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OPINION

An illuminating question

The gents' toilet here at SSERC is one of those stygian spaces made possible by modern, if noisy, ventilation techniques. It is without windows or any other natural lighting and is lit instead with fluorescent tube fittings.

As respectable and reasonably informed scientists and technologists, we like to think that we are a fairly green lot - in the environmental sense that is. This results in an ongoing but minor difference of opinion as to whether or not, post ablution or *aprés le déluge* as 'twere, we should or should not switch off the lights.

One person might say that in the interests of energy efficiency we should save electricity and switch on and off at each visit. The other vows that this significantly shortens the life of the fluorescent tubes and argues that the energy costs in manufacture and of obtaining the raw materials used for any replacements need also to be brought into the overall green equation. They will point to the relatively low power consumption of the tubes themselves compared to tungsten filament lamps and to the costs of repacement tubes. The other camp will counter that it is not enough to look at the nominal rating of the tubes but that the energy dissipated as heat by the chokes needs also to be remembered and then fluorescent fittings as a whole seem somewhat less efficient than we all assume.

Some might go even further and point to the fact that fluorescent coatings used in lighting tubes contain things like beryllium compounds and other ecotoxic nasties. That complicates the argument yet again since any increase in the rate of tube replacement means an added burden on the environment when the old tubes are disposed.

Needless to say this mild difference of opinion has never been resolved. The pattern of our light switching continues to conform well with chaos theory.

I find it fascinating that even in an establishment so thick with qualified professional scientists and technologists we cannot decide definitively on the best course of action to deal with such an apparently simple problem in an optimally environmentally friendly way.

It would make an excellent problem for a school science or technology project[1]. Pupils would have to search out or obtain by measurement, all the data which would have to be evaluated to resolve such an environmental dilemma.

Not the least of the potential benefits might be an appreciation of a general need to identify and then balance the many conflicting factors which can influence such seemingly simple environmental decisions.

It may also help to make a beginning in putting at least some of us scientists and engineers in a different light. Not a few young people tend to see science and technology as discplines based on indisputable fact - a digital world of black and white and hard-faced decisions taken *sang froid* and *sans ethics* with an insufficient regard for consequential environmental damage. Unfortunately at the moment those young people too often are right.

Too simple by half?

The lessons of our light switch problem could equally usefully be learned by those adults, some engineers and politicians for example, who continue to believe that complex environmental questions are amenable to simple straightforward solution. You know the sort of thing: traffic congestion is obviously sorted by building more roads. The huge problem of profilgate usage and wastage of water in one part of the UK is addressed by piping the stuff from here to there so that eventually the water table may be the same level everywhere ie lower.

Such issues should have primacy in a post-industrial Scotland whose remaining natural assets are possibly its most precious because in pan-European and global terms they are now so scarce. Factors related to such assets and to environmental quality will exert an ever increasing influence on the decisions of both native and inward investors.

Investment is one thing. Exporting a whole quality of life and importing ecological damage is another. We just have to find more subtle and sophisticated ways of tackling environmental issues.

Failing that, would the last Scot to leave please switch off the lights.

1.Should anyone decide to have pupils investigate the "switch or not to switch off" dilemma - do let us know the outcome. We could do with a new green issue over which to chew at tea breaks.

Safety Notes

CSYS Microbiology and the Code of Practice

Background

We have received a number of enquiries on apparent conflict between advice given in the Strathclyde Regional Council booklet "Safety in Microbiology" [1] and some of the suggested learning activities for the Microbiology topic of the CSYS Biology Arrangements [2].

The majority of Scottish EAs have either adopted, or adapted, the Strathclyde documents and issued them as their own Code of Practice (CoP). Any significant clash with the recommendations of the Biology Panel of the Scottish Examination Board is a potentially serious problem. Fortunately however, those difficulties which have been indicated are more apparent than real. Few cannot be resolved by twin applications of the principles of COSHH and commonsense.

Code of Practice

The original guidance which became the Code of Practice was drawn up by a Safety in Microbiology Committee convened as a working party by Strathclyde Regional Council Education Department. The impetus for the review came partly from a consensus that some earlier guidance had perhaps erred too far on the side of caution and that this had slowed down developments, especially in biotechnology education. The bigger influence however came from a need to draw up a rational policy to meet the requirements of the Control of Substances Hazardous to Health Regulations [3] micro-organisms used in the workplace being covered by that legislation.

Provenance

For the purposes of meeting risk assessment and control measures requirements as central parts of COSHH, the HSE had from the outset accepted the need to recognise existing, authoritative advice. The principle that such advice both represents the results of "general" or "generic" risk assessments and provides suitable means of controlling risks is now well established.

The Code of Practice drawn up by the Strathclyde Review Group and now widely used by other EAs is firmly based on such principles. It is intended as a succinct, working document but nearly all of its recommendations are based on two primary sources both of which are recognised by the HSE as authoritative. These are Topics in Safety [4] and Microbiology : An HMI Guide [5].

Safety in Microbiology : Principles

In carrying out any microbiological risk assessment in an educational context a number of salient risk factors are recognised. These are, briefly :

- organism(s) used;
- source of the organism;
- likelihood of chance contamination;
- nature of the culture media;
- incubation temperature;
- scale (volume of media);
- containment;
- expertise of teacher, technician and students.

It is these factors which led to the concept of "Levels of Work" first described in SSERC publications and adopted since by the ASE [4] and by the English Department for Education (DFE) in its HMI Guide [5].

Interaction

It is important to remember that none of the risk factors listed above acts in isolation. Altering one factor may well influence another. Taken together however, as a mental checklist, they can provide a most useful way of assessing and then controlling microbiological risks. This is the approach which has been followed in examining the apparent conflict between the Code of Practice and the Scottish Examination Board's Arrangements for Biology at CSYS level.

Learning Activities

Although all of the Learning Activities in the CSYS Arrangements are in the "suggested" category there are a number of areas which may cause problems for those teachers whose EA operates according to the Strathclyde Code of Practice or a close variant. The learning activities in question are as follows (with sub-topic references):

"1(d) Winogradsky columns

2(a) ii Isolate yeast from grape skin and ferment sterile juice/glucose.

3(b) Transfer of fruit spoilage organism from infected to fresh fruit.

4(c) Isolation, culturing and re-inoculation of suspected pathogens using orange and *Penicillium digitatum*, ..., *Penicillium expansum*.
Effect of *Uromyces phaseoli* on bean root growth".

Comments and conclusions

SSERC approached the Chairperson of the Review Group who agreed that the activities in question were clearly out of step with the guidance in the Code of Practice. It was agreed however that the central issue then became whether suitable control measures could be suggested which would reduce the risks to acceptable levels. An element of flexibility was built into the code from the outset to cope with such circumstances. Areas outwith the code are not automatically ruled out. If organisms other than those listed in the Appendices, or procedures not allowed for in the code, are to be used what is required then is that a risk assessment be carried out and be approved by the employer. In most cases this will be the Education Authority.

We therefore asked members of the original Review Group to reconsider these suggested activities against the Code of Practice and the Supplement to it (Level 3 work at post-16). There were, of course, differences of opinion. It has not been difficult however to resolve these and find a consensus on most of these practical activities. These comments and the conclusions which flow from them are presented below in the same order as the list of suggested activities.

1(d) Winogradsky column

Not every member of the Group had first hand experience of this practical. Those who had were in agreement that it should be retained since it is one of the few ways at school level in which one can demonstrate microbial ecology, succession and the sulphur cycle[6].

Fig. 1 - Development in a Winogradsky column (after Fry)

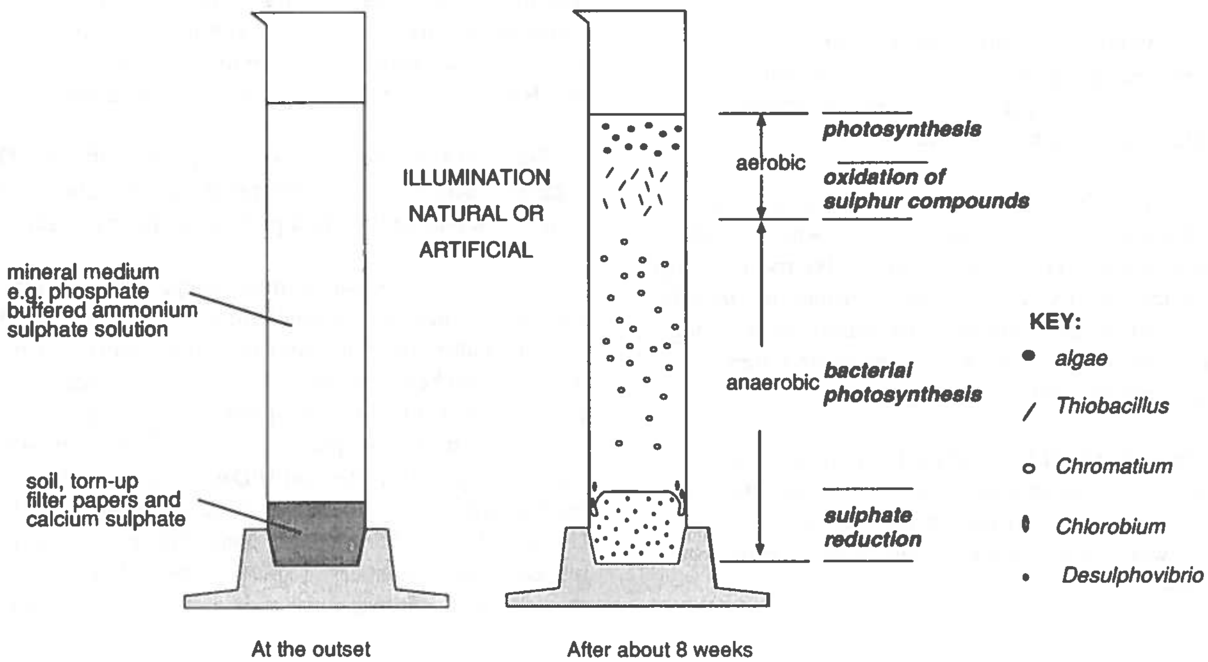
The activity in essence involves the inoculation of a mineral-based liquid medium with soil. The medium may simply be held undisturbed in a tall form vessel such as a gas jar or measuring cylinder so that concentration gradients may develop within the medium (see Fig.1 below). In somewhat more sophisticated versions the medium may be re-circulated as a percolating liquid.

Over time a microbial succession occurs in the column. As various elements in the medium become depleted different micro-organisms become dominant since they are better able to exploit the remaining medium or to synthesise for themselves certain nutrients. Columns may be illuminated so as to demonstrate the existence of photosynthetic bacteria.

The most obvious potential conflicts with the Code of Practice are :

(a) Some texts [e.g.6, 7] suggest the addition of pond mud to the soil in order to ensure the presence of sulphate reducing organisms such as *Desulphovibrio* bacteria. Use of pond mud as an inoculum is however specifically ruled out in the code.

(b) In static columns an oxygen concentration gradient will develop. Fully aerobic conditions will occur at or near the surface becoming increasingly anaerobic down the column as evolved gases displace the oxygen. One or two older texts may suggest the use of Winogradsky's medium in sealed containers in deliberately arranged totally anaerobic conditions so as to demonstrate the presence of nitrogen fixers such as *Clostridium pasteurianum*. Deliberate, fully anaerobic culture of bacteria is not covered under either the basic provisions of the Code of Practice nor the Level 3 supplement.



Recommendations

1. Certain aspects of the use of Winogradsky columns and Winogradsky's medium are valuable and should be retained.

2. Liquid media or percolating liquids should contain only inorganic compounds when it is unlikely that pathogens will grow in the soil even were it to be contaminated.

3. Only garden soil is to be used for the inoculum with pond or river mud being avoided (some "recipes" call for the incorporation of chopped up filter papers at the base of the cylinder and this is acceptable).

4. Soil sampling sites should be chosen carefully so as to avoid those recently treated with animal manures or contaminated by animals. Soil samples should be handled using gloves (household rubber gloves will suffice) in order to avoid contamination through cuts or abrasions on the skin.

5. Steps should taken to prevent and contain any spillage. As with all liquid cultures secondary containment is advisable and the columns should be stood in an outer spillage tray of sufficient volume to contain all of the contents of the culture vessel.

6. Since tall-form vessels are used they should be supported in some way so as to prevent their being knocked over.

7. The material should be sterilised by autoclaving before disposal.

2(a) ii Isolate yeast from grape skin and ferment sterile juice/glucose

Here any apparent conflict with the provisions of the Code may easily be avoided. The syllabus entry is best seen as being in two parts. This is because there are two possible lines of controlling risk.

The proviso 2.6 in the part of the code dealing with Level 1 work was to avoid excessive growth of moulds and production of spores which might give rise to allergy in some individuals as well being a nuisance as *microbial weeds*. Control can therefore be exercised either through containment or by using a known organism rather than a mixture from the surface of the grapes.

There thus would be no objection to inoculating a solid medium on a slope or plate with inocula from grape skins providing general provisions of the code are followed and cultures were merely observed and the culture vessels kept closed.

It would seem both unnecessary and unwise however to transfer such cultures or to seek to grow them to provide a large enough inoculum to ferment sterile glucose solutions.

That is if the word *ferment* implies a relatively large scale operation. It would be better then to inoculate the glucose solution with a bought-in dried wine yeast. If grapes are to be the source of the organism then the scale should be kept small - say no more than 50 cm^3 of glucose solution.

If the latter were done then the liquid medium should contain only glucose and not have any added yeast extracts or nitrogen compounds since these might encourage the growth of contaminants. Grape skins would form the inoculum rather than any isolates.

The system should be held anaerobic so as to produce alcohol and therefore an air-lock (bubble trap or similar fermentation lock) should be fitted. Aerobic conditions will produce larger numbers of yeast cells and are to be avoided since wild yeasts other than *Saccharomyces* sp. may grow. A small number of wild yeast strains are known to cause illness in humans and these are more likely to be serious contaminants in aerobic culture.

Careful disposal is required

3(b) Transfer of fruit spoilage organism from infected to fresh fruit

This is amenable to a similar approach to that adopted for the practicals using naturally occurring yeasts. Again control is best afforded either through use of a known organism rather than an uncertain mixture or by containment. The major concerns also are the same. That is, the potential for the release of large numbers of spores to which people may well become sensitised and then allergic and the establishment in the lab of microbial weeds which will then become persistent contaminants.

There are a number of answers to these problems. The suggested activity may be interpreted as "inoculate fresh fruit with a pure culture of a plant spoilage organism".

Alternatively use containment. Aseptically transfer, with inoculating tools, a small piece or scraping from the skin of a naturally rotting fruit so as to infect fresh fruit which is then held and observed through a closed container. It would also be appropriate for scrapings from the original fruit to be plated out onto a mould medium (such as potato dextrose agar [PDA]) so as to demonstrate the organisms involved. Again these plates would be kept closed and no further transfers done. This is to prevent the release of large numbers of spores. Disposal procedures would be as described in the code.

cont./

Rhizobium

Although this item was not raised in the original enquiries it was also felt that similar problems were met with in this entry :

3(a)"Isolate Rhizobium from root nodules; infect legume seeds with this".

This would be better if changed to two activities and perhaps the second part of it should read:

"infect legume seeds with inocula from a culture of *Rhizobium sp*."

4(c) Isolation, culturing and re-inoculation

This has been interpreted both as an extension of 3(b) and as one way to demonstrate Koch's postulates for establishing pathogenicity. Unfortunately the organisms named in the SEB Arrangements are two *Penicillium* species - *P. digitatum* and *P.expansum*.

