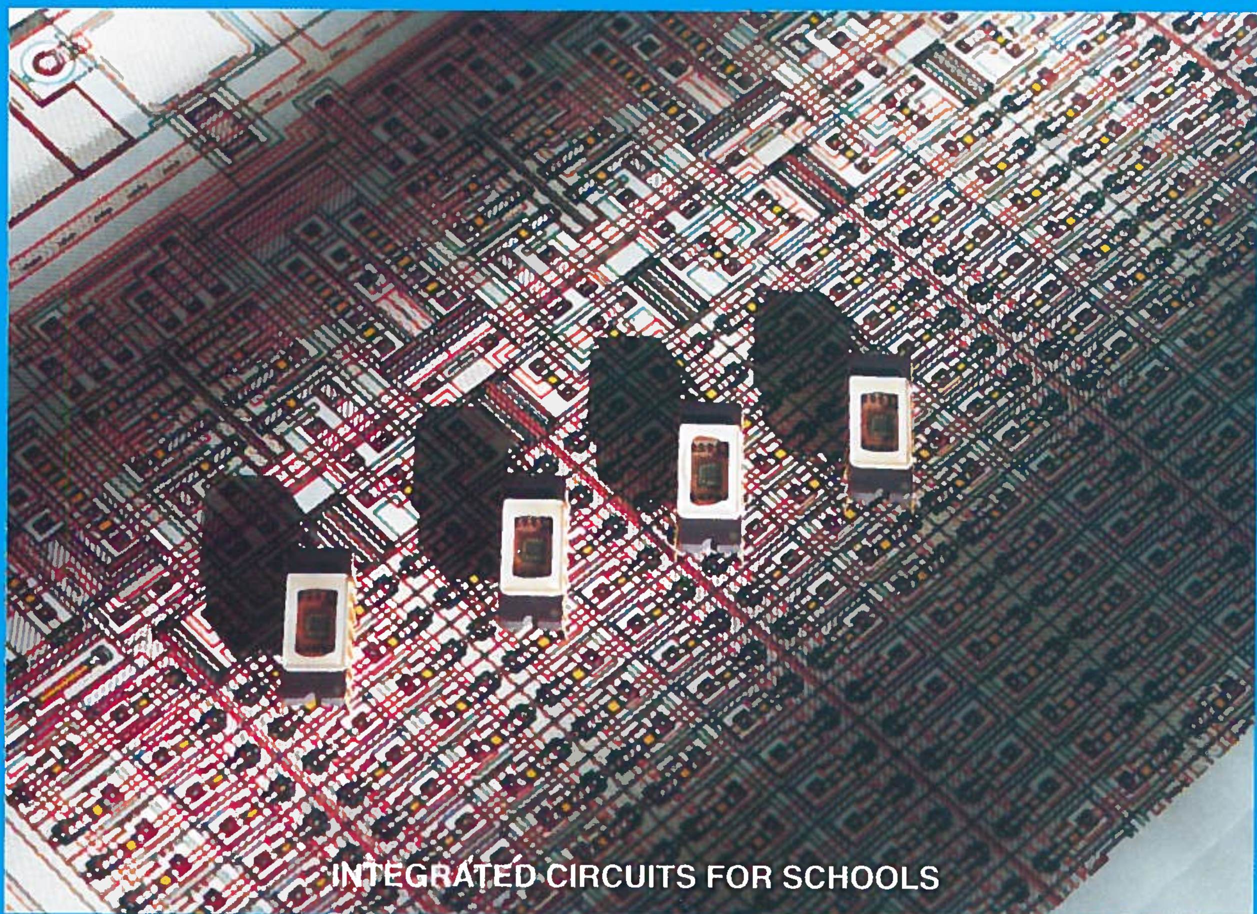
SCOTTISH SCHOOLS EQUIPMENT RESEARCH CENTRE



Science & Technology Bulletin

For: Teachers and Technicians in Technical Subjects and the Sciences

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Contents

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FOREWORD

Sponsorship

This bulletin issue has been sponsored through the Schools Chip Project. We are most grateful to the organisations concerned : Edinburgh University, Motorola, Compugraphics and Scottish Enterprise.

Professor John Robertson of the Electrical Engineering Department of Edinburgh University has very kindly provided us with a short account of the main aims of this exciting project.

The Schools Chip Project

Microelectronics has had a very significant impact in schools, most noticeably through the introduction of powerful but relatively cheap desk-top computers. Behind the keyboard, the work is done by a few integrated circuit chips and several aspects of the operation of these devices are already covered in the curriculum. There are, however, serious impediments to effective teaching through lack of materials and data which are suitable for classroom use. This applies even to the restricted range of topics that are currently in the curriculum and the options for further development to include many of the most important features of the new technology are almost non-existent.

This is a serious state of affairs for higher education and industry. Electronics is an international business that plays a key role in all aspects of working and leisure life. The evolution of integrated electronics has been predominantly technology-driven in that it exploits well established scientific principles in increasingly sophisticated ways. Nonetheless if it is excluded from the school system there could be some very serious knock-on effects. Fortunately some solutions are possible. This bulletin issue introduces a chip set that has been specifically designed for use in schools. The concept was first tested in a pilot project funded by Edinburgh University. Peter Bates, at that time Principal Teacher of Physics at Firrhill High School, was seconded to the Electrical Engineering Department for two years to develop the prototype chip and to evaluate it in a few Lothian schools.

The main phase of the project was undertaken by a consortium consisting of Edinburgh University, Motorola, Compugraphics and Scottish Enterprise. There are four chips in the set and they demonstrate resistors, transistors and logic gates, optoelectronics and timing circuits. There are potential applications at all levels of the curriculum in Physics and Technological Studies.

The masks for the new integrated circuits were made by Compugraphics International in Glenrothes and the silicon was produced by Motorola in East Kilbride. This approach gives full commercial specifications. The manufacturing process is identical with that used to make the standard CMOS digital circuits that are already widely used in schools. The new chips are the precursors to these digital building blocks and provide the hitherto missing link to basic physics and material properties. To assist classroom demonstration, all the devices are encapsulated in ceramic packages with glass lids.

The project will be formally launched on 23rd October and about 100 schools will take part in an extended evaluation of the new chip set. Thereafter, it is planned to make the devices available through normal commercial distributors. For further information please contact Professor John Robertson at the address given on the inside rear cover of this bulletin issue.

INTRODUCTION

Editorial

Crying Wolff?

In its issue of the 28th August The Times Educational Supplement gave one of its rare nods in the direction of science and technology teaching. In its reporting of this year's British Association for the Advancement of Science meeting it quoted some interesting snippets from a number of Sirs and Profs. Several such contributions from those and such as those - Sir David Attenborough, Professors Black and Durant amongst them - were helpful and positive.

It cannot be but difficult however to find something new to say on the problems facing British science or engineering and the teaching on which both ultimately depend. Any student of the history of these matters could tell you that periodically they have been subject to such comment and debate since certainly the First World War and probably back to George III and beyond.

What I found less than helpful was a quote from Professor Heinz Wolff. I have heard him speak several times in recent years. The latest of these occasions (and it might be the last) was that of his acceptance speech at the Edinburgh Medal ceremony earlier this year. Much of what he had to say was useful positive stuff on the need for the general citizen to have early contact with things technological and to develop a relevant scientific and technological vocabulary.

In that speech Professor Wolff also made a jokey reference to the possible negative effects of health and safety on the quality of science and technology education. Some of those both in the audience and in the know as to SSERC's safety role allowed themselves a smirk or two. Unfortunately for them a petit bijoux of a smirkette was also to be seen on these lips of mine. This was because we have always recognised the dangers of over-reaction to health and safety requirements and of a mindless traffic warden approach to such matters.

Professor Wolff's achievements both in his own research and in his contributions to the development of a wider public understanding of science and technology are undoubtedly of the highest order. Since that Edinburgh Medal ceremony I have looked forward therefore to the development of his thinking on such matters. In particular I was expecting something more positive than his original humorous asides. Judging by the TES quote from the British Association's jollies I am going to be disappointed :

"He also blamed Health and Safety leglislation, which he said had made science teaching dull in its quest for safety. *Anyone who hasn't bubbled hydrogen sulphide through cadmium sulphate and got a thick yellow precipitate hasn't lived*, he said."

That may or may not be so. It's all a matter of taste - or in this instance your sense of smell (same thing really). What I find disappointing and by now somewhat annoying is the continuing lack of any positive suggestions from Prof Wolff as to what we do about it. Regular readers of this journal will also be aware of our aversion to this kind of shallow argument wherein two potentially compatible elements are presented instead as opposites. This, it seems, meets some deep seated British (Anglo-Saxon?) psychological need for confrontational debate. Would that issues were always so simple.

It is a complete and utter nonsense to set high quality, exciting and inspirational teaching against health and safety as though a choice is to be made between the two. Which would you rather have : expensive coal or women and children still in British mines hauling tubs of coal and operating ventilation doors? Got a solid fuel stove? How about an enterprise education project with the added bonus of a cheaply swept chimney?

Professor Wolff has fallen into a trap. He will not be lonely. There are already far too many of the science and technology education establishment down in that particular hole. Theirs is the error of confusing employment leglislation, such as COSHH, the main thrust of which is the longer term protection of the health and welfare of teachers and technicians as employees, with pre-existing duties and obligations to prevent acute or chronic harm to pupils. It may not suit everyone but Health and Safety legislation can't be shooed away merely because it may be somewhat difficult to implement

I also take issue with a second inference from such statements as his ". . . hasn't lived" assertion. This sort of denouncement by nostalgia really isn't helpful. I would be the first to admit that I foolishly got embroiled in a scientific and technological career because of some inspirational, spectacular and apparently hairy demonstrations. Whilst I might welcome a renaissance of some or possibly much of that kind of teaching activity I certainly would not accept a lowering of safety standards as the price.

The demonstrations I watched were acceptably safe because the teachers who carried them out knew exactly what they were doing, had assessed the risks and taken due precautions. They did not ignore health and safety in their teaching but integrated it into their material. A danger of a suck-back would be pointed out and the need to insert a reversed wash bottle as a trap would be indicated. This is part of the long-established professional disciplines of scientific and engineering activity. If you should doubt it then read (or probably in Heinz's case re-read) accounts of the working methods of the greats like Bunsen. The best mental image I can conjure is of that great man, Sir Humphrey Davy. I keep seeing him spinning in his grave at the thought of wasting all that time on those damned miner's lamps!

If there is a danger to the quality of education from health and safety leglislation it lies in unthinking approaches to the management problems it brings in its wake. At their worst these may yet drown us all in a sea of prohibitions or crush us flat under the weight of forms and records.

Heinz Wolff is in a position to exercise great influence on the development of science and technology education. His potential is not however unipolar.

Christmas closure

Please note that the Centre will be closed from lunchtime on Wednesday the 23rd December 1992 until the morning of Tuesday the 5th of January 1993.

SAFETY NOTES

Apparatus defects - electrical safety

OPAX stereomicroscope - nae earth!

We had a letter in early September from a biology teacher informing us that his four brand new OPAX model BST stereomicroscopes had just failed their school's GS23 inspection. He was astonished! The problem was caused by the absence of protective earthing, yet the insulation system was of the type that required an earth conductor. Accompanying the teacher's letter were photocopies of correspondence with OPAX.

To the local authority's original complaint, Opax issued this denial on 3rd June: "..... We would like to confirm that this instrument is supplied with a standard 3 core mains cable and does therefore have an earth wire."

On 12th June the teacher himself wrote back to OPAX pointing out that as each microscope had been fitted with 2-core cable, no instrument was earthed. There being no response from OPAX by the end of August, he contacted SSERC for assistance.

It seemed to us that the best procedure at this stage was to call in Trading Standards and ask them to investigate. However we stayed our hand on that resort, and tried once again with the gentle art of correspondence. This time, it did the trick. On 11th September, OPAX wrote to the teacher to say how they would be glad if he would return his microscopes, how they would look forward to carrying out this work for him, and that there would be no charge for this alteration.

So there you have our little story. If something's not right, sort out the facts, decide what needs to be done, and ask for the fault to be sorted. If the company stalls, keep persisting. Should your own good efforts fail, and in this instance the teacher was clearly up against a fairly intractable supplier - not, I think, a typical one - the Centre is usually always happy to assist.

So if anyone else has an OPAX BST stereomicroscope that isn't earthed, drop OPAX a line ...... We would be interested to hear of their reaction.

Beckman 9012 - fused on the neutral

It seems scarcely credible that a modern electronic instrument, with many clever, complex features, should have one of the worst kind of faults. Even more astonishing, it is the second oscilloscope - they came from different manufacturers - we have found in two years with this fault condition. The fault was found in our routine programme of testing new apparatus.

The instrument to watch out for is the new dual trace model from Beckman, the 9012. This has its supply line fuse on the neutral rather than on the live conductor.

Another safety concern of ours relates to the front metal panel of the enclosure. This has several unused cutouts which are covered only by the label membrane. We are not convinced that this is sufficiently strong to prevent children from inserting fingers inside the enclosure.

We understand at the time of writing this Safety Note that Beckman are responding to our criticisms and that the company are satisfied that the fault conditions can be rectified. We have still to be formally notified of their proposed actions.

If you have already purchased a Beckman 9012, we advise you to return it to your supplier and ask for it to be modified to a reasonable standard, which at the very least is the transference of the protective fuse from the neutral to the live conductor. Tait Components are the main Scottish distributors.

TECHNICAL ARTICLES

Practical work with Schools Chip 1 (The Semiconductor Materials Chip)

This article describes the structure of Motorola's Semiconductor Materials Chip, Schools Chip 1. It discusses some practical difficulties in working with the chip and provides you with ideas for practical work.

Description of Chip 1

Schools Chip 1 contains nine resistors, R1 to R9, laid out as shown in Figure 1. Six consist of heavily doped p-type silicon material. Of the three exceptions, R8 consists of n-type doped silicon. R4 is a metal track of an aluminium-silicon alloy. The final resistor, R9, is made from lightly doped p-type silicon.

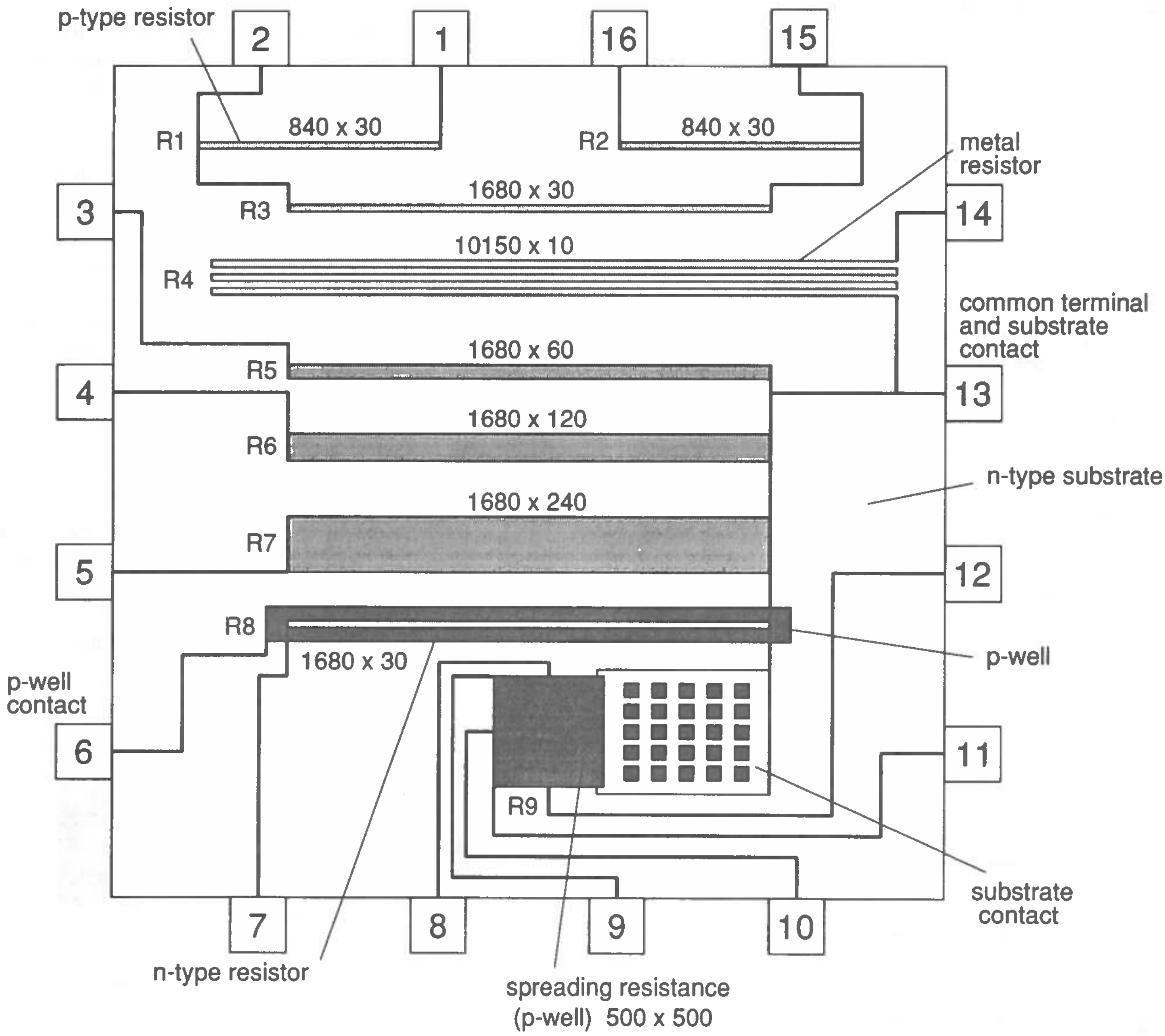


Fig. 1 - Physical layout of resistors in Chip 1, dimensions in microns

Label	Material	Resistance (Ω)	Length *l* (µm)	Width *w* (µm)	Thickness *t* (µm)	Max.power dissipation (mW)
R1	p-type silicon, heavily doped	1130	840	30	2.4	250
R2	p-type silicon, heavily doped	1130	840	30	2.4	250
R3	p-type silicon, heavily doped	2260	1680	30	2.4	250
R4	99% aluminium, 1% silicon	30	10150	10	1	250
R5	p-type silicon, heavily doped	1130	1680	60	2.4	250
R6	p-type silicon, heavily doped	565	1680	120	2.4	250
R7	p-type silicon, heavily doped	283	1680	240	2.4	250
R8	n-type silicon, heavily doped	870	1680	30	2.4	250
R9	p-type silicon, lightly doped	-	500	500	7.5	250

Table 1 - Resistor specifications

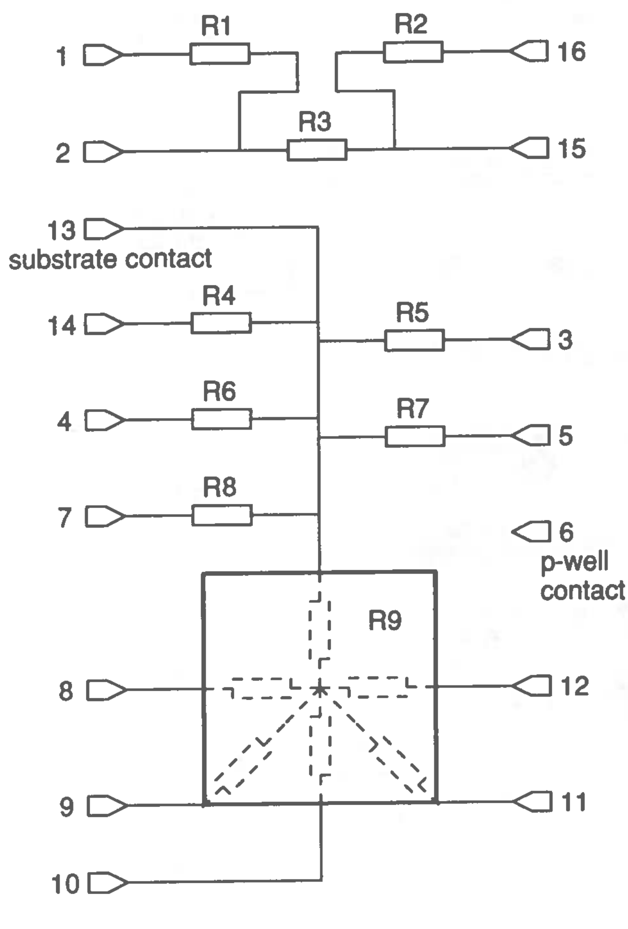


Fig.2 - Resistor interconnections

Resistor specifications are shown in Table 1. All doped silicon resistors are roughly 2.4 microns deep, except R9, which is 7.5 microns deep. The metal resistor R4 is about 1 micron deep.

The resistors are interconnected by metal conductors as shown in Figure 2. The n-type substrate on which all the resistors sit is electrically bonded to the conductor running to pin 13. (1 micron = 1 µm = 10^{-6} m)

Unlike any other integrated circuits, the four Schools Chips have been designed for educational purposes solely. Many of the structures have physical properties that relate to one another by simple proportion. This invites study. The simplicity is a prompt to investigation and application.

