherent set of statements builds up for the other physical quantities. On theother hand, if for example we took force as an analogue for electric potential, this would not work.

It is interesting to notice how force and power act as

Table 3.1 Comparison of electrical gravitational and hydrostatic quantities

PHYSICAL QUANTITY	ELECTRICAL QUANTITY	GRAVITATIONAL QUANTITY	HYDROSTATIC QUANTITY
potential	electric potential potential difference volt = joule/coulomb	specific potential energy joule/kilogram	pressure pascal = joule/metre^3
field	electric field intensity volt/metre = newton/coulomb	gravitation field strength newton/kilogram	hydrostatic field pascal/metre = newton/metre^3
force	force newton	force newton	force newton
current	electric current ampere = coulomb/second	mass flow kilogram/second	current metre^3/second
power (p.d. x current)	electric power = p.d. x current $\frac{\text{joule}}{\text{coulomb}} \times \frac{\text{coulomb}}{\text{second}}$ = joule/second = watt	power specific P.E. x mass flow $\frac{\text{joule}}{\text{kilogram}} \times \frac{\text{kilogram}}{\text{second}}$ = joule/second = watt	power = pressure x current $\frac{\text{joule}}{\text{metre}^3} \times \frac{\text{metre}^3}{\text{second}}$ = joule/second = watt

linking concepts between the three sets of quantities.

In our teaching we could do a lot more to demonstrate these links and perhaps help some pupils to go from more tangible mechanical concepts to more abstract electrical ones. The S.I. units provide a very elegant way of demonstrating this unity.

3.6 USE OF THE TERMS ELECTROMOTIVE FORCE, POTENTIAL DIFFERENCE AND VOLTAGE.

The continuing use of the term potential difference is usually defended on the basis that it keeps before pupils the idea that we are talking about an energy difference. The results of the questionnaire presented to pupils in S.4 and S.5 would indicate that that is not necessarily the case.

The term electromotive force tends to perpetuate the idea that we are talking about forces when considering batteries and for example induced e.m.f.s.

It would appear therefore, that there could be much to be gained in using the term voltage, suitably described and defined, in teaching and examining the physics course up to the Ordinary Grade. This idea is reinforced by a study of a number of physics text books written for German pupils.

The English word voltage can be translated into the German word Spannung . Spannung can also be translated as tension which clearly has connotations of force, but its normal scientific usage is chiefly electrical, force being translated as Kraft.

The important aspect for us is the German use of compound words which help to describe and qualify and which can be translated into English by analogous short phrases.

The following list could easily be used in teaching electricity for Ordinary Grade:-

German	English (Recommended)	English (Present)
elektrische Spannung	voltage	
Quellenspannung	source voltage	electromotive force
Klemmenspannung	terminal voltage	potential difference
Spannungsabfall	voltage drop	potential difference
Induktionsspannung	induced voltage	induced e.m.f.
effektive Spannung	effective voltage	
Anodenspannung	anode voltage	
Primarspannung	primary voltage	
Sekundarspannung	secondary voltage	

This list could be expanded to cover all the electrical work covered up to Higher Grade and beyond without using either of the terms electromotive force (e.m.f.) or potential difference (p.d.).

An examination of several sources provides us with a number of definitions for potential difference and its unit, the volt. These have one thing in common that they are all studied with reference to the load rather than the source. A selection of these is shown below.

"Pupils should acquire the ability to:

1 recall that the potential difference (p.d.) between two points is a measure of the work that has to be done to move one coulomb of charge from one point to the other.

2 recall that if 1 joule of work has to be done to move 1 coulomb of charge from one point to another the p.d. between the points is 1 volt. "

(Memorandum 31) (4)

"The potential difference (p.d.) between two points is the work done, or energy expended, in transferring unit charge between those points." (Webster) (26)

"If we require 1 joule of energy to transfer 1 coulomb of charge between the plates, we say that there is a potential difference (p.d.) of 1 volt." (Cackett et al) (27)

"The volt is defined as a joule per coulomb." (Jardine) (28)

For pupils who are learning this for the first time, somtimes in the third year and more normally in their fourth year, the format of the definition requires an ability to operate at a fairly high level. If on the other hand, the definition for potential difference were made from the standpoint of the source of energy, the intellectual level at which the pupil must operate may be reduced.

For example, if we change the definition for potential difference to

"potential difference is the energy given by an electrical source to one coulomb of charge"

and if in line with this we then define the volt by

"a potential difference of one volt will give to one coulomb of charge one joule of energy"

we have definitions which are more easily used and which are more direct. We could also without loss of accuracy, give these definitions for potential difference in terms of voltage.

"Voltage is the energy given by an electrical source to one coulomb of charge."

"A voltage of one volt will give to one coulomb of charge one joule of energy."

From these definitions we can build up the relationship between energy, charge and voltage.

A voltage of 1 volt gives 1 coulomb of charge 1 joule of energy

A voltage of 2 volts gives 1 coulomb of charge 2 joules of energy

A voltage of V volts gives 1 coulomb of charge V joules of energy

A voltage of V volts gives 2 coulombs of charge 2 V joules of energy

A voltage of V volts gives Q coulombs of charge Q V joules of energy

= E joules of energy.

Hence energy = charge x voltage

$$E = Q \times V$$

$$V = \frac{E}{Q}$$

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

$$1 \text{ V} = 1 \text{ J C}^{-1}$$

Using this approach we are offering pupils a treatment which should be within their capabilities mathematically. In addition we are placing a label on the physical quantity of voltage which points unambiguously to its unit the volt and the method of measuring it, the voltmeter.

3.7 SEPARATING VOLTAGE, CURRENT AND RESISTANCE.

The following definitions appear in the Oxford Illustrated Dictionary for the volt, ampere and ohm:-

volt - unit of electromotive force, the electrical pressure that if steadily applied to a conductor whose resistance is one ohm will produce a current of one ampere.

ampere - unit of amount or flow in an electric current, being that produced by one volt acting through a resistance of one ohm.

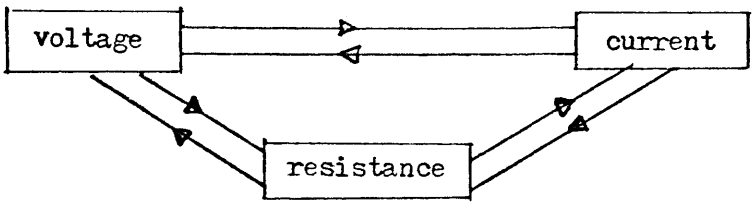
ohm - unit of electrical resistance, resistance of a circuit in which potential difference of one volt produces current of one ampere.

The most obvious difficulty with this set of definitions is the vicious circle in which they move. Secondly there is an almost cavalier jump between electromotive forceand potential difference. However these definitions do reflect the responses which many pupils and more mature students give for the three units.

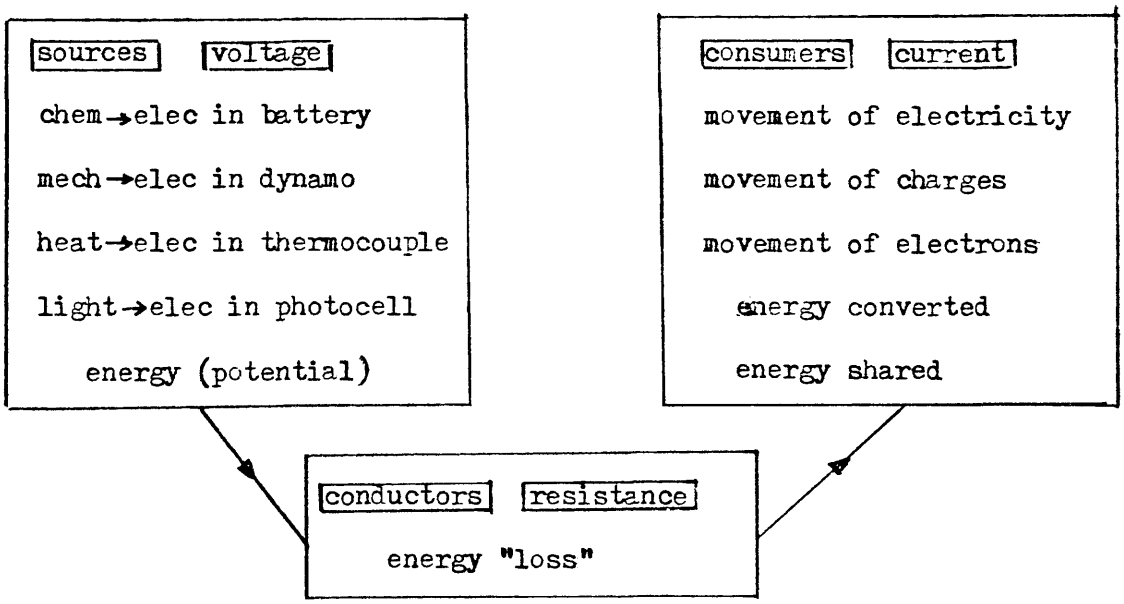
In the previous section, we noted how the popular textbook definitions for potential difference tended to look at what energy had been given to the charge and hence deduce the potential difference. In more practical terms it tended to look at the load and deduce the potential difference of the source.