The only *Penicillium* species listed in the Appendices to the Code of Practice is *Penicillium roquefortii*. This is because of a general concern over growing incidence of allergenic reactions to penicillin producers and to fungal spores. Nevertheless the demonstration that fungal infections can be transferred between plant tissues and the illustration of the application of Koch's postulates are useful learning activities.

We would suggest two possible approaches to minimise any risks. The first is to integrate this activity with 3(b) and utilise the same kinds of containment procedures. That would however lead to an incomplete demonstration of Koch's postulates.

The other possibility is the use of pure culture of a known organism in combination with a susceptible plant. Fungi causing soft-rots are one obvious possibility. *Erwinia carotovora* is one such but may not be the best choice because of ease of contamination of cultures. In addition we have anecdotal evidence that *Erwinia* species may be opportunist pathogens being associated with secondary infections in imunosuppressed patients.

The advice of one experienced Review Group member is that the *Botrytis cinerea/Pelargonium sp.* combination provides a reliable and easily managed system.

A major advantage of *B.cinerea* is the fact that it is easily identified because its appearance is so distinctive. In sporing condition the heads of conidia and formation of sclerotia make it highly unlikely that students will confuse it with some other mould.

The original inoculum should be from a bought in culture and the primary inoculation carried out by a teacher or technician. Students may then isolate the *Botrytis* from such infected plants. In terms of using isolates as further sources of inoculum this should be restricted to such named fungi and plates must be checked for possible contaminants before opening them to carry out transfer. Again the distinctive appearance of *Botrytis cinerea* should ease the spotting of any chance contaminants.

Uromyces phaseoli

The specialist safety advisers to the Review Group are of the opinion that there is no reason why this species should not be used at Level 3 and that it should be added to the list in the relevant Appendix to the code.

References

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2. *Scottish Certificate of Education, Higher Grade and Certificate of Sixth Year Studies, Revised Arrangements in Biology*, Scottish Examination Board, 1990.

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4. *Topics in Safety*, Ch.5, ASE, as revised 1988, ISBN 0 86357 104 2.

5. *Microbiology : An HMI Guide for schools and further education*, 1985 edition, as revised, HMSO, ISBN 0 11 270578 2.

6. *Educational Use of Living Organisms : Microorganisms*, P.Fry, Hodder & Stoughton for the Schools Council, 1977, ISBN 0 340 17052 2.

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Feature Article

A robot for the teacher?
A survey of users Part I

Bill Lindsay

This is the first in a short series of articles on robots and related devices intended for use in technology education at school level. The results of a survey of schools are summarised. These provide some insight into : the kinds of robotics equipment used in Scottish secondary schools; teachers' perceptions of the overall usefulness of specific models of teaching robot and of factors which seem to limit their usage.

Editor's Notes

This article is closely based on one of a series of papers prepared by Bill Lindsay of what was Jordanhill College of Education. Now, of course, that is part of the Faculty of Education of the University of Strathclyde. We are very grateful to Bill for permission to use his work in this way.

It is some seven years since we fulminated in these columns [1] about hardware led curricula in technology education and the need for sound educational criteria in specifying equipment for school use. It is pleasing that not only should someone now have carried out serious research into such issues [2] but that they should choose the SSERC Bulletin as a vehicle for publicising the results.

Introduction

This article is based on part of a research project which set out to try to determine those features which make robotics equipment suitable for classroom use. By means of surveys of schools both teachers and pupils were canvassed as to the features they expected of a robot designed for teaching purposes.

In addition to yielding much information on the expectations and perceptions of both groups of potential users, the survey results also suggested a number of other areas which justified further investigation. Some of the results of such additional research will be presented in other articles in this series. Topics so covered include a draft specification for a robot for classroom use and the results of detailed evaluation of two robotic systems.

Curricular context

The study was carried out in the particular context of Scottish school courses in Technological Studies [3]. The aims of this course include the development of :

- an understanding of technology as it is applied in industry and commerce;
- an awareness of the applications of technology in the community;
- a recognition of the need for responsibility to humanity and the environment and
- an appreciation of the need for flexibility by the individual with regard to work practices [3].

It is clear in the documentation for the course at all grades that, in order to assist the development of such attitudes and awareness, pupils should have first hand experience of a range of examples of contemporary technological devices and that these should include computing and robotics equipment.

Teaching and learning approach

Also implicit is the need for active learning, so called *hands-on* approaches. This is encouraged for a number of reasons:

- in order to develop confidence in handling equipment;
- to provide opportunities for pupils to solve practical problems in using technological devices for specified tasks and
- to provide a relevant technological environment, atmosphere even, which will suitably influence the attitudes of pupils and students.

The equipment used for the study of applications of robotics, control and computing systems is clearly an important part of this general technological environment. The safety, *user-friendliness*, reliability and overall fitness for purpose of such equipment may all be factors which significantly affect learning.

Broad criteria

It is important therefore to consider such technical features and to identify those factors which make such equipment particularly suitable for classroom usage. Also to be considered are the important constraints of cost, availabilty and finally of the physical space taken up by equipment both in use and in storage.

School survey

An obvious starting point for the work was first to gather data on current patterns of equipment provision in schools presenting Technological Studies. To that end the Scottish Examination Board was approached and data obtained on which Scottish schools were presenting pupils for Technological Studies at Standard Grade. As a result some 245 schools were selected to each of which a survey questionnaire was then sent.

Phase 1 questionnaire

This is not an appropriate article for detailed discussion of the actual design of the survey methodology and instruments. Broadly however the questionnaire was intended to gather three main types of information:

(i) details on types and models of robotics equipment currently held and used in the schools;

(ii) information on teachers' impressions of acceptability of levels of performance both of hardware and software and

(iii) information on teachers' expectations of robotics systems intended for teaching at school level.

For the convenience of respondents in providing data they were asked to match the equipment held in their school against those models already listed within the questionnaire. This list of models was compiled after a search of manufacturers' catalogues and of review papers.

Another set of questions sought information on teachers' perceptions of the suitability of the equipment held in their school. Categories used for this section were influenced by the earlier work of CLEAPSS [4], Post [5] and Howell [6].

The final section of the questionnaire was intended to gather respondents' views on what would be their requirements for a robotics system designed for classroom use. Here also the questions were influenced by the work of Post and Howell [4, 5].

Of the 245 questionnaires sent out, 98 were returned of which 81 were analysed (17 being late returns).

Survey results

What hardware is currently in use?

Table 1 shows the totals for each type or model of robot on the questionnaire list against which responses were made. Note that there were some listed systems for which there no responses indicating that none of that type were held in the schools in the sample. On the other hand very few unlisted models were mentioned as being in use.

Robotic system	Number	% of total
Fischer Technik robot	54	29
Lego buggy	49	26
Beasty robot arm	18	9.6
Trekker buggy	16	8.6
Mentor	15	8
Alfred	11	5.9
Economatics buggy	5	2.7
Lego robot arm	4	2
Armdroid robot arm	1	0.5
Logotron robot	1	0.5

Table 1

The total number of individual robotic devices held in the 81 schools was 187 with some schools each holding two or three different models.

Software

Respondents were asked to indicate the software used to control each of the robot types they had.

The most commonly used generic control package was *PROF* from Unilab. This was stated to be in use with the Lego Buggy; Trekker and the Fischer Technik Robot. (Subsequent discussion with teachers suggested that for the Fischer Technik device it is the *ARM* part of the *PROF* package which is used).

The other seven robotic systems present in the sample schools tend to be used with the software specifically supplied originally with the hardware. One school reported the use of a diy software package and a number of others indicated that might use more than one software package with the same hardware system. Unfortunately a disappointingly large number of respondents failed to indicate which software was used with their sytems.

Reasons for purchase

Teachers were asked to indicate how their robotics equipment had been selected and also who had made the decision.

In most cases systems had not in fact been chosen by end users but had been selected and purchased centrally by their education authority.

In the next largest category of response, the teachers all claimed to have acquired the system with a particular course or application in mind. However within that general type of response few gave more detailed specific reasons for choosing a particular system. Those who had considered cost effectiveness, or had obtained and followed recommendations from third parties or teaching colleagues were very much in the minority.

Since most systems had been chosen and provided centrally, that invites further investigation both of the criteria which the local authority had used in selecting a particular system and of any differences in levels of satisfaction of authority officers with their centralised choice and that of teachers and pupils as users. This is beyond the scope of this present article but it was suggested as another basis for further work.

How much are the devices used?

Respondents were asked to indicate, approximately, how many hours their robotics hardware was used in any school year.

Who uses them?

Responses were to be categorised as either "demonstration" or "hands-on" time the latter indicating pupil usage. It was notable that with the exception of the Beasty device, pupil hands-on time was said to be much greater than demonstration time. Hands-on time might be as much as three to five times greater than teacher demonstration time. Most of the devices therefore most of the time are used by pupils. This obviously has implications as to their robustness, reliability and ease of use.

If they are not used - why not?

Earlier discussion with practising teachers had suggested that there might be significant numbers of unused robotics systems in schools. This issue was thus specifically addressed within the questionnaire. Where a particular system had not been used or had fallen into disuse teachers were asked to indicate why this was so. Some of the language used in several responses was unprintable!

For most types of device the proportion of disused systems to the total number of that type held in schools was small and varied from model to model ranging from about 2 to 20%. In the case of Beasty however more than a quarter of the total in the sample schools were not in use. The case of Beasty will thus be looked at in more detail later in this article.

Other major reasons for not using systems were lack of teacher experience, time, training or a combination of these. These factors were not examined in any further detail in this phase of the project. These early findings nonetheless should be of considerable interest to those involved in training technology teachers both pre- and in-service.

Teachers' views on specific models

Respondents were asked to grade specific models on particular aspects of the hardware itself, the software supplied or used and the documentation. Each aspect was to be given a grade on a five point scale. In the graphical summaries shown (Fig. 1 & 2) the gradings on two of these aspects have been aggregated and mean scores derived.

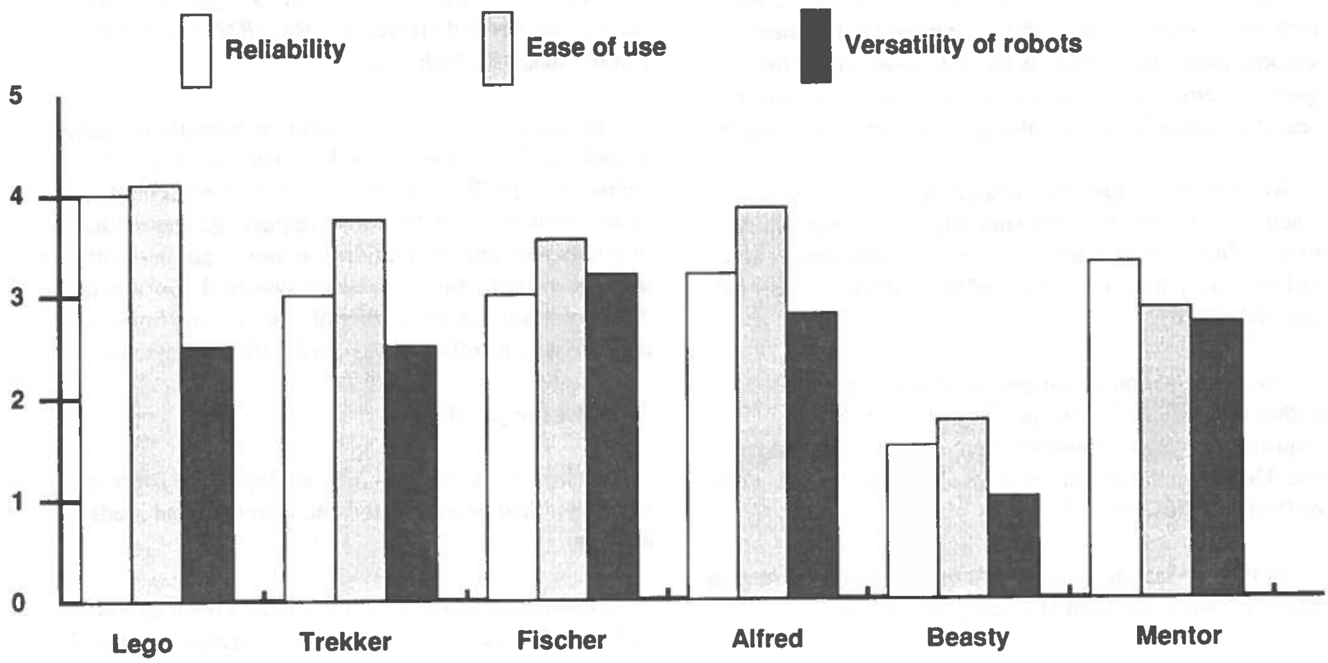

Fig. 1 - Hardware reliability, ease of use and versatility

Hardware ratings

Here the aspects on which teachers were asked to comment were: reliability, ease of use and versatility. The aggregated results are shown in figure 1 at the bottom of page 8 (facing).

The relatively good scores for the two buggies, Lego and Trekker, are of interest and it was noted that of the two, the simpler Lego device was more highly regarded for reliability and ease of use. The similar, middling, scores for versatility perhaps reflect a feeling that a buggy is not quite a robot in the accepted sense.

The model which came out least well from this survey was Beasty. The low scores for all three aspects of hardware performance echo the responses to questions on reliability and disuse earlier in the questionnaire.

Software ratings

Here users were asked to grade the software on five point scales for two features - the attractiveness of the user interface (the ways in which users may input commands and interact with the software etc.- in the jargon its *user friendliness*) and its ease of use. Not all users employed just one piece of sotware or that originally supplied with the device. This led to a more complex set of responses. For that reason a commentary is given on software features for each device in turn.

LEGO buggy

Such is the variety of software which has been employed in controlling this device a full account of user opinion would need another article. Because of this complexity the results could not be treated so as to represent aggregate opinion on Lego buggy software.

The results have therefore been separatly analysed for users of the software supplied with the device, PROF and the other commonly held third party supplied package CONTROL-IT. Whilst several other packages were in use no one of them had enough users to merit further separate analysis.

The results for the packages supplied with the device are of limited value since the detail of the software varies according to which firm supplies the buggy. In the sample surveyed at least two possibilities were mentioned - MFA (Unilab) and LEGO Lines.

In any event CONTROL-IT was clearly considered to have the better user interface and to be easy to use.

TREKKER

The majority of TREKKER owners continued to use the software supplied with it. That suggests that they are reasonably satisfied. The analysis was confined to the responses from such users. The results suggest that they found the software reasonably attractive and easy to use but not exceptionally so.

Fischertechnik robot

Only four out of a total of fifty four holders of this device (ca. 7%) continued to use the software originally supplied. The analysis suggests however that these users are very happy with the package. Perhaps this suggests a happy little band of enthusiasts?

The majority of users had gone over to third party software. Of these, twenty six were using either PROF or ARM

PROF users expressed reasonable satisfaction with its user interface and ease of use. It was rated somewhat more highly than ARM software even though the latter has a graphical user interface.

ALFRED

Users who responded to this section had all continued to use the original software. This could either be because of the difficulty in obtaining some other programming environment or their reasonable satisfaction with the ALFRED package. Looking at the results of the analysis the latter reason seems the more likely.

BEASTY

Apparently a most aptly named device! Users of this robot seem to consider the quality of its software user interface to be less than mediocre and its ease of use less than average.

MENTOR

As for ALFRED, users of MENTOR all indicated continued usage of the original software. Again there may well be technical reasons for that. The responses suggested that whilst software was reasonably easy to use the user interface was not seen as being at all attractive.