Also, unlike most other integrated circuits, each of the Schools Chips has a window (Fig.3) through which you can examine the internal structure.

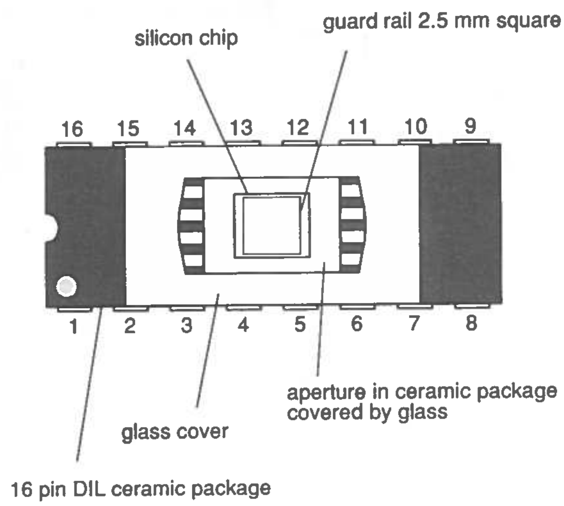


Fig.3 - Plan view of ceramic package with window

You thus can pick up tacit knowledge of what the structures are really like.The set of chips therefore forms a link in education between elementary instruction with simple discrete components and the more elaborate study on complex electronic structures in commercially available integrated circuits.

Practical difficulties

Before starting to work with this chip, you need to appreciate that the resistors cannot in general be treated as isolated components that may be wired up willy nilly in any order. The polarity of connections always needs to be considered! Excepting R4, the resistors consist of a layer of doped silicon diffused into a substrate or well composed of doped silicon of the opposite type. Because the boundary between these layers acts as a p-n junction, the polarity of the resistor supply should be chosen to ensure that the junction is always reverse biased - that is, unless you wish to investigate the junction itself.

By considering the structures of the various resistors, their electrical properties can be grouped as follows:

p-type resistors R1, R2 and R3

These are p-type resistors on an n-type substrate. Each resistor is directly connected to an external terminal via metal conductors that are isolated from the substrate. An electrical model of R1 is shown (Fig.4).

Resistors R1, R2 and R3 may be used singly or in combination with external signals of either polarity. If however they are connected to any other resistors, the p-n junction effect between the resistors and substrate needs to be allowed for. To avoid the diode effect, either ensure that there is positive polarity on the substrate contact (pin 13), or work with voltages not exceeding 400 mV.

Metal resistor R4

Resistor R4 is a metal track. By making it very long, thin and narrow, its resistance is high enough to be easily measurable. The film composition is pure aluminium with about 1% silicon added to maintain metallurgical equilibrium with the substrate silicon at the formation temperature (435°C). Its resistivity is slightly higher than pure aluminium. The film thickness is about one micron.

p-type resistors R5, R6 and R7

These are p-type resistors on an n-type substrate. Each resistor is connected in common by a metallic conductor which is electrically bonded to the substrate. Connection to this is made via pin 13. The opposite resistor terminals are connected to external pins 3, 4 and 5. The p-n junction effect between the resistors and substrate needs to be considered as shown in the electrical model (Fig.5).

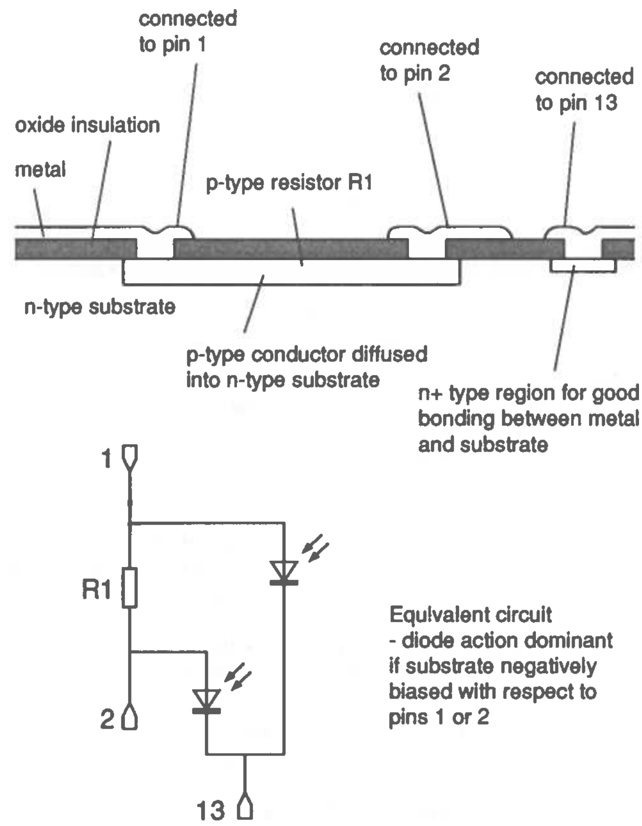


Fig.4 - R1 structure in section, and electrical model

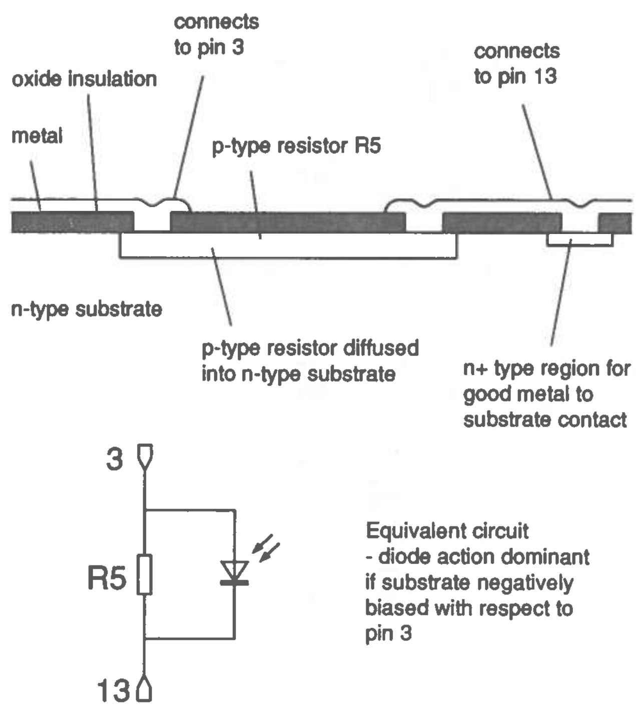


Fig.5 - R5 structure in section, and electrical model

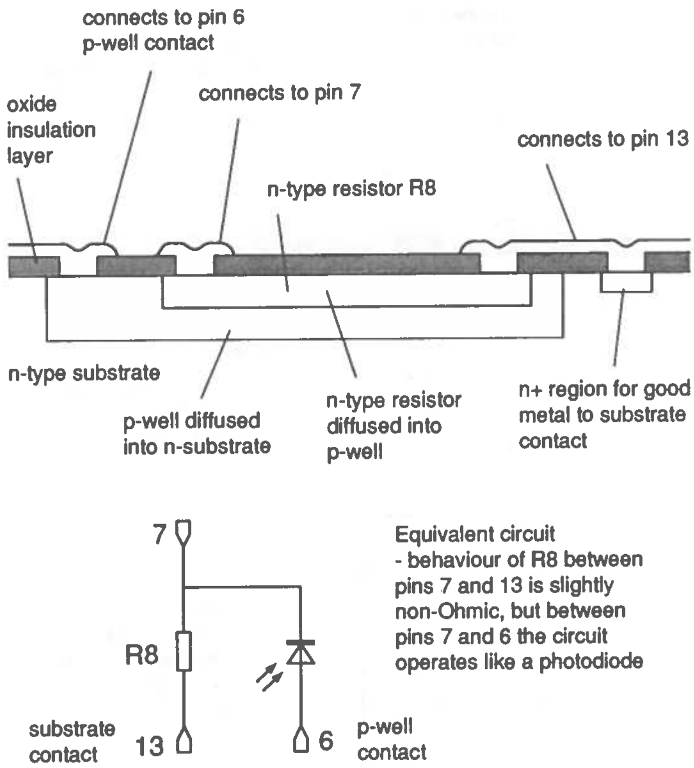


Fig.6 - R8 structure in section, and electrical model

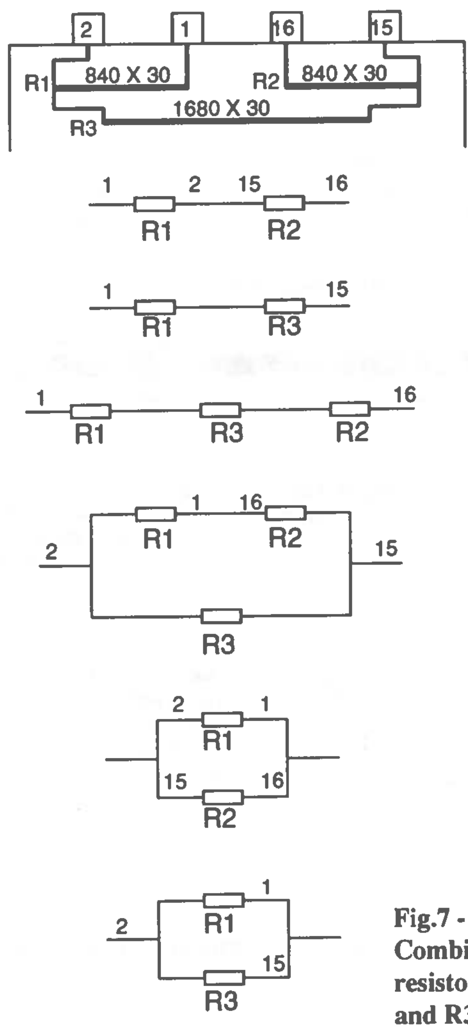


Fig.7 - Combining resistors R1, R2 and R3

n-type resistor R8

Resistor R8 comprises n-type doped silicon on a p-well diffused into the n-type substrate. The resistor terminals are 7 and 13, the latter being bonded to the substrate. External connection to the p-well is made through pin 6. An approximate model for R8 is given in Figure 6.

Spreading resistance R9 (p-well)

R9 is a square of lightly doped p-type silicon that has been diffused deep into the n-type substrate (7.5 microns). Five pins (8 to 12 inclusive) make point contacts to the resistor. An edge contact is also provided to pin 13. Current flow between the contacts is non-uniform. Therefore this component illustrates the concept of spreading resistance.

Resistance measurement problem

Digital multimeters measure resistance by pumping out a constant current through the external resistance. For instance, one of our multimeters delivers 1.3 mA when on its 200 Ω range, 69 μ A on its 2 kΩ range, and 20 μ A on its 20 kΩ range. The fact that multimeters operate as constant current sources may need to be considered in interpreting some of the weirder changes in recorded resistance when experimenting with the Chip 1 set of resistors.

Suggested practical work

Visual inspection

Without magnification, the overall chip dimensions can be seen to be about 3.3 mm by 2.7 mm. The sixteen leads connecting the chip to the outer terminals on the package are only just visible.

Under a stereo microscope with x 20 magnification, all the resistors can be resolved, as can the *Motorola* and other legends. By holding a ruler over the chip, resistor lengths can be measured in tenths of a millimetre. Most can be seen to be about 1.7 mm long. All the features on the chip can be seen to lie within a guard rail measuring 2.5 mm square. The wire lead diameters appear to be around 0.02 mm.

Under a microscope using reflected illumination from a bench lamp, almost the entire chip surface is in the field of view with a x 5 objective and x10 eyepiece. A x10 objective is useful for resolving further detail.

Colours are due to thin film interference effects since the silicon is covered by a thin transparent layer of silicon dioxide glass. Differences indicate changes in thickness or material type.

Resistance combinations

For the first wiring exercise, it would seem prudent to restrict usage to only R1, R2 and R3 (Fig.7), thereby avoiding p-n junction effects.

Use the resistance function on a digital multimeter to measure resistances of single resistors, and series and parallel combinations.

Because of the 1 : 1 and 1 : 2 resistance ratios, the combination rules for series and parallel should be readily discernible.

The chip should be mounted on breadboard. To make connection from a multimeter or power supply, there should be sets of leads which are 4 mm to miniature clip-on. Some short lengths of 0.6 mm insulated copper wire with bared ends should also be provided. A variety of lengths between 15 mm and 60 mm should suffice.

This initial experience might be used as a training exercise in the use of breadboard, and wiring the chip.

Factors affecting resistance

The lengths and breadths of the resistors are all specified. Comparing these with measurements of resistance, the proportional relationships $R \propto l$ and $R \propto 1/w$ can readily be obtained. Since the resistance layer thickness is constant across the sample, the latter relationship also implies $R \propto 1/A$.

The proportional relationship between length and resistance is apparent from measurements of resistance of R1, R2 and R3, and their series combinations.

The inverse relationship between cross sectional area and resistance can be seen by comparing the resistances of R3, R5, R6 and R7.

These exercises on length and area are really another way of considering the rules for series and parallel combinations. It can be thought of as playing with boxes. Each resistor can be envisaged as comprising of a group of square sectioned slabs of resistor material. These can be combined in any arrangement to give any value of resistance.

Each box can be thought of as representing a unit of resistance. If added in series (Fig 8), the box number, length and resistance all increase. If added in parallel, resistance halves for each doubling in width.

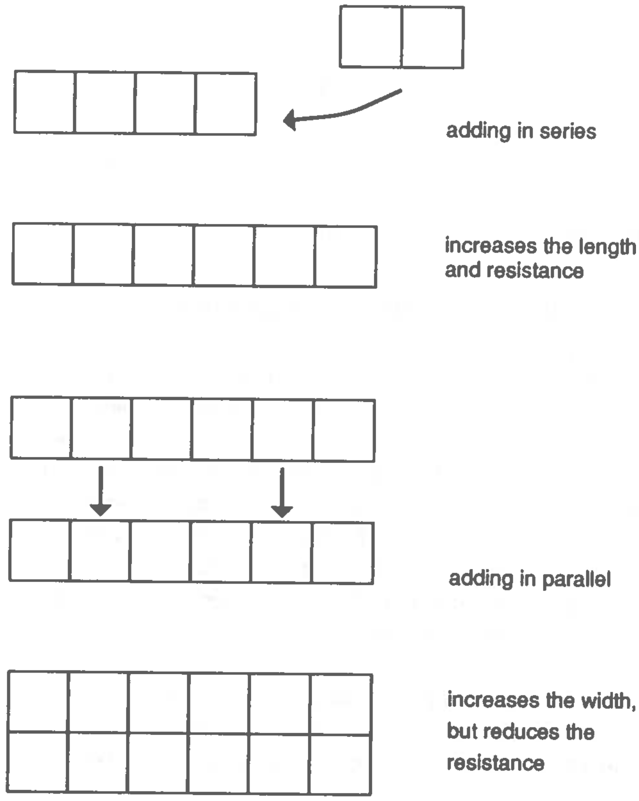


Fig.8 - Series and parallel combinations

It becomes apparent that any square of resistance material, whatever its surface dimensions, has the same resistance (Fig.9).

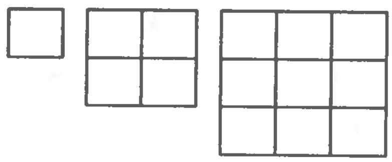


Fig.9 - Equal resistances

You may also wish to use the half square idea (Fig.10) to show that all geometries can be divided into squares.

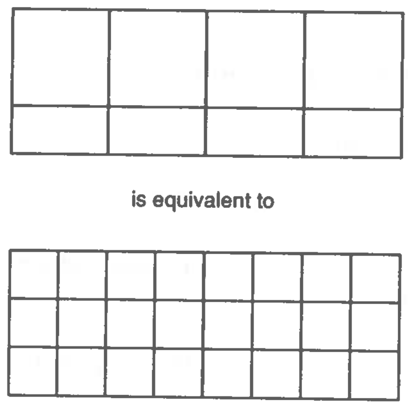


Fig.10 - Equivalent geometries

This is possible because thickness is uniform.

$$R = \frac{\rho l}{A} = \left(\frac{\rho}{t}\right) \cdot \frac{l}{w}$$

The bracketed term (ρ / t) is constant for a resistor material of set resistivity and thickness. The term is called *sheet resistance* and is measured in ohms/square.

Spreading resistance investigation

The resistances across the various contacts of the spreading resistor R9 can be measured and compared. If using pin 13, the resistor to substrate junction should be negatively biased. That is, the potential on pin 13 should always be positive with respect to any other terminal. To ensure this, the test probe from a multimeter's *OHM* terminal should be connected to pin 13, and the other probe from a multimeter's *COMMON* terminal should be connected to any other part of R9.

When interpreting the readings, the current path should be thought of as comprising an array of box-like resistors. This simplifies to a series of mixed-sized, square boxes (Fig.11).

Think of spreading resistor current flow as being analogous to water entering and leaving a tank through inlet and outlet pipes.

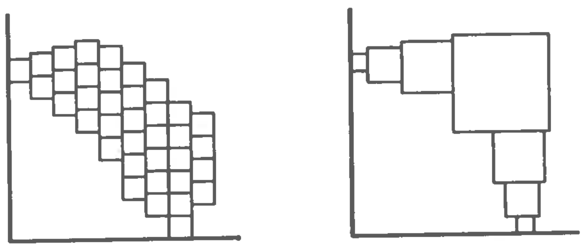


Fig.11 - Current path through spreading resistor

Resistivity determinations

Resistivity is calculated from the formula

$$\rho = R A / l$$

For the metal resistor R4, the resistance at 20°C is 29.6 Ω, giving a resistivity of

$$\rho = (29.6 \times 10 \times 10^{-12})/(10150 \times 10^{-6})$$

$$= 0.029 \times 10^{-6}\ \Omega\ \text{m}$$

This value is about 10% higher than the values for aluminium published in *Kaye & Laby*, or *The Rubber Handbook*, which relate to the pure form of the metal. Our higher value is caused by an increase in scattering within the resistor material due to the addition of silicon in the metal.

For p-type silicon, the resistance of R1 at 20°C is 1130 Ω, giving a resistivity of

$$\rho = (1130 \times 30 \times 2.4 \times 10^{-12})/(840 \times 10^{-6})$$

$$= 97 \times 10^{-6}\ \Omega\ \text{m},$$

which is between three to four orders of magnitude higher than the value for the metallic conductor.

Temperature dependence

If a finger is pressed firmly on the chip, then after a minute or so the resistance of the metal resistor R4 can be seen to rise by about 0.2 Ω, showing its temperature dependence. There is a greater amount of lattice vibration within the aluminium crystal. That causes more electron scattering, and therefore an increase in its resistivity.

For a fuller investigation, the Chip should be placed in an oven - perhaps a simple, home-made one - with an upper limit of 80°C.

A water bath may be used instead, provided that there is no immersion! A 100 cm^3 sized beaker is suitable. This should be sat balanced on top of the chip, waiting about two minutes to allow the temperature of the resistor to settle. The method suffers from the fact that there is bound to be a temperature gradient across the chip from top to bottom, the resistors never quite attaining the same temperature as the water bath. However by restricting the temperature range to within 20°C of room temperature - say from 0°C to +40°C - the error may not be too significant.

This restriction should also prevent the glass cover from being fractured by thermal shock.

The temperature coefficient α of the resistors may be found from the relationship

$$R_1 = R_0(1 + \alpha(T_1 - T_0))$$

Values in *Kaye & Laby* and *The Rubber Handbook* for the temperature coefficient for aluminium are 0.0045/°C (0°C to 100°C) and 0.00429/°C at 20°C respectively. The value obtained by us for the metal resistor R4, using the water bath method, was 0.0028/°C. At least it is the same order of magnitude! The error direction almost certainly indicates the failure of the resistor to attain the bath temperature. Clearly there is more here to investigate.

An out of balance bridge circuit (Fig.12) could be employed to monitor the chip's internal temperature. The fixed value resistors should be external components positioned in such a way that their temperature remains constant throughout the period of observation.

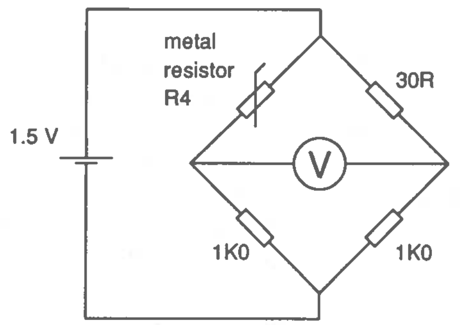


Fig.12 - Circuit to monitor chip temperature

A technique for nulling the temperature dependence of resistors can be shown by using any two of R1, R2 and R3 as potential dividers (Fig.13). Because the resistors are mounted alongside each other, they are subject to the same thermal effects. Thus their resistances shift by the same proportional amount. You should therefore be able to show that the ratio of the p.d's. dropped across them is independent of temperature.

