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SCOTTISH SCHOOLS SCIENCE EQUIPMENT RESEARCH CENTRE

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Digital meter

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(**continued** back inside cover)

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INTRODUCTION

Summer break

As in other years we shall suspend Saturday morning opening over what we all hope may be a Summer. This means that the last two Saturday openings of this school session will be on the 7th and 14th of June. We shall, as always, remain open on weekdays 9am to 5pm. Staff will be taking some annual leave on a rota basis. Should you wish to see a particular specialist postholder, you are advised to telephone the Centre prior to your visit.

Saturday morning opening will resume on the 6th of September, 1986. We will open also, perhaps unwisely, on the morning of the 13th of that month and thereafter on the **first two** Saturdays of each month until further notice.

Joke

The Chinese have the Year of the Ox (last year) and of the Tiger (this). Are we heading for every year being the year of the gimmicky theme? That well known wag of the world, Ian Morris ex-HMI, tired out at least one good joke at countless meetings during just such a year. He would start off his talk thus:

"This is 'Information Technology Year'
but we're not telling anybody".

We told you!

Remember - "Energy Efficiency Year" - announced in this section of Bulletin 149? Well, its all true. Educational seminars should already have been held before this issue goes to press. Possibly of more interest at yer actual chalkface - potential goodies! Better yet, these goodies may be directly relevant to Scottish science courses.

Courtesy of British Gas and the Department of Energy an "Energy Projects Pack" and an "ESMI" (Energy Studies Measurement Instrument) which measures both light and temperature, are being made available to schools at very reasonable cost. We have requested evaluation samples and will report further in early course.

Cost Index

What we did not, could not, tell you. Readers may recall that we were unable to publish the November 1985 figures for our consumables cost index. In the best apologist tradition we can honestly say that this was "due to circumstances outwith our control". Subscribers to the conspiracy theory of history will be disappointed but there was no plot to deny teachers ammunition in the battle for increased departmental allowances. Subscribers to that alternative view of history as merely an accumulation of minor c..k ups should however, be comforted.

The index stood at 339.04 in May, 1985. In May this year it was 364.83. This gives a percentage increase over the last year of 7.6%. Readers are asked to remember that this figure refers to our weighted basket of consumable items. It can give no reliable indication as to price trends for capital equipment. It is also historical, showing what has happened to consumables prices over the last twelve months. There are a number of reasons why the figure does not square with the latest year-on-year figure for the retail price index which is currently standing at about 3%. Science education inflation in 1985-86 has thus been running at a rate at least two and a half times greater than that of the RPI.

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S A F E T Y   N O T E S

Burning gloves

This hasn't, as far as we know, happened yet, but the potential certainly exists. Of the laboratory gloves commonly found in the catalogues particularly the disposable types, the majority are quite flammable. A wee check on the gloves in your lab. may be revealing!

The potential danger was pointed out to us by one who had observed S2 pupils, wearing outsized polythene gloves, heating copper sulphate crystals in a test tube. The tips of the gloves' fingers projected far beyond the pupils' own. Their fingers were dangerously close to the bunsen flame. The risk to health from a badly burnt hand caused by molten plastic sticking to the skin is much greater than that from a small splash or a bit of a crystal, albeit hot, landing on the back of the hand. In any case the skin of the hand is fairly horny and the copper sulphate could be rapidly washed off.

If only all pupils were about the same size and did not grow, such problems or that of safety specs balancing precariously on the nose-tip of an S1 pupil would not occur! Some supplier's catalogues show only one size of the cheaper type of disposable glove, which resemble the two flat outlines of a hand,welded together at the seams. Badly fitting gloves don't exactly give a good sense of touch or grip. Their use will almost certainly give rise to accidents caused by dropping of glass vessels or spillage because of poor manipulation.

If only misfitting gloves are available and the chemicals involved are not toxic via skin absorption then, in our opinion, the use of uncovered hands is preferable, being the lesser of two evils. However, the moral seems to be that at least two and probably three sizes of gloves should be stocked for use where this is justified on grounds of toxicity or corrosive action.

* * * * *

S C I E N C E   N O T E S

Solar Cells

This piece is more in the way of trade news but you might miss it there. In "Foundation Science Notes", Bulletin 141 we gave details on three types of solar cell of possible application in the Core Topic "Energy". Not long after that article was published, R.S. ceased stocking the naked cell stock no. 307-121 but continued to supply the encapsulated type (307-137). Now they have ceased listing any solar cells.

We have now found a possible alternative source of solar cells and have samples on order. These are of a similar type to the encapsulated cells from Browns of Edinburgh, being mounted behind lenticular faceplates. Four types are available from JPR Electronics. All have a claimed 0.45 V output with currents from 100 through 200 and 400 to 700 mA (all presumably off-load). One-off prices range from 84p to £1-98 depending on the cell size/output. Discounts are available for larger quantities. For example the price of the smallest cell type, G100, drops to 72p each for 25 or more.

Given the low operating current of the Portescap motor (SSSERC stock item no.373, £4-50) at 1 to 3 mA, it looks very likely that it and these JPR cells should combine nicely for Foundation Science use.

Also available from the same source is a 36 cell 6 or 12 V 'solar panel', type SM12/25, code 440-800 at £24-64 each or £19-70 per panel for 10 or more. This is 290 x 138 x 23 mm and housed in an aluminium case. Claimed output is a maximum 2.5 W at 12 V.

JPR's terms of business are a £20 minimum order value, postage/carriage at cost with next-day Securior delivery on request. Schools and colleges qualify for automatic account facilities and therefore delivery against an official order. They stock "...hundreds of other product lines at low, low prices."