Software summary

Overall the responses suggested a fair degree of user satisfaction with much of the software in use with robotics systems intended for school applications. MENTOR and BEASTY however stand out of the crowd with their low scores for the quality of their user interfaces. This indicates scope for improvements in these packages in particular.

Documentation

Most systems come with some sort of instructional paperwork. This may be no more than few sheets "to get you started" or may extend to a fulsome technical and educational manual covering aspects of hardware and software performance in depth as well as suggesting useful applications.

Again on a five point scale, respondents were asked to rate the paperwork supplied with each system for its standard of presentation, ease of reading and its structure.

The results of this part of the survey are shown as a block graph in figure 2.

In general none of the documentation supplied with the systems was rated highly. The paperwork supplied with the LEGO buggy was however consistently rated better than that for any other of the devices. Of those TREKKER and the Fischertechnik robot were seen as variable but with some good features whilst the documents supplied with ALFRED and MENTOR were rated only fair with BEASTY yet again bringing up the rear. (A revised manual has since appeared for MENTOR).

Specifications

It is difficult to draw comparative conclusions and state in a definitive manner which of these devices, if any, might be recommended as a "best buy". It is much easier to identify one or two which might best be avoided!

Not the least of the difficulties is that we are not comparing like with like in that the range of devices covers buggies as well as motorised arms more conventionally seen as robotics systems. One obvious need therefore is to define more closely that range of devices which can be useful in teaching about techniques of automation. Another is to draw up shopping lists as it were of desirable features in any educational robot.

To these ends a final section of the survey questionnaire gave respondents an opportunity to indicate the features which they would like to see in an educational robotic system.

It is not within the scope of this article to do justice to the responses to that section nor to the survey of pupils' opinions which followed. These aspects will be dealt with in Part II. It is however possible to draw some fairly firm conclusions from Phase 1 of the survey and these are presented as an overall summary.

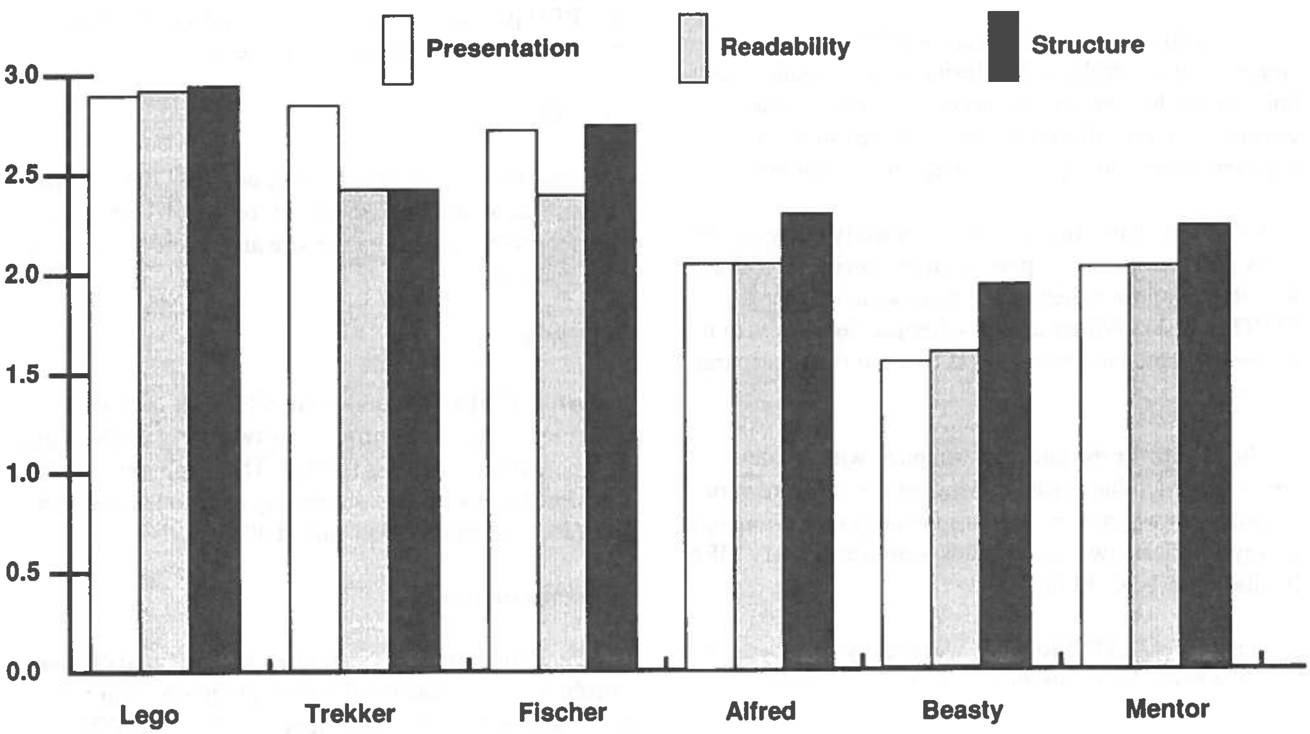

Fig. 2 - Ratings for quality of documentation

Overall summary

This survey revealed several significant problems attendant on existing practice:

- centralised purchase of robotics systems may result in the actual requirements of end users not being met;

- money invested in hardware and software has sometimes been wasted because of a lack of matching investment of time for familiarisation with devices and adequate training so that devices either remain unused or fall into disuse;

- the existing range of hardware is, with one notable exception, generally seen as being quite reliable, fairly easy to use but somewhat lacking in versatility;

- much of the software in use is judged reasonably satisfactory and attractive to use but within that there is a perception of considerable variability of quality across the whole range of available packages;

- the importance of good documentation should not be underestimated as a factor in classroom usage of robotics systems [6] and the resuts of the survey demonstrate that all of the systems could usefully be improved in this respect.

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Equipment Notes

Recirculatory fume cupboards

This section contains two articles.

The first describes the general features of recirculatory fume cupboards and provides technical and other guidance on their selection and use, for schools and non-advanced further education. The results of a recent testing and evaluation programme on four models are summarised. Detailed test reports on each model are also available on request. The second, shorter, article provides technical advice on alternative challenge tests. It deals with a current problem because of recent changes in the mode and cost of supply of sulphur dioxide syphons.

Introduction

Eight years ago we produced an Equipment Guide on ways to upgrade fume cupboards [1]. It contained, as an appendix, a test report on one of the suitable portable fume cupboards available at the time. This was of a ductless type now more commonly described as a *filter* or *recirculatory* fume cupboard[1].

Since then, more such models have become available and over the last year or we have been examining and testing those which are aimed at the schools market. The four models on which we report here are :

- *the Astec Environmental Systems SL*
- *the Erlab 806E.50*[2]
- *the Labcaire T300*[3]
- *the Safelab Blue Airone*

General principles

With the pressure to meet the requirements of legislation, particularly the need to provide adequate control measures (COSHH Regulation 7), there has been a flurry of activity in upgrading existing fume cupboards and in some cases providing cupboards where previously there were none.

1 For the purposes of this article we shall use "filter" as shorthand both for the fume cupboard type and for the filtration system (even though that may consist of more than one element).

2 This has a metal rear panel. The 806E.50 EC is similar but has a clear acrylic rear panel.

3 The recently launched T300-D is similar but has a higher sash opening and a more powerful fan.

Advantages

In such situations the recirculatory or *filter* type seems to be an attractive option mainly because of the lower capital outlay and the fact that it simply has to be plugged in. This removes the need for vast building works to fit a duct which may be very expensive and time consuming. This is especially so where the laboratory is on the ground floor in a building, with several floors above it.

Recirculatory cupboards have other advantages over fixed, ducted types. These include:

- the greater all round visibility allows the class to see a teacher demonstration experiment through the clear rear panel. In front of a traditional cupboard the teacher will obliterate most of the view;

- the lower initial cost; the prices of three of the models reported on are around the £2000 mark instead of a minimum of £5,000 to £6,000 for a ducted cupboard and extract system. It is true that replacement filters at £200 to £400 each are needed every four or five years and pre-filters more often. There will also be the cost of the gas detector tubes used, about £4 per year;

- the mobility of the cupboard; the trolley version can be shared between different labs and prep rooms;

- a saving in room heating costs; since the air drawn into a filter cupboard is recirculated, fresh air does not have to be drawn in from outside in order to replace it[4].

4 The make-up air drawn in by a ducted fume cupboard, with for example a sash opening 1 m wide by 0.5 m high and face velocity of 0.5 m s^{-1}, needs (0.3 x ΔT) kW to warm it up to the temperature of the room where ΔT is the difference between the inside and outside temperatures. This could easily amount to 200 kW hours per year or 1000 kWh over the expected life of a filter. The saving can be set against the cost of a replacement filter.

Disadvantages

Recirculatory fume cupboards have some disadvantages which also should be recognised:

- they are not suitable for handling very toxic volatiles in other than very small amounts or with low rates of release even when the filter is new;

- additional work in monitoring and maintenance is needed to check that the filter is still efficiently adsorbing gases and vapours;

- managerial supervision of the use of the cupboard is needed to ensure that

  (i) those chemicals which are poorly adsorbed are not released in large quantities and

  (ii) that the filter is not used beyond the point where breakthrough has occurred.

At present there is no particular problem in disposing of used filters as most Environmental Health Officers do not view used filters from school cupboards as *hazardous waste* in terms of the Environmental Protection Act and the Control of Pollution Act. Thus they can be disposed of with ordinary refuse. We would suggest that the used filter is wrapped in a polythene sheet (keep the bag it was supplied in) and placed with ordinary waste. If these filters subsequently are disposed of as landfill, then what would have been atmospheric pollution has been replaced by an extremely slow leaching to land and ground water.

Principles of operation

The fan drags the pollutants and air in the plenum chamber through the filter which adsorbs virtually all of the pollutants (Fig.1 - (a) top filter, (b) - filter in base).

The low concentration of pollutants in the exhaust is expelled with force into the room, thereby being further diluted by mixing with the room air. One manufacturer claims "zero emissions", but in practice although the efficiency of capture is often of the order of 99.9% or higher, it clearly cannot be 100%, since the pollutants can be detected in the exhaust air during the challenge tests.

It is probably more accurate, and safer, not to view these devices as fume cupboards, which we traditionally think of removing all the fumes to the outside. Rather they are but effective attenuators of the concentration of the fumes and pollutants.

For example, a filter with an efficiency of 99% will reduce a steady state concentration of 1000 ppm inside the cupboard to 10 ppm in the exhaust air. Trustfully this will be below the Occupational Exposure Standard (OES) for the gas concerned[1]. This already low concentration in the exhaust will be further diluted with the room air. The filter fume cupboard therefore is best regarded as a source with a very low rate of release into the room.

The filters have very large surface areas, certainly well in excess of 10 km^2 and are excellent adsorbers. However even this surface will eventually become saturated and the filter will need to be replaced before that point is reached.

Since most releases in schools are for short periods only and at low rates, it is most unlikely that the concentration in the room ever approaches the OES for any relevant gas. However if releases are lengthy, say during a project, then it is important to realise that the capture rate is not 100%.

1 Occupational Exposure Standard (OES) - this is the concentration judged to be capable of being breathed by most persons for a 40 hour working week, for 40 years of their life, without adverse effect to their health. It is really a guideline to what can be regarded as an acceptable level.

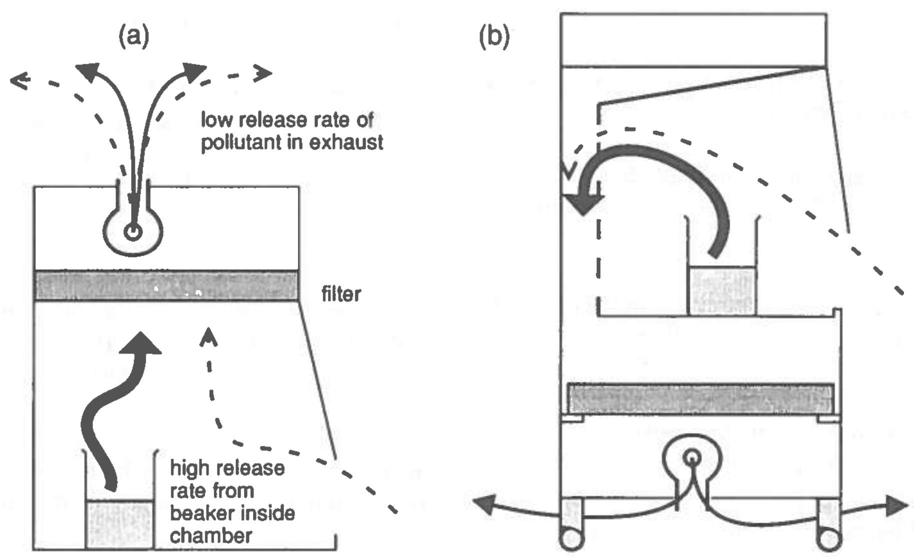


Fig. 1

Rate of release in cupboard (cm^3 s^{-1})	Efficiency of filter (%)	Rate of release in exhaust from filter (cm^3 s^{-1})	Concentration in ppm in room (300 m^3 with four air changes per hour) after specified time: 1 min	5 min	15 min	30 min	60 min	t_∞
50	0	50	10	43	95	130	148	150
50	50	25	4.8	21	48	65	74.5	75
50	80	10	1.9	8.5	19	27	29.5	30
50	98	1	0.2	0.85	1.9	2.7	2.95	3
50	99	0.5	0.1	0.4	1	1.3	1.47	1.5
50	99.9	0.05	0.01	0.04	0.1	0.13	0.147	0.15

Table 1 - Aerial concentrations of ammonia at various times from onset of release and for varying efficiencies.

The example in Table 1 above should make the point. If ammonia was being released at the rate of 50 cm^3 of vapour per second inside the plenum, the rates of release into the room for filters of different efficiencies are shown in column 3 and the concentrations at various times in a ventilated room can be calculated using the ready-reckoner provided in Appendix 6 of the SSERC *Yellow Book* [2].

The first row with an efficiency of zero corresponds to doing the experiment on the open bench or in a fume cupboard from which someone had removed the filter! The next two rows (efficiencies of 80 and 50 %) might represent well used filters whose capacities were being approached.

Fifteen minutes or less is a typical time of release and a glance down this column reveals:

- how dangerous it can be to use a filter which is approaching saturation. This reinforces the need for regular monitoring.

- how low the concentration of pollutant in the room air can be, even after a long time, if the filter has a high efficiency.

Note that the ready-reckoner in Appendix 6 of the SSERC booklet on Risk Assessments [2] is for a 300 m^3 room with 4 air changes per hour. Some modern labs with low ceilings might have only half this volume. The concentrations in such laboratories will simply be double those shown in the table.

If the substance being released has a much lower OES, e.g. chlorine with an 8 hour OES of 0.2 ppm, then even a low release rate of 5 cm^3 s^{-1} in a cupboard with a 98% efficient filter will result in the room concentration reaching the OES in just over 15 minutes.

In industry, or in particular medical applications, the filter is often designed to take out only one particular substance or family of substances. However in an educational laboratory the cupboard will have to deal with a wide range of chemicals and the filter for this purpose is usually a composite of at least three layers.

The main component of all layers is charcoal, which is particularly good at taking out solvents, though it will also have some capacity for inorganic acids and for ammonia. Some of the layers are specially treated to take out particular compounds, eg one impregnated with sodium hydroxide removes and holds acids well.

It is important to ensure that your cupboard is fitted with a filter which is appropriate for the chemicals used. If in doubt check with the manufacturer.

One pay-back for having a multipurpose filter is that the retention capacity for each class of substance is considerably less than that provided by one designed for a single substance.

