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Scottish Curriculum Development Service, Dundee Centre (SCDS) -see page 31.

Stocksigns Ltd., Ormside Way, Holmethorpe Industrial Estate, Redhill, Surrey RH1 2LG Tel.(0737) 64765 [See "Safety Signs.." p.8.].

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INTRODUCTION

Safety Surfeit

After a relatively quiet period we have an accumulation of reported incidents and safety information. At the drafting stage for this issue the need to publish material relevant to these problems was obviously upsetting the normal balance of specialist content. In fact 'Safety Notes' became so long we were tempted to cheat and transfer a note on toxic plant material into 'Biology Notes'! We resisted that temptation mainly because the incident referred to occurred in a combined science class. The realisation that much of the safety material to hand should be of general interest, followed fairly quickly thereafter. From there it was but a small step to a bumper edition of "Safety Notes".

Increasingly we have to remind ourselves that hazards well recognised and controlled by the specialist may be hidden traps for other unwary colleagues teaching integrated or combined science courses. Managing safety in a modern school science department is a more than ever a problem for the whole staff team. Therefore, long though it is, the whole of the 'Safety Notes' section may be of relevance to you - whatever your specialism.

Festive Season Closure

Please note that the Centre will be closed for Christmas from the end of business on the 24th of December, re-opening on the morning of the 30th. We will close again for Hogmanay at 5pm on the 31st, re-opening on Monday the 6th of January, 1986. In the wall-known words of that anonymous graffitist genius - "A Merry Christmas and a Happy New Year to all our readers!".

Erratum

Griffin Gremlins - again!

In Bulletin 145 we made an error in the telephone number given for Griffin & George. We missed out the 4 in the 041- London via Glasgow number. In Bulletin 146 we apologised for and corrected that error. In Bulletin 147 we did it again! "So what?" I hear you say but there is a small lesson for all here. Thinking we were clever we had drawn up the Bulletin 147 "Address List" by word processing an archived text file of the list from Bulletin 145. Who says only typesetters and textbooks perpetuate errors? Thank goodness the firm moves to Loughborough fairly soon. We can then have a whole new numbers game.

No Comment

Following our acronymic tail to the "Opinion" article in Bulletin 147, we have received two further topical suggestions. For rather obvious reasons the sources, both human and of the original educational usages, have to remain unidentified. We are sure, despite some contrary political opinion, that even folk as far down the socio-economic scale as Scottish teachers will be capable of at least identifying the latter. We shall continue to keep mum on the former! Here we go:

Going Round in Circles

and, reversing the order of the original

Silly Procedures Aggravating Technicians

We apologise to our readers outwith Scotland for this obscurantism. Nothing more quickly spoils an in-joke than an explanation.

Comment

To date we have not had any response to our invitation, in Bulletin 147, for units derived from the clytemnestra. We were given one definition which may be the beginning of a narcissist series. The following was received recently from David Tawney, Director of our sassenach sister Cleapse School Science Service:

"The kan is the unit (pre SI) of conceit.

And one Millikan is enough for anyone!

(Apparently, the famous measurer of e and c had a high opinion of himself.)"

We wonder if we have stumbled on the authorship of that other classic graffito:

"I used to be conceited but now I'm perfect".

* * * * *

Poisonous plant material

An object lesson - safety information

Accidental poisoning in children through the ingestion of toxic plant material has a long recorded history. Incidents have been sporadically reported in the educational literature for as long as most of us can remember. Over the years these incidents have led to the production of a variety of leaflets, posters and wallcharts warning against the more common dangers. However given that children are "naturally venturesome and independent" [1], and that safety fashions come and go, it isn't suprising that this problem has again been in the news.

The star turn has yet again been that golden mouldie of the school laboratory, Ricinus communis, known more vernacularly as the Castor Oil plant. The seed coat (testa) of this plant contains the powerful toxin 'ricin'. Nonetheless the seeds have long been used as an example of a dicotyledonous, endospermic seed which exhibits epigeal germination. More plainly, it has two seed leaves like a broad bean but unlike that example it also possess an endosperm (oily in this case). When it germinates its seed leaves are brought above ground. Absolutely essential knowledge for any future British citizen, as all our readers would agree.

More significantly perhaps, castor oil seeds happen to be pretty. They possess a seed coat with a nicely coloured, marbled pattern. It must be this aesthetic aspect that has allowed the lingering use of the seeds in germination studies, because there are several equally useful but less potentially harmful substitutes (for example, dwarf french bean or sunflower). Interestingly the incident which caused the latest stramash, in a long line of same, may have involved this more aesthetic aspect. The use of the seeds is suggested in the "Insight to Science" scheme in order to give practice in the use of keys.

In any event, a child in a school in England ate a castor oil seed and as a result became seriously ill. In March of this year a Scottish Sunday newspaper, well kent for the accuracy and seriousness of its reporting, gave the impression that the Scottish Education Department had announced a total ban on the use of castor oil seeds in Scottish schools. "Not so!" cry we, but probably too late for the rumoured ban not to have gained widespread credence.

What in fact took place was that the SED had sent out an eminently sensible circular letter on the 4th of February, 1985. This merely reminded folk of the danger from these seeds and of the need to take precautions to prevent the risk of eating them. Similar sensible advice was also issued by DES in England and the Association of Science Education [2]. The ASE Laboratory Safeguards Committee summed up the situation admirably. The gist of their advice was simply:

-that for some purposes the use of the seeds could be discontinued and

-that for others where visual observation of the whole seed is all that is needed they could be sealed in a transparent container e.g. be resin-embedded.

Why, readers may ask, go on at such length about a relatively small matter and a generally well known hazard? Well, it wasn't a small matter for the pupil who became ill nor no doubt for the parents and the teacher involved. But more importantly this recent mini-saga within Scotland provides a number of object lessons for the proper dissemination of safety information. The factors involved are such a common annoyance to SSSERC staff that we have even coined an in-house catch-phrase to describe the collective phenomenon - the "Ninhydrin Syndrome".

This syndrome has the following symptoms:

-rumour has it that a substance, thing or process is banned. No reliable primary source can be identified for the commonly held belief as to the existence of a ban.

-the ignoring of a prime safety rule that resistance to the dissemination of unreliable information is every bit as important as the circulation of reliable information.

-the ban is the only remedy mentioned. This is the digital, all or nothing, approach to safety. Accepted good safety practice; a search for substitutes, change of scale, containment with discontinued use as a last resort; is not proposed.

-the existence of a similar hazard in a wide range of other substances, things or processes is ignored. The nature of the hazard as only a specific example in a wider category of dangers is not mentioned. As a result attention is focused on the now fashionable, highlighted example and away from other potential hazards.

In the specific case of castor oil seeds this last symptom causes most irritation. There are many hundreds of poisonous plants with which children may come into contact in the UK [3]. As with castor oil the most dangerous are probably those that look like edible fruits or vegetables and/or are associated with products or other parts of the same plant which are edible in the broadest sense e.g. laburnum seeds which resemble peas, potato fruits which resemble tomatoes and where children know that the underground parts are edible, rhubarb leaves where children know that the stalks are fine to eat and might well not suspect that the leaves could be toxic. Castor oil with its harmless (or at least non-toxic!) oil and its very poisonous seeds is but one isolated example.

In addition many seeds and other plant parts, may well these days be contaminated with pesticides as residues or seed dressings.

A wide range of plant material is highly irritant or may cause allergenic reaction. A good example of the former is the now infamous Giant Hogsweed and of the latter many liliaceous bulbs. The CLEAPSE/SSSERC Hazcard "Plants and Seeds" is a source of further information on such dangers [4].

It is thus better to view this latest incident, as a timely reminder to teach children to be wary of tasting **any** unfamiliar plant material unless they have positive reasons to believe that it is safe to do so. To concentrate solely on getting in a lather with castor oil (to mix more than a metaphor?) is to do everyone a disservice.

References

1. A quote from the eminently sensible introductory section of the original 1967 edition of DES Education Pamphlet No.53 "Safety at School" -out of print.

2. "Education in Science", June 1985, ASE.

3. "British Poisonous Plants -Reference Book 161" 1980 Edition, HMSO for MAFF, ISBN 0 11 240461 8.

4. "Hazcards", 1981, CLEAPSE/SSSERC.

* *

Petrol-oxygen explosion and Macpherson's law

In keeping with traditional Scots pessimism, Macpherson's law is claimed by many as predating Murphy's and other more rudely named variants by several epochs. Combine that with the popular definition of Scottish foresight: as

"Never again!":

and you will understand why even knowledge of the law is no protection against its invocation.

The incident

One of the latest examples involved the demonstration, safe we thought until recently, of the explosion of one drop of petrol and a few cm^3 of oxygen in an open mouthed plastic syringe (see Bulletin 132). This had been carried out countless times by teachers and technicians without mishap. The school where it went wrong, thanks to Macpherson, was kind enough to report the incident to us in order to forestall its happening elsewhere.

In this particular case the class teacher's efforts had failed to produce the desired explosion. With the benefit of hindsight we would surmise that the petrol content of the mixture was probably too high. In his attempts to get a decent bang he may have worked the plunger of the delivery syringe to and fro' a few times. He would thus draw the rich mixture back into that syringe where it would mix with the oxygen already therein. When a colleague arrived to help, one of his first actions was to press the gas lighter switch. The inevitable flashback set off the now no longer too rich mixture, now in the delivery syringe. That syringe plunger was expelled with great force.

Reconstructions of the event as described above, operations being conducted from behind a safety screen, resulted in a 100% explosive success rate.

Precautions

(a) Protection

In the original incident no-one, fortunately, was hit by the syringe plunger. This was just as well since its velocity was considerable and may have resulted in serious injury. In such demonstrations even two safety screens of the usual flat type may protect the operator but only some of the audience. This is because there is no way of accurately predicting the flight paths of such explosively propelled objects. This particular incident illustrates again the wisdom of the recommendation that eye protection be worn whenever there is a forseeable risk of injury to the eyes (see also "Gas Taps" below).

(b) Prevention

Clearly the unusual and unexpected action of withdrawing some of the petrol vapour back into the delivery syringe can be avoided by:

(i) expelling all of the oxygen from the delivery syringe, thereby leaving it empty. A warning could be added onto the apparatus or on the worksheet. This might be taken as an invitation to investigation by the "naturally curious and venturesome" and could be counter-productive.

(ii) detatching the delivery syringe before igniting the mixture or isolating it by placing a screw clip on the tubing just below the explosion chamber. Whilst removing the danger this course of action depends on the operator and is therefore not completely fail-safe. Also its very tediousness is an invitation to omission.

(iii) fitting a non-return valve immediately below the explosion chamber. This was the sensible course of action taken by the school who experienced the accident. We tried both an inexpensive commercial non-return valve and a Bunsen valve made from a few pieces of scrap rubber and plastic tubing. The dimensions used for the latter are shown in Fig.1. Whilst the given dimensions are not critical, the dead space of the valve should be minimised by using as small bores as possible.