* * * * *

Digital meters

Abstract

New developments in A-D converter chip and LCD display technology have led to a number of reasonably inexpensive digital student meters and multimeters coming on the school market. An evaluation of student meters is described and a survey of digital multimeters is included. The place of such meters in school science is discussed with reference to available ranges and features.

Introduction

A consequence of the increased application of digital student meters may be the virtual supersession of the moving coil genre. Digital meters have the advantages of being ostensibly easy-to-read, electrically and physically robust with high accuracy.

A typical student digital voltmeter of range 0-19.99 V, resolution 0.01 V and accuracy ±0.3% ±1 digit will cost around £30. Compare this with what you might expect to pay for an equivalent moving iron (£25, ±2.5% accuracy) or moving coil meter (£25-£35, ±2% accuracy) and the student digital meter scores well on cost. Digital voltmeters also have the desirable standard features of high impedance and reverse polarity indication as well as an adequate digit height for demonstrations.

Digital multimeters offer an increased number of ranges and facilities for not much more than the cost of a student digital meter. They generally have better accuracy and resolution over low ranges but are recognised as being inevitably more complex to operate.

Arguments against the purchase of digital meters for S1 and S2 may be justified when some analogue budget bench meters can be obtained for £6 (e.g. Philip Harris Cat. Nos. P80120/9 & P80122/2). The user should question whether educational needs are met by five simple, less accurate and easily damaged analogue meters or one easy-to-read, accurate and robust student digital meter. Such questions are considered in the next section.

Where to use them

The student digital meter and multimeter have many applications at all levels in secondary school science for pupil and demonstration use as well as for trouble-shooting and maintenance applications:

S1 and S2

Most of the digital student meters evaluated are eminently suitable for S1 and S2 science from the standpoints of clarity, accuracy and robustness. Such meters can be put into an inexpert child's hands without the trepidation felt when giving out a moving coil meter. Children should have more confidence with the clear digital display, having been brought up on a diet of calculators and digital watches. It is hoped that they have learned to limit the number of decimal places they quote from LCD displays. However, this is not likely to be a problem as student meters display only two decimal places after the point. Digital multimeters are possibly unnecessarily complex for individual student use at this stage.

Chemistry

Ions and conductivity, conductometric titrations, redox and electrode potentials and cells are all areas of investigation that can be more accurately and safely undertaken (safe for the meter that is). The day may now be dawning when Physics ammeters can be used by the reputedly less-than-careful chemist. A croc. clip short circuit or reverse polarity on the carbon electrodes of conductivity flasks is unlikely to damage a digital meter. Therefore a single digital multimeter would be an excellent investment for a chemistry department if only for demonstration and testing purposes.

Physics

The characteristics of high input impedance and sensitivity, coupled with high accuracy, mean that the digital meter has much to offer the physicist in S3 to S6. The apparent breakdown of simple circuit theory due to impedance matching problems with analogue meters (discussed in more detail later) becomes less prevalent. A better understanding of circuits and their measurement may be achieved.

The few basic electrical quantities which are measured in Physics are a.c. and d.c. current and voltage. A class set of multimeters would seem to be a better choice in Physics than a set of student meters.

Biology

It is not immediately apparent how the digital meter may help the biologist when traditional curricula are considered. However, with the growing application of instrumentation e.g. sensors and computer interfaces, there is a need for a reliable and accurate tool to measure voltages. Simple interfacing to d-i-y sensors requires care in setting up with correct voltages and polarity. The digital meter is ideally suited to such an application. Some commercial sensors e.g. Philip Harris "Electronic Sensors For All" require a voltage measuring device such as a meter, interface, data-logger or chart recorder to display the relevant quantity. A simple digital student meter could be conveniently used with such sensors in the field.

Electronics

The many functions of the digital multimeter, particularly its high impedance voltage ranges, make it an invaluable instrument in electronics practical work. The clear display and inherently greater accuracy than analogue meters are additional factors in its favour.

Trouble-shooting & maintenance

The multimeter is a useful service aid. Resistance, continuity, a.c. voltage & current, diode and transistor testing facilities are commonly available. Additionally, the digital multimeter is compact and easier to handle than the cumbersome AVO type.

General remarks

1. Digital display

All the student meters evaluated and most of the multimeters surveyed featured $3\frac{1}{2}$ digit LCD displays of height 12 mm or 13 mm. The $3\frac{1}{2}$ means that there are four digits, the most significant of which is able to display only a 1 or a 0. This results in a maximum display of 1999. The three least significant digits can display 0-9. On student meter displays the decimal point is fixed between the second and third digits. It is the nature of the 12 bit A-D converter circuitry which enables such a range of figures of both positive and reverse polarity to be displayed. Any overvoltage or overcurrent is indicated on all types of meter by displaying a 1.

Some teachers may find the figure height adequate for demonstration work with an audience up to 3 metres away. Indeed the digital meter could replace many of the demonstration functions of either the ubiquitous AVO meter with complex scales or the archetypal demo meter and inherent parallax errors.

2. Accuracy etc.

One of the most important features of both digital student meters and multimeters is the marked improvement in meter accuracy over analogue meters. The best accuracy on e.g. voltage ranges from an analogue meter is around ±2% and is typically ±4% for cheaper meters. Digital meters commonly boast accuracy figures of ±0.3% ±1 digit.

This area abounds with definitions of meter performance and suffers from the oft quoted faults levelled at statistics:

> **uncertainty** a displayed value on a meter is only a representation of the real world interpreted by circuitry having finite limitations. The uncertainty in a displayed value is an expression of these limitations. The total of all uncertainties may be represented by the 'accuracy'. Digital meter data often shows this as a percentage figure of the displayed reading plus the doubt over any least significant digit e.g. ±0.1% ±1

digit.The accuracy of analogue meters is more often quoted as a percentage of full scale deflection (f.s.d.).

