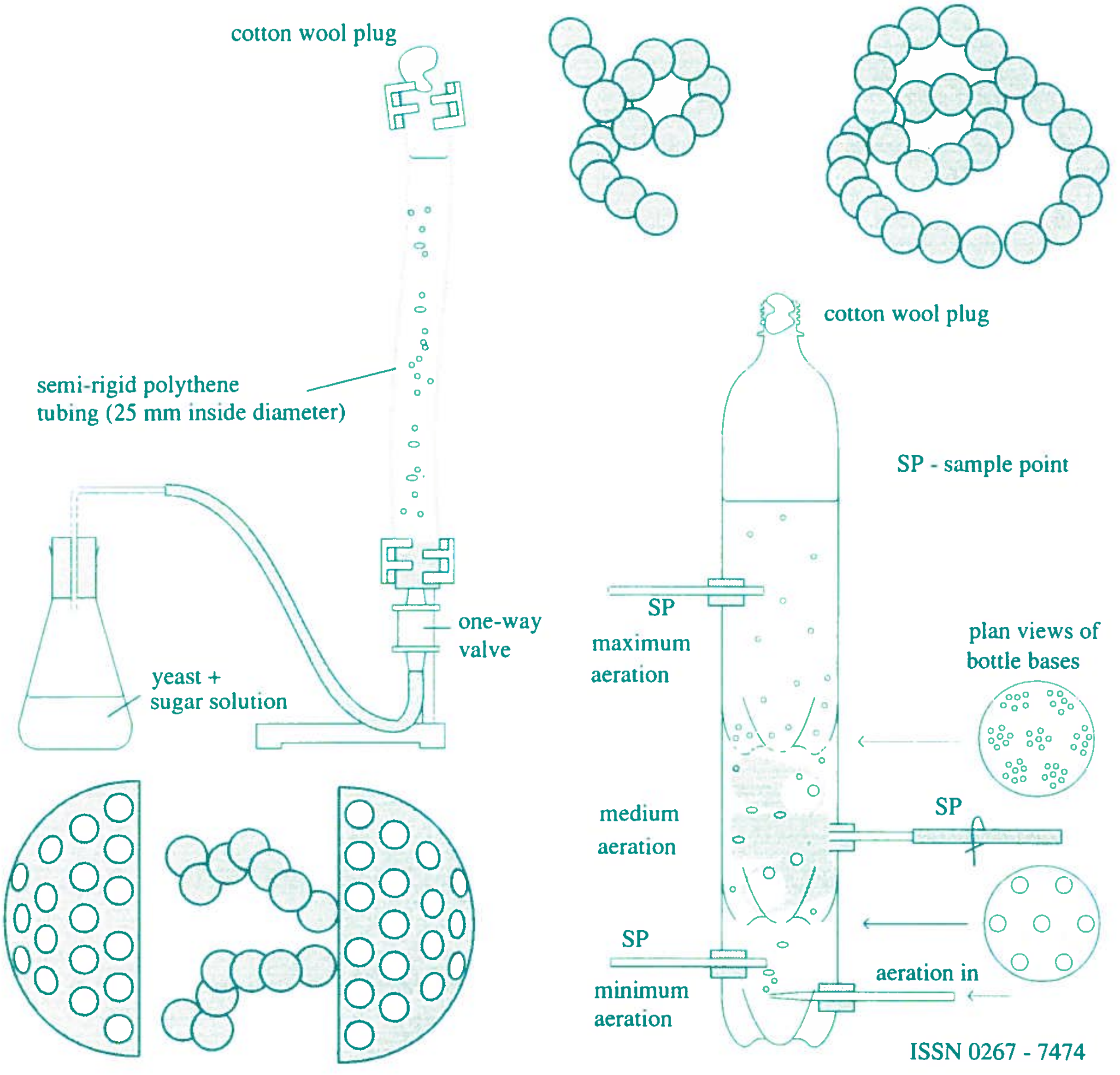
SCOTTISH SCHOOLS EQUIPMENT RESEARCH CENTRE



ISSN 0267 - 7474

Science & Technology Bulletin

For: Teachers and Technicians in Technical Subjects and the Sciences

Number 168 December 1990

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DCP Microdevelopments Ltd., Hillside Lodge, Ermine Street South, Papworth Everard, Cambridge CB3 8QA Tel. 0480 830997

Farnell Electronic Components Limited, Canal Road, Leeds LS12 2TU Tel. 0532 636311

Farnell Instruments Limited, Sandbeck Way, Wetherby, West Yorkshire LS22 4DH Tel. 0937 61961

Philip Harris Education:

2 North Avenue, Clydebank Business Park, Clydebank, Glasgow G81 2DR Tel. 041 952 9538

Lynn Lane, Shenstone, Lichfield, Staffordshire WS14 0EE Tel. 0543 480077

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RS Components Limited, PO Box 99, Corby, Northamptonshire NN17 9RS Tel. 0536 201201

SCC Research, 55 Falmouth Road, Springfield, Chelmsford, Essex CM1 5HZ Tel. 0245 251052

SCCC, Gardyne Road, Broughty Ferry, Dundee DD5 1NY Tel. 0382 455053

Science and Plants for Schools (SAPS), Homerton College, Hills Road, Cambridge CB2 2PH Tel. 0223 41141
For *FAST Plants* workshops in Scotland contact Mrs J. Main Department of Public Services, Royal Botanic Garden, Edinburgh EH3 5LR

Tait Components Limited, 20 Couper Street, Glasgow G4 0BR Tel. 041 552 5043

Training Agency : ASE-TVEI Initiative, TVEI 2, N705 T.E.E.D., Moorfoot, Sheffield S1 4PQ

Unilab Limited, The Science Park, Hutton Street, Blackburn, Lancashire BB1 3BT
Tel. 0254 681222.

Unipath Ltd. (formerly Oxoid), Wade Road, Basingstoke, Hants. RG24 0PW
Tel. 0256 841144 (media also available through local and other agents).

Brian Woolnough, Oxford University Department of Educational Studies, 15 Norham Gardens, Oxford OX2 6PY

The Centre is an independent national advisory service, solely controlled and largely financed by Scottish Regional and Islands Councils as Education Authorities. It currently incorporates the Science Equipment Research Centre and the Scottish TVEI Joint Support Activity Project:

STERAC (Science and Technology Equipment Research and Advisory Centre).

Printed in Great Britain by Bell and Bain Ltd., Glasgow

This issue of the Bulletin was produced using Acorn DTP on Acorn Archimedes computers. Resolution is 510 dots per inch (dpi).

Opinion

Where will it all end?

Looking today at my five month old son I am pleased to see how he can now hold his rattle in one hand and pass it to the other without dropping it. No doubt this could be incorporated as one learning outcome in a future 0.5+ test or some such assessment.

Why stop there? Perhaps some future genetic fingerprinting technique might save us all the bother of trying to put meaningless numbers on kids' abilities? Just think of the potential, *value-for-money* savings if we could achieve really early diagnosis of all those little piggies before whom no pearls need be cast. Not so ridiculous perhaps, in that if some present policies are to be much further projected, Aldous Huxley may well have prophetically written someone's manifesto for 2084 or earlier.

It was sufficiently onerous to be put under the pressure of an *11+* exam. I thought that a tender enough age to be potentially made or broken. I was unreliably informed by my primary school head that, in his ill-considered judgement but based on my test results: "You will get two or three 'O' grades at most and will do well to complete a craft apprenticeship". Suffice it to say that neither Fife Education Committee nor SSERC were such benevolent employers as to accept me with only those qualifications, as so prophesied.

Proposals for National Curriculum style testing of Scottish 7 year olds seem to me to merely pitch primary teachers and their charges into the same bureaucratic quagmire in which secondary schools currently wallow.

My experience of many, if not most, primary school teachers is that they plan all that they do very thoroughly. By such thorough professionalism they often as not make learning an enjoyable, as well as an effective, process. The happiest, and most alert children you might see in any secondary school are those you may meet up from some *feeder* primary (that in itself is possibly an insult) on a pre-entry visit to the *big school*. As science or technology teachers you probably put on a show of all your most exciting experiments or activities and enjoy the reaction.

Look at those self-same kids again half way through third year. Not so many happy faces then, I'll warrant. And this results despite all that structure, differentiation, progression and assessment.

What then, is the answer? Surely we have to ask ourselves as parents, teachers or both - why do we want to educate our children? Is it to benefit us or to benefit them? Are they simply feedstock for the latest educational plant to satisfy whatever industrial, educational, social and economic demands have the highest current priority or are simply the fashion of the day? Or are they to be their own men and women, shaping their own destinies, at their own pace, upon a solid base of unbiassed education and an unforced assimilation of knowledge, skills and attitudes?

Meanwhile, outwith my reverie, my son has just dropped his rattle and he's been sick all over me. Could this be the beginnings of the end, a fine career already down the drain?

By the way, to all you literary doubting Thomases out there, I know that Aldous Huxley didn't write "*1984*". That was the other guy wasn't it? Shows just how vital it is to learn your dates. Pass the soma someone. Please!

INTRODUCTION

(By "Inky Finger III?")

Christmas closure

The Centre will close for business on the afternoon of Friday the 21st of December 1990 and will open again on the morning of Thursday the 3rd of January 1991.

Yet another farewell

Well, we gave warning (Bulletin 167) that this issue might carry just such a sub-heading. Another of our short term, fixed contract, JSA project staff has given up the unequal struggle. This time, at least, the lad has served out his full sentence with only a month or so remitted for good(?) behaviour.

We refer of course to one Derek McLaughlan, JSA Project Officer, biologist and now, well known man about Edinburgh. Scottish science education's answer to yuppiedom has been upwardly (?) mobile yet again (eat your heart out Willie Melvin!).

Derek has taken up an APT science post with Lothian. His duties will be split between Firrhill High and the Royal Blind School. Thus in a way he will be renewing old ties. The original Firrhill and Blind School partnership came about as one result of an SED funded Research Fellowship held by Colin Weatherley, who at that time was on secondment from SSERC.

We will all miss Derek's cheery, if somewhat stirring, presence. So too I'm sure will all the teachers and technicians who got used to 'phoning and writing to him for information and advice. I have never known a staff member build up a client base so rapidly. He may be doing the wrong thing going back to classroom teaching. I'm suprised a certain Education Department didn't headhunt him as a marketing consultant.

The Royal Blind School is only just up the road from the Centre and we look forward to continuing contact with Derek. We've been thinking we might give him a part-time contract, just to pop in now and again to wind up all and sundry and thereby keep the place ticking over.

Have you read . . ?

Germane to the arguments raised in the "Opinion" section of the last Bulletin issue and in the "Comment" section in this (next column) is a recent research report from the Department of Educational Studies at Oxford University.

The report is entitled "Making Choices - An Enquiry into the Attitudes of Sixth-formers (sic) towards Choice of Science and Technology Courses in Higher Education". Copies are available at £5 each from the editor, Brian Woolnough, at the address given on the inside front cover of this bulletin.

Comment

The "Opinion" section in the last issue no doubt upset a number of members of the Scottish educational establishment. I do hope so. Others we would wish less to upset may also have seen the piece as merely one more in all too regular a series of OTT whingeing sessions. We would ask them to consider the following statistics as evidence of the ongoing rot to which we referred in Bulletin 167.

In September of this year "The Scotsman", in co-operation with the Scottish Universities Council on Entrance, listed those courses on which places were still available through the UCCA Clearing Scheme. Of 137 such courses 104 (76%) were in science, engineering and other technology related areas. That 76% is the mean of figures from six of the Scottish universities (Edinburgh being conspicuous by its absence). The range went from 50% for Stirling (but that was because only two courses were unfilled the *non-technological* one being that other *hard* subject, maths) and went up to 87% for Aberdeen.

If mathematics and other *purer* subjects requiring high levels of numeracy are added to the science and engineering courses, then the figures make even sadder reading. As the universities eased their requirements for entry, the Central Institutions and the EA Higher and Further Education establishments immediately reported knock-on effects on their own course uptake figures and entry requirements.

On the rare occasions I was invited abroad to address science and technology education audiences (e.g. English ones) a useful opener was often the "Here's tae us...!" statement that although Scotland could boast only 10% of the UK's population it produced 20% of its scientists and engineers. There is evidence that we may have recently slipped a point or two. The figures quoted above give me no cause for comfort as to our likely future performance.

A final statistical point must be openly directed toward the Howie Committee whose members are currently looking at the revision of courses in S5 and S6.

It is suggested that Scotland's disproportionately good track record in attracting students to science and engineering is possibly linked to social differences. (Now,be careful what you say here!). That, in turn, tends to produce less of a bias towards what have often been perceived as subjects and courses leading to the mainstream, *clean hands*, professions.

Anything that the Howie Committee might do to restrict exit points[1] in S5 and S6 could thus attract a double penalty. At the very time we desperately need more young people with high qualifications in science and technology we might discourage that sub-cohort[2] of potential students we most need to attract.

1 One for the jargonists there,

2 - and another!

Announcements

Science And Plants For Schools

Fast Plants - Workshop

Another workshop building on the success of the first Scottish Fast Plants Workshop (12th Nov 1990), has been organised. This will provide a further opportunity for biology teachers to invigorate their teaching of Plant Science. The workshop is entirely 'hands on' and, writing as a participant in the November event, one not to be missed.

Date: Saturday 13th April 1991

Time: 10.00 - 16.00

Place: Royal Botanic Garden Edinburgh

Cost: £5 (including refreshments and light luncheon)

A booking form and further information are available from:

Mrs J Main
Dept.Public Services
Royal Botanic Garden
Edinbugh EH3 5LR

Places are limited to 36 (note that the previous course was heavily over-subscribed)

Cross-curricular projects

An ASE-TVEI Initiative

The Association for Science Education (ASE) and the Training Agency have announced their first major joint venture. The TVEI Sub-committee of the ASE is co-operating with the TVEI office of the Training Agency to encourage the development of cross-curricular teaching materials.

The two bodies are jointly running a "Win a Computer" competition for integrated teaching packages involving science and at least two other subjects. The exemplar materials are to be suitable for use with 14 to 18 year old students.