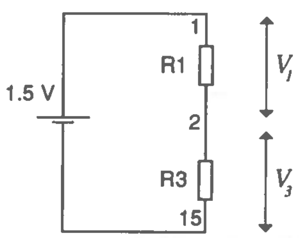


Fig.13 - Temperature independent circuit

Light dependence

The resistors, apart from R4, show a small light dependence. As the explanation is quite complicated, you are advised not to investigate this effect at depth.

We record here merely the pattern of observations which occur, making no attempt to interpret them.

To produce dark conditions, the chip was covered with an empty 35 mm film canister. Light conditions were normal daytime room lighting.

R1 to R3 and R8	Resistance diminishes with increasing light intensity; e.g. R3 = 2.26 kΩ (dark), R3 = 2.22 kΩ (light) (effect more marked under one polarity for some resistors)
R4	Light independent
R5 to R7 and R9	If p-n junction reverse biased, resistance diminishes with increasing light intensity; e.g. R6 = 565 Ω (dark), R6 = 562 Ω (light) If p-n junction forward biased, resistance increases with light; e.g. R6 = 565 Ω (dark), R6 = 568 Ω (light)

V-I characteristics of resistors

V-I readings can be obtained in the usual way for all the resistors (Fig.14), except that for R5, R6, R7 and R9 the supply polarity should be chosen so that it reverse biases the p-n junction between the resistor and substrate (connect substrate contact pin 13 to positive side of supply if using any of these resistors).

The maximum power dissipation in the chip is 250 mW. The current should be limited by working only with a very low voltage supply, or adding a series resistor, or using both of these means. Because of its low resistance, R4 is the resistor most in need of protection.

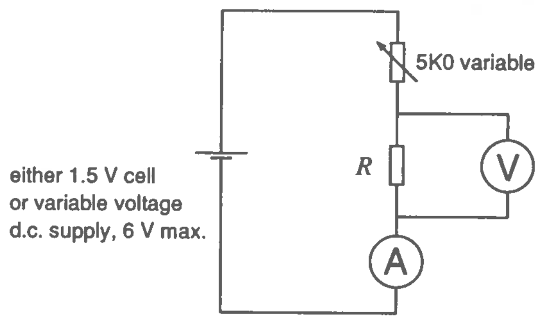


Fig.14 - Circuit for investigating V-I resistor characteristics

For all the resistors, there is a linear relationship between *V* and *I* for low currents and no illumination.

V-I characteristics of p-n junctions

These can be obtained using any of the methods described in Bulletin 172 [1]. The most accurate of these is illustrated here (Fig.15).

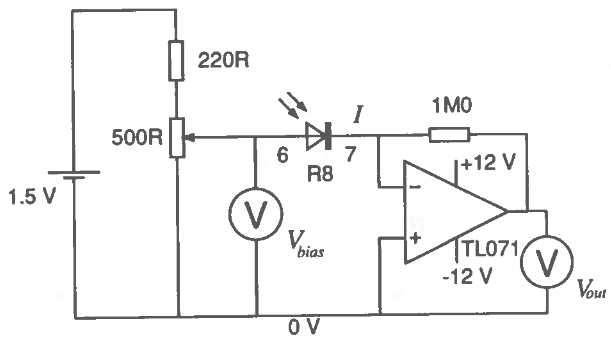


Fig.15 - Circuit for investigating V-I p-n characteristics

It shows a forward biasing voltage being applied to the p-n junction between the n-type resistor R8 and the p-well into which it is diffused. The p-well contact pin 6 is connected to the positive bias potential. The resistor contact pin 7 is held at 0 V by the action of the op-amp.

This op-amp circuit behaves as a current to voltage converter. The current I through the p-n junction continues entirely through the 1 MΩ feedback resistor to establish a p.d. V_{out} across it. This is registered on the voltmeter. The current I is related to V_{out} by Ohm's Law:

$$I = V_{out}/10^6$$

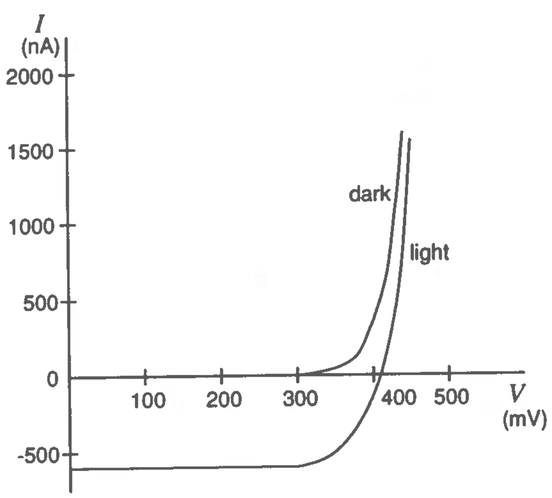


Fig.16 - V-I curves for R8 p-n junction

There are p-n junctions between all the p-type resistors and the n-substrate, and also between the n-type resistor R8 and its p-well. All are light sensitive and behave like photodiodes. An example characteristic set of curves for R8 is shown (Fig.16).

Hall effect

To exhibit the Hall effect, the spreading resistor R9 should be used. It is a square slab of doped silicon, with electrical contacts on every side. An assumably uniform current can be driven across R9 by connecting the substrate contact pin 13 to the positive terminal of a supply, and commoning the three opposite terminals (pins 9, 10 and 11) to the supply's negative terminal (Fig.17). If a voltmeter is connected across pins 8 and 12, a Hall voltage is registered in the presence of a magnetic field.

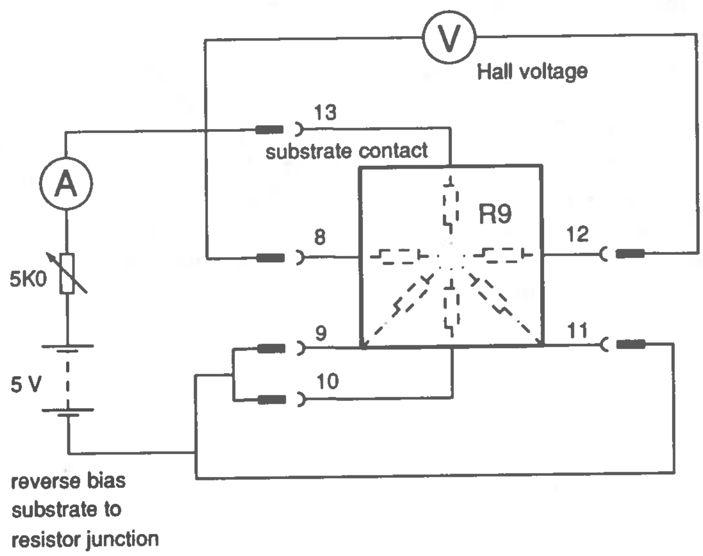


Fig.17 - Circuit to exhibit Hall effect

As before, the current should be variable, but capable of being limited, either by keeping the supply voltage down, or by incorporating a series resistor.

The field should be strong. A single magnadur magnet face down on the chip suffices, and a partner mounted underneath the breadboard strengthens the field and enhances the Hall voltage (Fig.18). Five times more effective still are neodymium magnets, modern rare earth magnets that have recently become available.

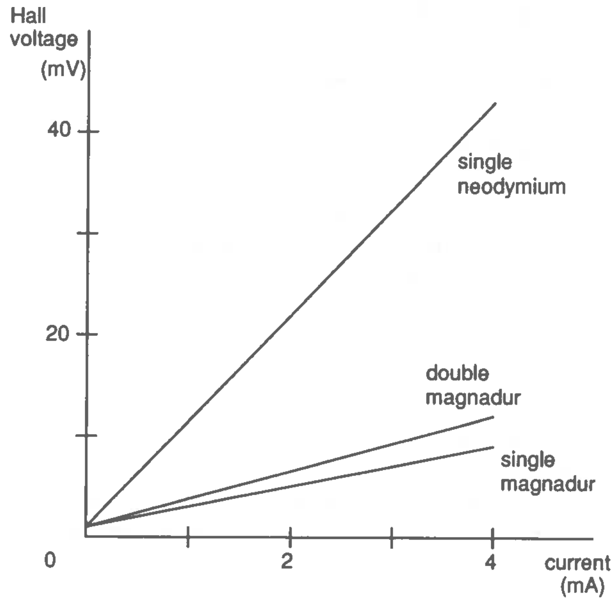


Fig.18 - Hall voltage dependence

D-A converter

Because the resistors are in a simple 1 : 2 : 4 : 8 ratio, and because they are thermally matched, they lend themselves to being used in D-A conversion circuits. Two ideas are shown.

Binary weighted converter

Using the four resistors R3, R5, R6 and R7 (Table 2), a *binary weighted converter* can be constructed (Fig.19). This gives 4-bit conversion. Some care should be taken to keep the substrate positively biased.

Resistor	Relative value	Resistance (Ω)
R7	*R*	283
R6	2*R*	565
R5	4*R*	1130
R3	8*R*	2260

Table 2 - Resistor values in binary weighted converter

Using a -1.5 V signal supply voltage and 1 kΩ feedback resistor, the output signal V_{out} when all the switches are closed is :

$$V_{out} = -(-1.5)[(1/R) + (1/2R) + (1/4R) + (1/8R)] \times 1000$$

To prevent the op-amp's output becoming saturated, a ±15 V dual rail supply should be used with the resistor values shown (Table 2). The size of a 1-bit step is about 0.69 V.

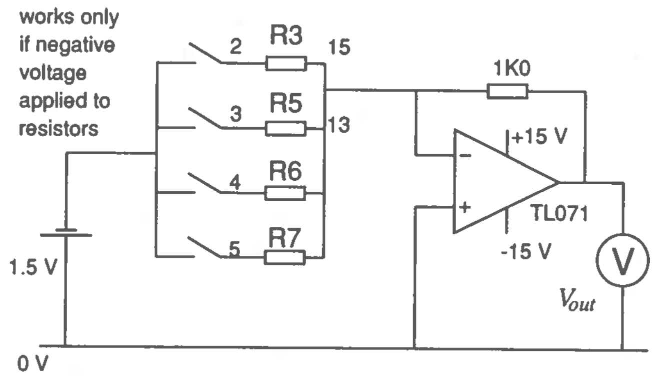


Fig.19 - Binary weighted converter circuit

R-2R ladder network

In practice, because of the difficulty of trying to match resistors of widely differing values, D-A converters usually employ another type of resistor network that uses only two resistor values. This is the *R-2R ladder network.*

Only a 2-bit converter can be built from the resources on one chip, but two chips could be cascaded to provide 4-bit conversion. The resistors to use are R1, R2, R5 and R6 (Table 3).

Resistor	Relative value	Resistance (Ω)
R6	*R*	565
R1	2*R*	1130
R2	2*R*	1130
R5	2*R*	1130

Table 3 - Resistor values in R-2R ladder network

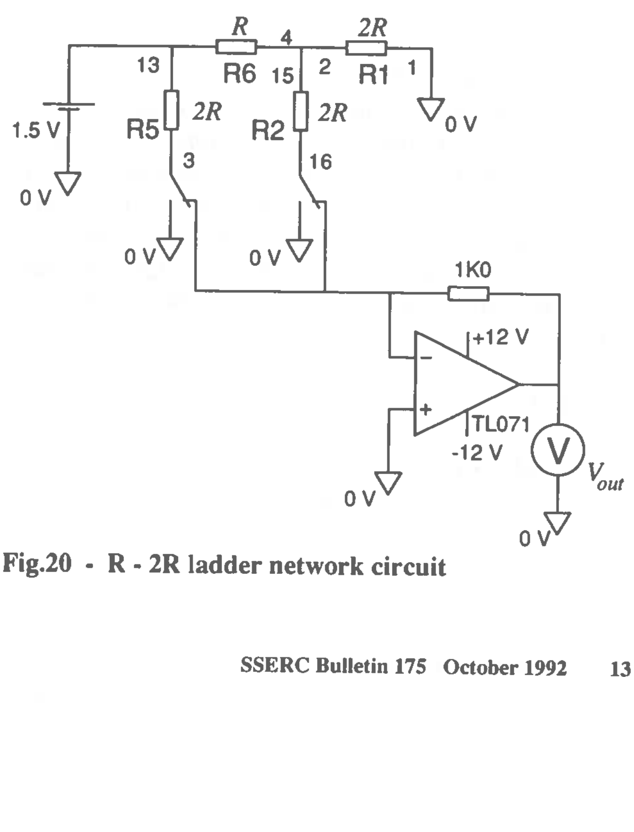


Fig.20 - R - 2R ladder network circuit

The circuit (Fig.20) ensures that each branch in the resistor network is equally weighted. For instance, current from the 1.5 V signal source precisely divides in two at the first junction it meets because the resistance to 0 V line on both routes is equally $2R$. And so it is at each successive node down the R-2R ladder network.

In both D-A circuits (Fig's 19 and 20) the value of the op-amp feedback resistor is only 1 kΩ. It deserves comment. This value acts as rather a heavy load on the op-amp output, causing the voltage at which the output saturates to be reduced. In both these circuits, you get away with using a feedback resistor as low as this with our choice of op-amp, the TL071. But as a rule of thumb, this is really as low as you should normally work with.

Summary

The article illustrates some ideas for practical work with Schools Chip 1, one of a set of four chips specially devised for schools by Edinburgh University, Motorola and Compugraphics.

The structures on the chip have many common physical features, but differ from one another by sometimes only one or two physical factors. Many of these differences relate to one another by simple proportion. In science, the design therefore lets you devise experiments to investigate what happens if? In technology, the design lets you choose the optimum structure from a selection of related parts. From either stance, it lets you look at modern semiconductor engineering. The basic materials - conductors, semiconductors and insulators - and the basic structure - the p-n junction - are there to explore. And perhaps even to marvel at!

Acknowledgements

The author attended a three day course on the Schools Chips run jointly by Edinburgh University, Motorola and Compugraphics and is indebted to the organisers from these establishments, namely Professor John Robertson, Tony Joyce, Mark Richards, and their colleagues. He also acknowledges use of the teaching materials written jointly by John Robertson and Peter Bates, now head of the electronics department at West Lothian College of Further Education. A final thank you goes to John Robertson for his comments on the text.

Reference

1. *Higher Grade Physics : Photodiodes*, SSERC Bulletin 172, January 1992, pp 16-21.

Chips 2, 3 and 4

The other three chips are briefly described below.

Chip 2 : MOS Transistor Chip

This contains eight field effect transistors, four n-type and four p-type, whose surface areas differ from one another by simple ratios.

Additional to making circuits such as logic gates, and static and dynamic RAM, matters to investigate include:

- effect of size?
- is the device symmetrical?
- how does substrate and well bias affect operation?
- effect of light and temperature on leakage current?

and so on.

Chip 3 : Optoelectronic Chip

This contains nine diodes, six being designed as photodiodes. The surface areas of the diodes relate to one another by simple ratios. Some structures are compact (planar diodes). Others are greatly elongated with a large edge to surface area aspect (edge diodes).

There is scope to investigate diode characteristics, which can be related to area and edge effects, speed of response, optical and electrical frequency dependence, power generation and photodiode arrays - amongst other things!

Chip 4 : Ring Oscillator Chip

Unlike the other chips in the series, the Ring Oscillator contains complex electronic structures. The basic oscillator comprises 401 inverters. These can be used in total, or selected in smaller stages using on-board decoding facilities. There is also a divider, giving division between 2^5 and 2^{20}.

There is scope in this structure to

- investigate the dependence of frequency on voltage, temperature, time, light and number of stages;
- estimate the delay time of a single inverter;
- estimate the speed of an electrical pulse;
- estimate the power requirement per stage, and the total power dependence on frequency;
- find the mimimum working voltage;
- investigate capacitive loading.

TECHNICAL ARTICLES

Revised Higher Grade Chemistry - radioactivity

Practical work relevant to Unit 8 : Radioisotopes in the revised syllabus is described.

Introduction

This account concentrates mainly on methods for the detection of radon and in particular the use of TASTRAK.

We begin however with some notes on other areas of Unit 8, where practical work on ionising radiations is either required or is useful in illustrating the learning outcomes. For these activities brief details or signposts to readily available equipment and other sources of information are given.

Some of these materials and necessary items of equipment have been in use in school physics departments for many years and should not need to be separately purchased for chemistry.

Safety

Teachers handling the radioactive materials described, or any others, should ensure that they are following the relevant regulations by observing *Local Rules* and the practical recommendations given in the *SSERC Explanatory Notes* [1].

In summary, the main ways of minimising any radioactive dose are provided by:

- reducing the time of exposure

- keeping at a distance from sources and only handling the sealed sources with tongs, i.e., making use of the inverse square law

- using perspex shields

- wearing gloves and conducting the measurement of the half-life of protactinium in a tray lined with a proprietary bench protector/absorbent (such as Benchcote).

Sources are to be carefully and securely stored. They are to be logged in and out. Radioactive Hazard warning signs should be displayed.

Nature and properties of radiation

The relevant syllabus entry for this section of the work is shown in Table 1.

LEARNING OUTCOMES	*ACTIVITIES*
LO 5 Describe the nature and properties of alpha-, beta- and gamma radiation	*Observe a demonstration of the absorption of alpha radiation by paper, beta radiation by thin aluminium and gamma radiation by a thick piece of lead*

Table 1 - Learning Outcome 5

Practical demonstration

This is best done with proprietary kits such as those made by Panax, Griffin, Harris or Irwin. The best sources to use are:

Am-241 (mainly α with weak γ),
Sr-90 (β) and
Co-60 (γ)

Other useful items in the kit are:

- a collimator if you want to show the deflection of β - particles in a magnetic field, and

- a rack and bench stand for holding sources and sheets of absorbers.

Since alpha radiation is absorbed by air it is necessary to hold the the GM tube close to the Am-241 source, measure the radiation and then to interpose paper, aluminium etc.

Random nature of decay

The relevant syllabus entry is as shown in Table 2.

The randomness of radioactive decay will be encountered whenever a series of background counts is taken for any experiments or other measurements. It thus may not necessarily be examined as a separate and specific item.

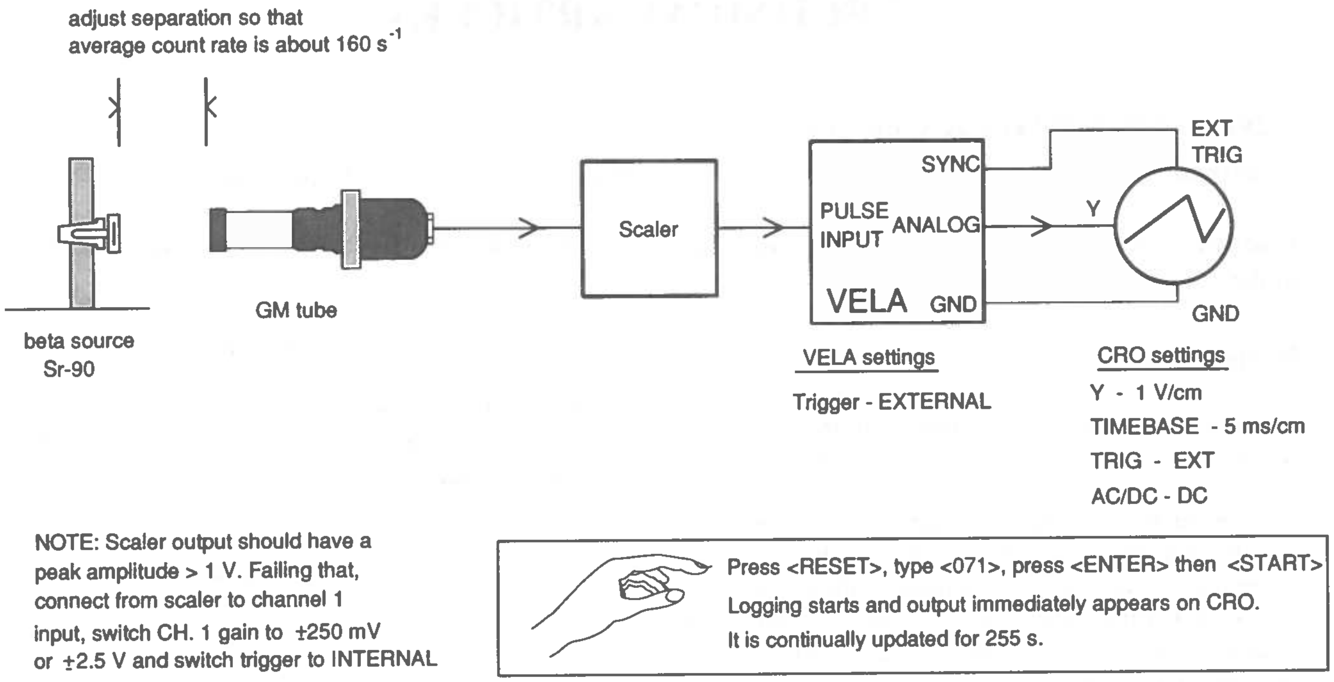


Fig.1 - Following a decay, manual or semi-automatic reading

LEARNING OUTCOMES	*ACTIVITIES*
LO 7 State that the decay of individual nuclei within a sample is random and independent of the chemical or physical state	*Use a simulation or watch a demonstration of the decay of a radioisotope. (Measurements of count rate can be captured by computer and displayed)*

Table 2 - Learning Outcome 7

VELA has relevant programs. With the set-up shown in Fig.1 and using program 07 a scatter of count rates can be built up and displayed in real time on an oscilloscope screen [2]. With program 09 a frequency curve showing the bell-shaped Gaussian distribution will be built up.