The manufacturers vary in the manner they quote accuracy. Some give an overall accuracy figure interpreted as the uncertainty in any given reading. e.g. the possible error in a reading of 10.00 V on a meter with a quoted ±0.3% accuracy is ±0.03 V. Such single figures are less reliable than others which quote an accuracy as a percentage figure plus the uncertainty in quoting a least significant digit. e.g. the total error in reading 10.00 V on a meter with accuracy ±0.1% ±1 digit is ±0.02 V.

resolution an expression of the smallest voltage or current value that may be measured as a discrete unit. Because a meter can resolve 10 mV amounts as 0.01 V does not mean it can necessarily measure such voltages accurately. Precision is essentially the same as resolution.

The smallest voltage that can be resolved on the student voltmeters evaluated is 10 mV and appears on the display as 0.01. Similarly the resolution of the majority of student ammeters is 10 mA and appears on the display as 0.01.

With the increased number of ranges on multimeters comes a consequent increase in the resolution offered. e.g. on the 0-200 mV scale of a typical multimeter the resolution offered is 100 uV.

3. Input impedance

Many of the digital voltmeters and multimeters have very high input impedance i.e. 1 MΩ would be on the low side, 10 MΩ normal, but 100 MΩ or above unusual. However, the latter may be required in certain specialist fields in which case a d.c. amplifier or electrometer might be employed. This approaches the ideal of infinite meter resistance. Measuring problems will occur when the impedance of the circuit or component approaches to within three orders of magnitude below that of the voltmeter. The meter allows some current to pass through itself thereby significantly affecting the voltage drop across the component or device measured. This problem is far more severe when working with moving coil meters, whose typical input impedance sensitivity is of the order 1 kΩ/volt. Digital voltmeters are capable in most situations of not affecting that property which they set out to measure.

4. Bipolar inputs

Student and multimeter types have autopolarity indication on the display. When a reverse voltage or current is applied a minus sign "-" appears next to the most significant digit. The meter is therefore not damaged by connecting to it the wrong way round.

5. Tracking a changing signal

Digital meters are not without their drawbacks. The least significant digit may alternate and confusion may occur over whether it signifies a change in signal or not. From our evaluation tests against a more accurate meter an alternating final digit may be best interpreted as the higher figure.

It is sometimes difficult for users to appreciate the rate of change of voltage/current from a digital meter display. However, such difficulties are perhaps overstated and it is often feasible to follow one of the digits which is moving at a trackable rate. Further developments may see the wider application of LCD bar graph displays used alongside a digital display. Several up-market multimeters already have this feature, e.g. (Fig.10).

6. Ranges

All the student voltmeters surveyed had a single range of 0-19.99 V excepting the Griffin Microammeter with 0-1 V, 0-10 V and 0-100 V multipliers. None of the manufacturers provide information on calibration of their meters as this is presumably factory pre-set. If you suspect a voltmeter reading it may be checked by connection to a standard Weston cell (1.02 V). The digital meter should have a high enough impedance to discount the effect of the cell's internal resistance.

The majority of current measuring meters have a nominal full scale of 19.99 A but it is specified that currents measured should not exceed 10 A.

Even so, it is considered unlikely that any school experiments or equipment will be able to deliver currents in excess of this except when using NiCad cells or lead-acid batteries.

7. Battery life

All the meters evaluated were powered by 9 V PP3 type batteries. The battery life figures quoted in Tables 1 and 2 were for an Ever Ready 'Silver Seal' zinc/carbon battery from current drawn and manufacturer's battery specifications. A more detailed survey of battery running costs for meters will appear in a future Bulletin.

8. Robustness

All the meters surveyed appeared robust and secure with the exception of a clip-together arrangement used by Griffin (see the 'Specific remarks' section on the Griffin meters).

Student digital meters

Design

Three design philosophies have been adopted by the student meter manufacturers. Their relative merits and demerits are outlined below:

a. single function ammeter & voltmeter (Figs. 1-4)

pros

- clear and simple. A voltmeter is taken to measure volts and an ammeter to measure amps.

- no confusion over whether it reads micro, milli or straight.

- no add-on attachments.

con

- in buying for simplicity and clarity the penalty is that this is not the most cost-effective approach.

Fig.1 - Griffin ammeter

Fig.2 - Griffin voltmeter

Fig.3 - Harris ammeter

Fig.4 - Harris voltmeter

b. combination ammeter/voltmeters (Fig.5).

pros

- better value for money than single function meters covering the same ranges.

- convenience of having current and voltage ranges to hand in one instrument.

cons

- two multifunction meters are still required to make simultaneous measurements of voltage and current.

- possibility of incorrect connection.

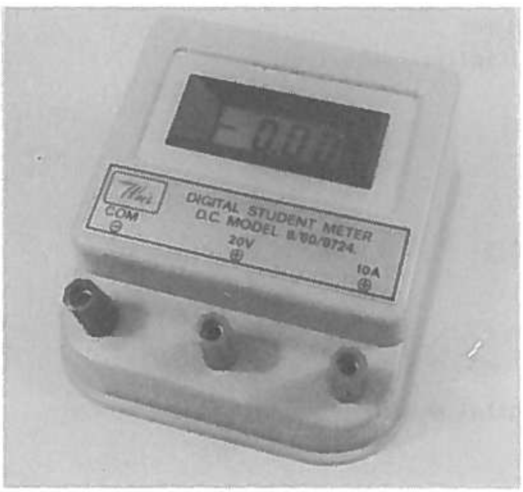

Fig.5 - Weir meter

c. basic meter with shunt & multiplier accessories (Figs.6,7).

pros

- better precision than single function or combination meters on lower ranges.
- marginally less expensive than other student meters to cover limited ranges.

cons

- multimeter will achieve the functions of a range of shunts and multipliers with greater convenience and lower cost.