Unfortunately, the lead time for our bulletin and that for the ASE-TVEI announcement of details of the competition itself mean that this present notice will be published sometime after the closing date.

We are aware however, that a number of Scottish entries were received before that deadline. We will be watching this development with interest. We intend to publish details of the winning package and of any other entries likely to be useful for Scottish courses, both within and outwith TVEI and Extension.

Trade News

Harris Analogue Colorimeter

Our testing and usage of a sample analogue colorimeter from Philip Harris (Cat.No. C29419/2) has revealed a fault which it appears is present in a batch of 50 or so.

Members of this batch all have a serial number beginning "W90B" followed by three further digits. Harris have to date traced 30 out of 50 of this batch, leaving another 20 to find. The fault arose because an earth lead was omitted from the construction but this did not show up on test because the colorimeter was earthed, secondarily, by the oscilloscope used to conduct the tests.

We emphasise that it is only those analogue colorimeters with W90Bxxx serial numbers which have this fault. Should you be holding such an instrument Harris would like you to arrange for its return in order that the fault may be corrected.

New RS range of tools

In November RS Components Ltd. announced a competitively priced selection of "Value Plus" tools to run alongside their existing range. The firm tells us that this new range is the result of a huge evaluation and selection programme which has been going on in the RS test labs for some considerable time.

In addition to the electrical and electronics items you would expect from RS, the "Value Plus" range also has a choice of engineering, mechanical and woodworking tools as well as spirit levels, calipers and magnifiers which extend the range into testing and inspection.

All of the new items are listed in the latest (November 1990 - February 1991) full RS catalogue but to mark the launch of the range RS have also produced a separate, 25 page brochure - "RS TOOLS".

LogIT portable data logger

SCC Research and DCP Microdevelopments, joint developers of the LogIT datalogger and software have just announced a Version 2 upgrade for their LinkPack software. This should be available in January 1991 and existing users will be able to obtain it merely by returning the original disc to DCP (see Address List).

Version 2 will be functionally complete but there will be further upgrades to support the new sensors under development.

Those later upgrades will only be required when such sensors are purchased.

Common data format

There are, of course, several other data capture devices now on the educational market in addition to loggers such as LogIT. In our Feature Article in Bulletin 167 we specifically mentioned and encouraged, development of facilities for the integration of captured experimental data into spreadsheets and databases. Such facilities have been around for some time now in research as well as in Higher and Further Education teaching labs.

One of the things holding back such work for use in schools has been the lack of a common data format. We were thus encouraged to hear on the grapevine that a number of suppliers have got together recently to seek agreement on such a format in order to encourage the development of a wider software base for science and technology applications.

Safety Notes

Apparatus defects - electrical safety

Our routine evaluation programme of apparatus has brought to light a number of potentially dangerous defects in electrical products. These are described below. It should be noted that specific products will only be named and dealt with in this way when:

- the problem is historical and there is a need for remedial action (for which we may have secured agreement from, and the active participation of, suppliers and manufacturers);

- significant private discussions with the supplier and, or, manufacturer, over a period reasonable in relation to the degree of risk, have failed to provide satisfactory action and remedy, or possibly any response at all;

- it is reasonable to assume that large numbers of the item are currently being purchased in the absence of information on the defect(s) and that private circulation of safety warnings would not reach a sufficiently wide audience;

- there are combinations of such factors.

Isotech oscilloscope, model ISR 420

This otherwise well engineered new product suffers from two dangerous features - namely, single pole switching on the neutral conductor, and a see-through 4 mm earth socket on the rear of the enclosure giving ready access to HT conductors within.

We understand that the suppliers - RS Components - have themselves acted, responsibly, to rewire the switch to be on the live conductor only, and insulate live parts within the rear of the enclosure on new stocks of their product. However the actual manufacturers, a Taiwanese company we understand, are not willing to replace the non-captive 4 mm socket with a captive type.

We disagree with this decision on the grounds of accident history and for operational reasons connected with customer convenience in carrying out inspection and testing in accordance with the requirements of HSE Guidance Note GS23. We have both written to, and met with, RS to tell them so.

If you have already purchased any of these scopes, RS stock number 253-620, and find that they are defective as described contact RS and ask them to replace, or modify to a reasonable standard, your goods.

Bench power supplies from BBH Power Products

This note refers to models in the low cost 5000 series, e.g. model numbers 5007, 5017, etc., which are supplied by Farnell Instruments Ltd. (order codes E895007 etc.) and Farnell Electronic Components Ltd. (order codes 148-585, 150-062, etc.).

In a recent routine check-up of power supplies in this popular range we found that the manufacturers had introduced a design change which is unacceptable to us. This affects all units manufactured since 1988.

The original version which we had tested, reported on and subsequently recommended, had self-tapping screws to fasten together the two parts of the enclosure. However the modified version uses plastic studs, which we find are removable by hand. Such is the ease with which these studs can be undone that in under 10 s it is possible to open the enclosure of the 5007 without the aid of tools.

Clearly this is an unacceptable risk.

If you have any BBH bench power supplies with these plastic securing studs contact BBH Power Products for a set of *TAPTITE* screws and instructions for replacing the studs. We understand that the replacement is a reasonably simple operation.

Linnaeus power supply

The power supply we comment on below was supplied to us by Philip Harris. We understand that this model is also available from other distributors.

DC supply, dual rail, ±15 V (Harris stock number P70236/0)

This supply has not been sufficiently well designed to prevent excessive overheating. We recorded temperature rises of 50°C on the exterior of the enclosure, and 96°C within. This overheating caused the plastic material composing the enclosure to soften and deform, a paper label on the transformer to char, and epoxy resin used to bond a heatsink to the transformer to fracture.

The Electricity at Work Regulations 1989 require that electrical equipment shall be of such a construction as to prevent, so far as reasonably practicable, danger. We do not think that the design of this product properly complies with this requirement.

If you have any supplies of this model we suggest you return them and ask for your money back.

Another overheating supply

We had a complaint from a school who had been forced, against their better judgement by contractual purchasing arrangements, to buy a bench power supply to power a 12 V soldering iron. They had found that the heating elements in their irons burnt out and it seemed to them that the supply voltage was too high. Could we investigate?

We did, and not only did we agree with their diagnosis that the supply was inappropriate, we also found that it overheats dangerously, which is why we write about it here.

The supply in question is the Altai, model number 1203, as supplied by Tait Components. It has a metal enclosure with a power transistor mounted externally on the rear on a large heat sink. If used to power one soldering iron, the temperature rise of the enclosure is very nearly 30°C, and of the transistor, just under 70°C - i.e. 70°C above ambient. If however a heavier load were to be applied, the temperature rise on the exterior of the enclosure becomes 65°C, and on the transistor - 92°C.

These temperature rises are unacceptable and dangerous. They do not comply with certain, relevant British Standards and thereby effectively infringe statutory regulations. If you have any of these supplies, return them to the vendor and demand a refund.

Rapid switches

We had a letter from a school to complain that although a switch they ordered from Rapid Electronics (order code 75-0185) is specified in that company's catalogue as being suitable for 240 V a.c. the switches they received were marked "125 V AC".

The safety issues relating to this incident concern both the school and us. Were the school, in good faith on the basis of the catalogue's specification, to have wired up these switches to a 240 V a.c. conductor, the system they were controlling would be potentially dangerous. There is clearly a risk in trusting such published specifications.

We wrote to Rapid on receipt of the complaint in June asking them to look into this discrepancy and suggesting, politely, that it pointed to a requirement, on their part, to tighten up on specifications. They have not so far replied to this enquiry, nor to another (see below) we made at that time.

This company has built up significant sales with schools, particularly so in recent years. Trade and sales are dependent on trust. Our trust in them is dwindling fast.

Problems with acidified dichromate(VI)

The SEB chemistry course at the higher grade includes some prescribed pupil activities (PPAs) in Unit 2 which utilise acidified dichromate(VI) to test for reducing properties in alkanols, alkanals and alkanones.

We recently had a report from a Principal Teacher of Chemistry that the reaction of this reagent with ethanol and ethanal had been occasionally somewhat violent. He had used the scale and procedure as described in the published materials for Unit 2 and sometimes the reaction mixtures had been ejected from the flask.

We repeated these procedures as described and we did manage on some occasions to get sudden, vigorous boiling of the flask contents. This had more of the appearance of sudden ebullience in a superheated liquid than of the results of violent exothermic chemical reaction.

The weaknesses of the method as described, seem to us to lie in a combination of inappropriate scale and in imprecision in other details such as what temperature "hot water" is meant to be.

The published instructions show a beaker of "hot water" in use as a small scale water bath. It is common practice to use hot water from a kettle to supply such arrangements. Were that the case, then such a water bath could be well above the boiling points of any alkanol, alkanal or alkanone placed within it before the addition of any acidified dichromate reagent. Taking that with the recommendation to add 2 cm^3 of that reagent could explain much of the problem, especially if the dichromate were added more or less in one big dollop rather than in small portions, pausing to allow the reaction to proceed.

The other problem posed here is that of the undesirable levels of organic vapours which are evolved in the method as described. This is of particular concern with regard to ethanal. Although not so listed in our UK, legislation, ethanal is designated as possibly carcinogenic both by the IARC (International Agency for Research on Cancer) and German governmental agencies. It is however placed in the IARC third category ("possibly carcinogenic to humans") and many other substances used in schools are to be found in this and other such IARC categories. But, they also are acceptable for educational use so long as they are handled with the due respect that their toxicology demands.

Nevertheless, COSHH requires that exposure to any such substances be reduced as far as is possible. At the scale originally described there would certainly be unacceptably high levels of vapour in a room where ten pupil pairs were each keeping 10 cm^3 of ethanal, b.p. 21°C, in a water bath at about 90°C for more than about half a minute.

A simple and effective control measure against this risk to health is to reduce the scale. We tried small scale methods with a variety of proportions, concentrations and order of addition of the reactants. We found the best of these to be the addition of 1 cm^3 of acidified dichromate in two 0.5 cm^3 portions (from a calibrated, plastic transfer pipette) to 2 cm^3 of the alkanol (/al/one etc.). This gives a clear colour change which is easier to note because of a lesser dilution of the green colour by a large excess of the reductant.

Even smaller scales, using only drops of the reactants, will still work well. Some texts describe dropwise additions of the reagent to a total volume of alkanol etc. of only 5 to 10 drops. This pragmatic procedure avoids the problem that using the same volume of different organic compounds will result in each case in a different number of moles of reductant. It thus removes the need for a large excess of reductant.

Small scale working has a number of advantages. A colleague from another institution once summed these up, in an expression which he coined as:

"The Three Es"

E - for greater *economy*

E - for being kinder *ecologically*

E - for greater *effectiveness*

Microbiological Safety

Additional organism

A recent development in the area of microbiological safety in Scottish education has been the publication, by Strathclyde Regional Council, of "Safety in Microbiology - a code of practice for schools and non-advanced further education" [1].

Other Scottish EAs have, with minor modifications, adapted and adopted this document to their own use. In order to further enhance the teaching of microbiology, and to cut down the subsequent paperwork, we are recommending that all Scottish EAs consider adding a particular organism to their *approved list(s)* in any such codes of practice.

The organism in question is the bacterium *Methylophilus methylotrophus* (optimum incubation temperature 30°C). This is the micro-organism developed and used by ICI for the production of 'Pruteen', a single cell protein. It is an obligate user of methanol as a substrate. Current teaching materials [2] describe a pupil practical which utilizes *M. methylotrophus*.

It should be noted that the lists of approved micro-organisms in "Safety in Microbiology" [1] and in "Topics in Safety" Chapter 5a [3] are both based on that first published in "Microbiology - an HMI guide for schools and further education" [4]. This original source clearly states that the list is not definitive and that other organisms presenting similar, low, degrees of risk may be used if competent advice is taken.

References

1. "Safety In Microbiology - A code of practice for schools and non-advanced further education", 1989 Strathclyde Regional Council.

2. "Biotechnology", 1988 Lothian TVEI & TVEI Open Learning Network.

3. "Topics in Safety", 1988, ASE, 2nd Edition.

4. "Microbiology : An HMI guide for schools and further education", 1985, DES, HMSO.

Glass envelope insulation on tank heaters

We are concerned at the usage of glass as a functional layer of insulation in certain electrical immersion heaters operating at 240 V. Equipment where this might be found includes some heaters designed for use in aquaria but now also found in certain fermenters and p.c.b. etchant tanks, where the contents may have significant conductivities.

In the Administrative Memorandum to the "Electrical Equipment (Safety) Regulations 1975" (S.I.1366) the counting of a glass envelope as functional insulation was apparently disallowed, and heaters of such construction were no longer to be retailed.

Under a 1988 amendment to BS 3456, it would seem that such glass enveloped heaters are again acceptable for retail, and use in aquaria, so long as the envelope passes a specified impact test.

Following the reintroduction of this form of insulation on heaters in other recently produced school apparatus we contacted both the Health and Safety Executive and Trading Standards Officers for advice. The HSE's specialists have advised us that in order to comply with the Electricity at Work Regulations, tank heaters with glass envelopes should be operated at a voltage not exceeding 25 V supplied from the secondary winding of a mains isolating transformer. Failing that - and clearly second best - mains voltage equipment of this type should only be plugged into fixed socket circuits which are afforded supplementary protection by an r.c.d. with a rated tripping current not exceeding 30 mA.

This second best route would seem to us to be reasonably acceptable for rooms that have permanently installed r.c.d. protection. Temporary protection through an r.c.d. socket outlet adaptor would be far less acceptable - especially for portable devices which may be continuously run such as fermenters and where the removal and absence of a detachable r.c.d. may easily go unnoticed.

Aquarium set-ups may be further complicated by the need also to protect other circuits such as those for lights, time-switches and aerator pumps. There, either an r.c.d. protected, fixed installation, socket outlet should be used or an integral r.c.d. should be a fixed termination on a single supply cable to a master control and distribution box (we can supply details if required).

Both CLEAPSS and ourselves have previously expressed strong preference for such single mains supply arrangements for school aquaria. Separate, mains inputs leads for lights, heater/thermostat, aerator etc. not only look untidy but also prove difficult to protect and may significantly increase the risks of electric shock.