This link between load and source tends to be perpetuated in pupils' minds and for this reason they tend to find it difficult to look at each concept in isolation.

Using voltage in preference to potential difference, we can represent the links formed by the pupils as



To separate these concepts we must try as far as possible to identify experiments and examples which can relate to and define each one on its own. One way of doing this is to separate sources and consumers. If we try to identify what is happening in different voltage sources to the electric charges on one hand, and then identify what happens to them in the consumers or loads on the other, then we could go some way to eliminate problems on electrical circuits later.



Characteristics of sources, consumers and conductors.

Fig.3.4

Some of the easily identifiable characteristics of electrical sources, consumers and conductors are shown in figure 3.4.

Focusing first of all on electrical sources, the important feature is the voltage which exists between its terminals. This voltage measures the potential energy available in electrical form. The voltage is due to an energy change taking place for example from chemical energy to electrical energy in a battery and from mechanical energy to electrical energy in a dynamo. The energy of an electrical source can be considered to be a fuel. It is important to note that the source cannot give out its energy until a consumer is attached to it. No electric current exists in the source until a consumer is attached to it. The size of the electric current depends on the consumer.

Focusing now on the electrical consumers, we note that if they are not connected to an electrical source nothing happens. When they are connected,,the obvious characteristic is the current which exists in the consumer. This current carries the energy from the source and changes it from electrical energy into some other form for example mechanical energy in an electric motor and heat energy in a lamp. Electrical consumers are therefore really energy converters.

The rate at which energy is required by the consumer is matched by the rate at which it is given out by the source. This is achieved by varying the current through the source and consumer. The source supplies the current demanded by the consumer (within its capabilities).

Many pupils tend to see the voltage and current in a source as fixed quantities and therefore make mistakes when presented with a problem where the load and hence the current demand changes.

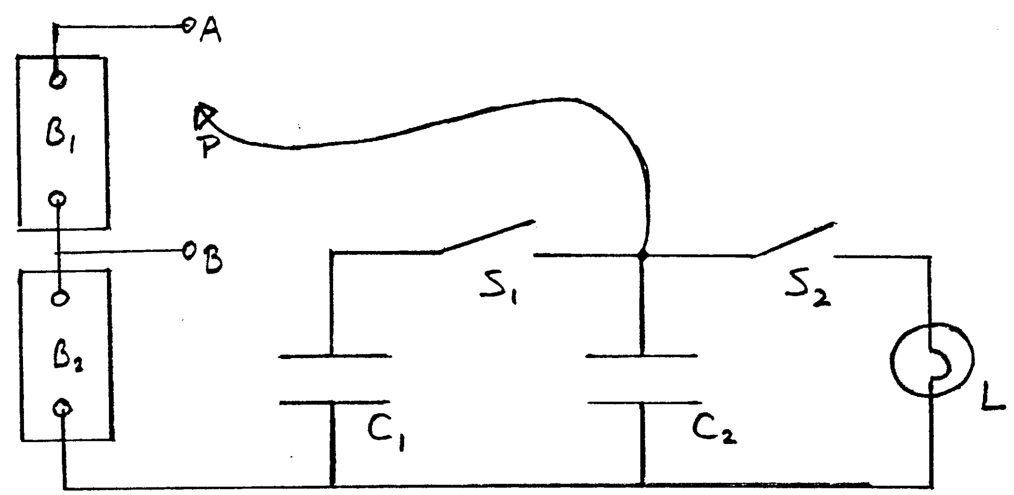
Focusing finally on the electrical conductors which are necessary to join the sources and consumers, we find that the characteristic property of these is resistance. A perfect conductor passes electricity without any opposition. No energy is therefore required to pass it.

However in practice all conductors present some opposition to the movement of electricity, some more than others. In electrical terms the energy required to allow the electricity to pass is observed as a voltage or voltage drop across the conductor. When we finally come to measure the opposition or resistance we have to do it in terms of voltage and current. This is when we can find the vicious circle we noted at the beginning of this section.

To separate voltage, current and resistance successfully we require experiments which demonstrate their characteristics as simply as possible. Very often suitable experiments come from their defining equations.

(a) Giving a "feel" for the volt as one joule per coulomb

The following demonstration is slightly dishonest insofar that it does not strictly speaking use one coulomb but it does use a unit charge. The circuit diagram is shown in figure 3.5.



Demonstration of "joule per coulomb"

fig. 3.5

In the diagram two 6V nife batteries B_1 and B_2 or equivalent are connected in series. A is therefore at 12 V with respect to G and B is at 6 V.

C_1 and C_2 are equal capacitors of value 10 000 uF. They are joined in parallel by the switch S_1 which allows either C_2 only to be used or C_1

and C_2 together. The terminal P on the flying lead attached to C_2 is used to charge up the capacitors to 12 V or 6 V by touching A or B. The switch S_2 is a normally open push switch which discharges the capacitors through the lamp L which is rated at 6 V and 6 W.
In use, either the single capacitor C_2 is charged to 12 V or the two capacitors $C_1 + C_2$ are charged to 6 V. This has the effect of giving the same charge at two different voltages for investigation.

The demonstration is given in two stages. With S_1 closed the capacitors are charged to 6 V. Our "coulomb" has therefore been given 6 joules of energy. With the capacitors disconnected from the battery they are discharged through the lamp by closing the switch S_2. The lamp is observed to give out a flash of light. The experiment is repeated several times to show that the flash has the same brightness and duration each time.

With S_1 open, capacitor C_2 is then charged to 12 V. Our "coulomb" has now b en given 12 joules of energy. Once again, with the capacitor disconnected from the battery it is discharged through the lamp. On this occasion a brighter flash of light is observed but of shorter duration. The "coulomb" has delivered more energy to the lamp but has passed through it more quickly. This experiment is then repeated to show the nature of the flash under these conditions remains constant.

This demonstration has been well received by post school students as part of a concept course. It shows effectively how an electrical source gives out energy to a consumer. It shows the effect of the same charge being given different amounts of energy and it shows how the rate at which the charge moves i.e. the current depends on the voltage.

(b) A gravitational analogue for voltage.

Jeffrey (1979) (7) describes a mechanical analogue which can be used to illustrate a number of effects observed with electricity and in particular provides an effective gravitational analogue for voltage. The description which follows is paraphrased from this article.
The apparatus consists of an array of polystyrene spheres mounted on the ends of small expendable springs which are in turn mounted on a board at the positions shown in figure 3.6. The polystyrene spheres represent the atoms in a conductor and a large ball bearing is used to represent an electron or charged particle, depending on the stage the pupils have reached.

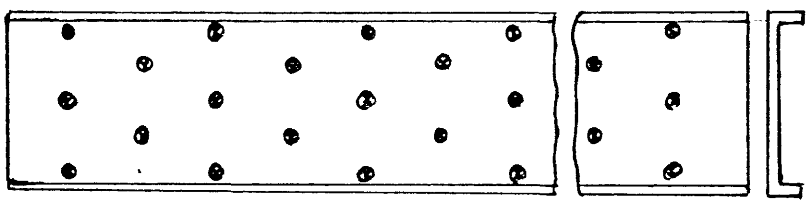


Fig. 3.6

A possible approach to the concept of voltage is to place a length of nichrome wire alongside the board and connect it to a power pack. When the power pack is switched on the wire will become hot. We may then ask how might the hot wire be simulated by using the model? By referring back to the sections on the particulate nature of matter and how we make heat flow, pupils should be able to state that the polystyrene spheres should be vibrating. This can easily be demonstrated by shaking the board.
We may then ask whether a charged particle (the ball bearing) can be used to produce the same effect.
Rolling the ball in at one end results in a few spheres vibrating and the ball quickly coming to rest. Hopefully pupils will now suggest raising one end of the board. If this is done, the ball will travel down the board in a random fashion, leaving behind an array of vibrating spheres. If additional ball bearings are allowed to 'flow' through the 'conductor' it will remain 'hot'.