Evaluation and test criteria

To obtain a measure of the overall effectiveness of this type of fume cupboard we have to consider the following major elements:

- performance, within which fall aspects such as efficiency of capture; face velocity and containment;

- other safety aspects such as electrical circuitry, stability and fire risks from the filter itself;

- ease of use, which covers mobility, internal services, opening size and work surfaces etc.

Performance

Efficiency

The efficiency of capture is measured for a variety of chemicals. This is done by releasing the chemical inside the cupboard at a known rate (mg s^{-1} or cm^3 s^{-1}) and measuring the concentration of pollutants in the exhaust air with gas detector tubes (we currently use those made by Draeger). The uncertainty in the reading of these tubes in nearly all cases resulted in an error of ± 0.1% or less in the calculated percentage capture.

Solvent vapours or hydrogen chloride are released by boiling gently some of the liquid, weighing before and afterwards, timing the operation. Clearly it is not always easy to arrange for a particular value for the release rate. Sulphur dioxide and hydrogen chloride were released at both high and low rates.

All of the cupboards passed these tests (Table 2 below) and each provides adequate attenuation of the concentrations of the fumes and vapours, but as can be seen, there are some differences. It is only fair to point out to readers that two of the cupboards had quality control problems which greatly reduced the apparent filter efficiency.

The first set of filters sent with the Blue Airone had very low efficiency. Another contribution to low overall efficiency was an unwelded joint in the metal casing, which allowed fumes to bypass the filter. The second batch of filters were satisfactory; the manufacturer stated that the flaw had only happened in one batch.

In addition a specific design feature can contribute to the same problem. The Blue Airone was the only one of the four cupboards not to have guides which help to locate the filter correctly with a good overlap on the seal.

cont./p.18

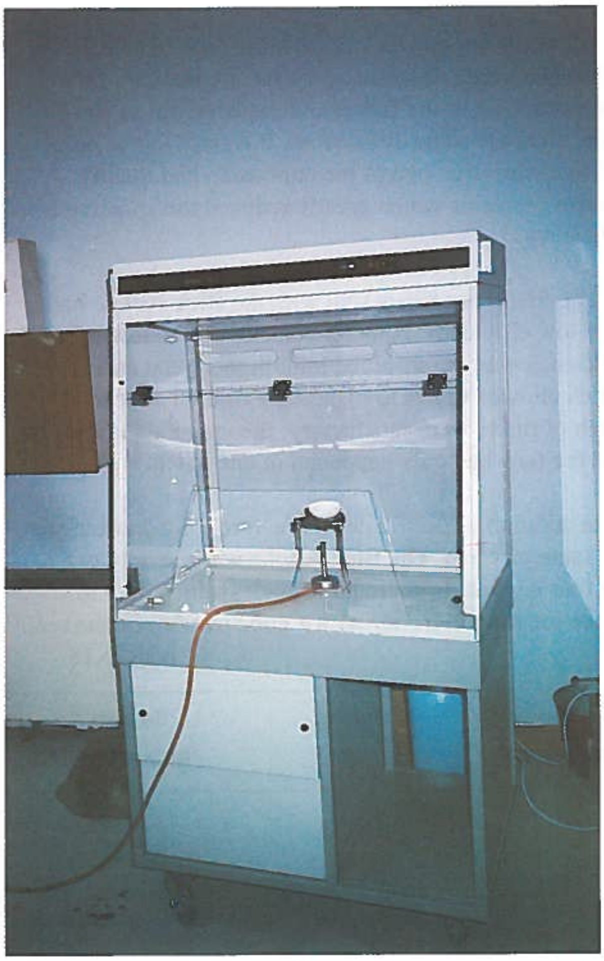
Cupboard manufacturer	Astec		Erlab		Labcaire		Safelab	
Model	SL		806E.50		T300		Blue Airone	
Filter efficiency								
Sulphur dioxide								
rate of release (mg s^{-1})	29.0	68.2	30.6	134.8	26.2	95.5	33.9	136.4
efficiency of capture (%)	99.3	98.1	98.9	98.5	99.5	99.1	98.6	99.4
Hydrogen chloride								
rate of release (mg s^{-1})	20.3	78.6	32.8	34.6	28.7	111.5	27.9	41.8
efficiency of capture (%)	99.9	99.8	99.9	99.9	99.8	99.9	98.3	96.7
Ammonia								
rate of release (mg s^{-1})		39.6		78.5		32.2		49.2
efficiency of capture (%)		99.3		99.9		99.9		97.2
Methylbenzene								
rate of release (mg s^{-1})		124.5		225.6		91.2		120.5
efficiency of capture (%)		98.8		99.9		99.7		97.1
1,1,1-trichloroethane								
rate of release (mg s^{-1})	105.7	576.4		283.6		325.9		237.5
efficiency of capture (%)	99.6	98.4		99.4		98.4		97.5
Face velocity (m s^{-1})		0.41		0.46 (0.71)		0.46		0.36
Containment and smoke test		pass		pass		pass		pass
Filter mass (kg)		14		15		18		15

Table 2 - Fume cupboard performance

Model : SL

Manufacturer : Astec Environmental Systems Ltd.

Agent/Supplier : Direct from above



Dimensions	1840 x 990 x 700 mm (H x W x D) (external)	
Construction	acrylic glazing on epoxy coated steel, enclosed cupboard underneath	
Services fitted as standard	fluorescent lights, 2 x 13A sockets	
Work surface	glass reinforced plastic (GRP)	
Price including trolley & filter		£2183
Optional extras	- drip-cup, water tap, connecting hose & drain	£213
	- gas taps & connecting hose (quick release couplers)	£113
Delivery		£75
Replacement filter (14 kg)		£189
Prefilters (pack of 10)		£84

Model : 806E.50

Manufacturer : Erlab DFS

Agent/Supplier : Bigneat Ltd

Dimensions	bench mount 1125 x 845 x 630 mm (H x W x D) on trolley 2025 x 845 x 630 - 900 mm trolley but lower trolleys are available	
Construction	acrylic glazing with corner stiffeners of steel set on tray; head filter unit sitting on top	
Services fitted as standard	one 13A socket but low wattage only	
Work surface	6 mm toughened glass	
Price including trolley & filter		£3298
As above fitted with drip cup and gas tap but with pvc work surface and no connecting tubes		£3398
Delivery :	carriage at cost	
Replacement filters 2 x 7.5 kg needed		£407/pair
Prefilter (1)		£25

Model : T 300-D

Manufacturer : Labcaire Systems Ltd

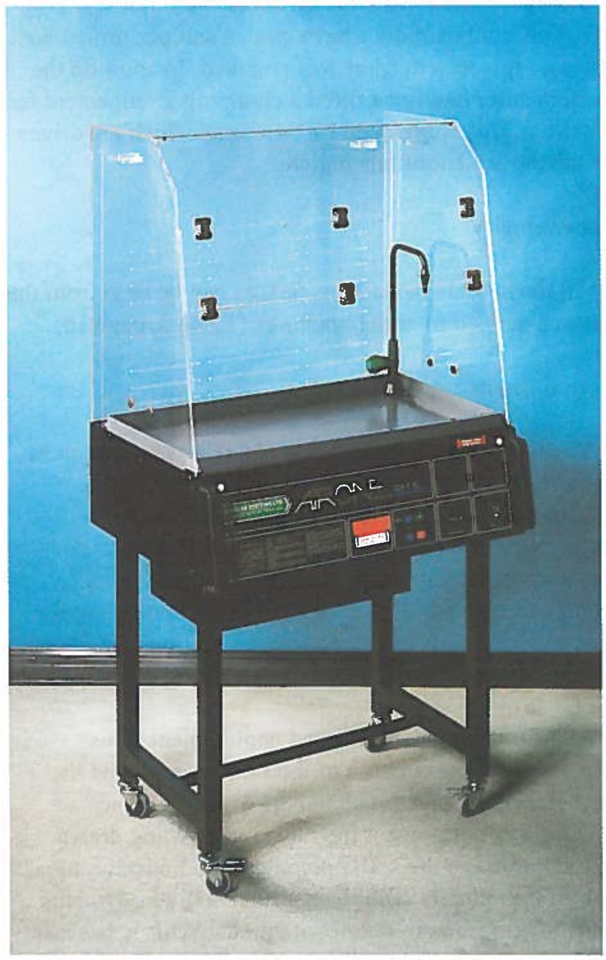
Agent/Supplier : McQuilkin & Co

Dimensions	1850 x 1040 x 700 mm (H x W x D) (external)	
Construction	acrylic glazing on epoxy coated steel, enclosed cupboard underneath	
Services fitted as standard	fluorescent lights, 2 x 13A sockets	
Work surface	glass reinforced plastic (GRP)	
Price including trolley & filter		£2165
Optional extras	- drip-cup, water tap (remote control), connecting hose & drain	£182
	- gas tap (remote control) & connecting hose (quick release couplers)	£98
Delivery		£95
Replacement filter (18 kg)		£195
Prefilters (pack of 10)		£75

Model : Blue Airone

Manufacturer : Safelab Systems Ltd

Agent/Supplier : Direct from above



Dimensions	1616 x 840 x 650 mm (H x W x D) (external)	
Construction	acrylic plenum set on filter unit housed in open epoxy coated steel trolley	
Services fitted as standard	none	
Work surface	stainless steel	
Price including trolley, filter & installation		£2284
As above fitted with drip-cup, water tap but on epoxy work surface, connecting hose & drain - gas tap, & 13A outlet		£2504
Delivery		£65
Replacement filter (15kg)		£345
Prefilters (pack of 12)		£109

Efficiency/ cont.

Safelab recommend that a challenge test be carried out on fitting a new filter before using it. They assured us that quality control is now improved and that the design will be changed, with guides being fitted in future models.

The first filter for the SL model also did not seal properly. This cupboard does have guides and performed well when a replacement filter was received. In addition the manufacturer has since fitted a clamping arrangement for the filter. This is operated by two cams which are driven by the movement of one handle.

Face velocity

All the models passed this test, as can be seen from the values averaged over the openings (Table 2, page 15).

Containment

Tests for containment meant checking that no fumes leaked back out through the opening in the sash or through any other cracks, etc. This was done by measuring the concentration of sulphur dioxide at an operator's breathing zone when the valve on a syphon inside was opened. Observing the movement of smoke from smoke pellets and from the preparation of aluminium chloride provided further useful evidence.

All four cupboards had good containment. This depends on a combination of the face velocity and the geometry of the plenum chamber. A very low face velocity will not prevent the fumes from being drawn back out through the sash opening. Paradoxically, too high a face velocity combined with a non-aerodynamic shape often results in poor containment. This is because of the turbulence and vortices set up.

Filter life span

The mass of the filter will give some overall estimate of the total retention capacity, though probably not of how it is apportioned between the different classes of compound or pollutant types.

It is not easy to give a comparison of the lifespans of different filters as this will depend on both:

(i) the amount of use and hence on the total load of different chemicals adsorbed by the filter and

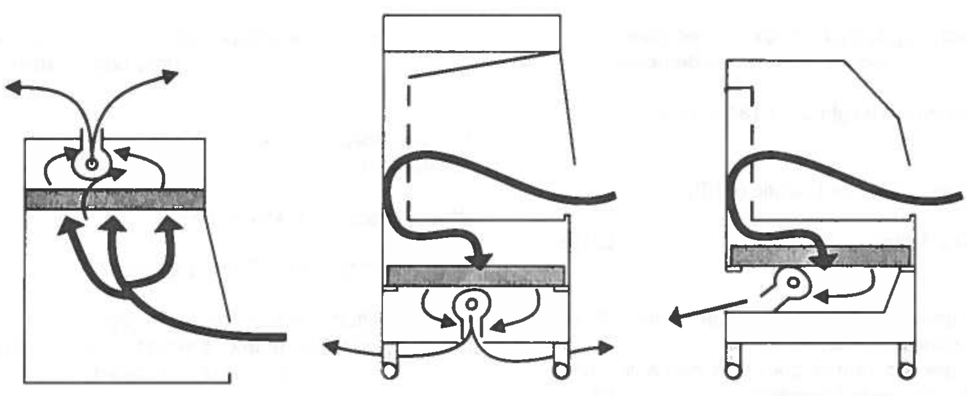
(ii) on the *retention capacities* of each filter for each of the classes of chemicals released.

Figures for the latter would be useful indicators of the relative lives of filters, but we are far from satisfied that the basis of measurement of retention capacities supplied by the different manufacturers was the same. Publishing these figures would be misleading and would be unfair to those manufacturers who had the measurements made on a fair basis.

As explained above there is some overlap in the selectiveness of each filter layer and it can be a case of robbing Peter a little to pay Paul. That is, if the quota for acids is slightly exceeded then the capacity for solvents will be reduced a little.

Exhaust direction

The 806E.50 cupboard with the filter and fan above the chamber directs the attenuated fumes upwards at the ceiling, so that they are very well mixed with the laboratory air before reaching people's breathing zones (Fig.2(a)). The SL and the T300 blast the fumes downwards at the floor. From there they will spread outward in all directions (Fig. 2(b)).



(a) (b) (c)

Fig. 2 - Direction of exhaust air (a) Astecaire 806E.50 EC (b) SL and T300 models (c) Blue Airone

The Blue Airone directs the fumes backwards and downwards at roughly 45 degrees; this will blow the exhaust fairly directly at any pupils sitting behind to watch a demonstration (Fig. 2(c)).

Effect of heat on filter

The filter of the 806E.50 is above the chamber and would be badly damaged if a bunsen were accidentally left on without the fan running. The column of very hot air may burn a path through the filter. The other three cupboards do not suffer from this problem, though the acrylic glazing ceiling on the small Blue Airone gets very hot and creaks! It would obviously be bad practice to leave a burner on without the fan running. None of the operating instructions carry a warning to avoid this.

Electrical Safety

All of the cupboards were inspected and tested for compliance with the common international standard for laboratory equipment etc (IEC 1010 [4]). What faults were found were few and minor in nature. All of the manufacturers who had such faults indicated to them undertook to make the necessary simple modifications in future production.

Examples were the slightly high chassis-to-earth resistance in the 806E.50 and a loose mains IEC chassis plug (male input socket) in the same model.

Stability

The three cupboards with the filter under the work surface were very stable. The Blue Airone was the most stable and the one most easily manouvered. The head containing the filter housing etc. on the Erlab model weighed 45 kg. yet the bench mounted model tested by us was stable when tilted through 10 degrees. We are more than a little concerned that this heavy head just sits on the four walls without any means of fastening, especially when the trolley-mounted version is considered.

Fire risks

It might seem reasonable to worry that a filter containing a few litres of a flammable solvent might present a serious fire risk. We have had reports from other test labs who saturated filters in flammable solvents, allowed them to air dry and then played a bunsen flame on them. No ignition of the solvent occurred and the only thing that burned was the plastic casing of the filter.

These results somewhat allay our own concern.

Mobility

All of the models tested are available in trolley form with lockable front wheels. The three with the under-bench filters are all less than 1840 mm in height and will easily go through the modern 2 metre high laboratory door. On the standard trolley base supplied, the 806E.50 is just over 2 metres tall but a trolley customised to less than the standard 900 mm can be ordered. The operating instructions for the 806E.50 state that if the bench top model is moved, the 45 kg head (or 30 kg without the filter) has first to be removed and then replaced. The Blue Airone is the smallest and most manoeuvrable of the four.

One nice idea on the T300 is the revolving rubber bumper on each of its corners; this will save much paintwork from damage.

Services

Electrical outlets

The SL and the T300 are fitted with two 13 A sockets as standard. The single socket on the 806E.50 is really there to allow you to fit the optional extra lamp; it can be used for low power devices, like stirrers and many instruments, but not for hot plates.