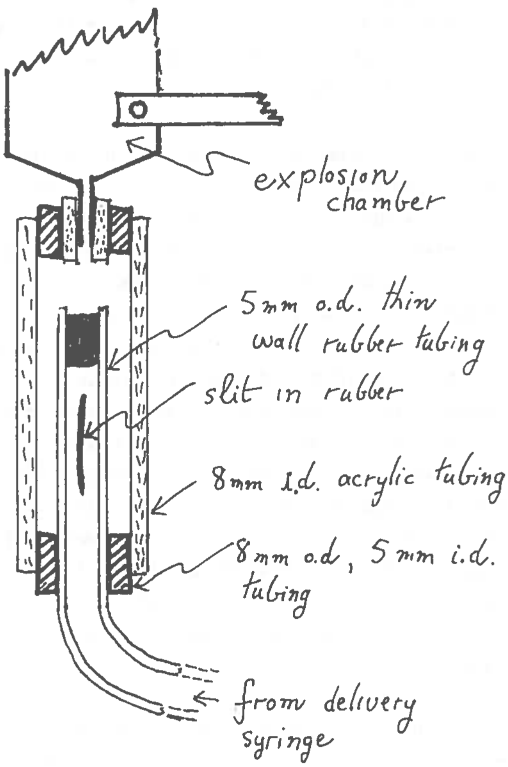

Fig.1

The Bunsen valve has the virtue of being both extremely effective and cheap (for its potential disadvantages see "Bunsen Valves" below). The plastic non-return valves of the type commonly seen in most catalogues from major school science suppliers (e.g.Macfarlane Robson, catalogue number 235/0355/00, price £1.15) was found to fit very neatly onto the Luer fitting of the syringe. However, use of a short length of rubber tubing made for a more positive connection (Fig.2).

This device is not perfect. A fairly fast flow is needed to close the valve and some back-flow is possible prior to complete closure. In contrast a Bunsen valve remains closed, unless a forward pressure is exerted.

By being peverse and cussid we managed, with half a dozen short sharp strokes, to draw enough of the vapour into the non-return valve to cause an explosion within it when the gas lighter was next sparked. Nevertheless when this valve is fitted the resistance will be obvious to anyone who might accidently or unwittingly attempt to withdraw the petrol vapour/ oxygen back into the delivery syringe.

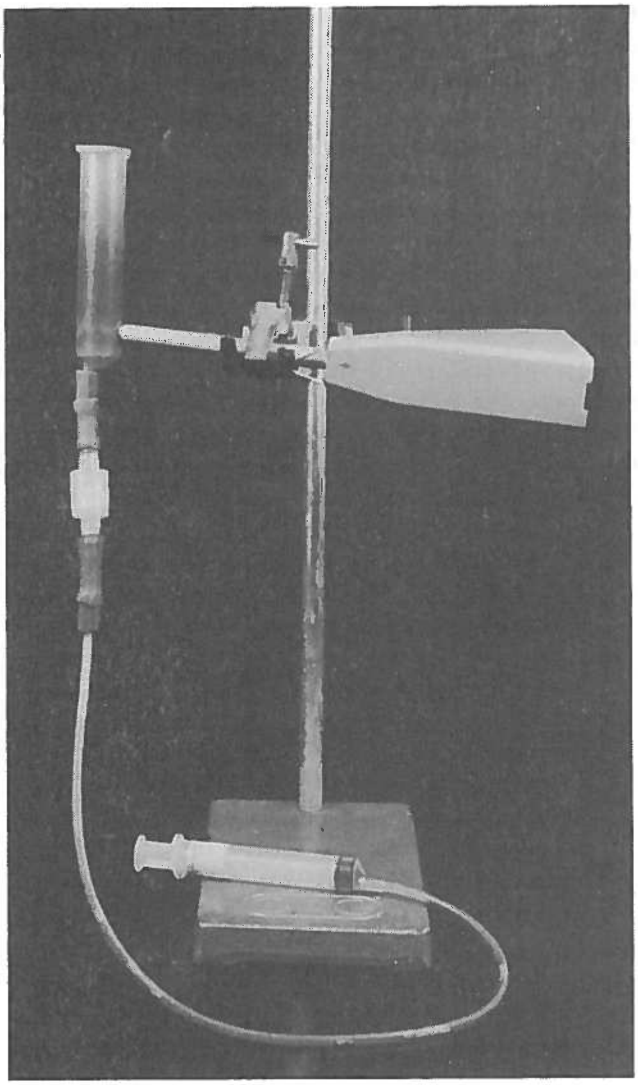

Fig.2

This little episode shows not only that 'universal truths' such as Macpherson's Law are unavoidable, but also that often there are ways of modifying potentially hazardous situations in anticipation of their fulfillment.

*　　　*

Bunsen valves

Some readers may remember reported cases of accidents caused by Bunsen valves which stick. They may then be loathe to use them for the application described above. Indeed several such cases involving blow-outs in heated combustion tubes led the ASE Laboratory Safeguards Sub-committee to recently give advice on the use of this type of valve ("Education in Science, June 1985).

Reported accidents usually involve the use of such valves for pressure relief, e.g. on the top of a conical flask to allow the escape of say hydrogen liberated from the reaction of iron with dilute sulphuric acid during the preparation of iron(II) sulphate or in some analytical procedures, yet preventing the ingress of air after the reaction has subsided. However in the application as decribed for the petrol/oxygen explosion, should the valve stick it will be fail-safe. It will only be a nuisance, rather than a hazard, in that it prevents the oxygen being driven into the explosion chamber.

Failure of Bunsen valves is usually caused when the rubber tubing becomes perished and seals the slit. It is important not to use rubber tubing which is too rigid or thick-walled. Soft silicone rubber tubing can be used with advantage for this component. Before using a Bunsen valve it is prudent to examine any rubber for perishing by chemical attack. With any valve, Bunsen or other, it is important to check prior to use that it is actually functioning.

Despite several reported incidents the ASE sub-committee, even for those other applications - "...still consider it safer to use a Bunsen valve than not to do so: a blow-out is preferable to suck-back".

*　　　*

Gas tap fittings

We have received a report of a recent incident in England where a gas explosion resulted in injuries to five pupils and a teacher. The prime cause of the incident is believed to have been failure of anti-rotation devices on the gas tap fitting. We understand that, in view of the potential for a similar occurrence in Scottish schools and colleges, the Scottish Education Department has issued a circular -

"Laboratory Safety:

-Gas tap fittings
-LPG (Liquified petroleum gas)

The circular deals also with LPG because of the possible exacerbation of the problem with a gas which is denser than air and where dangerous accumulations within voids and wells are thus more likely to occur. We would again stress that the use of LPG was not the prime cause of the explosion.

Action on the SED circular will be, at least in the first instance, more the province of advisory and architectural services staff rather than of teachers and technicians. In order to assist EA staff who will be responsible for any necessary remedial work on gas fittings, SSSERC has provided SED with a short set of technical notes which have been appended to the circular.

A major reason for drawing attention, in these pages, to the SED circular lies in the final paragraph of the letter which we quote below. This will serve to further reinforce our earlier statement on eye protection (see above "Petrol-oxygen explosion and Macpherson's law").

> "Finally, we are informed that photographs of one of the injured pupils, taken after the accident, clearly showed from the pattern of injuries that she had been wearing protective goggles. This had obviously saved her eyes from possible damage. This aspect of this particular incident should serve to underline the importance of wearing eye protection even during routine laboratory work".

* *

Picric Acid

Earlier this year there was a considerable stooshie over the problems with the disposal of picric acid (2,4,6-trinitrophenol). Unfortunately a lot of dust was kicked up by the media. As usual this got into the eyes of many, who then understandably got a somewhat distorted picture of the hazards connected with the use and disposal of this substance. At the time we had a large number of telephone enquiries which we answered directly. However now that the cloud of dust has had time to settle we can publish a more considered view of the substance and its hazards.

Despite the recent panic, the Laboratory Safeguards Sub-committee of the ASE has been unable to establish that there has ever been any accident in a school during the use or disposal of picric acid. An excellent summary of salient safety information is to be found in "Education in Science", No.113, June 1985. For the benefit of those Scottish teachers who are not ASE members (shame on you!) we can summarise the main points of the Sub-committee's advice as follows:

> Picric acid is explosive but is also difficult to detonate. Stored wet, it offers no explosion risk. Note though, that its metal salts (picrates) are dangerously sensitive and are used as detonators. Care must thus be taken to avoid metal salt formation for example it should not be stored in bottles with metallic screw tops. Picric acid itself is very toxic. This probably is its most hazardous property; its TLV is 0.1 mg m^{-3} by skin absorption.
>
> Its two main uses in schools have been as a powerful acid dye and as a component of some biological fixatives and stains. There is no reason why such usage should cease. The main requirement is that the substance be stored wet. Checking the dampness of any stored picric acid should be part of routine checking on other chemicals which need special storage arrangements e.g. sodium under oil/paraffin, phosphorus under water, or on those which deteriorate in storage e.g. potassium.

Unwanted samples may be disposed of by dissolving in a large volume of water, and slowly flushing away to waste. Take care to avoid accumulation of the substance in sink traps. An apparatus for automatically diluting and flushing away such waste substances was illustrated in Bulletin 73 (see also page 51 of "Topics in Safety", ASE 1982).

* *

Ethyl benzoate hydrolysis

Recently a school reported occasional problems with this organic preparation when carried out as per Section E1 of the revised edition of SCDS Memorandum 16 [1]. (See also [2,3 &4] for similar descriptions of the preparation).

Despite the use of anti-bump granules, on a number of different occasions the flask contents had erupted violently through the top of the reflux condenser. This resulted in hot, 10% sodium hydroxide being sprayed around the work-station. The use of a larger flask had not improved matters. At the request of SCDS, Dundee Centre we have been investigating the problem at the bench. The operation was repeated nine times in SSSERC. Experimental conditions were varied as to:

(i) type of anti-bump device

(ii) type of heat source, i.e. bunsen via gauze or sand tray or electric heating mantle

(iii) rate of heat supply.

At first sight this appears to be a minor problem of detailed technique. However during our investigations a number of interesting points of more general application did emerge.

With normal usage of a bunsen no problems of spillage from frothing were experienced. Only when this burner was turned down low was there uneven refluxing and the first signs of a tendency to bump.

No significant differences were observed in the effectiveness of anti-bump granules (BDH 33009), glass beads or porous pot fragments in preventing bumping and eruptions.

No problems were met with on heating the flask and contents with a full flame, through a gauze, from a 'macro' burner (a normal lab. type rather than the micro-burner recommended in Sect.E1, Memo 16). This however is bad practice as it results in the condensation line moving up toward the top of the condenser. The object of refluxing is to keep volatile reactants in mutual contact.

There is thus little to be gained, in terms of good technique, from over vigorous heating. In contrast, from the safety point of view, we found that only when a very slow rate of heating was used was there even the hint of a bumping problem or incipient eruption.

Our trials with a simmerstat controlled electric heating mantle did result in eruptions of sodium hydroxide spray. It would seem in this case that it is the uneven application of heat which causes the eruptions. With a simmerstat or similar 'energy controller' the heat supply is either full on, or off. The difference between a "high" and a "low" setting rests on varying the periods of the fully-on and fully-off states, hence the uneven heating. One additional disadvantage of simmerstat controllers is an increase in the strain set up in the glass of the flask. Another, more minor for most school applications, is that the switching of the bimetallic contacts can cause arcing and be a source of ignition.