Plotting a decay curve

One of the easiest decays to follow is that of protactinium especially if you use a scaler with an automatic reset. The method using a protactinium generator is tried and tested and has been adopted by your physics colleagues; all the necessary equipment will probably be available already in the school (Fig.2).

It is just a case of giving the generator or *cow* a good shake, inverting it under the GM tube and then counting for 10 second periods allowing 5 seconds to note the reading and reset the counter for the next 10 second sampling. With the counter switched to automatic reset, the rest period is long enough for the count rate to be directly plotted onto the graph paper; the whole operation is complete in little over half an hour and the half-lives can be read off the graph.

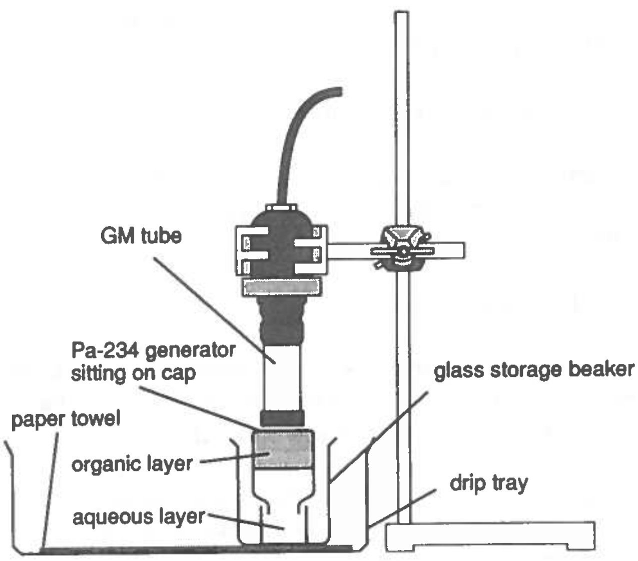


Fig.2 - G-M tube and protactinium generator

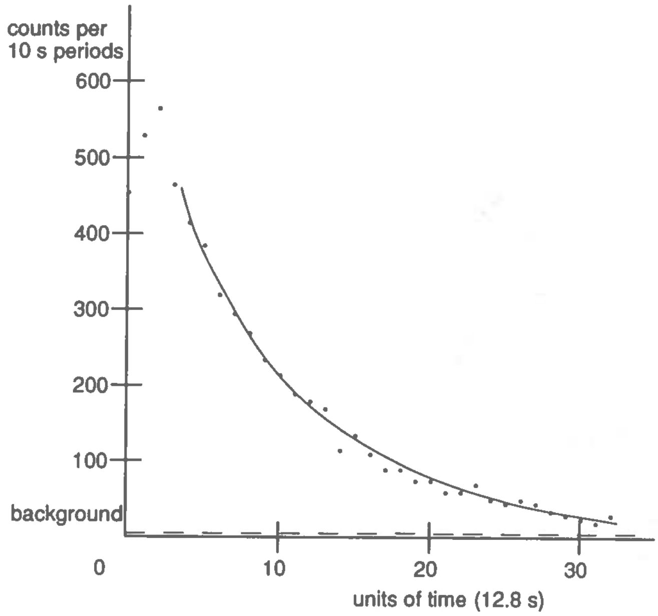


Fig.3 - Decay curve from protactinium-234

The plot shown in Fig.3 was produced with a Harris Digicounter (Cat. No. P67410/8) set to "automatic" with a 10 second counting period. It will sample for 10 s, hold the final cumulative count for 2.8 s, then reset and count for the next 10 s, etc. If a repeat is wanted all that is needed is another shake of the cow! Note that the observed count rose during the first minute. This is not cold fusion! The organic layer was still separating during the time the first few readings were being taken.

Details are available in Bulletin 158 [3], or in Standard Grade Physics Technical Guide Vol. 2, Activity 30 [2]. If either of these is not available to you please let us know and a copy of the experimental details will be sent. Your attention is also drawn to an update article on the protactinium generator in the *Technical Tips* section of this current issue of the Bulletin.

The above method is convenient and the graph plotting is finished as soon as the decay is close to completion. The use of a datalogger or interface and computer confers little or no advantage. In any case the drawing of the graph by hand gives experience and practice in the handling of half-life calculations as required in Learning Outcomes 8 and 9. We know however that there are some who like to interface everything that moves or ticks and so will provide a few pointers.

Note that the use of Thoron generators or *cows* is no longer allowed in Scottish schools. This is because of the near impossibility of meeting the contamination limits laid down in the Ionising Radiations Regulations. This discontinuation followed best advice from NRPB and relevant HSE specialists. For some as yet unfathomable reason - since it may put them in breach of the Regulations - English and Welsh schools have been allowed by the DFE Administrative Memorandum 1/92 to continue using these open, powder based, sources.

Interfacing

Four possible ways of interfacing are to use the following means:

- VELA and an oscilloscope. This shows a poor quality trace in real time, but at the end the data can be abstracted and manually plotted or the data can be downloaded to a BBC Microcomputer and then plotted using Datadisc.

- The 'Simple GM Interface' and Harmony software package from Unilab (Cat. No. 532.006, £87.84). This will allow you to display the data graphically, to plot $\log_e$(count) against time, to read off the decay constant from the slope of the log graph and hence to get the half-life. The level of maths is akin to that used in the kinetics section of CSYS Memo 16, and may be considered too difficult for many Higher pupils.

- *Teller* software and the Unilab (*big orange box*) Interface. These may well be available in the physics department.

- the Harris *Ratemeter Sensor* (T12440/1, £79.20). When used with a standard GM tube it produces a voltage proportional to count rate. This is an addition to their Blue Box sensor range and its output is suitable for use either with the Datadisc connector box or their newer *Universal Interface*.

Sources of background radiation

Again the relevant syllabus entries are tabulated below (Table 3).

LEARNING OUTCOME	*ACTIVITY*
LO 11 Give examples of the common sources of background radiation, to include cosmic radiation, radon (as a decay product) and artificial sources.	*Prescribed Practical Activity.* *- measure the background count of radiation.* *- GM counter can be interfaced with a computer to record and display results.* *- background alpha radiation (due to radon and its decay products) can be measured by using the plastic, CR-39 or TASTRAK) which is then etched by sodium hydroxide solution.*

Table 3 - Learning Outcome 11

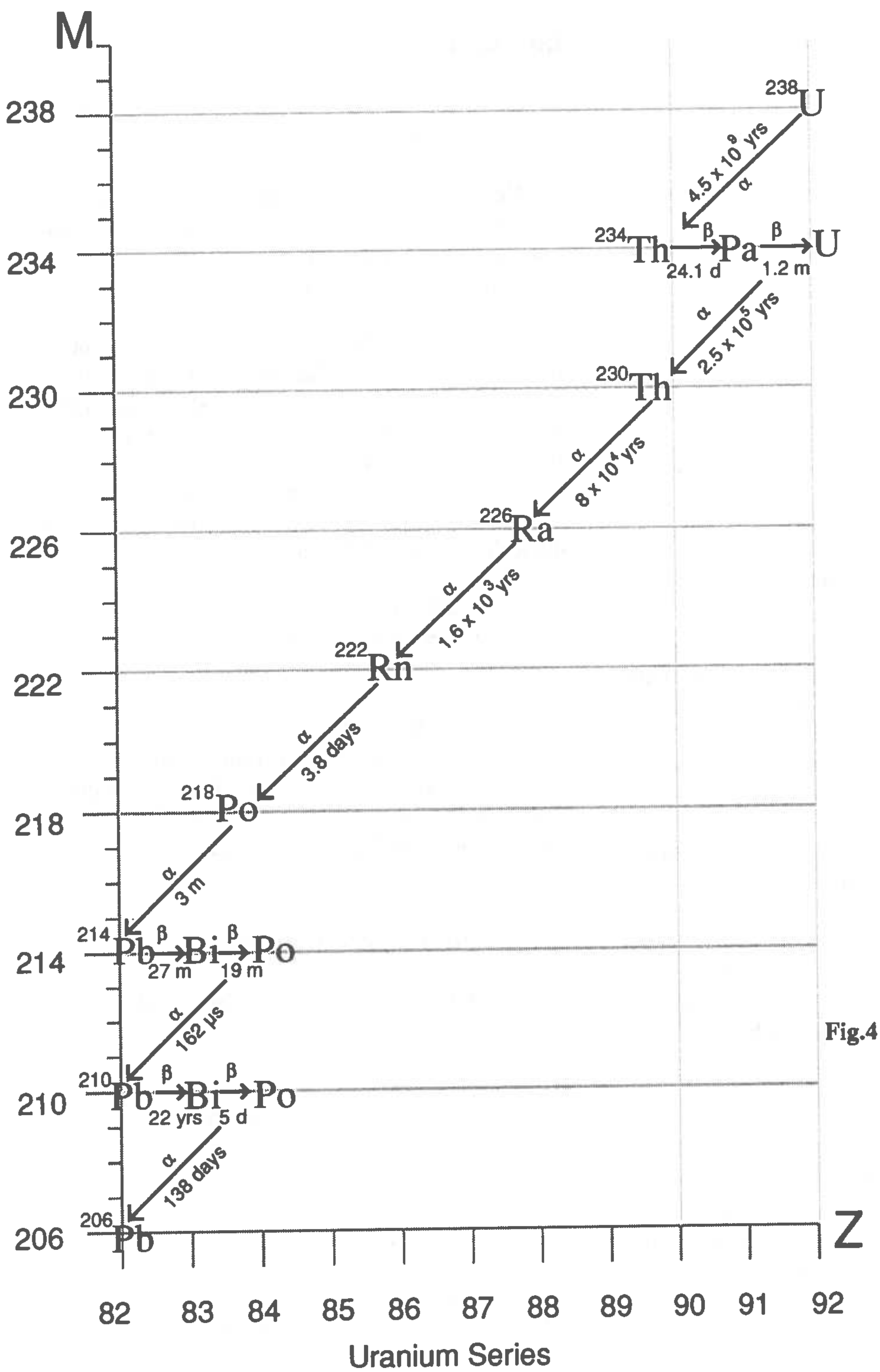


Fig.4 - Uranium-238 decay series

Possible practical work

This can include:

- measuring the background activity of the air in the lab with a GM tube and scaler

- repeating the measurements with the end window of the GM tube close to samples of various rock types collected locally and elsewhere. Counts on such samples will usually have to be over a longer time period, say 100 s or greater, to see any differences from background. If you are getting a significant difference above the background count in period of 10 s, take care how you subsequently handle that sample of soil or rock!

- estimating radon levels in different rooms at home or in school either measuring the activity of the dust collected with a vacuum cleaner [4] or by using TASTRAK [5].

More details on how radon is generated and of suitable methods of measuring it are given in the next section.

Radon formation

Radon-222 is one of the intermediate daughter products in the decay chain starting from ^{238}U (Fig.4) ; the latter is ubiquitous in most soils and rocks, but can be present in higher concentration in some granites and shales . The greater the concentration of ^{238}U in the soil or rock type the higher will be the rate of formation of radon.

Uranium-238 has a longer half life than its daughter products. During the earth's lifetime (4.5 x 10^9 years) much of the ^{238}U will have moved through its decay chain and the amount of radon (^{222}Rn) in a given rock and soil will be fairly constant. Being gaseous it diffuses through porous rock types like sandstone or through cracks. At depth most of the radon gas will decay into solid daughter products before it can reach the surface. However the half-life (3.8 days) is long enough to allow radon gas formed near the surface to escape into the atmosphere before decaying.

Once in the air the solid daughter products of radon usually become adsorbed on fine particles of dust. These may be inhaled. It is a pity that radon does not have a very short half life, for then most of it would decay into solid daughters before it left the ground.

There is also a small contribution of radon (^{220}Rn) which is formed in the decay series which starts with thorium-232. The amount of radon escaping into the air from this source is generally small due mainly to the shorter half-life of this isotope (55 seconds).

Variation in radon levels

National and international

Some areas of the U.K. have higher concentrations of radon than others, particularly at recognised 'hot-spots'. Typical orders of magnitude of activity figures are:

> 100 to 1000 Bq kg^{-3} in soil and 100 Bq m^{-3} in houses in the UK [5].

The corresponding figures from a survey in one part of North America are somewhat different, being:

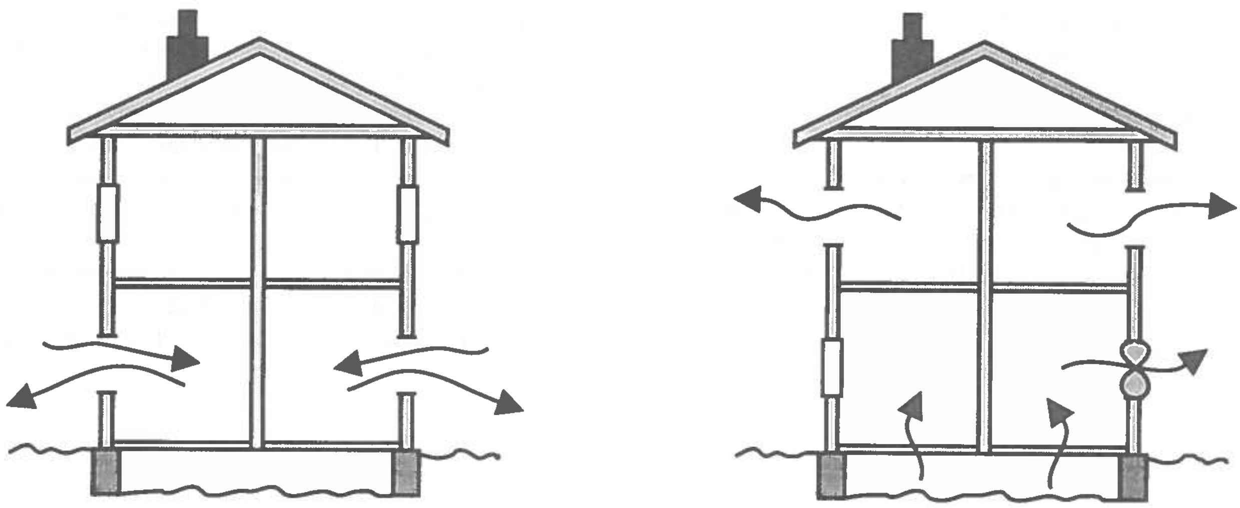
> tens of kBq m^{-3} of soil, 5 to 10 Bq m^{-3} in outdoor air and 50 Bq m^{-3} in a house [6].

Within buildings

Air inside buildings has higher concentrations of radon than the air outside. This is mainly because of a chimney or stack effect. When a building is heated the hot air inside rises and air pressure in the ground floor rooms is reduced to slightly below that of the atmosphere. Thus radon in the soil underneath the house is driven up into the lowest rooms.

The concentration of radon in a house will be increased by its having :

- soil with higher concentrations of uranium underneath it;



upper windows closed, ground floor ventilation limits radon entry as pressure is equalised

upper windows open, ground floor windows closed, extractor fan on,
this type of ventilation increases entry of radon as internal pressure is reduced

Fig.5 - Effect of ventilation on radon levels

- porous sandy soil or broken rock rather than compacted clay in the top layers just underneath the house;

- a bigger chimney effect due to size and geometry of the house and the amount of heating used; ventilator extraction fans will also decrease the pressure inside;

- reduced ventilation (for example through draught-proofing as part of energy conservation measures, which can more than treble the radon levels).

Paradoxically opening the windows on the upper floor can add to the chimney effect and draw more radon into the lower floor (Fig.5).

Radon in water

Radon can also be transported into a house dissolved in water and be released when that water is heated in the open. The gas is very soluble in water (23 cm^3 in 100 g water at 25°C and 13 cm^3 at 50°C). When water containing radon is heated, as in cooking or in a shower, a lot of dissolved radon will be driven out into the air. The kitchen and the bathroom can indeed be relatively dangerous places with levels of up to four times that found in the living room.

It is interesting and revealing to calculate the mass of radon driven out of a litre of water saturated at the lower of the above temperatures. A nice little teaching point is the trend in solubilities of the inert gases in water; the values for helium, neon, argon, krypton, xenon and radon show a rise in solubility with increasing atomic number. Some water supplies from deep wells or from aquifers may contain high concentrations of radon, but most surface waters contain little.

Other scintillating liquids

Doing this calculation reminded me of a certain night aeons ago. After one of those many evenings between sitting the last paper of finals and awaiting the dreaded list which would eventually be pinned up in the cloisters, I returned to the chemistry department with a few collaborators to carry out some unfinished fundamental research.

A drop of the dark liquid fed into the Prof's spanking new Vickers mass spectrometer revealed largish amounts of partially deuterated ethanol and ethanoic acid in addition to the normal hydrogenated variety. Since that time we have speculated about the water supply for this brewery having flowed through radioactive rock formations in the Wicklow mountains.

Health considerations

When air containing either radon or its daughter products adsorbed on small dust particles is inhaled, various mechanisms will ensure that a proportion is trapped in the lungs. The polonium-218 formed by the decay of the radon can become absorbed into the tissue of the bronchial walls.

As can be seen from the decay chain in Fig 4, two of the nuclides, Po-218 and Po-214 both decay by alpha emission and have short half lives. Their decay will cause a lot of damage to tissues since alpha particles are both heavy and highly charged. This internal exposure to radiation can lead to lung cancer.

The total annual effective dose equivalent of radiation from natural origin received by a person in the UK is about 1870 μ Sv. Almost half of this comes from radon and its decay products. Clearly it is worthwhile to take measures to reduce the intake of radon. There is evidence of synergism between smoking and exposure to radiation; that means that the effects of the two exposures are multiplied rather than additive.

The HSE, who are of course concerned with the Health and Safety at Work Act, state in their free leaflet *Radon in the Workplace* that employers are required to take remedial measures if the concentration is shown to exceed 400 Bq m^{-3}. The Action Level for homes is 200 Bq m^{-3}, the lower level reflecting the fact that most individuals spend more time in their houses than at work.

One education authority has stopped school parties visiting caves in the Peak District. Levels of up to 150,000 Bq m-3 have been found on still summer days.

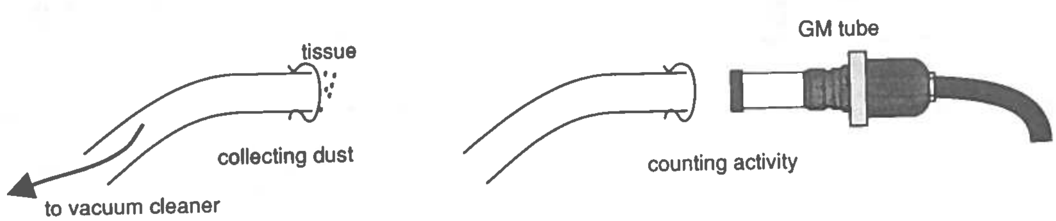


Fig.6 - Vacuum cleaner tube end and GM tube

Radon detection methods

Adsorption and measurement of activity

One ideal way would be to adsorb the gas on activated charcoal for a set number of days and then measure the gamma ray activity of the charcoal. Only those with friends in university departments will have access to an appropriate counter. If you do have such facilities available it would be interesting to compare the results with those obtained using TASTRAK.

Air filtration with vacuum cleaner

This is almost a poor man's version of the above. A vacuum cleaner is run for an arbitrary time, say ten minutes, drawing air though a 'filter' of toilet paper or other tissues. The activity of the dust collected is measured with the end window of the GM tube close to, but not touching, the dust (Fig.6). Doubling the time of dust collection gives twice the activity.

If times of dust collection are kept constant, good comparisons of radon activity can be made between cellars and upper rooms or between the same room at different times of the day. For example the activity in a room which had been closed overnight may be compared with that at varying times after any windows have been opened.

This method is described in detail in Bulletin 161 and elsewhere [4]. Its two big advantages are both the ease and speed of measurement, and the incredibly low cost of the one consumable item. A further extension here is to attempt to plot a decay curve for the radionuclides trapped on the dust filter. From that curve it might be possible to measure the half-life and identify some of the daughter products.

Since the used tissue paper will have become mildly radioactive, it is advisable to dispose of it carefully in ordinary refuse.

TASTRAK

This has an advantage over the vacuum cleaner method in that it gives the activity in absolute units. TASTRAK plastic plates have been calibrated against sources of known activity. The method is so easy and safe that many primary schools have been able to use it as part of a nationwide survey of radon in buildings. The two disadvantages are the high cost of the consumable material and the time taken to get a result; exposure times are long and the exposed plates have to be sent off to TASTRAK Analysis Systems Ltd (TASL) at Bristol for processing.

TASL estimate the plates to have a 'shelf life' of six months if they are kept inside their special envelope stored in the freezing compartment of a fridge.