Finally we would stress that, although glass envelope heaters and heater/thermostats are again commonly on sale in pet stores and aquarists' supplies shops, other types not so relying on the glass for insulation - whilst more expensive - are still available.

Pipeclay triangles

We have received copy correspondence from Philip Harris which warns of possible flaws in batches of pipeclay triangles supplied by them after 1st of April 1990. To date there has been only one reported incident of fracture of such a triangle during certain conditions of heating.

If you ordered pipeclay triangles from Harris after the relevant date you should by now have received a letter from the company drawing your attention to this hazard and offering free replacements.

Printed circuit board manufacture - hazards and protection

Introduction

The Centre was asked by the Central Support Group for Electronics for advice on protection measures which should be taken when making p.c.b's. This advice was subsequently published by SCCC within a teachers' guide [1]. We think that it is also worth publishing in the Bulletin because not every teacher or technician who sometimes makes a p.c.b. will see the SCCC guide. We also think that it is a model on which assessments for some other processes might be based.

The advice is given in tabular format, as suggested by the HSE. One particular process is described. It has been divided into sixteen stages as shown in the left hand column. The risks associated with these stages and the corresponding measures to contain them and protect personnel are shown in the right. A numerical estimate of the relative danger provided that the protection measures, or controls, in COSHH jargon, are adopted is given in the central column. Where this table indicates a need to do so then warnings as to the risks and the measures suggested to control them have been indicated also to the students by means of pictograms and text at relevant points in the SCCC published workcards [2].

Although the advice is largely a COSHH assessment, it is not entirely so because some of the risks are non-chemical.

The article is not itself a description of p.c.b. manufacture. Readers looking for such instruction are referred to other sources [3] [4].

Risk assessments should take account of the combination of both the inherent hazards associated with substances and the methods with which they are used. This implies that a separate risk assessment should be carried out before changing any of the methods described here even although the same hazardous substances are to be used.

Some minor changes have been made to the version published by SCCC; in particular some rinse periods have been lengthened. Safety advice, like software, is only ever 99% complete!

Equipment and materials list

You are referred to reference [1] for guidance in what to buy excepting one item, hydrated iron(III) chloride etchant crystals. These we recommend you buy from Farnell Electronic Components (order code 141-311) rather than from Rapid because of the superior and safer packaging of the Farnell product.

This is not meant to be an encouragement!

There is a danger that by publishing this advice, teachers and technicians who do not at present make p.c.b.s might be encouraged to start without having appropriate need to do so. We strongly advise those of you in this category - the majority of our readers - not to, unless you have reasons which are compelling.

Appropriate ones would be curricular requirements such as teaching the techniques on a small scale basis, as in the SEB Short Course, Electronics Construction 2 or the need to make a large batch of a particular circuit where the savings in time are felt to outweigh the risks of contamination to personnel and the environment. We suggest that where small batch runs of up to ten circuits are built, other techniques such as soldering to stripboard, or wire wrapping would be preferable.

Acknowledgements

The Centre is grateful to the NDO for Electronics, Ian Downie, to other members of the Central Support Group for Electronics, and to Phil Cohen, The Edinburgh Academy, who have made helpful improvements to our original draft.

References

1. "Electronic Construction 2", 1990, SCCC, Teacher's Guide.

2. Ibid. Pupil Materials.

3 "Constructional Techniques", 1984, Memo 1, Microelectronics Monographs, SSERC.

4. "PCB modular preparation system", November 1989, RS, RS Data Library no. 9962.

Hazards

ultraviolet radiation	denaturing of cornea, erythema (or redness) of skin, skin cancer, toxicity of ozone
sodium hydroxide pellets and solution	corrosive, especially to eyes and skin
iron(III) chloride crystals and solution	corrosive, especially to eyes and skin
dilute hydrochloric acid	irritant, or corrosive
drilling	danger to eyes

Activity	Estimate of danger 1 = low 10 = high	Protection
1. Mask design and layout The design should allow the board to be held either with tongs or with a temporary handle when it is being used with a chemical reagent.	1	If the board is to be handled with tongs leave a 1 cm unused strip along one edge. Otherwise fit a temporary handle: drill and tap a thread into the end of a 200 mm long plastic rod and use a nylon machine screw to fasten the rod to a suitably sized, pre-drilled hole in the board.
2. Exposure of mask Expose the photo-resist board for 8 to 10 minutes in an ultraviolet exposure unit with the lid down. The exposure time depends on the type of photo-resist and the particular exposure unit used. (Take care to position the mask and photo-resist board correctly in the ultraviolet exposure unit.) Do not expose the board to any undue daylight before developing.	1	Use a proprietary ultraviolet exposure unit with a light-tight box and lid. A micro-switch interlock which switches off the lamps if the lid is opened is a desirable feature. If such a switch is not fitted, do not switch on the unit while the lid is open. Ventilate the work area to disperse any ozone produced.
3. Preparation of developer Weigh out 20 g of sodium hydroxide, dispensing from the 80 g RS sachet (stock no. 551-299) to a dry beaker on a balance. Retain the remaining 60 g for use in step 9 (photo-resist stripping). Add 1 litre of cold water to a p.c.b. dish (nominal size 8″ x 10″) in a water bath adjacent to a sink. The bath is required for heating the solution of sodium hydroxide at a later stage (step 9). The water temperature should be a little below the optimum developing temperature, 22°C. Very slowly add the sodium hydroxide to the water, taking care to disperse the sodium hydroxide throughout the solution, and stir until the sodium hydroxide has dissolved. The exothermic reaction should warm up the water to about 22°C. 1 litre of developer should be sufficient for processing ten boards each measuring 80 mm by 100 mm .	5	Wear eye protection (goggles), gloves and protective clothing throughout steps 3 to 14. Take care that the corners on photo-resist board, which are exceedingly sharp, do not puncture the protective gloves. Sodium hydroxide is a corrosive reagent. Unlike acid burns, contact with the skin does not usually cause immediate stinging. By the time any pain is noticed, the burn is liable to be deep. Any sodium hydroxide making contact with the skin or eyes must be washed off immediately with lots of water. Likewise any spillage or drips must be cleaned up immediately and the contaminated surface washed with lots of water. Use sodium hydroxide as sold by RS Components (stock no. 551-299). This consists of a pack comprising six 80 g sachets. The exact amount required in this procedure is 80 g. Developing takes 20 g, to which is added the remaining 60 g for resist stripping. There will thus be no need to store opened sachets. Sodium hydroxide reacts with water to produce heat. Do not therefore dissolve sodium hydroxide pellets in warm water, and do not heap a large amount of pellets

		together when dissolving as the resulting local heating might be severe. Ventilate the work area to prevent the build-up of fumes.
4. Develop photo-resist Gently agitate the exposed board in developer at 22°C for 20 to 30 s. This removes the etch resist from the areas that have been exposed to ultraviolet light, leaving the track pattern protected against etching. This stage is complete once the track pattern has darkened to a blackish colour - actually a dark metallic blue.	5	Manipulate the board with the handle or with tongs, gripping the board at a part where there are no tracks.
5. Rinsing the exposed board Carry the board to the sink and rinse it in gently flowing water for a few seconds.	2	Do not rinse in forced water as splashes of sodium hydroxide might occur.
6. Preparation of etchant Add 1 litre of warm clean water to a plastic developing dish (nominal size 8″ x 10″). Place the dish in a water bath and warm up to between 45°C and 55°C. Gradually add 500 g hydrated iron(III) chloride (hydrated ferric chloride) crystals to the dish and stir until they are completely dissolved. This may take 5 minutes or longer. 1 litre of etchant should suffice for processing five or six boards measuring 80 mm x 100 mm each. The water bath should either be adjacent to the sink, or to the other water bath.	5	Use hydrated iron(III) chloride and not iron(III) chloride, the anhydrous form of iron(III) chloride, which reacts violently with water producing large quantities of heat. The anhydrous salt is a blackish powder, whereas the hydrated salt is brown and crystalline. Farnell Electronic Components stock hydrated iron(III) chloride in 500 g tubs (product code 141-311). Buying this size of pack avoids having to weigh out from larger stock and the chemical is double packed, bag within tub, giving you secondary containment. Hydrated iron(III) chloride, in crystalline form and in solution, is a corrosive reagent. Do not allow contact with either skin or eyes. Wipe up drips and spillages immediately. Contaminated clothing may be impossible to clean. Solutions of iron(III) chloride give off an unpleasant smell, probably caused by traces of hydrogen chloride formed by the reaction of iron(III) ions and water. The work area should be well ventilated to dissipate this. Note that the dish containing iron(III) chloride solution should be in a separate water bath from the dish containing sodium hydroxide solution. Two baths are required to avoid having to lift dishes of reagent in and out of a single bath, with a consequent risk of a large scale spillage.
7. Etching Place the developed board in the dish containing the etchant. Gently agitate the board continuously to and fro in the reagent, holding the board using the handle or tongs. The copper will be etched away from areas unprotected by the etch resist. Lift the board out occasionally to inspect. The first change is the tarnishing of the copper from its original shiny state. The appearance remains the same for some time until eventually the layer of copper starts to become completely dissolved. The first signs of this appear at boundaries. Inspect the	5	Manipulate the board with the handle or with tongs, gripping the board at a part where there are no tracks.

board more frequently at this stage. Dab the board in and out of the etchant keeping it near the surface. Completely remove the board from the etchant as soon as all unwanted copper is etched away. Etching usually takes between 6 and 12 minutes to complete. The colour of the etchant turns through use from a mustard yellow to a dark greeny black. The rate of change depends on the number of boards processed and the area of copper being etched off.		
8. Rinsing etched board Carry the board to the sink and rinse it in gently flowing water for between 1 and 2 minutes.	2	To avoid splashes contaminating the surroundings and the person rinsing the board, do not use forced water when rinsing.
9. Preparation of stripper Observing the precautions described under step 3, add the remaining 60 g of sodium hydroxide left over in the sachet from step 3 to the dish of sodium hydroxide solution previously used for developing. Stir until all the sodium hydroxide has dissolved, then switch on the water bath heater and warm up the solution to 45°C.	5	Steps 9 and 10 can be avoided by using a p.c.b. eraser to remove the photo-resist (step 15). However the complete removal of photo-resist is better achieved by chemical means. Do not switch on the water bath heater until all the sodium hydroxide has been dissolved.
10. Stripping photo-resist (Part 1) Place the board in the dish containing the stripper and gently agitate for a period of 2 minutes. The copper tracks should change from a dark metallic blue colour to a bright copper appearance.	5	Manipulate the board with the handle or with tongs, gripping the board at a part where there are no tracks.
11. Rinsing after stripping Carry the board to a sink and rinse it under cold flowing water for a period of 1 minute to remove all traces of stripper. Gently dry the board with a paper towel.	2	Do not use a forced water flow as splashes of chemical reagent might occur.
12. Neutralising the etchant Iron(III) chloride solution can be disposed of directly only into earthenware or p.v.c. sinks. If the sink is of stainless steel, use a plastic bucket or basin in the sink as a temporary receptacle. Plug the drain outlet from the sink, unless using a plastic container. Use either a moulded polypropylene water (or filter) pump (e.g. Harris C35825/6), or a syphon pump, to transfer most of the reagent from the dish to the sink (or plastic container). Once as much as reasonably possible has been transferred, carry the dish to the sink and pour out any remaining reagent. Leave the contaminated dish beside the sink for cleaning.	6	Remove most of the reagent by pumping to avoid having to lift and carry the full dish. Iron(III) chloride is a corrosive reagent which can rust stainless steel and make holes in copper and lead waste pipes. It should always be neutralised before disposal and should not be put into a stainless steel sink unless it has been neutralised.
13. Disposal of chemical reagents Transfer most of the sodium hydroxide to the sink (or plastic container) by pumping, allowing it to mix	6	Remove most of the reagent by pumping to avoid having to lift and carry the full dish.

with the iron(III) chloride solution, which it neutralises to produce a gelatinous precipitate. Remove the pump from the water tap, unplug the drain and flush the precipitate down the sink with copious quantities of water. This should remove most of the iron(III) chloride staining. Lift the dish containing the remainder of the sodium hydroxide solution and empty it into the other dish so as to remove any residual stains of iron(III) chloride. Then dispose of it to the sink. Rinse the sink and both dishes with water.		
14. Acid rinse Rinse all containers, the sink, the tongs and the chemical resistant gloves with about 200 ml water to which has been added about 50 ml of dilute hydrochloric acid. Then give all surfaces a final rinse with water.	2	Sodium hydroxide has a tendency to cling to surfaces. This contamination cannot easily be washed off with water, and therefore should be removed by applying an acid rinse. Gloves, protective clothing and eye protection can be removed after this stage is over.
15. Stripping photo-resist (Part 2) Rub the copper tracks as necessary with a p.c.b. eraser to remove any remaining photo-resist.	1	
16. Drilling Drill out holes in the board to allow the insertion of component leads. Use an electric hand-drill set up vertically in a stand. Use 1 mm diameter drills of either tungsten carbide or high speed steel (HSS). These drills do not blunt easily, but, being brittle, are easily broken.	2	Wear eye protection. Do not use a pillar drill because of the risk of producing the fine dust which such a high speed machine can generate.

Seno Workstation - p.c.b. manufacture

We recently purchased one of these kits for evaluation. It is made by Mega Electronics Limited and was supplied to us by Rapid Electronics. Its dual-chamber etching bag has been designed to prevent any handling of corrosive chemicals and its specially designed applicators of other chemicals avoid the need to work with any other corrosive fluids. It is thus claimed that it has been specially designed to minimise risk. Does it live up to its promise?

Disturbingly there are several features which are completely unsatisfactory. These all impinge on safety and are:

1. none of the substances in the kit are identified by chemical classification;

2. the bag containing the etchant is not labelled as such, nor is it marked "corrosive";

3. the bag containing the etchant neutraliser is not labelled at all;

4. the health and safety warning in the notes supplied is inadequate and misleading;

5. the instructions show dangerously misleading photographs of a pupil carrying out various stages in the process - peering into an illuminated ultraviolet exposure box, holding up to eye level the etchant bag, etc. (the pupil wears no form of protection, neither to eyes, hands, nor clothes).