Thyristor controlled heating mantles, a little more expensive and less commonly used at present, provide a steady supply of heat at a selected rate. They would be free of many of the problems associated with simmerstat controlled devices.

For many applications the old-fashioned water, or oil, bath with a thermometer in the heating liquid are to be preferred. These provide a more even rate of heating.

Therefore we would recommend:

Use of a moderate to large flame on a normal lab. bunsen (e.g. Flamefast 701), rather than the cautious application of a small flame.

This ensures sufficient agitation to break up and mix the two otherwise immiscible layers.

Not recommended is:

The use of an electric heating mantle with a simmerstat or 'energy-regulator' controller.

We are grateful to the school which reported their difficulty with this preparation and for expressing concern on behalf of others. Hot sodium hydroxide spray is certainly very unpleasant stuff. Care should therefore always be taken with this reaction and eye protection worn. Particular care should be taken that the preparation apparatus does not impede access to the gas tap or other heating controls.

References

1. Scottish Curriculum Development Service, Dundee Centre, 1982, "Practical Work in CSYS Chemistry", Memorandum 16.

2. Rendle, Volkins & Davis, 1972, "Experimental Chemistry - a Laboratory Manual", Arnold, ISBN 0 7131 2343 5.

3. Gerrish and Whitfield, 1977, "A Modern Course of Organic Chemistry", Longmans, ISBN 0 582 35150 2.

4. Lambert and Muir, 1966, "Practical Chemistry for Advanced Level", Heinemann.

* *

Safety Signs - a reminder

In Bulletin 128 we referred to the Safety Signs Regulations 1980, which came into force on the 1st of January, 1981. These required all new signs erected by an employer to conform with the specifications in the Regulations. These same regulations further referred to BS5378 Part 1 1980.

The period of grace given for older signs already in situ before 1st of January, 1981 and which did not comply with these specifications comes to an end on 31st December, 1985. Those older signs will have to be replaced before that date.

For anyone not clear as to the specifications and details, one of the best ways to obtain such information is to make use of the extensive free literature and wall posters available from the manufacturers and suppliers of signs. The variety of available safety signs is very great. The obvious danger of using too many signs and thus detracting from the few that are esential should be avoided. The names and addresses of a number of suppliers of signs are given in the address list on the inside front cover of this bulletin.

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BIOLOGY NOTES

"Microbiology - An HMI guide.."

The "HMI" referred to are, strictly, those of the Department of Education and Science. The "guide" is not for them but for "schools and non-advanced further education" [1].

This important publication became available very recently. It is an update of "Education Pamphlet Number 61" which was also an HMSO publication for DES. Its English origin did not prevent pamphlet 61 being widely used in Scotland as an authoritative source. This time there was Scottish input because DES kindly invited SSSERC to attend some meetings of the group revising the document and gave us the opportunity to comment on the various drafts.

We have mentioned the new document here in "Biology Notes" rather than in the safety section for two reasons. Firstly the document deals with much else besides safety. It provides a good general guide to the educational usage of micro-organisms. Secondly, unfortunately and we hope unwittingly, it seems to give the impression that much industrial microbiology should only receive theoretical treatment. We trust that our review below on enzyme kits, as well as other reviews to follow in future issues, will restore the balance.

Enzyme technology kits

Abstract -

A number of kits are analysed for relevance to current and possible new Scottish biology courses. Reference is made to earlier, more detailed reviews by another author as well as to a proposed SSSERC Guide.

Introduction

Some years ago we attracted criticism from certain quarters of the Establishment for an outburst, in a bulletin "Opinion", on so-called Scots editions of suppliers' catalogues.

The offending article complained of an unwelcome Sassenach attitude prevalent during the introduction of the revised SCEEB biology courses. This is well described by the phrase "A thistle logo that'll do". It is always nicer, if uncharacteristically genteel, for us to be able to offer early positive and constructive advice. Despite any rumours to the contrary, it pains us to deliver literary smacks to fingers.

We had a pleasant surprise in the results of our evaluation of enzyme technology kit contents in relation to the demands of Scottish courses. It was good to find a sigificant number of syllabus entries to which the kits had direct relevance. This was particularly so even with the somewhat conservative, draft Standard Grade material we have seen (just a glance, honest!). Although stalled for the present it seems that in the curricular stakes, with typical tortoisoidal style, the Scots team are again leading from behind.

Even without direct syllabus references to the more technological aspects of enzymology, parts of these kits would be applicable to a lot of school-based biology. Enzymes and their properties crop up as ".....a topic dealt with at all levels and so an ideal vehicle to show biotechnology at work to all ages" [2].

Other, detailed reviews

The first by John Tranter, of the Centre for Life Studies in London, we have already quoted [2]. John has also written other reviews [3,4] for the ASE Apparatus Review scheme. Readers wishing more detailed accounts of individual experiments are referred particularly to those reviews. SSSERC is also trying out some of the experiments and will publish a more overtly opinionative stand-alone Equipment Guide.

Convenience, costs and 'quiche'

In Bulletin 144 [5] we outlined some of the philosophical, educational and operational arguments related to kit usage in technology teaching. Iteration seems pointless. The interested reader is referred to the original articles for that detail.

Here we concentrate on the questions of curricular relevance and value for money.

Earlier reviews [ibid.] identified important criteria in judging the value for money aspect. Some kits contain novel media or disparate ingredients which would be difficult or time-consuming for an individual teacher to assemble. Nearly all of the kits suggest and document novel experimental procedures. To be fair to the suppliers we would point to the common failure of teachers to appreciate the high development costs of what appears in a kit as a mere piece of paper.

A few of the kits come dangerously close to failure on the "quiche" question, having lots of flavour but not much substance [6]. Teachers may be struck too by both the apparent similarities in the Gerrard and Harris kits and differences in price.

We are informed that in both cases several kits were developed from work by Dr.D.B. Johnson at the University of Galway. He worked directly with Harris Biological in the U.K. and with Kemtec in the U.S.A.

Gerrard re-import the Kemtec kits. This confusing circumstantial combination explains the similarities (same originator), and differences (different curricular requirements) of content, as well as the price differentials (re-importation).

Summary Tables

Tables 1 & 2 summarise the applicability of currently available kits from Gerrard Biological and Philip Harris Biological. It should be noted that the "Standard Grade" analysis is necessarily tentative. It is based solely on draft information, supplied for purposes of consultation and comment.

Letters and/or numbers in the first column of Table 1 are references to syllabus sections. For sixth year studies the letters are just a simple encoding of the unit/topic title followed by the section number. Because of its early draft status, no section references are given for the Standard Grade syllabus. Numbers in brackets after the kit title entry refer to the actual experiment in that kit. This device provides some cross referencing to the detail on kit functions given in Table 2. Where no such numbers are given, the kit is either only loosely applicable, for example by virtue of suggested extension activities, or is of interest in its entirety. Detailed examination of Table 2 should in most cases decide the issue.

Table 2 indicates prices, catalogue numbers and the broad experimental content of individual kits as well as giving some idea of their generality of application.

References

1. HMSO for DES, "Microbiology: An HMI guide for schools and non-advanced further education", 1985, ISBN 0 11 270578 2.

2. Tranter J., "Breakdown", Resources Section, "Times Educational Supplement Scotland" (also in the English edition), 22nd February 1985.

3. Tranter J., Apparatus Reviews, School Science Review, March 1985, **66** , 236, 574-575.

4. Tranter J., Apparatus Reviews, School Science Review, June 1985, **66** , 237, 823-825.

5. SSSERC, "Opinion" and "MFA Review" Bulletin 144, February 1985.

6. With apologies to John Gordon and Pat McKay, Microelectronics Educational Development Centre (MEDC), Paisley College - see p.9, "ITEMS", 4 December, 1984.

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GRADE	SUGGESTED PRACTICAL	HARRIS BIOL. Kit/Exp. Reference	GERRARD BIOL. Kit/Exp. Reference
SIXTH YEAR STUDIES (CL\I\4)	Types of enzymes - related to the type of reaction catalysed. Effect of temperature, pH on enzyme activity, Enzyme inhibition, extraction, specificity. Metabolism of sugars by yeast.	Basic Enzymology Kit (ALL) Introduction to Enzymes (2 3 4) Effect of temperature on Enzymes (1 2 3) Effect of pH on Enzymes (1 2 3)	Enzyme Teaching Kit (1,2)
SIXTH YEAR STUDIES (MICRO IV4)	Microbial Industrial Processes (Demonstration of)	(Aspergillus oryzae) Pectin Breakdown (1)	Enzyme production Enzymes in Industry Enzyme & Cell Immobilisation
SIXTH YEAR STUDIES (MICRO III:2)	Breakdown of cellulose by soil organisms. (Biodegradable)detergents Transfer of fruit spoilage organisms from infected to fresh fruit	Cellulose Breakdown Kit (2) Enzyme Biotechnology Pectin Breakdown (2 3)	Enzymes in Home(1) Enzymes in Industry(3)
"O" GRADE (11:5)	Useful applications of micro-organisms eg. fermentation, bread and cheese making. Food spoilage by microbial contamination. Pathogenic micro-organisms.	Immobilised Enzymes Enzyme Biotechnology Aspergillus Oryzae Cellulose Breakdown Kit Pectin Breakdown Kit	Enz. & Cell Immob. Enzymes in Indust. Enzymes in Home

Table 1.

GRADE	SUGGESTED PRACTICAL	PHILIP HARRIS kit Exp. Reference	GRIFFIN & GEORGE kit Exp. Reference
"O" GRADE (1:5)	Anaerobic respiration in yeast or germinating seeds. Practical applications of fermentation in commercial and everyday use.	Immobilised Enzymes (3 6 7 10)	Enz.& Cell Immob. (2)
"O" GRADE (2:3)	The role of digestive enzymes using as examples amylase, pepsin, and lipase.	Introduction to Enzymes	Enzyme Teaching Kit(2) Enzymes in Home(3)
"O" GRADE (1:4)	An introduction to enzymes and their properties covering synthesis and degradation reactions. Effects of pH and temperature.	Introduction to Enzymes Effect of pH on Enzymes Effect of temperature on Enzymes	Enzyme Teaching Kit
STANDARD GRADE	Investigate the effect of change in pH on enzyme activity.	Introduction to Enzymes(3) Effect of pH on Enzymes	Enzyme Teaching Kit(2)
STANDARD GRADE	Investigate the effect of changes in temperature on enzyme activity.	Introduction to Enzymes(4) Effect of temperature on enzymes.	Enzyme Teaching Kit(2)
STANDARD GRADE	Design and carry out experiments to investigate the effect of temperature variation on yeast activity.	Immobilised Enzymes	Enzyme & Cell Immobilisation

Table 1.