Water, gas and drainage

When these services are fitted as optional extras, the SL and the T300 have armoured hoses with quick release couplings. These can be fitted or undone in seconds. They have a self-sealing socket which will fit on a *T* piece plumbed in to the existing water and gas supplies close to the areas where the cupboard is to be used. The drain outlet tube can also be fitted in a similar way. The T300 has a separate under-bench space to store these umbilicals when they are not in use.

These service options on the Blue Airone and the 806E.50 models are not normally supplied with armoured connector tubing, but it can be specially ordered.

On the T300, the controls for the gas and water are remote, mounted on the outside of the front panel, but the taps on the service options for the other cupboards are directly on the taps inside.

If there is a gas tap at the cupboard, the umbilical tubing should be of the armoured type with a self-sealing connector; for if the cupboard is mobile accidental movement will put strain on the tubing and may disconnect it, resulting in a flood of water or large leak of gas.

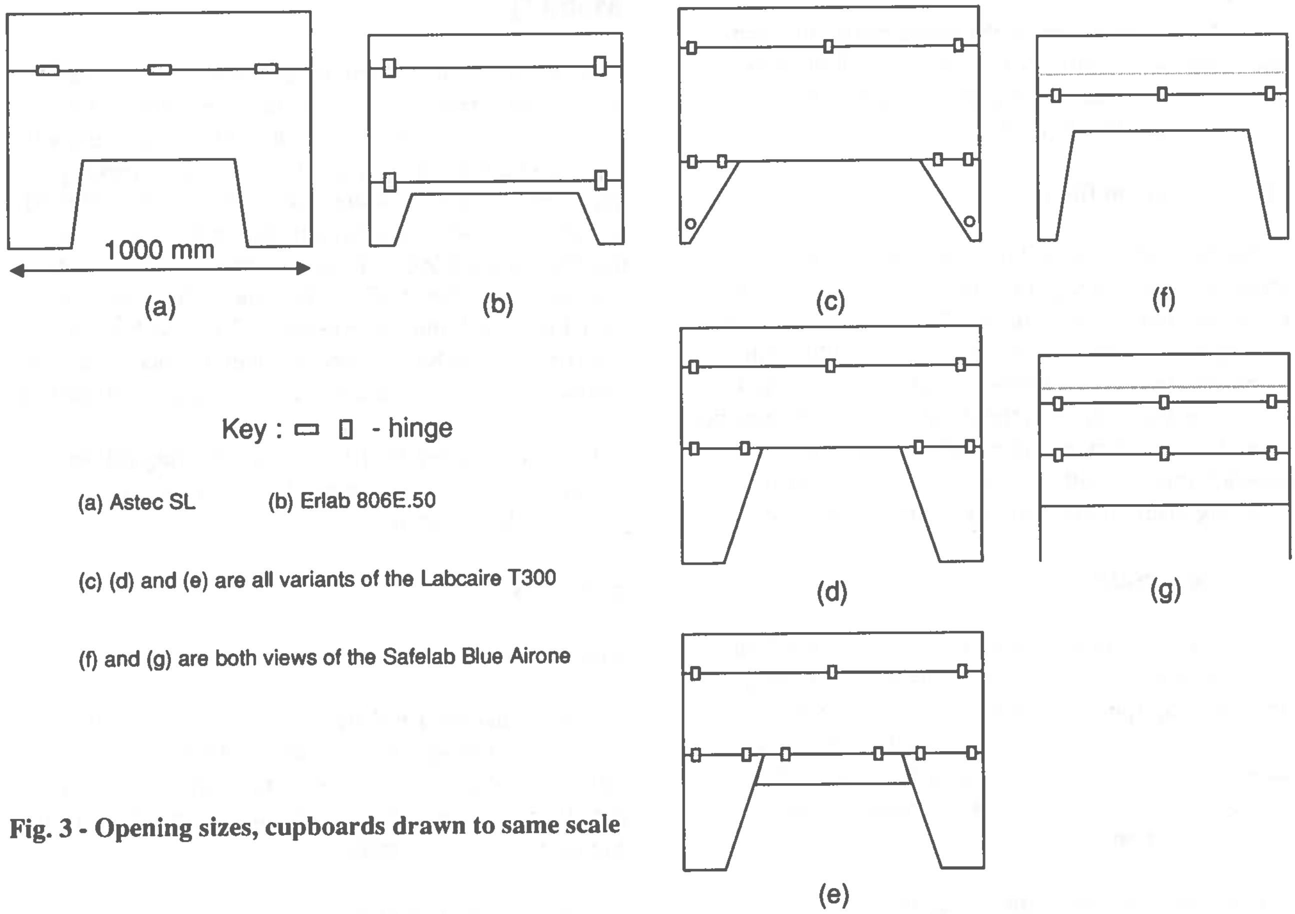


Fig. 3 - Opening sizes, cupboards drawn to same scale

Openings

The style and size of the openings vary greatly as seen in Figure 3 above.

Design Note 29, [3] written mainly for ducted fume cupboards with sliding sashes, states that the height of the bottom edge of the sash above the working surface at the maximum working opening should be at least 400 mm. This is to allow the handling of tall apparatus and yet provide some protection for the operator's face. The sliding sash can and should be lower than this during an experiment to afford more protection and better containment, but not so low that the resulting increased face velocity blows out bunsen flames.

The minimum openings in the front panels of the SL (Fig.3 (a) [340 mm]) and in the Blue Airone (Fig.3(f) & (g) [360 mm]) allow the manipulation of fairly tall apparatus at the cost of some of protection for the operator. The T300 version shown as Fig.3(c), the 806E.50 (b) and the Blue Airone version shown as (g) all have much lower openings. These offer more protection and probably better containment at the expense of ease of manipulation of apparatus. However the height of the opening on the last two can be greatly increased by hingeing back the upper flaps. The T300 D variant shown as Fig.3(e) provides the advantage of both worlds.

Work surfaces

The largest work surface areas are to be found in the SL and the T300. Made in the form of a glass reinforced plastic (GRP) tray with moulded lips round the edges they also act as spillage trays. The GRP tray is very serviceable and resistant to most chemicals, provided the time of exposure is not too long, but would be damaged by a red hot crucible. However, on both these models, it is easily slid out for cleaning or for replacement.

The stainless steel tray on the Blue Airone is the smallest and the toughest but, as is well known, stainless steel seldom lives up to its name. The tray is dished and will provide good containment for spillage.

The 6 mm toughened glass work surface on the model 806E.50 will be the most resistant to chemicals. A tray underneath it is both the structural base and a spillage tray. The glass is very robust and a tripod could be repeatedly knocked over without any damage to the surface.

The larger sizes of work surface of the SL and the T300 make these two models a little less manoeuvrable, but the larger area means less congestion and therefore makes for greater safety in handling equipment and materials.

Filters

Two filter related factors impinge on ease of use. These are the ease of carrying out efficiency monitoring and of filter replacement.

Both operations are physically easier for the three cupboards whose filters are located under the work suface. They are simply slid in between two guides in the SL and the T300, but on the Blue Airone four thumb-screws have to be undone to release the filter.

The overhead filter in the 806E.50 model is in two parts, which makes reasonable what would otherwise be a very difficult manual handling task.

A suitable and stable stepladder or other platform is needed for monitoring the filter efficiency of the Erlab 806E.50, but for the other three the operation is much more convenient. For the Blue Airone the gas detector pump only needs to be held against the exhaust. For the SL or T300 it is inserted into a special port in the rear.

Alarms

Some other models have fitted, as an optional extra, a solid state gas detector which will give a warning when breakthrough occurs. Whilst these sensors are very convenient, they are not equally sensitive for all the gases likely to be used. Even where they are fitted, filter monitoring still has to be done with a gas detector tube.

Abnormal flow rates

Abnormally low air flow obviously will impair the operation of a cupboard and they may arise because, say, of a partially blocked filter. Alternatively, too great an air flow will occur should the filter be absent or just badly seated.

The main filter will probably last 4 to 5 years given the normal rate of usage but the prefilter, which is designed to remove dust and fume particles, will become partially clogged and have to be replaced much more often. One way of knowing when this stage has been reached is an observed drop in the face velocity.

An excellent and simple device on the Erlab 806E.50 model was the permanently fitted *Dwyer flap* type anemometer which, though not highly accurate, provides useful indication of the air flow rate.

The SL, T300 and Blue Airone models however all have pressure transducers between the filter and the fan. This is intended to detect a fall in the speed of the airflow and indicates a warning in the form of a light or sound.

The SL and the T300 alarm systems will also give a warning if a filter is absent or a filter seal broken.

Instructions

Whilst there are differences in the detail of operating instructions, in all cases they give sufficient information to enable the installation and, where relevant, assembly of each model of cupboard. The SL and the T300 come ready assembled, only requiring the wrapping to be removed and the filter and pre-filter fitted before plugging in. The other two come partly in *flat-packs* rather like some kitchen furniture.

The main differences in the operating instructions include :

(i) details on which gases the filter will adequately adsorb.

Erlab's operating instruction booklet for the 806E.50 model has a very full list of chemicals and marks some of them as being not suitable for use with the cupboard. This booklet is aimed at the wider industrial market and refers to continuous releases. The UK supplier, Bigneat, stated that most of those marked as being unsuitable for use can in fact be used safely for small scale work.

The other three suppliers in their instructions present a list of some 13 or more chemicals commonly used in schools along with a list of efficiencies of capture for those chemicals. Warnings are given that low molecular mass substances like hydrogen or carbon monoxide are not well adsorbed. Although ammonia is of low molecular mass, it is well adsorbed because of the special impregnations made on one of the layers.

(ii) user-friendliness

The various instruction booklets etc[1]. vary in ease of comprehension particularly with respect to the described methods for monitoring the efficiency of filters. Those for the T300, the SL and the Blue Airone, supply full details of the release rate to be used, eg the rate of bubbling of sulphur dioxide or the mass of a particular solvent to be boiled off in a specified time. They all also give pass/fail concentrations for the exhaust.

Those for the 806E.50 model though, are more comprehensive and at the same time less empirical or simple. The instructions for this model recommend that when the steady state concentration of that pollutant inside the enclosure is 200 ppm, the concentration in the exhaust of a chosen test pollutant should not exceed 1/100 th of its OES or MEL. Those with the necessary back-ground knowledge could, no doubt, readily calculate both a suitable release rate and pass/fail concentration for a given likely pollutant. But it would have been more helpful had these been given. Any owners of these cupboards who are

1 The Blue Airone has an abbreviated version of the instructions enamelled on the outside of the cupboard itself.

Overall Summary

All four mobile fume cupboards will be suitable for handling the usual practical work of the type and scale normally encountered in a school, though more care and planning will be needed for some project work if it requires longer releases of some gases.

There are differences in price, size, ease of monitoring, size of work surface and in the ease of making connections to water and gas supplies. In the stated optional extras only one model, the T300, has the gas and water controls on the exterior.

We would make the following overall assessments:

Astec	(SL)	A
Erlab	806E.50 EC	B[1]
Labcaire	T300	A
Safelab	Blue Airone	B[2]

Where A = most satisfactory for use in Scottish schools and non-advanced FE; B = satisfactory and C = unsatisfactory.

1. The efficiency of capture of the filter system in this model is very high. The lower rating is given however mainly on two grounds - relative pricing and the ramifications of having a filter above the chamber with the sole support being the chamber walls.

2. This B rating is conditional on the problems associated with the filter being fully resolved as we were assured they would be and that improved quality control will be maintained. In other circumstances this model would be rated C - unsatisfactory. B rather than A was awarded mainly because of a disproportionately large price for what is a relatively small cupboard.

References

1. *Fume cupboards in schools*, (SSERC) 1985.

2. *Preparing COSHH Risk Assessments for Project Work in Schools* [also known as The Yellow Book], (SSERC), 1991.

3. *Design Note 29, Fume Cupboards in Schools*, DFE, Architects & Buildings Branch, March 1982.

4. *IEC 1010, Safety requirements for electrical equipment for measurement, control, and laboratory use. Part 1 : General requirements*, International Electrotechnical Commission, 1990 and subsequent amendments.

Monitoring of recirculatory filters

Introduction

Sulphur dioxide has been routinely used as an acidic gas with which to challenge the relevant parts of the compound filters of recirculatory fume cupboards. Unfortunately the gas is no longer available in the relatively cheap form of a liquid under pressure in a syphon made largely of aluminium. It is now sold in containers of stainless steel. This has increased the price several-fold.

Alternative challenge tests

If you cannot afford nearly £150 for 500 g of sulphur dioxide, then another way of testing the efficiency of capture of acidic fumes every term will be needed. We have carried out trials of possible alternative methods, some of which were miserable failures. However the good news is that of those that worked, two were fairly straight forward.

Sulphur candle method

A scaled down version of an old method of greenhouse fumigation was used. The rate of sulphur dioxide formation seems to be roughly proportional to the surface area of the burning sulphur - some good kinetics or possibilities for a wee project here? At the smaller end of the scale this initial development work was done with the sulphur in a crucible suspended from a weighted cantilever arm which rested on the pan of a balance.

This allowed the burning sulphur to be inside the cupboard and the balance to be outside. The observed rate of sulphur dioxide production for a 15 cm^3 crucible was 0.3 g min^{-1} and fortuitously this is very close to the rate of sulphur dioxide release which is recommended for challenge testing - bubbling the gas at 2 cm^3 per second.

A tiny fraction of the sulphur will be given off as sulphur fume. Though too small in amount to have any noticeable effect on the results, it will pass through many of the filters and create a haze in the room.

The quantity of sulphur to cover the bottom of the crucible, about 2 g, burns for about the same time as it takes to measure the concentration of sulphur dioxide in the exhaust. Consequently there is no disposal problem. Should too much sulphur have been taken it is a simple matter to extinguish it by placing a cover or lid over the crucible. The same crucible can be kept for the same task the next term and be kept with the monitoring kit.

One bit of particularly good news is that the sulphur used in this test costs less than a tenth of the sulphur dioxide from the old aluminium canisters.

Hydrogen chloride

A 100 cm^3 evaporating basin of concentrated hydrochloric acid placed on top of a 250 cm^3 beaker of boiling water soon starts to release hydrogen chloride. Of five runs the rates of release were:

	mg s^{-1}
	27.9
	13.8
	26.4
	28.7
	<u>20.3</u>
Mean =	23.4 mg s^{-1}

This is approximately three times the challenge presented by the 2 bubbles per second of sulphur dioxide.

The concentration observed in the exhaust could simply be raised three times from that presently stated in the manufacturer's instructions for monitoring. At the end the acid can simply be poured into a large volume of water and neutralised before disposing to waste in a sink outside of the cupboard.

More details of these possible methods have been given to the manufacturers who will no doubt offer their own methods for monitoring filter efficiencies.

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Finite-element analysis : modelling resistor behaviour

The article introduces finite-element analysis, which is a mathematical method for modelling physical processes in complex structures. The method is applied to the spreading resistor R9 in the Semiconductor Materials Schools Chip in order to obtain a value for sheet resistance.

Introduction

In Chip 1, resistors R1, R2, R3, R5, R6 and R7 all consist of p-type doped silicon of uniform dopant density and depth. Their surface dimensions relate by simple proportion. For instance length varies by a 1 : 2 ratio, width by 1 : 2 : 4 : 8 ratios and area by 1 : 2 : 4 : 8 : 16 ratios (Fig.1).

It can be useful to think of each resistor as comprising of a series of square cells of silicon (Fig.2). This leads to the surprising concept of sheet resistance wherein different square samples of resistor material of whatever size all have the same resistance provided that the depth and material type don't vary.

