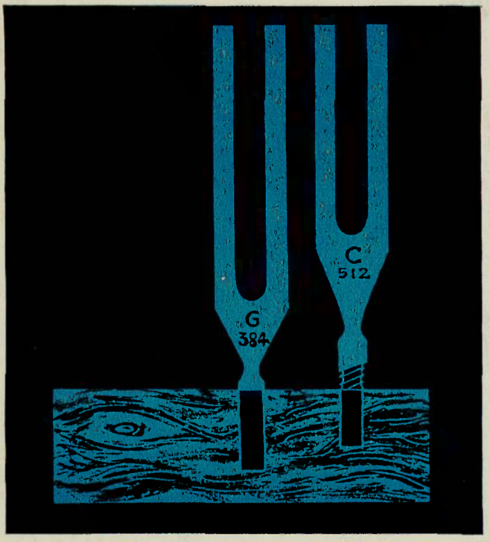
Junior Science
file copy

Nuffield Junior Science

Apparatus



A Source Book of Information and Ideas

Collins

Nuffield Junior Science

Apparatus

The Nuffield Junior Science Project is a large scale experiment in education, in which young children were introduced to the excitement of practical investigation and scientific observation. The record of what they did forms the hard core of these publications.

The preparation of the books has been possible only because the writers were able to benefit from the experience and feedback of teachers on an unprecedented scale. It was an investigation involving hundreds of teachers and thousands of children in widely scattered and different parts of the country.

The teachers involved attended national and local courses and met regularly in teachers' centres which were established in their areas. They tested, appraised, and returned their findings to the Project leaders. Their criticism and suggestions enabled the leaders to reform and rewrite their ideas.

The result is a set of books intended to help teachers who want to use science as a part of their work. The books are:

TEACHER'S GUIDE 1
TEACHER'S GUIDE 2
APPARATUS: *a Source Book of Information and Ideas*
ANIMALS AND PLANTS: *a Source Book of Information and Ideas*

Teacher's Background Booklets:
MAMMALS IN CLASSROOMS
SCIENCE AND HISTORY
AUTUMN INTO WINTER

In this book there are 241 pieces of apparatus described and pictured. Improvisation forms the main theme. Most of the suggested apparatus is made by adapting everyday items and much of it has been designed as well as made by children. This is deliberate because it is important that, before work is undertaken with specialized equipment, the child should have had the vital experience of creating for himself the means of solving problems which he has posed for himself. The book is intended not only for reference, to support teachers who are making a start, but also to be an example and stimulus for the creation of further apparatus.

21s.

Nuffield Junior Science

Apparatus

A Source Book of Information and Ideas

Nuffield Junior Science

Teacher's Guide 1
Teacher's Guide 2
Apparatus: a Source Book of Information and Ideas
Animals and Plants: a Source Book of Information and Ideas

Teacher's Background Booklets:

Autumn into Winter
Science and History
Mammals in Classrooms

Nuffield Junior Science

Apparatus

A Source Book of Information and Ideas

Collins London and Glasgow

First published 1967

Published for the Nuffield Foundation
by William Collins, Sons & Co., Ltd.

The photographs in this book were taken by Brian Bracegirdle, College of All Saints, Tottenham

Printed in Great Britain
Collins Clear-Type Press: London and Glasgow

Foreword

It is appropriate that the second group of books to be produced by the Nuffield Foundation Science Teaching Project should be designed to help in the primary schools. For the emphasis on enquiry and involvement which is characteristic of 'Nuffield Science' is also a feature of the approach which many primary schools have adopted with striking success. The books produced by the Nuffield Junior Science team will, we hope, suggest topics and methods to many teachers who are interested in the contribution which science can make to the education of younger boys and girls.

The Junior Science, like the other Nuffield courses, has many parents. Practising teachers (particularly, of course, the members of the Junior Science team), the Consultative Committee, and the Schools Council have all played a large part; and a particular feature of this project is that the Local Education Authorities concerned in the trials of the material have set up science centres—a move which should have far-reaching results in encouraging local initiative in curriculum development. In a number of areas, the trials have been conducted simultaneously with the trials of the Nuffield Junior Mathematics Project, and this has provided a useful link between the two activities.

It is even more true of the Junior Science than it was of the Nuffield 'O' level Science that the process of helping teachers with new courses is a large and continuing one. A beginning has been made, and the Schools Council (with the cooperation and support of the Foundation) is taking responsibility for the next stage. These books are therefore the first fruits of what will be a larger harvest.

Brian Young
Director of the Nuffield Foundation

Contents

'Children are people. They grow into tomorrow only as they live today.'

JOHN DEWEY

Introduction

While the chief intention of the Junior Science Project is to encourage children to isolate their own problems and to devise their own experiments and apparatus, we realize that there are some teachers who feel that they would like more direct help and advice. This book is designed to show them what apparatus other teachers and children have produced and it is hoped that it will help teachers by example and that it will give them some indication of the kind of materials that it may be useful to have readily available so that the children can get on with the work. We feel sure that given this kind of help and experience, the teacher will gain confidence and feel less and less need for direct support in assisting the children to develop their own interests.

Science is an empirical subject. It is concerned with the practical working out of ideas through the manipulation of materials in such a manner as to lead to discoveries. Children are naturally great experimenters; their lively curiosity ranges widely over all manner of living and non-living things around them. This reaction to their environment they seek to work out in practical terms. Sometimes, it is through the manipulation of materials to produce answers to some of their problems. At other times, if suitable material is not to hand, they will use what odds and ends they can find to bring them towards the sort of answer they have in mind.

The main purpose of this book is to place before teachers some ways of developing the materials which have been found useful to children in aiding this process of finding answers. It has been said more than once that the Nuffield Junior Science Project is concerned much more with starting points than end products. With this in mind the book concerns itself particularly with some developments of the use of materials which may open the way for further developments by the children, others by the teacher, or, sometimes, a combination of both the efforts of the child and the adult. It is not proposed to give a complete treatment of the use of any particular piece of equipment. Rather, it is hoped that the teachers and children who use this book in its early stages will themselves contribute further ideas from working out the possibilities in the field, so that in its final editions there may be a much wider range of apparatus presented to the future users, and all of it arising from situations truly rooted in practical work.

It will be seen that much of the suggested apparatus is really the adaptation of everyday items to use with work in science. This has been a deliberate policy, not only because it is felt that ready-made standardized equipment common to the laboratory may be too expensive, but also because that equipment represents on the whole a maturity and sophistication of view for which many children are not yet ready. In addition, it is important that before work is undertaken with specialized equipment the child should have had the vital experience of creating for himself the means by which he will solve the problem which he has posed for himself. This is well in accord with the child's natural way of working. If you observe a child when he is setting about his own pursuits, it is quite common to see him assemble the various materials required in the situation from those immediately to hand. This is just the sort of attitude it is hoped will grow up in children's reactions to the situation in science.

If genuine problems and interests have been aroused by the child's reaction to his environment, then it is quite natural that he will turn to the nearest things that are to hand in his efforts to solve these problems and to continue these interests. Few children will have the opportunity to draw upon specialized pieces of equipment for this purpose, so first we must provide for children working with materials that are readily to hand. These on the whole will be the odds and ends found in the average home. Many of them will have been discarded from all sorts of home activities. The lively-minded youngster will approach his work in science very much in terms of: 'Here is a problem. What material can I use in my search for an answer?'; and so in an elementary sort of way he will not only design an experiment but also set about the practical task of working the problem out. This is just as it should be. There is a great creative value in manipulating the apparatus and devising the setting up of experiments of all kinds. Furthermore, it will begin a process in which, as the child's experience grows, so will his need for a greater sophistication in the sort of materials and apparatus that are to hand, and in which he himself will grow towards a use of the more conventional sort of apparatus that we associate with the science work of older children.

So it is in this book that improvisation forms the main theme. There will be references in its later sections to some conventional devices which in themselves have proved either indispensable or so evocative in their nature that they should be included from the outset in the equipment of the average classroom. The materials themselves that children use will often be of such a nature as to point the way towards some of the answers that they are seeking, and not the least of the purposes of this book is to bring to teachers' notice some of the possibilities of quite mundane odds and ends in bringing about these aims. Again, we hope that children will look upon their equipment as essentially amenable to use in a variety of ways according to the needs of the situation.

There will no doubt be as many variations on some of the themes as there will be users, and it is hoped most sincerely that teachers will share with us their own ideas and the development of some of the ideas in this book so that we in turn may incorporate them in future editions in order that an even greater number may share in them. The different sections of the Nuffield Foundation Science Teaching Project are in themselves shared enterprises whose combined effect will be, it is hoped, to bring from teachers to teachers the most valuable elements of the benefits experienced. It is our earnest hope that those who use these early editions of this book will send in their suggestions and criticisms and, above all, their own ideas for inclusion in future editions.

Section 1

Elementary electricity

Introduction

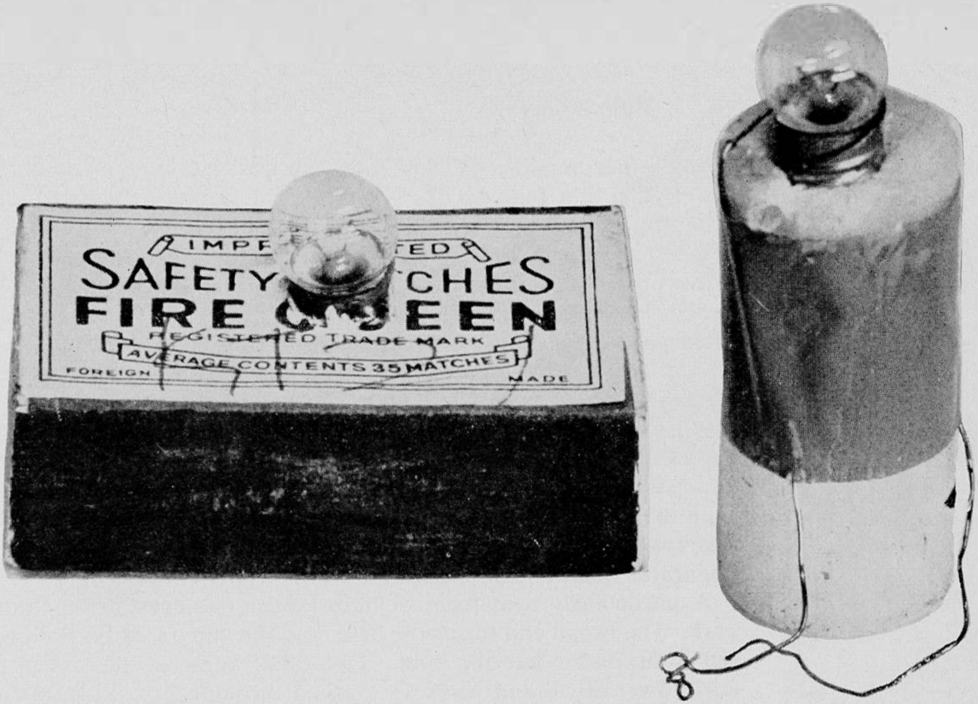
Teachers are always interested to see the work of children, particularly when it reflects a high degree of originality and skill. The work illustrated in the early part of this section comes from boys and girls of average ability in an ordinary urban school possessing no particular advantages by way of equipment or working space, and certainly having all the normal sort of problems which come in the average primary school. These children were in their fourth year of primary school. None had been selected to go on to grammar or technical schools, and all would proceed to the nearest secondary modern school. Thus, it can clearly be claimed they represent the average ability range from the child population of this particular area.

The essence of the approach throughout was to present the children with opportunities to solve problems which had arisen genuinely as a result of their own work. Sometimes, these problems were basic to making a start on a particular investigation. Thus, there were several very original attempts at making bulb holders. An essential stipulation in this instance was that the child should rely upon everyday odds and ends as the raw material for his apparatus. In the pages that follow, it will be seen how ingenious and resourceful minds responded to the various situations, drawing imaginatively upon miscellaneous materials of all kinds. The source of supply for wire was a local scrap dealer. The rest of the material came from a large odds-and-ends box kept in the classroom. Some of its items were brought by the children from their homes. The only things supplied by the teacher were bulbs and batteries.

There was a minimum supply of simple tools such as small screw-drivers, pliers, and junior hack-saws. Rulers, scissors, and Sellotape completed the equipment. Nearly all the work was done on ordinary school desks. There was one firm table in a corner of the room, which served as a sawing bench and a general working area for jobs which would be likely to cause some damage to desk tops. A very good routine soon developed without any undue emphasis by the teacher upon what to do where, etc. With such limited facilities, inadequate raw material, and often quite unsuitable items, the finish of some of the pieces of work was bound to be crude. This was not altogether a bad thing, as it exposed so clearly the pattern of pupils' thoughts and work, and many of the items clearly showed the intense thought and energy which had gone into making the ideas take shape.

The items used and created are put forward, not principally so that teachers will feel that they should be copied, but rather to indicate the range of work that may be expected to develop with normal children following this creative pattern of experimentation. It is hoped this will enable the teacher to be prepared for some of the paths of development which may take place, and at any rate to be aware of the sort of scope that children of this age group might be expected to need, if their work is to become that kind of science which is essentially exploration, creation, and action.

Some teachers may feel that they would prefer a small degree of prefabrication of the apparatus that the children use. They may feel they have neither the facilities nor the inclination to begin this work in such a spirit of 'from the ground up'. Moreover, they may well feel that through the supply of a certain basic minimum of equipment, the child will be freed further to explore the central core of a problem rather than be confronted by a series of difficulties mainly concerned with tackling it at all. Therefore, set out in the latter part of this section, there is a series of basic items of prepared equipment which the child may use experimentally in many different ways. Incidentally, all of this equipment can be constructed by children, using elementary tools and having the minimum of assistance. Some teachers feel that this system allows children to get to the essential business of experimentation more quickly. It is also felt that by having to hand some small stock of ready prepared material, the child can get to work more quickly on particular problems as they arise. Furthermore, teachers themselves will have a stock of material to which children can readily be directed without an undue amount of the teacher's time being taken up by these particular interests whether they are those of individuals or of small groups. There is, too, the point that at some time in the evolution of the child's work there comes the major need for those materials which markedly assist the solution of problems rather than those that provide an immediate preoccupation with making the elements of the apparatus. There arises, too, an educational point of particular significance in this connection: as the children's thinking and ability to perceive underlying significances and interests evolve, so they want to have more sophisticated types of apparatus. As secondary education proceeds we see a greater degree of sophistication of apparatus of all kinds. It is therefore greatly to the child's benefit if he can be allowed to develop naturally towards using these more sophisticated types of equipment, and above all appreciate their purposes and service in solving problems. At the heart of all this work, whether it be at primary or secondary level, is the essential process of discovery. The apparatus is merely the means towards this end. It would be as wrong to overstress improvisation, as to overstress the need for greater sophistication of apparatus. Neither should become hindrances in the working-out of this essential process of exploration and discovery.



1. Bulb holders A

Here are two successful attempts to improvise bulb holders. The first is made from an empty matchbox. The drawer part has been discarded and a drawing pin inserted through the centre of the underside. The point of the drawing pin provides a contact for the base of the bulb. A hole is pierced in the centre of the top of the box and the bulb screwed into this until the base contact meets the pin point. Wires are led from the drawing pin and the top of the bulb itself, so providing the necessary leads to batteries and other circuits. In practice, the limitations of this type of holder soon became apparent when bulbs needed changing or circuits demanded longer leads and rewiring, etc.

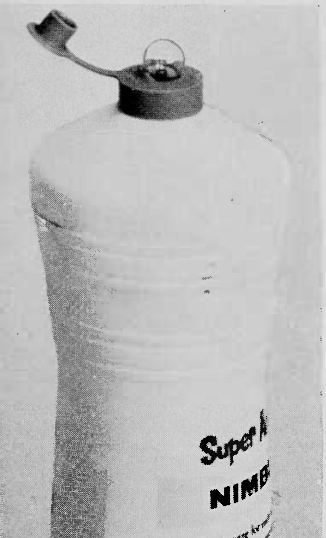
The second bulb holder illustrated consists of a stub of a candle with a hollowed out section at one end. Wire for the base contact is led through a hole pierced in the candle, so carrying the wire to the base of the bulb. The bulb itself is 'screwed' into the hole and when it is held firmly, a wire is attached to the top, so giving the second contact. A band of Sellotape fastens both wires firmly to the side of the candle, thus leaving scope for connections without disturbing the contacts. This type of bulb holder proved more serviceable than its matchbox counterpart.

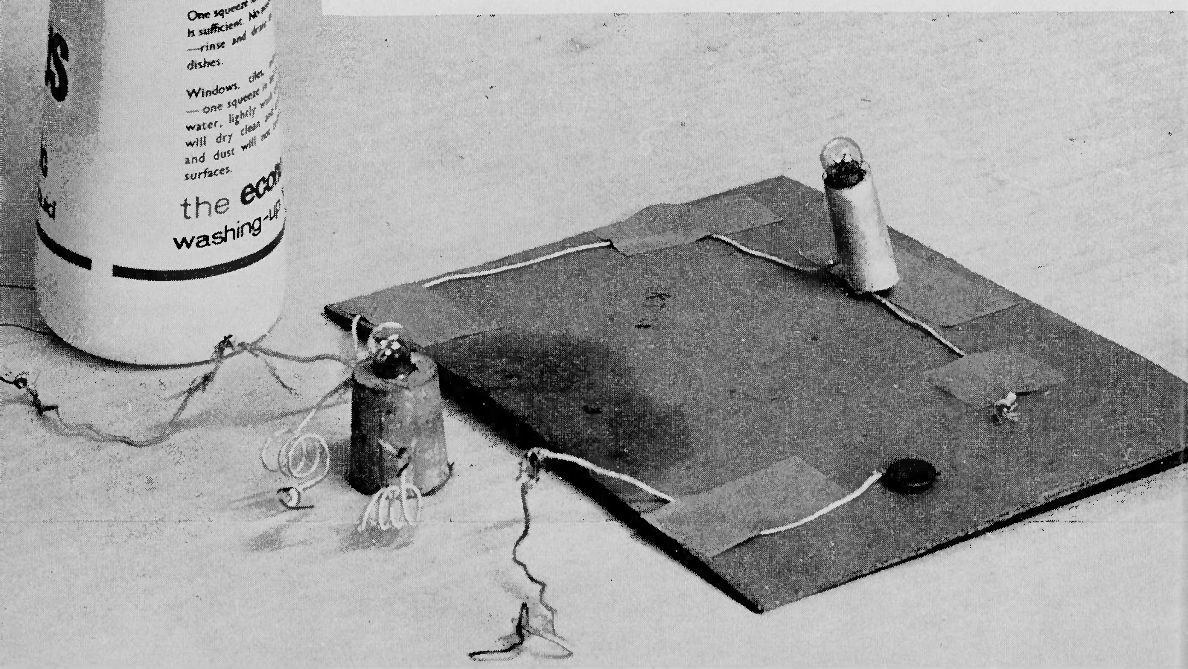
2. Bulb holders B

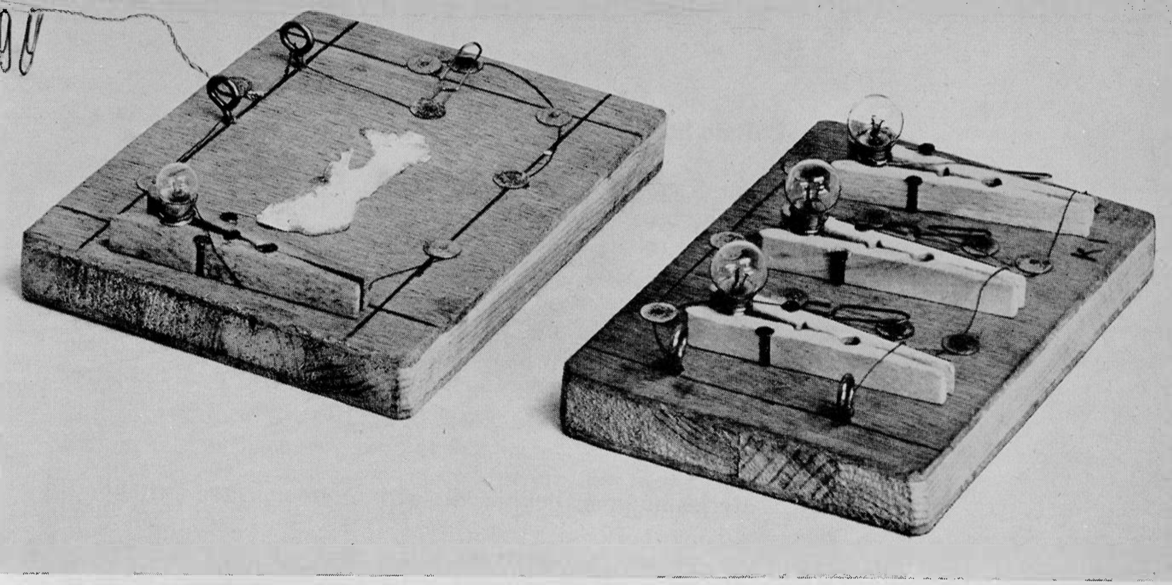
Three other versions of this basic piece of equipment are shown here. The first bulb holder is made in an empty detergent bottle. The stopper has been removed and the bulb screwed into the opening left there. A hole pierced in the base of the container leads wires up through the inside to the side and bottom contacts of the bulb. These wires are held in place with Sellotape. It was found in practice that the empty container was surprisingly unstable.

Another group of children set to work on the problem of producing a stable base to the bulb holder and so made the version seen on the right of the photograph. This consists essentially of a piece of cardboard for the base. The bulb itself is held in a tube of paper which is fastened finally with Sellotape. The wire connections to the bulb are also held in place with Sellotape. Drawing pins provide stub type contacts so that there is no need to raise the wiring, and the apparatus is more stable than the other version.

A particularly neat form of bulb holder has been made from a cork. The broad end forms the base, and the narrow end is hollowed out to accommodate the bulb. Two other holes are pierced in the cork lower down and wires are pushed through these to form contacts, one with the base of the bulb, and the other with the side. Fairly stiff wire has been used for this job and in part this helps to keep the bulb firmly in its holder. The ends of the wire are bared so that contacts can be made readily with other parts of the circuits.





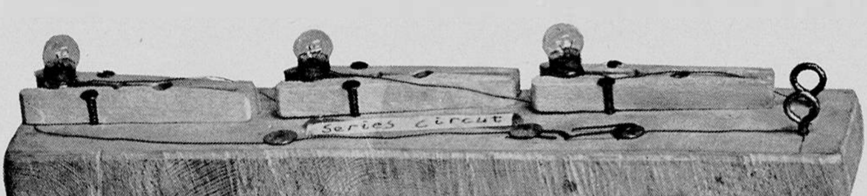


3. Bulb holders C

Some experiments demanded a type of bulb holder which could be fixed firmly to a base. An adaptation of an ordinary spring peg for this purpose is shown on the left of the photograph. The spring has been removed and the bulb placed in the curved part of the peg. Two tacks hold the peg firmly together and at the same time attach the holder firmly to the base. The lower contact to the bulb is provided by a drawing pin placed in the baseboard beneath it. The upper contact is made by securing a piece of bared wire inside the grip of the peg. Two other features worth noting on this piece of apparatus are the use of metal eyes as terminals and of paper clips and drawing pins to make an elementary type of switch.

The example on the righthand side shows a further exploitation of this spring peg method of making bulb holders and wiring them into circuits. Here a form of parallel circuitry has been developed in a compact manner on this baseboard. The use of metal eyes as terminals and drawing pins and paper clips as contacts and switches has been further exploited and the whole piece of apparatus has been formed into quite a compact unit on this block of scrap plywood. It is interesting to notice how the shape of the original block of wood has to some extent determined the layout of the material.

The photograph below is described on the next page.



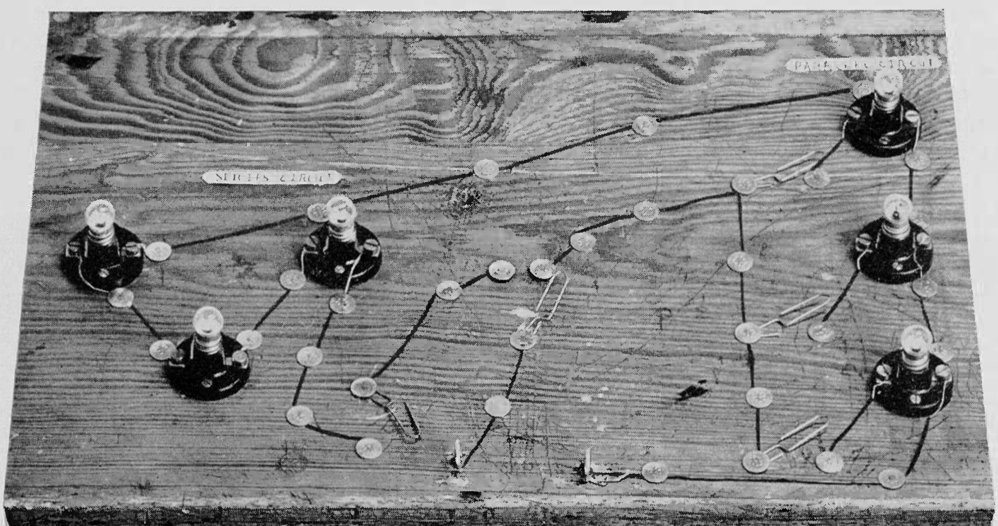
4. Bulb holders D

The illustration at the foot of page 19 shows a further logical development of the use of the spring peg type of bulb holder. This time an alternative method of wiring has been adopted, the series circuit. Notice how the pupil has selected a long, narrow strip of wood to accommodate the various components. It is important to have a variety of raw material available so that the pupil is able to make decisions on the fitness of various materials for his purpose. Again metal eyes have been used as terminals, and drawing pins and paper clips form the essential components for switches and junctions in the circuit.

5. Series and parallel circuits with interconnected switching

Below is shown a most ingenious exploitation of circuitry. Here, using the crudest materials, an extremely involved system of switching has been devised so that a single current source can be switched into the parallel and series circuits in various ways. A large baseboard was needed for this job and it can be seen that the most suitable piece of wood was from an old desk seat. This was among other pieces of material in the classroom store of wooden scraps.

It is worth noting how drawing pins were used, not only to hold down the wires but also to form junctions and terminal points. Bent paper clips provided switches, and metal eyes the terminals to which the current source was connected. It was clear to the children that for this sort of job improvised bulb holders were really not satisfactory. It is worth pointing out, too, that this marked one of the points of development in their own thinking, when they saw the need for prepared apparatus so that they would be freed from improvising these units and be able to get ahead with the main job.

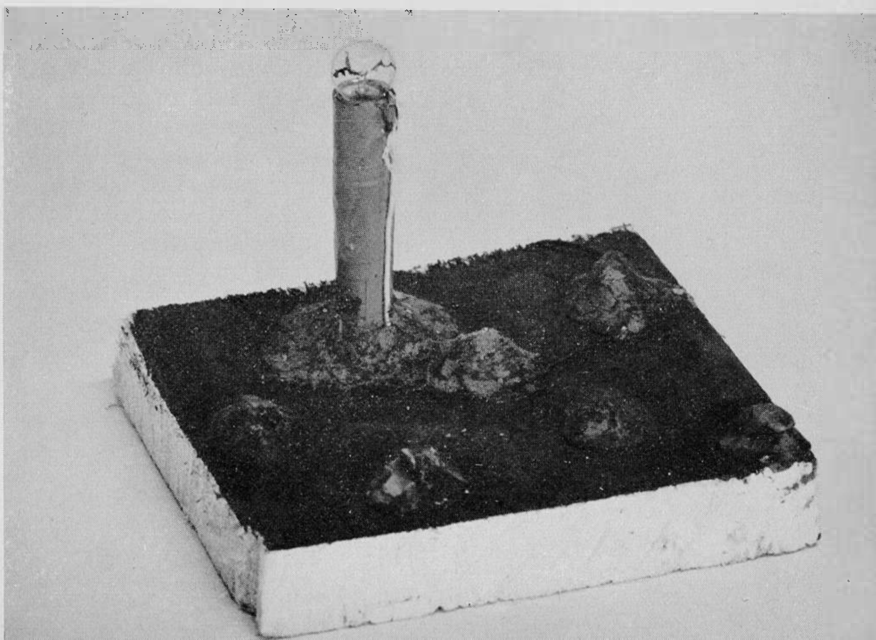


6. Application of the simple circuit

The children's exploitation of their discoveries in circuitry varies in complexity from the unusual work illustrated on previous pages to the more elementary apparatus in the photograph below. Here the simple circuit has been adapted to light the bulb in this miniature lighthouse. The body of the lighthouse itself is a paper tube of a suitable size to accommodate the bulb. A piece of wooden rod of the diameter of the bulb has been selected from the class's supply of scrap material, and layers of paper and Sellotape have been wound around it to form the column of the lighthouse. On top of this, the bulb is held in place by a blob of Plasticine.