- add-ons can be a muddle.

- decimal point may be in the wrong place.

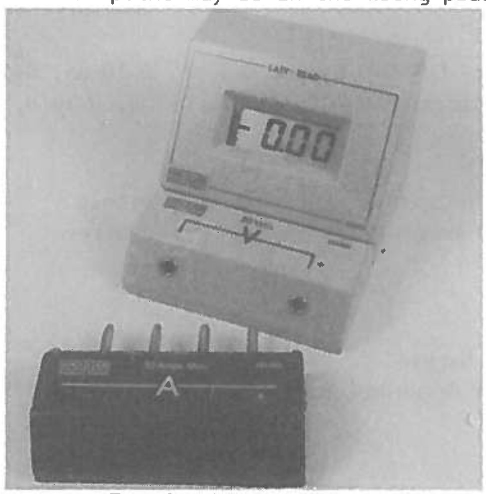

Fig.6 - Unilab meter

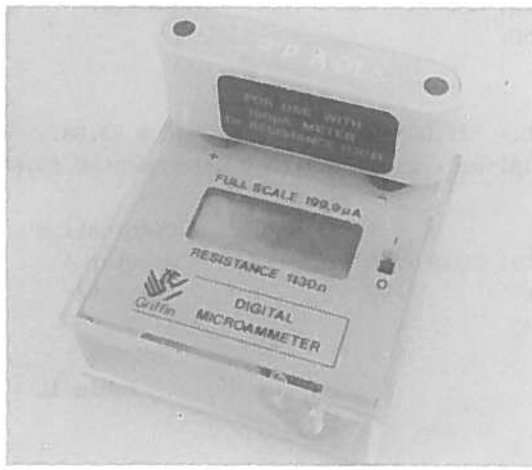

Fig.7 - Griffin microammeter

Overview - what's on the market

Supplier, Meter & Price	Cat. No.	Function type	Input impedance (Ω)	Battery & life (hours)	Accuracy quoted by manufact.
Griffin & George Digital ammeter £31.00	EHA-100-R	single ammeter	0.008	9 V PP3 400 not suppl.	none
Griffin & George Digital voltmeter £31.50	EHB-200-W	single voltmeter	10M	9 V PP3 400 not suppl.	±1 digit ±0.1%
Griffin & George Microammeter £31.50	EHA-910-P	basic meter microammeter, ammeter & voltmeter	0.011	9 V PP3 400 not suppl.	none

Shunts:- EHA-870 range, 0-1 mA, 0-10 mA, 0-100 mA, 0-1 A, 0-10 A. 1st 3 @ £10.95 each, others £11.75.
Multipliers:- EHA-880 range, 0-1 V, 0-10 V, 0-100 V. First 2 @ £11.75 each, 0-100 V @ £11.93.

Supplier, Meter & Price	Cat. No.	Function type	Input impedance (Ω)	Battery & life (hours)	Accuracy quoted by manufact.
Philip Harris Digital Bench Meter £31.04	P78160/0	single ammeter	0.019	9 V PP3 250 not suppl.	±0.3%
Philip Harris Digital Bench Meter £31.04	P78150/8	single voltmeter	10M	9 V PP3 250 not suppl.	±0.3%
Unilab 'Easy read' Digital Meter £23.50	523.001	basic meter voltmeter & ammeter	0.020 for shunt 10M for multiplier	9 V PP3 5000 supplied	none

Shunt:- 523.003 0-10 A attachment @ £3.88.
Multiplier:- 523.004 0-20 V attachment @ £3.60.

Supplier, Meter & Price	Cat. No.	Function type	Input impedance (Ω)	Battery & life (hours)	Accuracy quoted by manufact.
Weir Digital Student Meter £33.45	SMD 1020	combination ammeter & voltmeter	0.015	9 V PP3 1270 supplied	±1 digit ±0.3%

Table 1. - Student digital meters

Accuracy performance tests

All student meters were subjected to voltage and current tests against a calibrated Thurlby 1503-HA high accuracy multimeter.

The set voltages tested were:
10 mV, 50 mV, 500 mV, 1 V, 5 V and 10 V.

The set current levels tested were:
10 mA, 50 mA, 500 mA, 1 A, 5 A and 10 A.

The following table shows how the manufacturers' specifications compare with the test results. SSSERC has drawn up the following minimum specifications which we think all student meters should meet:-

Voltage 0-19.99 V, ±0.5% of reading ± 1 digit.

Current 0-10 A, ±2% of reading ± 1 digit.

If the meter is within SSSERC specification it achieves a 'pass' verdict. Any deviation from the SSSERC specification is detailed:

Meter	**Manufacturer specification**	**Verdict**
Griffin & George		
Digital ammeter	none	fail 15-20% low.
Digital voltmeter	±1 dig. ±0.1%	pass
Microammeter	none	fail 5% low (see 'Specific comments').
Philip Harris		
Digital Bench ammeter	±0.3%	pass 0.4-0.6% high over 5-10 A.
Digital Bench voltmeter	±0.3%	pass
Unilab		
'Easy read' Digital Meter	none	pass on voltage & current
Weir		
Digital Student Meter	+0.3%	pass on voltage & current

Table 2 - Accuracy performance

Specific comments

Griffin single function Digital meters (Figs.1,2)

These meters suffer from some confusion on the display faces due to their similarity. The darker grey base of the voltmeter distinguishes it from the light grey ammeter base although the difference is not obvious at first glance. The meter cases have sharp, angular edges and are less pleasing to handle than other student meters evaluated.