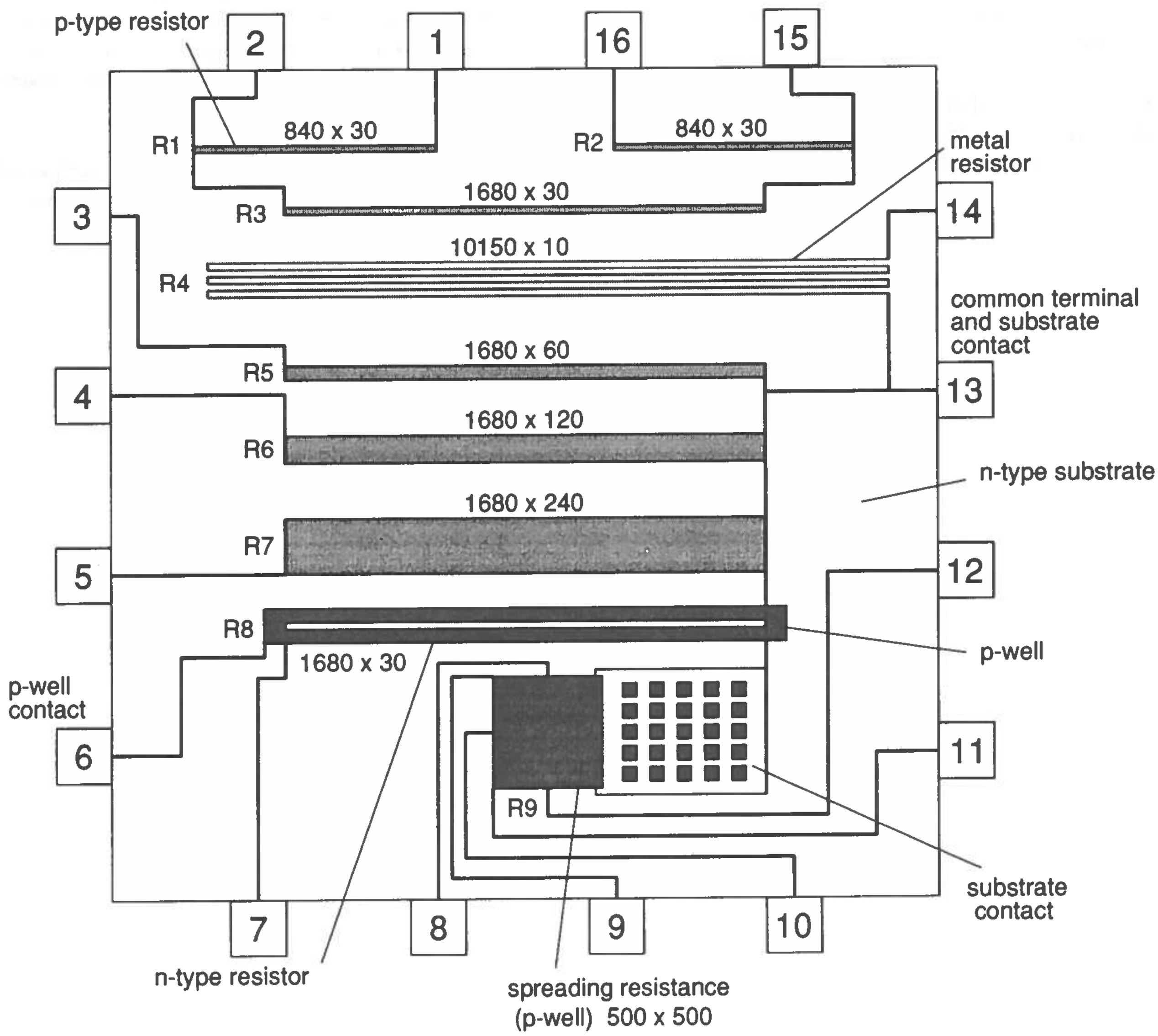


Fig. 1 - Physical layout of resistors in Schools Chip 1, dimensions in microns

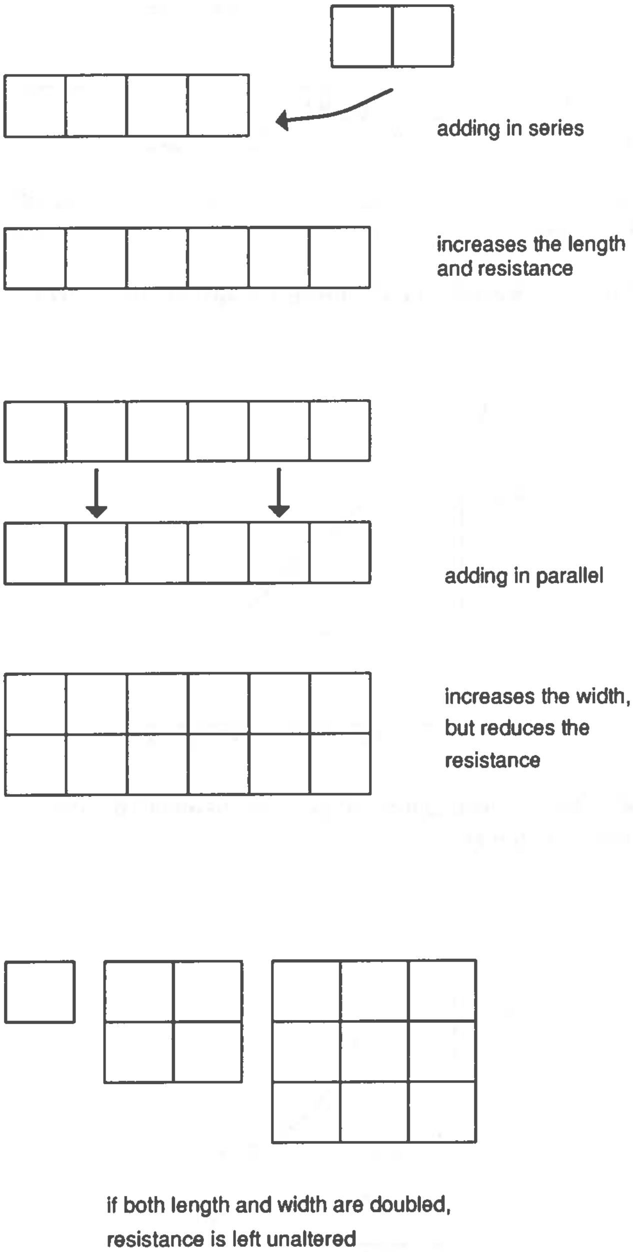


Fig. 2 - Sheet resistance concept

Resistor	Length l (µm)	Width w (µm)	Number of squares	Resistance (Ω)	Sheet resistance (Ω/sq)
R1	840	30	28	1130	40.4
R3	1680	30	56	2260	40.4
R5	1680	60	28	1130	40.4
R6	1680	120	14	565	40.4
R7	1680	1680	7	283	40.4

Table 1 - Sheet resistance of heavily doped p-type silicon resistors in Schools Chip 1

The sheet resistances for all six above resistors work out to the same value of 40.4 Ω/square (Table 1). One purpose of this article is to show how the sheet resistance of one of the other resistors on the Semiconductor Materials Chip, R9, can be obtained. Once this value is known, the Hall effect can be utilized either to obtain a value for the bulk mobility of holes in silicon[1] or, if a value for mobility is assumed, to obtain an absolute measurement of magnetic induction. But explaining how to go about that is meat for another article.

The spreading resistor R9 comprises of a square of lightly doped p-type silicon measuring 500 µm by 500 µm. There is an external electrical contact to one of the edges of R9, and external point contacts to each of the other corners and to the centres of each of the other edges (Fig.3). These contacts are labelled by the pin-out numbers on the chip DIL package.

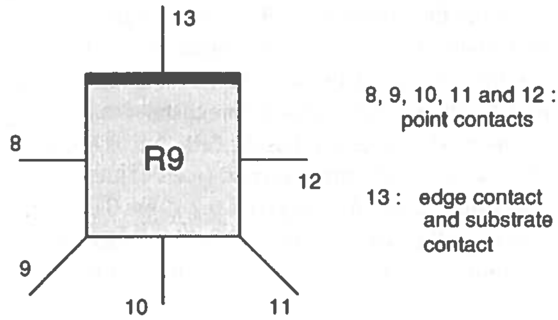


Fig. 3 - Edge and point contacts on square resistor R9

Unlike the other resistors on Chip 1, it is not possible to measure the sheet resistance of R9 directly. This is because R9 does not have a pair of edge contacts on opposite sides of itself. What you have to do is to allow current to pour into R9 from its edge contact and to drain away from one or several of its point contacts. The non-uniform flow of current produces a non-linear potential gradient across R9. From analysing this, a value for sheet resistance can be obtained.

[1] Because R9 is composed of p-type silicon, the mobile charge carriers are holes.

Finite-element analysis

This offers an easy mathematical means of solving problems that otherwise, by traditional ways, would be rather difficult. The physical structure under analysis is broken down into lots of little cells. Some particular boundary cells are assigned fixed values. All the other cells are left to float to whatever value they want to, subject only to the constraint that the value of a floating cell is the average of the values of its neighbouring cells. The modelling is done on a spreadsheet. The values of each cell are computed by turn. When values for all the cells have been computed once, you return to work them out a second time, and then a third, and so on until all the values stabilize and do not register changes between computa-tion cycles. This process is called *iteration.*

To see how the method works, let's start with a simple example where the outcome is well known. Suppose you were to model the potential gradient in a length of uniform resistor material such as a piece of resistance wire. Let the p.d. across the wire be 10 V. You then make up a model with a single column spreadsheet that has 21 rows[1]. The model therefore has 21 cells A1, A2, etc. to A21. The two end cells are assigned fixed values; *A1* is given the value 10.00; *A21* is given the value 0.00. Each intermediate cell is assigned a value midway between its two adjoining cells. For instance the function for *A2* is

$$A2 = {}^1/_2(A1 + A3)$$

However this step requires to be justified.

You could argue from an empirical viewpoint that averaging is obviously correct. It is well known from straight wire potentiometry that the potential gradient along a uniform wire is constant provided that self heating is negligible.

A theoretical argument is harder to construct - but here goes! Suppose you were to measure the electric current at two points in the circuit, the point where current enters the resistor, and the point where it leaves the resistor. Both measured values of current will be identical, or at least within the reading error range of your ammeter. Therefore it follows that the number of mobile charge carriers entering the resistor is equal to the number leaving per unit time. The net charge in the resistor is therefore zero. It then follows that the potential gradients within localized parts of the resistor are linear because non-linear gradients are associated with non-uniform distributions of charge (Figs. 4 (b) and 4(c)).

1 Any reasonable integer would do. By picking an odd number such as 21, the number of inter-cell boundaries is even and is closely related to our decimal numbering system. Also, when you come to test the theory by measuring the voltages on point contacts on the centres of edges, an odd cell number provides you with a mid-edge value.

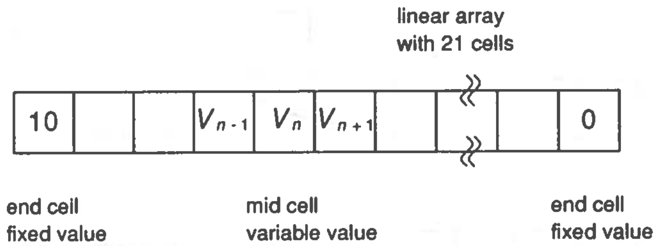


Fig. 4a - Resistor model using 1-d spreadsheet array

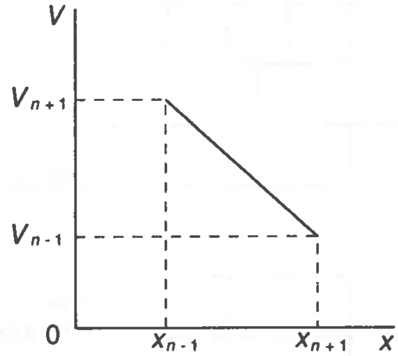


Fig. 4b - Linear potential gradient associated with zero net charge

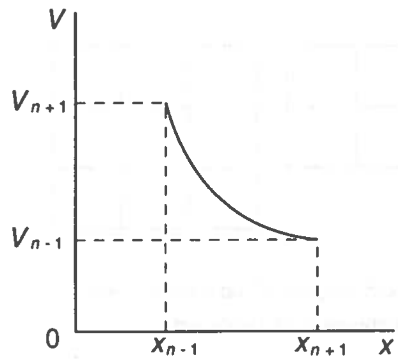


Fig. 4c - Non-linear potential gradient associated with non-uniform distributions of charge

Therefore intermediate values can be found by averaging:

$$V_n = {}^1/_2(V_{n-1} + V_{n+1})$$

The initial values taken by the cells are shown in Fig.5. At this stage only the values of A1 and A21 are of consequence. The actual values of intermediate cells at this first step of the computation are of no eventual consequence.

	A
1	10
2	7.50
3	5.00
4	5.00
5	5.00
6	5.00
7	5.00
8	5.00
9	5.00
10	5.00
11	5.00
12	4.99
13	4.98
14	4.96
15	4.92
16	4.84
17	4.69
18	4.38
19	3.75
20	2.50
21	0.00

1st iteration

	A
1	10
2	8.12
3	6.25
4	5.00
5	5.00
6	5.00
7	5.00
8	5.00
9	5.00
10	4.99
11	4.98
12	4.97
13	4.94
14	4.89
15	4.80
16	4.65
17	4.38
18	3.91
19	3.13
20	1.88
21	0.00

2nd iteration

	A
1	10
2	8.44
3	6.87
4	5.62
5	5.00
6	5.00
7	5.00
8	4.99
9	4.99
10	4.98
11	4.96
12	4.94
13	4.89
14	4.81
15	4.67
16	4.45
17	4.10
18	3.55
19	2.73
20	1.56
21	0.00

3rd iteration

	A
1	10
2	8.63
3	7.26
4	6.09
5	5.31
6	5.00
7	4.99
8	4.99
9	4.98
10	4.96
11	4.94
12	4.89
13	4.82
14	4.71
15	4.54
16	4.27
17	3.87
18	3.28
19	2.46
20	1.37
21	0.00

4th iteration

	A
1	10
2	8.77
3	7.54
4	6.44
5	5.62
6	5.15
7	4.99
8	4.98
9	4.96
10	4.94
11	4.90
12	4.85
13	4.75
14	4.62
15	4.41
16	4.10
17	3.67
18	3.06
19	2.26
20	1.23
21	0.00

5th iteration

	A
1	10
2	9.15
3	8.30
4	7.49
5	6.76
6	6.13
7	5.63
8	5.26
9	5.00
10	4.81
11	4.66
12	4.51
13	4.32
14	4.08
15	3.76
16	3.37
17	2.88
18	2.29
19	1.61
20	0.84
21	0.00

10th iteration

	A
1	10
2	9.47
3	8.94
4	8.40
5	7.87
6	7.35
7	6.83
8	6.31
9	5.80
10	5.30
11	4.80
12	4.31
13	3.82
14	3.33
15	2.85
16	2.38
17	1.90
18	1.42
19	0.95
20	0.48
21	0.00

50th iteration

	A
1	10
2	9.49
3	8.98
4	8.48
5	7.97
6	7.46
7	6.95
8	6.45
9	5.95
10	5.44
11	4.94
12	4.44
13	3.94
14	3.45
15	2.95
16	2.46
17	1.96
18	1.47
19	0.98
20	0.49
21	0.00

100th iteration

	A
1	10
2	9.50
3	9.00
4	8.49
5	7.99
6	7.49
7	6.99
8	6.49
9	5.98
10	5.48
11	4.98
12	4.48
13	3.98
14	3.48
15	2.99
16	2.49
17	1.99
18	1.49
19	0.99
20	0.50
21	0.00

150th iteration

	A
1	10
2	9.50
3	9.00
4	8.50
5	8.00
6	7.50
7	7.00
8	6.50
9	6.00
10	5.50
11	5.00
12	4.50
13	4.00
14	3.50
15	3.00
16	2.50
17	2.00
18	1.50
19	1.00
20	0.50
21	0.00

200th iteration

Fig. 5 - Successive iterations in deriving a 1- d resistor model

By the 10th iteration, the values of every cell have started to adjust. However it takes 200 iterations for the potential gradient to become sufficiently uniform such that all of the potentials are correct to 3 significant figures.