Much more time was spent on the manufacture of the lighthouse, its piece of rock, and the surrounding sea area than in the devising of the simple circuitry. However, this still involved a considerable element of critical selection of the suitable materials for this job. The base in this case consists of a piece of thick plastic insulating material which has been painted suitably. The rocks and base of the lighthouse have been built up with plaster of Paris and then painted.

Some children seem to need opportunities to consolidate their work through practical diversions which exploit their simple discoveries and relate them to various situations. This particular piece of work illustrates the fact well. It was almost as if the use of simple circuitry needed to be set in a wider context than the purely scientific one. Naturally, the children's needs for this sort of diversion along the route of their progress will vary considerably. At the same time it is no little part of the teacher's responsibility to recognize this need and to provide means for its expression.



7. The electric torch

The discovery element is not a single-sided situation as it is seen in its development in school. As often as not, it will involve in the main the rediscovery and emulation of work done many times by previous generations. This does not in any way diminish its value. Quite surprising possibilities open up when the child lends his mind to the problem of rediscovering the essential features of some situation embodying some of the scientific principles that he has been studying and thinking about.

The illustration opposite shows a quite unusual piece of work. The applications of simple circuitry had been the object of both discussion and experimentation in this particular class. Now a boy had set himself the task of making an electric torch from the ordinary materials at his disposal. A sweet carton provides the body of the torch. It is lined with metal cooking foil. This is suitably connected around the bulb, which is held in place by a piece of cardboard and Plasticine. A wire connection fastened with Sellotape to the base of the bulb runs to one side of the paper clip switch. The drawing pins, forming the other contact, pierce the carton and make contact with the metal foil lining. The batteries are inserted and the top is held in place with Sellotape. The top of the torch has been made from a plastic bottle top (which the boy found when he searched at home) with part of it cut away. The cut-away part has had a window of celluloid inserted into it, so completing the article.

This particular piece of work provided a very rich educational experience for this child. It involved creative processes of thought and hands, as well as considerable scientific planning of the kind of circuit suitable for this situation. True, the child had before him a commercially made torch from which he gained much inspiration and information but then, in sharp contrast, to produce his own he had not only to search for suitable materials but also to adapt them to the ends in view. The kind of thinking which produced this improvised electric torch is just the kind which it is hoped will produce rich and fruitful work in science in the years ahead. These basic experiences, not only in mastery of materials, but also in the mastery of ideas, are surely an essential part of the child's development and it is of supreme importance for children to have them in the greatest possible number and variety.

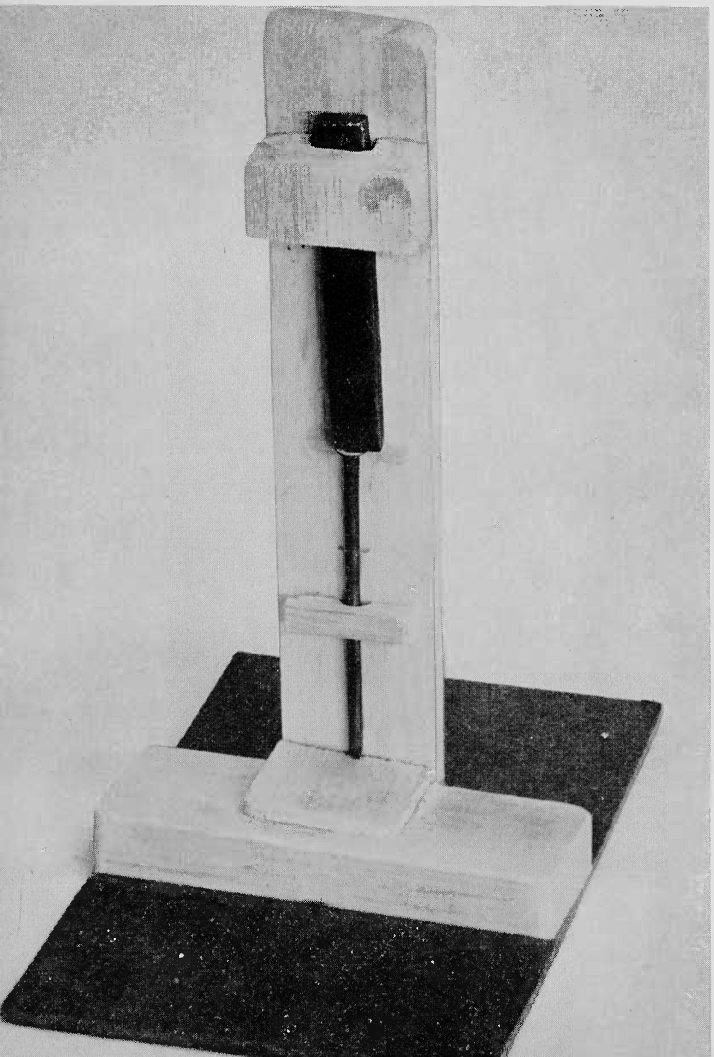

SMARTIES

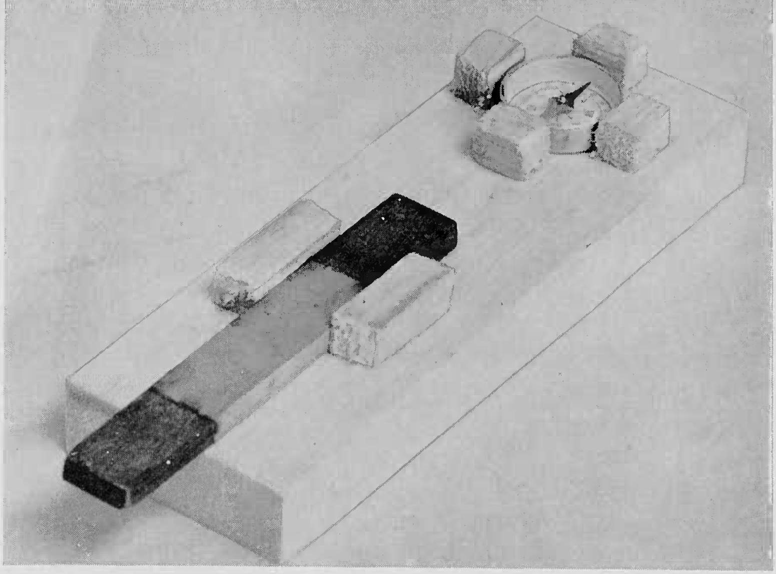
8. Magnetism A

As a result of investigations with magnets, most of the traditional ground introducing children to the phenomena of magnetism was covered in one way or another. However, here and there unusual pieces of apparatus were devised by the children in the process.

In the illustration below there is an interesting piece of apparatus to investigate the problem, 'Is there a limit to the length of metal through which a magnet can pass its power?' This piece of apparatus is made from balsa wood, glue, and a piece of hardboard. The balsa component is scooped out with a knife and the edges finished off with glass paper.

It will be seen that a considerable amount of thought went into the designing of the various simple components of this apparatus. The hardboard base came as an afterthought when problems of keeping the material stable arose as the magnet was placed in the upper position. Provision was made, not only to keep the magnet steady, but also to insert pieces of paper and other materials between it and the nail to see if the passage of the magnetic force would be interrupted by these means. Various lengths of nails were tried, as well as leaving the apparatus set up for a different period of time with different lengths of materials. In fact, the variations upon this theme which the children devised were quite extraordinary. There was certainly no dearth of questions, and equally, this simple piece of apparatus met most of the requirements of the various situations they wanted to test. Furthermore, it had the great advantage of being designed deliberately to help them answer their problems.





9. Magnetism B

Techniques of measurement of all kinds recur throughout work in science. Here an awareness of this is reflected in the apparatus illustrated. It was developed after a series of experiments had been undertaken with magnets, exploring the effect of one magnet upon another, and so on. Now the effect of a magnet upon a compass was under consideration. Again, the raw material is balsa wood shaped with a penknife and having various pieces stuck into place with balsa glue.

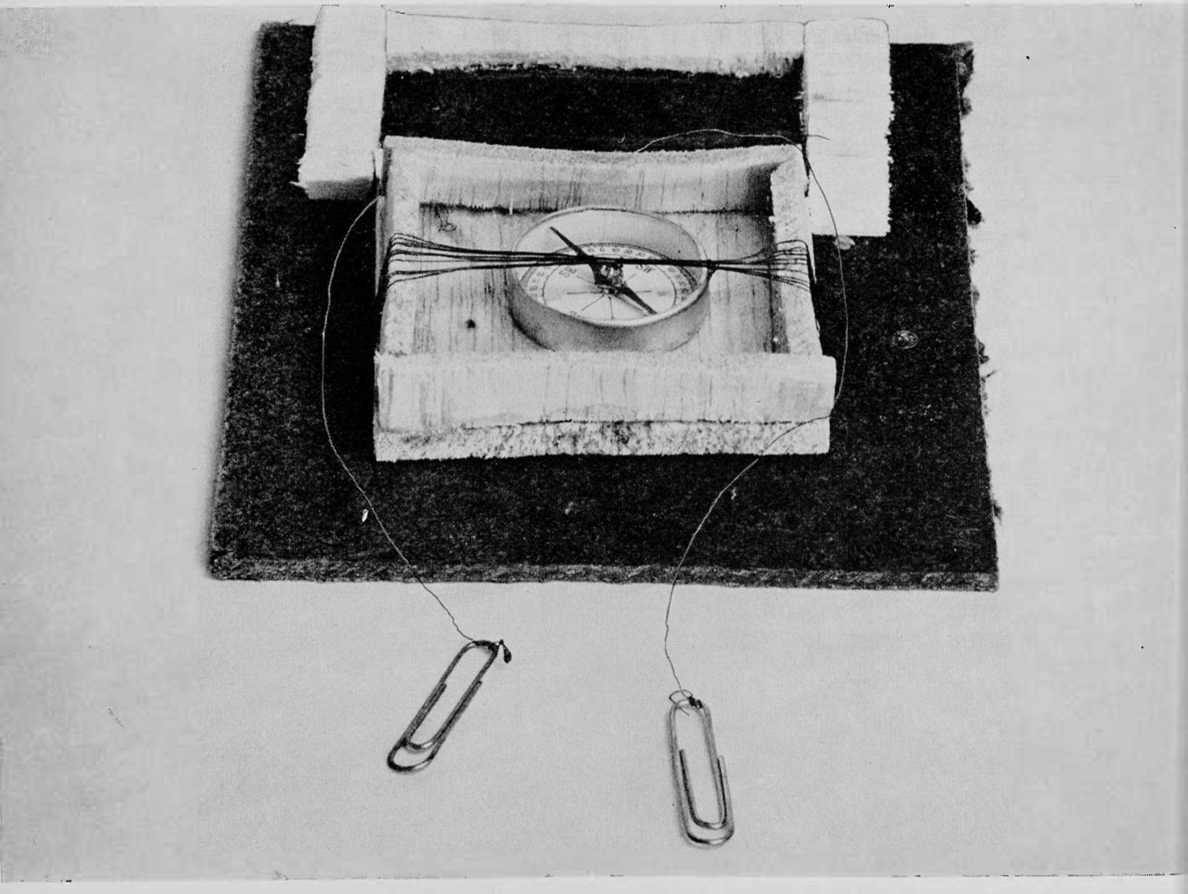
This apparatus enabled measurements to be made, not only of distances between the magnet and the compass needle, the effect of north on north, north on south, etc., but also the effect of passing various materials between gaps of various sizes and, indeed, passing magnets between the magnet and the compass needle.

Numerous other pieces of experimentation went on with this simple device. Distances were carefully measured and the effects noted, for example, of passing a knitting needle through the gap; passing a magnetized knitting needle through a one-inch gap, then through a half-inch gap; passing an unmagnetized needle through; passing a brass rod, a glass rod, and so on. The two simple guide blocks of balsa wood contributed considerably to the precision with which the magnet was manipulated. This was a good illustration of the rule that in most successful experimentation, the simple means produces the most satisfactory results.

10. Current detector A

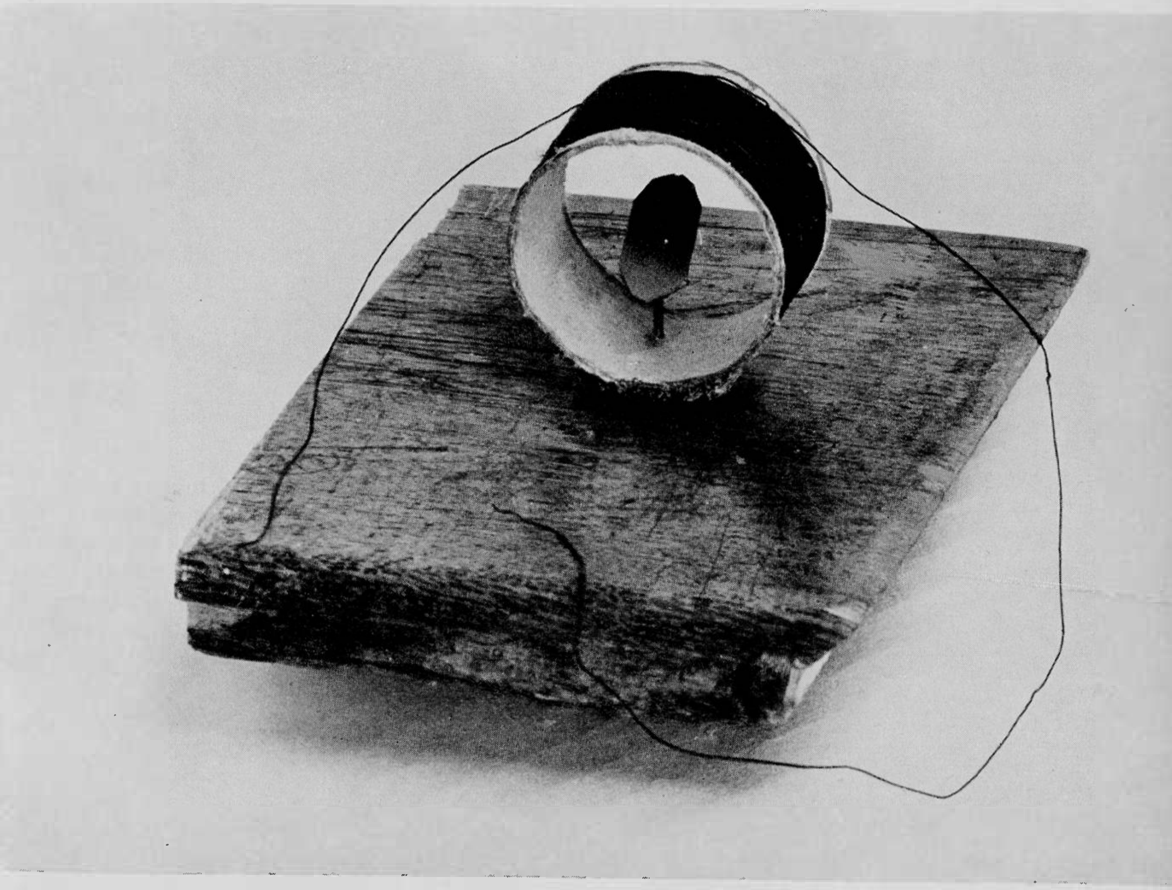
The investigation of electromagnetic effects can produce much fruitful apparatus-making. The illustration shows one early model in this series of experiments. Balsa wood is the medium; in the foreground the use of paper clips as terminals is illustrated well. The strips of balsa wood on the back of the baseboard are so placed as to hold the battery in place firmly whilst the experiments are going on.

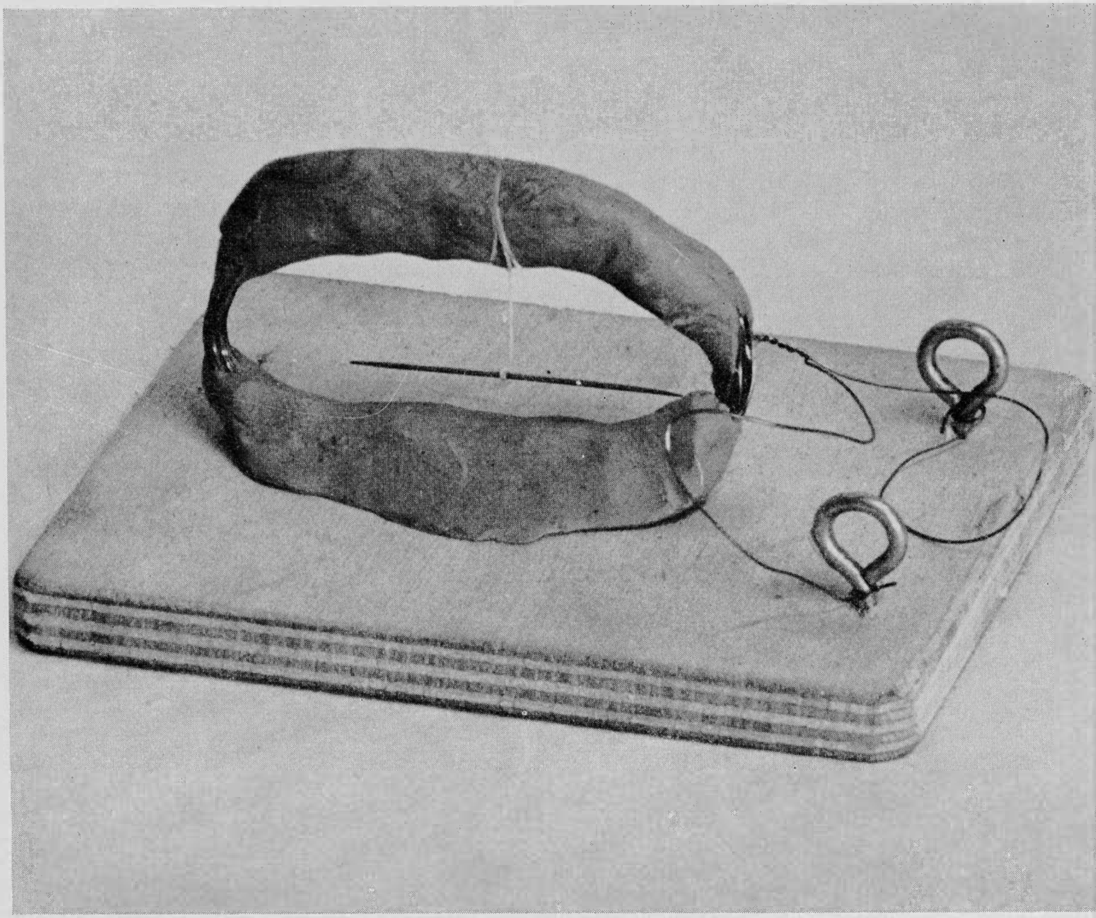
Again, quite a range of questions was thrown up by this apparatus: How many turns of wire would produce the greatest movement in the compass needle? What spacing of the turns of wire? What would happen if a multi-cord cable were made from thin strands of wire? What would happen if wire were wound in several directions—would there still be a reaction? The construction of the apparatus in this case was essentially a means towards the end of investigation, and certainly not an end in itself.



11. Current detector B

This illustration shows a further variation on the theme of investigating electromagnetic effects. The apparatus devised here is reminiscent of standard textbook apparatus common to other stages of education. However, in this context its purpose is rather different. The base is an offcut from a piece of old desk. The former, around which the wire was wound, is a section of a cardboard tube. A compass needle has been fabricated specially from a piece of tin plate, cut to shape with tinsmith's snips that conform to a safety pattern, and the whole thing swings on a pin stuck through the former. Many experiments were tried, not only with the number of turns of wire put around the former, but with putting the turns in different directions, with putting wires in more than one direction, and so on. The results were carefully noted. The apparent crudity of the device did not prevent it stimulating many questions, and some of the principles which became apparent as a result certainly led to developments in other directions.





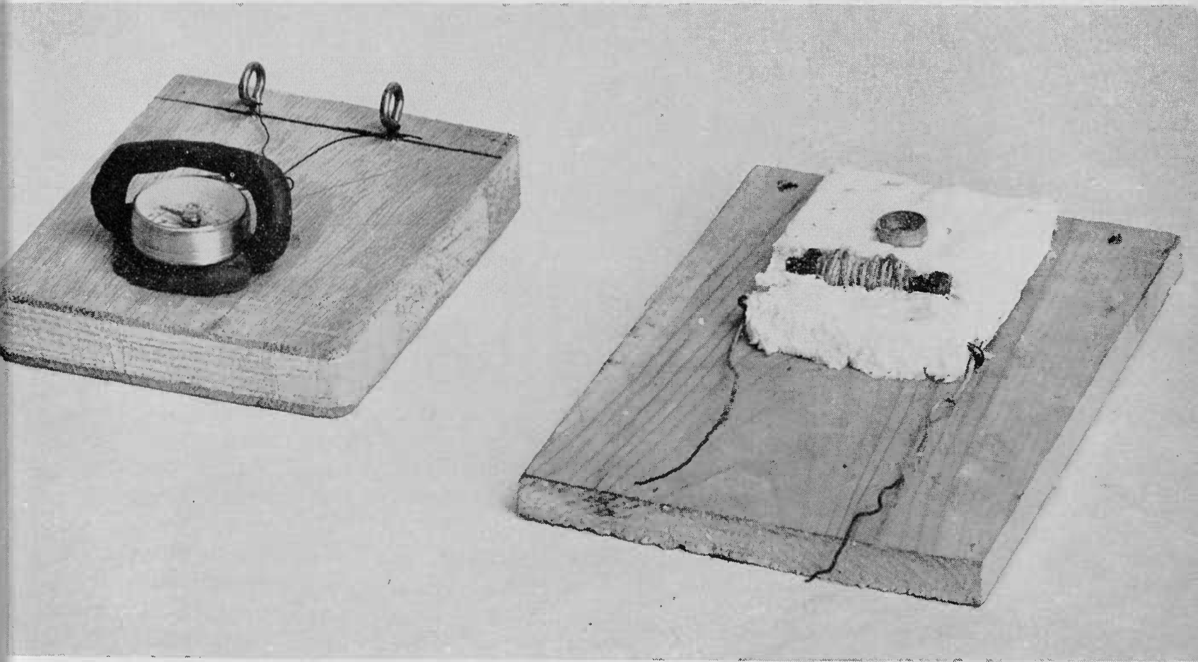
12. Current detector C

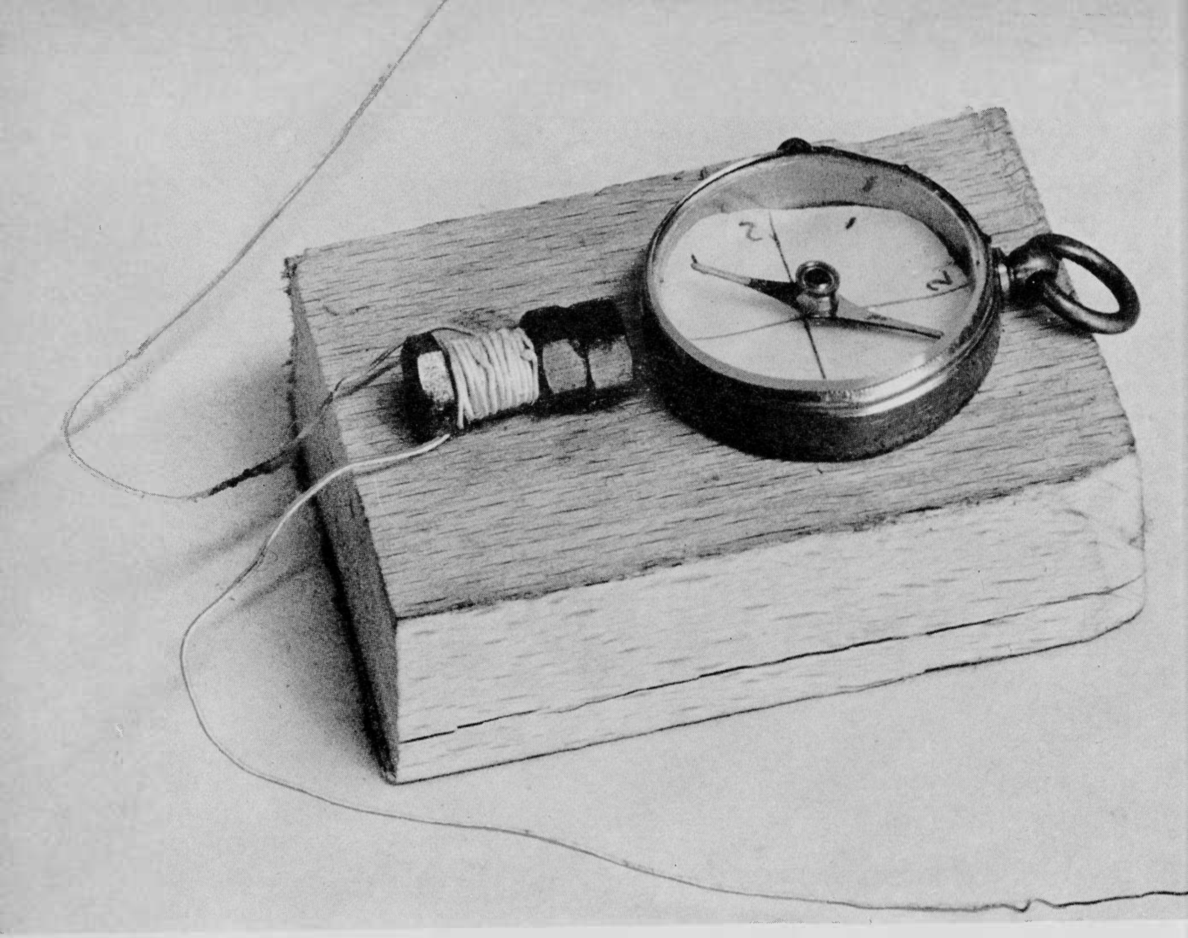
Here is a much more sophisticated effort to extend investigations of electromagnetic effects. Coils of wire each containing different numbers of turns have been made up and then encased in Plasticine to keep them rigid. A magnetized needle is suspended from about the mid-point of the coil. The ends of the wire are connected to the terminals as illustrated. The baseboard is made from an offcut of plywood, found in the scrap wood box of the classroom.

13. Current detector D

This illustration shows two further examples of ingenious pieces of apparatus constructed from scrap materials in the pursuit of further investigation into problems of electromagnetism. The apparatus on the right consists of a baseboard made from an offcut of boxwood. A small square of polystyrene packing material has been stuck to it and hollowed out to accommodate the compass. At a distance from it a further hollow has been made to accommodate an ordinary bolt. This bolt has previously been 'softened' by lying in the fire overnight and so being made into a variety of soft iron. Experiments were made with varying the number of turns placed round this bolt, and observing its effect upon the compass needle.

On the left is a further variation on this piece of apparatus, which also combines some of the features of others previously illustrated. Instead of the crude compass needle made either from a magnetized needle or piece of tin plate, a pocket compass itself is inserted inside the former of wire covered with Plasticine. Curtain-eye terminals are used as in previous pieces of apparatus.