6. the ends of the steel rod securing the seal on the etchant chamber are sufficiently sharp and barbed that it can rupture the polythene material, thus releasing the etchant.

Rapid have been requested and have failed to supply a list of substances contained in the Seno kit. Nor have they supplied appropriate materials safety data sheets. We are therefore obliged to advise you not to buy this product in its present form.

regularly by pupils and the majority of reports of damage came from those few responses we got from such sources. The only specific type of problem recorded more than once was the excessive loosening, or even loss, of the turnscrews which affix the actual faceshield to the brow band.

Vandalism

A worrying feature of damage reports was the incidence of deliberate vandalism. This was suspected or reported in 36% of all of the responses where breakage was recorded as a significant problem. Such deliberate damage included breakage of lenses or side frames, melting spectacle side frames in Bunsen flames and defacement of lenses with permanent marker pens.

Whilst vandalism seems almost a fact of life in some schools, however socially unacceptable that may be, it is particularly disturbing when it applies to equipment provided for the protection of pupils. It may also be a trout in the milk. It is possibly circumstantial evidence that a significant number of pupils, both reasonable and otherwise, actively resent having to wear some kinds of eye protection in practical subjects.

Scratched lenses

This would seem the most frequent of all reported problems with an incidence of 52% for spectacles and 60% for goggles.

At first sight the reports also seem to confirm conventional wisdom that polycarbonate lenses are more prone to such damage than are lenses of other materials. Some 40% of all reports of scratch damage (42 out of 104) involved polycarbonate lenses.

Caution is needed in interpreting the data however since in several cases the respondents reported scratch damage as a problem but did not know the nature of the lens materials.

A further complication may be that the majority of reports involve polycarbonate lenses simply because that is the material from which most eye protector lenses used in schools are made. This suspicion is reinforced by the fact that only about 10% of reports specifically named other materials (9 as "acetate" and 1 as "PVC").

Misting-up

Results here were suprising in that more reported this as a problem with spectacles (30%) than did so for goggles (9%).

At first sight this is doubly confusing since misting up has previously been cited as one of the major disadvantages of goggle type protectors.

We can only offer a combined explanation for such unexpected responses. It would seem that some teachers and technicians had confused "misting up" as caused by condensation of water on the lens surfaces with damage from fine scratches. The relatively low incidence of reports of misting as a serious problem with goggles may be due to the number of improved designs now available with much better guarded vent arrangements.

Remediation

Replacement lenses

Only 9% of respondents mentioned the availability or fitting of replacement lens elements to the protectors held by them. This facility is thus still not widely known about or used.

Repolishing lenses

Again, this was apparently neither well known nor widely attempted. Only 4% of all returns reported attempts to repolish lenses. Of those few reports, only one recorded any success and that was with metal polish. Two reports were on the use of jewellers' rouge or ceric oxide, which had only been partially successful and certainly not worth the time and effort expended.

More folk reported their efforts in merely cleaning eye protectors with hot water and detergent, remarking particularly on how time consuming that may also prove. A small but significant number (10%) specifically mentioned their concern over issues of hygiene where eye protection was shared.

Storage arrangements

Reports revealed that the majority of respondents had made the obvious connection between careful storage and minimising scratching and other damage to protectors. About two thirds of reponses recorded some kind of special storage arrangement. The scope of such arrangements was however fairly wide. It ranged from the minimalist approach of merely keeping the bags or boxes in which the protectors had been originally supplied (13%) right through to specially constructed pigeon holes (12%).

Other arrangements specifically mentioned included hooks and hangers (20% or so), some made like the *mug trees* used for the storage of cups and coffee mugs, collections of cloth pockets as used for the storage of shoes (8%), lined-out deep drawers or *tote* (carrying) boxes (13%).

Some apparently excellent arrangements were also simple. One such was the use of bent nails covered with rubber tubing (an idea from an island's school, Shetland - where else would nails be used so imaginatively?). Those who used boxes or pigeon holes reported that whilst they were effective, they used up a lot of space. One excellent suggestion was that suppliers should consider providing their eye protectors in boxes which could be fitted together on site to form a storage unit.

General and specific conclusions

No simple answers

These survey results reinforce our view that there is no single best solution to the provision and ensurement of use of eye protection in schools.

Lack of space precludes full discussion of all the factors which complicate the issue. The principal problems can however be more simply listed and described as follows:

- schools are forced to buy eye protection as minority customers in a big, largely occupationally oriented and thus adult based, market;

- in that market the goods are perceived, in large part, as at least semi-disposable, being replaced whenever wear and tear so requires;

- occupational users often each face specific types of risk of injury to the eyes and are required to wear routinely their own personal set of protectors often to guard against a particular type of risk. Educational users on the other hand may face a wider range of risks but only in particular places and only for restricted time spans so that the issuing of personal sets of protectors is perceived, certainly for pupils, as neither necessary, practicable nor, for that matter, affordable.

The issues are therefore complex and it is unlikely that policy decisions on patterns of provision in education can be simple and straightforward. For schools the major factors affecting such decisions would seem to be as follows:

Comfort versus caution

There are conflicts between apparent user preferences for spectacle type protectors and the desire of advisers, other EA staff with health and safety responsibilities, and teachers for the fuller degree of protection afforded to pupils' eyes by goggles (especially in guarding against chemical splashes and projectiles with peculiar angles of trajectory). The difficulty here is that 90% protection worn 100% of the time is likely to be 90% effective and thus better than 100% protection worn for any less than 90% of the time.

A number of our correspondents reporting "goggles only" provision specifically remarked that this was a regionally imposed policy and that they would have preferred either a mixed provision or even spectacles only. Where specific reasons were given these were usually connected with comfort or fit and pupil attitudes to wearing the protection provided. Only one reply indicated an EA policy for spectacle provision where the respondent would have preferred goggles only.

Newer types of spectacle type protector are worthy of further consideration in this connection. These are of the type, often called "eyeshields" (see Figure 1) and which have browguards and lateral protection pieces.

As always there is "no free lunch" here in that they are not the cheapest of spectacle type protectors and with some models the side pieces may cause some loss of peripheral vision. However they may provide more effective protection than simple spectacles against chemicals or objects projected at odd angles. They begin to approach the standards of protection offered by some types of goggle. All but the youngest and smallest of pupils may find them easier and more comfortable to wear. They may also be worn over normal prescription spectacles. Some models of such protectors came in for particular praise in the survey responses.

Provision pattern

The survey results reinforce our view that provision of one type of protector only may well be misguided. The HSE has been consistent in expressing the view that the pattern should be:

spectacles often,

goggles sometimes,

full face protection occasionally

Our sample was far too small for us to presently consider publishing details of those specific models which were praised, or indeed of those condemned, by our respondents. We will however follow up some of the leads so provided and will take the information into account when giving advice on purchasing. We are also looking at the possibility of a limited evaluation and testing programme, partly based on the survey results.

Replacement cycles

It was obvious from the scratching and other damage reported that many schools were not being provided with replacement eye protectors as often as they should. One school reported heavy scratch damage to polycarbonate lenses on one class set of eye protection but added that this should be no cause for surprise since the sample in question was at least 20 years old.

Given that the requirement for the wearing of eye protection "whenever there is a forseeable risk of injury to the eyes" is statutory and contained within "The Protection of Eyes Regulations" it would seem that at least some educational employers and managers need to give more attention to their replacement policies.

Storage arrangements

Replacement cycle times clearly may be lengthened through more effective storage arrangements. Reasonable degrees of effort in this area promise to be cost effective.

Matters for designers and makers

A number of general and detailed points emerged which are worthy of the attention of some makers and sources of supply.

Briefly, these were as follows:

1. More effort could usefully be put into post-moulding quality control, in particular weeding out poorly finished samples with rough edges to frames etc.

2. Improved designs are required for headband anchorage points on some models of goggle and in others the headband itself is of too low a quality and insufficiently robust. In the case of anchorage points both greater ease of adjustment and more protection against breakage need attention.

3. Consideration should be given to the more utilitarian design of packaging so as to allow its recycling as part of a longer term storage arrangement.

Matters for policy makers

EA and other advisers, including health and safety specialists, as well as classroom teachers need to be more aware of the balance to be struck between the degree and type of protection inherent in different kinds of eye protector and the probability that the protection will be accepted and actually worn.

This balance is further complicated by the fact that for some students the need to wear such protection may be an attractive feature of a practical subject. For others that requirement may actually become a major turn-off. It may even lead to the protective devices being perceived as an uncomfortable and sometimes unnecessary nuisance.

As our survey showed, this dislike is manifested in its extreme form as deliberate damage. Whilst such sheer vandalism is not something we should ever condone, we may need to be more sensitive to the pupil preferences of which it is, perhaps, ultimately a symptom. Do we need another survey - one wherein we ask pupils and students for their views on eye protection?

Acknowledgement

The extracts from BS 7028 : 1988, shown in reduced form as Figure 1 in this article, are reproduced with the permission of BSI. Complete copies of the Standard can be obtained by post from the address given on the front inside cover of this bulletin.

Technical Articles

Standard Grade Biology

- further practical tips

In Bulletin 165 we announced our intention to publish short notes to assist teachers and technicians over any minor practical difficulties which crop up as the course materials are implemented. The following, short, pieces deal with such snags in two practicals for Topic 7 : "Biotechnology : Sub-topic C - Reprogramming Microbes" [1].

Milk agar and enzyme action

Media problems

In the "Exemplar" materials a method is described for investigating the action of biological and non-biological washing powders on milk agar plates. The technicians' guide recommends that the plates are made up with milk powder in nutrient agar. Our experience shows however that this addition of nutrient agar tends, not suprisingly, to encourage the casual growth of micro-organisms. On one of our recent training courses such milk agar plates suffered significant airborne contamination from *Micrococcus sp.* We recommend, therefore, that plain, technical agar (Unipath [previously known as "Oxoid"] Agar No. 3) is used instead of any nutrient agar.

Agar No.3 is widely available from the usual biological suppliers both as a powder (ca.£15/100 g) or in tablet form (£14.50/100 tablets - e.g. from Philip Harris). It is a basic agar which will, by itself, not encourage the growth of micro-organisms and, in this context, is safer to use.

The second point to note is that if rehydrated skimmed milk is autoclaved it is likely to caramelize. St.Ivel "5 pints" seems especially prone to this problem. For this particular practical it would be acceptable, so long as our other advice is followed and only unenriched basic agar is used as the setting agent, to dissolve the dried milk powder in sterile water and then add it to the autoclaved agar. You should ensure that the agar has cooled sufficently before adding the milk suspension.

Veracity problems

Some of you who have already presented for Biology at Standard Grade may have noticed that this experiment is more complex than at first it might appear. Something which we highlight on our training courses is that non-biological washing powder, alkali and even autoclaved biological washing powder will produce some clearing of milk agar plates.

It seems that the apparent proteolytic action of biological washing powders and detergents is only partly attributable to enzymic action. At least some of the effect observed is connected with the alkaline nature of these proprietary compounds. It is also interesting to compare the rate of 'clearing' between ordinary washing powder and the liquid form of the same brand. Liquid detergents are particularly fast at clearing the milk agar.

Immobilised Enzymes

Colour coding

You may find it useful, when immobilising different enzymes, to colour code the beads. The exemplar makes reference to the use of methylene blue in this connection. It is also possible (and fun) to use different food dyes. Only a very small quantity of food dye, 1 or 2 drops, needs to be added to the alginate. Using different colours for different enzymes may help classroom management, particularly when several pupils or pupil pairs may be carrying out different enzyme experiments at the same time.

Modelling

A perforated ball containing beads is an analogue useful in explaining the mechanism of immobilisation of organisms and enzymes. We first saw this idea being demonstrated by John Scholler a member of the staff at the National Centre for Biotechnology Education (NCBE).

John's models used a practice golf ball for the alginate bead with small spheres trapped inside to model organisms such as yeast cells. We have since adapted the idea to allow the use of *Poppit* beads either singly or in chains. This means the use of larger, perforated, plastic balls of about 85 mm in diameter and known as "the Teamster" by Abbey Ltd. These we obtained from a local sports shop for 60 pence each. Similar balls are however widely available from other retail outlets including those of some of the major supermarket firms.

The idea is illustrated diagramatically in Figure 1. It really doesn't require much in the way of further explanation save that short, straight chains of *Poppit* beads may be pushed through the holes in the ball. Should the beads need to be removed, or if shapes other than straight chains are to be used, then the ball has to be carefully split in half. The two halves are then glued together again with a suitable adhesive such as *Evostik*.

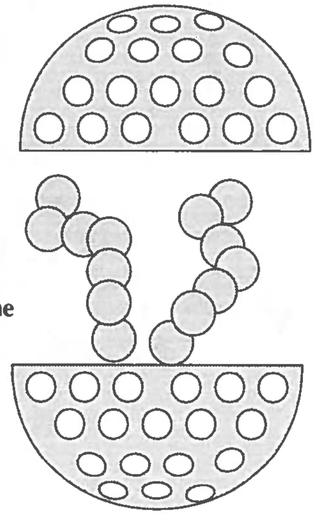


Fig. 1 Immobilised enzyme

Straight, unbranched chains representing only primary molecular arrangements are good enough models of enzymes at Standard Grade. The idea may however be extended for use at the Higher if fine, nylon thread (e.g. fishing line) is used to tie the *Poppit* bead constructions into shapes representing secondary structures (see Figure 2).

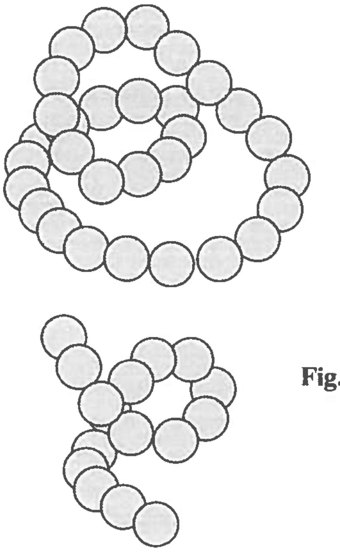


Fig. 2 Polypeptide chains

Reference

1. "National Exemplar Material for Standard Grade Biology : Topic 7 Biotechnology : Sub-topic C", 1989, SCCC.