GRADE	SUGGESTED PRACTICAL Kit/Exp. Reference	HARRIS BIOL. Kit/Exp. Reference	GERRARD BIOL.
STANDARD GRADE	Investigate the effect of amylase on starch	Effect of temperature on Enzymes(2) Introduction to Enzymes	Enzyme Teaching Kit(2) Enzyme Production Kit
STANDARD GRADE	Carry out simple experiments to investigate the technique of immobilisation, especially of whole organisms eg. yeast	Immobilised Enzymes	Enzyme & Cell Immobilisation
STANDARD GRADE	Carry out simple experiments to investigate the action of "biological detergents."	Enzyme Biotechnology(3)	Enzymes in Home(1)
STANDARD GRADE	Follow simple instructions for making cheese.	Enzyme Biotechnology(1)	Enzymes in Industry(1) Enzymes in Home(2)
STANDARD GRADE	Observe and describe the catalase reaction in living plant/animal tissue with hydrogen peroxide solution.	Non applicable	Non applicable
STANDARD GRADE	Obtain and present information about the effect of a catalyst in a chemical reaction	Introduction to Enzymes Enzyme Biotechnology Enzyme Specificity and Inhibition.	Enzyme Teaching Kit

Table 1.

S U M M A R Y   T A B L E   2 .   K i t   C o v e r a g e

Please Note that prices apply to the UK and are those which were to hand at compilation. They are given for comparative purposes only and should be checked before ordering. Note also that the entries on applicability provide only a rough guide as they depend on subjective interpretation of contexts.

A. GERRARD BIOLOGICAL

1.Enzyme Production Set, Cat.No. ZEA-200-G, £7.80

Demonstrates the production, by micro-organisms, of three important enzymes; protease, invertase and amylase. The presence of enzymes after incubation is verified by simple biochemical tests. Also included are instructions on handling cultures and on safety. Number of times directly applicable to Scottish biology courses: SYS 1; Standard Grade 1.

2. Enzyme and Cell Immobilisation Kit, Cat.No. ZEA-222-R, £24.

Six investigations. Number of times applicable: SYS 1, 'O' Grade 2, Standard Grade 2.

1:1 Enzyme immobilisation & recovery by magnetism.
1:2. Comparison of rates of reaction of free and alginate immmobilised invertase.
2:1. Immobilised cells in fermentation.
2:2a. Comparative performance study with yeast immobilised on varying concentrations of sodium alginate.
2:2b. Flow rates of calcium chloride over yeast pellets of varying diameters.
2:2c. Effect of chemicals on sodium alginate and on the viability of the cell wall.

3. Enzyme Teaching Kit, Cat.No. ZPK-360-C, £17-36

Two major groups of investigations Applicability: SYS 1; 'O' Grade 2, Standard 4.

1:a Assay of urease activity; 1:b Specificity & non-competitive inhibition, calculation of urease activity, competitive inhibition, effects of substrate & enzyme concentrations.
2: Amylase action; an assay, effects of pH and of heating.

4. Enzymes in Industry Kit, Cat.No. ZPK-420-W, £18-40.

Three groups of experiment(s). Kit also includes "Student Data Sheets" (worksheets).Applicability: SYS 2; 'O' Grade 1, Standard 1.

1: Use of rennet in cheese production.
2: Use of protease in the recovery of silver from photographic film.
3: Pectinase and fruit juice production.

5. Enzymes in the Home Kit, Cat.No. ZPK-400-N, £18-40.

Again three groups of activities. As above kit, contains "Student Data Sheets". Applicability: SYS 1; 'O' 2, Standard 2.

1: Use of enzymes in laundry products.
2: "Curds & Whey", milk coagulation by rennet and cheese production.
3: Proteases in meat tenderisers.

B.HARRIS BIOLOGICAL

1.Introduction to Enzymes Kit, Cat.No. M85858/0, £13-50
Four groups of investigations. Applicabilty: SYS 1; 'O' 2. Standard 3.

1: Demonstrating enzyme activity,(a)
invertase (b) amylase (c) protease (d) amlyase in saliva.
2: Enzyme specificity.
3: The effect of pH extremes.
4: The effect of temperature extremes.

2. Enzyme Biotechnology Kit, Cat.No.M85900/6, £14-55
Three groups of activities. Applicability: SYS 1; 'O'1, Standard 3.

1: Use of rennet in cheese production.
2: Pectinase in fruit juice production.
3: Enzymes in washing powders.

3. Effect of pH on Enzymes, Cat.No. M85865/8, £15-10.
Again three groups. Applicability: SYS 1; 'O' 1, Standard 1.

1: Effect of pH on invertase.
2: Effect of extremes of pH on stability of invertase.
3: Effect of extremes of pH on stability of amylase.

4. Effect of Temperature on Enzymes, Cat.No.M85870/1, £11-55.
Applicability: SYS - 1; 'O' 1, Standard 2.

1: Heat denaturation of Invertase.
2: Heat denaturation of Amylase.
3: The effect of incubation temperature on the activity of invertase.

5.Enzyme Specificity and Inhibition Kit, Cat.No.M85875/0, £16-15.
Applications: Standard 2.

1: Substrate specificity of invertase and amylase.
2: Inhibition of invertase.

6. Basic Enzymology Kit, Cat.No.M85860/9, £14-28.
The instructions for this kit are written at a more advanced level than the others reviewed here. This kit is probably most suited to work at SYS or even lower tertiary level. There are ten investigations. Number of times applicable: SYS 1 (for kit but several expts. useful).

1: How to demonstrate invertase activity.
2: The effect of time on enzyme activity.
3: The effect of incubation temperature on enzyme activity -the concept of optimum temperature.
4: The effect of substrate concentration.
5: The effect of enzyme concentration.
6: The effect of pH on enzyme activity.
7: Substrate specificity of invertase.
8: Inhibition of invertase activity.
9: Heat denaturation of invertase.

10: A composite experiment - substrate specificity, heat denaturation, pH inhibition.

7.Immobilised Enzymes Kit, Cat.No. M85910/9, £24-20.
Applications: 'O' 2, Standard -2.

1: Entrappment of yeast cells and their use in fermentation.
2: Immobilised glucose isomerase: an application in the sweetener industry.
3: Preparation and use of immobilised invertase.

8.Aspergillus oryzae Kit, Cat.No.M40647/4 £6-75.
A demonstration of saprophytic nutrition and fungal enzyme action using **A.oryzae** on starch agar plates.
Direct applicability: 'O' 1, but could easily fit in elsewhere in a less direct context.

9. Pectin Breakdown Kit, Cat.No.81725/5 £14-85
Three main investigations all using simple viscosity tests. Applications: SYS 2; 'O' 1.

1: Commercial pectinase.
2: Pectinase producing organisms in soil.
3: **Aspergillus oryzae** action on pectin.

10. Cellulose Breakdown Kit, Cat.No. M81715/2 £18
Similar to the pectin kit in using viscosity measurements but with carboxymethylcellulose (CMC) as substrate. Applicability: SYS 2; 'O' Grade 2.

1: Commercial cellulase.
2: Cellulolytic organisms in soil.
3: Growing cellulolytic organisms on CMC agar plates.

Note: There are also two other Harris kits - on starch and protein breakdown. These have not been reviewed herein since there is overlap with some of the more general kits.

* * *

Flux gate magnetometer

Abstract

The flux gate magnetometer is a highly sensitive, vector reading, magnetic instrument. A description is given of its operation and historical development. Its relevance and possible importance in physics education is discussed and some applications are described.

Introduction

We can appreciate the high sensitivity of the flux gate sensor by comparing its respective ranges and sensitivities with that of the Hall effect sensor. Some typical values are shown below.

typical ranges

Hall probe	0-10 mT or 0-100 mT
flux gate sensor	0-30 μT

typical sensitivities

Hall probe	100 μT/mV
flux gate sensor	15 nT/mV

Thus the flux gate sensor is more sensitive than the Hall effect probe by three to four orders of magnitude, typically.

We can see (Fig.1) how the ranges of these two sensors compare with some typical magnetic fields. In general the Hall probe is useful in investigations on fields which are due to strong, permanent magnets and electromagnets where the current inducing the field will be of the order of one amp; it is insensitive to the Earth's field. On the other hand the flux gate sensor is highly sensitive to the Earth's field, disturbances in the Earth's field and topographical and local magnetic anomalies; it would not be used to investigate strong fields such as found between the poles of permanent magnets.

Flux gate sensors can be manufactured to give a linear response. As with Hall effect probes they are direction sensitive and thus, because of their linearity and direction properties, will output a signal proportional to B cos θ where B is the magnetic flux density and θ is the angle between the direction of the field lines and the alignment of the sensor (Fig.2).

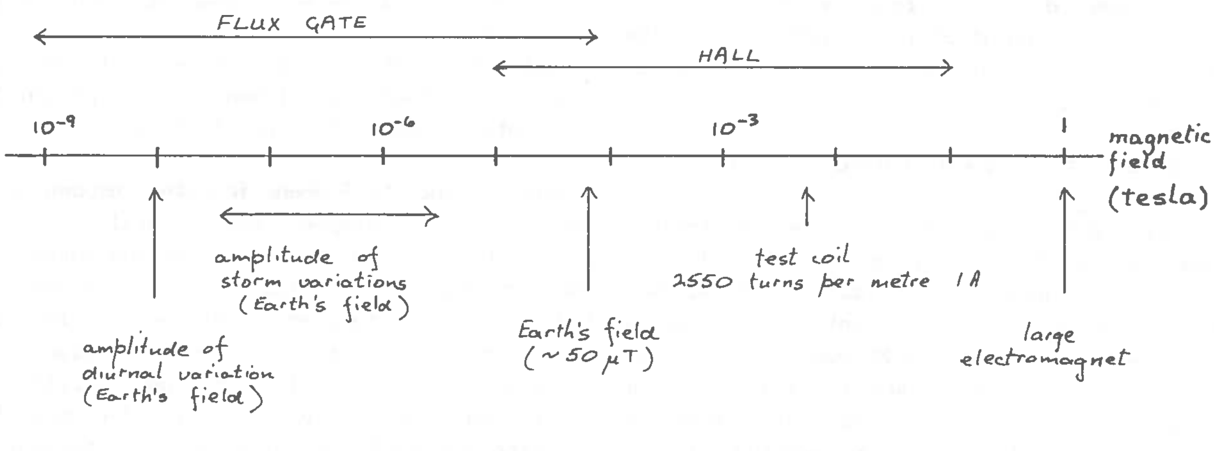

Fig.1 - Orders of magnitude of typical fields.

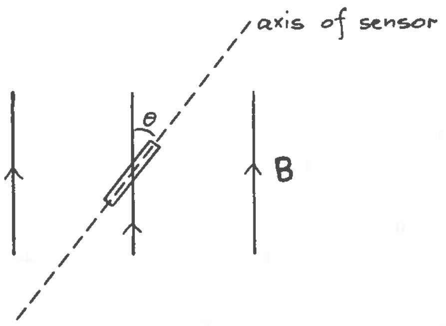

Fig.2 - Vector output.

Thus the flux gate can be regarded as a vector sensitive instrument and because it is sensitive to the Earth's magnetic field, has been used extensively in navigation.

It is suggested that the flux gate could have an important role to play in physics education because it is a direct reading, vector instrument giving the component of the vector field. No such other suitable instrument exists to satisfactorily serve this purpose. The Hall probe is unsuitable because it is only sensitive to strong fields which are necessarily locallized and non-uniform. It is because the flux gate is sensitive to the Earth's field which, throughout most of any laboratory is likely to be uniform, that one can exploit it to demonstrate the components of a vector field.