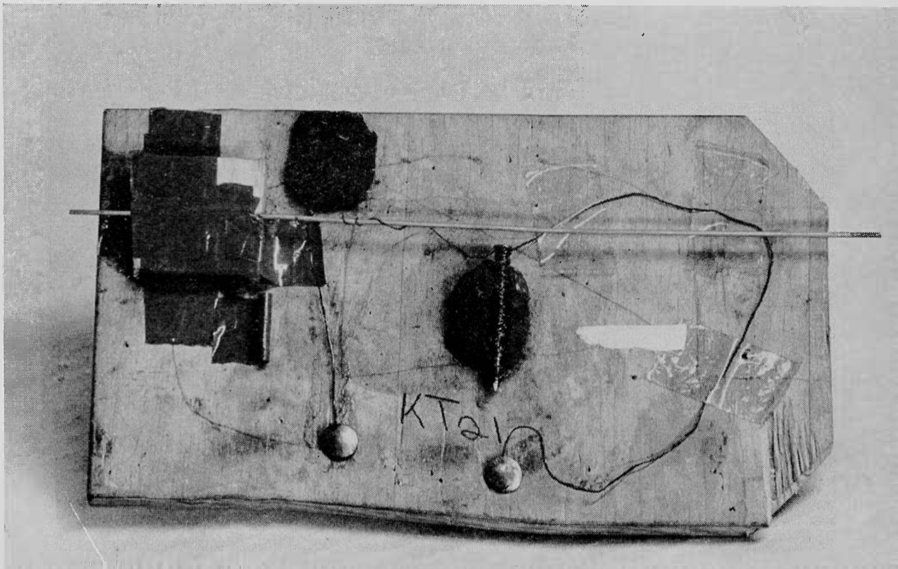


14. Current detector E

The apparatus shown is designed to examine the effects of varying the voltage passed through the coil of the electromagnet. A blob of Plasticine holds the compass down on the block of wood and another fastens the bolt with the turns of wire. In construction, this was used as the fixed element in the situation. Different voltages were applied to a coil of wire and the effects upon the compass needle were observed and read from the calibration on the card. The differences in voltage were obtained by coupling cells in series. This in turn was based upon discoveries which had been made in previous experimentation in which circuitry had been one of the central themes.

15. Buzzer A

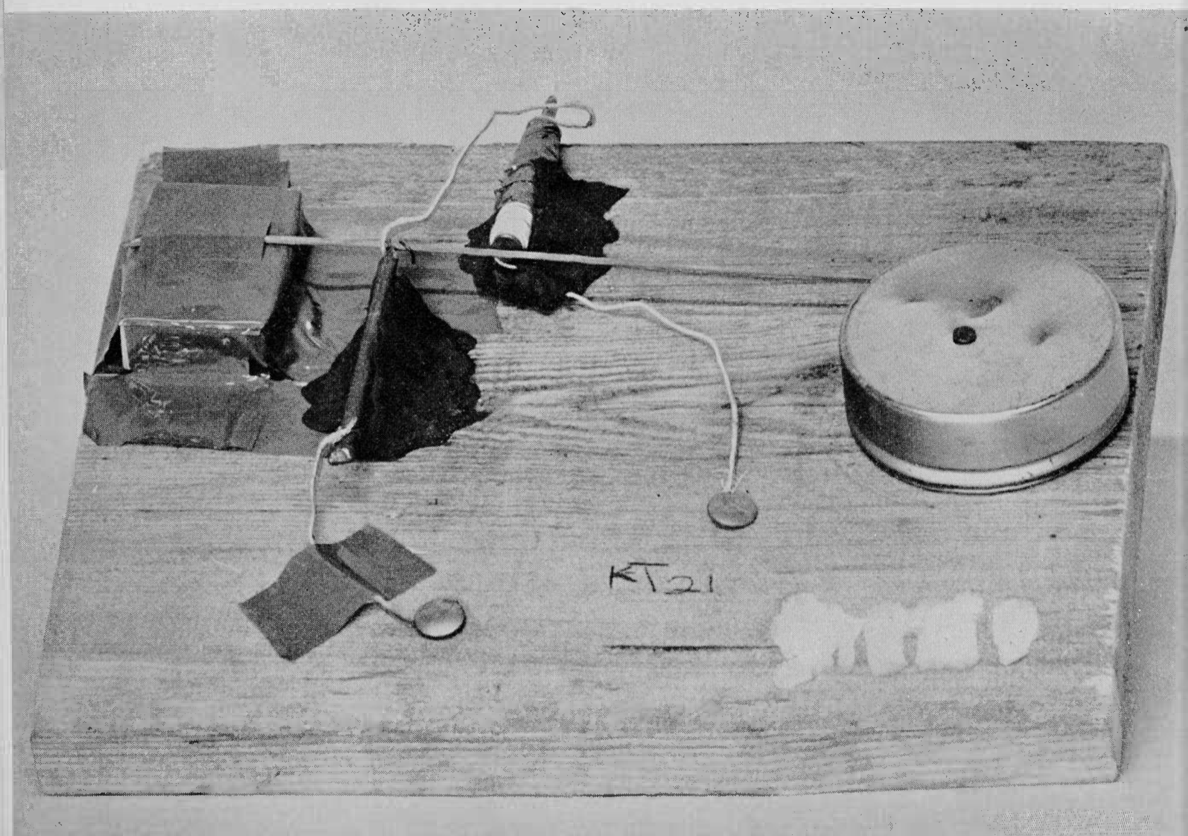
This extraordinarily crude-looking piece of apparatus represents an amazing piece of thinking on the part of the children who devised it. It is, of course, an elementary buzzer circuit involving the electromagnet and the 'make-and-break' principle. From the outset there were problems of size to consider. The basic element of the construction was to be the bicycle spoke which forms both the vibrator and the contact. Thus, a fairly large baseboard was selected. The next difficulty was fixing the spoke so that it had a free end as well as a fixed one and a fair degree of room for movement at a suitable point. This was overcome eventually by pushing the spoke through a matchbox and fastening this end down to the baseboard with Sellotape. This spoke, which was also one of the contacts in the circuit, needed a wire from one of the drawing pin terminals leading to it. It can be seen that this was eventually provided towards the fixed end. This was not how it was constructed at first, but the limitations of the situation were appreciated and the contact adjusted accordingly. The next essential element was the electromagnet. This was made by a familiar means of winding a coil of wire round a nail. This, incidentally, had been softened by heating it in a fire overnight. It became evident that problems of adjustment of the electromagnet would be involved, and this was provided for by mounting it on a blob of Plasticine. The connecting wires needed to be kept well clear of the vibrating spoke, and this was achieved with strips of Sellotape fastening the wire down to the baseboard and leading it carefully round to the other drawing pin terminal. This crude piece of apparatus worked reasonably well. When the current was applied the spoke vibrated and it was sufficiently loose at the matchbox end to make quite an audible sound as it moved to and fro.



16. Buzzer B

This illustration shows how improvements are soon made by children when they view their early efforts critically. The limitation of the preceding crude model soon became apparent, and this Mark II version introduced some new features.

The same essential method of fastening down the bicycle spoke has been employed, and Plasticine still holds the electromagnet in place. However, the points of attachment have been arranged rather differently. It was seen that there were several critical elements in the adjustment of the whole thing. These were provided for carefully, and then the empty tin was placed near enough to the free end of the spoke so that it would act as a gong. When the right position had been determined for this, the 'gong' was fastened to the baseboard with a tack. This whole apparatus made quite a creditable electric bell. Together with the model in example 15, this formed the basis of a teaching situation from which the essential features of the electric buzzer were deduced. The effect of this piece of thinking and teaching can be seen in the illustrations which follow.



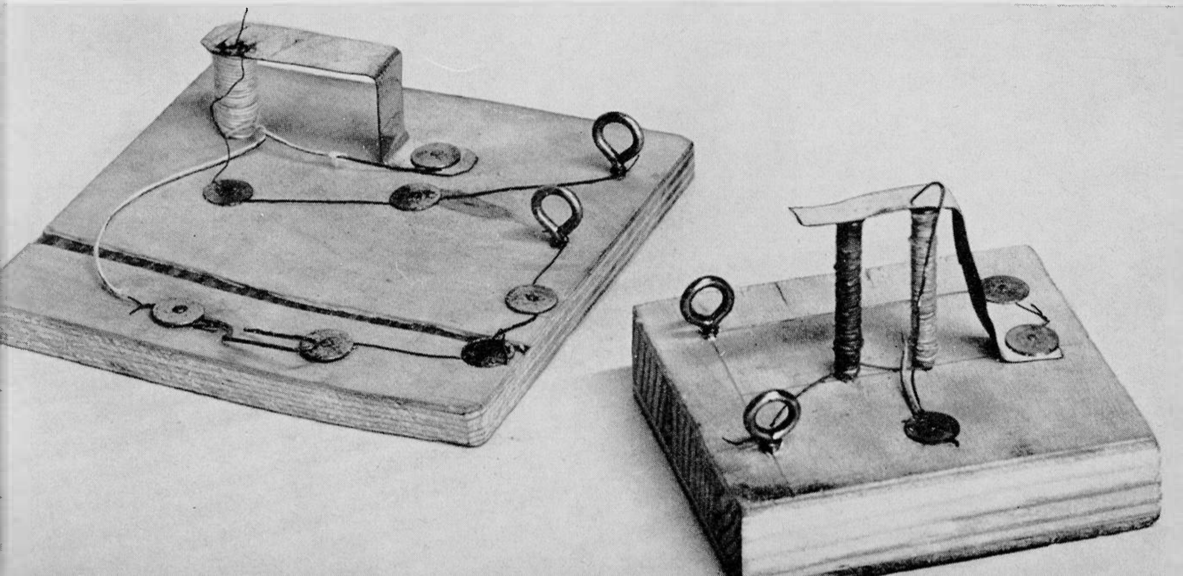
17. Buzzer C

The increasing sophistication of the work brought not only miniaturization, but also buzzers which performed much more efficiently. The model on the right shows the simplest form which first evolved. It was reasoned that if the single coil round a nail provided an electromagnet, then two of them would provide a much more powerful one. This approach in itself led to much experimentation in methods of winding and so on. The vibrator is made from a bent strip of tin plate cut from an old tin. A hole has been made in it with a nail to take the drawing pin which holds it on the baseboard. The tin plate strip has also been bent into approximate position and the make-and-break connection wire has been bent up to come into contact with it.

Precise adjustment is, of course, essential for the efficient functioning of the apparatus. During the construction of the model the tin plate strip and the make-and-break connecting wire had to be so bent that the necessary vibration and make-and-break could take place freely. Fortunately, the apparatus was sufficiently responsive to make a few preliminary noises when the adjustment was nearly correct. With much experimentation correct adjustments were found and the apparatus functioned quite well.

The variation on the lefthand model shows how a single large coil vibrator has had a switching mechanism built into its circuit. This is made from drawing pins and a bent paper clip. It has then been further modified, as an elementary Morse key. In practice, this whole piece of apparatus functioned surprisingly efficiently.

It should be noted that when there is a plentiful supply of scrap wood, the problem of cutting baseboards to size does not arise, as the pupil is able to select material approximately suitable for the job.

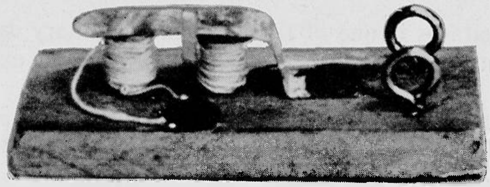


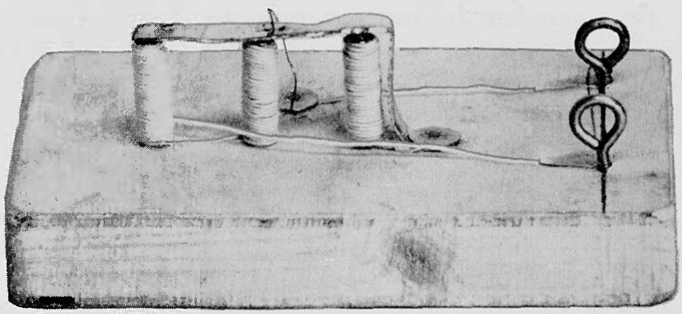
18. Buzzer D

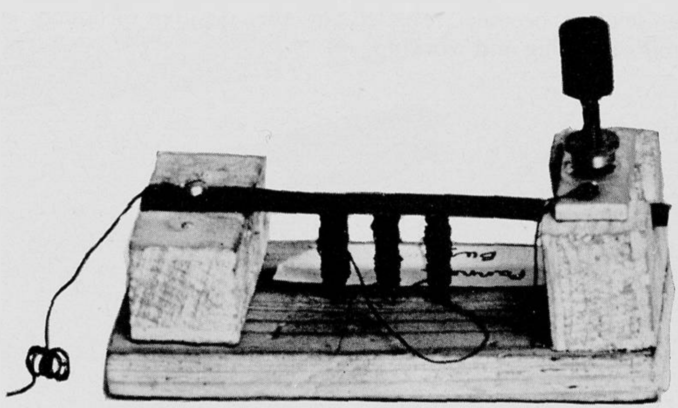
On the opposite page the three models illustrated show final efforts at the sophistication of this material. At the top of the page there is a surprisingly small version. By experiment it was found that power can be given to the electromagnets by making small ones with a larger number of turns of wire on them. After several attempts the whole thing was reduced to the sizes shown in the photograph.

In the middle of the page there is a model incorporating three electromagnets. This was a further stage in the pursuit of the problem of making the whole apparatus small, yet powerful. Quite a good effect was achieved by this model, but it threw up into highlight the need for constant adjustment to the vibrator. Much discussion centred around this problem and the resultant solution to it is seen in the model at the foot of the page.

The buzzer at the foot represents the limit to which these particular children were able to refine their material. The modification in design has allowed the use of a miniature hack-saw blade as the vibrator, sufficient power is given by the three electromagnets, and an interesting method of adjustment in the amount of vibration has been provided by the threaded adjustor at the end. This particular part of the apparatus was brought by one of the children from his home, where, of course, it had been used for quite a different purpose altogether. The production of this last piece of apparatus marks not only a very surprising development of skill, but also a high degree of planning and thoughtful insight. Many problems of design arose in the production of this piece of work. It is noteworthy, though, that it really has its roots in the crude apparatus which preceded it, described in examples 15, 16, and 17. Essential experiences that children have can remain either isolated or can be linked and synthesized to produce progress in all sorts of directions.







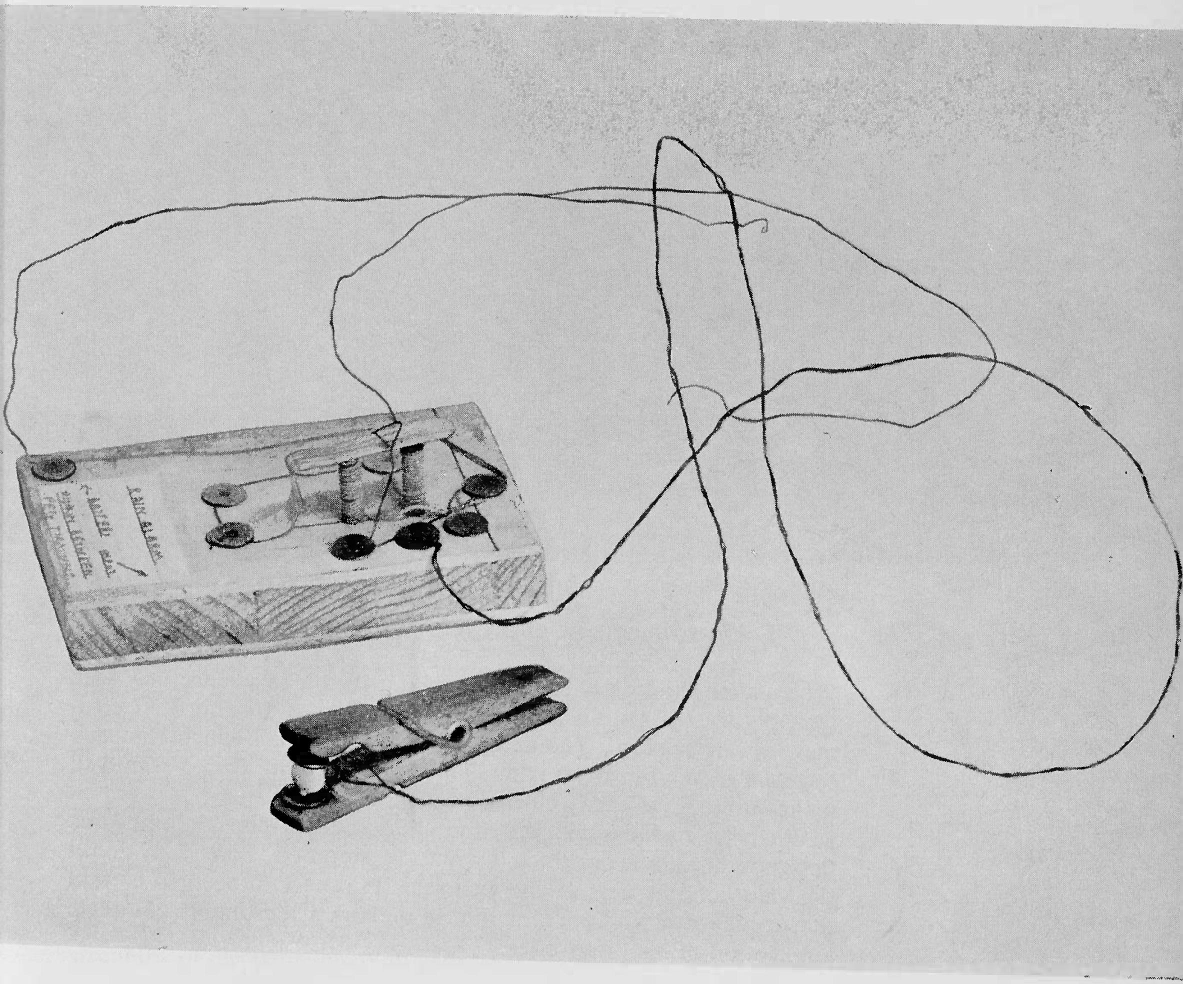
19. Rain alarm

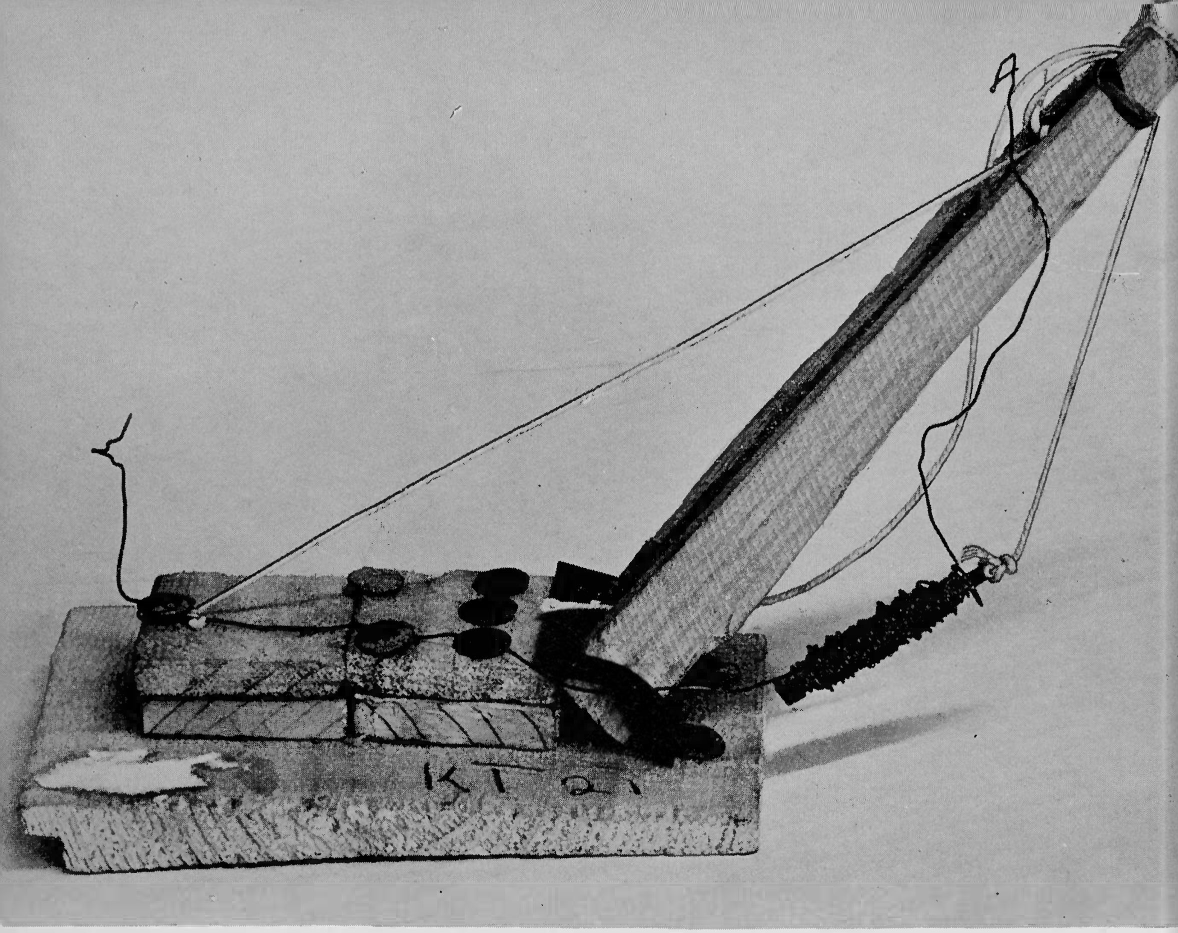
This apparatus is one of the most extraordinary developments. It also illustrates most clearly the essential link that exists between the scientific fact and its application in concrete terms. A most efficient buzzer had been made following the pattern of the previous successful models. This was now to be incorporated in a device which was called a 'rain alarm'.

The buzzer has a fairly long length of lead made up specially by the children. The lead terminates in two drawing pins which are placed on either side of the inside of the jaws of a spring peg. The jaws of the peg are kept apart with a junior Aspirin of the extremely soluble variety.

The peg device was placed outside the classroom through the window in an exposed position where any rain falling would soon moisten it. When the Aspirin became moist, it crumbled and allowed the jaws of the peg to close; this completed the circuit and sounded the buzzer.

Here is a complete synthesis between a project, an elementary scientific discovery, and its application in terms of a simple worthwhile device. The chain of problems posed by various difficulties in the creation of this apparatus can easily be seen. They ranged from finding a suitably soluble Aspirin tablet to making up a fairly long length of wire with the materials that were available. The idea of using the spring peg itself was most commendable, to say nothing of using the drawing pins to make contact at the end of the jaws. Work of this order is not only most encouraging to the child, but worth while, too, for the teacher, as the underlying aims of the science become revealed in the positive products of the pupil's thinking and working.

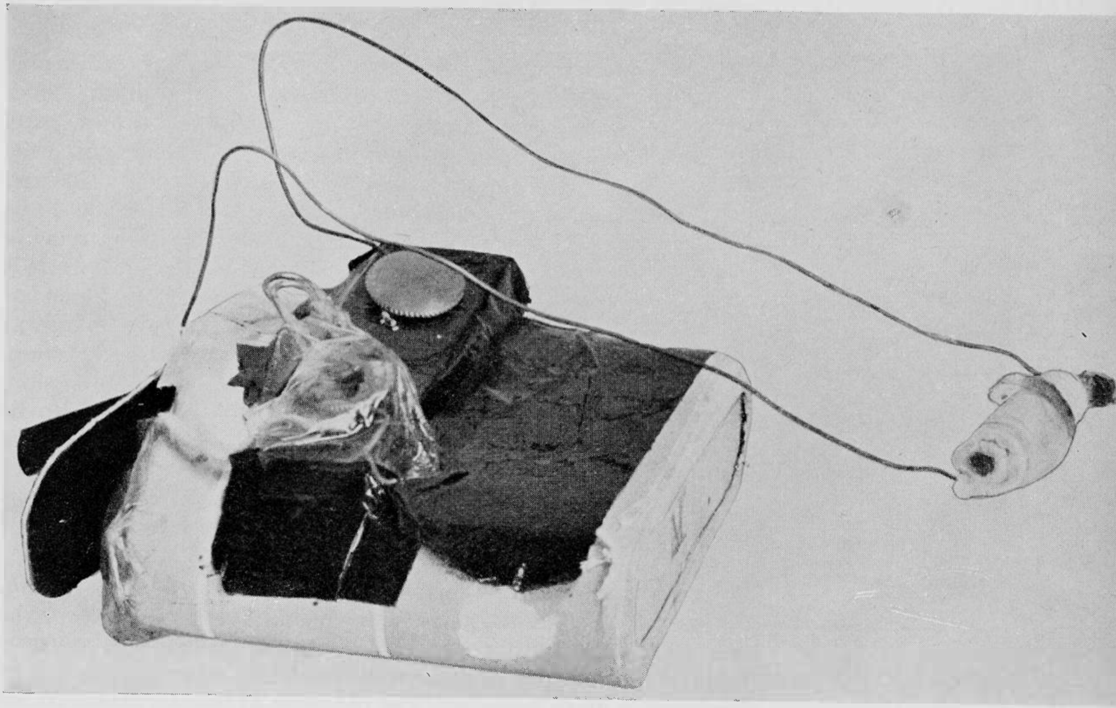




20. Electromagnetic effect A

When some children have discovered a principle in science they seek to apply it. In this illustration an application of the simple electromagnet can be seen. The magnet is wired to a nail which has been softened in the fire overnight. This, with the wire coiled round it, makes quite an effective electromagnet.

When he had devised this, the child spent a considerable time designing the crane on which it was to be mounted. Some may doubt the value of this part of the exercise. However, it seemed certain that it played a vital part for him in making a reasonably complete application of his discoveries.