The model can be used to perform experiments analogous to those described in (a) above. And in fact the most effective use of the two demonstrations is when one compliments the other.

For example, when one end of the board is raised by 9 cm the time taken for the ball to reach the end of the board lies between 11.5 and 14.5 seconds. Doubling the height and hence the energy supplied results in the ball taking between 7 and 8.5 seconds to pass through and produces a greater disturbance. The former case compares with our 6 V 'coulomb' and the latter with the 12 V 'coulomb'.

As we discussed in section 3.3 we can readily make comparisons between electrical and gravitational phenomena. Here we have a clear example of this.

In addition to the comparison described above, depending on the ability of the pupils some or all of the following points can be made:

1 (a) The ball will only travel from one end of the board to the other if it is given potential energy. This is achieved by raising one end of the board. The potential energy lost by the ball as it travels along is converted to kinetic energy of the polystyrene spheres.

(b) Charge will only flow throgh a conductor if a voltage exists between its ends. This voltage can be supplied by a cell or power pack. The energy lost by the charged particles passing through the nichrome wire appears as heat energy.

2 (a) In order to move along the board each ball bearing is given a certain number of joules of potential energy.

(b) The power pack must provide the charged particles with a certain number of joules of energy. The number of joules given to each coulomb can be used as a measure of the voltage, hence the idea of voltage in terms of joules/coulomb.

3 (a) As the ball bearing travels along the board there is a steady

3 (a) As the ball bearing travels along the board there is a steady reduction in its potential energy which is coverted into 'heat'.

(b) Along a uniform conductor there is a steady drop in voltage (the energy possessed by each coulomb).

4 (a) The ball experiences difficulty in travelling along the board as it collides with the spheres, i.e. its motion is resisted.

(b) Charge flowing through a conductor experiences resistance to its motion.

5 (a) Although the ball moves relatively quickly between collisions its average speed along the board is low.

(b) The drift velocity of electrons is smaller than the velocity between collisions.

The analogue described has met with some success when used with pupils ranging from second year to fourth year in Scottish schools.

(c) Giving a "feel" for the coulomb, the ampere and the watt.

It may appear strange to place the units of charge, current and power together in one section, but the same technique and apparatus can be used in each case.

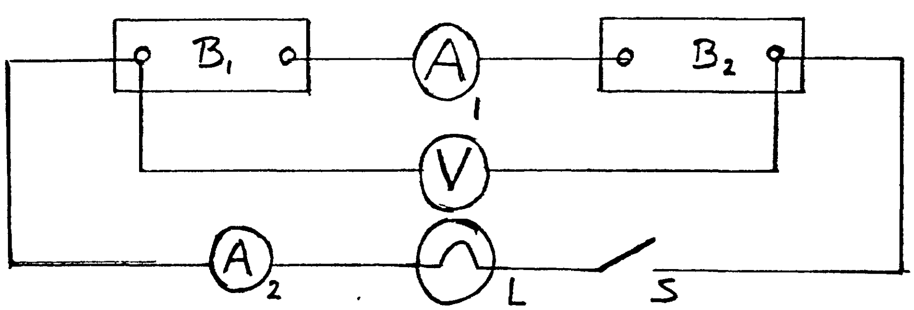


Fig.3.7

The circuit is shown in figure 3.7. B_1 and B_2 are two 6 V nife batteries. An ammeter A_1 is placed between them to measure the source current and the voltmeter V is connected as shown to measure the terminal voltage, nominally 12 V. The lamp L is rated at 12 V, 24 W and the ammeter A_2 is placed to measure the load current.

With the switch S open, it is important to demonstrate that although the terminal voltage is 12 V there is no current passing through the batteries. With S closed the readings on the two ammeters is the same, i.e. the source current is equal to the load current.

The reading on the ammeters is 2 A. With the aid of a stopclock the number of coulombs which pass every second can be called out, e.g. 2, 4, 6, 8, etc. This gives the pupils a "feel" for the rate at which they pass and the total number which have passed. Hence we embrace the ampere within this demonstration.

At the same time the lamp is giving out 24 J every second and again it helps the concept of power to call out the number of joules dissipated every second, e.g. 24, 48, 72, etc.

This technique can be compared with methods of measuring flow rates in liquids by counting the number of buckets filled in a certain time.

(d) Introducing "resistance".

Difficulties with the concept of resistance probably stem from the fact that it is usually defined by the ratio V/I in an experiment to rediscover Ohm's Law. Strictly speaking such a definition tells us how to measure resistance but does not necessarily give us a feel for the property itself. In addition we tend very quickly to refer to resistors when in fact we should be talking initially about conductors.

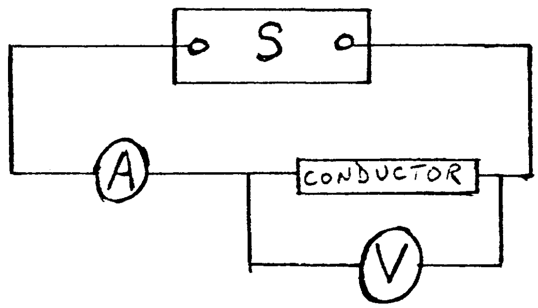
In teaching this part of the work we should therefore start from the standpoint of the perfect conductor and then investigate a set of conductors attached to a constant voltage source to find which is the best by placing an ammeter in series with each one. The conductor passing the lowest current is presenting the greatest opposition and hence may be said to have the greatest resistance . Having completed this sequence we are then ready to investigate the relationship between voltage across a conductor and the current through it.

One problem often observed by the writer in schools with this experiment is that relatively high resistance values are used and the current is therefore measured in milliamperes. It would be better if resistance values of a few ohms were used, capable of dissipating several watts, which would allow measurements to be made in volts and amperes.

The following sequence is offered as being an appropriate approach to the unit of resistance.

1. Investigate the relationship between current in a conductor and the voltage across it.

Fig.3.8



The circuit to be used is shown in figure 3.8. An ammeter is connected in series with the conductor being investigated and a voltmeter connected in parallel with it as shown. The voltage source S can give different voltages as required.

A typical set of results is shown in tables 3.2(a) and 3.2(b). These were obtained from two different conductors.

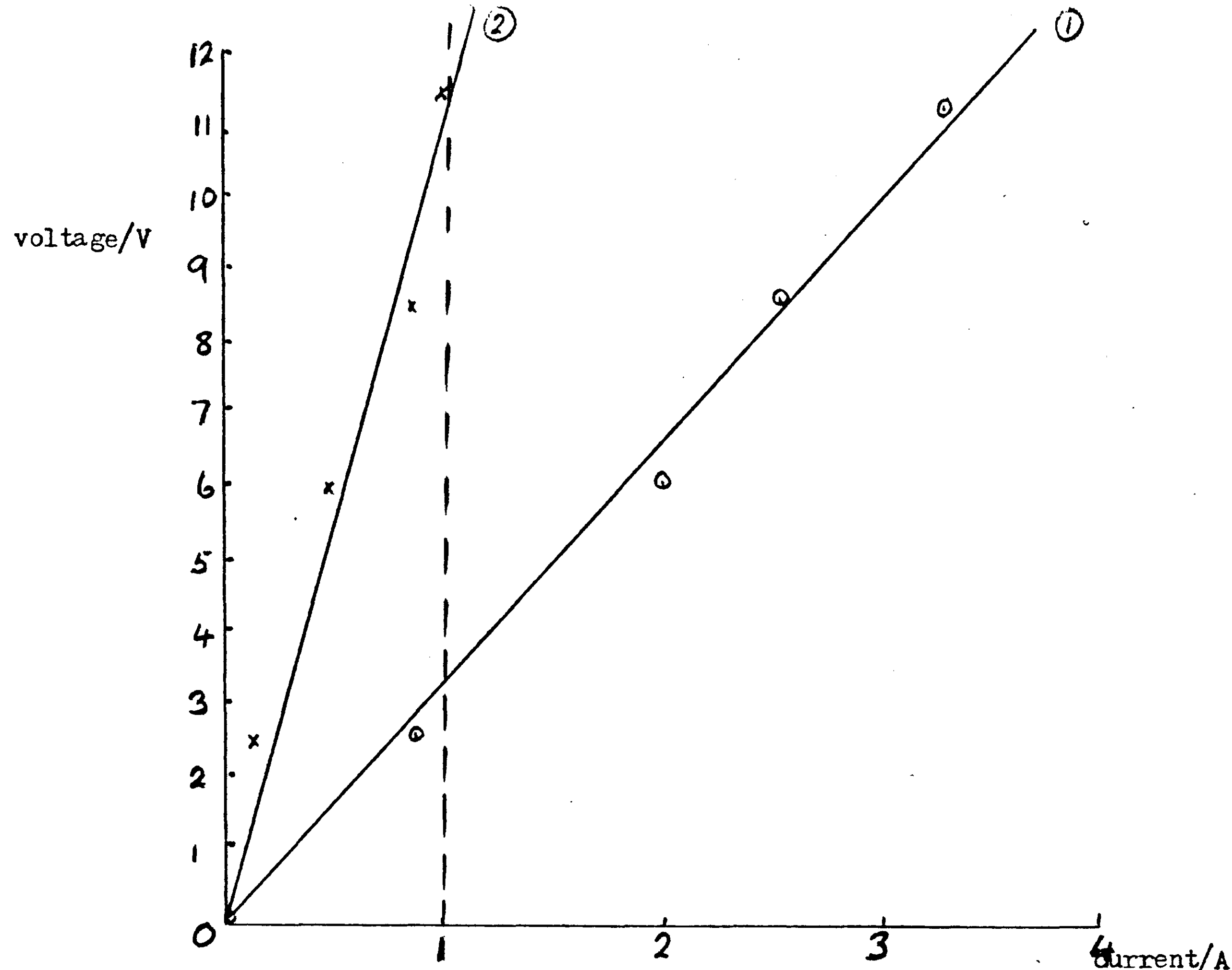
Table 3.2(a) Conductor (1)