Because the innards are distractingly visible through two clear plastic faces there is an obvious temptation for enquiring fingers to explore! Furthermore the clip-together construction of the cases is too insecure for general school use.

The ammeter sample tested was wildly inaccurate and would therefore be a poor investment. The voltmeter offers reasonable value for money but is by no means the best of those evaluated.

Griffin Microammeter (Fig.7)

This general purpose meter system offers a wide number of voltage and current ranges using shunt & multiplier attachments. These fit snugly into the 4 mm sockets placed, somewhat unconventionally, above the LCD display. They helpfully and clearly state that they are designed for use with this meter. Unfortunately, the label indicating the shunt or multiplier range is upside-down when viewing the LCD display. This problem has arisen because the attachments were originally designed for use with the Griffin high sensitivity moving coil microammeter. The 4 mm connections to the rear of the shunt or multiplier have no polarity indication apart from that shown on top. Further confusion may arise as the polarity indication is next to rivet holes which, on some accessories, look like sockets. Some multipliers supplied had blanking plugs fitted over these holes.

The meter construction is the same as the single purpose Griffin meters and the comments made earlier regarding security and similarity also apply here.

The decimal point is in the wrong place when using the 0-10 V multiplier and 0-1 mA & 0-10 A shunts are connected e.g. 10 V is displayed as 99.3 and 1mA as 99.4.

The overall impression is that the attachments are a muddle to use as well as being relatively expensive. The same facilities could be more conveniently and cheaply achieved by use of a digital multimeter. This system therefore offers poor value for money and is not recommended.

Philip Harris single function Digital Bench meters (Figs.3,4)

There is advantage in clear differentiation between ammeter and voltmeter functions in order that both parameters may be measured concurrently. Unfortunately, because the meter shells are of identical colour and construction there might be momentary confusion till the smallish legend 'AMMETER' or 'VOLTMETER' is read. Perhaps the user, or indeed the manufacturer, could usefully add larger labels or distinctive colour coding to distinguish the two.

The nicely rounded edges and slight tilt to the LCD display make these meters easy and pleasant to handle. They appear to be robust enough to stand up to the rigorous demands of school use.

The voltmeter is let down by a relatively low battery life and is too similar to the Harris ammeter. Harris point out that quoted meter accuracy is typical and not guaranteed.

Unilab 'Easy Read' meter (Fig.6)

The Unilab 'Easy Read' meter is of similar construction to their popular digital "Stop clock & Centisecond Timer" module. The basic meter has a robust, bright orange plastic case with four unmarked 4 mm sockets, the central two of which switch on the meter when shorted. Therefore when a multiplier or shunt module is plugged in, the sockets are shorted, and the meter switches on.

It is difficult to confuse the d.c. shunt and multiplier units as commendably one is dark brown and the other orange. When plugged in each unit continues the clean, smooth lines of the basic meter and shows, on the upper face, a schematic representation of how the meter should be connected into a circuit. The application of different measurement functions is further emphasised by mounting the shunt sockets at either end and the multiplier sockets together at the front.

The 'Notes for Use' state that the basic meter can operate as a millivoltmeter with a range of 0-199 mV. There is no indication of this on the meter itself and the display indicates 4.96 when measuring 50 mV. Unilab emphasise however, that they "did not intend that the . . . . meter be used without either attachment".

This meter plus attachments offers excellent value for money. Some thought has gone into the design of the attachments so that possible confusion over function is minimised.

Weir combination Student meter (Fig.5)

This was the only combination meter surveyed i.e. both ammeter and voltmeter functions housed in the same device. It is not impossible to carelessly connect to the wrong positive socket. Harm to the meter would be extremely unlikely as the current range is protected by a 15 A internal fusible link.

This meters appears to be the most robust, accurate and pleasing to handle of all the student meters evaluated. It is difficult to fault and is therefore highly recommended.

Digital multimeters

Design

The past two years has seen a vast increase in the range of low-cost digital multimeters on the market. Many meters, particularly those of Far East origin, have similar if not identical specifications. This is due to distributors and suppliers in this country badge-engineering their own name products. We have therefore tried to avoid surveying such duplication and as far as is possible show the reasonable price one should expect to pay for the features and functions described.

Multimeters, in comparison with student meters, offer more ranges and better resolution. At the lower end of the price range, function and range selection is commonly achieved by combinations of push switch (Fig.8), rotary switch (Fig.9) or multiposition slider switch. Of the three, the rotary switched models are slightly more expensive but are preferable on two counts: (1) less susceptible to switch malfunction, (2) easier to select the desired function.

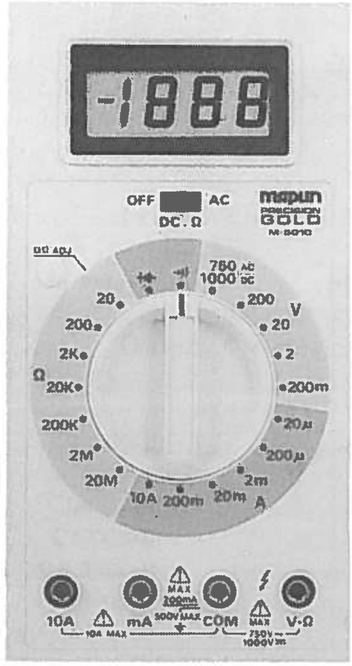

Fig.9

Minimum standard features

For school use, the minimum standard features that may be regarded as essential in a multimeter are as follows:

Function	Ranges	Resolution
d.c. volts	0-200 mV	0.1 mV
	0-2000 mV	1 mV
	0-20 V	0.01 V
	0-200 V	0.1 V
	0-750 V	1 V

accuracy 1: ±(0.5% + 1 digit)

a.c. volts ranges etc. as above

accuracy 2: ±(2% + 5 digits)