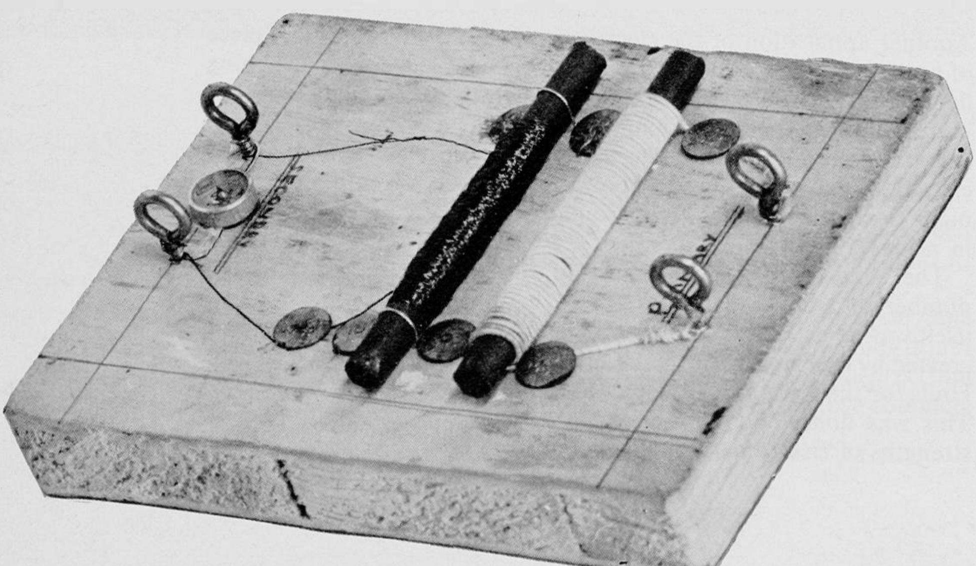
21. Electromagnetic effect B

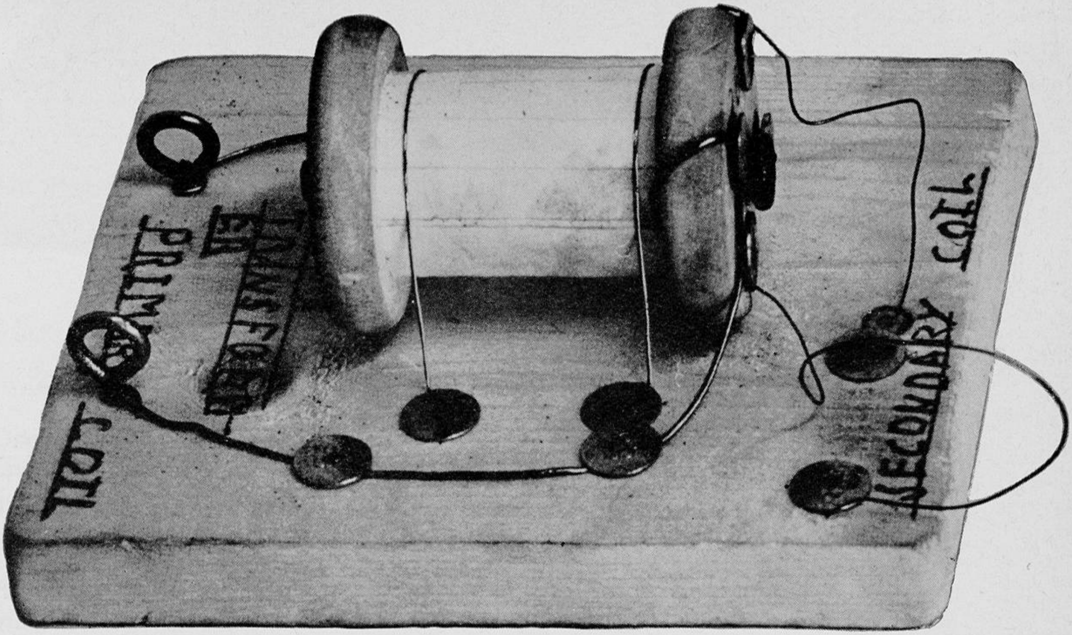
Another application of the electromagnet is illustrated in this piece of apparatus designed to be a pocket version. The simple switching device consists of a piece of balsa wood stuck with Sellotape to the battery front, with two joining contacts and a paper clip 'switch' swivelling around one drawing pin. Connections are made to the electromagnet which is a short bolt that has been left in the fire overnight to soften the iron. It is wound with three layers of wire held in place with layers of Sellotape.

The children tested the power of this magnet in terms of the number of tacks and the weight of nails it could raise. This in itself was an extension of their thoughts about the situation they had created by making this device—here was the need to test its efficiency. Units for the testing had to be devised and suitable tests carried out. This was done, and units of measurement for the calibration of strengths of electromagnets in general were produced.

22. Electromagnetic effect C

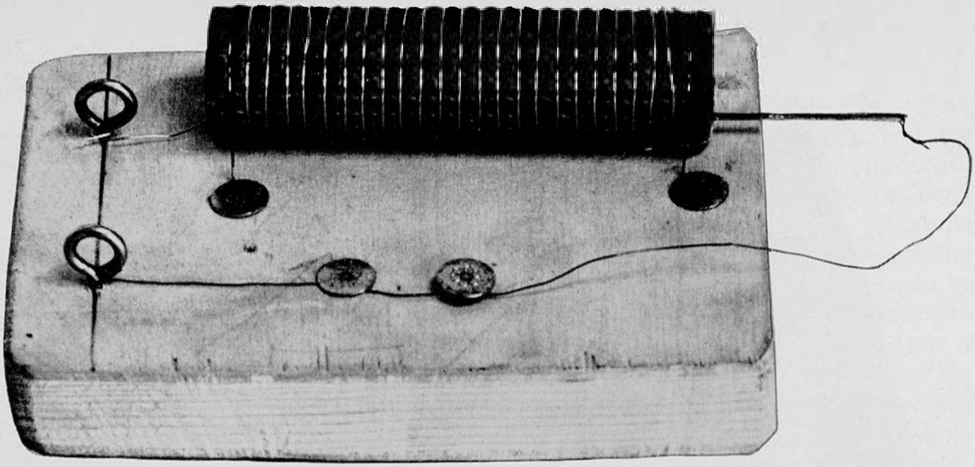
Intervention by the teacher is vital at strategic points if the learning process is to go forward in a worthwhile manner for the child. One such point is illustrated by the apparatus shown here. After much work on making electromagnets the teacher posed the question what might happen if two were mounted side by side and at a short distance from each other. A current detector was to be wired into one side of the circuit. The teacher left the child trying to devise the apparatus with which to investigate the problem. Here is the completed job. At the teacher's suggestion one electromagnet has been wound with thicker wire than the other. Otherwise there was no intervention by the teacher beyond the posing of the question. However, once devices of this sort are made, much discussion, involving the teacher, is necessary for the maximum worth to be gained by all from the children's discoveries. Note that small metal eyes have been used as connectors and that drawing pins hold wires in place. The cores of the electromagnet are sections cut from four-inch nails softened in the fire overnight. A plotting compass is used in the current detector which can be seen across the terminals at the left of the picture. The apparatus is mounted on a block of wood. It is interesting to see the guide lines which the child has ruled on the wood so that the components could be spaced evenly. This contrasts sharply with the work of other children, where a random placing of equipment is more apparent. The precision of this apparatus would be worth drawing to children's attention.





23. Electromagnetic effect D

The investigation of electromagnetic phenomena is taken a step further in this example. The coils are wound one on top of the other, with a wooden reel as a former. A nail has been inserted into the hole in the former to make a metal core. The coil is held in place on the baseboard by wire fastened across it with drawing pins on either side. The other connections are led either to eyes on one side or to drawing pins on the other. This piece of apparatus could open the way to a great deal more work. It also represents one of the points at which this work may be best set aside, as it marks a point of difficulty beyond which many children will find it hard to pass in terms of genuine discoveries. This was felt by the teacher to be one of the situations when interest could be deflected to the related topic of the behaviour of electricity in different substances, particularly in different kinds of wire. Example 24 shows how this was developed.



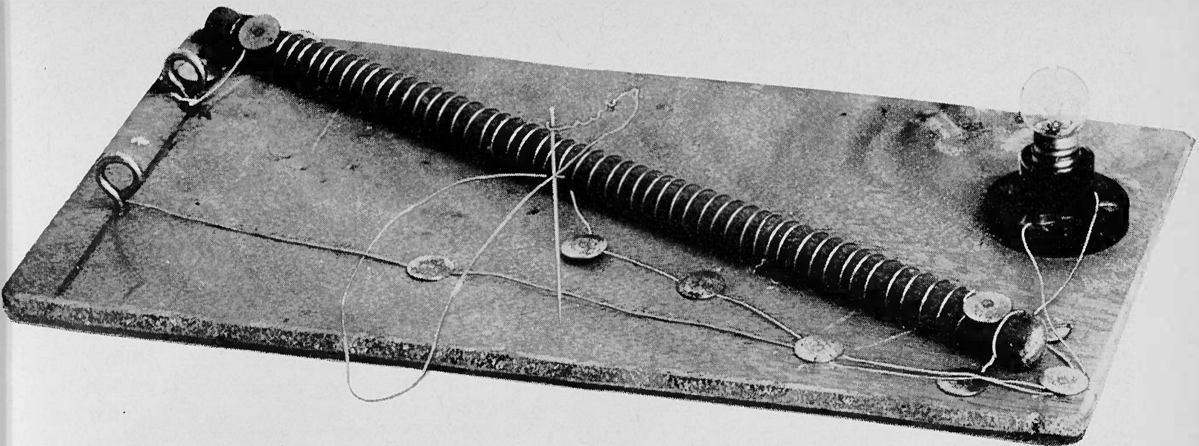
24. Resistances A

Lengths of nichrome wire were made available to a group of children who had previously experimented with the electromagnet and coils. The illustration above shows the sort of equipment that emerged as a result of experimentation with lengths of wire. The rather unruly straight length of wire has in the end been wound onto the cardboard tube to make it more manageable. A needle on the end of a length of wire makes a suitable movable contact.

When this piece of apparatus was wired to a lighting circuit its effective control of the brightness of the lamp was noted. This led naturally to the development of the apparatus by another child using much the same idea, but this time incorporating a lamp into the circuit itself. This is illustrated in example 25.

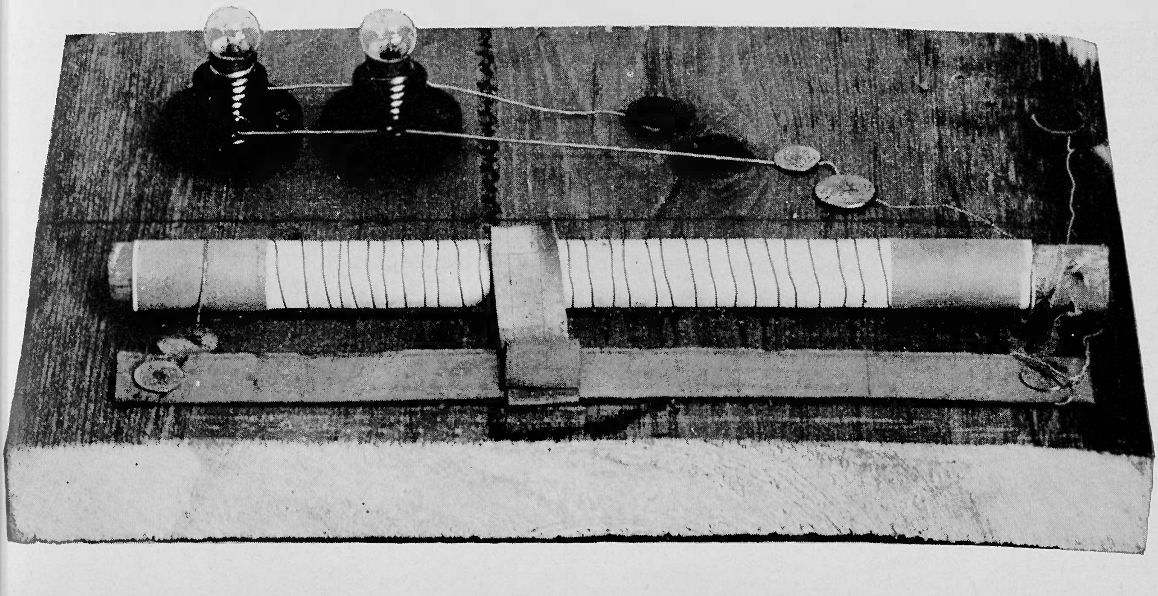
25. Resistances B

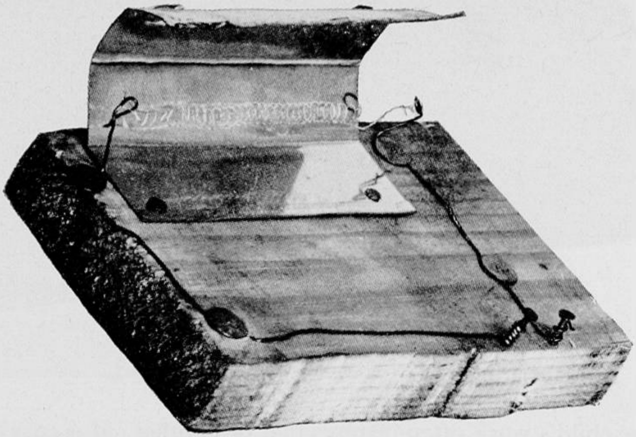
It will be seen from the photograph at the top of the next page that this variation of the previous theme is in some ways more ambitious. A much longer piece of resistance wire has been wound around the length of wooden rod. The same device for the variable contact is used here. An interesting variation on the previous piece of work is the introduction of the lamp holder. The children discovered that when a battery was connected to the metal eyes which act as terminals, the illumination of the lamp could be controlled by moving the needle along the wired rod. The diagonal mounting of the rod on this piece of wood shows some ingenuity in accommodating the materials available to the purposes in mind.



26. Resistances C

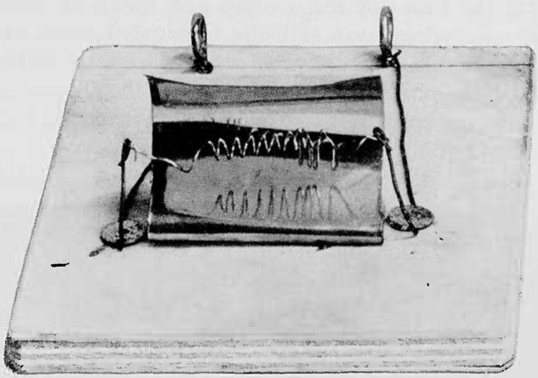
One child's work often inspires that of another. It is easy to underrate the value of this sort of thing in the teaching and learning situation. The illustration below makes this point well. Here a child has taken the basic theme as exploited by other children and improved upon it immeasurably. Here there is a variable resistance controlling two lights mounted on the same baseboard. It will be seen that the circuitry, too, is interesting, in that the lamps are wired in parallel and both are interconnected with the resistance. The resistance itself consists of wire wound round a piece of rod as a former; pieces of case strip form the slide for the contact and also the contact itself. This piece of mechanism was skilfully fabricated from very crude materials. The whole concept was worked out to form a most effective piece of equipment. Also it shows well the advance, not only in an appreciation of the fundamentals of the situation, but also in thinking of technical improvements.





27. Resistances D

The child's lively interest allows him to see leads in many directions. Investigating some of the properties of resistance wire and talking about them with the teacher led some children quite naturally to produce miniature models of everyday applications of these properties. Here are two illustrations of model electric fires made from

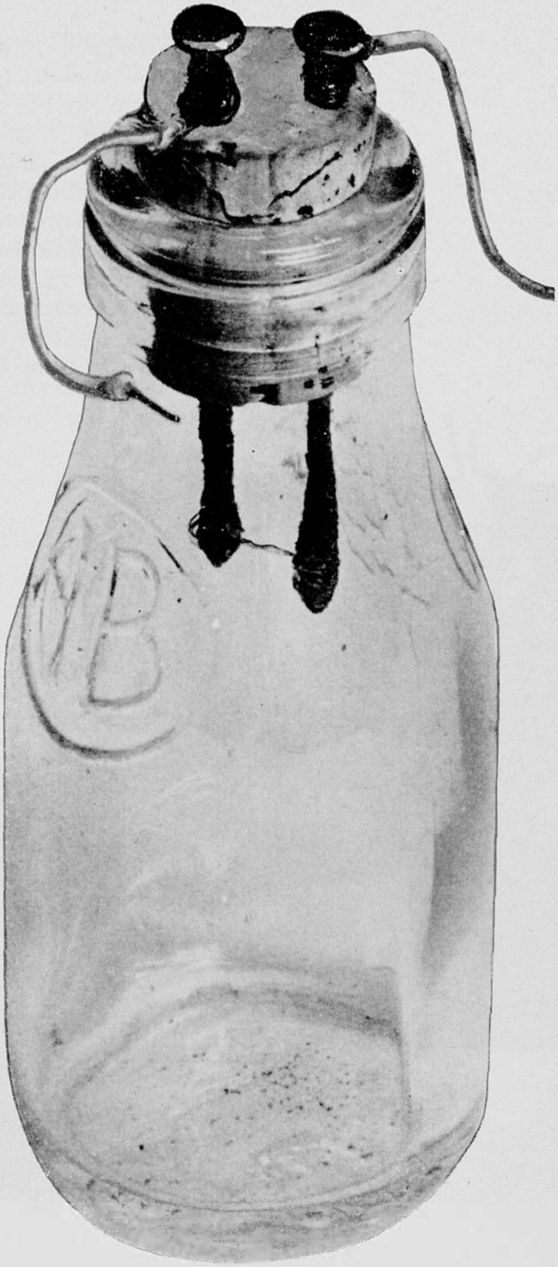


short lengths of resistance wire. An appreciable amount of experiment was needed to produce suitable lengths of wire for this purpose. The reflectors were added primarily to give realistic effect to the models. Had the children and teacher wished, there would, of course, have been opportunity for further work to have developed here.

28. Resistances E

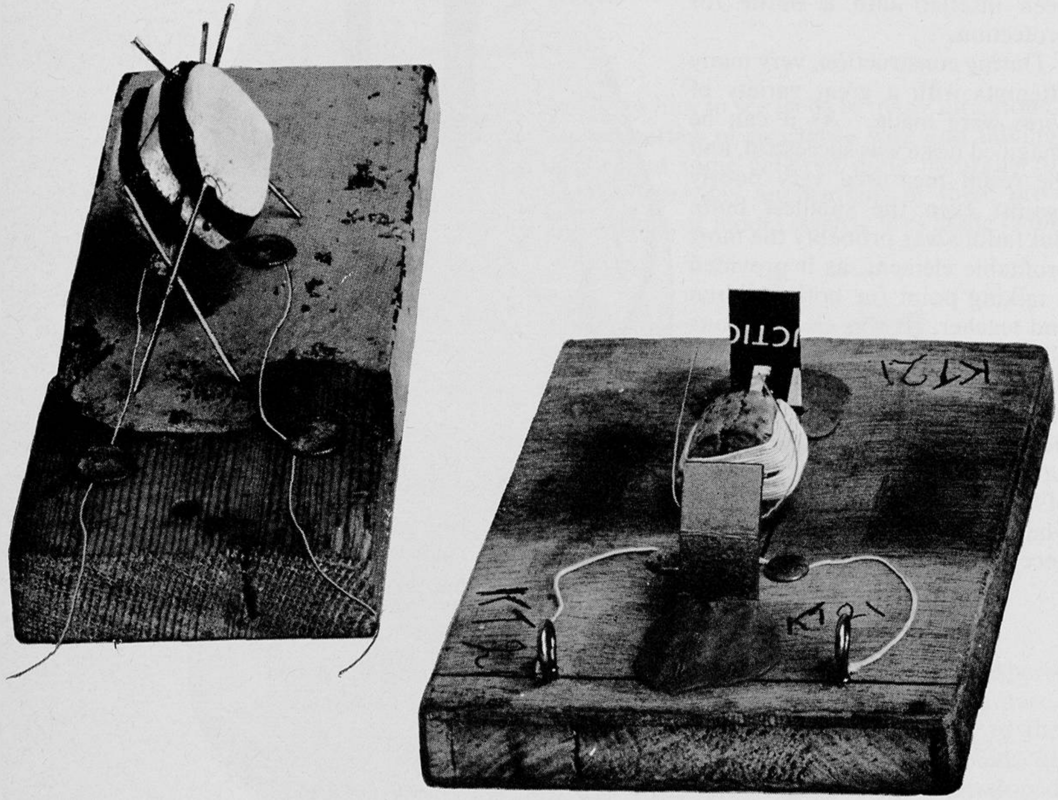
It is a short path of progress from experimenting with a miniature electric fire to attempting to make an electric light by similar means. The route to success is, however, a much longer one, as the child found. The illustration here shows the basic apparatus around which this work centred. A large cork holds two nails which act both as contacts and as spacers for the lighting element. This has been inserted into a bottle for protection.

During construction, very many attempts with a great variety of wires were made. As it can be imagined none was successful, and the result measured very poorly against even the smallest bulb. But failure was probably the most profitable element, as it provided a talking point for both children and teacher. It was also a means of bringing children to the use of books in science, once they had set aside their firsthand work. Both first- and secondhand means have their places in the education of the child, and it is fortunate when they can be given significance in situations such as this one.



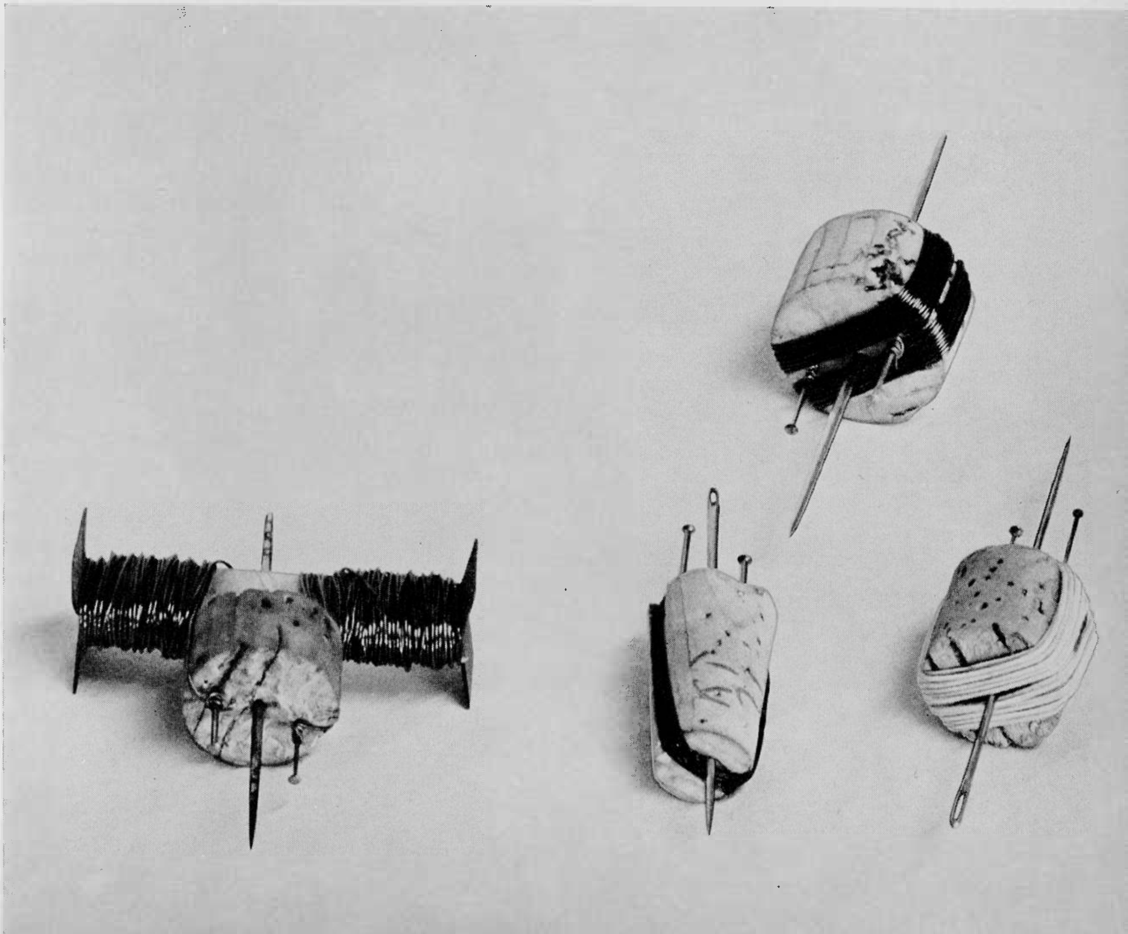
29. Electric motor A

Wood for baseboards needs to be about half an inch thick. Bearings for an armature can be made easily from needles inserted into the wood at angles to each other as illustrated. End play, which is rather a problem when a motor is running, can be checked by means of simple cardboard brackets placed at either end of the main shaft. These brackets can be held in place with a blob of Plasticine, drawing pins, or Sellotape. The armature should be extremely free-running in its bearings. A steel needle used as the main shaft for the armature should prove satisfactory in bearing against the steel of the needles which form the main bearings. The brushes which convey the current to the coil are made by merely allowing two contact wires to touch against contacts sticking out of the armature.



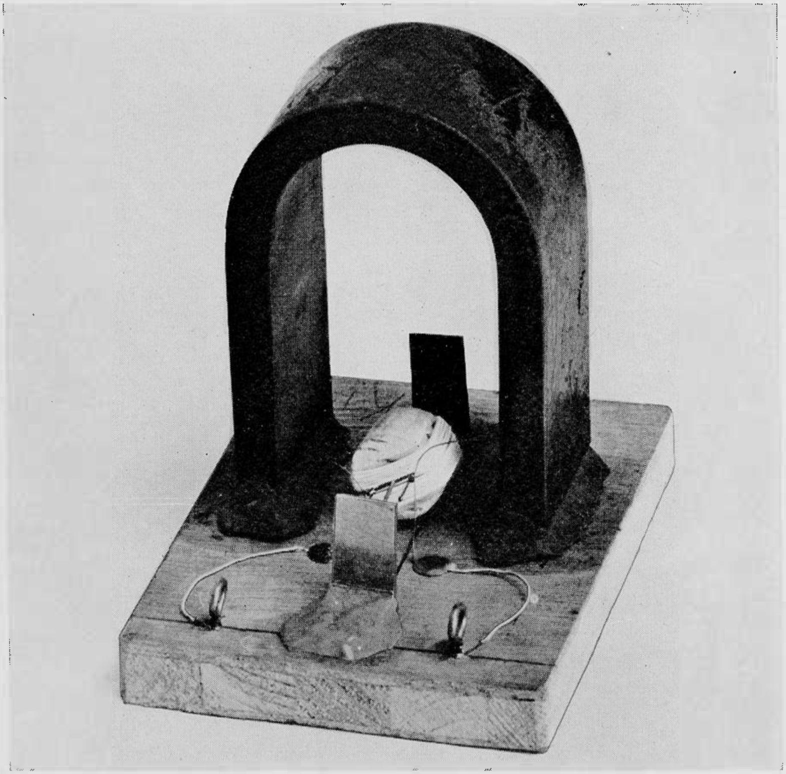
30. Electric motor B

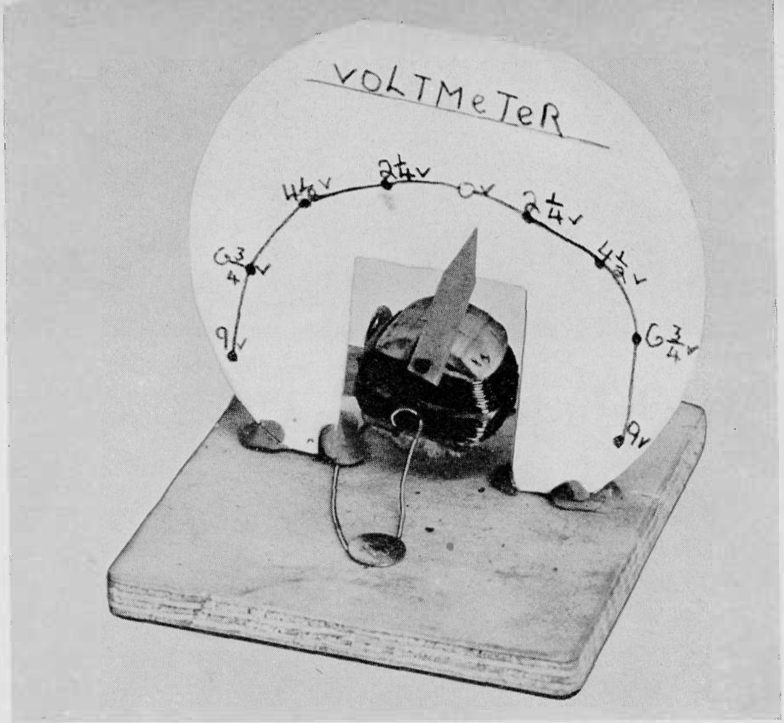
This illustration shows a group of armatures ready-wound. The body of the armatures is conveniently formed by a cork, but a piece of shaped balsa wood will serve. It was part of the experimental procedure for the children to discover the best form of winding for the armature, the most effective number of turns of wire, the best weight of wire to use, and so on. The contacts to the pins, which will in turn touch against the brushes, should be tightly made. The positioning of the cork form on the needle which acts as a shaft is important, and the best point of balance can be found by trial and error. The armature should spin very freely when placed on the bearings. In practice, the large armature which is illustrated in the picture was not really successful as it introduced mechanical problems in the design of the motor with which the pupils were not ready to deal. The lighter cork or balsa wood based models worked much better.