It is suggested that the relevance of the flux gate to physics education is not primarily in the study of magnetism, nor Earth magnetics, but of vectors and fields.

Historical background

It is worth considering the historical development before giving an outline of the principle of operation. The author has for long been intrigued by its devious contrivance. However development can be traced to Michael Faraday and his discovery of electromagnetic induction; the flux gate is one of a line of induction instruments which has been under development ever since. Seen in its historical context, its principle of operation is not that outlandish.

For a fuller account of the development of induction magnetometers the reader is referred to the book by Hines [1] to which acknowledgement for much of the detail in this section of the article is given.

Perhaps the simplest form in this lineage was the **rotating coil Earth inductor** (Fig.3). This was a vector sensing instrument; the size of the output signal being a sine function of the angle between the axis of rotation of the coil and the magnetic field. It could therefore be employed to determine the alignment of the Earth's field and hence could be used for navigation. Such an instrument had been used as an aircraft compass in an early transatlantic flight.

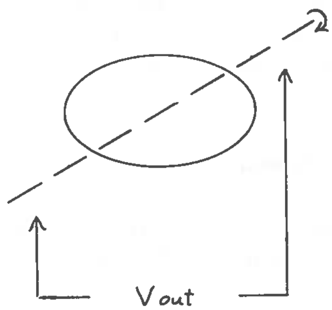

Fig.3 - Rotating coil Earth inductor.

This developed into the **Gunn compass** in which the rotating coil was wound round a rod of highly permeable material, thereby increasing the sensitivity. With the development of the Gunn compass we have two elements of the present day flux gate, a coil and an easily saturated core.

Next in line the **Siemens inductor compass** had a pair of coils wrapped round parallel, highly permeable rods (Fig.4). An alternating current was used to energize the coils and this assembly of rod and coil was rotated in the Earth's field such that the core was alternately aligned and orthogonal to the field. The permeability and excitation current were carefully selected so that the impedance of the windings became a maximum and minimum twice each per revolution. Therefore the current in the coils was modulated sinusoidally at twice the frequency of rotation.

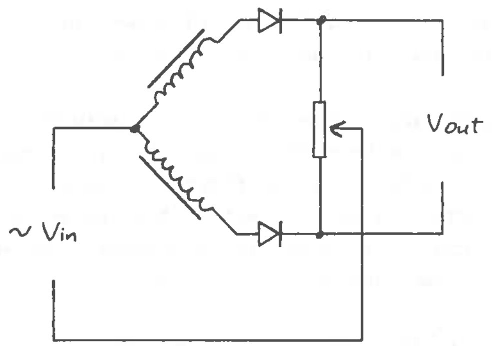

Fig.4. - Siemens inductor compass.

The Siemens inductor compass introduced the sinusoidal excitation current into the family of inductor instruments.

The **Aga-Baltic compass** followed next. This also had two soft iron cores each enclosed in its own excitation winding. However the cores were parallel on the same axis (Fig.5) and the sense of the windings was such that the field in one core opposed the field in the other. The excitation windings were driven by an a.c. supply of 48 Hz.

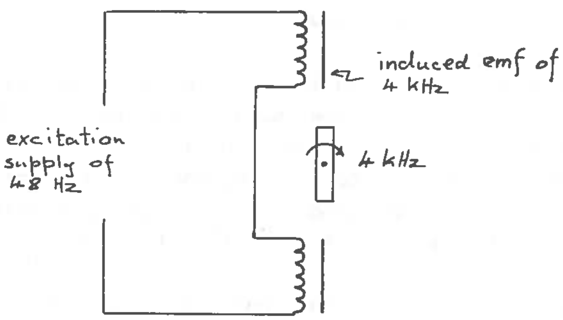

Fig.5 - Aga-Baltic compass.

Unlike the earlier inductor instruments the coils and core of the Aga-Baltic compass were not rotated. Instead there was a permanent magnet which rotated at 4 kHz midway between the cores. This induced a 4 kHz flux within the cores which thereby modulated the signal on the excitation lines.

Therefore the signal from the windings was a complex mixture of 48 Hz and 4 kHz. The ambient Earth field had also an influence on this signal (Fig.6). A phase sensitive meter was used to monitor the output which was dependent on the relative directions of the Earth field and cores.

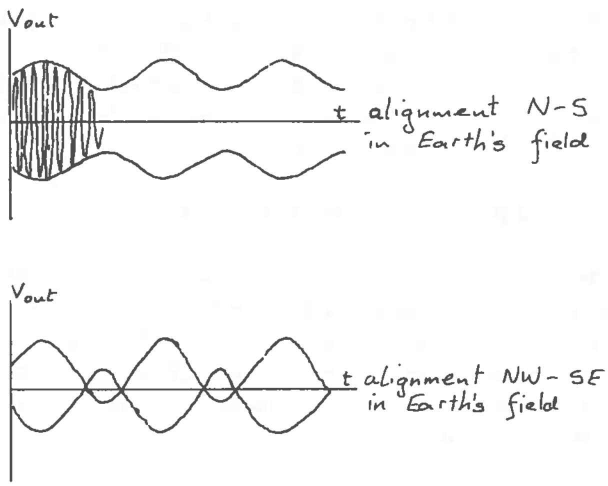

Fig.6 - Output from Aga-Baltic compass.

The Aga-Baltic compass introduced another important development, namely a stationary core with winding. With the dispensing of the rotating magnet, and by driving the cores into saturation, the instrument becomes the flux gate magnetometer.

Reviewing the story so far, the magnetic inductor compass had evolved towards having the following characteristics:

(1) a highly permeable core or cores with surrounding excitation coil or coils,

(2) an assembly which was stationary; it did not rotate in the Earth's field, and

(3) a sinusoidal a.c. signal which was applied to the excitation windings,

In consequence the flux within the core had two elements due to (a) the excitation signal and (b) the component of the Earth's field which was parallel to the long axis of the core. In order to understand the principle of operation one has to analyse that flux within the core and the signal which is induced in surrounding windings.

In finishing this historical review the reader might want to place dates to these inventions. The Gunn compass was devised in the early 1920's, the Aga-Baltic in the late 30's. Subsequent flux gate development took place during, and after, the Second World War.

The term 'Flux Gate' was used in a patent that was taken out by Pioneer Bendix in the 1940's. It may be that the term began as a proprietary trade name, but rather as with sellotape and the hoover, it is now used generically.

Principle of operation

Many forms of flux gates have been devised. For example, some have single or twin core(s), some have single, double or multiple winding(s), etc. Apart from these physical variations there are four distinct modes of operation which are commonly employed:

fundamental frequency inductor
second harmonic inductor
peak output inductor
pulse difference inductor

Each would require a separate analysis. The following is an explanation of the second harmonic inductor. But two sorts can be met with, single- and twin-core. It would seem that the latter is the more common and this, therefore, is the type described.

The sensing element consists of two parallel, high permeability cores (Fig.7).

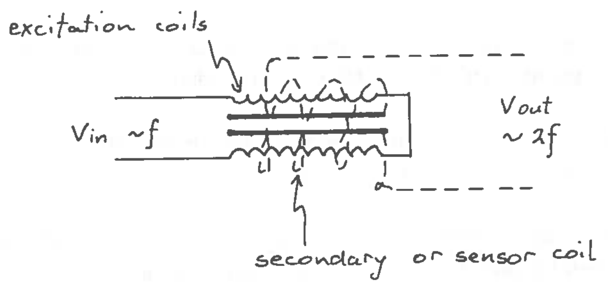

Fig.7 - Two-core flux gate sensor.

There is a separate **excitation** winding around each of these cores, the windings being wired in series such that when a d.c. signal is applied to the windings there will be an equal but opposite flux in each core. The net flux generated outside the core pair is consequently zero.

A **secondary** (sometimes called **sensor**) winding surrounds the twin cores and excitation windings. This secondary coil is therefore used as a sensor of net changes in flux within the core pair, as will occur when there is an asymmetry between the flux in one core and the other.

The following symbols are defined thus:

B_o = excitation field

B_{om} = amplitude of excitation field

B_{os} = magnitude of excitation field which causes saturation

B = field within core

B_s = saturation field within core

B_e = component of Earth's field parallel to cores

E = e.m.f. in secondary

f = excitation frequency

The cores are driven into saturation by an a.c. signal which can be sine, square or other. For the purpose of this explanation it is taken as sinusoidal. The excitation frequency is typically in the 1 to 8 kHz range. If B_o is the excitation flux in air, the amplitude of this flux is B_{om}.

Consider initially the core pair aligned at right angles to the Earth's field and free from local stray fields. Therefore $B_e = 0$ and the flux B generated axially within the core pair will be due solely to the excitation signal. The B-B_o curve is shown in Figure 8a.

If the two cores and their respective excitation windings are labelled 1 and 2 the flux generated in air by each winding will be in anti-phase (Fig.8b). Therefore if the cores are identically matched the flux therein will be symmetrical about the zero flux state (Fig.8c).

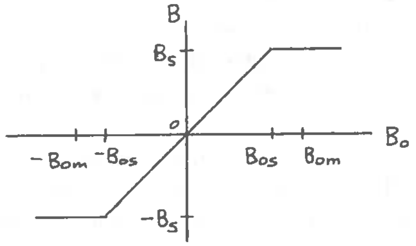

Fig.8a - B-B_o curve.

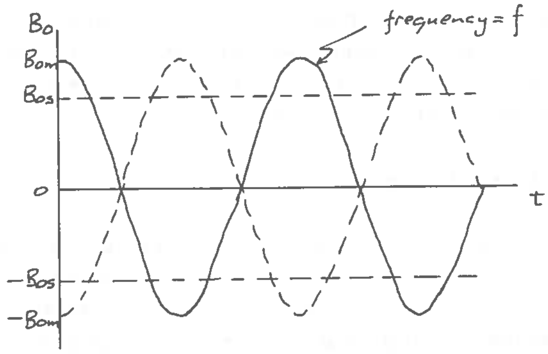

Fig.8b - (B_e = 0) Flux in air due to excitation coils

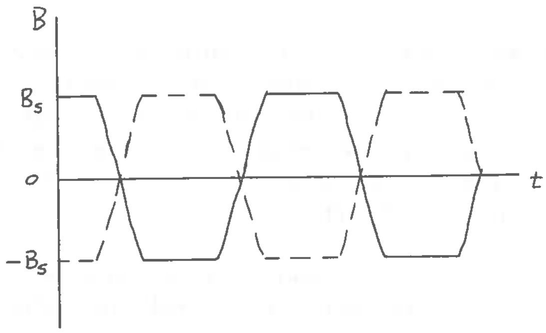

Fig.8c - Flux in cores (B_e = 0)

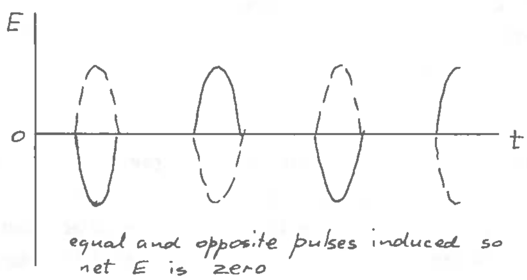

Fig.8d - E.M.F. in secondary winding (B_e = 0)

By differentiating the flux time curve we can obtain the voltage E across the secondary coil, E being proportional to dB/dt. Because changes in flux are symmetrical, equal and opposite pulses are generated in this secondary coil (Fig.8d) and the net e.m.f. will be zero.