Technical description

TASTRAK is a polymer derived from allyl diglycol carbonate (commercially known as CR-39). It is sensitive to α - particles, low energy protons and heavier ions, but is insensitive to β - particles, γ - rays, X - rays and sea level cosmic rays. This selectivity makes it a very useful material.

We do not have details of the radiochemistry of the process, but clearly it involves the breaking of some bonds by the α - particles to leave a weak or an active site which can be further exploited by the 'developer', 6 mol l^{-1} sodium hydroxide at 98°C. These developed tracks are visible under a microscope at x 100 or x 200 magnification or if projected from a slide projector. There is no equivalent of a fixer and if the developed plate is later struck by any α - particles, then latent images will be produced. However without a second development they should remain invisible.

Procedures with TASTRAK

Handling the plates

The plastic detection plates are sent out from TASL in a sealed aluminised bag with instructions to store in a fridge. When required, cut open one seam of the bag, remove the number of plates required by their edges and reclose the bag carefully, again storing the remainder in the fridge. Handle the plates by the edges. Each has a unique number inscribed on it and this is useful for identification purposes when you are setting up a lot of plates for dose measurement in different sites. Make a yoghurt pot radon detector as shown in Fig.7 keeping the scribed side upwards. Radon can diffuse through the Clingfilm.

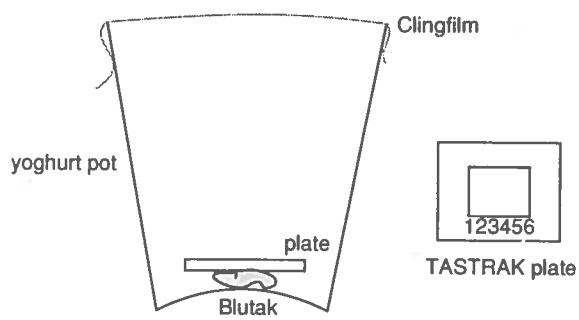


Fig.7 - Yoghurt pot detector

Exposing plates

Set the detector for a known number of days in the place where activity is to be measured. Fourteen days has been suggested as a preliminary trial, but several months may be needed to collect a reasonable number of tracks. When used for monitoring houses in America a year's exposure has been recommended. In addition to the insides of buildings the radon concentrations in the outside air at soil surface level can be measured by placing the detectors on the soil with a polythene tent rigged over it to provide protection from the weather. Here the pots should be placed upside down.

Soil measurements

Another type of measurement is the activity of the soil itself. Insert the plate into the soil and mark its position with a small stake or plant label. After exposure clean the soil off the exposed plate by holding it under running water.

Return the set of 25 plates to TASTRAK Analysis Systems Ltd for processing and state whether you intend to count the tracks using a microscope or a slide projector since the processing for the latter is different.

Counting tracks

The tracks are mostly at right angles to the surface of the plate and hence many appear in cross-section. These look like small circular bubbles in the TASTRAK plastic. A few particles entering at an angle produce more of a pear shaped droplet. Those plates which were inserted in the soil will have in addition other shapes more like clusters of miniature cloven hoof prints thought to be caused by minerals containing uranium and thorium salts.

The number of tracks in six different fields of view are counted and the average calculated. From such averages overall activities may be estimated.

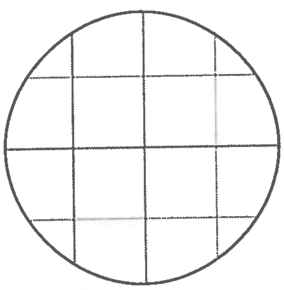


Fig.8 - Field of view on graticule

Microscopy

Measuring the area of the field of view

The first task is to measure the field of view of the microscope with the chosen eyepiece and objective combination (magnification). Place a stage micrometer (graticule) on the stage and count the number of divisions across a diameter (Fig.8) to arrive at the total diameter D of the field in mm. From there calculate the area A of the field from πr^2, where r is $D/2$. An example is given below for an Olympus model HSC.

With a x10 objective, x10 eyepiece (magnification of 100)

$D = 1.8$ mm
$r = 0.9$ mm
$A = \pi \times r^2$
$= 2.549$ mm^2
$= 2.549 \times 10^{-2}$ cm^2

With a x 20 objective this came to 0.64×10^{-2} cm^2

These calculated areas were almost identical to those found for the same objective and eyepiece combinations on a Griffin Gamma 40 microscope.

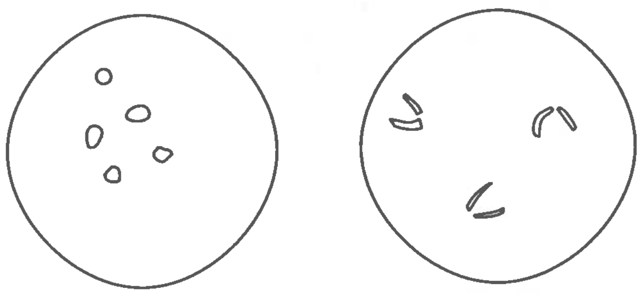


Fig.9 - Diagrams of two exposed plates

Calculating activities

Place the exposed, developed plate on the microscope stage and count the number of tracks in the field of view. They will look something like Fig.9 . Move the plate to five other positions and again count the number of tracks in each field of view. Calculate the average.

Now scale up the counts per field of view to counts per cm^2 and use the appropriate formula below to calculate the activity:

for air using the 'standard yogurt pot detector',

$$\text{activity in Bq m}^{-3} = \frac{(5.3 \pm 0.5) \times (\text{track count cm}^{-2})}{\text{exposure in days}}$$

for soil,

$$\text{activity in Bq kg}^{-1} = \frac{12 \times (\text{track count cm}^{-2})}{\text{exposure in days}}$$

These formulae can be simplified if both the field of view and the length of exposure remain constant. This is so if the same microscope and magnification and the same exposure time are used.

For example, using a microscope with the same field of view as the Olympus or the Griffin Gamma a rule of thumb would be that:

> *a count of 1 track in the field of view collected in 1 day's exposure would represent radon levels of 207 Bq m^{-3}. Results can be worked from this by simple proportion.*

If initial measurements indicate very low levels it is better to repeat the exposure on new plates for a longer time.

Projection method

If you have decided to use the slide projector method be sure not to use it for other than small exposures; otherwise the scribed 1 cm square on the plate will come up like the Milky Way and counting will be difficult if not impossible.

A simple calculation will show that if the radon detector were left in the average lower ground floor room or cellar with levels of say 60 Bq m^{-3} for 14 days the number of tracks collected in the 1 cm square would be about 200. Reducing the number of days exposure to four or five days in this case would give more manageable results. If you had no idea of the likely levels it would be wise to expose three or four radon detectors for different lengths of time. Alternatively subdivide the square into eighths or sixteenths with a fine felt-tip pen.

The slide projection method is ideal if you want a class or group to deal with this topic together. In fact comparing two projected images of plates with greatly different densities of tracks gives a strong, instant impression of the differences in activities.

Development of exposed plates

You only need undertake your own developing if you have purchased sheets of TASTRAK and cut them into plates yourself. Otherwise processing is free for the pack of 25 plates bought as the kit. The process involves handling relatively concentrated alkali and needs care. In what follows we assume that the person carrying out development will be a competent chemist or technician.

Apparatus

A 400 cm^3 squat form beaker used as a developing bath can accomodate about 5 plates at a time. If this is convenient prepare 300 cm^3 of 6.25 mol l^{-1} sodium hydroxide and pour into the beaker. Place this beaker in a water bath with the water level of the bath slightly below that of the sodium hydroxide solution. Fasten the plates onto miniature bulldog clips and hang them on a glass rod as shown in Fig 10.

You can check that the plates will be immersed by trying them in an empty beaker of the same size held alongside the one with the sodium hydroxide in it. Make any necessary adjustments to the heights of plates now.

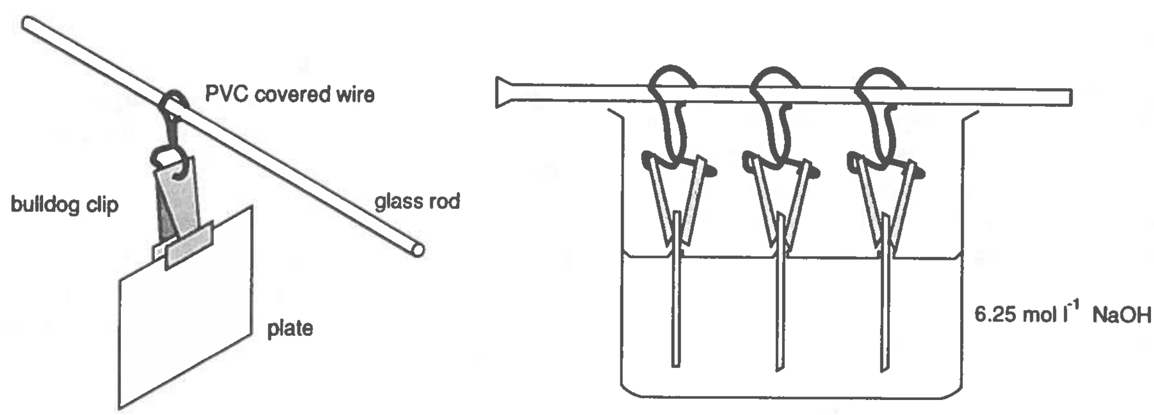


Fig.10 - Plates on rack and in batch of etchant

When the water in the bath is boiling, support the rod on the top of the beaker and the plates will be nicely immersed. After one hour switch off the waterbath. Carefully lift the rack and transfer the plates into a beaker of water to rinse off the excess alkali. Add a few cm^3 of 1 mol l^{-1} hydrochloric acid to the water to clear off any remaining alkali and rinse well by gently running water into the beaker to remove the acid.

In our trials the bath of etchant stayed around 99°C for most of the time but the recipe recommends a temperature of 98°C. To compensate for this the time of developing was reduced by 5 minutes. Clearly if the recipe cannot be followed exactly, the answer calculated from the formula determined by a calibration procedure may be slightly inaccurate.

Risk Assessments

6.25 mol l^{-1} sodium hydroxide solution is extremely corrosive.

Wear gloves and eye protection during preparation of the solution and processing. Use of a PVC apron would also be indicated.

An aerosol will be formed during the preparation and a well ventilated room or fume cupboard should be used. The solution can be used a few times if kept in a stoppered bottle. For final disposal run into a sink filled with water, neutralise with 2 mol l^{-1} hydrochloric acid and run to waste.

Costs

Squares	- pack of 25 plus kit; squares pre-scribed and numbered	£26.95 including VAT and p&p
Sheet	- 310 x 310 mm approx. this size should give at least 100 squares	£25 plus VAT and p&p

Cutting the sheet

With care the sheet can be cut into small squares. Admittedly 6 or 10 fields of view will take up very little of the sheet and you might, in the interests of economy, be tempted to make the cut pieces very small. This, however, will be more difficult to do without touching the surface. Furthermore it will be more difficult to grip small pieces by their edges only.

The sheet comes wrapped in a plastic film inside the aluminised plastic envelope. Do not remove the plastic film. Lay the sheet on a leaf of clean paper and, about 20 mm in, mark a line parallel to one edge.

Place a ruler along the mark and score a line with the corner of a small screwdriver dragged along the ruler. As in cutting glass apply gentle pressure on the narrow strip and with a small amount of luck it should come away. The strip then can be scribed at right angles to its length, every 20 or 30 mm or so and the resulting squares snapped off.

Goggles must be worn during the scribing and snapping operations. The plastic is hard, but quite brittle and sawing even with a fine bandsaw tends to produce many cracks inwards from the cut edges.

References

1. *Protection against Ionising Radiation in Science Teaching - Explanatory Notes on local rules for teaching establishments (SOED Category C)*, SSERC, 1987.

2. *Standard Grade Physics : Technical Guides*, Vol.2, *Unit 3 - Health Physics*, SSERC, 1992.

3. *Radioactive decay experiments using protactinium-234*, Physics Notes, Bulletin 158, SSERC, October 1987.

4. *Radon in buildings - a simple detection method*, Physics Notes, Bulletin 161, SSERC, October 1988.

5. *A national survey of background alpha particle radioactivity*, Camplin, G.C.et al, Physics Education 23, 212-217, IoP, 1988.

6. *How much radon is too much?*, Atwood, C.H., Journal of Chemical Education, Vol 69, No. 5, (May 1992), 351.

Other useful information

Radon in the Workplace, HSE Leaflet IND(G)123L available free from HSE.

A Householder's Guide to Radon, 2nd edition 1991, available free from the Scottish Office Environment Department. This 18 page booklet discusses how radon gets into houses, what the statistical risks to health are and how remedial building measures may be taken.

Living with Radiation, NRPB 1989. Price £3.50 from HMSO. This covers a wide spectrum of aspects including naturally occurring radiation, occupational exposure to ionising radiation, the effects of radiation, etc.

Radon in the Home, Martin, R.B., Journal of Chemical Education, Vol. 68, No 4, (April 1991), 275. This very short article shows by simple kinetic mathematical analysis that even fairly regular ventilation of a home is an inefficient way of reducing the levels of radiation; removal of radon before entry to the building is much more efficient.

Get to know your VELA - for chemists, Birrell, I.J., Instrumentation Software Ltd.,1988.

TECHNICAL ARTICLES

Biology and Human Biology
Thermistor applications

Scottish curricular contexts for such applications are indicated. Working circuits are provided which give excellent linear responses : one for general physiological work and others of ranges for ecological and other environmental investigations.

Introduction

A number of possible physiological applications of thermistor based devices occur in the new syllabuses at the Higher Grade (Table 1).

Over the years we have published a number of circuits and experimental procedures which use such temperature sensors (see for example ref.[1]). These designs tended to get simpler with each successive bulletin article. That's the good news : the bad being the resultant scattering of relevant information over a number of SSERC sources. One purpose of this present article is to try and pull all of that together into a form directly useful to biologists. A more practical aim is to provide technical details both of a suitable thermistor mounting and of a stripboard layout for a working circuit. Much, but not all, of this detail has already been published in our Technical Guides for Standard Grade Physics [2].

Technical background

Thermistors are devices whose resistance varies with temperature. Those of the negative temperature coefficient (n.t.c.) kind described here are sensors whose resistance falls with a rise in temperature. Qualities which make them useful - especially in biology - include: smallness, speed of response, accuracy and precision. They are the preferred sensor for applications requiring high sensitivity but generally over a relatively narrow working range.

The thermistors we recommend for this sort of application are known as R-T curve matched types. These are somewhat more expensive than the run-of-the mill types used as general detectors of overheating, for example, in electronic circuits.

Linear response

Thermistors tend to be basically non-linear devices and if they are not used with care that may lead to inaccurate measurement. The R-T curve matched thermistor specified (RS 151-215 or SSERC 641, same item) has however a precisely defined transfer function of resistance versus temperature. When connected into a suitably designed, but simple, circuit with the thermistor in series with a fixed resistance[1] it can be constrained to give a linear output. This means selecting a series resistor accurately matched both to the thermistor and the desired temperature range [1].

The circuit shown in Figure 1 overleaf has been designed to be linear across the range 20 to 40°C, which is just right for many physiological studies. The shape of the transfer function (Fig.2) (relationship of the output voltage to variations in the quantity being measured) remains linear irrespective of the supply voltage. But the sensitivity is dependent on that voltage. Where the supply is from a 1.5 V cell the sensitivity is close to a 15 mV change per degree Celsius. Were a calibration graph drawn up then resolution to 0.1°C or better is possible.

[1] So producing what the physicist or electronic engineer would call a potential divider circuit.

SYLLABUS	*TOPIC REFERENCE*	*LEARNING ACTIVITY*
Biology	*Regulation in Biological Systems 1. Physiological Homeostasis (c) (iii)*	*Investigate role of skin in temperature regulation (Teachers' Guide : Note 4)*
Human Biology	*Life Support Mechanisms Section 4i*	*Effect of exercise on ventilation rate of lungs*
	Section 4iv	*Response of body to rapid heat loss*

Table 1 - Curricular references to thermistors

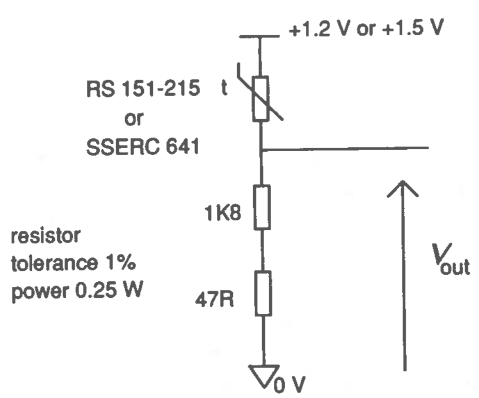


Fig.1 - Thermistor circuit giving linear response

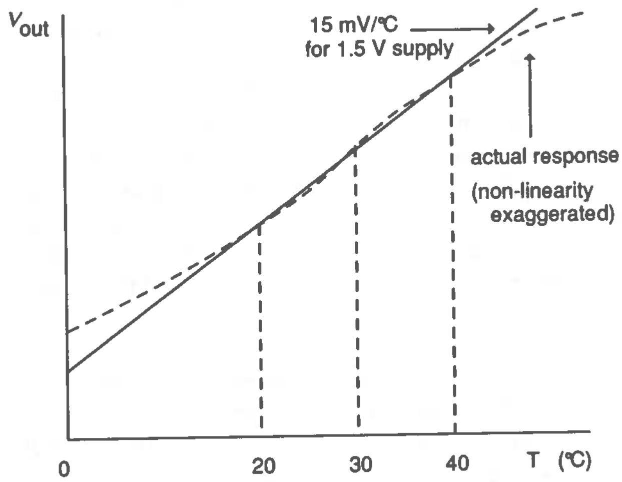


Fig.2 - Transfer function of thermistor circuit (Fig.1)

The recommended 1.5 V supply voltage should not be exceeded since the resistive heating of the thermistor itself might then become significant.

Construction and use

Thermistor probe assembly

To prevent their shorting, the leads from the thermistor should be electrically insulated. We recommend that this be done with layers of heat shrink sleeving. Three sizes are needed : diameters of 1.6 mm, 2.4 mm and 3.2 mm (see Fig.3). Also required are two 25 mm lengths of insulation removed from 1/0.6 mm insulated wire.

Connection - thermistor end, and flying lead

The thermistor should be connected into the circuit with a flying lead made up from a twisted pair of either 10/0.1 mm or 7/0.2 mm insulated copper wire. This lead is made up as follows:

Cut two 25 mm lengths of insulation removed from 1/0.6 mm insulated wire. Slide these sleeves of insulation up the thermistor legs to the bead. Cut the excessive uninsulated length of the thermistor legs down, to leave just 5 mm uninsulated.

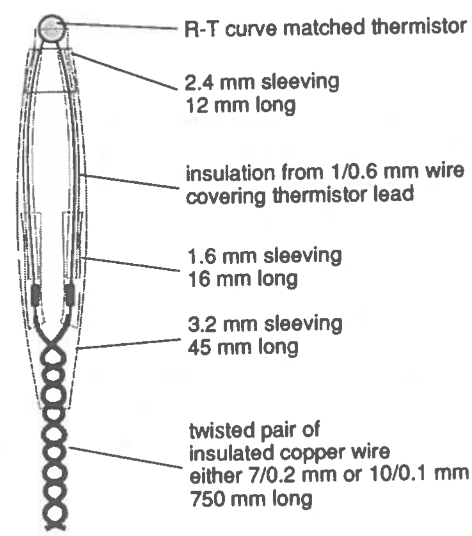
Cut two 750 mm lengths of 10/0.1 mm (or 7/0.2 mm) insulated copper wire. Strip one end of each of these by 5 mm. Tin and solder these to the thermistor. Cut two 16 mm lengths of 1.6 mm diameter heat shrink sleeving and slide them up the wires until they are fully covering the solder joints. Shrink this sleeving. This is done by using the side - not the tip - of the soldering iron to gently heat the sleeving until it shrinks over its entire length.

Now slide another piece of sleeving - this time a 12 mm length of 2.4 mm diameter - up over the assembly until it covers the thermistor to its equator (Fig.3). Shrink this piece as before.

Use a small vice to gently hold the pair of 750 mm leads immediately beyond the solder joints. Stretch the free ends taut in a V-shape and carefully turn the wires into a series of neat twists.

Cover the whole assembly as far the equator of the thermistor with a 45 mm section of 3.2 mm sleeving. Shrink this final piece so as to seal the top and bottom of the assembly and lend support to the solder joints.

Finally fit a 20 mm length of 2.4 mm diameter sleeving over the other end of the twisted pair, leaving 15 mm of free wire protruding. This secures the twists in the wire.



heat shrink sleeving, 1.6 mm Farnell 107-462
2.4 mm Farnell 107-463
3.2 mm Farnell 107-464

Fig.3 - Insulating and waterproofing thermistor leads

Connection - stripboard end

Strip each of the other ends of the twisted pair by 3 mm and tin them. Take one SK1 type socket housing (Fig.4) (or three way cable shell) and two crimp terminals.