31. Electric motor C

A completed motor is illustrated here. Some points worthy of note are the outward position of the wire which forms the brushes, and the fact that a very strong permanent magnet was used. This makes for the most effective kind of motor of this design. To run easily the motor requires at least $4\frac{1}{2}$ V. It should also be kept in mind that it will not be of the self-starting variety, so that an initial spin will be needed to get it to start when the batteries have been connected. When the motor is in operation small adjustments to the position of the permanent magnet can be made so that the most effective position for it is found. This should then be marked on the baseboard. Thus the apparatus can be dismantled, when the motor is needed for another occasion, and re-assembled quite easily. These are awkward items to store unless they can be taken apart.

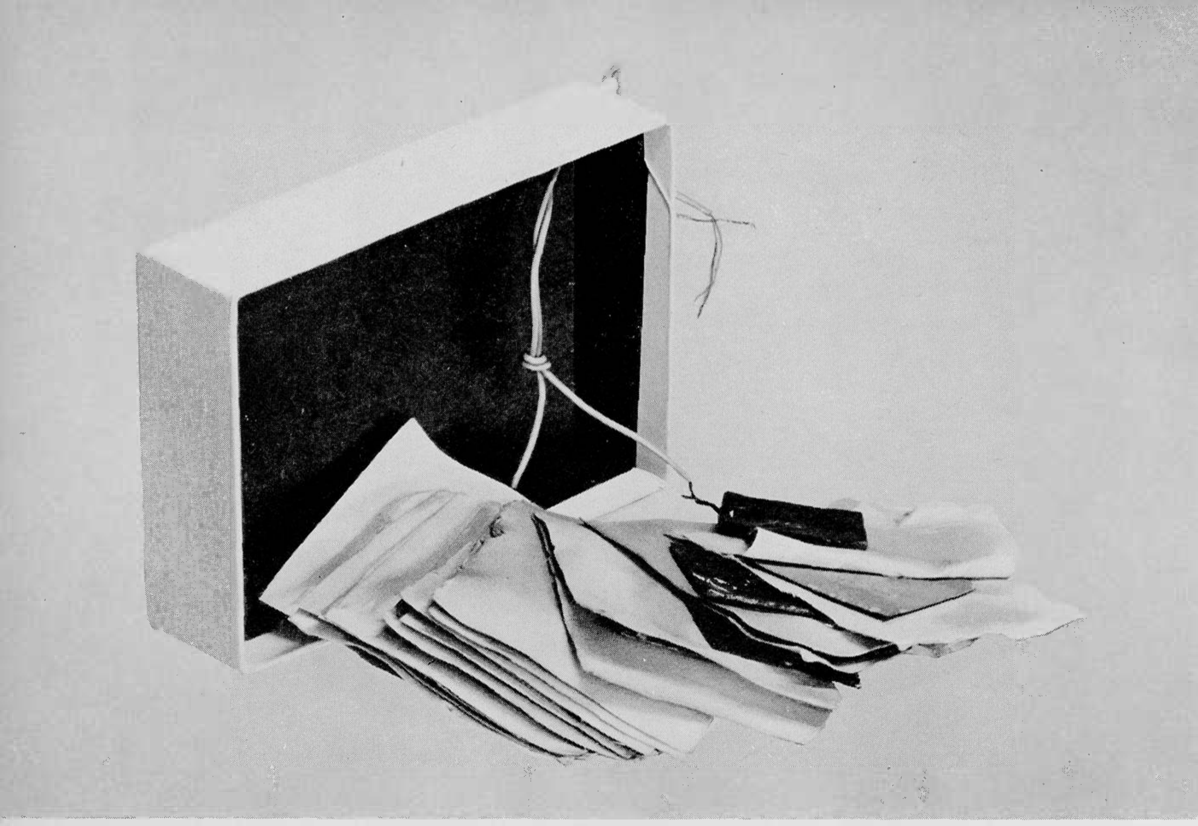




32. Voltmeter

After the construction of some of the electric motors, one boy's interest branched and led him to attempt the making of a simple voltmeter. This illustration shows the finished job. It is calibrated against batteries of measured voltage. The effect of the reversing of polarity has also been discovered and is provided for on the dial of the instrument. Basically it consists of a suitably wound armature which carries a pointer and is mounted in bent wire bearings which in turn have been brought into the circuit. The whole apparatus is mounted on plywood and the calibrated card is fastened to it with Plasticine. The magnet is housed behind the card.

Though this was a crude attempt at instrument-making it reflected considerable thought on the pupil's part and a really creative attack on one of the basic problems of science, that of instrumentation and measurement. This piece of work could well form the foundation for many further discoveries, not only in this immediate field, but in the wider one of measurement and its use as a tool in the hands of the scientist.



33. Wet cell

As work proceeded, so interests widened and the children's awareness of the application of some of their discoveries to the field of everyday life increased. This wider curiosity brought the posing of a great number of questions and a desire to carry out investigations over a wide field. Some of these fields the teacher recognized as being potentially useful for the child to work in. Others were less profitable, as some of the examples illustrated on the following pages will show. The illustration shows an attempt to make a simple cell. The girl who made it described it aptly as a wet cell. It consists of alternate zinc and copper pieces separated by blotting paper saturated in brine. When it was set up its effectiveness was tested on one of the simple current detectors that the children had made earlier. Some of these are illustrated in the previous pages. The cell certainly provided a current, a very weak one, not enough to light even a 1·5 V bulb!

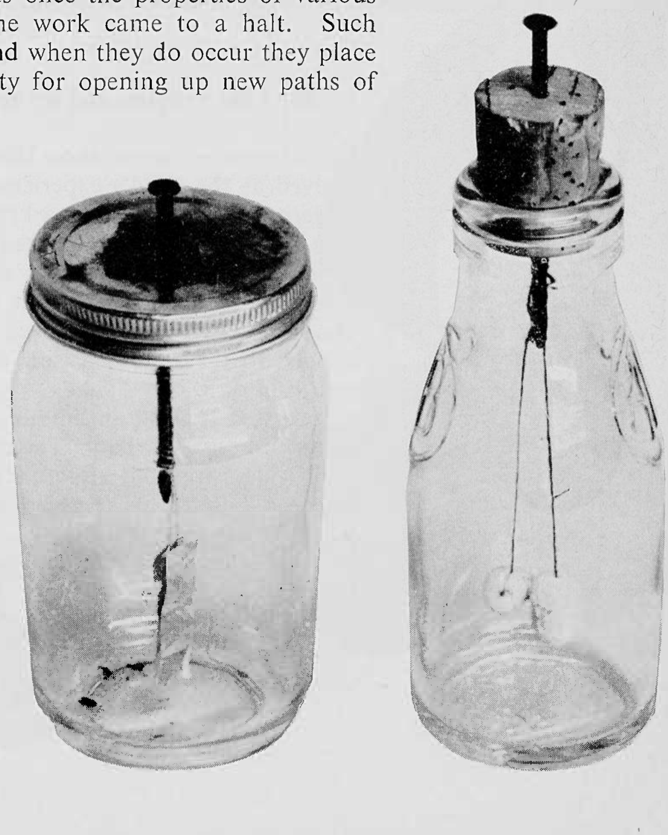
34. Electroscopes

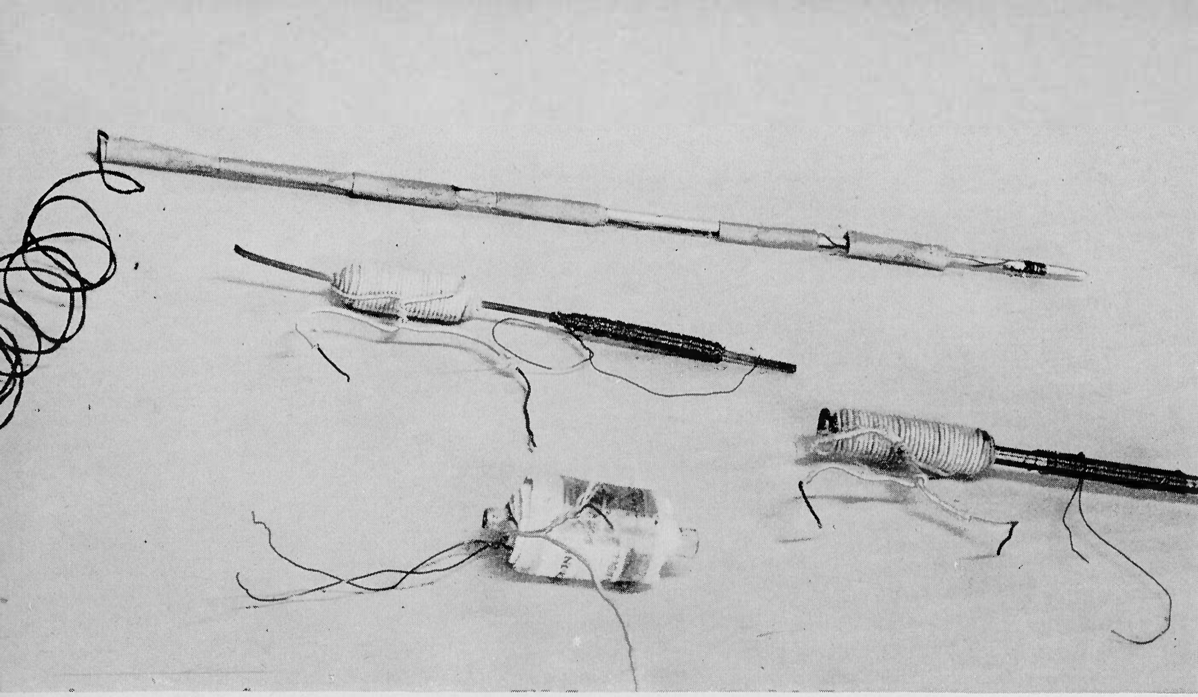
This work with electricity had naturally heightened the children's interest in books about the subject. The illustration shows two electroscopes they made. This was inspired by work they had been reading about. Both models worked effectively and gave interest and amusement for some time.

The model on the left consists of an empty jar with a metal top. A hole is made in the metal top so that the nail will fit fairly loosely. This hole is then filled with sealing wax. The nail is heated in a candle and then put carefully through the wax so that it is insulated completely from the rest of the metal top by a layer of sealing wax. Thin pieces of aluminium foil are tied to the end of the nail. The nail and the foil are then carefully inserted into the jar and the top is screwed down.

The model on the right shows a nail pushed through a cork to which two pith balls have been attached by thread. A bottle of a suitable size has been found to hold the whole piece of equipment.

Interesting though these pieces of work are, they proved in practice to be of limited value, as once the properties of various materials had been discovered the work came to a halt. Such occasions as this are inevitable, and when they do occur they place upon the teacher the responsibility for opening up new paths of interest for the children.





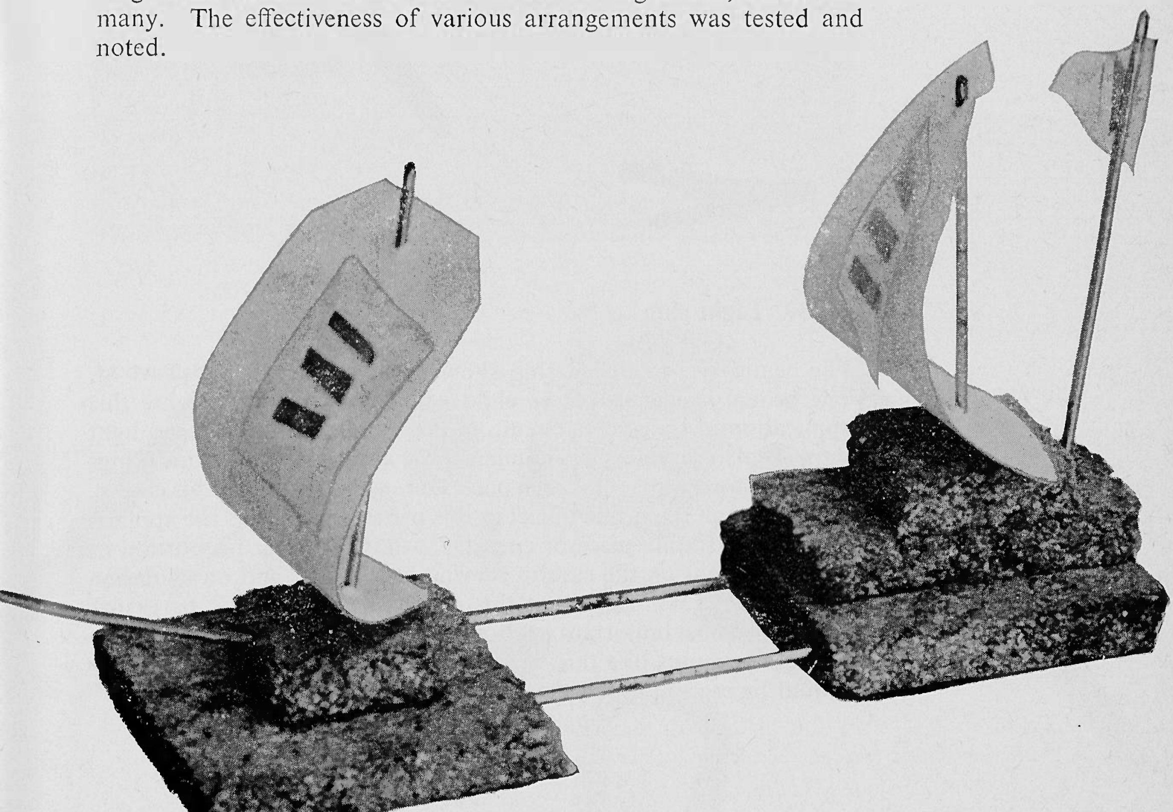
35. Coil winding and its applications

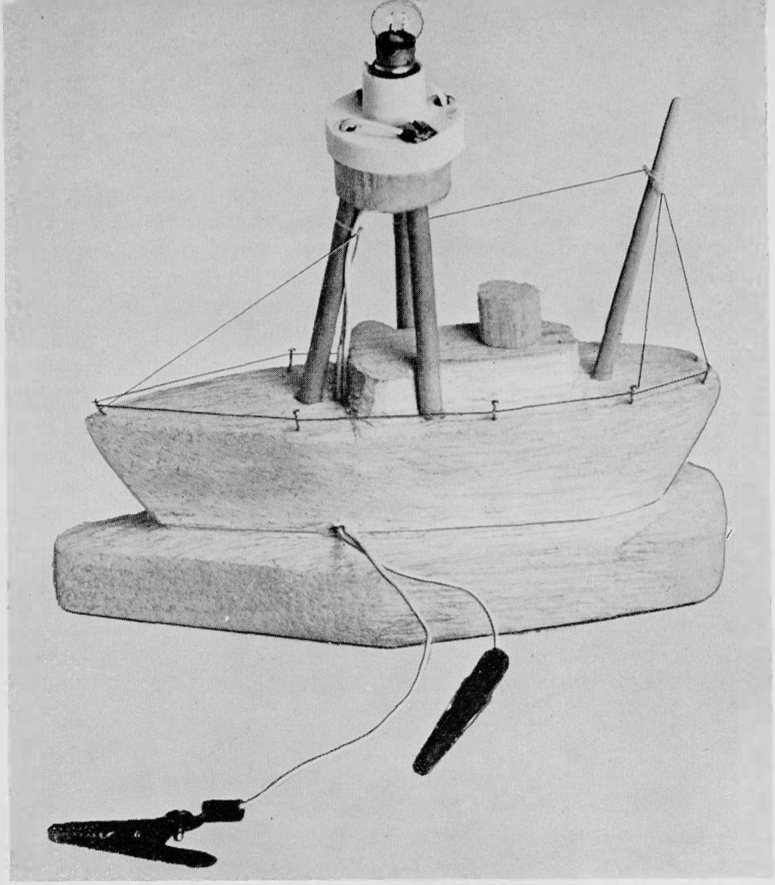
This illustration shows three interesting pieces of coil winding which evolved as the child's experience enlarged. The fourth object is a soldering iron, made from a knitting needle. In the last, the supply wire for the current is fastened to the needle with layers of sticky paper put round it, and at the end a short length of nichrome wire is wound tightly onto the bare metal of the knitting needle. The children found that when a current from a 6 V battery was applied to the soldering iron, the end became just hot enough to melt thin resin-cored solder. Whilst the life of the tool was short it represented a most ingenious attempt to reproduce an everyday application of electricity. The coil winding was noteworthy not only for its precision, but also for the evolution of the thinking, which led eventually to the production of the induction coil which can be seen in the foreground. Here again it would have seemed opportune to build upon this structure which the children had made for themselves by their own discovery. However it was equally wise to set it aside, for the order of difficulty of the problems that were arising was such that the children had neither the maturity nor the skill to cope with them, or in some cases even to recognize them.

36. Magnetic boats

The simple boat illustrated below has several interesting features about it. Basically it consists of pieces of cork to represent the boat's shape. These are joined by two needles previously well magnetized by stroking them with a strong magnet. They are placed so that the north-south polarity is running fore and aft of the ship. The other needles which form the masts and the bowsprit have also been magnetized and placed suitably so that their polarity will in the main follow that of the two needles in the base.

When the children had made this, they worked out an ingenious remote control system by exploiting the field from several strong magnets which they placed around the plastic bowl in which the boat was floated. A valuable by-product to this piece of work was the building-up in the children's minds of the idea of fields of influence, in this case of the magnetic field. They made several versions of this model ship, each with different arrangements of the magnetized needles. Some had few needles magnetized, others had many. The effectiveness of various arrangements was tested and noted.



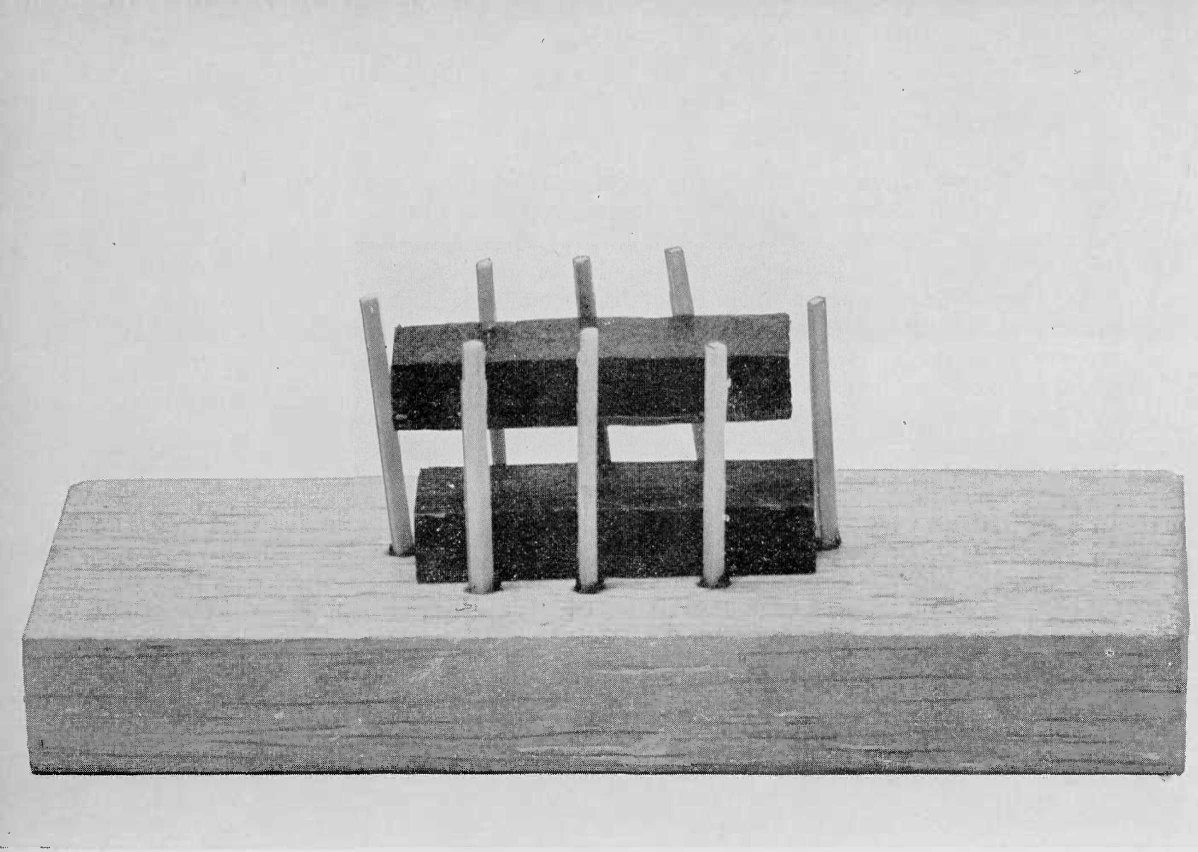


37. Light ship

The beautifully modelled ship shown here is made of balsa wood. The primary purpose of the child who made it was to house this application of the simple circuit, in the form of the model of a light ship. It also serves as a reminder of the child's need to work things out in his own way, at his own pace, and in the medium of his choice. And although the prime object in this piece of work was the application of this simple piece of circuitry, a much greater proportion of time was spent on the careful carving of the boat and on its design and finish. It was right that this should be so, for this particular child. It is most important to allow opportunities for ranging round a point of stimulus like this. Children need to do this, and teachers should be ready to offer them the chance as it occurs.

38. Magnets

This illustration shows the range of magnets and allied materials that it is helpful to have available for the children's practical experimentation. A piece of lodestone forms a useful link with work in history, which may well provide a starting point for some investigations. Phenomena in magnetism are better discovered if the magnets in use are really strong. The two 'Eclipse' type bar magnets shown are extremely useful in this context. The larger power magnet, which is horseshoe-shaped and has the thicker metal keeper (and is also made by Eclipse), is the type to have for magnetizing other steel objects such as hack-saw blades, knitting needles, or bicycle spokes. Each of these steel objects has proved extremely useful for this kind of work. The traditional type of cylindrical magnet has a part to play, though its power is often disappointing in comparison with the others. When smaller sizes of magnets are required, the button and small bar magnet, also made by Eclipse, are versatile pieces of equipment to have. In the centre of the picture a cheap type of horseshoe magnet is shown. It is wise to have magnets of various strengths available as these in themselves pose questions which it is well worth the child following up.

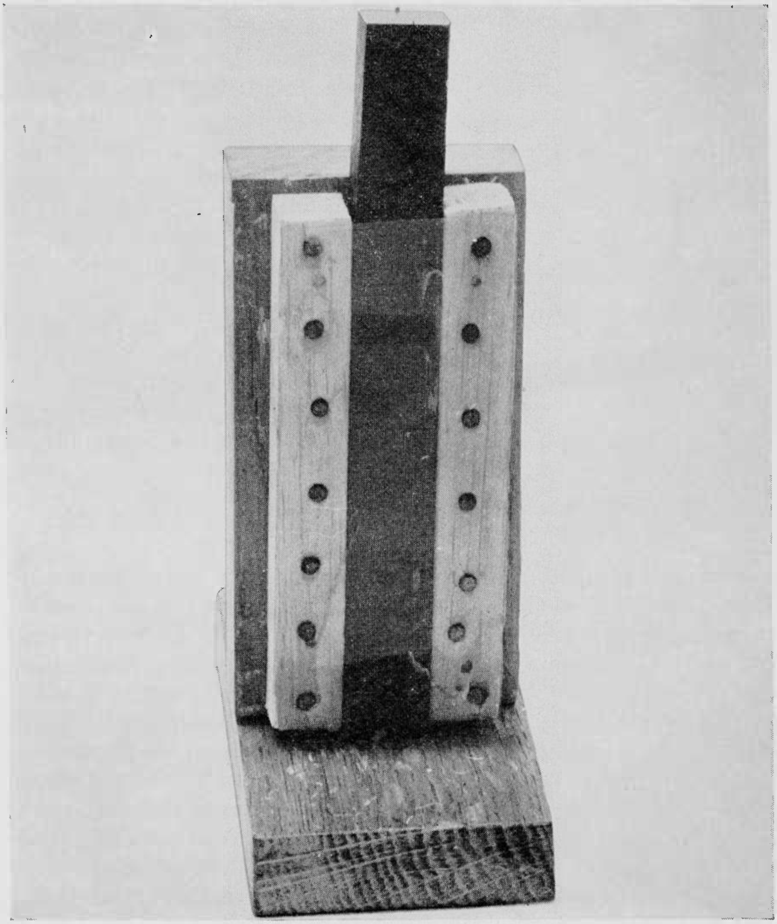


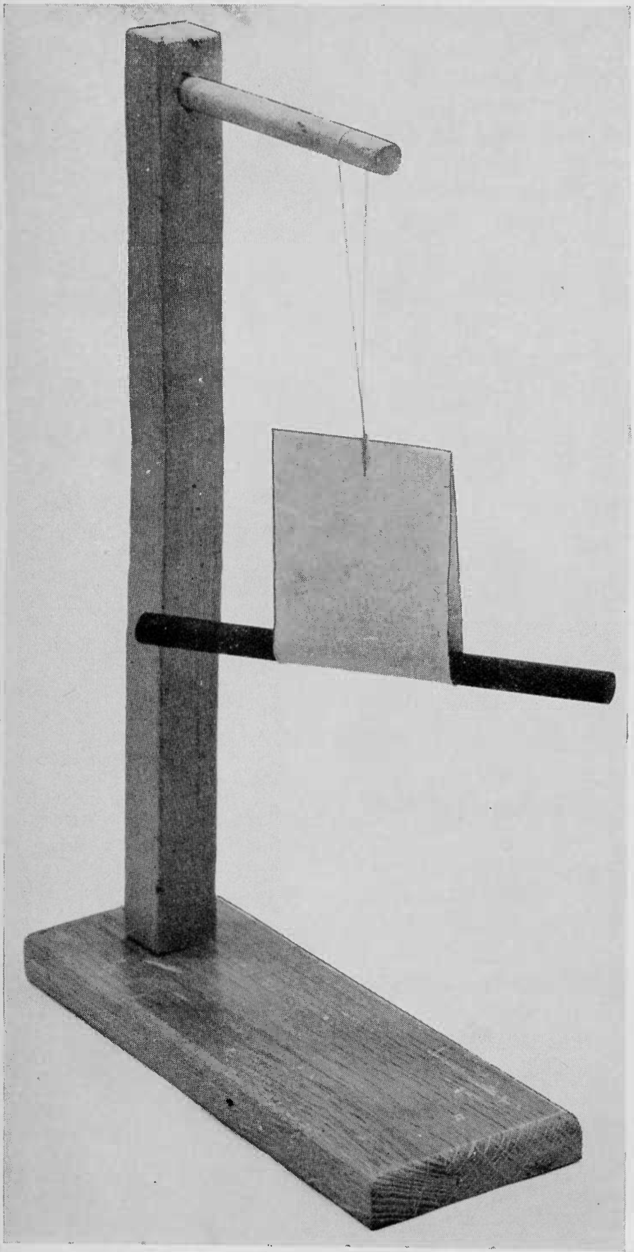
39. Magnetic repulsion A

Whilst one of the earliest experiences of children when they play with magnets is of the power of magnetic attraction, it is equally important that they should experience magnetic repulsion. The illustration shows an interesting way of posing queries about this phenomenon without the active intervention of the teacher. This is the kind of object the teacher may like to leave out at some convenient point in the classroom, say on a display table or in a work corner. It consists of a block of balsa wood pierced in eight places with a bradawl and with matchsticks inserted in the holes. The spacing is sufficient to accommodate two Eclipse bar magnets. The effect can clearly be seen from the picture. This apparatus, too, opens the way for investigation into the working of many magnetic toys. By analogy the children can begin to understand how these toys work and how they are constructed.