Although analysing a 1-dimensional resistor structure might seem trivial because you already know what the outcome should be, it serves as a test of the method. You can now proceed with some justified confidence in applying your method to the square resistor, R9, with its one edge connector and several point contacts.

Suppose you model R9 with current flowing from the edge connector (pin 13) to one of the corner point connectors (pin 11). Current is drawn from a 10 V supply. Because pin 13 also connects to the n-type substrate on which R9 sits, its electrical polarity must be held positive with respect to pin 11 to prevent R9 behaving as a

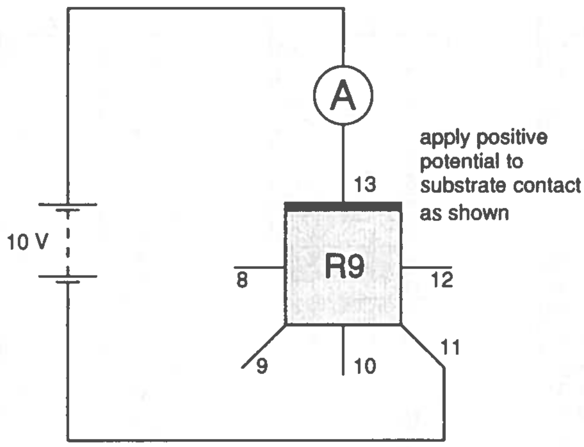


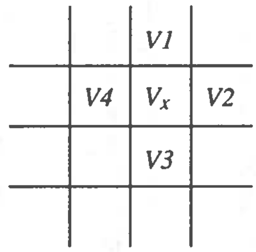
Fig. 6 - Circuit supplying 10 V across R9: 1 - point drain contact

forward biased diode (Fig.6).

You can model the distribution of potentials on R9 by creating a 21 x 21 array (Fig.7). Any reasonable array dimensions will do. If a smaller array were to be used, the outcome would be less precise - and in some examples less accurate. If the array were larger, the time to complete the iteration might be overlong.

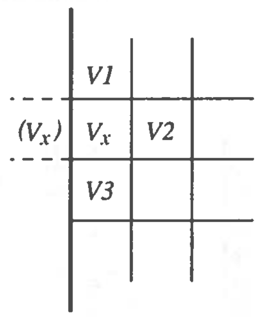
The spreadsheet has rows numbered from 1 to 21, and columns labelled from A to U. All the cells along row 1 are assigned a fixed value of 10. Cell U21 is given a fixed value of 0. These represent the p.d. of 10 V applied across pins 13 and 11. The potentials on all of the other cells are given values which are mathematical variables. This variable is called V_x.

The potential on a central cell V_x is given a value which is the average of the values in its four adjoining cells:



$$V_x = {}^1/_4\,(V1 + V2 + V3 + V4)$$

Because current does not leak across the edge of resistors, the p.d. across an edge is zero. We can therefore imagine there to be a cell (V_x) in the insulation whose value is equal to the resistor boundary cell value V_x. The expression for an edge cell is therefore:



$$V_x = {}^1/_4\,(V1 + V2 + V3 + V_x)$$

which simplifies to

$$V_x = {}^1/_3\,(V1 + V2 + V3)$$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
2	9.83	9.83	9.83	9.82	9.82	9.82	9.81	9.81	9.81	9.80	9.79	9.79	9.78	9.78	9.77	9.77	9.76	9.76	9.76	9.76	9.76
3	9.66	9.65	9.65	9.65	9.64	9.64	9.63	9.62	9.61	9.60	9.59	9.58	9.57	9.56	9.55	9.54	9.53	9.52	9.52	9.51	9.51
4	9.49	9.48	9.48	9.47	9.47	9.46	9.44	9.43	9.42	9.40	9.39	9.37	9.35	9.34	9.32	9.30	9.29	9.28	9.27	9.26	9.26
5	9.32	9.32	9.31	9.30	9.29	9.28	9.26	9.24	9.23	9.20	9.18	9.16	9.14	9.11	9.09	9.07	9.05	9.04	9.02	9.02	9.01
6	9.15	9.15	9.14	9.13	9.12	9.10	9.08	9.06	9.03	9.01	8.98	8.95	8.92	8.89	8.86	8.83	8.81	8.79	8.77	8.76	8.76
7	8.99	8.99	8.98	8.97	8.95	8.93	8.91	8.88	8.85	8.81	8.78	8.74	8.70	8.67	8.63	8.59	8.56	8.54	8.52	8.50	8.50
8	8.84	8.83	8.82	8.81	8.79	8.76	8.73	8.70	8.66	8.62	8.58	8.53	8.49	8.44	8.40	8.35	8.31	8.28	8.26	8.24	8.23
9	8.69	8.68	8.67	8.65	8.63	8.60	8.56	8.52	8.48	8.43	8.38	8.33	8.27	8.22	8.16	8.11	8.06	8.02	7.99	7.96	7.95
10	8.54	8.53	8.52	8.50	8.47	8.44	8.40	8.36	8.30	8.25	8.19	8.12	8.06	7.99	7.92	7.86	7.80	7.75	7.71	7.68	7.66
11	8.40	8.40	8.38	8.36	8.33	8.29	8.24	8.19	8.13	8.07	8.00	7.92	7.84	7.76	7.68	7.60	7.53	7.47	7.42	7.38	7.36
12	8.28	8.27	8.25	8.22	8.19	8.15	8.10	8.04	7.97	7.89	7.81	7.72	7.63	7.54	7.44	7.34	7.26	7.18	7.11	7.07	7.04
13	8.16	8.15	8.13	8.10	8.06	8.01	7.96	7.89	7.81	7.73	7.63	7.53	7.42	7.31	7.20	7.08	6.97	6.87	6.79	6.73	6.70
14	8.05	8.04	8.02	7.98	7.94	7.89	7.83	7.75	7.67	7.57	7.46	7.35	7.22	7.09	6.95	6.81	6.68	6.55	6.44	6.37	6.32
15	7.95	7.94	7.91	7.88	7.84	7.78	7.71	7.63	7.53	7.43	7.31	7.17	7.03	6.87	6.71	6.54	6.37	6.21	6.07	5.97	5.91
16	7.86	7.85	7.83	7.79	7.74	7.68	7.60	7.52	7.41	7.29	7.16	7.01	6.85	6.67	6.47	6.27	6.06	5.85	5.66	5.52	5.44
17	7.79	7.78	7.75	7.71	7.66	7.59	7.51	7.42	7.31	7.18	7.03	6.87	6.68	6.47	6.25	6.00	5.74	5.47	5.22	5.01	4.88
18	7.73	7.72	7.69	7.65	7.59	7.52	7.44	7.34	7.22	7.08	6.92	6.74	6.54	6.30	6.04	5.75	5.43	5.08	4.73	4.41	4.21
19	7.68	7.67	7.64	7.60	7.54	7.47	7.38	7.28	7.15	7.01	6.84	6.64	6.42	6.16	5.87	5.53	5.14	4.69	4.20	3.70	3.33
20	7.65	7.64	7.61	7.57	7.51	7.44	7.34	7.23	7.11	6.95	6.78	6.58	6.34	6.06	5.74	5.36	4.91	4.36	3.68	2.88	2.07
21	7.64	7.62	7.60	7.55	7.49	7.42	7.32	7.21	7.08	6.93	6.75	6.54	6.30	6.01	5.67	5.27	4.77	4.14	3.29	2.06	0.00

Fig. 7 - Spreadsheet values after 1000 iterations : 1 - point drain configuration

Circuit configuration	R9 terminal	Terminal function	Measured value (V)	Spreadsheet value (V)
1 point drain	13	*source*	10.00	(10.00)
	12	*floating*	7.31	7.36
	11	*drain*	0.00	(0.00)
	10	*floating*	6.71	6.75
	9	*floating*	7.63	7.64
	8	*floating*	8.41	8.40
2 point drain	13	*source*	10.00	(10.00)
	12	*floating*	6.54	6.59
	11	*drain*	0.00	(0.00)
	10	*floating*	4.62	4.76
	9	*drain*	0.00	(0.00)
	8	*floating*	6.55	6.59
3 point drain	13	*source*	10.00	(10.00)
	12	*floating*	5.77	5.80
	11	*drain*	0.00	(0.00)
	10	*drain*	0.00	(0.00)
	9	*drain*	0.00	(0.00)
	8	*floating*	5.76	5.80

Table 2

- Comparing measured values of potential with values computed on the spreadsheet

Similarly the value for a corner cell is

$$V_x = {}^1/_2\,(V1 + V2)$$

The values shown in Figure 7 are after 1000 iterations, by which stage they have almost settled down to a steady state. A three-dimensional plot (Fig.8) of the spreadsheet values gives a graphic illustration of the distribution of potential gradient within the resistor.

As a check on the validity of the method, the computed values have been compared with measured values at the point contacts (Table 2). Data has been taken from three circuit configurations where the variable is the number of contacts used to drain current from R9. Except for one instance, measured and calculated values are in agreement to two significant figures. The correlation would seem to indicate that our finite-element analysis method is more or less right.

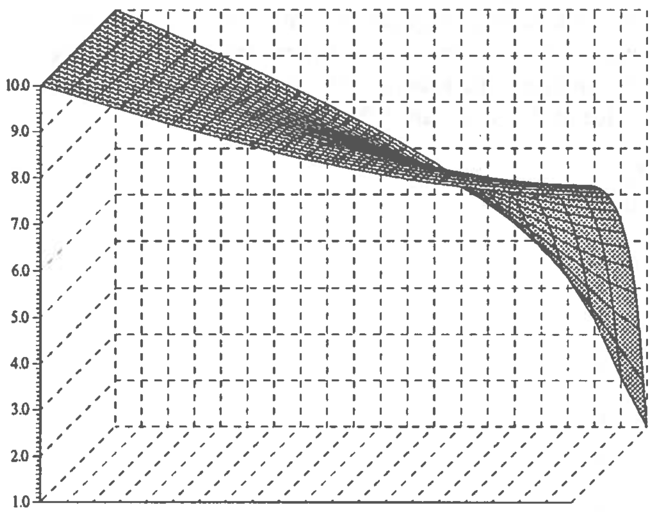


Fig. 8 : 3 - d plot of distribution of potential

Sheet resistance calculation

The spreadsheet for the 1-point drain circuit (Fig.7) shows that the potential along row 2 - the row adjacent to the edge connector cells - is very nearly uniform. From the spreadsheet, the average p.d. between rows 1 and 2 (V_c) is 0.207 V. From measurement, the total current (i_t) through R9 is 3.98 mA. Therefore the current flowing through each single cell is 3.98/21 mA.

Sheet resistance (R_s) works out at

$$\begin{aligned} R_s &= (21\,V_c)\,/\,i_t \\ &= (21 \times 0.207)/(3.98 \times 10^{-3}) \\ &= 1.09\ \text{k}\Omega/\text{square} \end{aligned}$$

Configuration	V_c (V)	$1/V_c$ (V^{-1})	R_t (k)
1 point drain	0.207	4.84	2.38
2 point drain	0.333	3.00	1.48
3 point drain	0.42	2.38	1.18
edge drain	0.50	2.00	-

Table 3 - Data from several circuit configurations

A better estimate of R_s can be obtained by using measurement and spreadsheet data from all three circuit configurations (Table 3).

The total resistance R_t for each R9 configuration is

$$R_t = V_t / i_t$$

In every case, the p.d. across R9 (V_t) is 10 V. By substituting for i_t, the relationship for R_t becomes

$$R_t = (10\,R_s) / (21\,V_c)$$

If the measured values of R_t are plotted against $(V_c)^{-1}$ and the line is extrapolated, the line is seen to go through the origin (Fig.9). This is further confirmation that sensible data is produced by finite-element analysis.

If R9 had been manufactured with two edge contacts on opposite sides, the p.d. (V_c) between adjacent rows in a 21 x 21 array would be 0.50 V, assuming for consistency with the other configurations that the total p.d. across R9 was 10 V. Sheet resistance (R_s) can then be read off the extrapolated line against a $1/V_c$ value of 2.00. This gives a value of 980 Ω/square ± 30 Ω/square.

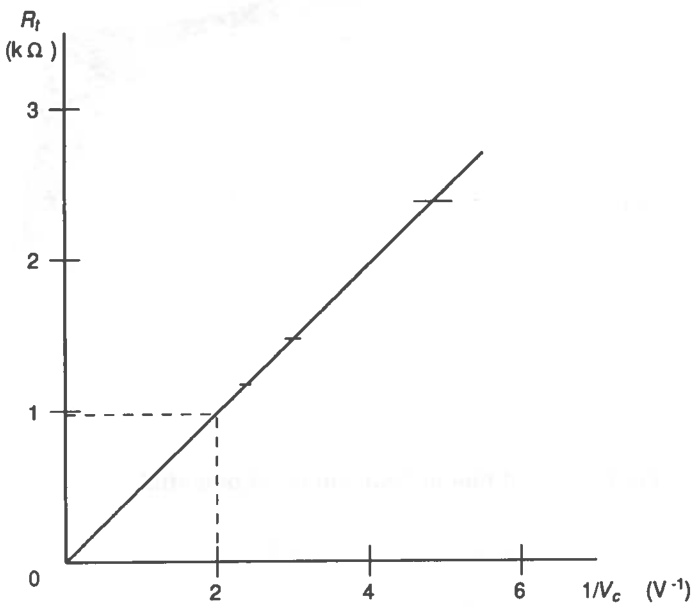


Fig. 9 - Finding sheet resistance from R_t versus $(1/V_c)$ graph

Spreadsheets and finite-element analysis

Spreadsheets have many convenient functions for this type of work:

- formulae can be copied from cell to cell with automatic and appropriate changes to cell references;

- the calculation of each cell value can be repeated for a user specified fixed number of iterations, or until a specified difference is reached;

- the cell values can be plotted on a 3-d graph.

The spreadsheet examples shown in this article were made on *Eureka*, which is sold by Longman Logotron, and run on an Archimedes machine with 4 Mbyte of RAM. One benefit of using *Eureka* is that it is relatively easy to learn how to operate. Version 1, which we have been using, is unable to handle automatic iterations. However Version 2, due to be released in July, does have this facility.

Eureka is not able to plot 3-d graphs of the sort shown in this article. Figure 8 was prepared by transferring data from a *Eureka* file to *Graphbox* from Minerva.

Finite-element analysis can be carried out on other spreadsheet packages such as *Pipedream*, *Lotus 1-2-3* and *Excel*. For instance *Excel*, which runs on PC and Apple Mac machines, is able to perform automatic iteration and has suitable 3-d graphing facilities.

There are other fields where finite-element analysis can be used. Stress patterns in loaded beams can be modelled in exactly the same way mathematically as has been shown here for the distribution of electric potentials in resistors. Temperature distributions in a surface however would require different modelling to take account of energy losses from boundaries and surfaces. Modelling the potentials due to electrostatic charges would also require a different mathematical treatment.