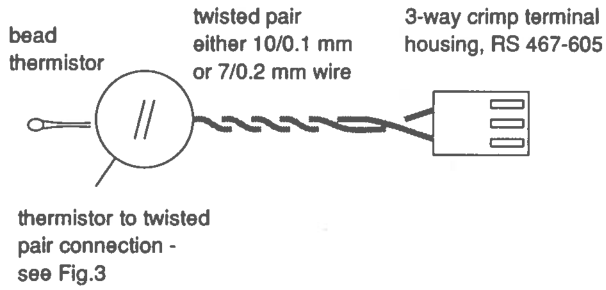


Fig.4 - Flying lead connector

Place one of the tinned wire ends in a crimp terminal RS 467-598 making sure its insulated part lies between the outermost crimp legs and that the inner legs are either side of the tinned wire. Using snipe nosed pliers press down an inner crimp leg over the tinned wire end and then repeat for the other leg. Using the same technique press down the outer crimp legs over the insulated portions of the wire. Repeat the whole sequence for the other wire in the pair.

The next step is to assemble the socket housing. Holding the SK1 housing in one hand and the crimp terminal assembly in the other : slide the made up crimps into the two outer holes leaving the centre hole unused. Gently push in the crimps until you hear a click as the clips engage. This SK1 housing will marry up with a matching male terminal provided on the stripboard circuit (Fig.5).

Stripboard circuit

A suitable stripboard layout is provided in Figure 5. Note the arrangement for strain relief where the supply leads enter the board. Those unfamiliar generally with the production of circuits on stripboard are referred to source [3].

Displaying signals

The output from the circuit is a voltage which is directly proportional to temperature (in this case 15 mV per degree Celsius - see above). This output may be read on the voltage ranges of a digital multimeter. By means of a calibration such voltage readings may be translated into temperatures. But, if all that is needed is an indication of a change and its rough magnitude such translation may not be nececessary.

Since the output voltage of this simple circuit is referenced to ground, it can be applied directly to the input of a datalogger or computer interface (Fig.6). Provided that the temperature to be sensed is in the specified range (20°C to 40°C) any logger or interface with an input specification of 0 to 1 V should be able to accept the output signal from this circuit. Given suitable software with a calibration routine, data may then be displayed directly in the correct units of temperature.

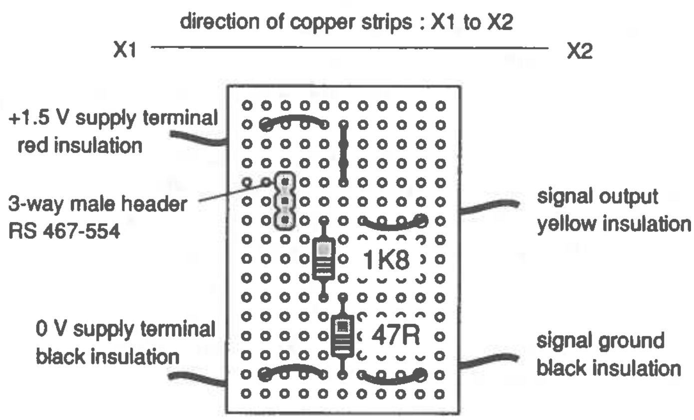


Fig.5 - Stripboard layout of circuit

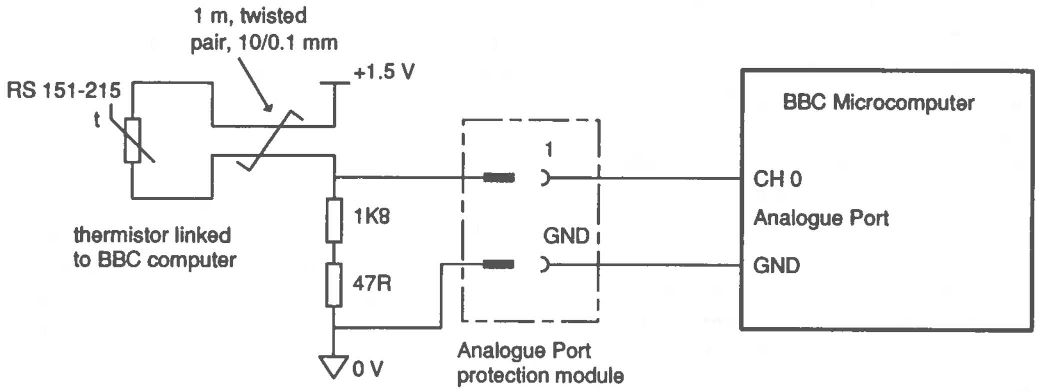


Fig.6 - Circuit to monitor temperature by computer

Physiological applications

Homeostatis

This sensor/circuit combination is that referred to in Note 4 to the SCCC Teacher's Guide to Revised Higher Grade Biology : "Regulation in Biological Systems" [4]. The activity suggested is an investigation of capillary dilation or constriction. The technique involves the use of a thermistor detector on the extremities of one limb with the same area of the opposite limb being subjected to a large change in temperature. This may be extended by looking also at changes in skin temperature as a subject temporarily affects their core temperature by, say, drinking a large glass of iced water or a mug of hot water, tea or coffee.

Of all the physiological applications of this device this is possibly the trickiest. Care is needed to establish good, steady thermal contact between thermistor and skin surface. Patience is required. This is because initially the thermistor will be at room temperature. When placed on the skin it will warm up and then eventually stabilise. It is imperative that time be allowed for that stable state to be established. If the conditions are altered too soon any small changes in skin temperature will be masked by the continuing rise from ambient in the sensor temperature.

When successful, it is well worth the trouble taken since there are so few other practical ways in which to demonstrate an homeostatic mechanism with a human subject.. The suggested complementary activity of direct observation of the nail bed capillaries with a stereomicroscope is also well worth doing. The hint given in the Teachers' Guide to clear the skin at the nail bed with liquid paraffin is a good one.

This same set of practical activities also finds application in the Human Biology course at the Higher Grade and may also be useful in relevant SEB Short Courses in Health Studies.

Temperature profile along a limb

When it is stated that normal human body temperature is 37°C this strictly refers to a mean, internal temperature (known as the core temperature). Temperatures at various points on the surface of the human body may be markedly lower than this core figure. This can be graphically illustrated by running a thermistor sensor along a limb so producing a rough temperature profile.

The sensor is placed high on the upper arm within the oxter and left to equilibrate. Select a total sampling time of about 10 s. Start sampling and slowly, smoothly run the sensor down the arm to the tip of a finger taking the 10 s allocated.

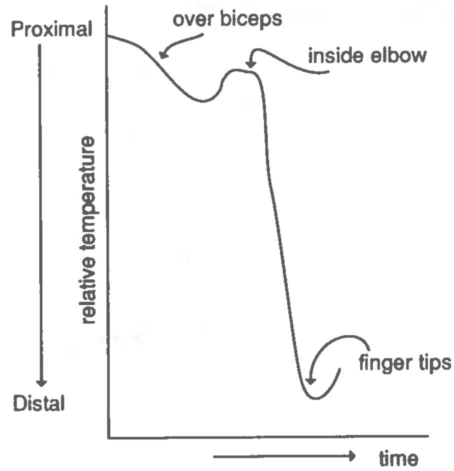


Fig.7 - Temperature profile betwixt oxter and fingertip

Such a profile is shown (Fig.7) for a human arm, running from oxter to fingertip. The temperature under the oxter is close to 37°C, hence it is one of those secondary sites occasionally used as an alternative to taking oral temperatures. Note however that the temperature falls steadily down the limb except at the inside of the elbow where the brachial blood supply runs closer to the surface. Temperatures at the fingertips may well be several degrees Celsius below that at the oxter.

Similar investigations may be performed to trigger discussion on why it is that ear lobes suffer so from the cold and why so much body heat may be lost from the upper surface of the head. Why do ears and face redden when temperature has to be controlled through heat loss? (Hence the expression hot and bothered!). Why do fingertips, ears and face, particularly, tend to turn blue in very cold weather? Because it can generate many such questions this is good science.

Ventilation rate of lungs

Inhaled air is cooler than exhaled air. If the sensor is held close to the lips then breathing in and out over it will produce a signal related to the pattern of breathing. This signal may be logged and displayed in similar manner to that for temperature profiles when the sort of trace shown in Figure 8 may be produced.

Disinfection

Whenever a temperature sensor has been used in taking oral, skin or breath temperatures it should be disinfected between use by one human subject and the next. For skin measurements rather than oral measurements this disinfection may be carried out in class within the lesson.

Wash the thermometer probe in either soap and warm water (up to 60°C) or a detergent such as a proprietary

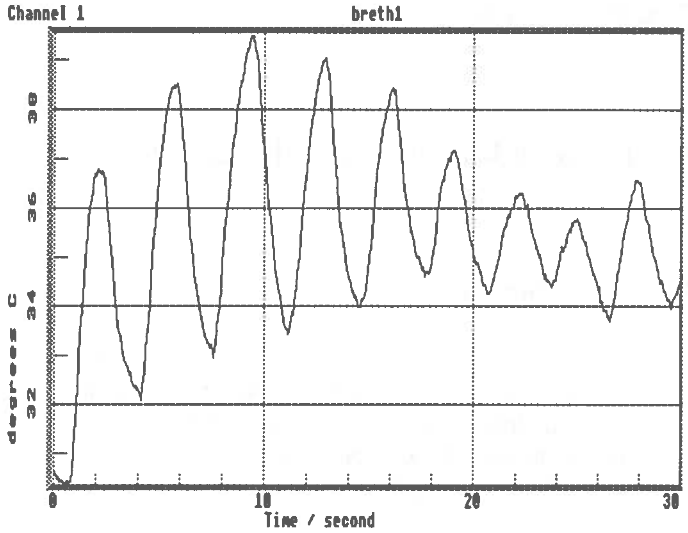


Fig.8 - Temperature variation of air entering and leaving mouth

washing up liquid in warm water and rinse thoroughly in clean, warm water.

This procedure is based upon advice given by the Employment Medical Advisory Service (EMAS) of the Health and Safety Executive.

Environmental applications

The circuitry so far described is particularly suited to physiological applications. Given a simple design change, which involves no more than the selection of a different value for the fixed series resistor, the linear response may be tailored to other applications.

With a series resistance of 4704 Ω (made up from standard values e.g. 4.7 kΩ in series with 3.3 Ω) the device becomes linear over the range -10°C to +30°C. It then becomes more generally useful for applications such as logging for meteorological purposes etc. If the total resistance in series with the thermistor is 4656 Ω (3.9 kΩ in series with 680 Ω and 68 Ω) then the linear range becomes 0°C to +20°C. This somewhat more sensitive circuit will find a use in investigating microclimates as well as covering weather observations for most of a typical school session.

Both circuits are illustrated in Figure 9. The selection of resistor values for other temperature ranges is described in Bulletin 162 [1]. Resistor tolerances of 1% should probably suffice, but for the best performance, 0.1% tolerances should be used. Resistors of this standard are stocked by RS Components.

References

1. *Thermistors : Simple means of getting accurate temperature data*, Technical Articles, Bulletin 162, SSERC, April 1989.

2. *Standard Grade Physics : Technical Guides, Vol 2, Unit 3 : Health Physics*, SSERC, 1992.

3. *Constructional techniques : Circuit design and layout, Soldering*, Microelectronics Monographs 1, SSERC, 1984.

4. *Regulation in Biological Systems*, Exemplar Materials, Higher Grade Biology, SCCC, 1990.

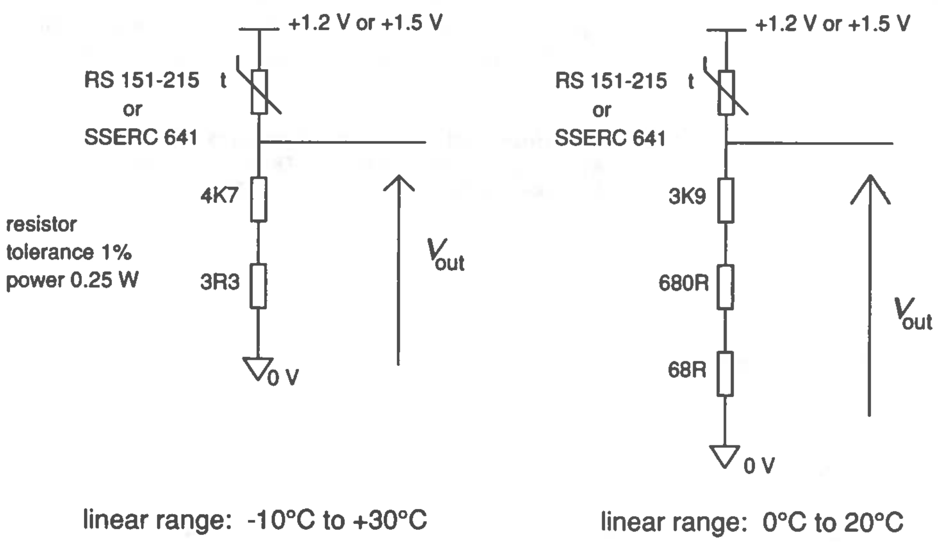


Fig.9 - Circuits for environmental applications

EQUIPMENT NOTES

PASCO Introductory Rotational Apparatus ME-9341 and Centripetal Force Accessory ME-9414

Our evaluation report consists of a description of several experiments with this apparatus. These compare experimental data with values calculated by theory.

A quick summary of the equipment can be found at the end of the report.

Introduction

This is the simpler of two sets of kits supplied by PASCO Scientific for the study of rotational mechanics. A performance matrix for the physical concepts covered by it and its more complex sister apparatus is shown (Table 1).

Provision for studying three groups of concepts (Table 1) has not been made. However it would be a fairly simple matter for the experimenter to modify the equipment to look at these concepts because the apparatus is sufficiently crude, and I don't mean that in the pejorative sense of the word, to accept being modified.

There is partial provision for studying moments of inertia, the apparatus including three differently shaped bodies: disk, bar and annulus. However there is no assembly whereby the mass distribution can be varied. Such an assembly could readily be contrived by the experimenter. Indeed the apparatus notes indicate how this may be done.

Construction

The basic apparatus comprises three parts, which may be quickly and easily assembled. They are a horizontal base with three levelling feet and central ball bearing, a vertical, hollow shafted, spindle and a platter with three fixed hub wheels (Fig.1).

There is an appreciable amount of friction, which must be taken into account in most experiments. When the main platter alone is running, typical values of angular deceleration due to friction are from 0.1 rad s^{-2} at low speed to 0.3 rad s^{-2} at high speed.

There is also a significant amount of play between the spindle and the bearings it fits into on the base and the platter, which can cause the platter to rock. This effect has significance when using the centripetal force track.

Measurement of angular speed

The apparatus provides clamps for mounting either a photogate or Smart Pulley with which to measure angular speed. The latter was used in the evaluation. The Smart Pulley was supplied with PC software. However, because of lack of availability of a PC, an Acorn BBC Micro-computer was used to analyse the Smart Pulley signals, software being written by ourselves. This recorded 40 sets of data, updated every second, consisting of measurements of the pulse frequency f_{SP} from the Smart Pulley light gate. It also graphed values of f_{SP} versus time t, which helped the experimenter judge what was happening.

Physical concepts	Introductory Rotational Apparatus ME-9341 with Centripetal Force Accessory ME-9414	Complete Rotational Dynamics System ME-9280
Centripetal force	1	0
$\tau = I\rho$	1	1
Rotational collisions	1	1
Linear motion to rotational motion collisions	0	1
Moment of inertia	(1)	1
Principal axes	0	1
Rotational energy	1	1
Simple harmonic motion	0	1

Table 1 - Performance matrix for the two sets of rotational mechanics apparatus from PASCO

Typical streams of data recorded when the main platter was decelerating due to friction are (Hz)

69 68 66 64 62 61 59 57 and

39 38 36 36 34 33 31 30 etc.,

and when accelerating due to an external torque are (Hz)

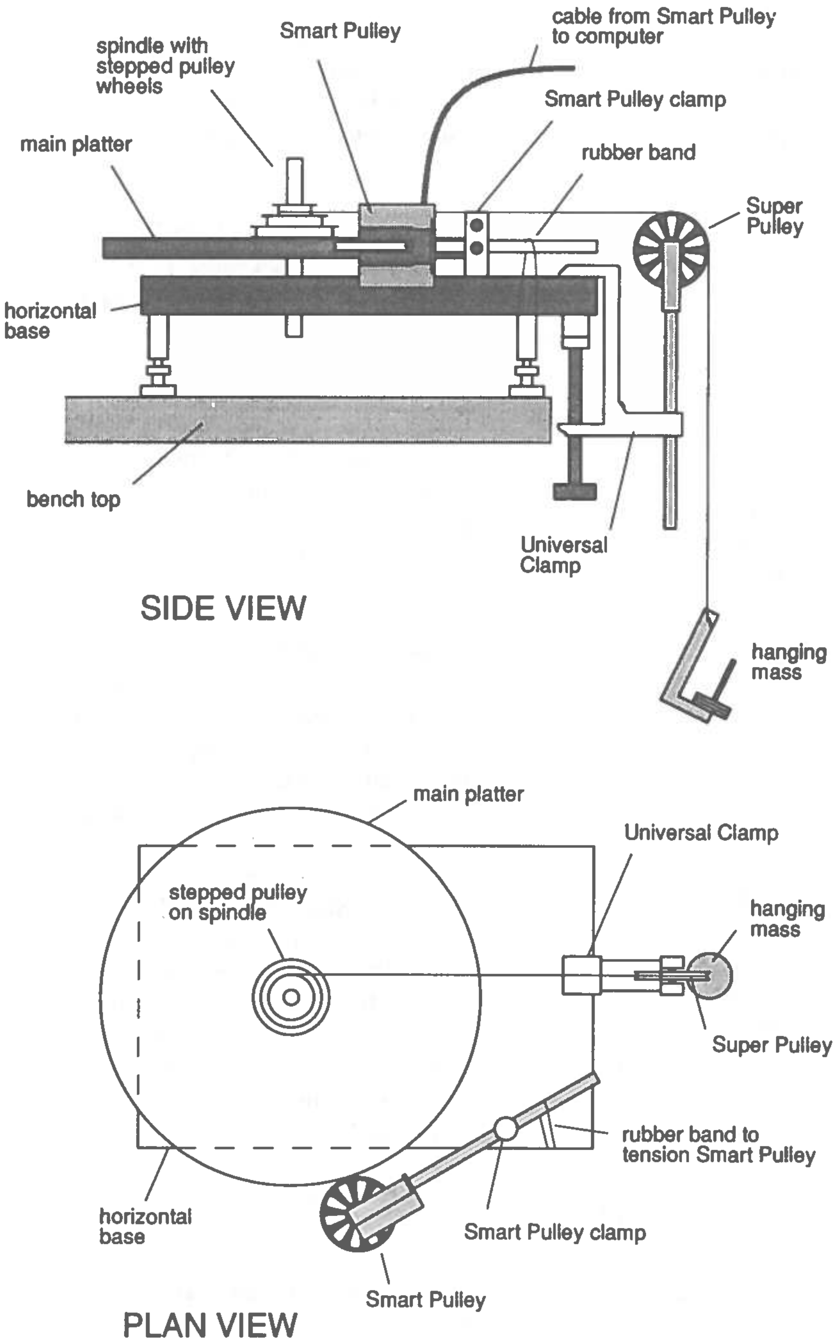
8 13 20 26 32 37 43 48 53 58 63 etc.

Because this method of counting rounded off data values to the nearest whole digit, the values were graphed and the best straight or curved line fitted as appropriate. This increased the precision of the method, the standard deviation lying between 0.3 Hz and 0.5 Hz, depending on the run of data.

It was noted that if the tension in the elastic band holding the Smart Pulley against the platter rim was too slight it disengaged intermittently resulting in a saw-tooth kind of graph of angular velocity versus time. Once recognised, the fault was easy to rectify.

The Smart Pulley has 10 slots. The radii of the outer rim of the Smart Pulley and main platter are 2.54 cm and 12.7 cm respectively, giving an angular velocity ratio of 5:1. The angular velocity in radians per second of the main platter is therefore obtained from

$$\omega = (1/5)\cdot 2\pi f_{SP}\cdot(1/10) = 0.1257 f_{SP} \qquad [1]$$



Angular acceleration versus torque

A PASCO Super Pulley with Clamp ME-9448 was mounted at the edge of the laboratory bench. Unfortunately the clamp jaws were found to be insufficiently wide to grip the apparatus base - surely a design flaw that separate pieces of apparatus aren't mutually accommodating. (It is acknowledged that the Instruction Manual refers specifically to employing a Universal Clamp ME-9376A for this purpose.) Thread was run from the platter hub over the Super Pulley to a hanging load.

Theoretical values of angular acceleration α_{th} were obtained from

$$\alpha_{th} = (mgr - \tau_f)/(I + mr^2) \qquad [2]$$

where m is the mass of the falling load in kg;
g is the acceleration due to gravity (9.81 m s^{-2});
r is the radius of the hub or pulley of the main platter in m;
τ_f is the frictional torque in N m; and
I is the moment of inertia of the main platter in kg m^2.