40. Magnetic repulsion B

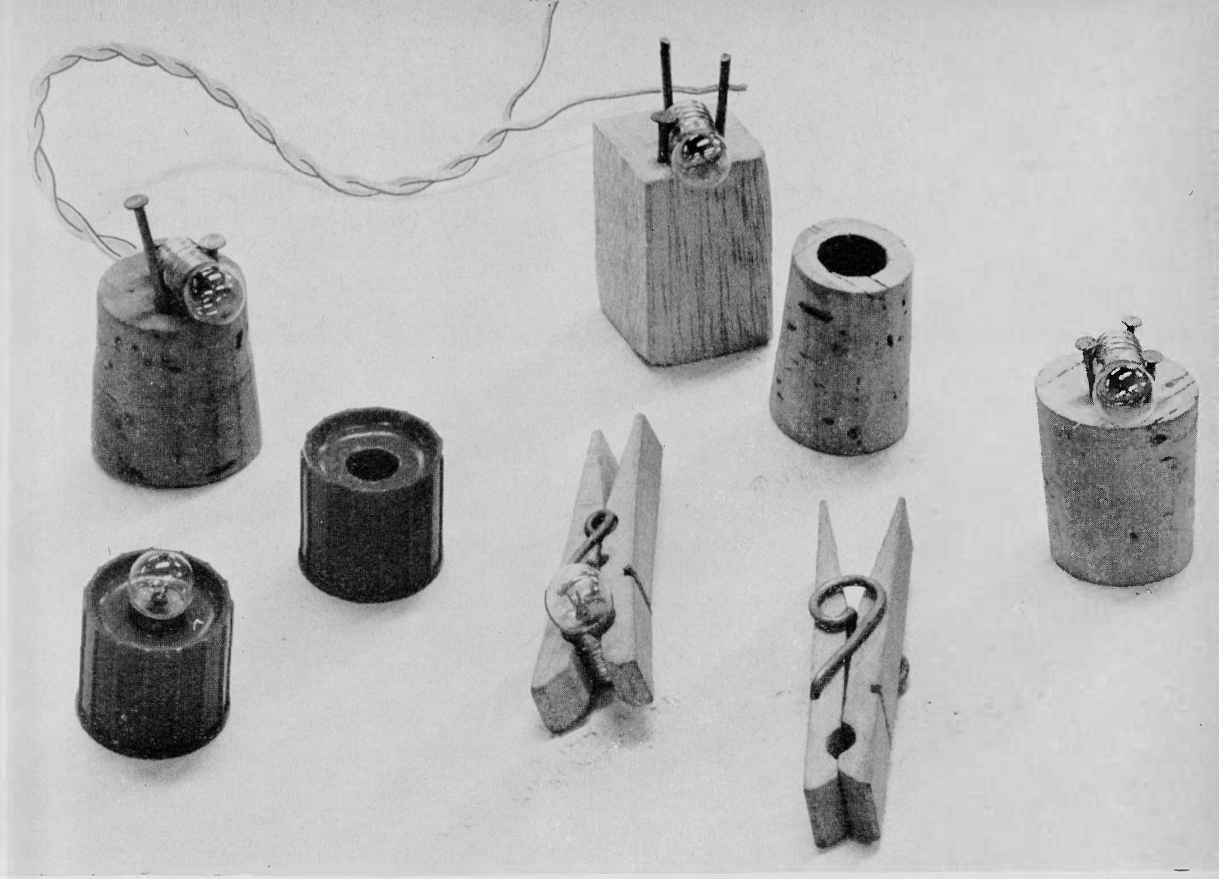
This illustration shows an alternative method of constructing a simple holder for magnets. Here, a wooden framework has been glued together, two balsa wood spacers have been stuck on either side of the magnet, and a piece of acetate sheet or celluloid has been pinned across the front to retain them. This is a more robust holder for magnets than example 39, but is perhaps a less dramatic way of posing a problem, and less stimulating.





41. Free swinging magnet

The behaviour of the free swinging magnet is an important matter for children to study. The photograph shows a simple device to make this investigation as effective and easy as possible. The wooden stand has been made from odd pieces of wood nailed together, with a wooden dowel inserted at the top of the stand as a bar from which to suspend the magnet. The need to use wood is obvious in this instance. The paper stirrup which supports the magnet is suspended by nylon threads, which are free from torsion. This is important, otherwise the magnet will not be free to rotate and find its own free-swinging position. When children use this device, they may want to try the effect on several magnets used in a similar way. They will not gain sufficient evidence from studying the behaviour of just one magnet.

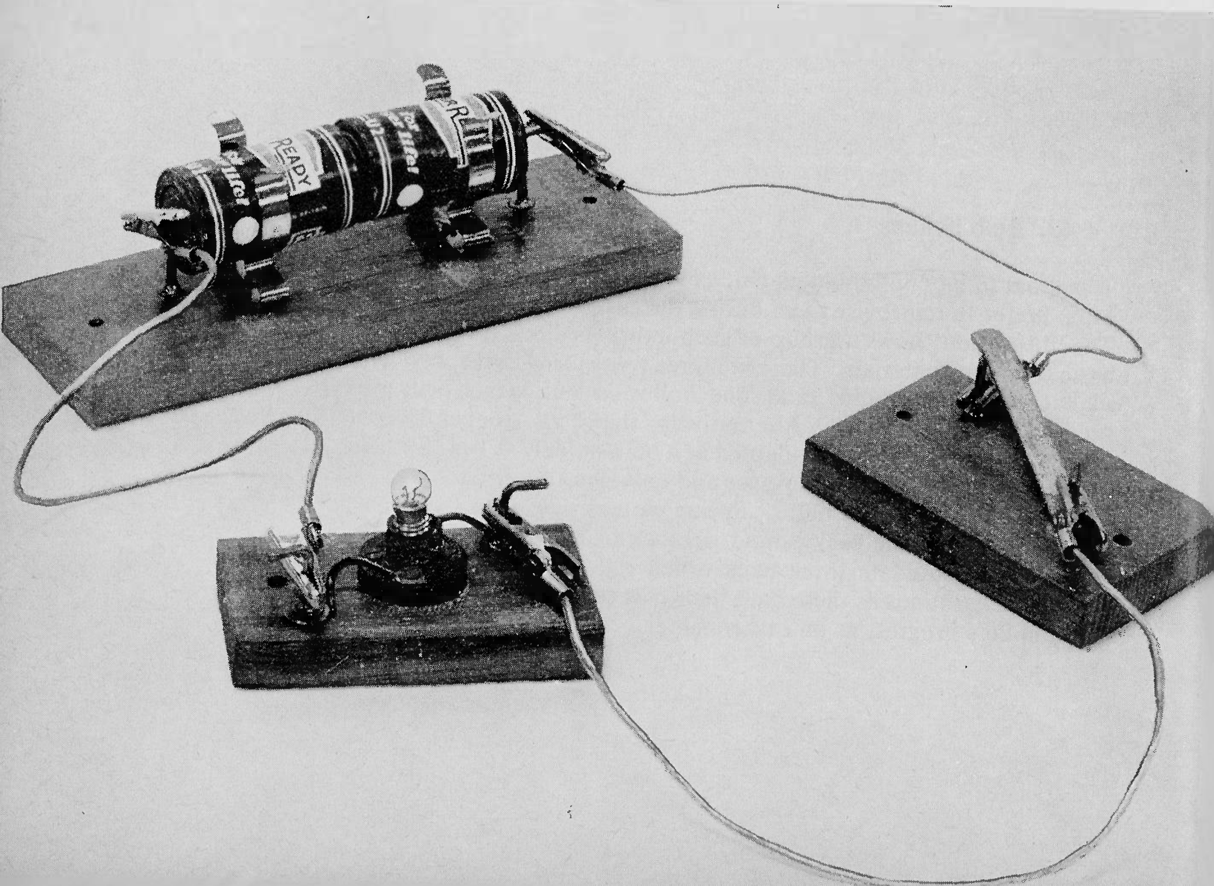


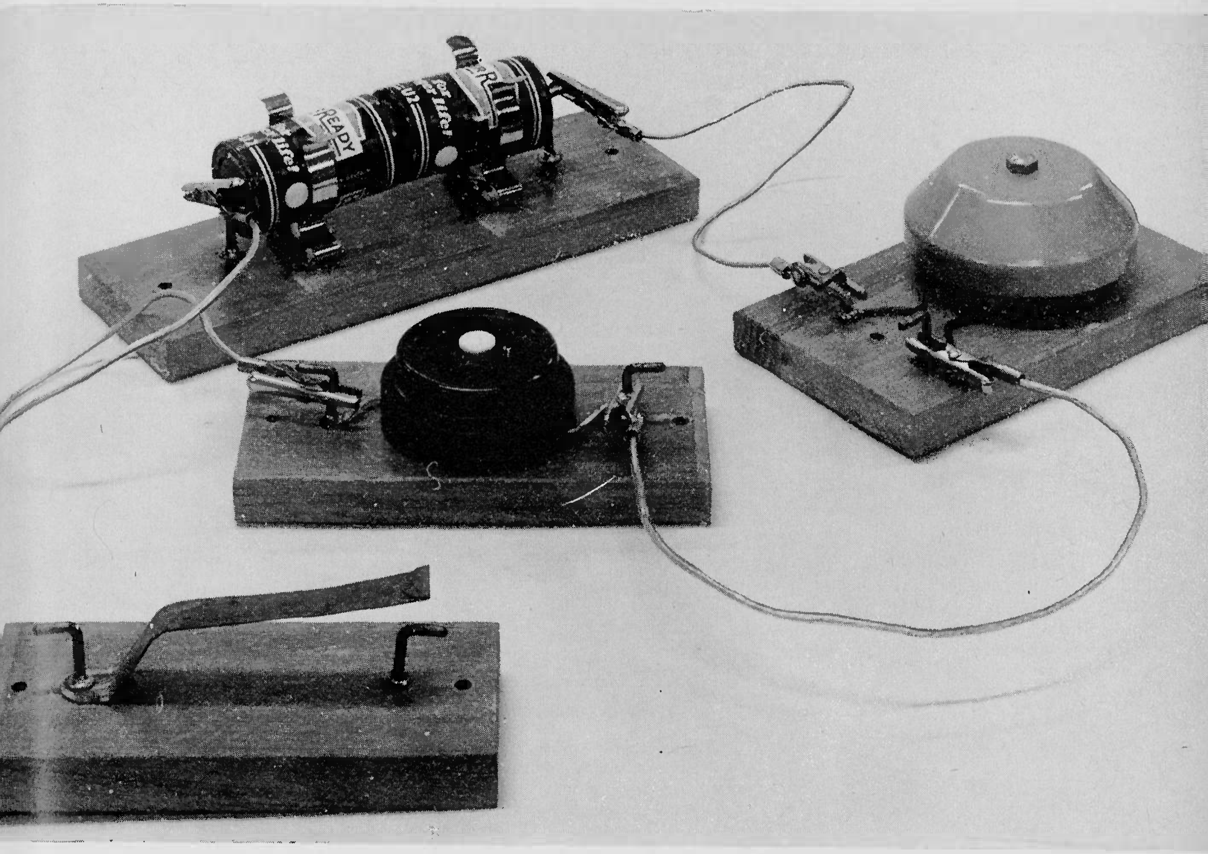
42. Bulb holders E

It is usual to buy bulb holders but, as has been seen earlier, children often prefer to improvise them during the early stages of their work. The illustration shows a group of such improvisations using various basic everyday materials. There are three types using corks, two with nails to retain the bulbs, and one hollowed out, which will also hold a bulb quite firmly. Alternatively, the screw-stopper from a detergent bottle can also be adapted as a bulb holder. A hole is made in the centre of the plastic stopper and enlarged to a suitable size to accept the thread of the bulbs. Spring clothes pegs are excellent as bulb holders. In the background, a block of balsa wood has been used to accommodate three nails which retain the bulb in place. Such improvisations as these have their part to play at various stages in the child's progress as an experimenter.

43. Simple circuit

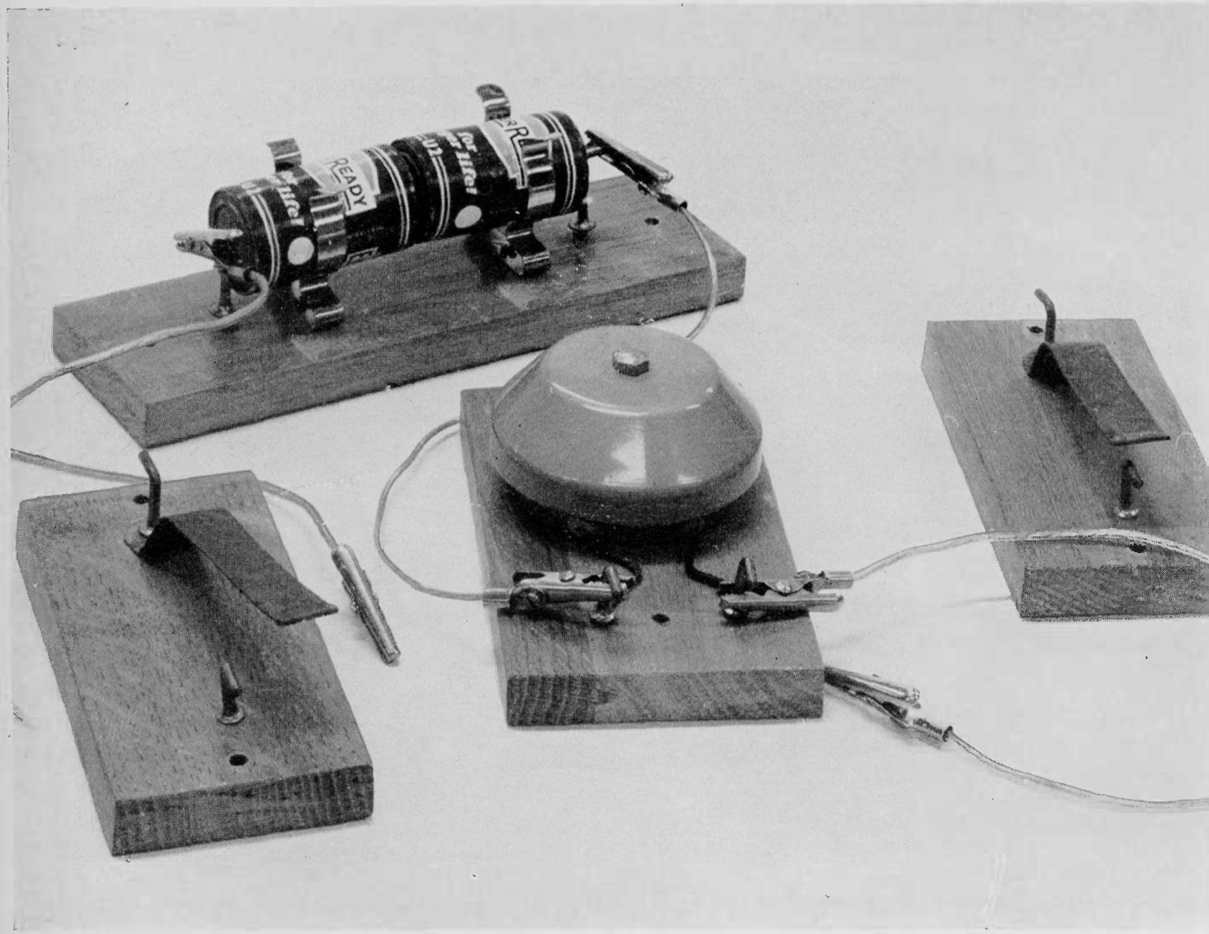
If the study is to be primarily concerned with circuitry and behaviour of electricity, it is sometimes worth while to put in the children's way apparatus which will relieve them of too much improvisation. Otherwise, this might well get in the way of investigations which are their main concern. This illustration shows three pieces of prefabricated equipment: a battery holder, using Terry clips to retain the batteries in place, with the end contacts bearing against right-angled cup hooks. In the foreground, a bulb holder has been mounted on a block of wood, with the contacts again made by cup hooks on either corner. The switch has been made from a piece of steel strip, held down at one end by a cup hook and contacting another at the other side of the block of wood. These cup hooks take the place of terminals, and provide contact points for the leads which terminate in crocodile clips. If these leads are made up in quantity, in lengths of 1 ft and 2 ft, the child will have little difficulty in connecting the components of any circuit. The picture shows a simple circuit which has been connected on a basis of experiment.





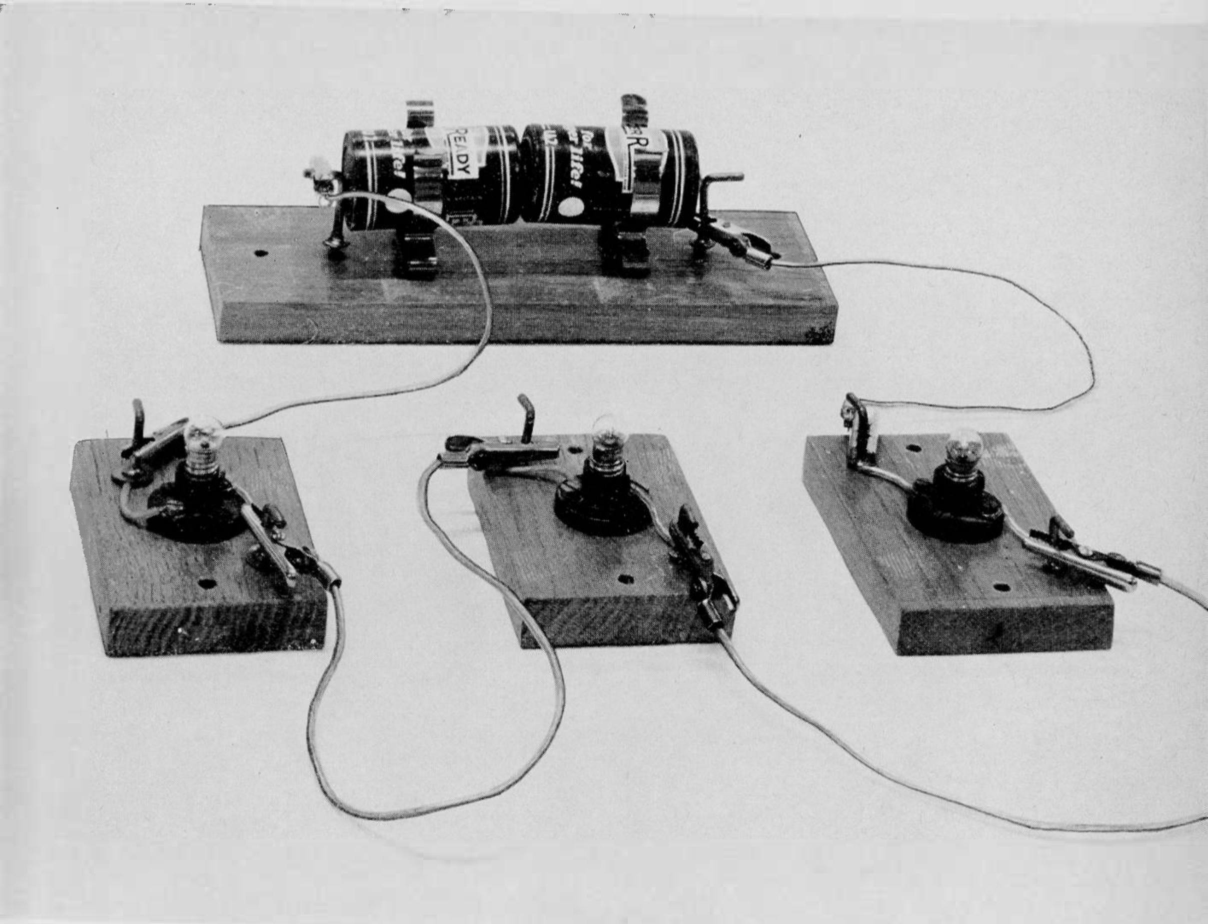
44. Simple bell circuit

This illustration shows a further exploitation of the method of mounting components for experimental work. A bell has been mounted on a wooden block with the lead brought out to cup hooks which act in place of terminals. A traditional bell push has been similarly mounted. In the foreground a simple Morse key is illustrated. This consists of a piece of spring-steel case-strip bent to approximate shape, fixed at one end by a cup hook, and left free at the other to contact a second cup hook. It will be seen how easily the crocodile clip universal connectors can be placed around the cup hooks, as the circuit is built up on an experimental basis.



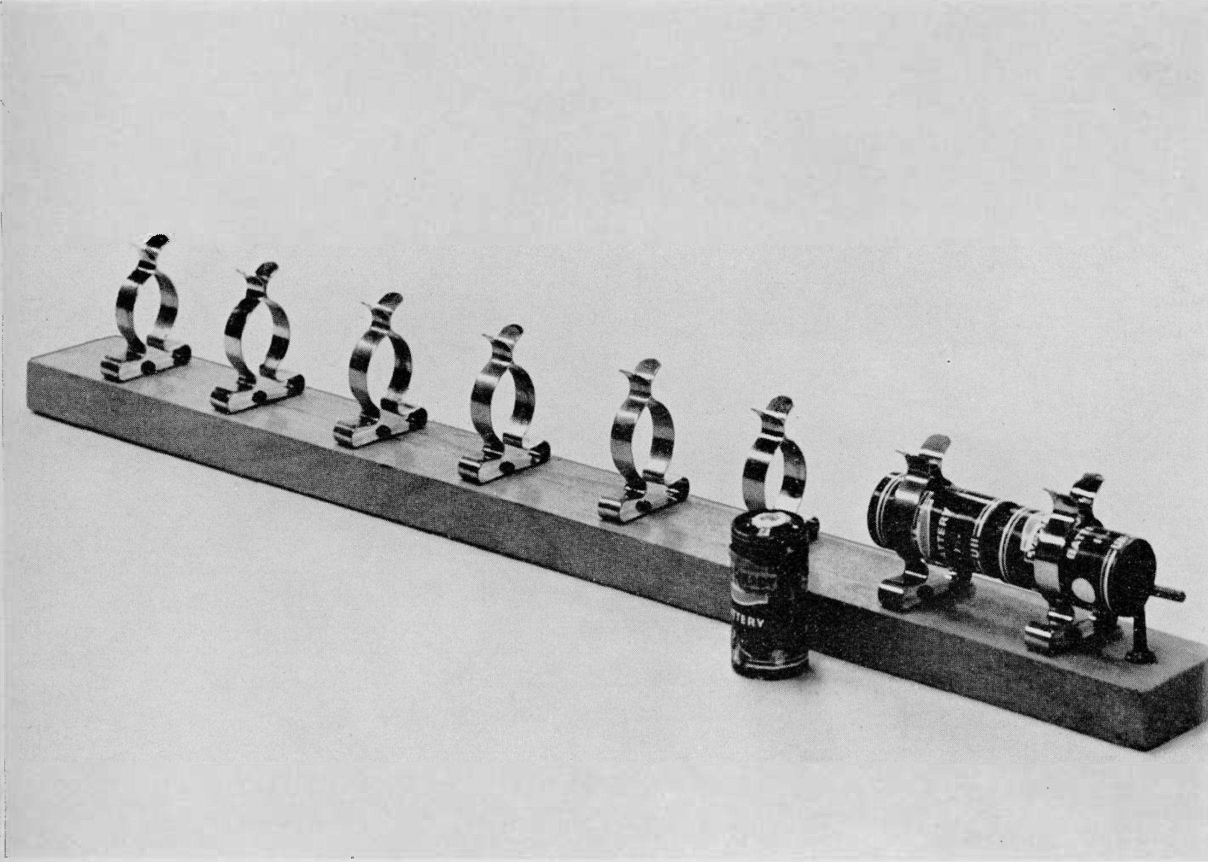
45. Morse signalling circuit

With apparatus such as this, it can be seen that children require little by way of instruction, as in itself the apparatus is of the kind that will provoke a questioning approach and an experimental procedure. Here, the components have been placed in such a way as to suggest a simple signalling system, involving a single bell and two Morse keys. A good supply of universal connectors is needed so that there is plenty of scope for trial and error in the connections, as the children seek their way to the correct circuitry.



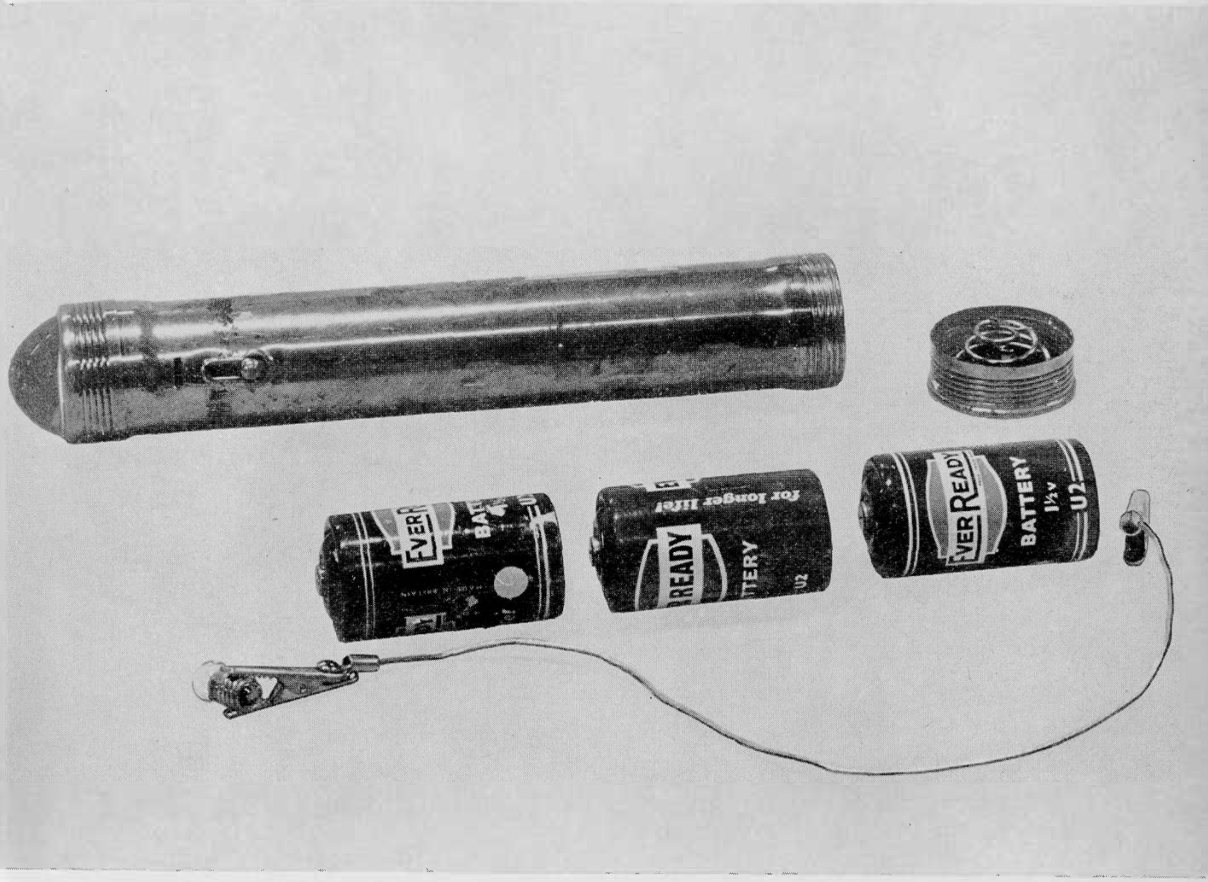
46. Series circuit A

It is well worth while mounting a supply of bulb holders and of Terry clips to accept batteries, so that plenty of experimentation in circuitry can go on. This photograph shows the building up of the simple series circuit. Naturally, an alternative manipulation of the wiring would bring the parallel circuits within the scope of this piece of work. If the length of the leads is restricted to 1 and 2 ft then the range of the work will be physically contained within reasonable limits of the working space available in most classrooms.