[Pupil Workcards G6 - Investigating *biological* and *non-biological* detergents; G8 - Immobilised enzymes].

Technical Articles

Fermenters - Part III

Practical tips are given on the construction of a model of a continuous fermentation system. Two further models are described which provide contexts for simple investigations of problems in biochemical engineering.

Introduction

"Batch" and "continuous" fermentation systems were distinguished in Part I of this article [1] and Part II [2] provided hints and tips on the construction of a model batch fermenter. This present article expands on the use of such constructional techniques in modelling continuous fermentation and other systems.

Continuous fermentation

Although continuous systems have been widely investigated on laboratory and pilot plant scales, few such processes have yet been widely implemented on an industrial scale. Single cell protein production has been one of the more notable of such applications. Examples include ICI's "Pruteen" production from methanol feedstock and Rank Hovis MacDougal's process for mycoprotein. Other continuous process techniques, such as those employing immobilisation of organism or enzyme and continuous passage or circulation of substrate, have also been commercially implemented.

Criteria for modelling

In order to model satisfactorily a continuous fermentation process, the system must illustrate the essential feature that conditions within the vessel remain relatively constant. The rate of conversion of substrate into biomass and products has to be held in balance with both the rate of addition of fresh substrate and that of the removal of product. The system has to be a biological version of a *chemostat*.

SSERC model

The model which we designed and constructed used three plastic bottles (see Fig.1). The first of these, a 2 litre size, provides a substrate reservoir, the second at 1.5 litres a fermentation vessel and the third - another 2 litre size - a collection vessel or product receiver.

Constructional and other tips

The parts, materials and tools required are more or less as for construction of our simple batch fermenter but, obviously, several of each of some items will be needed. The basic techniques are however identical. Part II of this article [2] thus provides the necessary technical detail.

The substrate reservoir

The 2 litre bottle used for this part of the system needs two ports. One is cut in the base to accept a size 17 bung to take glass and rubber tubing to form the outflow. A second, smaller port is cut near the shoulder of the bottle and fitted with a smaller bung and a glass tube carefully packed with non-absorbent cotton wool. This acts as a vent. The actual mouth of the bottle is however to be sealed with its original cap or other closure.

The outflow tubing must be sufficiently flexible to allow close control of flow rate by means of adjustments to a tubing clamp. This low-tech flow control is probably the trickiest part of the whole exercise.

Silicone tubing is ideal for use in the sections to be clamped, but it is relatively expensive. You will probably have to settle for the most flexible rubber tubing you have to hand. Overall rigidity, and thus better stability, can always be added by use of other sections of polythene tubing married to the silicone or rubber tubing with tubing connectors or short sections of glass. The distal end of this tube, where it enters the reaction vessel as an inflow tube, can be fitted with a Pasteur pipette to further reduce the flow rate of medium into the reactor.

A dark bottle may prove useful as a reservoir for systems intended to run for a while and where otherwise algal growth might be a significant nuisance.

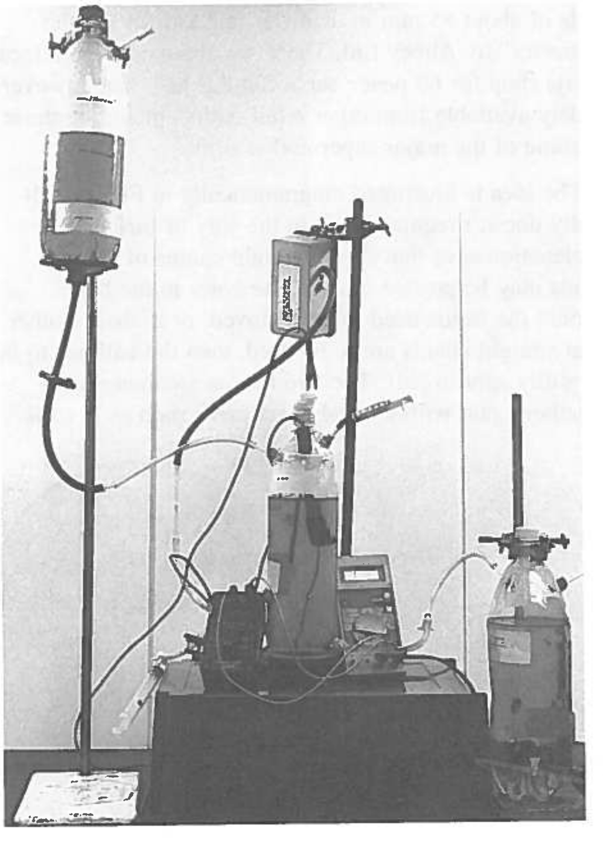


Fig. 1

The reactor vessel

Essentially this is similar to our simple batch fermenter [2] but with the addition of some extra ports and other features.

Additional ports:

- a basal port to allow removal of the product to the receiver vessel; again this is fitted with a flexible outlet line which can be controlled with a clamp;

- instrumentation and control ports, up to 4: one for addition of acid or alkali, one for a pH probe, one for a temperature sensor and possibly one for an oxygen electrode;

- a sampling port to allow checking of the progress of fermentation.

Other features:

- a stirrer bar or follower (say 25 mm), to allow magnetic stirring as agitation additional to that provided by aeration (this means a careful choice of bottle since one with a smooth internal base is needed - some types have ridges which foul the stirrer bar);

- for yeast fermentations, a hydrometer in the culture inside the bottle (optional*).

*This is suggested in some references but may prove difficult in practice. We found that inexpensive hydrometers tend to be too long for easy introduction into a 1.5 litre bottle and that bubbles cling to the hydrometer, affecting the readings. The Boots' hydrometers we used cost £1.70 and were 21 cm long. Samples had to be removed from the fermenter to a measuring cylinder for readings to be taken.

The product receiver

The receiver vessel can be any suitably large container but if aseptic collection of products is proposed then any openings from the receiver to the environment need to be guarded with filters. For non-demanding applications sterile, non-absorbent cotton wool will again suffice for this.

We found a 2 litre plastic bottle to be ideal for the purpose. This bottle was provided with 3 ports - two high up on the shoulder and one near the base. One of the two upper ports was fitted with a short glass tube and filter as a vent. The other provided an inlet for a collecting tube running from the base of the reactor vessel. This collection tube was fitted with a polythene, miniature stopcock to control the flow of product siphoning from the fermenter vessel.

The third, basal, port was fitted with a tube and clamp, or a second stopcock, to allow products to be drawn off from this receiver vessel. The mouth of the bottle was sealed with the original screw cap closure.

Applications

As you might imagine, the crude method of flow control means that the initial setting up of such a continuous fermenter system can be a bit tricky. Nonetheless we have successfully used such a simple set-up for both aerobic and anaerobic work with yeast. That work included some use of instrumentation and data-logging. Certainly, even for mere illustrative purposes, it is well worth the effort spent in its construction. It also provides an excellent starting point for project work and more sophisticated models.

Developments

Downstream processing

"Product", as used above, is a misnomer if all that happens is that a mixture of organism and both unconverted and converted substrate is allowed to overflow into the receiver and this outflow is balanced by inflow at the other, reservoir, end. Product recovery more usually involves a sequence of operations in which the converted substrate undergoes progressive concentration and purification.

One way to develop this aspect of the model is to use an immobilisation technique. If the organism, yeast say, is entrapped in alginate beads then separating off the product does indeed become a simple matter of removing the converted substrate in liquid form, leaving the entrapped organism behind.

In aerobic fermentations with yeast it may well be the organism itself or some derivative of it which is the product. Balanced inflow and outflow does not then stretch the analogy too far.

Some problems of scale-up

Once fermenters pass the laboratory or small scale pilot stage then real engineering problems begin to be met with. These are usually rooted in biological requirements for optimal growth, etc., but these have to be balanced against economic and constructional constraints.

Improving agitation (anaerobic)

In anaerobic fermentations, oxygen has to be excluded and that obviously rules out the use of aeration as a means of agitation. Agitation increases efficiency because it breaks up cellular clumps and keeps individual cells in intimate contact with the substrate solution.

For some anaerobic systems, oxygen has to be excluded at the outset. For others, such as that with yeast, it is sufficient for fermentation to get quickly underway and for any oxygen initially present to be so flushed from the system by the developing stream of CO_2. Clearly any arrangement which speeds up that flushing and then maintains both the exclusion of oxygen and agitation of the culture has the potential to improve the overall efficiency of the process.

These are the principles behind an idea in an excellent ASE Resource Book [3] - one which we have tried and recommend for project work.

The idea is to link tall-form fermenters - model towers - in series one with another. The "waste" CO_2 evolved at the top of a first fermenter is fed into the bottom of a second and so on (see Fig.2). The first vessel may itself be a tower, or a more conventional vessel such as a conical flask. The temperature of a flask is more readily maintained in a water bath so as to get the initial fermentation quickly underway.

Any sort of long thin tubes will do, but if they are clear then so much the better since the progress of fermentation may be partly gauged by direct observation. In our work, semi-rigid polythene tubing (30 mm o.d., 25 mm i.d.) was fitted with no. 25 bungs and tubing with strategically placed one-way valves.

Investigations

One obvious aspect to look at is the length of the lag phase and thus the time to the onset of the log phase in such coupled, tall form fermenters compared with those in more conventional systems.

The agitation by the CO_2 should improve overall efficiency in the rate of production of alcohol or use of sugar substrate. Does it do so?

Improving agitation (aerobic)

Aerobic fermentations on the other hand require a readily available supply of oxygen to the organism. In a tower or column fermenter this requirement presents problems in scaling up a process. As air bubbles travel up the tower their size tends to increase. This lowers their surface area to volume ratio, which in turn decreases the rate of oxygen transfer to medium and organism.

The introduction of baffles into a tower will improve aeration rates. The baffles break up the airstream giving smaller bubbles and thus better O_2 transfer. Plastic bottle assemblies provide opportunities to model and investigate such problems of biochemical engineering.

For our model (Fig. 3) we selected three clear lemonade bottles of the same volume (1.5 litre) and diameter. Two of these were cut across one third up from the bottom and holes were then drilled in the base of one. These two sections of bottle were then sleeved together, with the basal holes in the middle of the assembly, and the joint secured with a silicone sealant.

In the upper of these sections, pieces of 30 mm o.d. polythene tubing were placed diametrically so as to form X shaped baffles. Holes drilled in this plastic tubing assembly further increase its efficiency in breaking up the air stream.

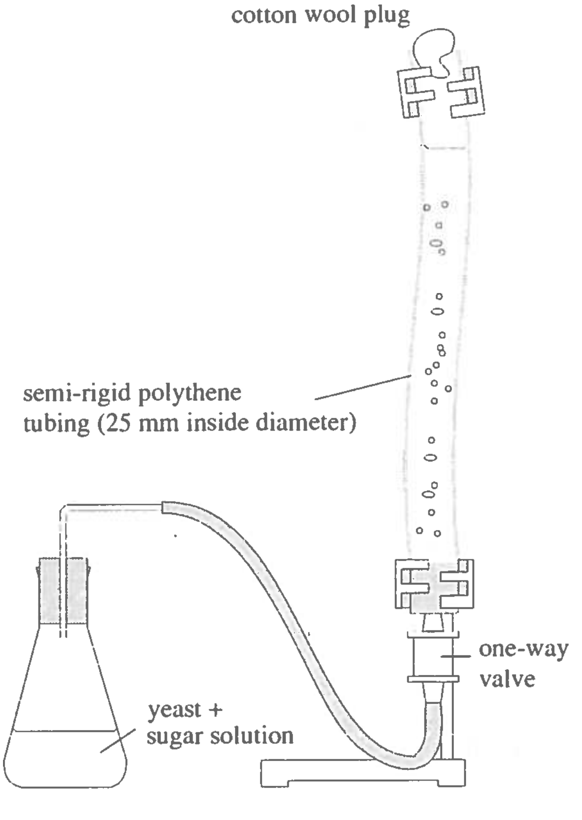


Fig. 2

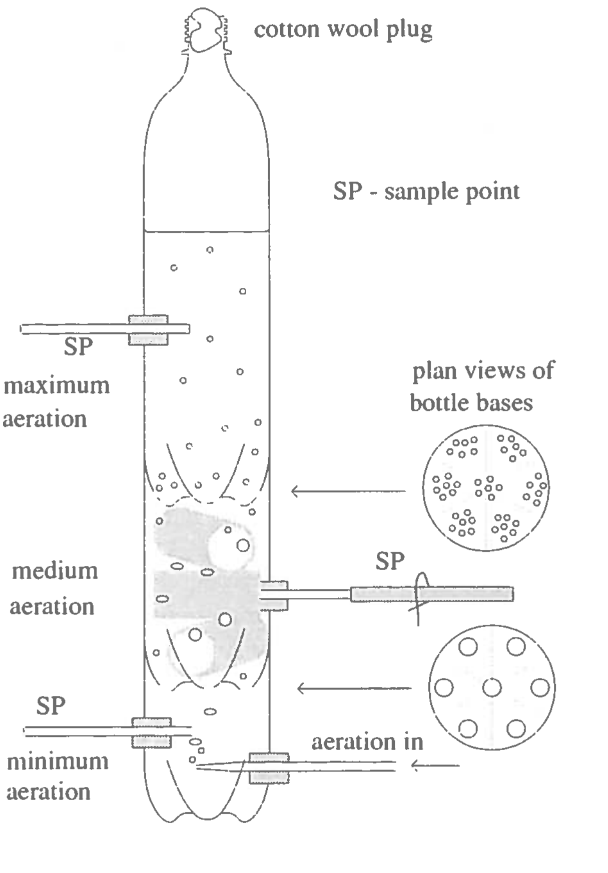


Fig. 3

The third bottle was made into a batch fermenter, as described in Part II of this article [2], except with the addition of a number of holes drilled in its base. This third section was then sealed into place above the chamber with the X-shaped baffle. Ports were made in each section to provide sampling points.

The result was a tall-form fermenter (Fig. 4) with three chambers in each of which different aeration conditions prevail. The base chamber relies on the entering airstream, the next receives bubbles broken up by the holes in the base, and the last, bubbles broken up by both baffle and holes.