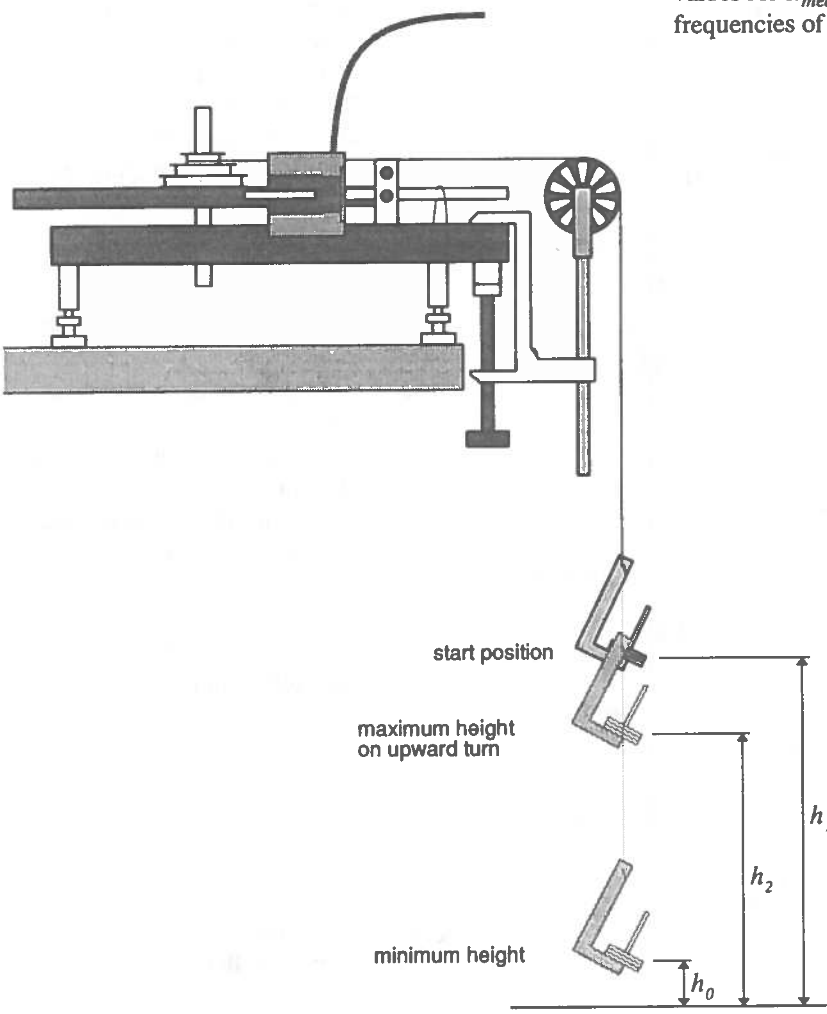
Fig.1 - Introductory Rotational Apparatus and ancillary parts

Smart Pulley frequency f_{SP} (Hz)	Angular velocity ω (rad s^{-1})	Clockwise angular deceleration α_{exp} (rad s^{-2})	Anticlockwise angular deceleration α_{exp} (rad s^{-2})	Mean angular deceleration α_{mean} (rad s^{-2})	Frictional torque τ_f (mN m)
10	1.26	0.121	0.126	0.12	0.9
20	2.51	0.147	0.153	0.14	1.1
30	3.77	0.168	0.182	0.16	1.3
40	5.03	0.180	0.204	0.18	1.4
50	6.29	0.185	0.200	0.20	1.5
60	7.54	0.214	0.222	0.22	1.7
70	8.80	0.237	0.244	0.24	1.8
80	10.06	0.261	0.240	0.26	2.0

Table 2 - Dependence of frictional deceleration and frictional torque with angular velocity

Six sets of readings of f_{SP} versus t were obtained for each hub wheel, small, intermediate and large, with loads varying by 10 g steps from 10 g to 60 g. Values of angular acceleration α_{exp} in rad s^{-2} were derived from the gradients through the first six or so graphed points of (f_{SP}, t), applying the relationship [1].

Two separate methods were used to measure frictional torque τ_f.



Firstly the main platter was spun by hand and allowed to decelerate naturally. The deceleration was not constant, but was found to diminish as the platter slowed down. Values for clockwise and anticlockwise decelerations also differed (Table 2).

The values of α_{mean} in the fifth column (Table 2) were derived from taking a linear plot through values of α_{exp} versus ω for both senses of rotation. Note however that the values for α_{mean} are around 10% too low at Smart Pulley frequencies of about 30 Hz.

Taking the moment of inertia of the main platter as 7.5 x 10^{-3} kg m^2, values of frictional torque versus angular velocity were then worked out (column 6 in Table 2).

Whereas this method indicates the manner by which frictional torque depends on angular velocity, it does not take into account the contribution made by the thread running over the Super Pulley, which was not employed in the above measurements.

This contribution can be assessed using the technique described in *Experiment 4* in the Student Notes supplied with the apparatus by PASCO. If $h_2 - h_1$ as defined in the Notes is the difference in heights of the load due to frictional torque, and if θ is the angle through which the platter turns (Fig.2),

$$\tau_f = mg\,(h_2 - h_1)/\theta \qquad [3]$$

Fig.2 - Determination of frictional torque

The method yields an average value for frictional torque during the period when the platter accelerates from rest under an externally applied torque to a maximum velocity and decelerates back to rest as the thread rewinds on the hub.

Several determinations with a load *m* of 30 g, and with different hub wheels, and with a mean Smart Pulley frequency of 25 Hz, yielded values for τ_f lying between 1.3 mN m and 1.4 mN m. These values are about 15% higher than the ones tabulated above as obtained by the first method, which did not include the Super Pulley. However including the non-linearity in τ_f versus f_{SP} found at 30 Hz, this discrepancy lessens.

It is therefore concluded that the contribution to τ_f made by the Super Pulley and a 30 g load is somewhat under 10% of the residual contribution from the bearing on the apparatus base.

The dependence of the load contribution to τ_f was also checked. It was found that for a load of 100 g and an average value of f_{SP} of 50 Hz the value of τ_f was 2.3 mN m. It therefore appears that the Super Pulley starts generating a sizeable amount of frictional torque at loads between 30 g and 100 g.

Comparison between measurement and theory

Angular acceleration α_{exp} was determined by entering values of f_{SP} versus *t* into a computer program and calculating the gradient and standard error of the line of regression. There is a 95% likelihood of the error range to contain α_{exp}.

Values for measured and theoretical angular acceleration, α_{exp} and α_{th}, are tabulated against load, *m*, and hub radius, *r*, below (Table 3). The moment of inertia *I* of the platter is taken to be 0.0075 kg m^2. Frictional torque τ_f is taken to be 1.0 mN m.

Sample calculation

For a 30 g load applied to a 1.5 cm radius hub, the theoretical value α_{th} of the angular acceleration from relationship [2] is

$$\alpha_{th} = (0.03 \times 9.81 \times 0.015 - 0.0010)/(0.0075 + 0.03 \times 0.015^2)$$

$$= (0.00441 - 0.0010)/(0.0075 + 0)$$

$$= 0.45 \text{ rad s}^{-2}$$

Discussion on results

Values of α_{th} are consistently lower than values of α_{exp} by around 10% excepting for loads of 10 g and 20 g, where the disparity is greater. There are several reasons.

1. Values of *m*:

The masses and mass carrier, which are supplied as part of the Centripetal Force Accessory ME-9414, were weighed several times and average values found to be

mass carrier	4.94 g (± 0.01 g)
5 g mass	5.11 g
10 g mass	10.33 g
20 g mass	20.29 g
50 g mass	50.44 g

The values for *m* used in calculating α_{th} were therefore too low by about 1%.

2. Values of *r*:

The diameters of the hubs were measured. Average values were

1.5 cm hub	29.90 mm (± 0.05 mm)
2.0 cm hub	40.07 mm
2.5 cm hub	50.05 mm

These errors are insignificant and can be ignored.

	r = 1.5 cm		*r* = 2.0 cm		*r* = 2.5 cm	
m (g)	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})
10	0.11 ± .01	0.06	0.16 ± .01	0.13	0.24 ± .01	0.19
20	0.34 ± .02	0.26	0.46 ± .02	0.39	0.58 ± .01	0.52
30	0.49 ± .02	0.45	0.75 ± .03	0.65	0.91 ± .04	0.85
40	0.73 ± .03	0.65	1.02 ± .03	0.91	1.30 ± .06	1.17
50	0.97 ± .03	0.85	1.42 ± .07	1.17	1.68 ± .07	1.49
60	1.14 ± .04	1.04	1.58 ± .06	1.43	2.00 ± .06	1.82

Table 3 - Values for measured (α_{exp}) and theoretical (α_{th}) angular acceleration (first comparison)

However inspection of the manner by which thread bundles on the hub revealed a significant error. The effect is most pronounced on the small hub (1.5 cm radius). The effective radius was estimated to be swollen to 1.6 cm because of overlapping layers of thread - an effect made worse by using PASCO Braided String rather than thread, which would have been thinner.

It had been noticed during the measurement period that the falling load *m* would occasionally jerk. This can be attributed to either an oblique wind, or overwind, or combination of the two. The result is a discontinuity in the ω - t graph.

The values of *r* used in the calculations of α_{th} were therefore too low by about 1 mm.

3. Moment of inertia *I*:

From the Instruction Manual, the specified value for moment of inertia is 7.75 x 10^{-3} kg m^2. It was early on recognised that this value is erroneous. A slightly lower value of 7.5 x 10^{-3} kg m^2 was therefore used for *I* in the original computation of α_{th}.

However the size of the error is larger than first realised. The actual moment of inertia seems to lie between 7.0 x 10^{-3} kg m^2 and 7.1 x 10^{-3} kg m^2.

Recomputation of angular acceleration

The theoretical angular acceleration α_{th} was recomputed using values of *m* which are 1% higher than their nominal ones, of *r* which are 1 mm greater than the hub radii, and a value of *I* which was 7.0 x 10^{-3} kg m^2. The recomputation used values of τ_f which depend on the average angular velocity for the period over which the angular acceleration α_{exp} was measured. These values of τ_f are shown in Table 4.

Revised values of α_{th} are shown in Table 5. It can be seen that there is now close agreement with the measured values α_{exp} excepting the 50 g value with the 2.0 cm hub, which may have been caused by erroneously using a 55 g load.

Rotational collisions

The Introductory Rotational Apparatus contains an auxilliary platter, steel bar and steel ring for further experiments on moments of inertia, and for studying rotational motion collisions.

Measurements of angular velocity before and after collisions have been compared with respective values of moment of inertia. Good correlations can be obtained.

1.5 cm hub			2.0 cm hub			2.5 cm hub		
m (g)	f_{SP} (Hz)	τ_f (mN m)	*m* (g)	f_{SP} (Hz)	τ_f (mN m)	*m* (g)	f_{SP} (Hz)	τ_f (mN m)
10	5	0.9	10	10	0.9	10	10	0.9
20	10	0.9	20	15	1.0	20	15	1.0
30	20	1.1	30	25	1.2	30	30	1.3
40	25	1.2	40	30	1.3	40	35	1.3
50	30	1.3	50	35	1.3	50	35	1.3
60	40	1.4	60	40	1.4	60	40	1.4

Table 4 - Values of frictional torque τ_f used in revised computation of α_{th}.

	r = 1.5 cm		r = 2.0 cm		r = 2.5 cm	
m (g)	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})	α_{exp} (rad s^{-2})	α_{th} (rad s^{-2})
10	0.11 ± .01	0.10	0.16 ± .01	0.17	0.24 ± .01	0.24
20	0.34 ± .02	0.32	0.46 ± .02	0.45	0.58 ± .01	0.59
30	0.49 ± .02	0.52	0.75 ± .03	0.72	0.91 ± .04	0.92
40	0.73 ± .03	0.73	1.02 ± .03	1.00	1.30 ± .06	1.28
50	0.97 ± .03	0.94	1.42 ± .07	1.30	1.68 ± .07	1.65
60	1.14 ± .04	1.16	1.58 ± .06	1.58	2.00 ± .06	2.00

Table 5 - Values for measured (α_{exp}) and theoretical (α_{th}) angular acceleration (revised comparison)

Experimenting with the Centripetal Force Accessory

The employment of a hollow spindle to facilitate the suspension of a mass carrier beneath the rotational apparatus base is elegantly simple (Fig.3). Because of this feature, the trolley track is minimally simple. However a drawback in some laboratories is the need for the base to straddle two benches, or two or even three laboratory jacks on one bench.

The trolley track was found to be unsteady - partly because of play on the bearing, and partly because of insufficient support between it and the main platter. Because of this defect, the track tilts whenever the vehicle is at the extremity of its run, but levels when the vehicle reaches the centre. There is therefore a gravitational force F_g acting in opposition to the force $m_a g$ exerted by the hanging weight. There is also a force F_f due to sliding friction on the trolley.

The dynamical equation for the trolley when it starts to move inwards is

$$m_a g - F_f - F_g = mR\omega^2$$

where m is the mass of the trolley, R the distance from the trolley centre to the spindle centre and ω is the angular velocity.

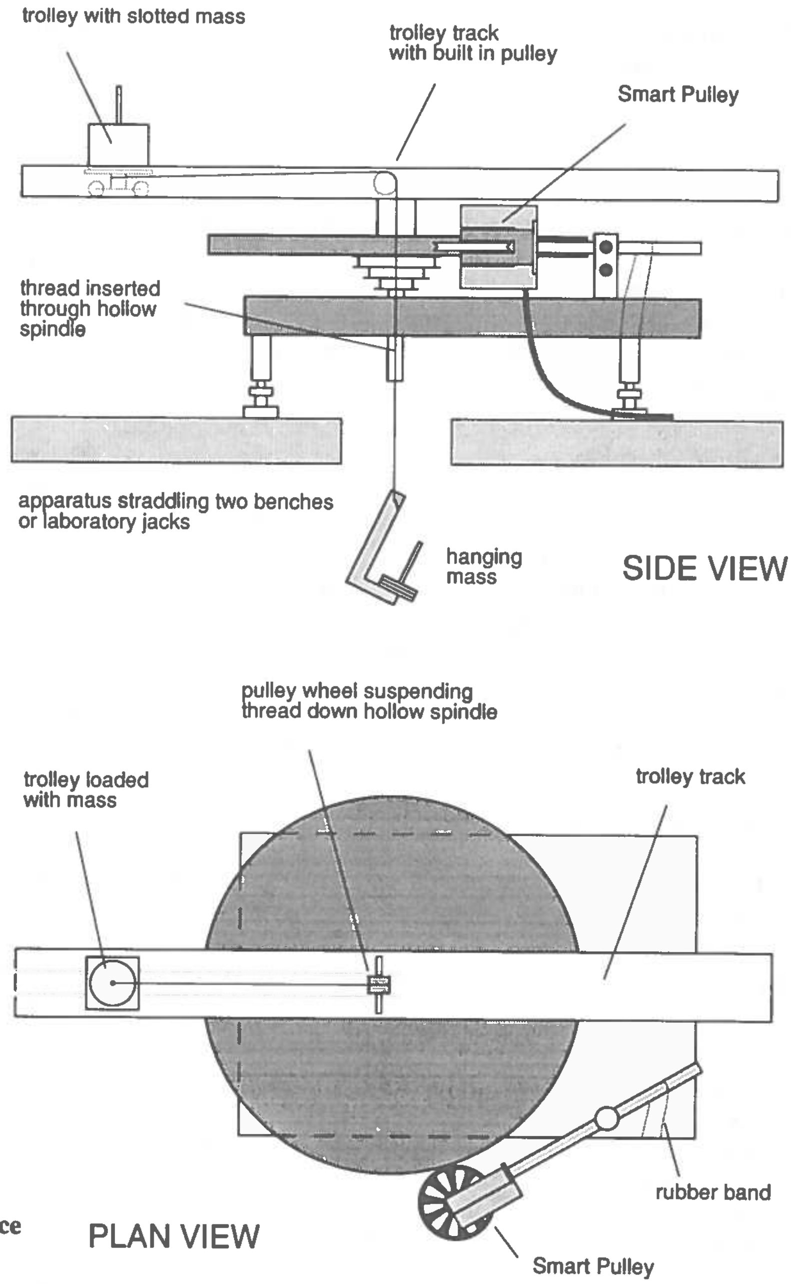


Fig.3 - Introductory Rotational Apparatus with Centripetal Force Accessory

The method in the Instruction Manual for determining angular velocity is clever. It is done by spinning the track with an angular velocity just sufficiently high for the trolley to sit at rest relative to the track. As the platter slows down with friction, the force exerted by the load hanging on the thread, $m_a g$, exceeds the force required to maintain the circular motion of the trolley, and the trolley moves inward. At the instant just as the trolley begins to move, the accelerating force on the trolley comprises the centripetal force of the hanging mass minus F_f and F_g combined. By using a computer to plot a graph of f_{SP} versus t, the sudden increase in angular velocity (Fig.4) caused by the trolley moving inwards enables a measurement of f_{SP} at that critical point to be made.

(Figure 4 was prepared by logging the counts per second from the Smart Pulley using VELA on program 07.

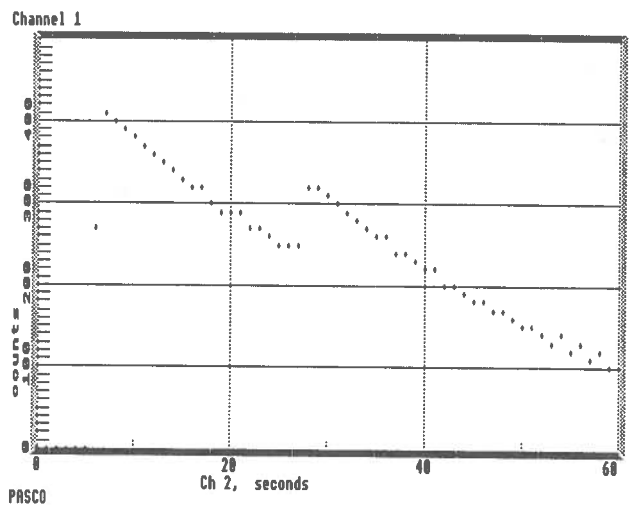


Fig.4 - Angular velocity versus time

The electronic data was then transferred to an Acorn Archimedes Computer and plotted on Datadisc PP (Harris, A29068/3)).

I have not tried to quantify the separate magnitudes of F_f and F_g. Together, they are around 54 mN when the trolley carries a 100 g mass. Commenting on the tilt of the trolley track, PASCO reckon that the force due to the slope is an order of magnitude less than that due to friction, and thus may safely be ignored. They believe that stiffening the supports to the track would not help significantly.

Apparatus notes

The Instruction Manual and Experimental Guide supplied with the apparatus by PASCO give an adequate description of the apparatus and how ancillary equipment can be used to measure angular velocity. They contain a series of student worksheets for laboratory practicals. These are backed up by laboratory notes for the teacher outlining the theory that underlies the practicals and giving tips on usage. The notes are well written and illustrated.

List of apparatus

The following PASCO apparatus has been referred to in the text. It includes the two main items reviewed, together with some ancilliary equipment. Sterling prices are those that pertained before the pound devalued.

Introductory Rotational Apparatus	ME-9341	£172
Centripetal Force Accessory	ME-9414	59
Super Pulley	ME-9450	8
Universal Clamp	ME-9376A	15
Smart Pulley with		
IBM software, Manual, Accessory Kit	ME-9421	131
IBM Software and Manual	ME-9384	62
without Software or Manual	ME-9385	49

Versions of the Smart Pulley specicifed here have 15-pin D connectors to link to IBM or compatible computers. There are also versions for the Apple II series of computers. Details, inclusive of a software listing, whereby the Smart Pulley can be used with the BBC Computer can be obtained from the Centre (at no charge).

Summary

PASCO Introductory Rotational Apparatus ME-9341 and Centripetal Force Accessory ME-9414

1. The apparatus comprises several separate parts, which are readily assembled and broken apart. Because of this, the student is encouraged to experiment, and to think about the equipment's limitations.
2. The apparatus is of simple construction and is reasonably robust. It is simple to operate.
3. The apparatus can satisfactorily be used for quantitative experimental work. Agreement, in general, can be found between theory and experiment within the 3% to 4% uncertainties which pertain, provided that sufficient care and effort is taken.
4. The main platter is significantly affected by friction, and this cannot be ignored if quantitative relationships are being investigated.
5. There is play on the bearings which slightly spoils the performance of the Centripetal Force Accessory. The defect is compounded by the way the centripetal force track is supported on the main platter. However the fault is not very significant.
6. Angular velocity can be satisfactorily measured with the Smart Pulley used in conjunction with either a frequency meter or, preferably, a microcomputer. The robustness of the Smart Pulley is questioned, but we understand from an overseas teacher who uses Smart Pulleys that this has not been troublesome.
7. All the basic concepts of rotational mechanics in the Scottish CSYS Physics syllabus (upper secondary school level) can be investigated with this apparatus either directly, or with minor modification.
8. The notes supplied with the apparatus are clear, adequately complete and helpful.
9. This is the lowest priced kit for studying rotational mechanics presently on the UK market.
10. The apparatus is fun to work - partly because of its limitations, which prompt you to think of what you are doing.