voltage/V	current/A
0	0
2.5	0.8
6.0	2.0
8.5	2.6
11.0	3.3

Table 3.2(b) Conductor (2)

voltage/V	current/A
0	0
2.5	0.2
6.0	0.45
8.5	0.8
11.5	1.0

2. We now graph these results as shown in figure 3.9.



Graph of voltage versus current for two conductors

Fig. 3.9

In the experiment we found that conductor (1) passed a larger current for a given voltage than conductor (2). Conductor (1) presents less opposition to the current than conductor (2). Conductor (1) can be said to have less resistance than conductor (2). We notice that the gradient of the graph for conductor (1) is less than the gradient for conductor (2). The gradient can be used to give a measure of the resistance of a conductor.

3. We investigate the implications of the results and formulate Ohm's Law

The graphs obtained are straight lines. This shows that the current in the conductors varies directly as the voltage across them. Many similar experiments have been carried out which are brought together in the statement called Ohm's Law which says:-

"The current in a conductor, held at constant temperature, varies directly as the voltage between its ends."

If the voltage is V and the current is I, we may write

$$V \propto I$$

$$V = \text{a constant} \times I$$

$$\frac{V}{I} = \text{a constant} \qquad \text{---------------(1)}$$

4. We now investigate how Ohm's Law can give a method of measuring resistance.

In trying to place a measure on the resistance of a conductor we try to find the number of volts required to cause a current of one ampere in the conductor.

For conductor (1) 3.2 V cause a current of 1 A. The resistance is therefore 3.2 V A^{-1}.

We give this unit a special name, the "ohm" (Ω).

i.e. 1 V A^{-1} = 1 ohm

The resistance of this conductor is therefore 3.2 ohm or 3.2Ω.

For conductor (2) 11.5 V cause a current of 1 A. The resistance is therefore 11.5 V A^{-1} or 11.5 .

We note that in each case we have measured the gradient of the graph and have therefore measured $\frac{V}{I}$ in equation (1) above.

This equation may therefore be written

$$\frac{V}{I} = R \qquad \text{-----------------(2)}$$

where R is the resistance of the conductor.

The usual form of this equation is

$$V = R\,I$$

where V is the voltage across the conductor in volts ,

I is the current in the conductor in amperes ,

and R is the resistance of the conductor in ohms .

The steps outlined in this section to separate voltage, current and resistance, represent no more than the minimum which should be given if the concepts are to be understood, or alternatively could be considered to be what would be taken as good teaching of the subject.

CHAPTER FOUR

4. RECOMMENDATIONS

In this chapter the recommendations which are offered stem from the observations reported in chapter 2 and from the pedagogical comments made in chapter 3. It would appear to be reasonable to list them for the three main groups of pupils investigated, firstly for pupils in the top of the primary school aged between ten and twelve years in classes, primary six and seven; secondly for pupils following the Scottish Integrated Science Course in the first two years of secondary school aged between twelve and fourteen years; and thirdly for pupils following the Scottish Certificate of Education physics course at Ordinary Grade around fourteen to sixteen years old in the third and fourth years of secondary school. Clearly what is suggested for this last group can impinge on the treatment given to material for the Higher Grade physics course in fifth and sixth year.

4.1 A possible course for Scottish Primary Six or Seven.

We have to recognise here that the science content of the Primary School curriculum varies a great deal and depends to a great extent on the interest and knowledge of the teacher. In many schools very little is taught at all. Several primary school teachers remarked that they would find difficulty in answering the questions presented to the pupils in primary seven. In addition, since we cannot assume a uniform exposure to science in Primary School we have to ensure that what may be attempted does not increase the problems of teachers in secondary school when they introduce electricity to the whole intake from their feeder primary schools by having some pupils who consider they have "done it all" and others to whom the material is completely new.

The approach suggested focuses on domestic electrical appliances of which it is hoped the teacher has some knowledge and of which the puils should have some knowledge.

The emphasis is placed on the importance of matching the voltage of the source to the working voltage of the appliance as a consumer. No real attempt is made to define voltage, but power, current and frequency can be given simple working descriptions. The main objective here is to show that there is a distinction between voltage, current and power.

Clearly the source is identified as a source of energy to be consumed or converted by the consumer.

Theme - Matching Electrical Sources and Consumers (Users)

1 Introduce idea of complete circuit.

2 Identify circuits in torches, models, etc.

3. Introduce switch as method of placing gap in the circuit.

4 Identify conductors and insulators.

5 Introduce cell or battery as energy source.

6 Introduce lamp, electric motor, bell, etc., as energy consumers (users).

7 Identify voltage of common batteries from label.

8 Introduce the volt as the unit of voltage.

9 Identify the working voltage of lamps which could be used in a torch, cycle lamp, hand lamp, etc.

10 Identify the working voltage of miniature electric motors, buzzers, bells, etc., and choose appropriate electrical source .

11 Identify the working voltage of a cycle dynamo and select appropriate lamps to use with it.

12 Identify the working voltage of motor car components such as lamps, motors, radio, etc., by inspecting car or car handbook.

13 Identify the electric mains voltage.

14 Identify the working voltage of appliances such as electric lamps,

irons, toasters, washing machines, power drills, overhead projectors, etc.

15 Recognise the importance of matching the voltage of the source to the working voltage of the appliance.

16 Identify the other information given on appliances such as power rating, current rating and frequency.

17 Explain power rating as the rate at which energy is taken from an electrical source.

18 Introduce the watt as the unit of power.
State that 1 kilowatt = 1000 watts.

19 Identify appliances with a low power rating and those with a high power rating.

20 Recognise that highest power is used for heating and cooking; lowest power is used for lighting and electronic equipment such as television.

21 Explain electric current as flow of electricity through appliance.

22 Explain current rating as the size of this flow.

23 Introduce the ampere as the unit of current.

24 Introduce the equation

$$\text{watts} = \text{volts} \times \text{amperes}$$

25 Assume the electric mains voltage = 250 volts.
Calculate current in appliance from

$$\text{amperes} = \frac{\text{volts}}{\text{watts}} = \frac{250 \text{ volts}}{P \text{ watts}}$$

26 Introduce fuse as safety device which melts if current in appliance is too large because of a fault and hence disconnects it from the source.

27 Identify appliances requiring a 3 ampere fuse and those requiring a a 13 ampere fuse using the equation in (25).

28 Inspect a 13 A plug. Identify the correct wiring code and good wiring technique.

29 Identify the function of a transformer to provide a low voltage supply for model railways, T.V. games, calculators, etc.

30 Emphasise the danger of connecting appliances with low working voltage directly to electric mains supply.

31 Introduce the kilowatt-hour as the unit to measure electrical energy consumed by household.

32 Calculate the energy used by some appliances.

33 Identify frequency as the number of times alternating current changes direction in 1 second.

34 Compare direct current from battery with alternating current obtained from mains or a cycle dynamo.

Clearly such a course would give rise to a need for Inservice Training of the teachers involved as many at present do not have sufficient background knowledge. It would be interesting to compare the performance of pupils leaving Primary school who had followed such a course with the original sample described in section 2.10.