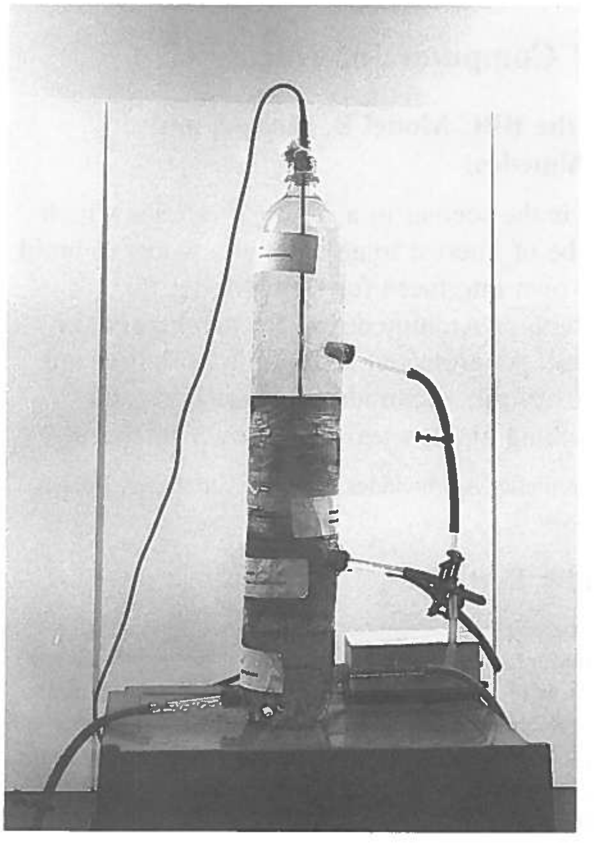


Fig. 4

Investigations

The effects of these differing conditions on the growth in cell numbers may be investigated by withdrawing culture at each of the three sampling points. The model may be further developed with different designs of baffle - holed plates for example, or fitted with a central aeration tube to model air-lift technologies.

References

1. "Fermenters - Part I", SSERC, "Equipment Notes", Bulletin 166, June 1990.
2. "Fermenters - Part II", SSERC, "Technical Articles", Bulletin 167, September 1990.
3. "Biotechnology - A Resource Book for Teachers", J.Dunkerton and R.Lock, ASE Occasional Paper, 1989, ISBN 0 86357 1115.

   (Highly recommended in the context of this Bulletin article.)

Revised Higher Grade Physics Experiments

The revision of the Higher presents you with opportunities. Are there ways of improving your existing stock of experiments - perhaps by making use of new technology? - perhaps by other traditional means? Which new items of equipment do you need to buy? Which old items should you hang on to; and do you still need gold leaf electroscopes?

SSERC cannot answer these questions for you, but we can prompt you to ask them and offer advice on which to make up your own mind. Our advice is contained in a set of notes on experiments. Costing a mere £1.00 to cover photocopying and postage, a copy of "Revised Higher Grade Physics Experiments" should help you make informed decisions.

The notes include:

- outline descriptions of some thirty odd experiments;
- references to fuller descriptions;
- lists of apparatus referenced to SSERC H and S Grade Equipment Lists.

The notes do not offer a complete coverage of practical work in the syllabus, but should, we trust, in ad hoc fashion meet most of the difficulties liable to be encountered.

To obtain a copy, please write or 'phone with your order.

Technical Articles

DIY Computer Interfacing II

(for the BBC Model B, Master, and Archimedes)

This is the second in a series of articles which will be of interest to anyone who wants to build their own interfaces for BBC Model Bs, Masters, or Archimedeses, for datalogging or control. As promised in Bulletin 167, here are details of the Archimedes printer port, and something about writing your own software.

Hereinafter Arc includes A3000; Beeb means Master or Model B.

Printer Port

If the printer is disconnected, off line, or switched off, a computer hangs up when data is sent to the printer port. It refuses to continue executing the program which sent the data, and you can only get control of the machine back by pressing escape. The computer hasn't gone to sleep: it is simply repeating a short loop of instructions, waiting for a signal from the printer saying it's ready for more data.

This loop of instructions is part of the operating system - it's provided to make it possible for you to print. Without it, the computer would send data much faster than the printer could keep up, and you'd just print garbage - and not much of that. When you're controlling a model, in general outputs are maintained in any particular state for a significant length of time, and the timing is determined by the program. The model has plenty of time to react to each change, and the computer doesn't need a handshake signal from the model to confirm that the data has been received. If there is any feedback, it is likely to be information about the environment, or the state of the model, rather than about the data transfer process itself.

If you're controlling something with a Beeb you can write to the printer port directly, rather than using the operating system routines. This is done by saving the required output to memory location &FE61 - which isn't really memory at all, it's the printer port output register. Because you aren't using the operating system routine, the computer never checks to see if the external device has got the message, and doesn't get stuck when it doesn't get an answer from a printer.

You can't do this on an Arc, because the printer port output register doesn't occupy a fixed address. This is a consequence of the Arc's sophisticated memory management system - and a small price to pay! The easy solution for DIYers is to make your model simulate a printer, and 'print' the required output.

At one end of the cable from the printer port to your model, connect pin 1 (STB) to pin 10 (ACK), and pin 11 (BSY) to pin 17 (0V). Grounding BSY (Busy) tells the computer that the printer is not busy, and connecting STB (Strobe) to ACK (Acknowledge) lets the computer shake its own hand!.

If you make these same connections on Beeb leads, then programs using only the printer port, and written to 'print' to your model, will work equally well on Arcs or Beebs, without alteration.

Getting information back into the computer

The printer port of the computer only sends, and cannot receive, information - other than the simple handshake signal. This is fine for open-loop control; but you'll soon want to build something more sophisticated. You want the program to react differently according to what happens, what feedback it gets from the outside world. You can monitor up to four analogue voltages on the analogue port, and up to eight digital signals on the user port. The user port is bidirectional - each of the eight lines can be independently used for either input or output.

User and analogue ports are fitted as standard on Beebs; on an Arc they're an optional extra. There are several makes available[1] for both Arcs proper and A3000s - we have an Acorn IO podule in an A310, and a Morley Electronics podule in an A3000. Both seem to be perfectly satisfactory; we can't speak for others, and we haven't done exhaustive tests on any yet. An Arc user port is an Arc user port is an Arc user port: there are no subtle differences either in the way they're programmed, or in their connections (unless there's something actually wrong with them). The same is true of the analogue port. The Morley board, and the IO podule for the A310 and A400 series, have both - but the Acorn board for the A3000 has no analogue port.

Again, the user port on the Arc doesn't reside at a constant address. You have to use operating system calls to access it too.

1We hope to do a proper market survey soon. The Unilab offering is especially interesting, as it has three user ports, one of which emulates a Beeb printer port. It also has an analogue port, and a 1 MHz bus.

Writing a simple program

Concentrate first on the overall structure of what you want to do. A simple open-loop control program consists of a *sequence* of actions at set time intervals, thus, for example:

Turn on warning light
Wait 5 s
Run motor no. 1 for 90 s
Wait 10 s
Open solenoid valve
Wait 90 s
Close solenoid valve
Run motor no. 2 for 20 s
Turn off warning light
Finish

This could be translated very straightforwardly into a BASIC program like this:

```
REM >Control1
PROCWarnOn
PROCWait(5)
PROCRun(1,90)
PROCWait(10)
PROCOpen
PROCWait(90)
PROCClose
PROCRun(2,20)
PROCWarnOff
END
```

(Note: it really doesn't matter what line numbers you use - the program never refers to them! They will be there regardless, of course.)

and then all we'd have to do is write the PROCedures; and it would indeed be possible to write procedures that would do each of these things.

There is a difficulty, however. To switch on the warning light, we have to insert a 1 into the appropriate bit of the printer port register. Let's say this is bit 3. We want the register to look like this:

bit:	7	6	5	4	3	2	1	0
contents:	0	0	0	0	1	0	0	0

Binary number 00001000 is decimal 8, so we put decimal 8 into the register:

```
VDU 2,1,8,3
```
[1]

[1] This works on any machine, with the special lead. If you haven't made the special printer simulating lead, use ?&FE61 = 8 on a Beeb or Master.

For the user port, use *FX 151,&60,8 on Arc or Master, or ?&FE60 = 8 on Beeb or Master

Ignoring the PROCWait for the moment, the next thing is to switch on motor no. 1. If this corresponds to bit one, the register should be:

bit:	7	6	5	4	3	2	1	0
contents:	0	0	0	0	0	0	1	0

Binary 00000010 is decimal 2, so we put 2 into the register:

```
VDU 2,1,2,3
```

But now we've switched off the warning light! To have both on, we'd need

bit:	7	6	5	4	3	2	1	0
contents:	0	0	0	0	1	0	1	0

which is 00001010, or decimal 10.

With our first attempt at the main program, each procedure would have to know what else was supposed to be on, in order to avoid switching them off! Knowing a little about the design of the bottom level procedures enables us to write a much better top level design:

```
REM >Control2
Motor1 = 2 : Motor2 = 4
Warning = 8 : Solenoid = 16
PROCOutput(Warning,5)
PROCOutput(Warning + Motor1,90
PROCOutput(Warning,10)
PROCOutput(Warning + Solenoid,90)
PROCOutput(Warning + Motor2,20)
PROCOutput(0,0) : REM Turns everything off
REM then waits zero time
END
```

The waiting procedure is incorporated into the output procedure, since there is a time delay associated with every change of output. The program is much easier to read, and the one procedure is much easier to code:

```
DEF PROCOutput(I,Time)
VDU 2,1,I,3
REM Beeb without special lead: ?&FE61 = I
T = TIME
REPEAT UNTIL TIME - T > Time * 100
REM 100 gives true seconds
REM  use less than 100 to run faster
ENDPROC
```

Repetition

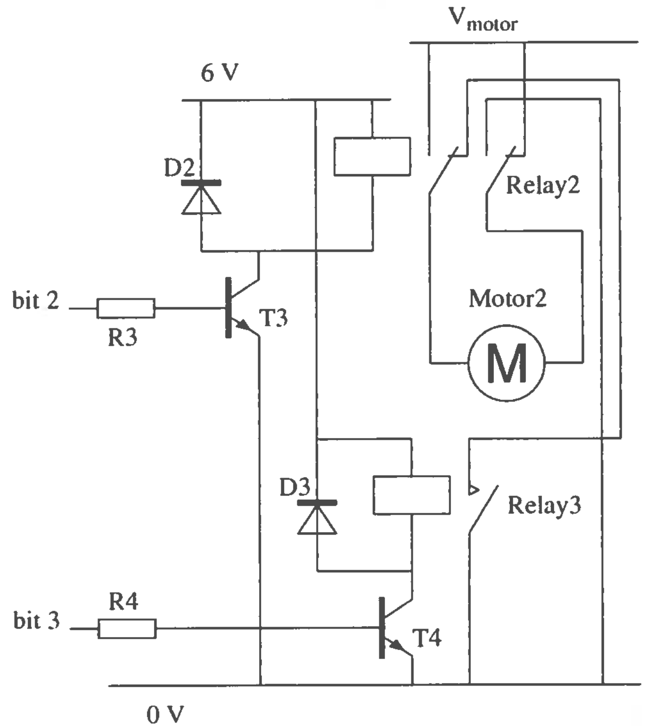
Often we might want to repeat a sequence of actions a number of times:

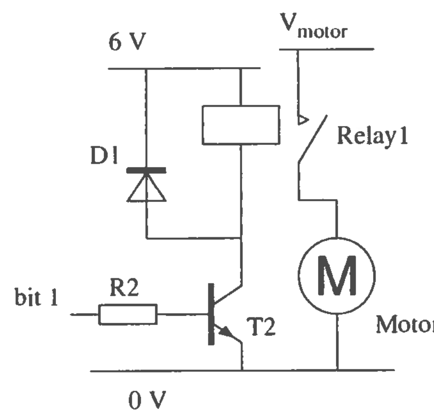
Turn on warning light, wait 10 s
Run motor 1 for 30 s, wait 30 s
Repeat the following 10 times:
  Run motor 2 forwards for 10 s, wait 5 s
  Run motor 2 backwards for 10 s, wait 5 s
(end of repeating section)
Turn off warning light
Open valve, wait 30 s
Close valve, finish

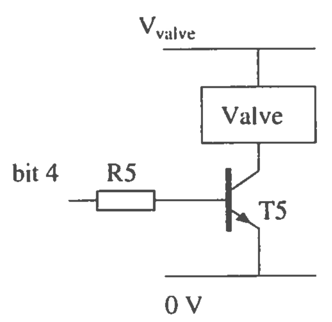
In BASIC this could be:

```
REM >Control3
Warning = 1 : Motor1 = 2
Motor2F = 4 : Motor2R = 8
Valve = 16
PROCOutput(Warning,10)
PROCOutput(Warning + Motor1,30)
PROCOutput(Warning,30)
FOR Count = 1 TO 10
  PROCOutput(Warning + Motor2F,10)
  PROCOutput(Warning,5)
  PROCOutput(Warning + Motor2R,10)
  PROCOutput(Warning,5)
NEXT
PROCOutput(Valve,30) : REM Warning now OFF
PROCOutput(0,0)
END
```

In this case we've used two bits for motor no. 2, one for each direction. We've also allocated the bits differently. The allocation of bits is quite arbitrary: you just have to make sure the circuitry connects to the corresponding points on the printer port! Fig 1 shows one way the circuits could be arranged for this application.







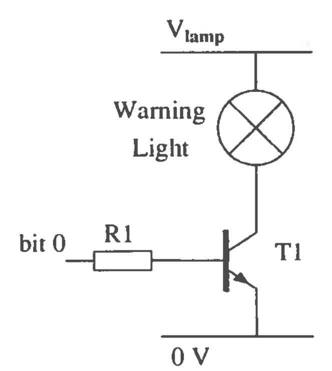


Fig. 1 Typical circuits (matching Control3)

Note that these circuits are intended to be exemplary, not prescriptive!

We have suitable relays in our surplus stock, item no. 738, 75p each.