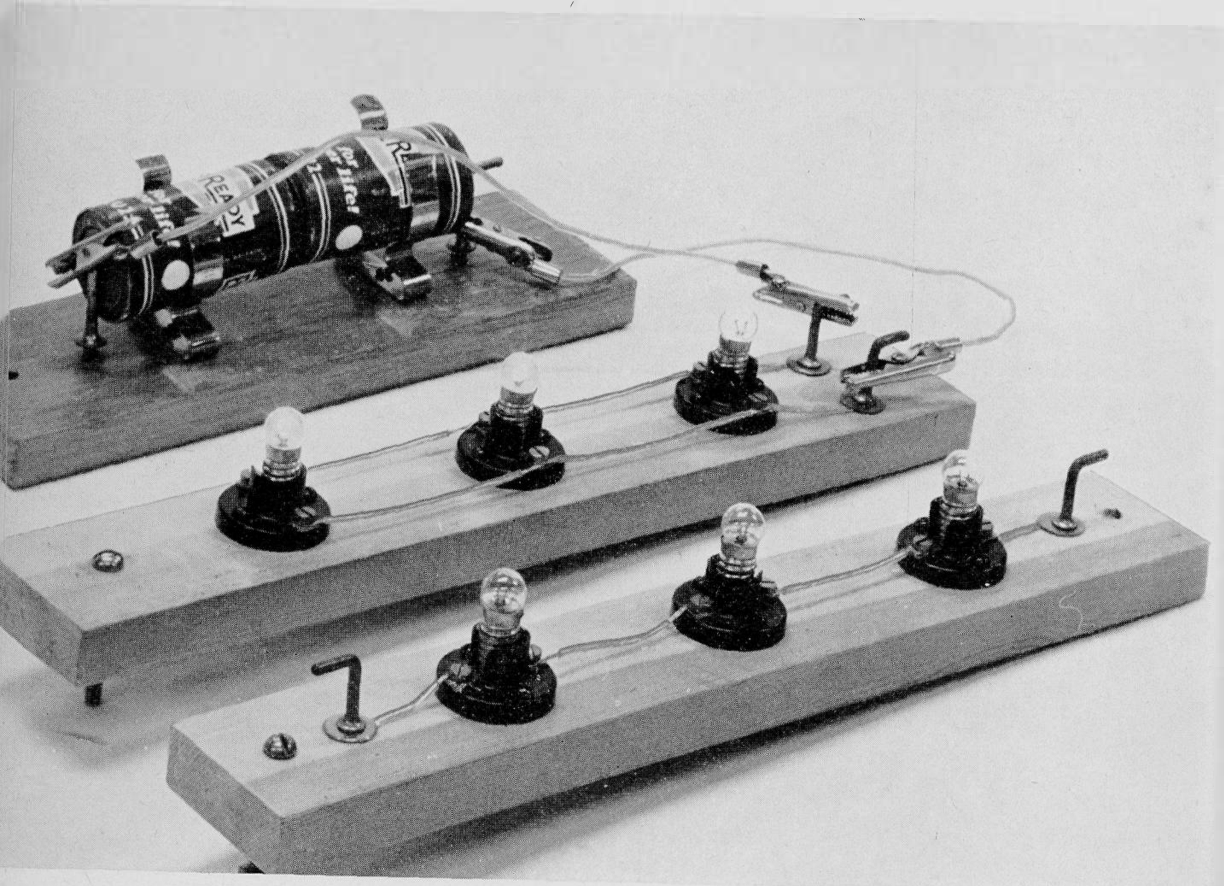
47. Series circuit B

In work on series circuits, particularly when lamps are put in series, children seem to get the idea that a reduction in total power always takes place, because of the dimming of the light output as each fresh lamp is added to the circuit. A corrective to this can be arranged by introducing the apparatus illustrated here. It is merely a batten, terminating in a cup hook and accommodating a series of Terry clips to hold cells which can be added one by one. The increase in voltage can either be detected from a meter or the behaviour of a lamp placed suitably in the circuit.



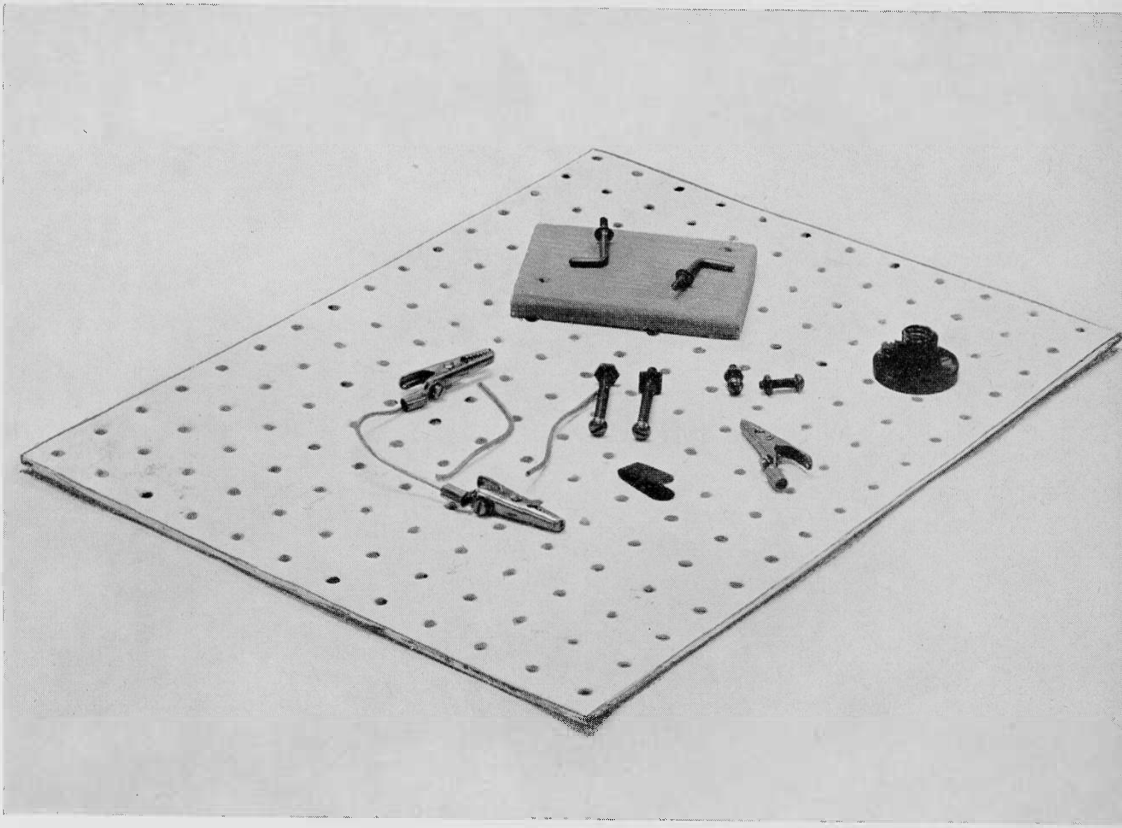
48. Electric torch circuit

An application of the series circuit can be seen in the electric torch. The working of the torch is not as easy for the child to discover as one might think. It may well be best to have available some components which will suggest a possible arrangement, and let the child have this as a springboard from which to begin his own investigations and thinking. This illustration shows how the situation may be arranged in a working corner or at some point in the room where practical work is to take place.



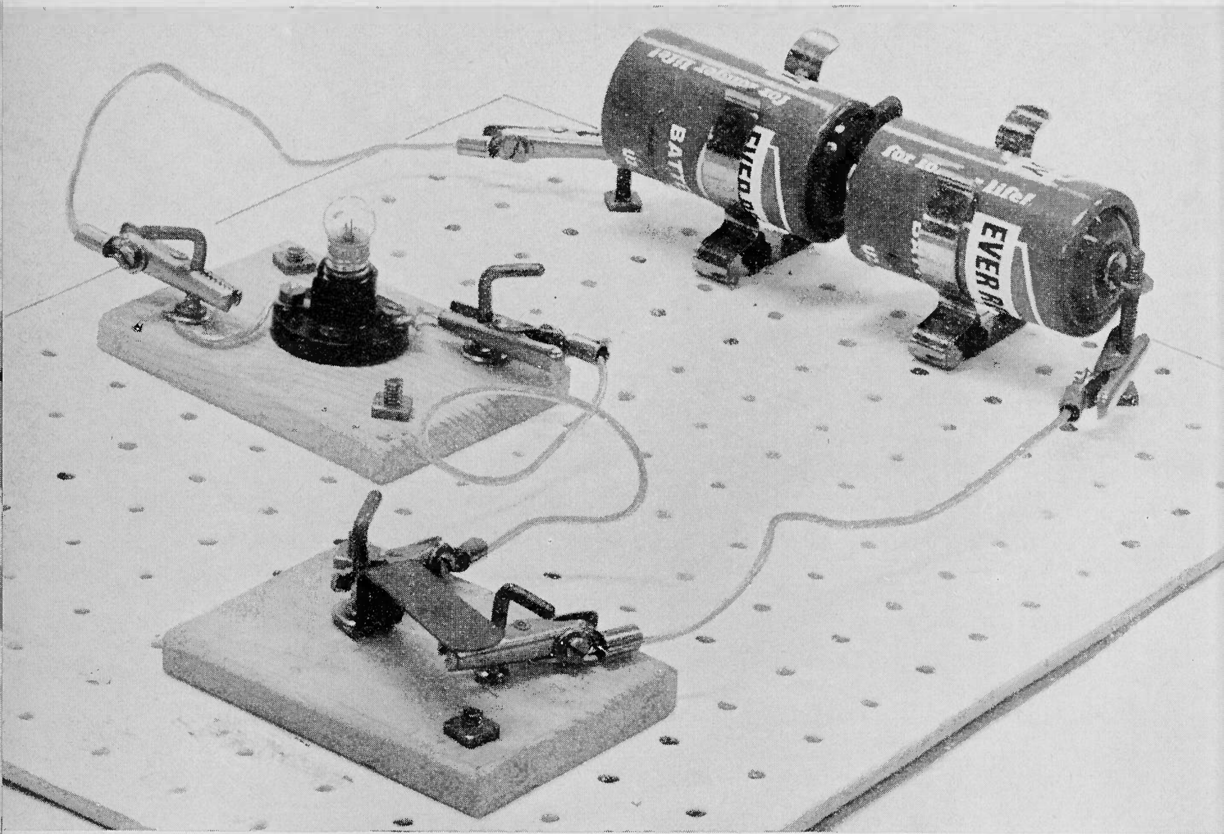
49. Series and parallel circuits

Not all children wish to tackle complicated circuitry before arriving at the heart of the question they are investigating. It is sometimes more efficacious to provide a prefabricated situation which lays bare the problem at once. This photograph shows a method of enabling a child to compare the series and parallel circuits. He has only two connections to make, though the rest of the wiring is quite clear for him to trace in the course of his thinking.



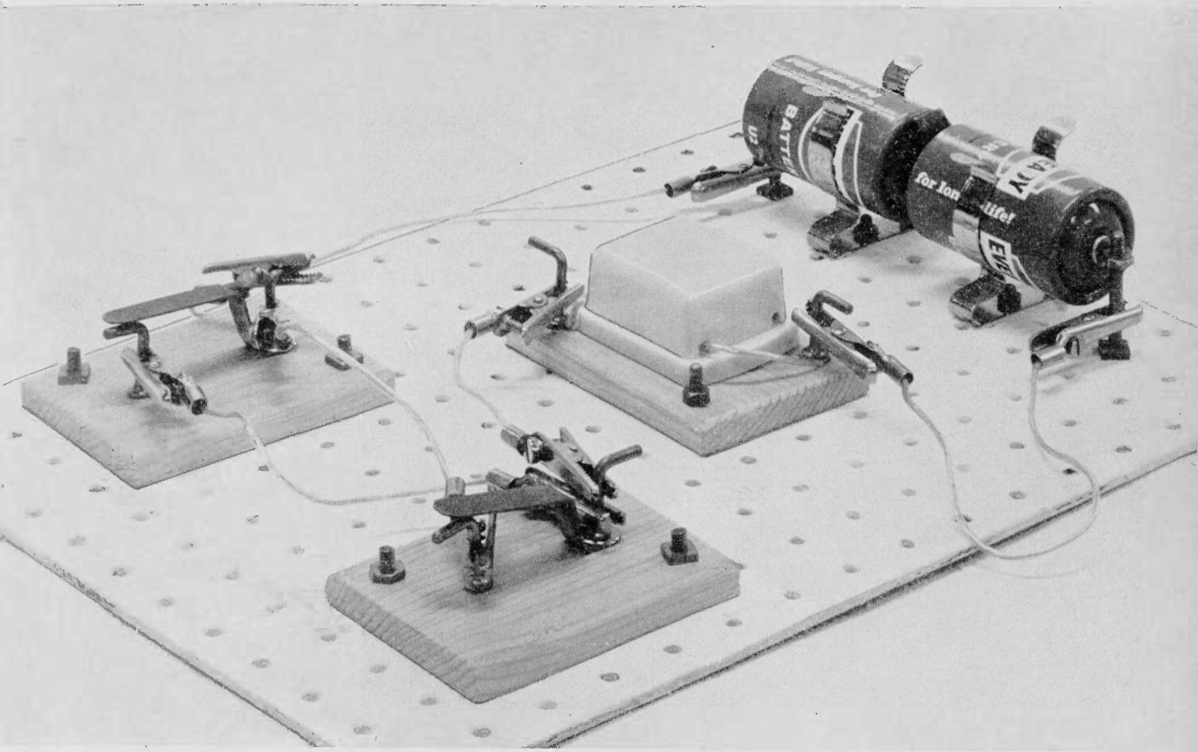
50. Baseboard circuits A

In some schools working space is extremely limited. A convenient method of containing work within a given area without placing undue overt restrictions upon the child, is by providing a basic working board. This photograph shows one kind. It is a piece of white painted pegboard about 12 by 9 inches in size, and the components for simple electrical circuitry are placed upon it. If it is desired, some of the components can be fastened to the board with thin nuts and bolts of suitable size for the holes in the pegboard. The child naturally works within the area of the board and so confines himself to a space compatible with the facilities of the classroom.



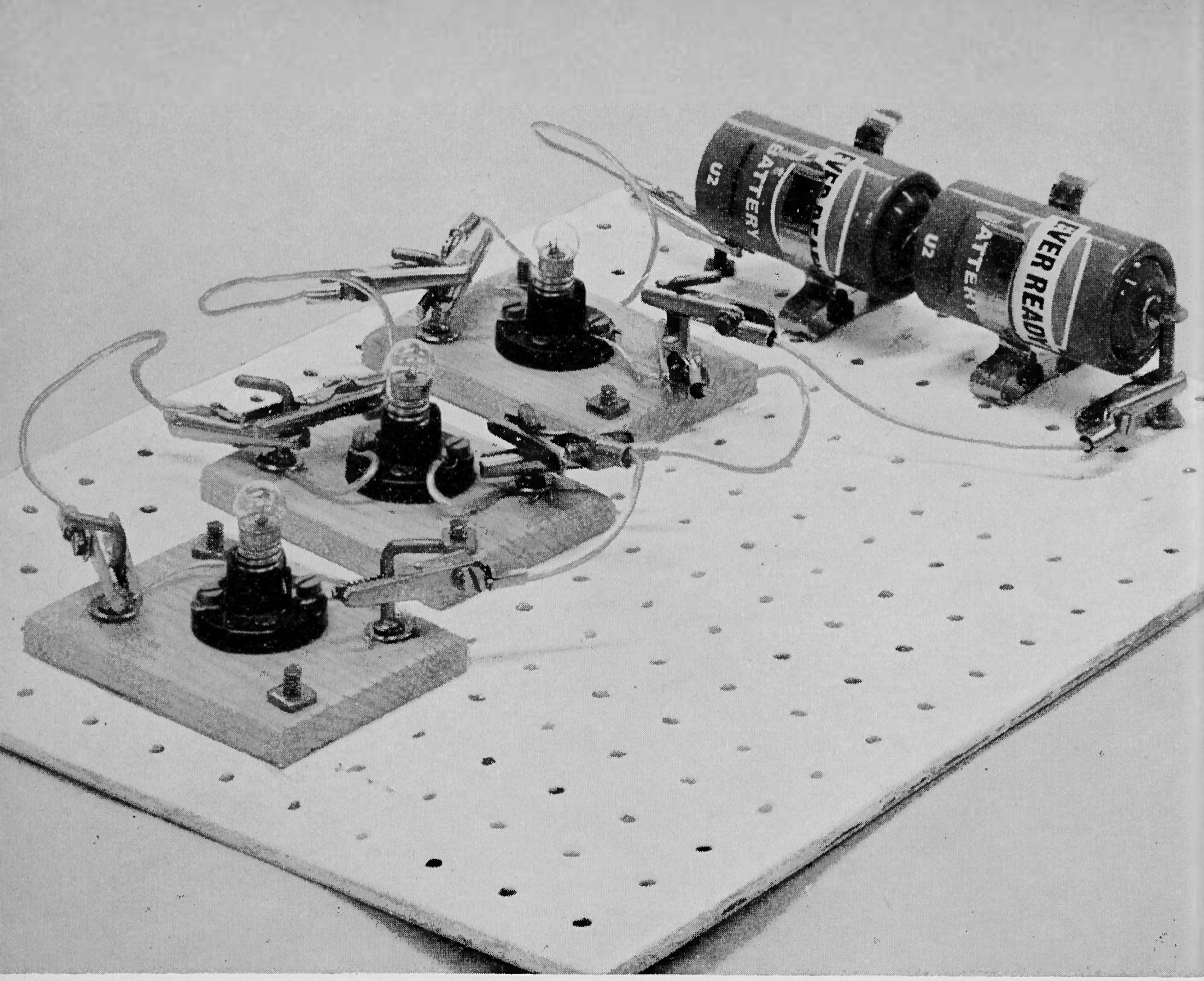
51. Baseboard circuits B

This illustration shows the board in use for the construction of a simple circuit, including a switch. It can be seen that all the components fasten easily to the board, and that contacts for the battery are made via longer bolts inserted through the pegboard to form connectors to either end of the batteries. One other advantage of this method of working is the ease with which the material can be stored after use.



52. Baseboard circuits C

Once a group of basic components has been produced, the variations in circuitry which the child may devise are quite large in number. Here, the illustration shows a circuit incorporating two Morse keys and a miniature buzzer all mounted on wooden blocks for easy accommodation upon the baseboard. Universal connectors made from a length of wire with crocodile clips at each end have been incorporated into this system. Small sized right-angled cup hooks form connectors to each piece of apparatus and thus avoid the problems raised by the use of terminals and loose pieces of wire.

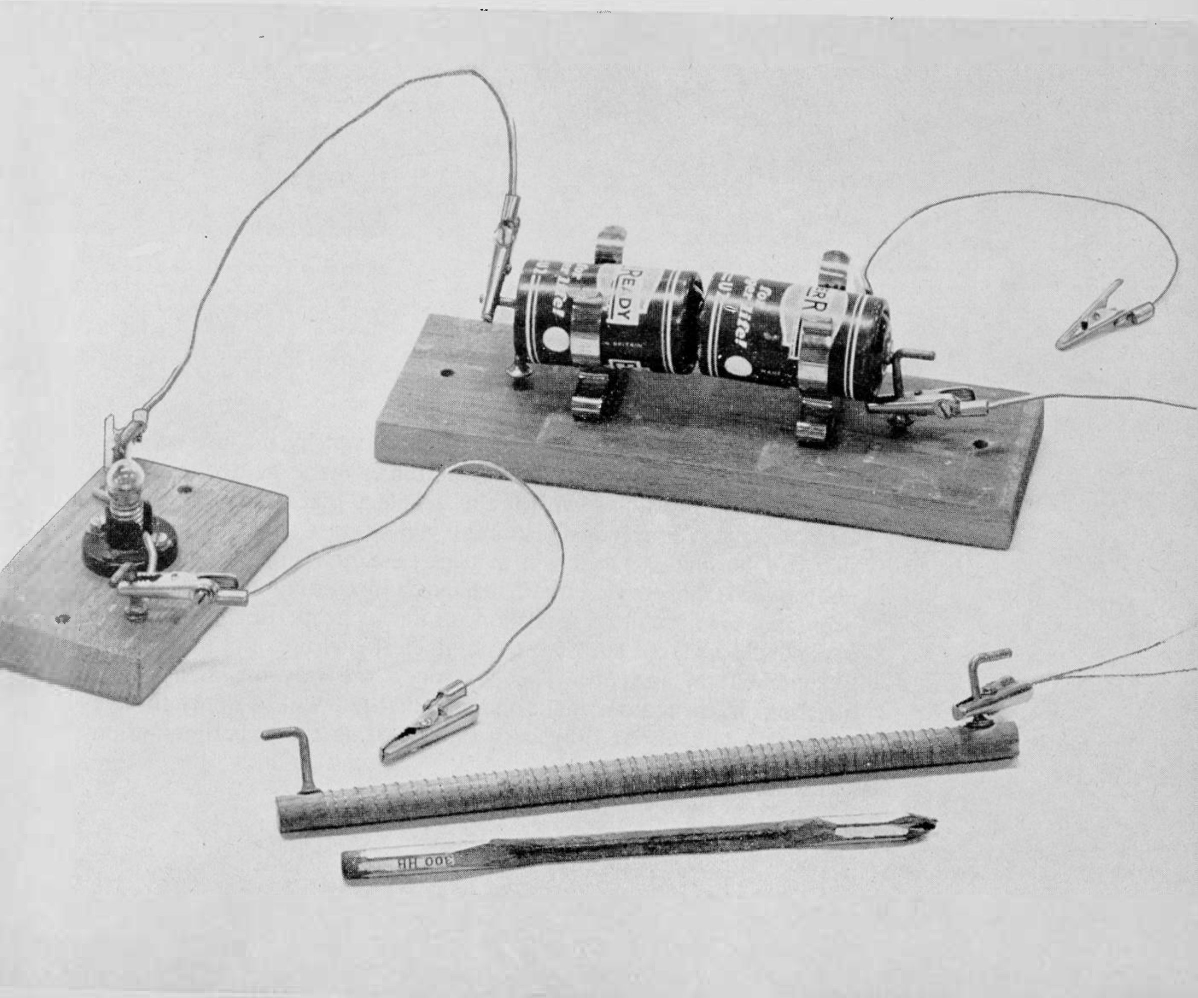


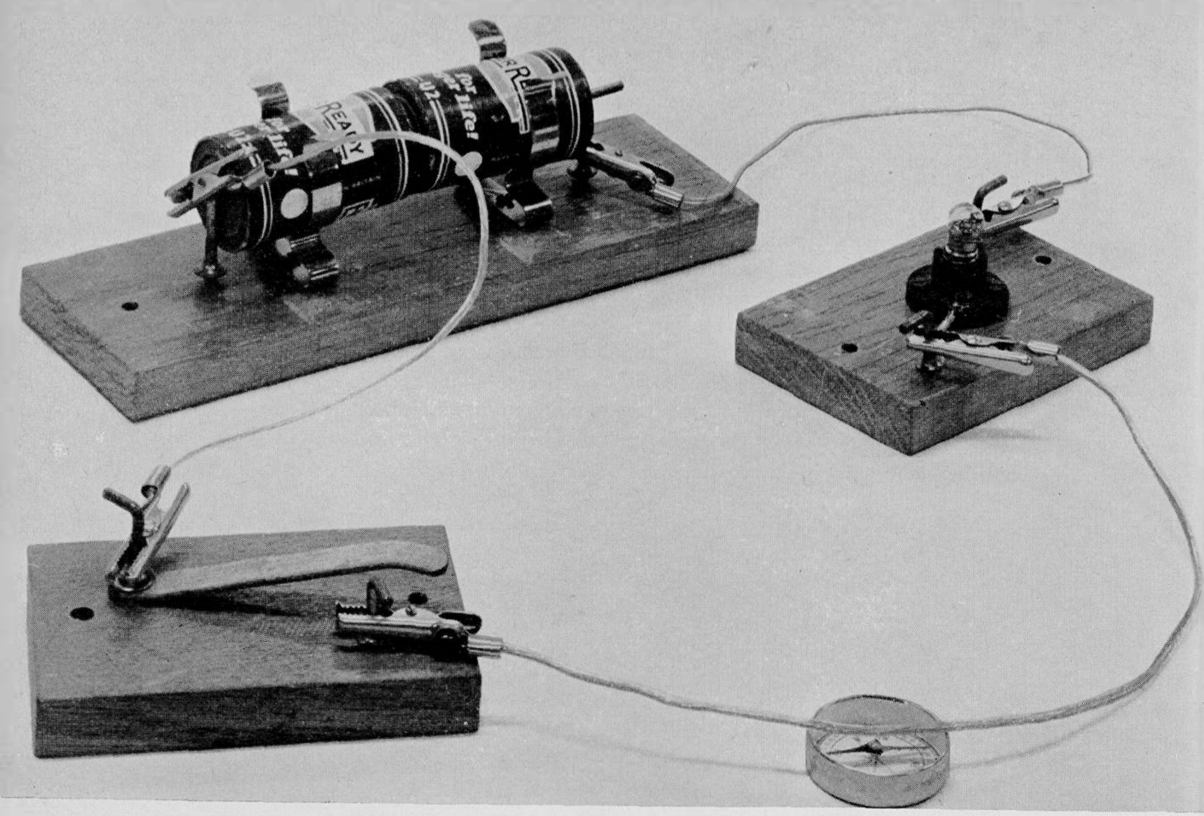
53. Baseboard circuits D

The number of components that can be housed upon this relatively small-sized board is well illustrated in this photograph. Not only has it accommodated the batteries, but also three lamp holders, mounted on wooden blocks and wired in parallel. This still leaves a considerable area for adding switching devices, should this be desired. As work proceeds this same system can house simple components for the construction of elementary radio circuits.

54. Resistance circuit

This illustration shows the components used for posing further problems on conductors. Early work usually concerns conductors and non-conductors in a fairly black-and-white fashion. Now, new problems are raised by the inclusion of resistance wire and (similar to these) of the section of lead pencil. The basic components of a lamp holder and battery holder with the universal connectors are used, with the simple former for the winding on of various lengths of resistance wire. In practice this has been the most convenient manner of handling lengths of wire in the restricted area of the average classroom working-top. Obviously, a range of other materials will also be included in this kind of study, and teachers and children will no doubt devise their own ways of handling these.



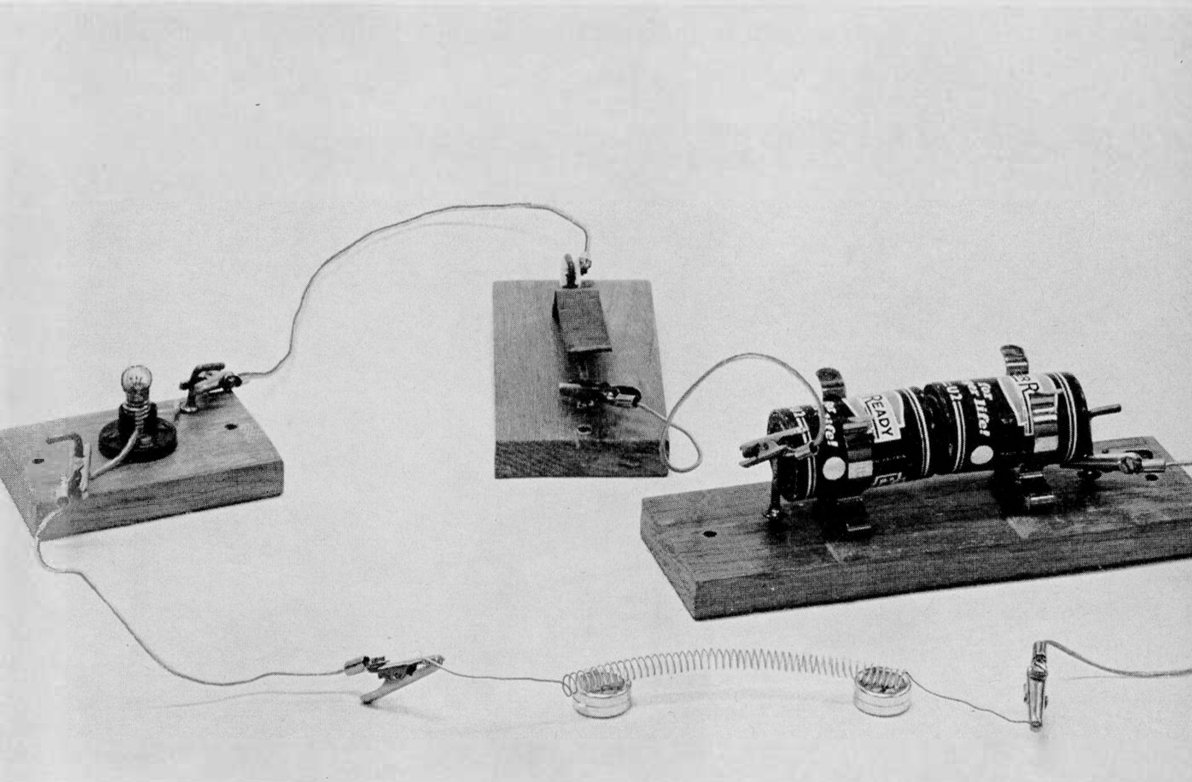


55. Electromagnetic effect E

The child's freedom to investigate is preserved by the use of these basic components although the situation is much guided and conditioned by the units which the teacher places at the child's disposal. In themselves, these units will suggest new arrangements that can be made, which will in turn pose new problems. In this photograph, the simple circuit, which children may know well, has been used to stimulate new thinking about its properties when a compass needle is placed at different points in the wiring, and the current is switched on and off. This will open the way for many fresh questions in the child's mind, and equally there will be many for the teacher to talk about fully with the child, as the experimentation proceeds.