4.2 Suggested Amendments to the Scottish Integrated Science Course - Section 7 - Electricity.

The syllabus followed by many schools to introduce electricity in the first year is laid out in the Teacher's Guide to the Scottish Integrated Science Course (5) section 7. In this the following teaching order is suggested: -

7.1 Electricity at rest - an introduction of static electricity which leads by observation of forces between charged rods to the idea that only two kinds of charge exist.

7.2 Electricity on the move - a demonstration that electrostatic charge is related to electric current. In this section the need for a complete circuit for current to flow is introduced.

7.3 Conductors and insulators - an identification of materials which pass and do not pass electricity.

7.4 All in a row - an investigation of the characteristics of series circuits.

Extension material for the least able shows that batteries may be connected in series.

Extension material for the average and most able investigates the use of switches, with further exercises on switching for the most able.

7.5 One above the other - an investigation of parallel circuits.

Extension material for the least able provides further experience of parallel circuits.

Extension material for the average and more able pupils allows them to investigate the distribution of currents in parallel circuits.

7.6 Opposing the current - an introduction to resistance and resistors.

7.7 Safety first - an introduction to the principle and function of a fuse.

7.8 Pushing the current - an introduction to voltage as 'electrical push' (specified elswhere as 'electrical pressure')

7.9 At home with electricity - an introduction to domestic electric circuits.

7.10 Plugging in - an introduction to good electrical practice when wiring a 13 A plug.

A number of difficulties have been found with this teaching sequence. In 7.1 many pupils have been observed to have difficulty in deducing that there are only two kinds of charge. In addition the relevance of this at this stage is debatable. In 7.2 the link between electrostatic charge and current electricity is rather forced and again its relevance is debatable.

Most pupils recognise a battery as a source of electricity and could probably more happily begin their study from this standpoint by introducing the need for a complete circuit if, for example, a lamp is to be lit. Immediately after this, could follow the introduction of the switch to provide an easy method of control.

In 7.4, we are investigating something which is not common practice except in Christmas tree lights. In addition we are putting in an awkward mixture of voltage current and resistance before these ideas have been properly discussed. Comparing the outcomes of 7.4 and 7,5 we find because similar lamps are used in both cases apparently the same results coming from two different circuits e.g. the current in a series circuit is the same at all points and the current in the branches of a parallel circuit is the same. In the latter case it would be better to use dissimilar lamps but show that they work to their natural brightness whether other lamps are connected or not. In 7.5 it should be emphasised that the voltage is the same.

In 7.8 the battery should be introduced as an energy source and the voltage introduced as a measure of the energy which can be supplied to the circuit together with the idea of 'electrical pressure'.

In many ways the ideas of 7.9 come too late. Most of the applications which pupils will meet in motor cars and in the home will be as parallel circuits. This is the basis on which the topic should be introduced. For many of the least able pupils, work which gave more experience of the complete circuit and possible ways of achieving this by different applications of switches would be more useful than trying to master the concepts of voltage and current.

We have a further possible source of confusion when we introduce both the voltmeter <u>and</u> the ammeter in this section. Since both instruments are often very similar, if not apparently identical, pupils more often than not fail to differentiate between the two instruments.

On the basis of the preceeding comments, the following alternative sequence is suggested :-

1 <u>The battery - an energy source</u>

The voltage of the battery is noted and a voltmeter connected across it. The stated voltage should be the same as the voltmeter reading.

2 <u>Consumers</u>

Lamps and electric motors are introduced as electrical energy consumers if connected to the battery. Energy conversion is mentioned.

3 <u>The complete circuit</u>

An introduction to the simple circuit using a battery and lamp to show the effect of connecting sources and consumers.

4 <u>The switch</u>

An introduction to a simple method of breaking the circuit and providing control.

5 <u>Conductors and insulators</u>

An introduction to materials which allow the circuit to be complete and those which do not. Identifies materials which pass electricity and those which do not.

6 <u>The electric current</u>

An introduction to the ammeter as a detector that electricity is flowing round the circuit. The original lamp can be replaced by others of different rating to show that the current is different. A small electric motor should also be included.

7 Parallel circuits

The components used in (6) are connected to the battery simultaneously. Each is observed to perform as though it alone were present. The voltmeter can be used to show that each has the same voltage on it.

Each circuit can be switched individually without affecting the others. This circuit can be compared with those found at home.

More able pupils can investigate the link between the current supplied by the battery and the currents in the individual circuits.

Alternative ways of forming parallel circuits can also be investigated.

8 Opposing the current

The effect of adding wire in series with a lamp on the current through it can be investigated. Different circuits can be tested to find the one presenting most difficulty - hence having the highest resistance.

9 Series circuits

The effect of connecting identical lamps in series is investigated. The current can be measured at points round the circuit and is found to be the same at all points. The series circuit can be compared with that for Christmas tree lights.

10 Electrical safety at home

The principle and function of the fuse is introduced. The correct wiring code for a three pin plug is demonstrated and practice given in wiring a 13 A plug.

11 Optional material

Recommendations (29) have been made on additional material which might be incorporated into this section to investigate the uses of switches in both simple applications and more sophisticated ones. It is anticipated that material could be selected appropriate to less able pupils to consolidate the concept of the complete circuit. On the other hand there are applications which should provide sufficient challenge to the most able pupils.

The discussion paper setting out the recommendations is shown in Appendix B.

12 Learning experiences

It is unfortunatethat perhaps due to a lack of expertise in this area many teachers only introduce the experiments which are given on the worksheets compiled by a working party set up up by the Scottish Central Committee on Science. While these experiments introduce the topic, they do not provide sufficient learning experiences to consolidate the concepts introduced in this section. It is therefore important that teachers should provide more learning experiences than are incorporated in this section in the published materials.

4.3 Suggested definitions and pedagogy for teaching electricity in the Ordinary Grade and Higher Grade physics course.

In general it is recommended that the terms electromotive force (e.m.f.) and potential difference (p.d.) be abandoned in favour of the term voltage used with suitable adjectives.

On this basis the following definitions are suggested with the term replaced shown in brackets :-

1 Source voltage (electromotive force - e.m.f.)

The source voltage of a cell or other power supply is the maximum potential energy per unit charge which it can give.

This is measured when the cell or power supply is not connected to an external circuit.

"A source voltage of 1 volt is able to give 1 coulomb of charge 1 joule of energy."

2 Terminal voltage (potential difference - p.d.)

The terminal voltage of a cell or power supply is the electrical energy which it gives to unit charge when it is connected to an external circuit and there is a flow of charge.

The terminal voltage is the voltage measured between the terminals of a cell or power supply when it is connected to an external circuit.

"A terminal voltage of 1 volt will give to 1 coulomb of charge 1 joule of energy to be converted in the external circuit".

3 Internal voltage

The internal voltage of a cell or power supply is the electrical energy per unit charge used in passing the charge through the cell or power supply.

The terminal voltage and internal voltage depend on the rate of flow of charge in the circuit, i.e. the size of the current.

source voltage = terminal voltage + internal voltage

4 Induced voltage

An induced voltage is the voltage created in a conductor which moves in a magnetic field or is placed in a changing magnetic field.

5 Resistance

The resistance of a conductor is the opposition it gives to an electric current passing through it.

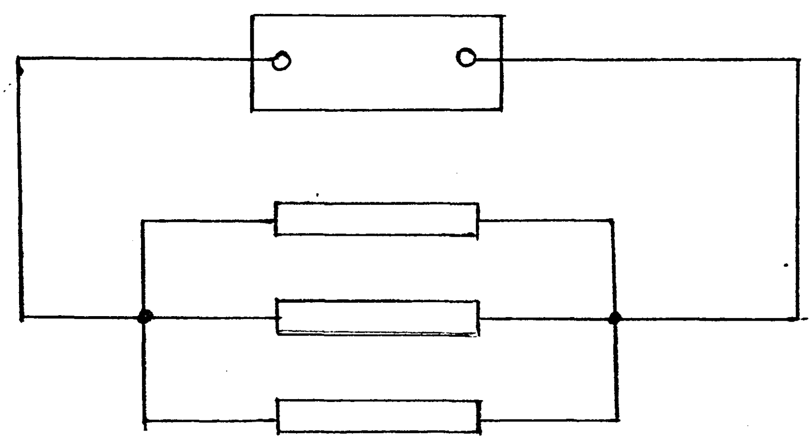
The resistance of a conductor is measured from the voltage required to cause a unit current to pass through it.