Caution

Our analysis has been based on applying 10 V across R9. Ten was chosen because it is a decimal number, and because we have a power supply with low impedance output that can precisely deliver 10.00 V. However quite a lot of self heating is generated in the resistor at this sort of voltage magnitude. To avoid problems with this, either get your measurements done quickly - 15 s is quite long enough - or work at a much lower voltage.

Acknowledgement

The Centre is very appreciative for the technical help given to us by Professor John Robertson of Edinburgh University.

Announcements

New publication

CSYS Physics : Electromagnetism

SSERC has prepared an Experimental Guide [1] which is intended to supplement the theoretical treatment indicated in the SCCC Teachers' Guide [2] to the Core Units of the revised Certificate of Sixth Year Studies Physics course.

Our guide provides technical detail both on the experiments suggested in the syllabus and a number of alternative or optional practical activities. These latter include use of the Schools Chip number 1 to demonstrate the Hall effect plus some interesting applications of the Teltron Fine Beam and Deflection e/m tubes. Datalogging is also provided for in measuring self-inductance of a coil by plotting the exponential growth of a current.

The SSERC Guide is intended solely as advice and technical assistance for those that wish them. Teachers as ever remain completely free to choose, devise and present practical work in accordance with their own plans for teaching the course. Indeed the Centre would welcome any suggestions for improvements, alternatives or additions to the experimental work described in the guide.

The SSERC Electromagnetism Experimental Guide runs to eighteen A4 pages or so and is available from the Centre at £3.50 per copy (incl. copying and postage).

References

1. *CSYS Physics : Electromagnetism : Experimental Guide*, SSERC, 1993.

2. *Revised Certificate of Sixth Year Studies, Physics Core Units : Teachers' Guide*, SCCC, 1991.

...

Chemical Modeller - new manuals/software

New software - It was just last year that we launched the SSERC Chemical Modeller, a molecular modelling software package for all Acorn Archimedes and A-Series computers. With the benefit of feedback from users and constructive criticisms in press reviews, the original has been refined through a couple of intermediate versions to the present incarnation of Version 3.1.

As before, the only requirements are that 2 Mbytes of RAM should be installed and the computer has a Riscos operating system. The program runs in mode 15 on a standard monitor with the Arm 2 processor. The presence of an Arm 3 obviously enhances the speed and smoothness of molecule rotations and manipulation.

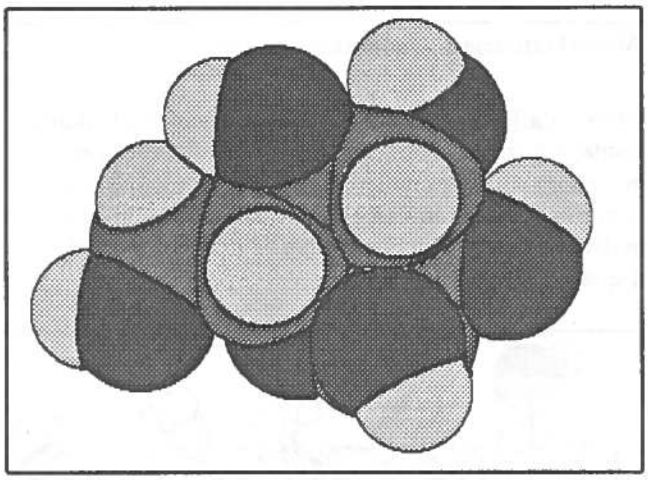
New manuals - There is a new General Manual which describes all the functions of the software and includes many screen captures which illustrate the features described. There is also a Teachers' Guide which sets out the dos and don'ts of operating the software. However, worry not, as the SSERC Chemical Modeller is designed to allow you to retreat in safety from those parts of the program you never intended to reach! Finally, a Pupils' Guide, which will no doubt be used as much by the teachers, provides clear examples and instructions on how to manipulate previously-saved molecules and thence build your own.

Same price - The complete single-user package is still only £52.50 and a school site licence at £84 (plus VAT).

Features

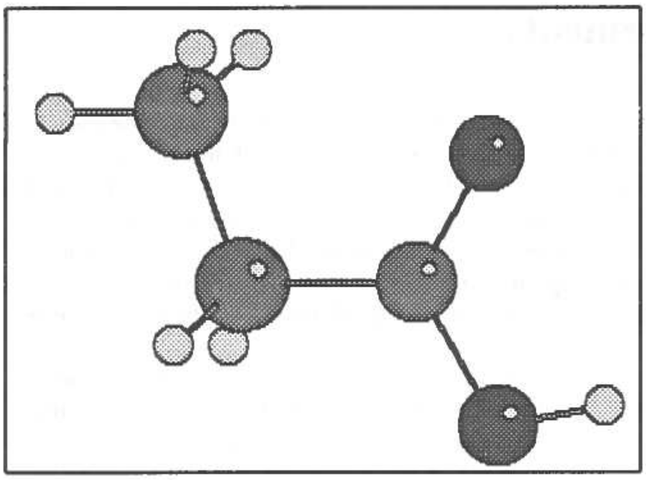
Pre-drawn structures - methane, ethane, propane, butane, hexane, octane, propene, ethene, ethyne, propyne, methanol, ethanol, glycerol, ethanoic acid, propanoic acid, palmitic acid, methyl ethanoate, glyceryl tripalminate, alanine, dialanine, fructose, glucose, sucrose, maltose, diamond, graphite, C-sixty, clonidine, BDNA, ammonia, carbon dioxide, ntrogen dioxide, water, sodium chloride and potassium chloride.

Ring structures - benzene, cyclohexane (boat & chair), cyclopropane, cis- & trans-decalin, napthalene, anthracene, phenanthrene, pyrene, furan, imidazoline, piperidene, pyridine, pyrrole, thiophene, benzofuran, iso-quinoline, indole and quinline.



A glucose molecule - Van der Waals spacefill

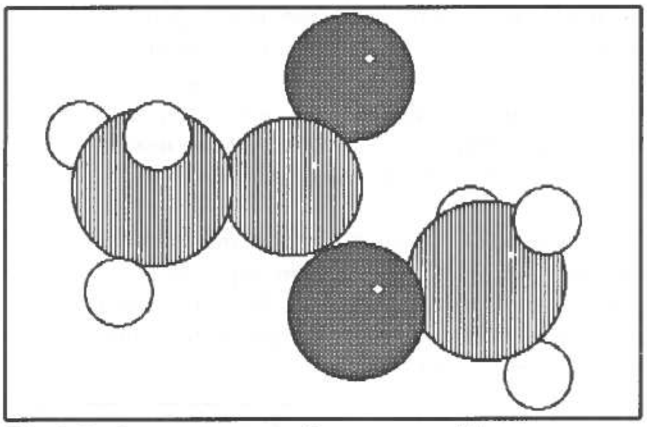
For more examples see over ---------->



Propanoic acid - ball and stick display

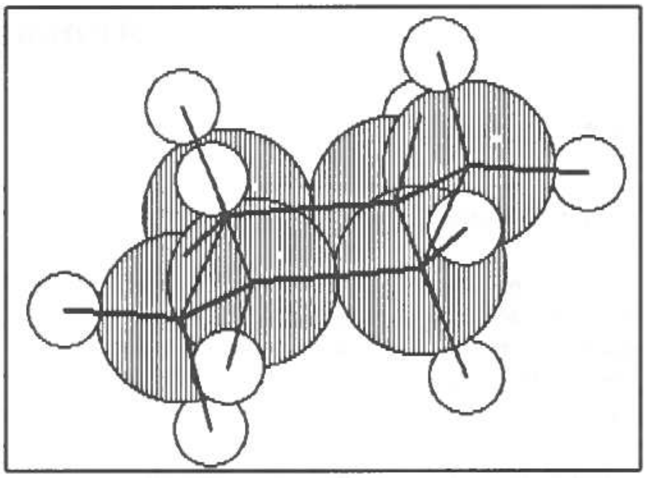
Types of structure displays available - The program can be fully operated by a mouse/trackerball and has clear and concise menu structures always available. Structures can be displayed as models i.e. coloured stick, simple space-fill with covalent radii, ball and stick, Van der Waals space-fill and dot surface with covalent radii.

Stick and space-fill models can also be displayed as red/green stereo 3_D images. Most manipulations are generally carried out on the stick models as they are the quickest to redraw, but rotations and translations can be carried out also on the space-fill representation.

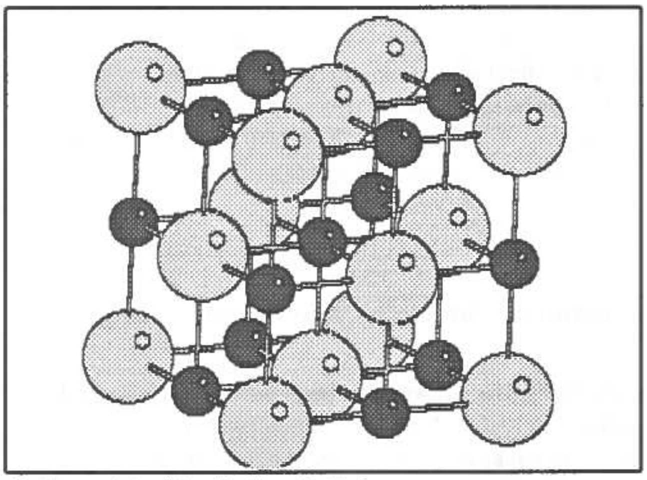


Methyl ethanoate - monochrome spacefill

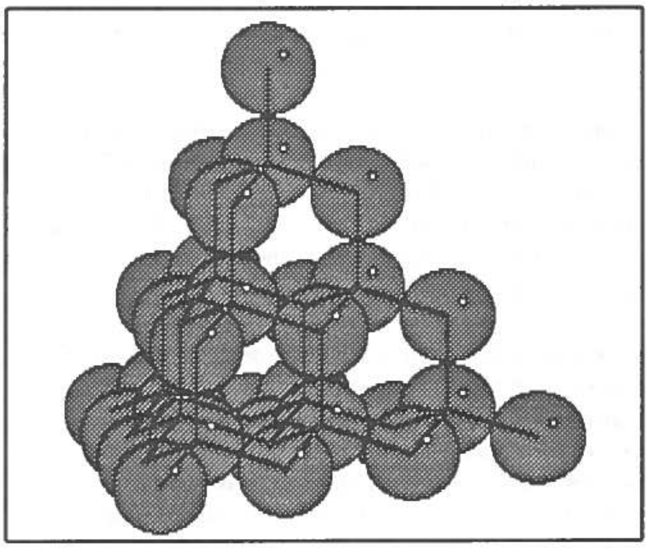
Manipulations available - The program allows building, displaying, manipulating and measuring of molecular models and includes molecular mechanics routines for minimising the steric energies of small to medium-sized molecules. Several molecules can be manipulated and displayed at the same time.



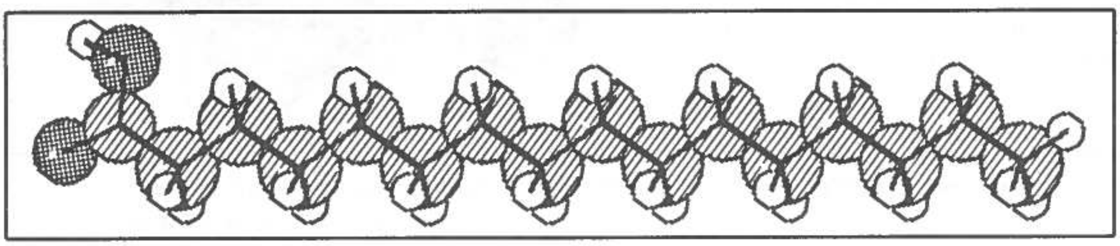
Cyclohexane (chair) - monochrome spacefill with spine



Sodium chloride - ball and stick



Diamond - spacefill with spine



Palmitic acid - monochrome display with spine included

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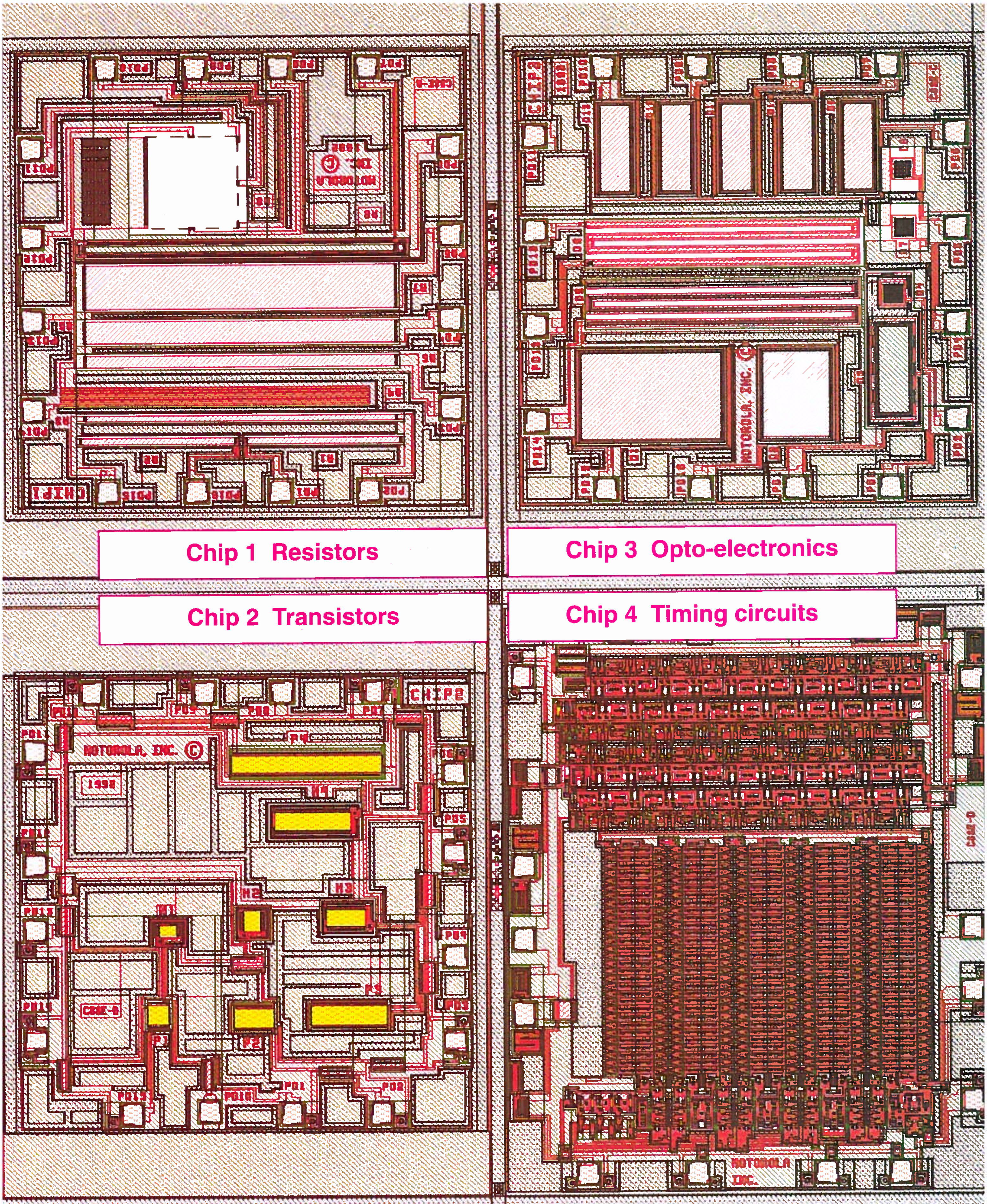

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