If, however, the core pair is not at right angles to the Earth's field, B_e will have a finite value which will affect the magnetization of the cores. This will result in one core reaching saturation before the other. Examination of the flux curves (Fig.9c) shows that the resulting asymmetry is directly related to the magnitude of B_e.

When these separate flux-time curves are differentiated the voltage pulses induced by core 1 are out of phase with those by core 2, but of almost equal magnitude. The output from the secondary winding therefore consists of a series of narrow voltage spikes at frequency 2f, twice the excitation frequency.

Obviously the greater the value of B_e the greater the imbalance between the cores and therefore the output voltage.

It can be shown by Fourier analysis that the second harmonic, that is frequency 2f, of the output signal from the secondary winding is a linear function of B_e under favourable circumstances. It is an essential requirement that saturation should occur in each core during each half cycle. For optimum performance the ratio B_{om} / B_{os} should be 1.4 / 1

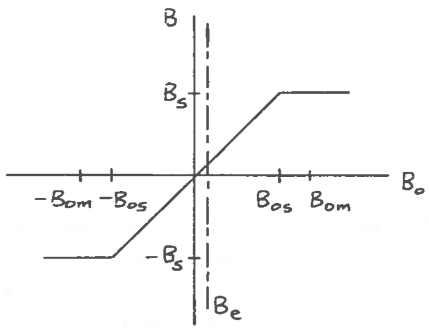

Fig.9a - B-B_o curve.

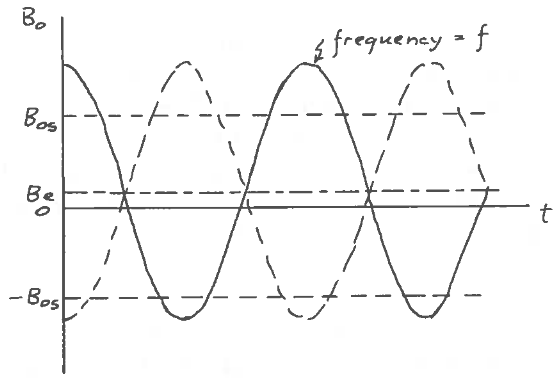

Fig.9b - Flux in air due to excitation coils ($B_e \neq 0$)

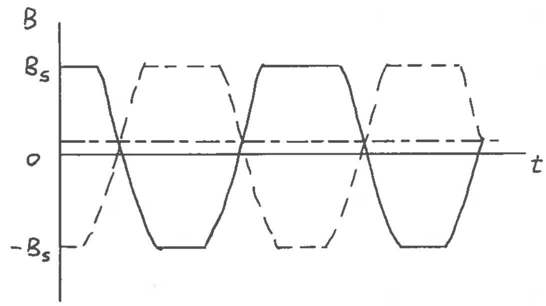

Fig.9c - Flux in cores ($B_e \neq 0$)

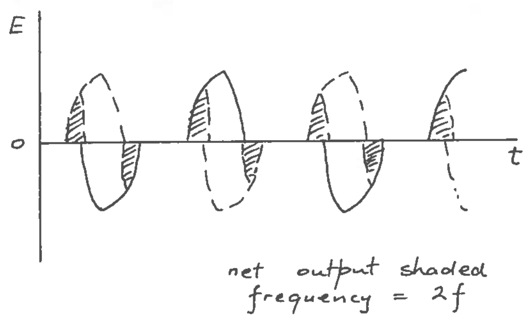

Fig.9d - E.M.F. in secondary winding ($B_e \neq 0$)

The cores should be of a highly permeable material such as Perm-alloy or Mu-metal. For good performance the length should be very much larger than the diameter. Hines gives the ratio 200 / 1.

The control system (Fig.10) consists basically of an oscillator, second harmonic band pass filter and detector. It is usual for the detector to contain a phase sensitive rectifier. This latter element is fed with a reference signal from the oscillator via a frequency doubler. The output is a d.c. signal of either polarity about zero volts depending upon the phase difference between the signal from the secondary winding and reference. Therefore the sign of the output will depend on the sense of the field detected.

Applications

Flux gates have been used for military purposes since the Second World War. It would appear that they were used by Britain in mine- and submarine-hunting, and in electronic compass and auto-pilot applications. In a World War II British patent there is a description of a three axis flux gate system which, with gyro-assisted attitude information, could be used to generate magnetic compass heading data.

As was shown in the historical introduction development work on inductor instruments had taken place in Germany in the 1930's. This work was applied during wartime such that a two axes flux gate system was deployed in the internal navigator of the German 'flying bomb'.

As is the way with devices which have military applications it would seem that flux gates and their principle of operation were classified secret for some years after the War. Indeed it is a reflection on their obscurity that we do not know of any physics textbook which carries a description of their operation. It is perhaps remarkable that such secrecy existed in that both sides in the conflict had been using the device.

More recently in 1960 a three axis flux gate system with a resolution of around 200 picotesla was developed to police the Nuclear Test Ban Treaty. A nuclear explosion in the atmosphere can generate perturbations in the Earth's magnetic field which might then be detected at a great distance.

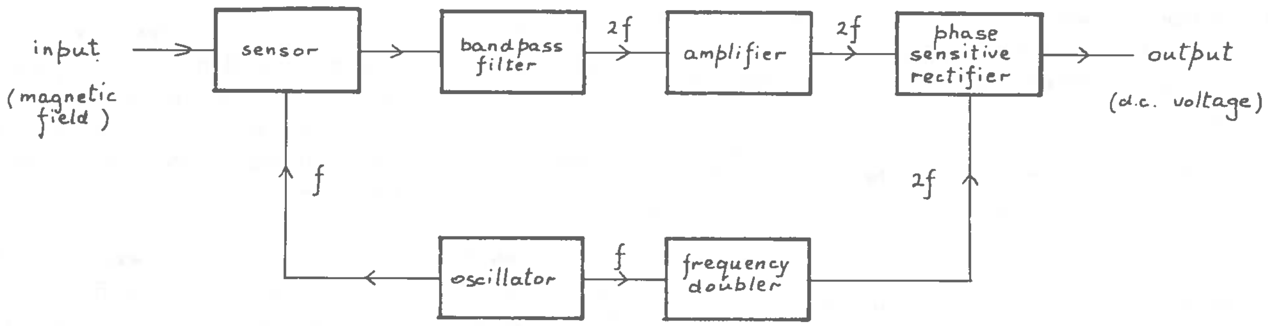

Fig.10 - Flux gate system - block diagram.

The high sensitivity of flux gates was exploited to detect such perturbations. However the Earth's magnetic field is itself naturally noisy and this monitoring system was abandoned.

Nowadays some non-military applications have been devised. One development is the availability of flux gate navigation systems for non-military purposes. Such systems are being marketed for use by yachtsmen. Another development is a system for tracing local magnetic anomalies. This is a two-sensor system which acts as a differential magnetometer, one sensor being mounted 50 cm above the other such that both are in alignment. In a uniform field the output from both sensors will be the same. However if the field is non-uniform, indicating a local anomaly, a difference in outputs exists. Such a system has been developed for use by archeologists. Features such as ancient ditches cut into the subsoil produce magnetic anomalies which can be detected by this means.

Flux gates are used in geomagnetic observatories to record fluctuations in the Earth's magnetic field. Several sorts of fluctuations occur including: (1) a diurnal effect produced by currents in the ionosphere which are caused by sunlight and (2) a random effect caused by the interaction of the solar wind with the Earth's field. The diurnal effect is larger in summer than winter. The random effect, when large, is described as a magnetic storm. The frequency of occurence of magnetic storms is related to the sun spot cycle. Variations as small as one part in ten to the power five of the total field intensity can be observed with flux gates. A reference to recent geomagnetic practice is given below [2]

Supplier

It was the appearance on the market of inexpensive flux gate sensors from Medical Magnetics which sparked off this article. There are two models available. The high sensitivity one is model SA1 (10-25 nT/mV); the low sensitivity one is model SA2 (30-60 nT/mV). Both systems include sensing elements and control circuitry, but in addition to this the user would require a 12 V supply and voltmeter, preferably digital.

The price of the systems is £65 for model SA1 and £45 for model SA2. Postage is £1 per unit.

Evaluation

Model SA1 was obtained for evaluation.

The sensing element is approximately 55 mm long by 7 mm square cross section. The cores and coils are hidden, being potted within a plastic case of these dimensions. The sensing element is connected via 45 cm of ribbon cable to the control circuitry within an instrument box.

A linearity check was carried out with the sensor mounted on the axis at the centre of a long straight solenoid and aligned magnetic east-west. The response was linear in one direction up to 15 μT which is just below the magnitude of the horizontal component, in Scotland, of the Earth's field. Sensitivity reduces gradually at fields above 15 μT, but one can draw a calibration graph up to 50 μT, the magnitude of the Earth's field, and take measurements within this non-linear region.

However, the sensitivity depends on the sense of direction, into or away from the field. Over the linear range, the difference in sensitivities is about 6%. This discrepancy mars the usefulness of the device in illustrating the cosine response.

In discussion with the manufacturer it would appear that the non-linearity may be caused by a mismatch between the sensor element and band pass filter. The manufacturer is confident that he can overcome this problem and have a product with a linear response and an output accurate to one degree of arc. If this promise is met the performance would be highly satisfactory.

Applications in physics education

As suggested earlier the main application is thought to be in demonstrating the cosine response of a vector field. Other applications might be in electromagnetism, geomagnetism and robotics. Three such applications are dealt with below.

Because the flux gate is highly sensitive it is likely to pick up local magnetic anomalies that are met with in laboratories such as the field from any ferrous screws and brackets which hold together laboratory furnishings. It is suggested that prior to some of these applications, in particular that of the cosine response, one should construct a non-magnetic workbench. A wooden box fastened with adhesive and brass screws would be suitable. The size should be about 50 to 60 cm cube and should be sufficiently large to accommodate any long axis solenoid that one may wish to use.

Cosine response of vector field.

The principle is to scale and offset the output such that when the sensor is aligned in the field it outputs a signal which reads +1.000. With the sensor turned through angle θ it reads cos θ. For example through 30°, +0.866, through 90°, 0.000, through 180°, -1.000, etc.

The simplest arrangement is to work on the horizontal plane of the Earth's field. Because of the large angle of dip which locally is about 70° care has to be exercised to ensure that the worktop is level. The workplace should be as removed as possible from any local steel structures such as reinforced concrete beams, girders, etc. There should be no small iron or steel artifacts within, say, 50 cm.

The sensor should be mounted centrally on a 360° perspex protractor (6" Helix). A rough and ready fixture with electrical tape or Blu-Tack might do, but it would be preferable to fashion a secure mounting. Such a mounting made out of a perspex block is shown in Figure 11.

Details of this mounting are given in Figure 12. If a milling machine is available the flux gate holder can be made from a block of perspex, or similar material, of suggested dimensions 70x30x12 mm. A cover, 70x30x2 mm, is required to hold the flux gate in position.