A conductor has a resistance of 1 ohm when a voltage of 1 volt causes a current of 1 ampere to pass through it.

The first three definitions taken together are required for the Higher Grade physics course in which the internal resistance of a voltage source must be taken into account. In the Ordinary Grade course we could simply modify the second definition for terminal voltage to that of voltage without loss of accuracy of treatment.

Associated with the problems of building appropriate definitions of concepts we find difficulties in analysis of circuits given in diagram form. Based on the experience of pupils' interpretation of the diagrams in items 14 and 15 of the questionnaire given to pupils in years four and five the following type of diagram is recommended for parallel circuits and should be used in years one and two when appropriate also.

figure 4.1



This type of diagram (fig 4.1) has the benefit of showing that each conductor is connected to the voltage source and therefore they have the same voltage across them. Discussions of how the source current is shared between the conductors is facilitated by the fact that the individual currents come from a common point.

The "ladder" type of diagram does not necessarily make it clear that the voltage is the same for all conductors and makes it very difficult to describe the distribution of currents in the circuit.

We have found in this investigation that most pupils are unable to explain easily the concepts of voltage and resistance. There is a continuous tendency to link voltage, current and resistance via Ohm's Law and great difficulty is found when attempting to look at each one separately

As an aid to achieving such a separation, it is recommended that the teaching strategies outlined in chapter 3.7 should be employed by teachers in their presentation of this topic. While detailed tests have not at this stage been carried out by the writer, teachers who have used some or all of the techniques have reported an improvement in pupils' grasp of the concepts of voltage and resistance.

It will be noted that the most detailed recommendations are offered in the earliest parts of the curriculum. However I feel that if these stages are well taught and properly understood then the later stages must improve.

The recommendations of this chapter are at present untested in any formal way. There is a need for a course such as that suggested for Primary School to make a start in preparing the educated layman to cope safely with electricity in the home. It may be that such a course should not be restricted to the Primary School. However, if a course like this is to be introduced, the materials for teachers and pupils will have to be prepared and evaluated and a considerable measure of in-service training provided.

Similarly there is an urgent need to evaluate the learning experiences provided by the Scottish Integrated Science Course section 7 and to increase their number and appropra**t**eness where possible. There is also a need to consider further what learning experiences are appropriate to the less able pupils, the middle range pupils and to the gifted pupils.

Finally, e.m.f. and potential difference, and the distinctions between them have emerged as aspects requiring further study both at the school and post-school level. The suggested change in nomenclature is one possible step in improving in improving understanding, but again has still to be evaluated in detail.

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Comment on Investigation Technique.

As already mentioned, the method used for the investigations at the three levels was the open ended questionnaire. This was chosen to allow the pupils to discuss in their own words the concepts and relationships between concepts, and to allow sources of error in calculations to be observed. The technique was successful in showing the limitations of vocabulary and expository skill which exists when pupils are asked to explain basic electrical concepts such as voltage and resistance. In the case of the primary school questionnaire it revealed some most unexpected results about the pupils' conception of the voltage of common batteries, the principle and use of the fuse and how parallel circuits may be connected. Against this one has to concede that the statistics which can be isolated from questionnaires of this type cannot be as sophisticated as from say those obtained from using multiple choice items with a large number of pupils. However, on balance, the information which did emerge, has provided the author with a considerable volume of sources of difficulty on which to base tutorial material on the teaching of electricity given to student teachers undergoing pre-service training.

R E F E R E N C E S

REFERENCES

1. Johnstone,A.H.; Mughol,A.R.: Concepts of Physics at Secondary Level, Physics Education, 1976, 11,7, 466-9.

2. Page,C.H.: Electromotive Force, Potential Difference and Voltage, American Journal of Physics, 1977, 45, 10, 978 - 80.

3. Scottish Education Department: Curriculum Paper 7, H.M.S.O., Edinburgh, 1972.

4. Scottish Curriculum Development Service: Specific Objectives for Ordinary Grade Physics, Memorandum 31, 1977.

5. The Scottish Central Committee on Science: Scottish Integrated Science Teacher's Guide Sections 1 to 8, 1977, Heinemann.

6. Scottish Curriculum Development Service: Science in S.1 and S.2, Memorandum Number 42, 1980.

7. Jeffrey, W.S.: Electricity Analogue, School Science Review, 1978, 60,211,313 - 5.

8. Renner,J.W.: Significant Physics Content and Intellectual Development, Physics Education, 1976, 11, 7, 458 -62.

9. Driver,R.: Pupils' Alternative Frameworks in Science, European Journal of Science Education, 1981, 3, 1, 93 -101.

10. Linn, M.C.: When Do Adolescents Reason ? , European Journal of Science Education, 1980, 2, 4, 429 - 40.

11 Johnstone, A.H.; Mughol A.R.: The Concept of Electrical Resistance, Physics Education, 1978, 13, 1, 46 - 9.

12. O'Sullivan, C.T.: Ohm's Law and the Definition of Resistance, Physics Education, 1980, 15, 4, 237 - 9.

13 Evans, J.: Teaching Electricity with Batteries and Bulbs, Physics Teacher, 1978, 16, 1, 15 - 22.

14. Fredette, N.; Lochhead, J.: Student Conceptions of Simple Circuits, Physics Teacher, 1980, 18, 3, 194 - 8.

15. Bullock, R.: The Use of Models to Teach Elementary Physics, Physics Education, 1979, 14, 5, 312 - 7.

16. Wilkinson, D.J.: A Study of the Development of the Concept of Flow with Reference to the Introduction of Electric Current in the Early Years of Secondary School, 1973, MA Dissertation, University of Leeds.

17. Osborne, R.J.; Gilbert J.K.: A Method for Investigating Concept Understanding in Science, European Journal of Science Education, 1980, 2, 3, 311 - 21.

18. Institut fur die Padagogik der Naturwissenschaften (IPN): Unterrichtseinheiten fur die Orientierungsstufe, Didaktische Anleitungen, Der elektrische Stromkreis, 1974, Ernst Klett Verlag, Stuttgart.

19. Flensted-Jensen, E.; Hanghoj, P.; Larsen, K.; Thomsen, P.; Sporg Naturen (Ask Nature) 1, 1974, Gyldendal.

20. Thomsen, P.: Ask Nature - A Danish Physics-Chemistry Project, Physics Teacher, 1977, 15, 6, 344 - 57.

21. Institut fur die Padagogik der Naturwissenschaften (IPN): IPN Curriculum Physik fur das 9. und 10. Schuljahr, Modelle des elektrischen Stromkreises, 1975, Ernst Klett Verlag, Stuttgart.

22. Scottish Certificate of Education Examination Board: Syllabuses and Notes, Physics Ordinary and Higher Grades, 1976, Dalkieth.

23. Mughol, A.R.: A Study in Concept Growth and Attainment in School Science, 1977, PhD Thesis, University of Glasgow, p.102.

24. Carter, D.: Energy, E.M.F. and Potential Difference. Discussion paper given in full in Appendix A.

25. Page,L.: Introduction to Theoretical Physics, 1932, Van Nostrand, New York.

26. Webster, M.: Essentials of Higher Physics, 1978, Heinemann Educational Books, London, p.58.

27. Cackett, G.; Kennedy, R.; Steven,A.: Core Physics, 1979, Oxford University Press, Oxford, p.185.

28. Jardine, J.: Nat Phil 'O' Text, 1973, Heinemann Educational Books, London, p.197.

29. Muir, J.B.: Scottish Integrated Science Course Sections 7 and 15, Extension Material - Applications of Switches, 1981. Discussion Paper submitted to the Central Committee for Science, given in full in Appendix B.

APPENDICES

APPENDIX A

DISCUSSION PAPER BY D.CARTER H.M.I.

ENERGY, EMF AND POTENTIAL DIFFERENCE.

In the integrated science course, exchange of energy is given great emphasis, unfortunately within the 'O' and 'H' grade physics course this is not exploited to the full.

In the teaching of EMF (which should never be written or talked about as Electromotive Force) and potential difference the starting points should be the energy converters - microphone, loudspeaker, bulb, photocell etc.

If between any two points in a circuit it is possible to convert from electrical energy into any other form of energy then a potential difference is said to exist between the two points e.g. with electrical into heat in an electric fire, with electrical into mechanical in a loudspeaker or motor. We talk about the Potential Difference across a loudspeaker, electric fire or electric motor.