Verdict

A - most suitable for use in Scottish schools and non-advanced FE.

(Code : A = most satisfactory, B = satisfactory,
C = unsatisfactory)

TECHNICAL TIPS

Protactinium generator problems

Several teachers have contacted us this year with problems related to the protactinium generator and half life of Pa-234 experiment. These problems have been looked into and, we think, resolved. They are described below.

1. *Radioactive decay not taking place* : Several schools simultaneously met with this problem earlier this year whilst tackling Unit 3 of Standard Grade Physics. The effect has been found to occur only with home-made brews, all of which had been made around 1988. These were all contained in polypropylene, stoppered flasks. The count rate from each of the flasks remained at about 10 s^{-1} irrespective of whether the flasks had been shaken, or inverted, or left undisturbed. The contents appeared to be noticeably depleted and there was an absence of layering between the aqueous and organic liquids.

The problem has been caused by the disappearance of the organic solvent. Over the passage of four years, all of the pentyl ethanoate has evaporated and vented from the flask.

Venting from these flasks had been observed by us some years ago when researching this experiment. The rate of mass loss of organic liquid was about twentyfold that of aqueous liquid. We also found that provided the flask had been securely stoppered, there was no leakage of liquid during inverting and shaking, yet venting persists slowly over a long time scale. The effect does not therefore appear to pose a risk of leakage of radioactive material.

There is fortunately a simple remedy. The flasks can be rejuvenated by topping up with pentyl ethanoate. This should take only a few minutes - inclusive of observing safety procedures.

The operation should be carried out in accordance with the procedures in Appendix IV of the Explanatory Notes [1]. The procedure for ensuring that the flask is securely stoppered is given in Bulletin 160 [2].

2. *Apparent absence of layering in Harris generator* : The most recent sample of protactinium generator from Harris uses an organic solvent different from the usual brew. The contents appear as a black or navy precipitate and there is no layering noticeable. However despite this apparent absence, the flask works normally. After shaking, protactinium is milked out into a top layer and its decay can be monitored.

3. *Leakage from Harris generator* : We have had one report this year of slight leakage from one of the early versions of protactinium generator from Harris - one of a batch distributed around 1988 which we believe to have been subsequently withdrawn by Harris because the cap seals had proved to be unreliable.

In the event of signs of leakage from a commercial generator, the supplier should be notified and asked to arrange for disposal. The generator should, until uplift, be stored in a glass beaker.

4. *Linear rather than exponential decay* : If counting begins immediately after shaking, three distinct periods can be distinguished. Taking 0 s to be the time at which the flask is placed on the drip tray, the count rate rises between 0 s and 20 s, falls at a constant rate between 20 s and about 60 s, and thereafter decays exponentially.

Reasons for this pattern are not properly understood. During the first period, the organic liquid is presumably still separating and rising. The middle, linear period is an interregnum when there may still be dynamical effects within the liquids. It is only during the final period that the decay of protactinium unobscurely appears.

When fitting an exponential curve through the data, discard the points obtained during the first 50 s.

5. *Storage of generator* : The generator should be kept in a locked store separate from the other radioactive substances [3]. If stored alongside other sources, there would be a danger that sealed sources might be damaged by acid fumes venting from the generator.

A lockable bench or wall cupboard, perhaps that in which the drip tray is held, can make an adequate store for the generator.

The generator must be kept in a glass beaker, cap uppermost, so that were the flask to leak, the store would not be contaminated.

References

1. "Preparation of the protactinium generator", Appendix IV, *Protection against ionising radiation in science teaching : Explanatory notes on local rules for teaching establishments (SED Category C only)*, SSERC, 1987, 42-44.

2. *The protactinium generator - stoppering the flask*, SSERC, Bulletin 160, June 1988, 7.

3. "Storage of protactinium generator", Section 88, *Protection against ionising radiation in science teaching : Explanatory notes on local rules for teaching establishments (SED Category C only)*, SSERC, 1987, 32-33.

Sodium flame pencil substitute

We understand that BDH, the company that supplied Griffin, Harris and Irwin with sodium flame pencils, have for the time being stopped producing these - it apparently being not worth their while. We are informed that the educational suppliers will try to persuade BDH to re-introduce this commodity.

As a substitute for the sodium flame pencil we recommend effervescing a sodium salt into the air entry to a Bunsen (as described in Bulletin 129 [1]). This is done by adding about 500 mg of sodium chloride to some 4M hydrochloric acid in a small crucible. This produces sodium halide. Add a small lump of zinc to cause effervescence and stand the crucible beneath the Bunsen's air entry.

The uptake of sodium into the Bunsen funnel is improved by fitting a large diameter cork over the funnel air entry, boring holes in opposite sides to allow air to flow into the funnel. A short length of plastic tubing should be fitted to one of these holes such that it hangs over the effervescing acid. Thus air rich in sodium is drawn into the flame (Fig.1). For variations in this method, please see the reference [1].

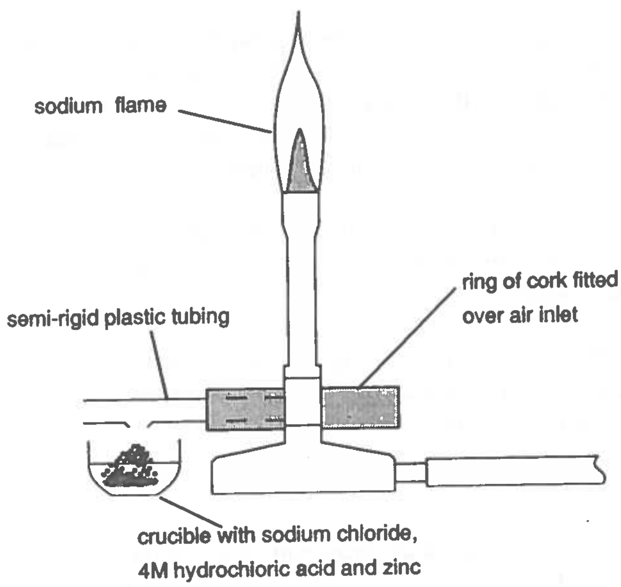


Fig.1 Producing flame coloration

The sodium vapour concentration in the laboratory quickly builds up such that any flame can be permanently tinged yellow-orange even although the sodium generator has ceased to operate. To prevent this from happening the reaction should be stopped as soon as it is no longer required and the room should be well ventilated.

COSHH assessment

As we do not have limits for sodium vapour concentrations, we cannot perform a quantitative assessment on the harm caused by this vapour. Nor do we have limits for hydrogen chloride vapour concentrations. Keep the room well ventilated by opening doors and windows.

Reference

1. *Methods for producing flame coloration*, SSERC, Bulletin 129, November 1981, 6-7.

Sodium street lamps

We recently acquired through the good offices of Lothian Region Highways Department a stock of 35 W, 240 V a.c. used, working, sodium street lamps for distribution to schools through our surplus sales service. As our technical advice on operating these lamps is scattered through three bulletin issues going back to 1975 [1], [2], [3], we thought it would be helpful to repeat it here. New information on operating the lamps has been included.

The control gear for SOX lamps is made by Thorn and is available from electrical trade suppliers such as Ross Electrical. The following parts, with Thorn reference numbers, are needed:

ballast	G53331.4
ignitor	G53311
capacitor 6 μF	GC2435
BC lampholder	BY226

Wiring instructions are printed on the ballast, and it should be remembered that the lamp, which fits into a heat resisting bayonet socket, should be fitted vertically with the socket at the top.

Constructional details are available on request to the Director. They provide guidance that complies with the Electricity at Work Regulations.

Lamp disposal

To dispose of a lamp, break off the outer glass envelope by nicking with a file and running a hot glass rod right round the crack. With a little manipulation and twisting, the central glass U containing the sodium can be extracted and the metal parts removed. The U contains neon gas under slight positive pressure so that if the glass pinch is broken off, gas escapes. The sodium it contains can usually be seen as a shiny deposit in the bend of the U, although some lamps have dimples in the legs of the U in which the sodium is supposed to collect.

Break off both legs of the U using the hot glass technique, near the middle, and add either ethanol or propan-2-ol to dissolve the sodium. Carefully wash the solution down the drain. If necessary the addition of solvent should be repeated at 24 hourly intervals until all the sodium has reacted.

The U tube should not be broken under water as has elsewhere been advised because in our experience the reaction does sometimes occur explosively, throwing bits of glass and burning sodium over a distance of 1 or 2 m.

Since there is a foreseeable risk of eye injury in this procedure, eye protection should be worn.

References

1. *Sodium street lamps*, SSERC, Bulletin 79, April 1975, 7.

2. *Trade News*, SSERC, Bulletin 122, August 1980, 10.

3. *Constructional details for the atomic absorption spectroscopy model*, SSERC, Bulletin 129, November 1981, 13-15.

4 mm stackable plug repairs

Plugs that have lost their grub screw can be kept in service by soldering the lead directly to one face of the hexagonal sectioned barrel. The junction should be at the bottom part of the plug at the pin end so that the plastic jacket fully covers the connection (Fig.1). Prepare the surface for soldering by filing off the chrome surface layer until the brass substrate is revealed. A length of about 8 mm should be so cleaned. Using a vice to grip the pin, tin both the prepared surface and wire and make the connection.

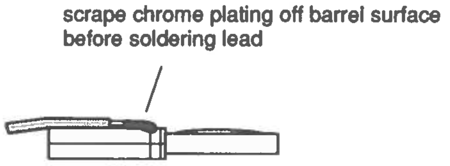


Fig.1 Lead soldered to 4 mm stackable plug

If however the wire spring is missing the plug should be discarded because no remedial action would seem to be feasible.

SSERC, 24 Bernard Terrace, Edinburgh EH8 9NX; Tel. 031 668 4421.
(Please Note: our Fax number - 031 667 9344)

BDH, (Head Office), Merck Ltd., Merck House, Poole, Dorset, BH15 1TD TEl. 0202 669700 Fax 0202 665599

Beckman Industrial Ltd., Astec Building, High Street, Wollaston, Stourbridge, West Midlands, DY8 4PG; Tel 0384 442394; Fax 0384 440252

Educational Electronics Ltd., (VELA suppliers), Woburn Lodge, Waterloo Road, Linslade, Leighton Buzzard, Bedfordshire, LU7 7NR; Tel. 0525 373666.

Farnell Electronic Components Ltd., Canal Road, Leeds LE11 0RG; Tel. 0532 636311.

Griffin and George Limited, Bishop Meadow Road, Loughborough, Leicestershire LE11 0RG; Tel. 041 248 5680, or 0509 233344.

Philip Harris Education:

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

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

Health and Safety Executive, Public Enquiry Service, Information Centre, Broad Lane, Sheffield S3 7HQ
Tel. 0742 892345 (Fax. 0742 892333)
HSE Freeleaflet Line Tel. 0742 892346

Instrumentation Software Limited, 7 Gledhow Wood Ave., Leeds, LS8 1NY; Tel. 0532 662505, Fax. 0532 661880.

Irwin-Desman Ltd., 294 Purley Way, Croydon, CR9 4QL Tel. 081 686 6441.

NRPB, 155 Hardgate Road, Glasgow G51 4LS Tel. 041 440 2201

Opax, 142 Silverdale Road, Tunbridge Wells, Kent TN4 9HU; Tel. 0892 525162

PASCO Scientific, 1010 Foothills Boulevard, PO Box 619011, Roseville, California USA 95661 - 9011; Tel. 0101 916 786 3800; Fax 0101 916 786 8905

Professor J.M. Robertson, Lothian Professor of Microelectronics, Department of Electrical Engineering, The University of Edinburgh, The King's Buildings, Mayfield Road, Edinburgh EH9 3JL; Tel. 031 650 1000 Fax 031 650 6554

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

Ross Electrical, 13 Macadam PLace, Dryburgh Industrial Estate, Dundee DD2 3XD; Tel. 0382 84151.

Scottish Enterprise, 120 Bothwell Street, Glasgow G2 7JP (Education Business Partnership - Willie Robertson), Tel. 041 248 2700

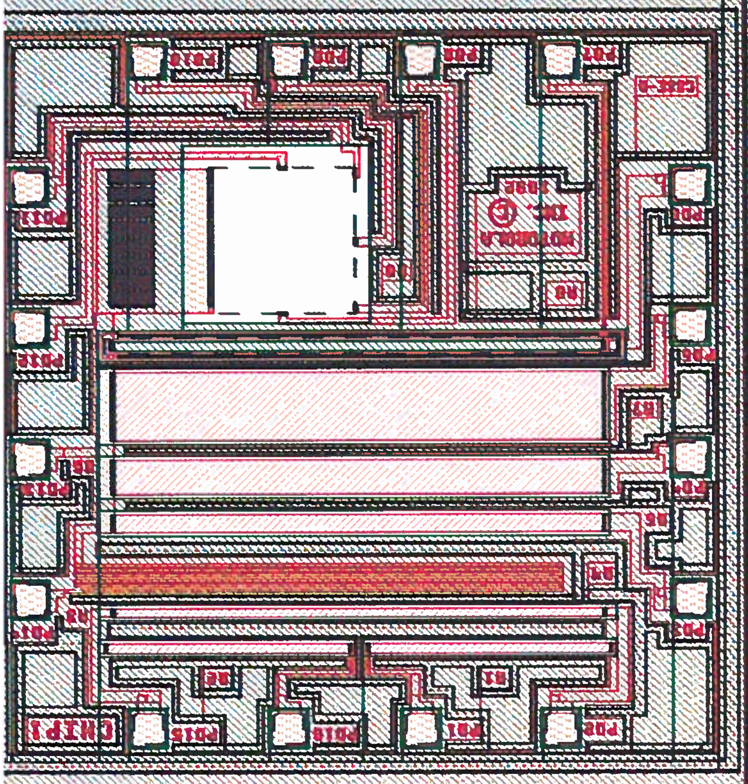
SCCC, Gardyne Road, Broughty Ferry, Dundee DD5 1NY; Tel. 0382 455053.

Scottish Office Environment Department, St.Andrew's House, Edinburgh EH1 3DE Tel. 031 244 2037

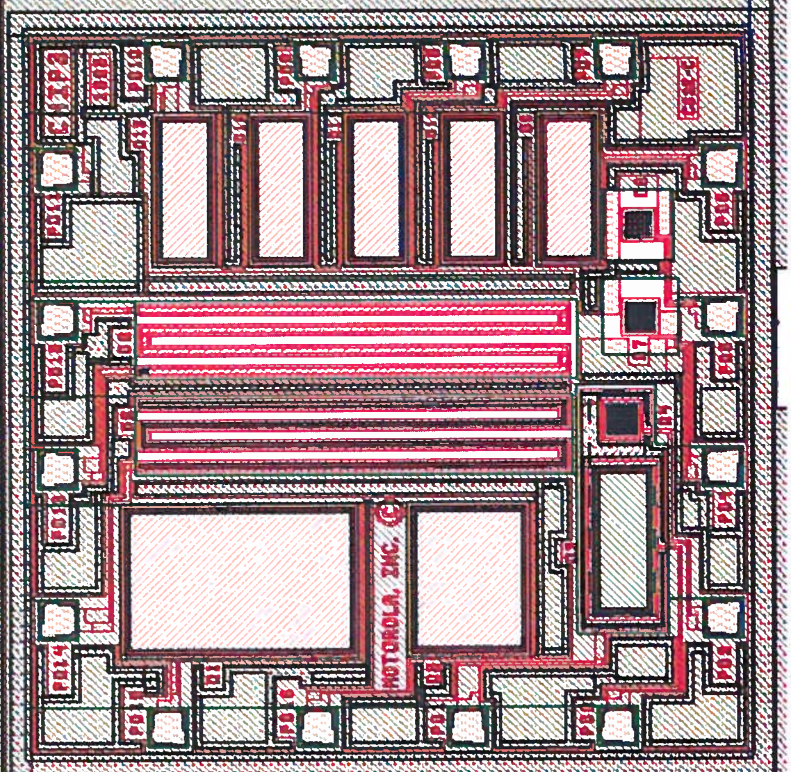
Tait Components Limited, 20 Couper Street, Glasgow, G4 0BR; Tel. 041 552 5043, Fax. 041 552 8826.

TASTRAK Analysis Systems Ltd., (TASL), H.H. Wills Laboratory, Tyndall Avenue, Bristol, BS8 1TL Tel. 0272 260353

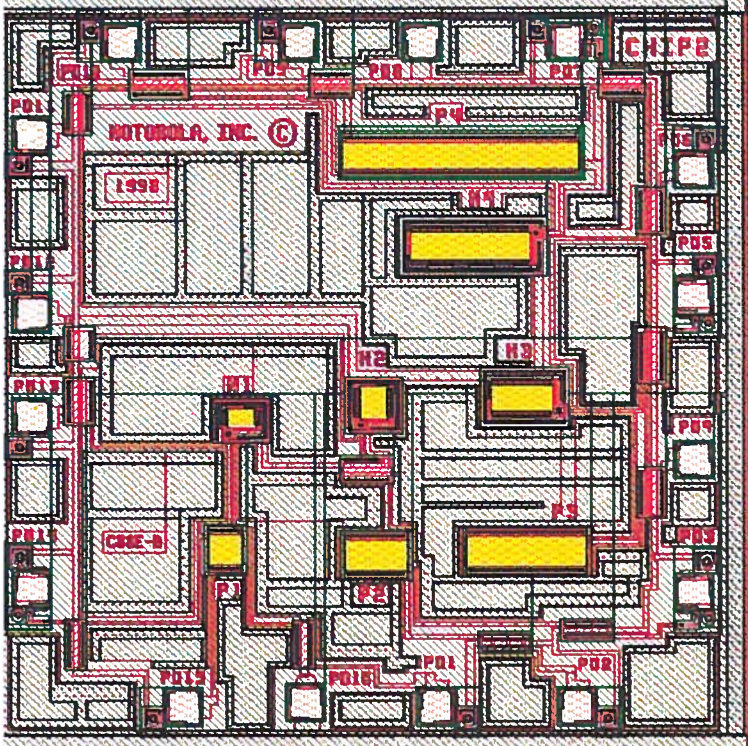
Unilab Limited, The Science Park, Hutton Street, Blackburn, Lancashire BB1 3BT; Tel. 0254 681222, Fax. 0254 681777.



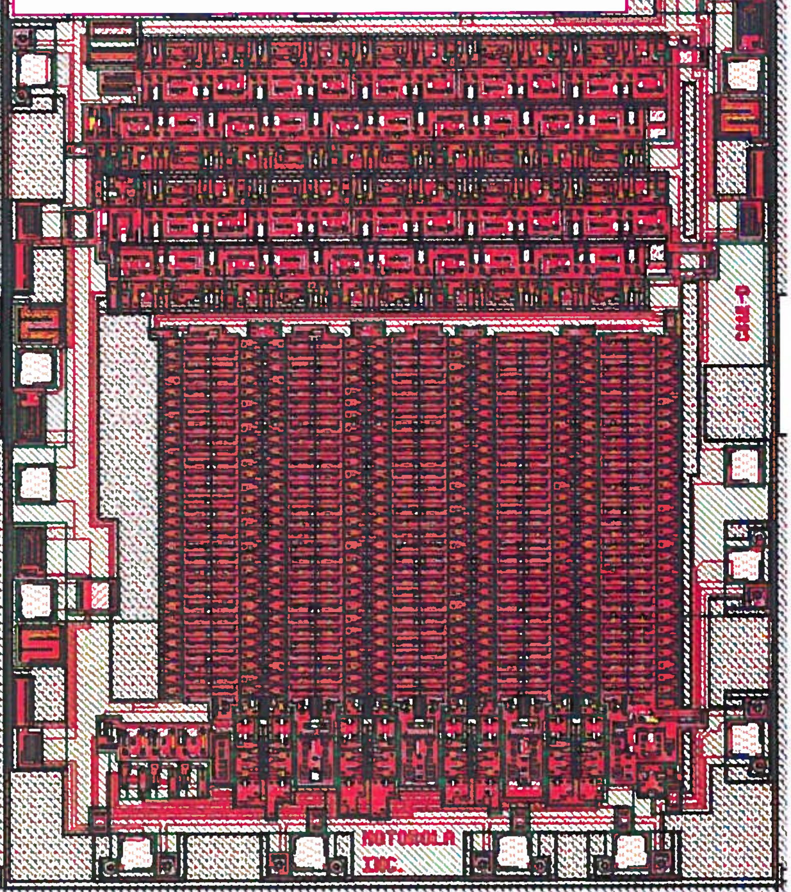
Chip 1 Resistors



Chip 3 Opto-electronics



Chip 2 Transistors



Chip 4 Timing circuits

Integrated Circuits for Schools from:

Edinburgh University **Motorola**

Compugraphics **Scottish Enterprise**