Any small cheap 5% 1 KΩ resistors would do for R1 to R5. All the diodes are 1N4001, or any 1 A rectifier type. All transistors are TIP31 unless you are sure the load won't exceed 200 mA, when BC184 will do. Our ex surplus relays are OK with BC184. See remarks on p.26 re other types.

Closing the control loop

Finally, a program could do different things according to what happens in the external hardware. This is feedback; with program control you are not restricted to simple negative feedback! Take a hypothetical example:

Wait until the start button is pressed
Turn on heater
Wait until thermostat operates
Turn off heater
Start motor, wait 2 s
If there is excessive vibration, do the following:
  Stop motor, operate siren
Otherwise:
  Continue running for 500 s
  Stop motor, operate green light
(End of alternative action section)
Finish

In BASIC:

```
REM >Control4
Start = 1 : Therm = 2 : Vibrate = 4
Heater = 1 : Motor = 2 : Green = 4 : Siren = 8
?&FE62 = 0 : REM set user port as all Input
REPEAT UNTIL FNInput(Start)
PROCOutput(Heater,0)
REPEAT UNTIL FNInput(Therm)
PROCOutput(Motor,2) : REM Heater now OFF
IF FNInput(Vibrate) THEN PROCOutput(Siren,0) : END
PROCOutput(Motor,500)
PROCOutput(Green,0)
END
```

In this case, the siren or the green light is left on when the program finishes. Some inputs may have the same numbers as outputs, because they are using a different port.

For this program we need a FuNction:

```
DEF FNInput(I) : REM Beeb version
IF ?&FE60 AND I THEN = TRUE
= FALSE
```

or for the Arc:

```
DEF FNInput(I)
SYS 6,150,&60 TO J
REM reads the user port into J
IF J AND I THEN = TRUE
= FALSE
```

and replace the line `?&FE62 = 0` in the main program by:

```
SYS 6,151,&62,0
```

When things get complicated

In the last program, we put two statements (instructions) on one line, after the `IF`, using a colon (:) in between. Sometimes you might want to make a whole lot of actions, or a repeating section, conditional in this way. Rather than trying to put several statements on a single line, with several colons, think of a suitable name for the whole of what you want to be conditional, and put it in a procedure, thus:

```
 ....
IF FNInput(heavy) THEN PROCUnload
 ....
DEFPROCUnload
REPEAT
  PROCOutput(CraneUp,10)
  PROCOutput(Warning + CraneDown,5)
  PROCOutput(CraneLeft,2)
 ...
UNTIL NOT FNInput(heavy)
ENDPROC
```

Producing a bi-directional analogue output

In Bulletin 167 we published a couple of digital to analogue converter circuits. These enabled a computer to control a variable voltage. However, they did not provide reversing facilities: Fig. 2 shows a simple 5 bit DAC with a bi-directional output. It's not exactly a precision drive - in particular, there is no guarantee that the centre off position is really right off at all! We leave it to the adventurous among you to cobble this together with Fig. 4 from last time to produce the 8 bit version with offset and span adjustment! (Solution next time?!?)

Let's say this is being controlled by bits 3 to 7 of the user port. We can now write a procedure to control the motor, which itself uses PROCOutput:

```
DEF PROCMotor(WhatElseIsOn,Speed,Time)
MotorBits = 128 + Speed * 8
PROCOutput(WhatElseIsOn + MotorBits,Time)
ENDPROC
```

Speed must be an integer between -16 and +15. If it has a fractional part, this will affect bits 0, 1 and 2, which are presumably being used for something else (RedLight, Siren or whatever).

The exact choice of bits to control different things is up to you - but you will have to think about the effect on the values allocated to the corresponding variables, and on the numbers in PROCMotor.

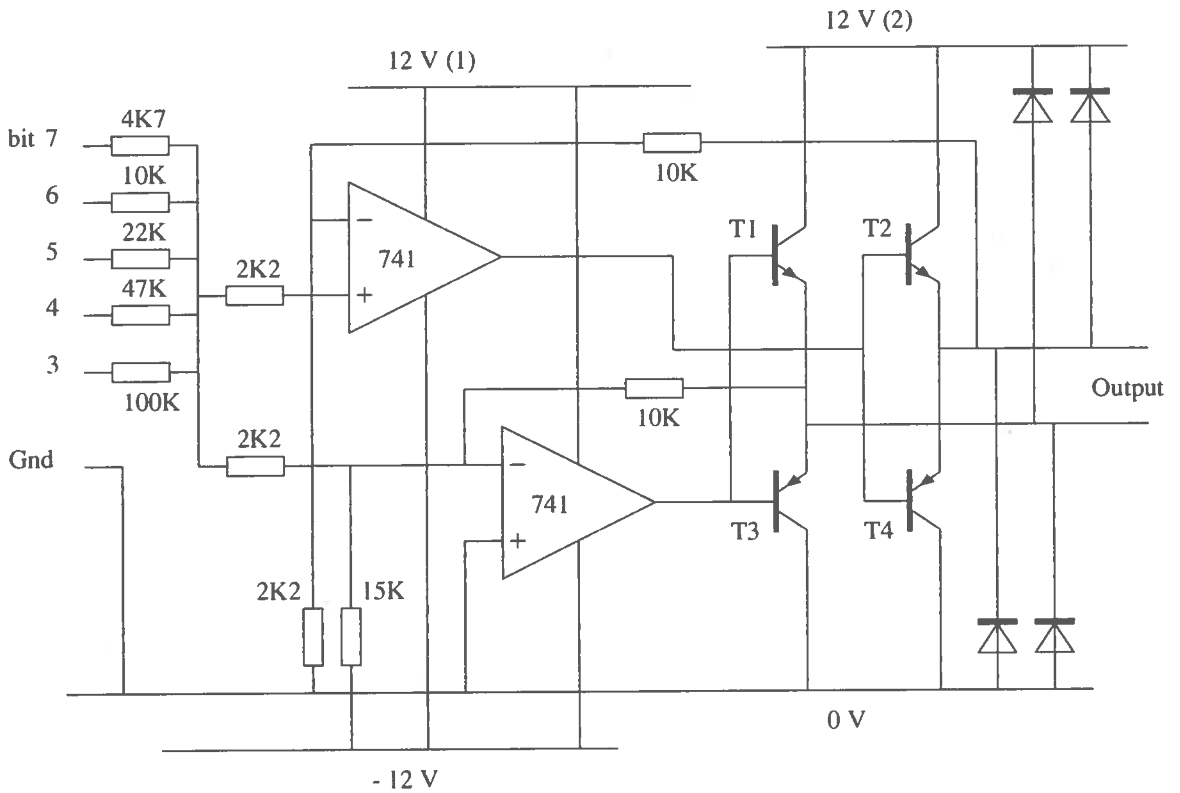


Fig. 2

All diodes are 1N4001 or equivalent, unless you are using a large motor, when you should use rectifier diodes capable of carrying as much current as the motor takes.

T1 and T2 are TIP31 unless you are sure the load won't exceed 200 mA, when BC184 will do. T3 and T4 are TIP32, or BC214 for small loads.

None of the resistors dissipate any significant power - any small cheap 5% resistors will do.

If you already have some transistors of other types, they will probably do! There is a wide range of possibilities. Make sure they can carry the largest current you expect the load to take, and get the NPN and PNP transistors in the right places!

Very occasionally, you may find you can't get much current out of some beefy transistors. This is probably because their amplification (h_{FE}) is not very large. The maximum output current is the base current multiplied by h_{FE}. The available base current is about 1 mA from the user port, 10 mA from the printer port, and 20 mA from a 741 op amp. However, h_{FE} is very variable from transistor to transistor, even of the same type or batch.

For very high currents, use Darlingtons. TIP110 and TIP115 would be suitable up to about 4 A.

Technical Articles

A platinum resistance thermometer

An accurate, electronic thermometer reading directly in degrees Celsius can be designed and constructed using a platinum resistance temperature detector in one arm of an out-of-balance resistance bridge.

Preamble

There are several curricular contexts wherein this idea can be of use:

1. The method can be applied in any technology project in which there is a need to monitor or set temperature in degrees Celsius.
2. Most instruments (especially d.i.y. at school level) are calibrated empirically. Most also have electrical outputs which bear no obvious relation to the quantity being measured. This one is exceptional. It offers a case study in instrument design. It is a contrast to empiricism. And it challenges the abler pupil to question the meanings of accuracy, tolerance and specification, and to investigate these practically.
3. Pupils studying the Revised Higher Grade Physics course are required by Learning Outcome 2.4.12 to be able to describe how to use the differential amplifier with resistive sensors connected in a Wheatstone bridge arrangement.

Theory

The revision of the Physics Higher brings about a change in the treatment of the out-of-balance bridge. It is now the out-of-balance voltage rather than current which is considered. This change is welcomed - not only because modern applications, apart from active bridges (but that is another matter), use voltage, but also since the bridge voltage is merely the difference in potentials between two potential dividers. The circuit can therefore be analysed using principles from Standard Grade Physics.

The above description is actually a simplification. It holds provided that the instrument measuring the out-of-balance voltage has an input impedance that is very much greater than the resistances in the arms of the bridge. This proviso is nearly always met.

Such a simplified analysis cannot of course be made when the out-of-balance current is monitored. Because ammeters have low, but not negligible, impedance it would then be necessary to use Kirchoff's rules for electric circuits to deduce what happens. That is beyond Higher Grade.

Design

Consider the resistance bridge circuit (Fig.1). R_1 is a platinum resistance temperature detector, a device whose resistance varies fairly linearly with temperature and whose sensitivity is reasonably high. (Table 1. Linearity diminishes for wider temperature spans.)

Temperature (°C)	**Resistance** (Ω)
0	100.00
1	100.39
10	103.90
100	138.50

Table 1 - Resistance/Temperature relationship

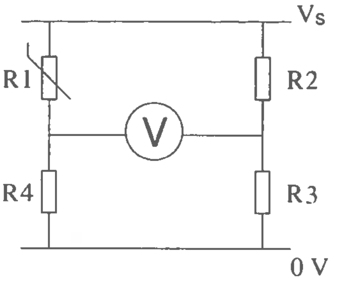


Fig.1
Out-of-balance bridge with resistive sensor

It follows that to get a linear output, we should use the sensor in a linear bridge of low sensitivity [1]. This is achieved by making $R_2 \approx R_1$, $R_3 = R_4$, and $R_3 >> R_2$.

The resistance of R_1 at 0°C is 100 Ω. The fixed value resistors can now be selected. R_2 is put at 100 Ω, and R_3 and R_4 are both put at 2.2 kΩ. Using these values the bridge is balanced when the temperature is 0°C, and the out-of-balance bridge voltage varies linearly, to a reasonably good extent, with temperature. The sensitivity depends on the choice of supply voltage, V_s.

The sensitivity has been chosen to be 1 mV/°C because a digital multimeter switched to a voltage range reading to 200 mV would display the actual temperature to a precision of 0.1°C. The requisite supply voltage works out to be 6.25 V. The calculation to obtain this is shown in an appendix.

Sensor

The platinum resistance detector used in our trials is the cheapest to be found in the RS Catalogue. It is stock number 158-238, and currently costs £5.16. A full specification can be found in the relevant data sheet [2].

The detector consists of a specially formulated platinum ink deposited as a film on an alumina substrate. This is protected by a ceramic coating. There are gold-plated end pads for connection to external conductors. The dimensions of the element are 30 mm x 4 mm x 1 mm.

Because the element might flex or break, and flexing changes its resistance, it should be bonded to the surface of a rigid body.

References

1. "Bridge circuits", March 1986, SSERC, Bulletin 150, pp17-19.

2. "Platinum resistance temperature detectors", March 1987, RS, RS Data Library no. 3914.

Appendix - Calculation of supply voltage to achieve a sensitivity of 1 mV/°C

The resistance of R_1 at 0°C is 100 Ω. If we assume that R_1 behaves linearly, which it nearly does, we can put

$R_1 = 100(1 + x)$

where x is a function of temperature and resistance. The value of x is 3.85 x 10^{-3} Ω/°C.

The out-of-balance bridge voltage can be thought of as a source of e.m.f., E. Provided the method of measuring E does not draw any appreciable current from the bridge, i.e. the measuring instrument has effectively got infinite input impedance, E can be obtained by potential division across the two arms of the bridge.

$$E = V_s \left[\frac{2200}{100(1+x)+2200} - \frac{2200}{100+2200} \right]$$

$$\Rightarrow E = V_s \left[\frac{22}{23+x} - \frac{22}{23} \right]$$

$$\Rightarrow E = \frac{22}{23} V_s \left[\frac{1}{1+x/23} - 1 \right]$$

$$\Rightarrow E = \frac{22}{23} V_s \left[1 - \frac{x}{23} + \left(\frac{x}{23}\right)^2 - \ldots\ldots - 1 \right]$$

$$\Rightarrow E = -\frac{22}{(23)^2} x V_s , \quad \text{for small } x$$

Suppose we wish a temperature rise of 1°C to produce a 1 mV increase in E. Then

$$10^{-3} = \frac{22}{(23)^2} .(3.85 \times 10^{-3}).V_s$$

$$\Rightarrow V_s = -6.25$$

Therefore the supply voltage V_s should be 6.25 V.

Equipment Notes

Unilab Alpha Kit

Some common failures

Inherent in any form of practical work in electronics is the occurrence, through misuse or abuse, of faults. It happens to circuits both breadboarded and in kit form.

As the Unilab Alpha Electronics kit is almost ubiquitous - there can scarcely be any secondary schools that don't have some Alpha boards - it is hardly surprising that we get a number of schools phoning to notify us of failures. From these reports, a pattern of common failures has emerged. We have consulted with Unilab on this. Not surprisingly, they too are aware of the same series of faults and have advice to offer on how best to avoid further problems. The purpose of this note is to describe the faults that are prevalent, explain why they seem to occur, and suggest some preventive measures we think you should take.