On the other hand if between any two points in a circuit it is possible to convert from any form of energy into electrical energy then an EMF is said to exist between the two points.

e.g. heat into electrical in a thermocouple

light into electrical in a photocell

mechanical into electrical in a microphone or dynamo.

And we talk about the EMF of a thermocouple, a photocell, a microphone and a dynamo.

The energy change takes place when there is a flow of charge (or an electric current in the circuit). If the energy change is J joules when the charge flow is Q coulombs, then the EMF or Potential Difference is said to be J/Q joules per coulomb - but the joule per coulomb is such an important unit we give it a special name - the volt.

i.e. 1 volt = 1 joule per coulomb.

Alternatively:- If the rate of change of energy is W watts when the current is I amps then the EMF or Potential Difference is said to be W/I watts per amp, but the watt per amp is such an important unit we give it a special name - the volt

i.e. 1 volt = 1 volt per amp.

Power should always be expressed as rate of conversion of energy and not as work done per unit time, and efficiency defined as

$$\frac{\text{Power Output}}{\text{Power Input}}$$

There is no need to intoduce the physics concept of work, but stick to energy changes.

APPENDIX B

DISCUSSION PAPER SUBMITTED TO CENTRAL COMMITTEE FOR SCIENCE - PHYSICS SUB-COMMITTEE BY J.B. MUIR

I.S.C. §§ 7 and 15 - Extension Material

Applications of Switches

1. This proposed extension of sections 7 and 15 is seen to be important as it reflects the normal application of electric circuits in the home, in automobiles and in industry. Most applications involve using a switch to complete a circuit either manually or automatically. The supply voltage is normally constant being either 240V in the electric mains supply or 12V in an automobile. The main abilities required from pupils is to identify when a complete circuit is required and to select the appropriate switch, or combination of switches, to allow them to do this.

2. The best way to give pupils appropriate experience of the applications of switches is to provide them with problem situations of varying complexity which they can analyse in consultation with the teacher and work out the appropriate solution from the information they have at their disposal.

   The heavily structured worksheet is not considered the best way to give this type of experience.

3. Clearly resources are required both by the pupils and the teachers. It is suggested that the following resources be provided:-

   (a) A summary sheet, in appropriate language, recapitulating the electric circuit and the need for a complete circuit, as it applies to operating a lamp, an electric motor, a bell etc.

   (b) A summary sheet recapitulating the function and construction of a switch.

   (c) An information sheet listing the main types of switch in common use. Examples of how each type of switch might be used should be given. The types of switch which should be included might be -

   single pole switch
   double pole switch
   single pole changeover switch
   double pole changeover switch
   temperature controlled switch
   light controlled switch
   tilt switch
   float switch
   pressure switch
   relay.

(d) Problem cards identifying practical situations requiring the use of switches. These cards should describe the practical problem and identify possible switches to be used. The pupils should design the appropriate circuit to give the desired effect and then build and test it. A list of possible examples is given in Appendix I.

(e) Detailed information sheets for the use of teachers and pupils giving possible solutions to the practical problems.

It is anticipated that the sheets will be helpful to teachers who are unfamiliar with the circuits. They would also be suitable for future reference by pupils.

Draft specimens are given in Appendix 2.

4. A unit of this kind is very important as it reflects what most pupils will experience.

As it does not require the concepts of voltage, current or resistance to have been mastered but simply the concept of the complete circuit it is suitable for use by the least able pupils. Clearly for such pupils the applications will possibly be simple ones but that does not make them any less relevant.

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Jordanhill College of Education

APPENDIX B.1

I.S.C. §§ 7 and 15 - Extension Material

Applications of Switches

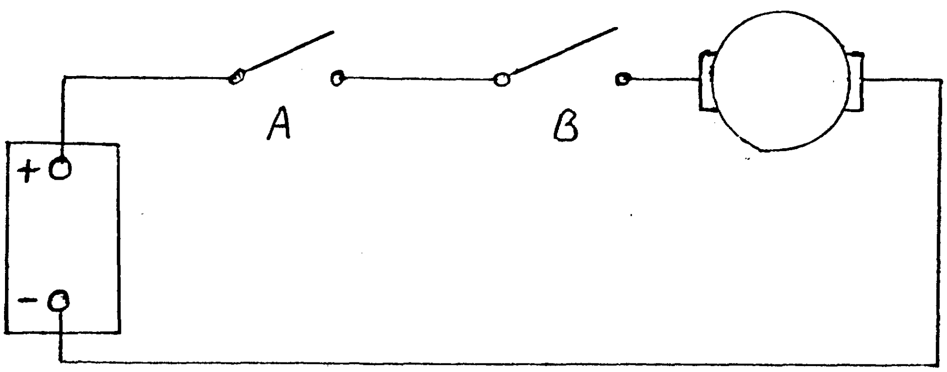
	Switches and Combination of Switches	Application
1.	Two switches in series	ignition switch + windscreen wiper switch
2.	Two switches in parallel.	car courtesy light switches
3.	Illuminated switch	door bell push
4.	Several switches in series	combination lock
5.	Single pole double throw switch	two way switching - upstairs/downstairs light
6.	Double pole double throw switch	reversing switch
7.	Double pole double throw switch	intermediate switch fitted in middle of two way switching circuit
8.	Temperature controlled switch	thermostats
9.	Relay	remote control
10.	Isolating switch	model railway points
11.	Sequence switches	traffic light control
12.	Logic switches	
	(a) two switches in series	AND gate
	(b) two switches in parallel	OR gate
13.	Light controlled switch, photo diode, photo resistor	burglar alarm, timing of vehicles
14.	Reed switch	weather proof switch
15.	Tilt switch	control of internal light for deep freeze cabinet
16.	Float switch	low liquid level warning
17.	Pressure switch	low pressure warning

J B Muir - Jordanhill College.

Applications of Switches - 1

Two switches in series

Ignition switch + windscreen wiper switch



A - accessory switch controlled by ignition key

B - windscreen wiper motor switch

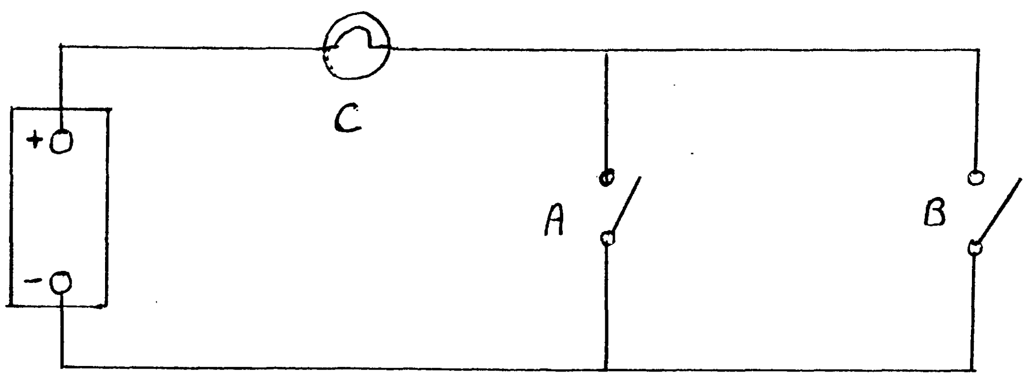
C - windscreen wiper motor

Switch A	Switch B	Motor
open	open	stopped
closed	open	stopped
open	closed	stopped
closed	closed	runs

Applications of Switches - 2

Two switches in parallel

Car courtesy light



A - switch on nearside door - switch is open when door is closed

B - switch on offside door - switch is open when door is closed

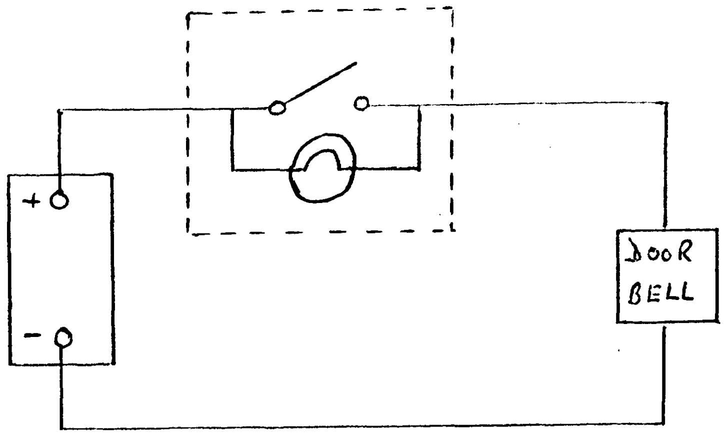
C - courtesy light.