A slot or channel is cut in the large perspex block 8 mm wide by 7 mm deep. Two holes are drilled and tapped for 6 BA at 30 mm centres. Two 6 BA clearance holes are drilled in the cover.

If a milling machine is not available the perspex would require to be cut in the following sizes and glued together.

base	30x70x5 mm
side 1	70x18x7 mm
side 2	70x4x7 mm
cover	30x70x2 mm

The block is then glued to the protractor ensuring the longitudinal axis of the fluxgate is over the 0° - 180° line or at least parallel to it.

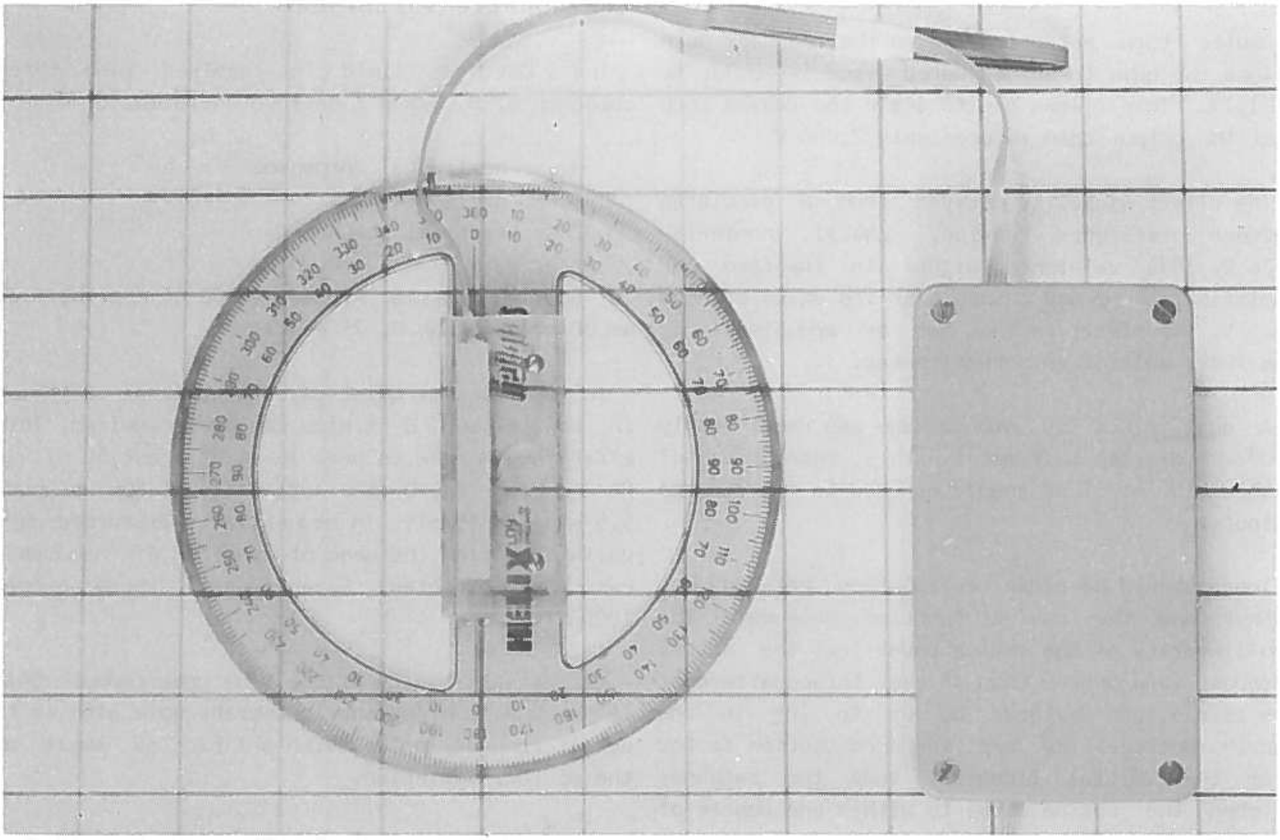

Fig.11. - Protractor with sensor

A perspex stud cut from 10 mm (approx.) rod should be attached to the centre of the bottom of the protractor. A grid should be prepared out of perspex sheet. It should have a suitable hole at the junction of grid lines which would act as the pivot for the protractor.

The electrical signal from the flux gate (model SA1) is about +5 V in the horizontal Earth field, +4 V in the null direction and +3 V in the reverse direction. The signal conditioning circuit (Fig.13) uses a summing amplifier (op amp 2) to add a negative offset signal to the flux gate output.

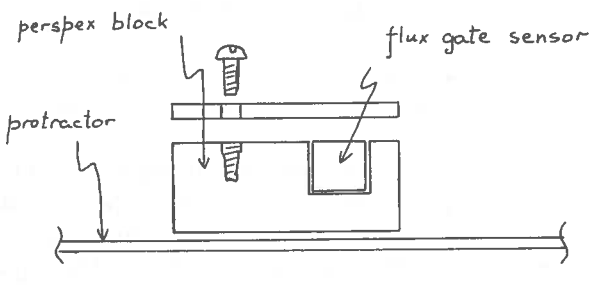

Fig.12 - Sensor mounting

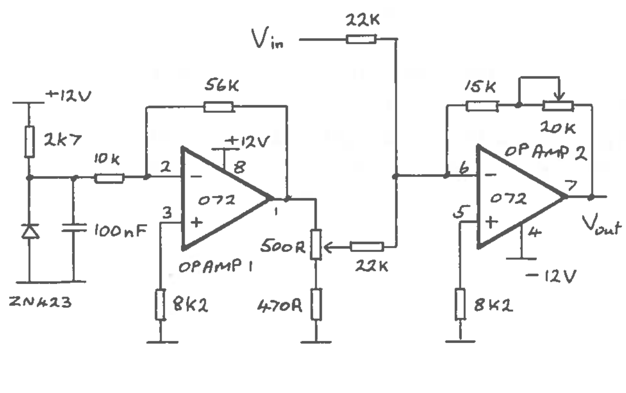

Fig.13 - Scaling and offset circuit

A multi turn potentiometer on the feedback path allows the gain to be adjusted from x(-0.7) to x(-1.7). This allows one to scale the device such that the output span is precisely 2.000 V.

The offset signal is derived from a precision voltage reference device, ZN423T, nominally 1.26 V. This reference signal is inverted and amplified by op amp 1 such that its value becomes -6.5 V. The offset is then set by adjustment of the 500R, multi turn potentiometer.

A dual BIFET op amp package was used, namely TL072. A digital multimeter with a resolution of either 10 or 1 mV should be used to monitor the output.

There should be close correlation between the output and the cosine function. Because of the non-linearity of the device under test the actual response was better than 4° over threequarters of the circle, but deviated by up to 10° in the fourth quarter. By applying a correction factor from the initial linearity test the response matched the cosine curve to within one degree of arc throughout the circle.

Mention ought to be made of the experience of using a vector sensing instrument. There is a negigible variation in output when the sensor is swung to and fro by 5° about the field direction. At 10° variation the response drops by only 1.5% from maximum reading. However around the null direction the response varies by nearly 2% of maximum output per degree of rotation. The cosine function is sufficiently commonplace that one tends to take its properties for granted. This experiment enables one to look at it afresh.

In some direction finders the highly sensitive nature of the cosine function at 90° has been exploited with a flux gate being used to sense with great precision the null component direction.

Geomagnetic variations

The Earth's field is resolved into three components, H, D and Z defined as follows:

H horizontal component
D declination
Z vertical component

In Scotland H is around 17000 nT north, Z, 46000 nT down and D, 7° west.

In magnetically quiet days the diurnal variation in the H and D fields can be recognized. This effect has a peak to peak level of about 50 nT in H and 10' in D (the latter translates at about 5.5 nT/' to 55 nT). In magnetically disturbed days variations from the mean of hundreds of nanotesla can be expected. Exceptionally these exceed 1000 nT.

As the sensitivity of the flux gate (model SA1) is around 15 nT/mV one is thereby able with it to detect changes in the Earth's field as small as the diurnal variation.

A record (Fig.14) of changes in the D field over a quietish 24 hour period clearly shows the characteristic swing in diurnal variation throughout that period.

In obtaining this record the sensor was clamped midway within a long axis solenoid which could thereby be used for calibration and a check on sense. The output was offset, amplified by 20 and fed to the Analogue Port of a BBC microcomputer. The sense was set such that a variation eastwards was up the screen thereby allowing comparison with records from standard observatories.

Technical details of the offset circuit and program can be obtained on application to SSSERC.

It is possible to compare records thus obtained with magnetograms from the two Scottish observatories, Eskdalemuir and Lerwick. These records are published once a month by the British Geological Survey in Edinburgh.

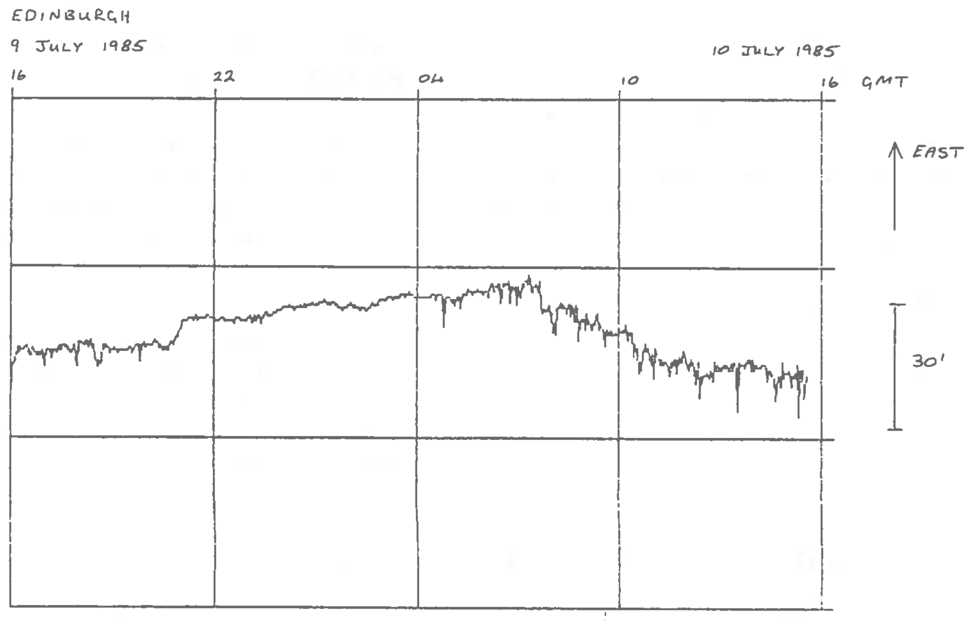

Fig.14 - Variations in D field

Comparison with the Eskdalemuir record confirms the shape of the diurnal variation curve. The magnetic bay at 2100 hours is evident. Minor fluctuations in daytime, seen as spikes in the SSSERC record, would seem to be locally generated noise of possibly an electrical nature. It is encouraging to note the long term stability of the trace. Drift was not apparent over a 60 hour period.

It would be preferable to carry out long term data logging of this type with a dedicated instrument such as the SSSERC data logger [3] or VELA, etc. rather than with a microcomputer; thereby one would not be tying down a microcomputer for an extended period. If this practice were to be observed one would require access to a microcomputer for only about quarter of an hour every few days in order to print out readings, process results and file data.