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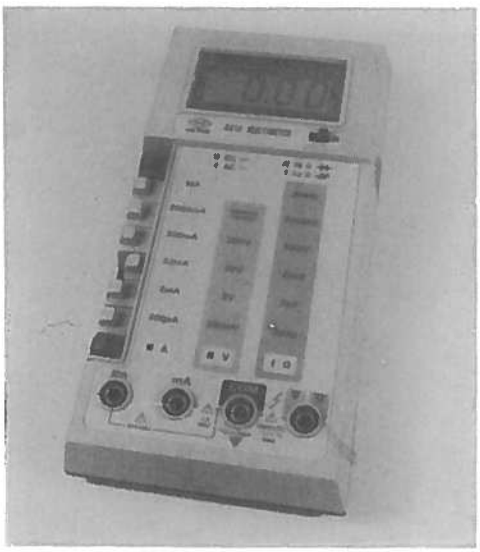

Fig.8

d.c. current	0-20 mA	0.01 mA
	0-200 mA	0.1 mA
	0-2 A	0.001 A
	0-10 A	0.01 A

accuracy 3: ±(2% + 5 digits)

a.c. current	ranges etc. as above	

accuracy 4: ±(2% + 5 digits)

resistance	0-200 Ω	0.1 Ω
	0-2 kΩ	1 Ω
	0-20 kΩ	10 Ω
	0-200 kΩ	100 Ω
	0-2000 kΩ	1 kΩ
	0-20 MΩ	10k Ω

accuracy 5: ±(1% + 1 digit)

Table 3 - Minimum standard features

Accuracy

Figures for accuracy are, in most cases, gleaned from manufacturers' specifications, but in some instances are taken from suppliers' adverts. Separate figures for accuracy are often quoted for different ranges and therefore any assumptions about overall accuracy derived from a single figure will not be totally reliable; the highest accuracy quoted is normally a figure which refers to one of the d.c. voltage ranges.

Each meter specification is compared with the minimum accuracies quoted in Table 3 and a pass (P) shown in Table 4 if it meets the minimum standard. An (F) indicates that the accuracy is less than the minimum required. If no information regarding the accuracy was available a "/" is shown.

Note:- the multimeters have been only surveyed and not bench tested.

As can be seen from Table 3 the accuracy of a.c. ranges is lower than the equivalent d.c.. This arises from the need for additional circuitry such as averaging converters or true r.m.s converters. If a signal is being altered or distorted the latter type of converter is more accurate.

The accuracy of a.c. voltage measurement can also be affected by the signal frequency. The majority of meters are designed to measure signals of frequency 50 to 500 Hz.

Safety

If multimeters are to see wider application in school science labs then it is desirable to have some overload protection eg. fuses, varistors and thermistors; particularly on high current ranges where shunt resistors can overheat. However, as was mentioned in the student meter evaluation, it is unlikely that the experiments or equipment met with in schools are likely to produce severe overload conditions. Indeed, in a school Physics department where 10 Soar 530 multimeters were piloted as a class set, only one blown fuse has resulted in 6 months.

Extra features

Perhaps a better buy still is an autoranging model (Fig.10); it scores over rotary models by way of having less switches to go wrong and is simpler to operate. As a further advantage for school use, some autoranging meters show the measured units within their LCD display.

model supplier & price	switch type	digits	accuracy 1 2 3 4 5	direct current V	 I	freq.	altern. current V	 I	res. R	extras
Beckman DM15 Fenwick £37.39	rotary	3½	F P P P P 0.8% basic	200 mV -1000 V	200 uA -10 A	50 -500 Hz	200 mV -1000 V	200 uA -10 A	200 Ω -20 MΩ	LD
Beckman DM20 Fenwick £47.00	rotary	3½	F P P P P 0.8% basic	200 mV -1000 V	200 uA -10 A	50 -500 Hz	200 mV -1000 V	200 uA -10 A	200 Ω -20 MΩ	LDGH
Beckman DM25 Fenwick £58.00	rotary	3½	F P P P P 0.8% basic	200 mV -1000 V	200 uA -10 A	50 -500 Hz	200 mV -1000 V	200 uA -10 A	200 Ω -20 MΩ	LDCGQ
Beckman DM77 Fenwick £46.00	auto	3½	P P P P P 0.5% basic	200 mV -1000 V	200 mA -10 A	50 -500 Hz	2 V -600 V	200 mA -10 A	200 Ω -2 MΩ	L
Beckman T100B Farnell £59.00	rotary	3½	P P P F P 0.5% basic	200 mV -1000 V	200 uA -10 A	/	200 mV -750 V	200 uA -10 A	200 Ω -20 MΩ	LCD
Fluke 73 Farnell £72.00	auto	3 3/4	F P F F P 0.7% basic	320 mV -1000 V	 -10 A	45 -1 kHz	3.2 V -750 V	 -10 A	320 Ω -32MΩ	LBDP
Hung Chang HC6010 Cirkit £33.50	push button	3½	P P P P P 0.25% basic	200 mV -1000 V	200 uA -10 A	50 -400 Hz	200 mV -750V	200 uA -10A	200 Ω -20 MΩ	L
As above for HC7030 @ £39.50 with 0.1% basic accuracy. Also available from Philip Harris as Bewa DMM 6010 GS, Cat. No. P81207/4, £64.71										
M105 Gold Maplin	push button	3½	P P P P P 0.5% basic	2000 mV -1000 V	1 uA -2 A	45 -450 Hz	200 V -750 V	/	2 kΩ -2 MΩ	L
£23.43 - also available from Armon as DM-105, £21.50, Cirkit DM-105, £21.50, Harris Electronics TMK VF-9, £34.95 and Alpha Omega Instruments as TMK VF9, £36.45										
M-6000 Gold Maplin £34.74	push button	3½	P P P P P 0.25% basic	200 mV -1000 V	200 uA -20 A	45 -400 Hz	100 mV -400 V -750 V @ 45-120 Hz	200 uA -20 A	200 Ω -20 MΩ	LD
M-5010 Gold Maplin £36.48	rotary	3½	P P P P P 0.25% basic	200 mV -1000 V	20 uA -10 A	/	200 mV -750 V	20 uA -10 A	20 Ω -20 MΩ	LCD
M-775 Gold Maplin £34.74	auto	3½	P P P P P 0.50% basic	200 mV -1000 V	20 mA -20 A	/	200 mV -750 V	20 mA -20 A	2 kΩ -2 MΩ	LCDM