Switch A	Switch B	courtesy light
open	open	off
open	closed	on
closed	open	on
closed	closed	on

Applications of Switches - 3

Indicator light in switch

Door bell push switch



In this application the lamp is connected in parallel across the switch. This combination is in series with the doorbell.

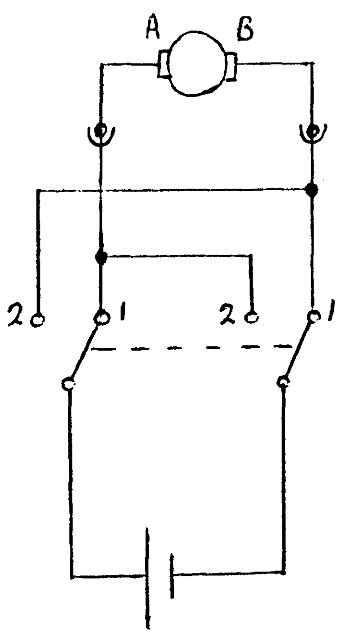
When the switch is open, the lamp is in series with the door bell, and sufficient current exists in the circuit to light the lamp. The current is not sufficient however to ring the bell. When the switch is closed, a short circuit exists across the lamp which goes out. The door bell is connected to its proper supply voltage, and the current is therefore large enough to make it ring.

switch	lamp	bell
open	on	silent
closed	off	rings

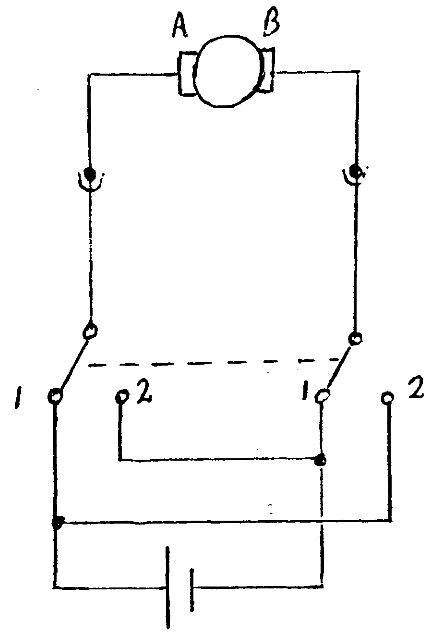
Applications of Switches - 6

Reversing Switch

Double pole, double throw switch



(a)



(b)

Switch Position	Motor Polarity	Motor Rotation
1	A + ve B - ve	clockwise
2	A - ve B + ve	anti-clockwise

The double pole double throw switch acts as two switches coupled together.

It is possible either to connect the supply to the input terminals of the switch or the motor. The alternative arrangements are shown above.

The switch is either in contact with 1 or 2 so there is no question of the cross wiring causing a short circuit.

Applications of Switches - 12(a)

Logic Switches

AND gate

In winter if the roads are dry and the temperature is above freezing point there is no danger of ice being formed. If the roads are wet and the temperature is below freezing ice will be formed. We also find that if the roads are dry and the temperature falls below freezing point no ice is formed and if the roads are wet but the temperature is above freezing point no ice is formed.

We can draw up a table to cover these possibilities. We head the column for wet conditions as "Rain" and freezing conditions as "Frost".

Rain	Frost	Ice Danger
no	no	no
yes	no	no
no	yes	no
yes	yes	yes

We can display this information in a different way.

If the answer to the question "does it rain" is "no" then we can write "0". If the answer to the question "does it rain" is "yes" we can write "1".

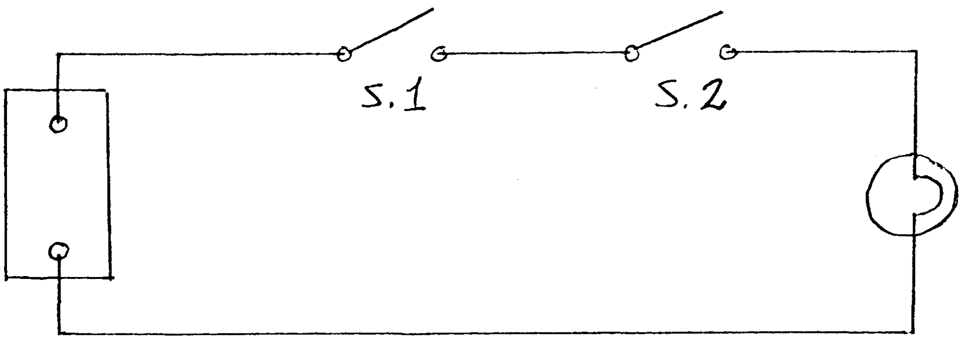
Similarly if the answer to "frost" is "no" we write "0" and if it is "yes" we write "1".

The revised table is shown below.

Rain	Frost	Ice Danger
0	0	0
1	0	0
0	1	0
1	1	1

Such a table is called a "truth table".

We can make up a simple circuit to give a warning of possibly dangerous conditions when ice will form on the road. This is made so that if rain and frost both occur a warning light comes on. This is achieved as shown below.



We arrange switch S.1 to warn if rain is falling. If it is open there is no rain, if it is closed it is raining. We arrange switch S.2 to warn if there is frost. If it is open there is no frost, if it is closed there is frost.

We notice that it is only if both switches are closed that the lamp comes on.

We can draw up a table to show the possibilities.

S.1	S.2	warning lamp
open	open	off
closed	open	off
open	closed	off
closed	closed	on

We can also draw up a truth table. If a switch is open and therefore cannot complete a circuit we call it "0". If it is closed we call it "1". If a lamp is off we call it "0" and if it is on we call it "1".

The truth table is shown below.

S.1	S.2	warning lamp
0	0	0
1	0	0
0	1	0
1	1	1

We notice that this truth table is similar to the one for the ice danger. It is only when rain and frost are at "1" that the ice danger is "1". It is only when both switches are at "1" that the warning lamp is at "1". This circuit could therefore be used to give the warning. The warning would be given when both rain AND frost occur.

The circuit is called an AND gate. This name is given because the lamp only comes on when S.1 AND S.2 are closed.

We can place any number of switches in series to make a more complicated AND gate.

Applications of Switches - 12(b)

Logic Switches

OR gate

In a large diesel engine it is important to know that the level of cooling is high enough to prevent the engine overheating. It is also important to know that the level of lubricating oil is high enough to ensure that the engine will continue to run smoothly. We require a warning either if the cooling water is low OR the lubricating oil is low.

We can set out our needs in a table.

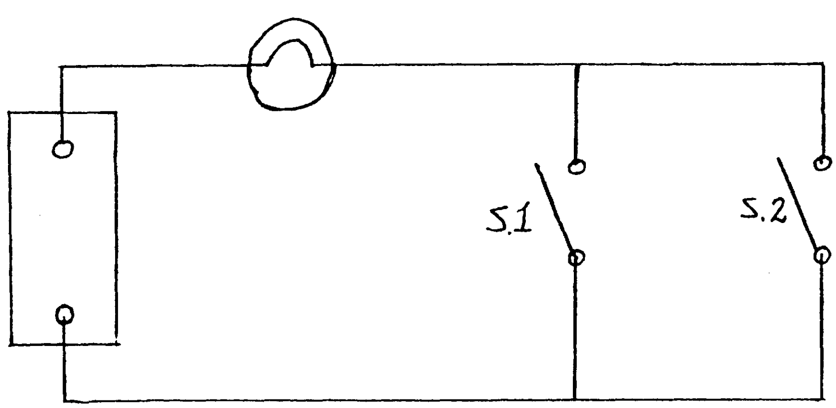
low water	low oil	danger
no	no	no
yes	no	yes
no	yes	yes
yes	yes	yes

We find this time there are three conditions when the engine could be in danger.

The truth table for this is shown below.

low water	low oil	danger
0	0	0
1	0	1
0	1	1
1	1	1

The warning system requires thst the lamp is on if one OR the other conditions occurs. This can be achieved if the switches are connected in parallel as shown below.



If S.1 is closed (1) the lamp is on (1). If S.2 is closed (1) the lamp is on (1). So either S.1 at 1 OR S.2 at 1 gives the warning. The truth table is shown below.

S.1	S.2	warning lamp
0	0	0
1	0	1
0	1	1
1	1	1

This truth table is the same as for the possible danger conditions. The circuit would therefore give the necessary warning.

This circuit is called an OR gate. This is because switch S.1 or S.2 provides a circuit and allows the lamp to come on.