The SSSERC data logger has been extended [4] with an Analogue Port comprising A to D converter and amplifier with offset and span control. This is the sort of usage that it has been designed for.

Robotics

It is suggested that a flux gate system might be employed in conjunction with a servo controller. In general a two axis system would be the more useful in that the output would be unambiguous. Medical Magnetics hope to develop such a system giving a resolution of one degree. The projected price is around £40.

Perhaps one day we will see flux gates in the sensor sections of the RS and Farnell catalogues, and complete instruments available from the educational suppliers?

Acknowledgement

The author wishes to acknowledge the helpful service from, and correspondence and discussion with, Mr R.S.Murphy of Medical Magnetics.

/cont. overleaf

References

[1] Hine, A., "Magnetic compasses and magnetometers", Adam Hilger, London, 1968.

[2] Stuart, W.F., "Geomagnetic observatory and survey practice", D. Reidel Publishing Co., Holland, 1984.

[3] SSSERC Memo 2, 1985.

[4] SSSERC Memo 3, 1985.

Components

item	Farnell	£	RS	£
dual op amp	TL072CP	0.67	304-239	0.71
voltage reference	ZN423T	0.95	283-233	1.00

* * * * *

SCIENCE NOTES

Ross and Lamont Model House

Readers may wonder why they have heard nothing from us on this matter. We assure you that we were not saving up for three houses in order to exchange them for a hotel on the Old Kent Road or Mayfair.

The problem has been that whilst the exterior of the house has remained the same, the design of the 'heating system' and other fittings has been evolving. At present we have evaluated three versions. The Mark 1 and Mark 2 versions have already been purchased by a number of schools.

The three versions may be identified as follows:

The Mk. 1 has a double filament bulb (36W 12V) which is permanently soldered in and is held in position by a wooden flange. The cable has three conductors to permit the use of the second filament if or should we say when the first one blows.

The Mk. 2 has a single filament bulb (6V 36W), mounted in a standard brass lampholder. The latter is secured to the floor by a mild steel ring. The replacement of bulbs is thus an easy operation.

The Mk. 3 differs from the Mk. 2 in that the 6V bulb is replaced by one at 12V, 48W.

Ross and Lamont will provide free of charge the new 12V bulb to existing house owners. But they need to send a stamped addressed jiffy bag, to the address shown on the inside cover. Mk. 1 owners will additionally have to obtain a lampholder if they wish to avoid the need to solder in the bulb. The in-line fuse presently on the Mk. 2 will be omitted from the Mk.3. In all versions the central room is heated by means of the car bulb and the rate at which heat transfers to the end rooms is gauged by the differences in temperature rises of those rooms.

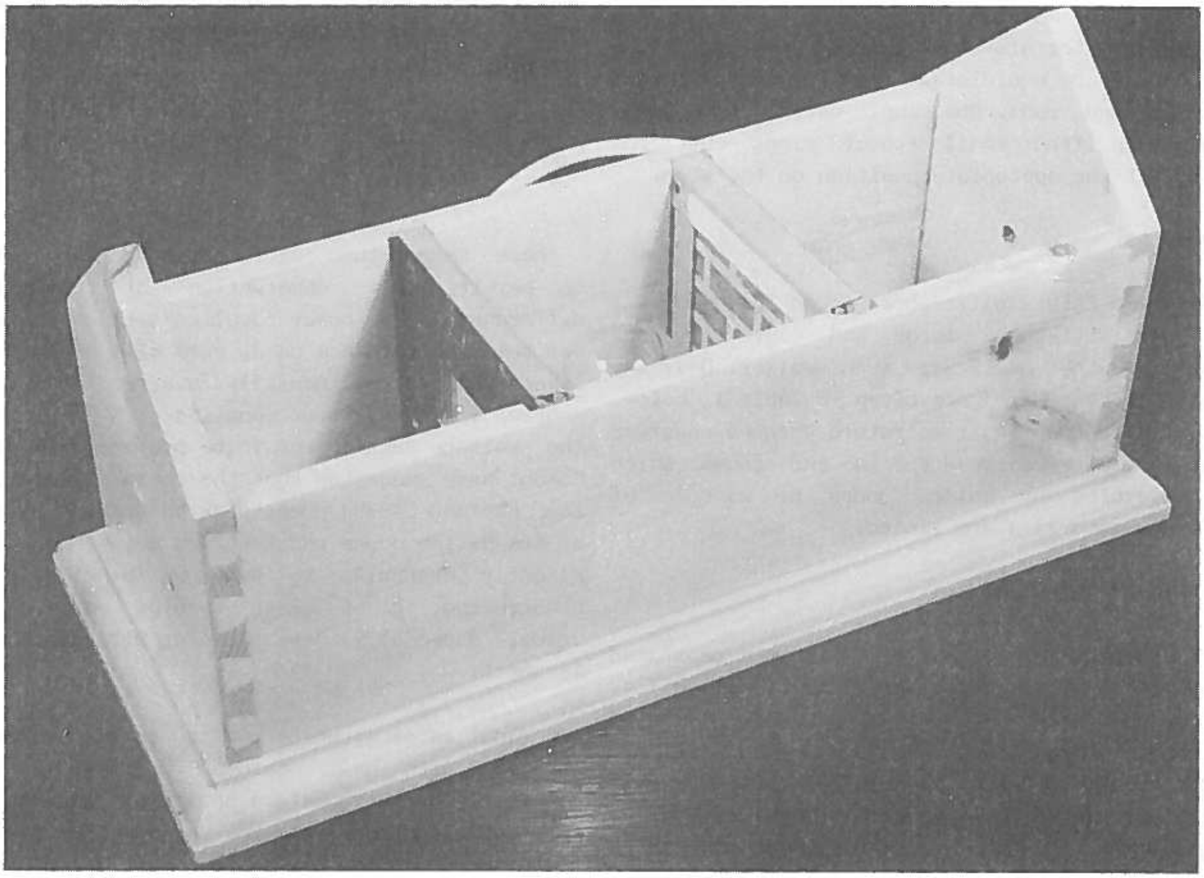

Fig.1

Walls of various materials, which are mounted in metal carrier frames, can be slotted into vertical grooves in the wooden outer walls.The two thermometers are inserted through holes in the two gable walls.(Fig.1) or into the roof spaces. The construction in pirana pine is robust with dovetail joints in the corners. The plywood roof section has an internal partition to separate the two halves of the roof space, thus enabling their temperatures to be compared.

The low voltage lamp should make the apparatus inherently safe. However the supply cable of the Mk. 1 is of the type intended for portable mains equipment, with blue, brown and green/yellow colour coding does seem a little confusing. An unthinking person might possibly respond automatically to these three colours by fitting a 13A plug and connecting up to the mains!

We would advise removing this cable and the fitting of 4mm leads and plugs. A permanent label marked "Low voltage -12 volts" should be attached.

The reason for using the three core cable was because of the clever trick of using a double filament bulb ---essentially a spare bulb already fitted. The snag is that when both filaments have blown a replacement has to be soldered in. A similar word of caution about cable colours used can be given to owners of the Mk. 2 and 3 which have a two core brown and blue cable.

The various 'walls' are very well constructed, but the small square cut out of a fibre glass insulating blanket will soon disintegrate and direct handling may cause irritation of skin or lungs. It is a good idea to use the real building materials where possible, but we feel this particular one should be contained in some way, say in a small light canvas bag.

The thermometers we happened to use gripped well in the holes, though you may have to enlarge these slightly. To make a valid comparison of any two insulating materials the two thermometer bulbs will have to be equidistant from the 'middle' wall of each end room. One simple device is to fit a stop, made from small rubber rings cut from tubing, at the appropiate position on the stem.

Results

The temperature differences found for the Mk. 1 and 3 were strikingly large and easy to read. Those for the Mk. 2 were much smaller. Only the results for the Mk. 3 are given in Table 1 below. The differences in temperature changes observed after 15 minutes between the two end rooms which are separated by walls, doors or windows of different materials are listed.

a) 'Wall' insulation

Room separated by wall of:			room separated by wall of:
single brick,	5°C	warmer than	cavity brick
cavity brick,	4°C	warmer "	filled cavity
single brick,	2°C	" "	4mm plywood
" " ,	2°C	" "	steel wall
" " ,	6°C	" "	plaster
" " ,	4°C	cooler "	glass
" " ,	2°C	warmer "	closed door
" " ,	4°C	cooler "	open door
" " ,	5°C	cooler "	open window
" " ,	3°C	warmer "	single glaz.
single glaz.,	6°C	warmer "	double glaz.

In our trials we used a power pack with a variable voltage supply and adjusted the output under load to 12V.

(b) Ceiling insulation

The roof space above the uninsulated ceiling was 10°C and 9°C warmer than the other roof space when the ceiling below the latter was insulated with fibre glass and expanded polystyrene respectively. It will not matter that the metal holders or 'slides' for the wall materials do become very hot, since a cooling-off break of about 15 minutes is needed between 'runs'.

Some slight signs of deterioration of the 'wall' surfaces were noticed when the lamp was left on for long periods.

Conclusion

These temperature differences are large enough to permit easy observation of temperature differences. If power supplies with continuously variable controls are used, care will need to be taken not to accidentally overrun the bulb and shorten its life. Power supplies with a lock on the voltage setting are to be preferred. Ross and Lamont have suggested that the raylamp socket of the Radford LAB59R power-pack be used. At a price of £24-95 the house and fittings may seem to be slightly expensive to some. We think it is well constructed, gives clear results and is good value, especially where time for DIY construction is short.

A final warning, which applies to all makes of 'houses' with heat sources in them, is that spirit-filled thermometers should be used. A small spillage of mercury into the corners of a confined space, which is going to be heated is highly undesirable, would be difficult to clear and would almost certainly mean the ditching of the 'house'. In any case, for this application spirit filled thermometers are sufficiently accurate and have the other advantage of the coloured liquid thread being more visible than mercury.

* * * * *

SSSERC MEMO 1

- **Constructional techniques** - solderless breadboard
  stripboard
  wire wrapping
  printed circuits

SSSERC MEMO 2

- **Data logging applications** - hardware and software
  removable memory unit
- **Bicycle speed logger**
  computer replay
  BBC, PET and Spectrum

SSSERC MEMO 3

- **Analogue application** - temperature logging
  flexible A-D converter
  hardware and software
  BBC, PET and Spectrum
- **Logic Families** - TTL
  metal gate CMOS
  silicon gate CMOS

The above publications are the product of a Research Fellowship in Microelectronics Applications, carried out at SSSERC and grant aided by Government and Industry.

The aim of the project is to encourage and help teachers and students of Science and Technical Subjects in Scottish secondary schools to incorporate Microelectronics and its industrial applications into their classroom work.

Single copies of the three publications are available at a price of £1.50, including postage and packing, from

SSSERC, 103 Broughton St., Edinburgh EH1 3RZ (031-556 2184 or 031-557 1037);

SCDS, Dundee College of Education, Gardyne Road, Broughty Ferry, Dundee DD5 1NY (0382-201201).

S.S.S.E.R.C.

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