Table 4 - Digital multimeter survey (continued over)

model supplier & price	switch type	digits	accuracy 1 2 3 4 5	direct current V	I	freq.	altern. current V	I	res. R	extras
M-5010EC Gold Maplin £52.13	rotary	3½	P P P P P 0.25% basic	200 mV -1000 V	200 uA -10 A	/	2 V -750 V	200 uA -10 A	200 Ω -20 MΩ	LCDMTQH
Soar ME-530 Advance Bry.	auto/ manual	3½	P P P P P 0.35% basic	200 mV -1000 V	200 uA -10 A	40 -500 Hz	2000mV -750 V	200uA -10 A	200 Ω -20 MΩ	LDC
£41.00 - also available from Griffin, Cat. No. EHL-490-E, £51.92										
Soar ME-540 Advance Bry.	auto/ manual	3½	P P P P P 0.50% basic	200 mV -1000 V	200 mA -10 A	40 -500 Hz	2000mV -750 V	200mA -10 A	200 Ω -20 MΩ	LDC
£33.00 - also available from Griffin, Cat. No. EHL-480-L, £41.54										
Soar ME-550 Advance Bry.	auto	3½	P P P P P 0.50% basic	200 mV -1000 V	200 mA	/	2000mV -750 V	200mA	200 Ω -20 MΩ	LC
£29.43 - also available from Griffin, Cat. No. EHL-470-S, £38.08										
TMK G44 Harris Elect. £49.50	rotary	3½	P P P P P 0.25% basic	100 uV -1000 V	1 uA -20 A	/	100 uV -750 V	1 uA -20 A	100 mΩ -20 MΩ	L
TMK G50 Harris Elect. £38.00	auto	3½	P P P P P 0.25% basic	1 mV -1000 V	1 uA -200 mA	/	100 mV -750 V	1 uA -200 mA	1 Ω -20 MΩ	LDC

Table 4 - Digital multimeter survey (continued)

Note 1 - many suppliers offer discounts for quantity e.g.

Advance Bryans:- Qty. 5-9 less 5%, 10-19 less 7.5%, 20+ less 10%

Note 2 - all prices shown are exclusive of VAT.

Key to 'extras' column

- L - low battery indication
- C - audible continuity indication
- B - analogue bar graph (Fig.10)
- M - memory
- D - diode test
- H - hFE transistor test
- T - temperature measurement
- G - conductance measurement
- Q - capacitance measurement
- P - power down when not in use

Suppliers (addresses inside cover)

Advance Bryans Instruments
Alpha Omega Instruments Ltd.
Armon Electronics Ltd.
Cirkit Distribution Ltd.
Farnell Electronic Components Ltd.
Fenwick Electronics Ltd.
Griffin and George Ltd.
Philip Harris Ltd.
Harris Electronics (London)
Maplin Professional Supplies
RS Components Ltd.
Tait Components Ltd.
Unilab Ltd.

* * * * *

Biotechnology and technobiology

Abstract

Nutrient film technique, a method used in commercial horticulture, is suggested as a possible illustration of some techniques of applied biology at school level. A basis for a small scale pilot system is described. Possible educational uses of the system, biological as well as technological, are suggested. Further development routes are indicated.

Introduction

There are a number of UK centres working on the educational aspects of biotechnology. The majority of current developments seem to be centred on applications involving micro-organisms and, often, fermentation technologies. Given a strict definition of modern biotechnology as having mainly a genetic, molecular and microbiological base that is understandable.

However we have decided to dig in some less crowded areas of this particular educational quarry. Firstly we didn't see much point in duplicating the work of others on fermenters. Secondly, although the use of fermenters can lead overtly to work on control techniques the biological aspects may be less than readily accessible.

Any soupy bacterial culture looks pretty much like another. One is usually reliant on indirect monitoring of growth through either microscopic observation or biochemical measurement of product. We looked therefore for an application which offered similar control possiblities but where indications of growth were macroscopic and thus more amenable to observation and measurement. As with illustrative biotechnology of a purer ilk, we were also looking for a number of environmental variables which could be manipulated. We decided to look at whole plant growing systems as possible study vehicles.

Nutrient film technique

Known, inevitably, as NFT this is a horticultural technique now fairly commonly in commercial use. It is a hydroponic growing method but one in which nutrient solutions at controlled temperatures are kept circulating over the roots of crop plants. On a commercial scale the growing channels under glass may be many yards long with systems covering in total upwards of an acre. (see Fig.1 for a diagrammatic representation).