56. Electromagnetic effect F

Here the work has been taken a stage further by the use of more than one compass needle for testing various parts of the circuit. Different shapes of wire have been experimented with and the illustration shows the final point when the spiral has been neatly wound round the pencil, and then connected into the circuit. The kind of help that the teacher gives is important, so that the work retains as much of the child's own initiative as possible. Often the strongest guidance is a casual remark.

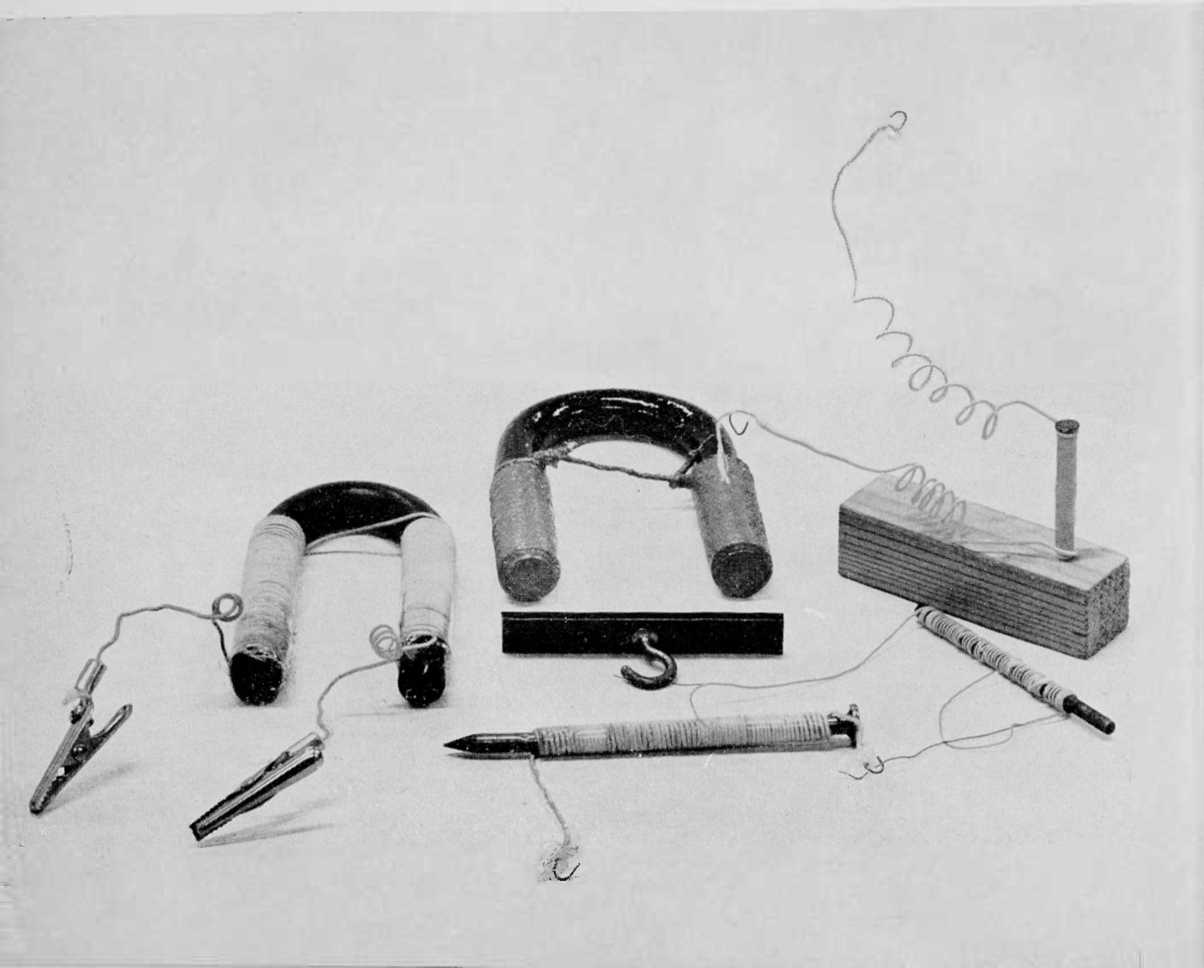


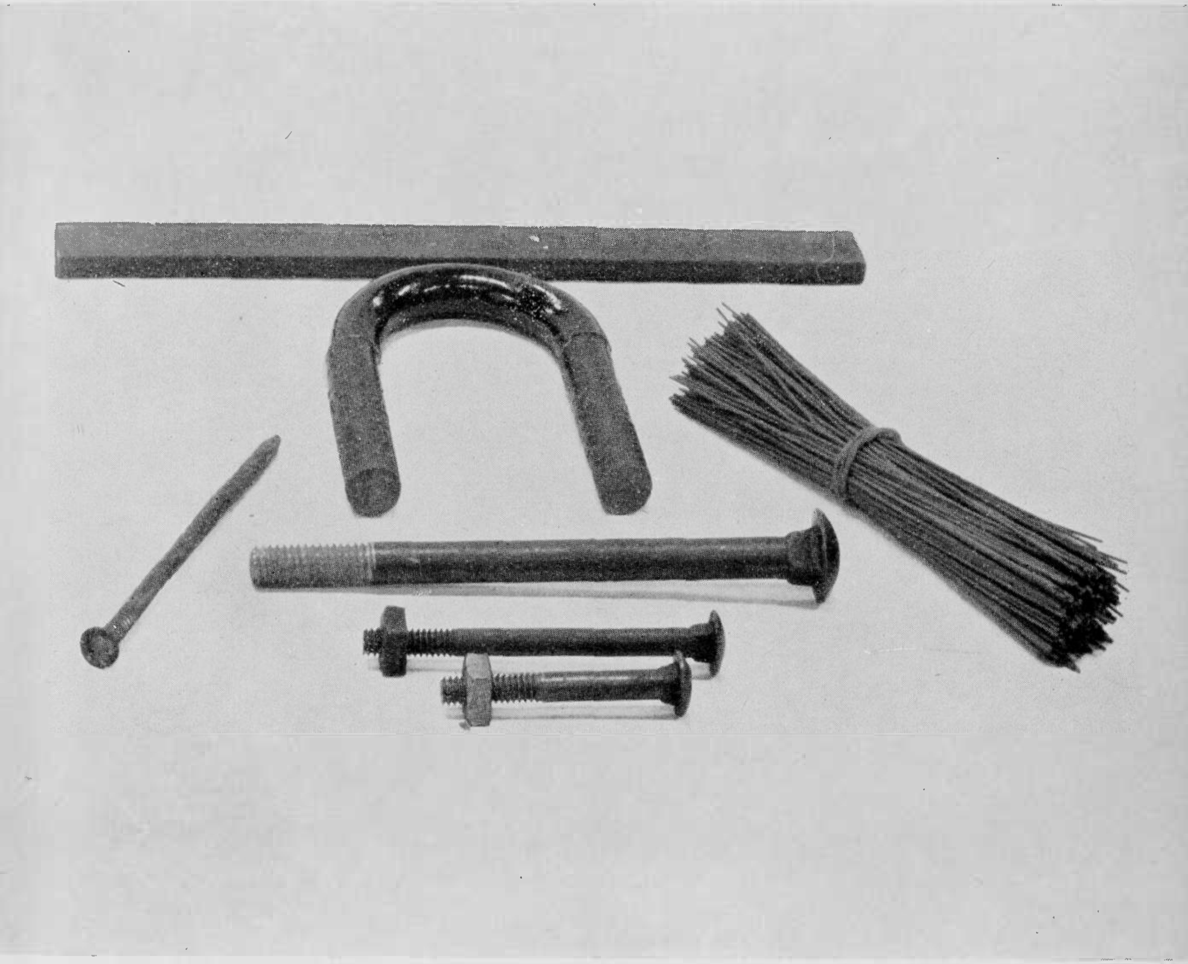
57. Electromagnets

This illustration shows a collection of materials that has been used in the study of electromagnetic effects. Work started with experimentation with nails.

A 3 in. nail is convenient to use as the head retains the beginning of the wiring, and the rest can be held into place with Sellotape. A block of wood makes a convenient holder for this type of magnet. The centre of the page shows an illustration of a commercially made electromagnet, and to the side of it is one wound by a child on a horseshoe-shaped former of soft iron.

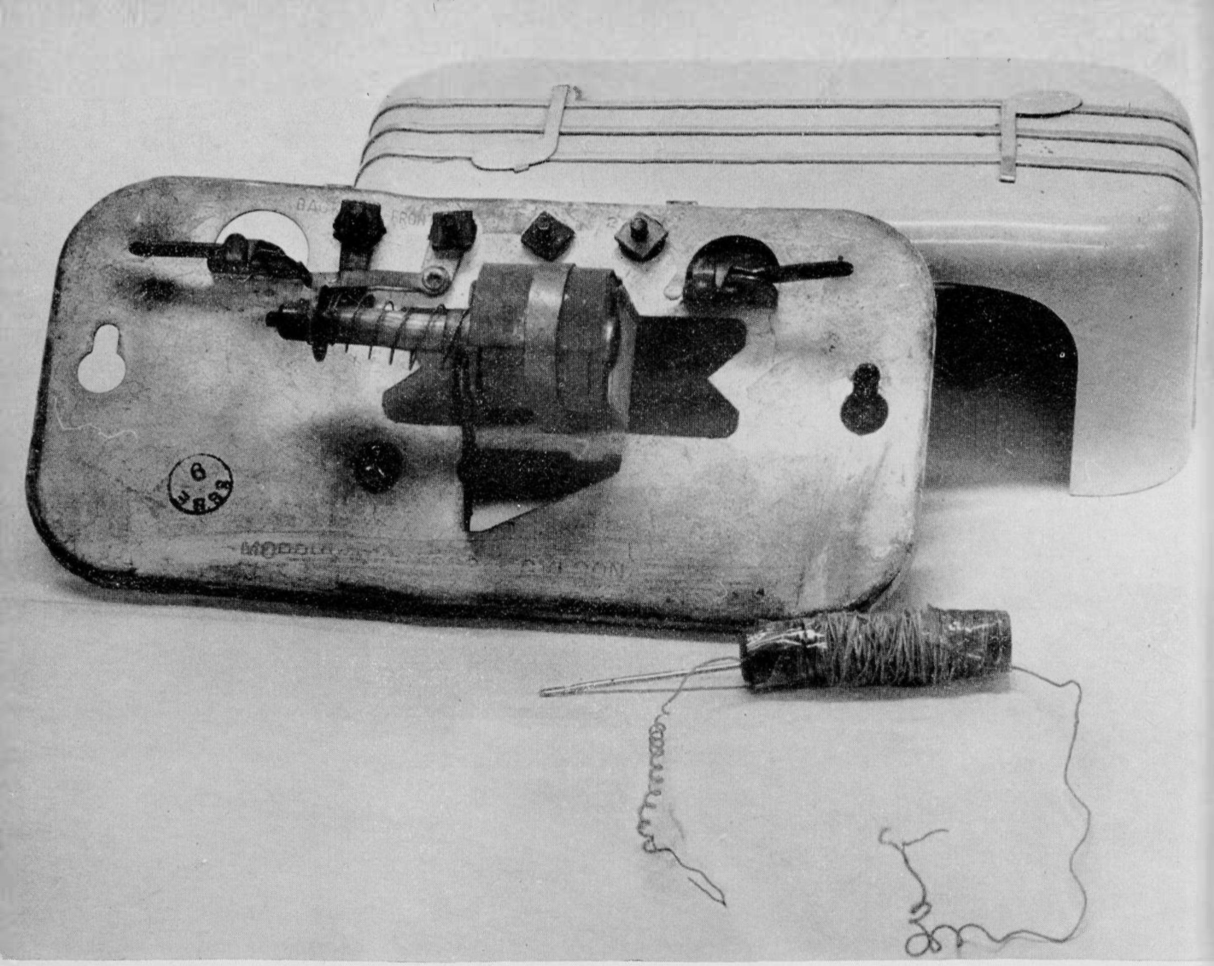
Work can be taken beyond the establishment of the electromagnetic effect, and go so far as to investigate the power of these magnets and what conditions their efficiency. For example, children can consider the effects of the number of turns of wire, of whether a magnet is powered by a 3 V or 6 V battery, of the length of life of the batteries, and so on.





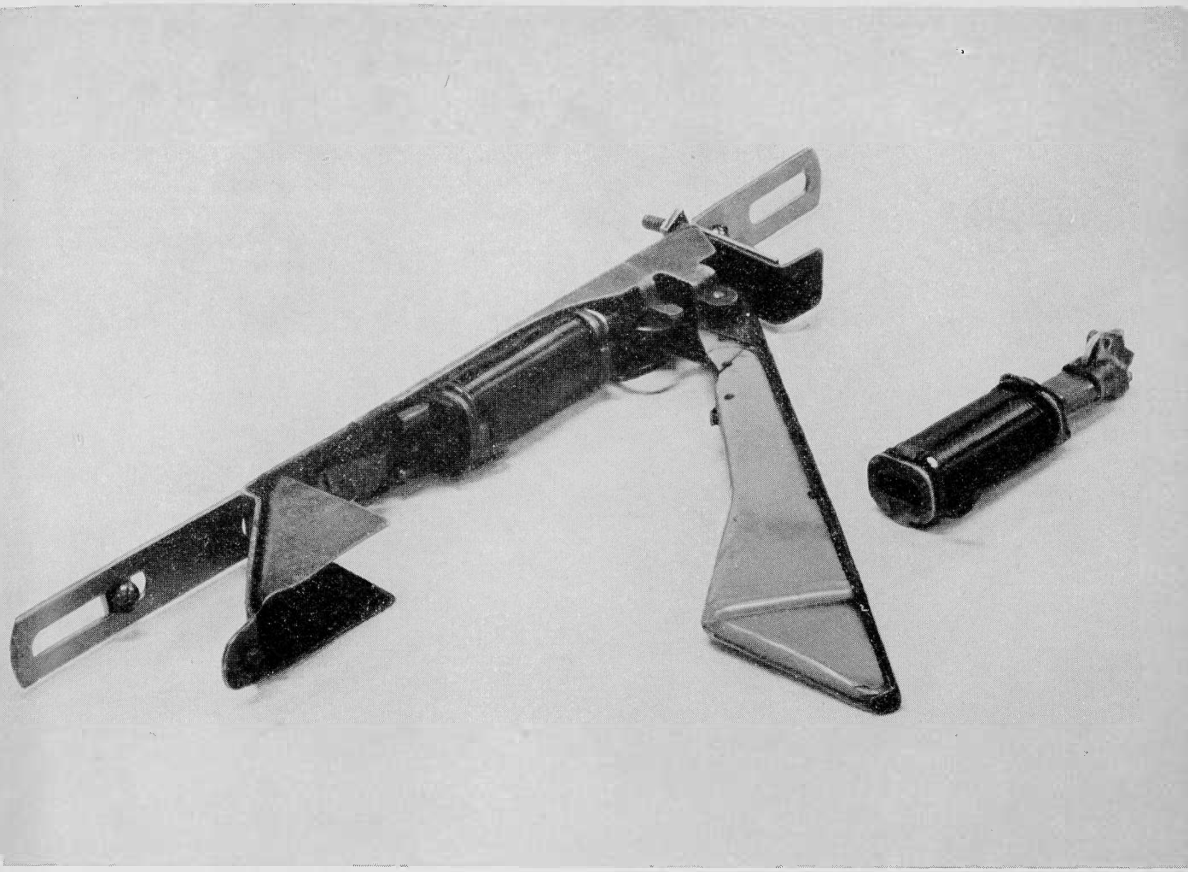
58. Electromagnets—core materials

This photograph shows a collection of materials of soft iron which the teacher may like to have at hand for this work. Nuts and bolts, and nails can be softened by placing them in the fire overnight and allowing them to become thoroughly annealed as the fire dies down during the night.



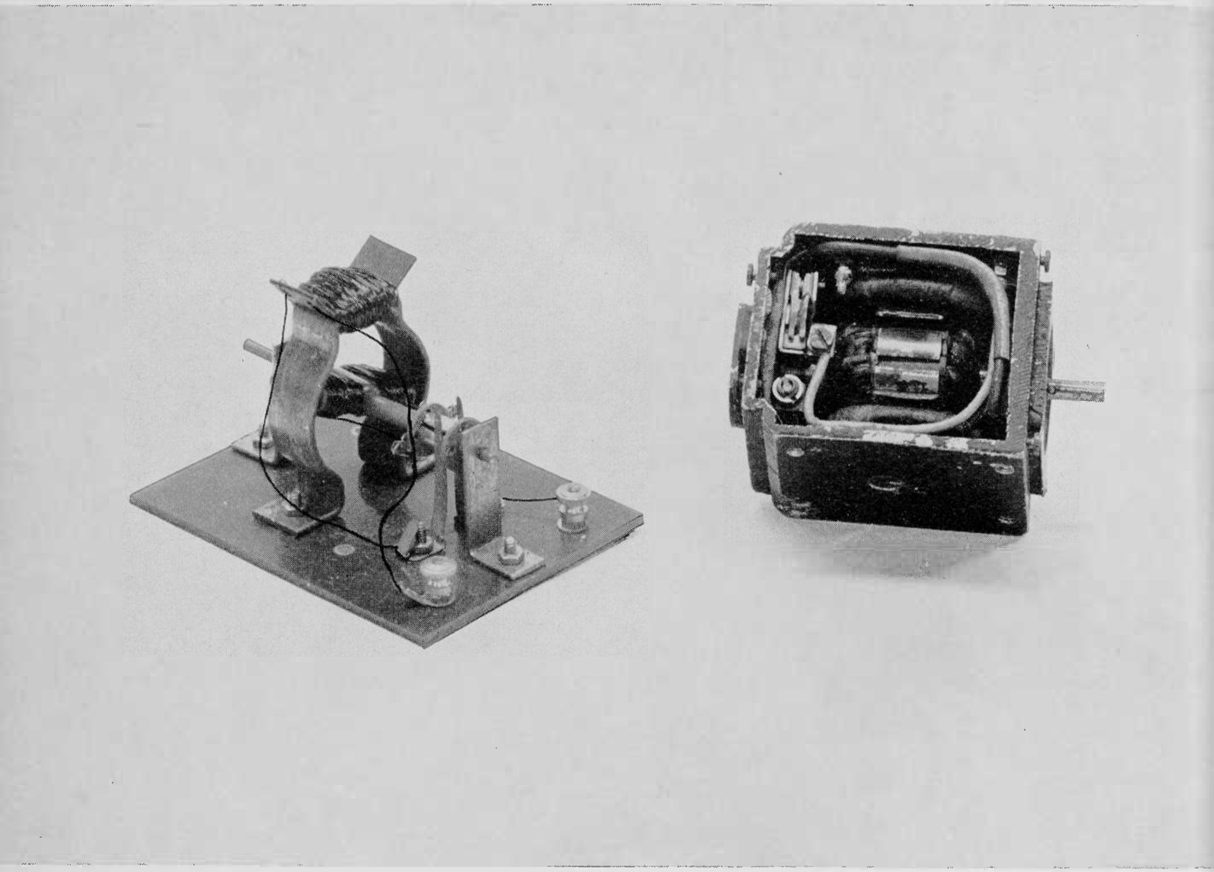
59. The solenoid A

Experimentation with electromagnets may lead to work with solenoids. A piece of apparatus made by a child is in the foreground of this photograph and it was this that opened the way for a group of children to investigate the behaviour of the solenoid, and then go on to some of its uses. In the background the larger object shows one of the domestic uses of this simple device. This is the basic mechanism from a door bell chime set. Older boys and girls soon see the possibilities that this kind of work opens up to make bell-chime outfits for themselves.



60. The solenoid B

This illustration shows yet another commercial application of the solenoid. It is worth children's while to investigate to see how the makers achieve the power that is needed to operate this device. They may, too, discover for themselves how the right choice of materials makes such a difference to the efficiency of the device that they are making or investigating. Several successful car semaphore sets were made by children not purely as a copying process, but as their own variations on the theme of the use of solenoids.

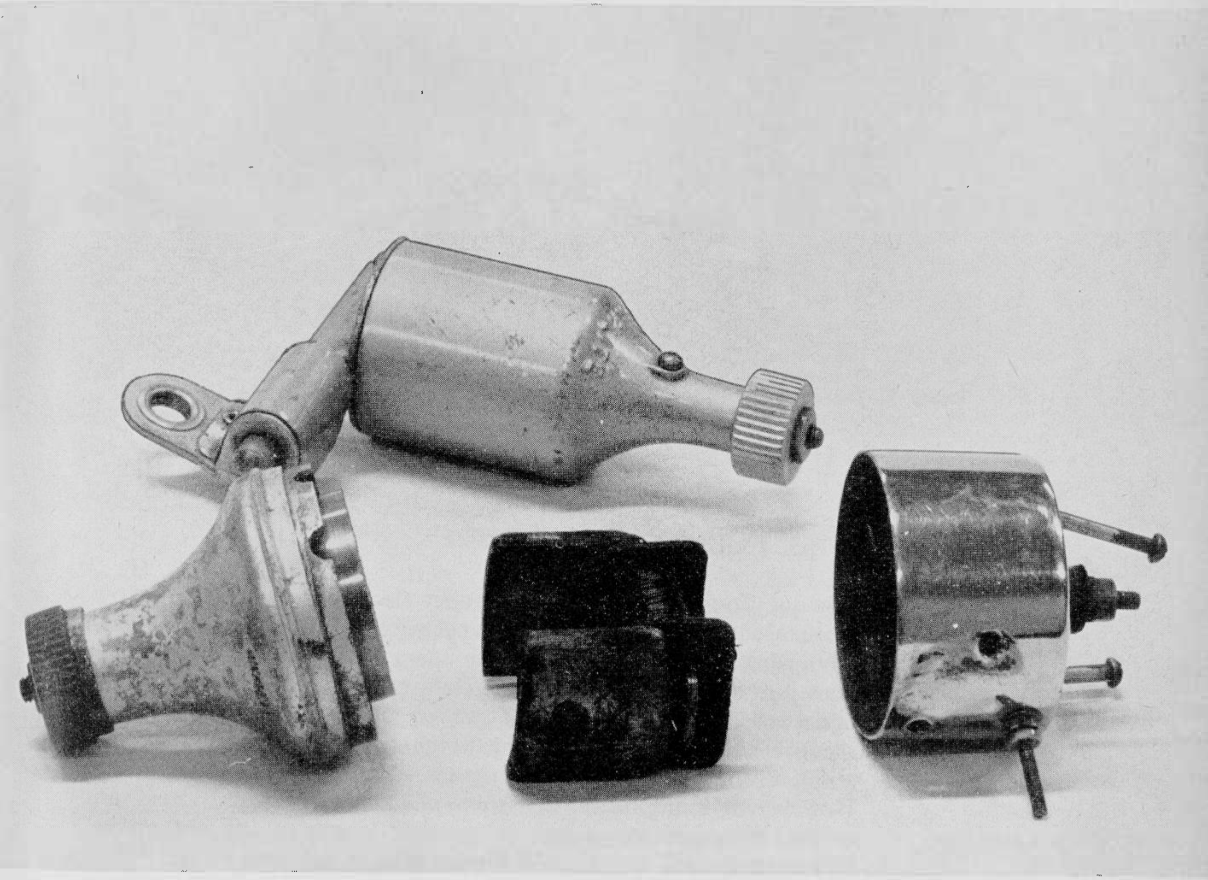


61. Electric motor

Earlier (in examples 29, 30, and 31) there were illustrations of children's work in devising simple electric motors. These were of a non-self-starting variety. It is sometimes a good thing for children to be confronted with the complexity of the really efficient article. This illustration shows a compact commercially produced self-starting electric motor. Beside it, is a child's simple model of an electric motor of the non-self-starting variety, which yet embodies all the principles that are in the more complex design. It will depend upon the child's point of entry into this sort of study whether the teacher uses the complex material or not.

62. The dynamo

Many boys and girls have dynamo lighting sets on their bicycles. Though they may be familiar with them as devices, their working is by no means easy for them to discover. This illustration shows the basic construction of the cycle dynamo. It is helpful for children to have equipment that can be readily dismantled, so that it can be experimented with, talked about, and thought about.



63. Cells and accumulator

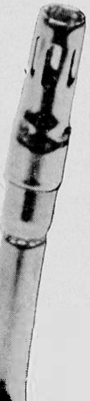
The questions may arise: 'Where does electricity come from? How is it stored? What are the significances of different-sized batteries? And what do the markings upon them indicate?' The last two questions are much easier for the children to try to answer than the first two. While fruitful work can go beyond an examination of the performance of the battery, some teachers have reservations about dismantling batteries to try to see what they are made of. However, it is important that there should be a range of batteries so that the problems of size, power, and length of life can all be investigated, and investigated freely at the child's own level.

64. Storage cells

Some children will want to attempt the storage of electrical energy, just to see if it can be done by simple means. This photograph shows a method of making a simple storage cell. The electrodes are pieces of lead strip separated by blocks of wood. A very strong solution of bicarbonate of soda is put into the jars, and the cells are charged by connection direct to another battery. The amount of electrical energy that can be stored in the cell in this way is disappointingly small, but nevertheless the child seems to gain a considerable sense of achievement from his successful attempt.

65. Electrical energy

Whilst it is doubtful if the child can appreciate what is meant by the term 'energy', no doubt he will use the word freely in his conversation. Nevertheless, it is right to give him a chance to think about it. Electricity is a form of energy which is versatile in its application. The photographs show a simple means of illustrating this versatility. From the store of energy in the battery, by suitable connections, light energy can be generated in the lamp. The relation between this and heat energy can be indicated by the behaviour of the element in the electric gas-lighter shown on the left. It is another of the thinking and talking points that it might be useful to introduce with the most able pupils.



66. Aluminium foil circuitry

Simple circuitry of many kinds can be built up by using strips of aluminium cooking foil. This is a versatile material, and can be used to provide a conductor base or covered with a layer of plastic to render it non-conducting in part. In short, simple circuitry techniques can be exploited with this material. The illustration shows some elementary work in this direction. On the right, a simple circuit has been made on a cardboard base using cooking foil strips held down with Sellotape for the connections. In the foreground a conductor base has been made and this has been covered with Fablon plastic cut away in suitable places for the circuit that was in mind. A whole range of work can be developed using this technique, and again it is something which may well come towards the end of the course, when the boys and girls are much more ready for miniaturization techniques and for more sophisticated uses of everyday materials.