In order of frequency, the three commonmost failures occur to the following boards:

- Power Supply Regulator, 223.001
- Transducer Driver, 223.040
- Latches (negative and positive edge triggered), 223.110 and 223.112

Power Supply Regulator

As far as we can judge, all the above problems have a common source that starts with the Power Supply Regulator. At their heart is the full-wave bridge rectifier circuit comprising four diodes. If the negative outlet rail is commoned to one of the outlets on the bench power supply (Fig.1) - as might inadvertently, but all too readily, happen if both were to be earthed - this would place one of the rectifier diodes directly across the bench supply. This diode would overheat and fail, and in doing so would be more liable to go short circuit rather than open circuit. This would then result, if the board is being supplied from an a.c. power supply, in negative cycles being conducted through the Power Supply Regulator downstream to all the other boards daisy-chained to it.

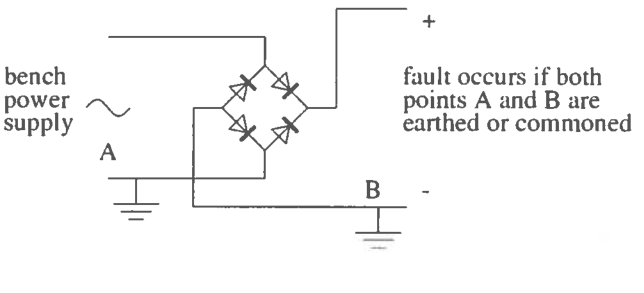


Fig.1 - Fault condition in Power Supply Regulator

Risk of eye injury

Occasionally, the build-up of gas pressure within the diode encapsulation is sufficient to cause it to rupture explosively. Since there is a foreseeable risk of injury to eyes, we think that measures to prevent eye injury need to be taken.

We understand that Unilab have been advising their customers to fit a 2 Ω, 2 W resistor in series with one of the pair of leads connecting the Power Supply Regulator to the bench power supply from which it draws its power. In the event of the bridge rectifier being mis-wired, the resistor, by either limiting the current, or fusing, should adequately prevent any of the diodes failing and going short circuit. Unilab further suggest that as the resistor would undoubtably get extremely hot under fault conditions it should be sited adjacent to the bench supply terminal where it is less likely to be handled than close to the Alpha board.

This seems to us to be reasonable advice to follow in the short term. By taking such a measure the risk of injury to eyes from diodes exploding would be effectively eliminated.

Over the longer term, we suggest that you should gradually phase out using this board and replace it with either a well designed, enclosed, bench power supply, or with a 6 V PJ996 battery and Battery Connector (223.002), or perhaps even with what is described below.

If these measures are not followed some other means of preventing eye injury would have to be devised. Two are given. Either a shield should be permanently fitted to the board covering the diodes, or, as a last resort because the wearing of personal protection should be the last resort in safety measures, pupils should be required to wear eye protection.

Redesigned board

Unilab inform us that the Power Supply Regulator has been redesigned and that the new version will be available, using the current stock number (223.001), as from January 1991. By replacing the full-wave bridge rectifier with a half-wave one Unilab hope to avert most of the diode shorts which the present design too readily seems to allow.

Downstream faults

It is highly probable that many of the failures of the MOSFETs in the Transducer Drivers and of the integrated circuits in the Latches have been caused by negative voltages on the supply rail resulting from failures in Power Supply Regulators. Both types of semiconductors are particularly susceptible to this form of damage.

These failures point to the importance of having a sound power supply and explain why we think that you should plan to withdraw from use, should you have these, the present version of the power supply board (223.001).

Alpha in Higher Grade Physics

Curricular context

As mentioned in Bulletin 167, Unilab are introducing new boards which, supplemented by boards from their Standard Grade Physics Kit, provide for the electronics part of the revised Higher course (also, for the CSYS Physics Optional Topic 2, Analogue Electronics, and for the Electronics Short Course, Analogue Systems).

The Higher Physics Alpha kit described below is not, in our opinion, particularly suitable in Higher Grade Technological Studies because it is more suited to accompanying didactic teaching rather than learning through the context of project work - the teaching approach suggested in SCCC publications. However although the boards may not be relevant, some of the ideas and applications would be: for instance, the treatment of potential dividers and resistance bridges.

The following application notes refer then specifically to the revised Higher Physics course, but as just discussed, would have relevance elsewhere.

Out-of-balance resistance bridge

Two Potential Divider boards (223.070) can be joined to construct a bridge circuit for out-of-balance bridge analysis. By using fixed value 1 kΩ resistors in three arms of the bridge and a decade resistance box whose resistance is varied by 1 Ω and 10 Ω steps on either side of 1 kΩ in the fourth arm, we are working with a bridge which is inherently non-linear except for very small changes in resistance (Fig.2). This arangement complies closely with the curricular requirements.

Having seen the relationship between the out-of-balance voltage and small changes of resistance in one of the bridge's resistors, the bridge should be rebuilt to include a resistive sensor. There are two applications which we recommend. One is the measurement of temperature using a platinum film temperature detector as described in the Technical Notes of this issue. The other is the measurement of force using a pair of strain gauges mounted on opposite sides of a cantilever. We hope to publish details of this second application in a future issue. Both applications can be built on two Potential Divider boards as in Figure 2.

Now build on breadboard!

The Potential Divider board has been cleverly designed to elucidate the electrical principle of potential division. Two such boards joined together (Fig.2) lay out in elementary form, and shed light on the principle of operation of, the Wheatstone bridge and the out-of-balance bridge circuit. These are examples of why kits are used in electronics teaching.

There is also a need in education to complicate, to mess up and have pupils disentangle, problems. And there is a need to wean them off the baby stage of circuit building for which educational kits provide. Having introduced bridge circuits through kits, this would be a reasonable opportunity in the Higher course, before encountering the complexities of chips, to require pupils to construct a bridge circuit, perhaps with a resistive sensor, on prototype board (Fig.3).

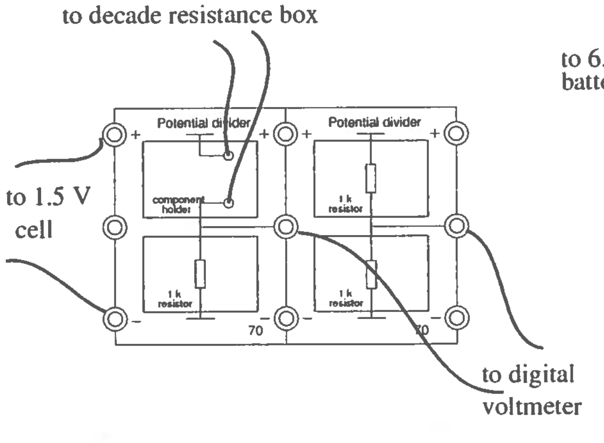


Fig.2 - Out-of-balance resistance bridge

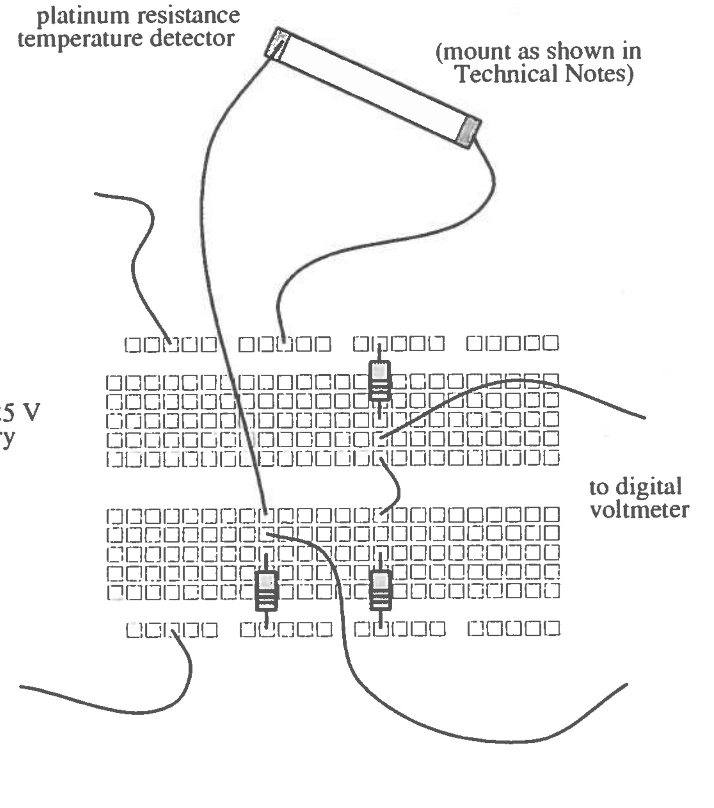


Fig.3 - Bridge circuit on prototype board

Op-amp power supply

The op-amp on the board designed for the Higher (Amplifier Investigations, 223.047) is a CMOS low power type made by Intersil, the ICL7612. It has a high input impedance of 10^{12} Ω, which is good, its output voltage can swing to within millivolts of the supply rails V_- and V_+, also good, and it can be operated off a dual rail supply within the range ±1.0 V to ±8 V.

This abnormally low supply voltage maximum requires care. It precludes the use of conventional dual rail bench power supplies, which are normally rated at ±12 V, or ±15 V. However any regrets we might have on that score are disarmed by being able to dispense with anything as complex as bench power supplies at all, or as fraught with risk as the Alpha Regulator Power Supply. A pair of 1.5 V zinc carbon cells, connected in series, with their common node designated as the 0 V rail, and their other terminals the +1.5 V and -1.5 V rails, is a simple, safe, cheap and effective supply (Fig.4).

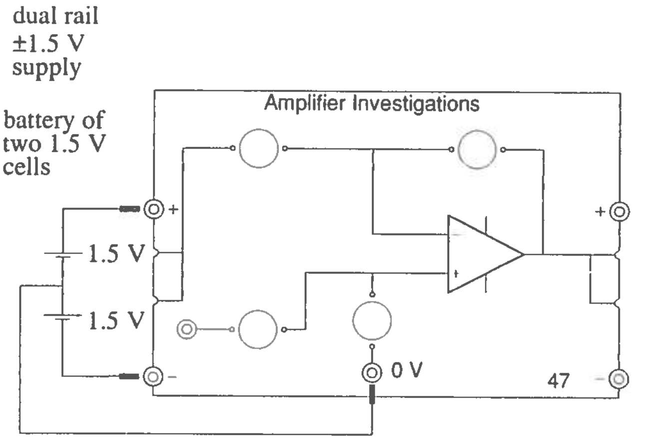


Fig.4 - Power supply for Amplifier Investigations board

DC signal characteristics

If a 4.7 kΩ Potentiometer Panel (223.078) is inserted in a Potential Divider board (223.070) and joined to the Amplifier Investigations board, the input voltage is variable between the extremes of the supply rails V_- and V_+. The op-amp is shown here wired as an inverting amplifier (Fig.5 and Fig.6).

Because of the op-amp's electrical characteristics, the input voltage should not be allowed to exceed the supply rail voltage V_s by more than 0.3 V, i.e.

$$|V_{in}| \leq |V_s + 0.3\ \text{V}|$$

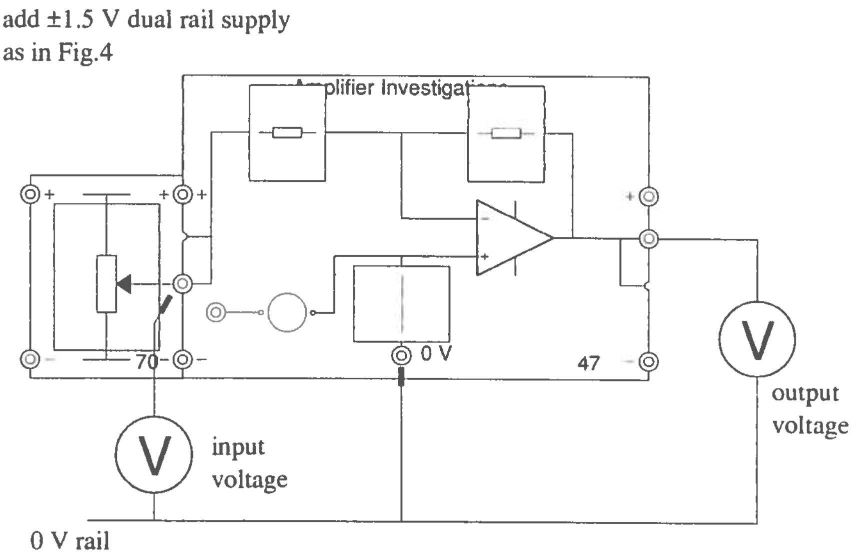


Fig.5 - Inverting amplifier with variable d.c. input signal: Board layout with voltmeters

Other applications

We trust that the few applications illustrated here, and the notes on the electrical characteristics of the op-amp, are sufficient guidance for other applications of this kit in the revised Higher to be self-evident.

Please note that the Amplifier Investigations board layout has been designed to simplify the building of all the op-amp circuits specified in the three relevant SEB courses mentioned at the beginning of this section. However some op-amp circuits not in these courses, such as the non-inverting and summing amplifiers, cannot readily be constructed on this board. If extension work on circuits outwith the syllabuses were to be undertaken, we suggest that it is done on prototype board.

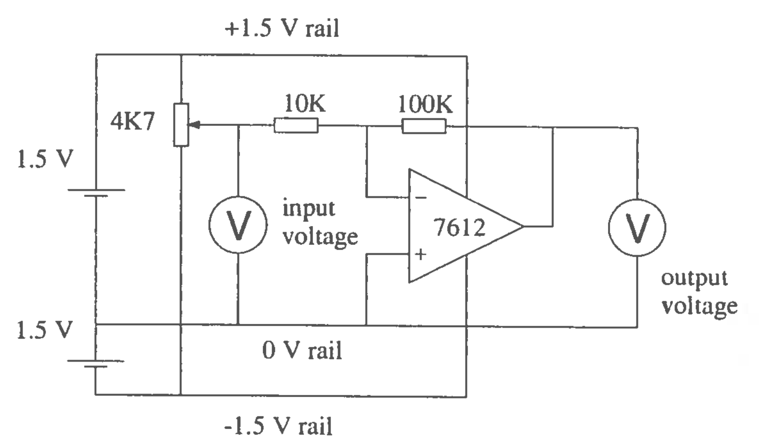


Fig.6 - Inverting amplifier with variable d.c. input signal: Circuit diagram

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