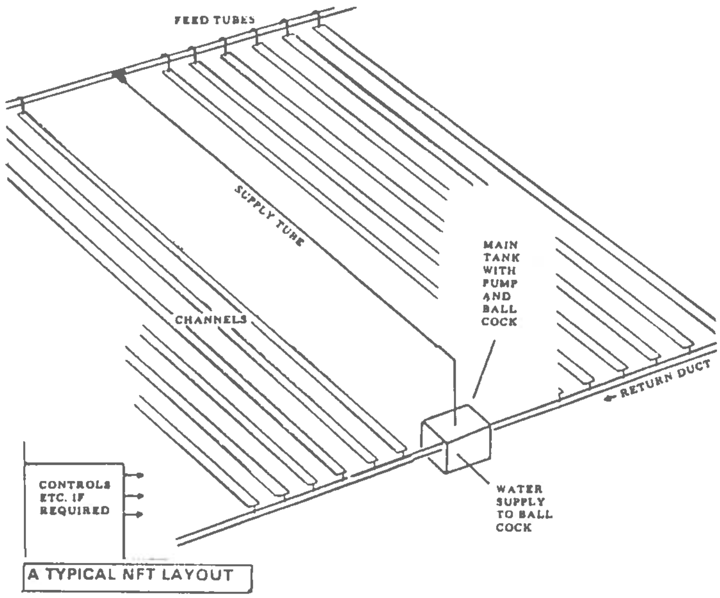

Fig.1

The major advantage of the method is that heating bills may be drastically reduced. This is because only the circulating nutrient is directly heated. The heating system does not have to cope with heating the total airspace inside a greenhouse or growing shed. Other potential benefits realisable in a well run system are higher crop yields and lower fertiliser bills. This is because the nutrient content of the circulating solution can be subject to monitoring and control. Because it is a soil-less method, salad crops such as lettuce remain clean and preparation for market is minimised.

Commercially available systems

Obviously most suppliers of NFT equipment to commercial horticulture are geared to fairly large systems. We have to date found only one, Nutriculture Ltd., which supplies a system for amateur use. This is their 'Gro-Tank' system supplied on a mail order basis. It is of a scale suitable for application at school level. Based on a channel of 16" width, the smallest system with a tank length of 3'6" costs £35-10. Also available are 4'6" and 4'10" tanks. The idea is that these can be used as modules configured to make the best of greenhouse space. Nutriculture also supply nutrient solutions, test kits, circulatory pumps and other accessories.

Small scale d-i-y

Nutriculture's prices are not unreasonable but the components parts for a useful system do mount up. We therefore tried our usual trick of adapting readily available vessels and components as parts for an NFT system. The result is shown in the photograph (figure 2).

The lamp frame housing the system provides additional lighting for indoor use and is only necessary if all-year use is contemplated.

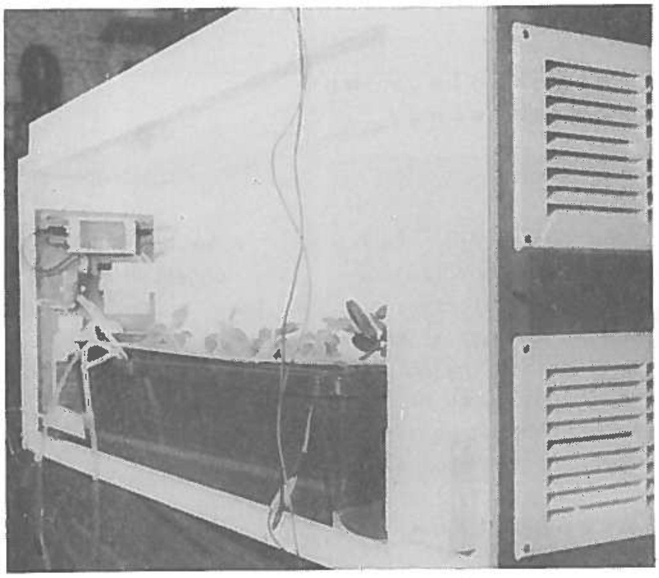

Fig. 2.

Constructional details for the lamp frame are given in the "Workshop" section of this issue. For the NFT system proper our initial description will leave out the fancy bits such as automatic level sensing and solution top-up. It is possible to start with a simple set-up and build in more sophistication as additional mini projects.

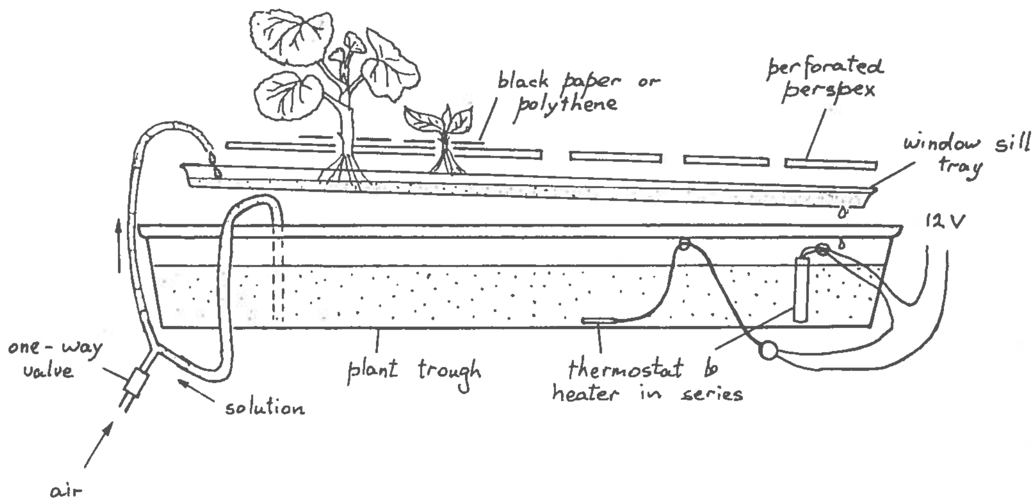

Fig.3.

For a simple core system all that is needed is some means of controlling the temperature of the nutrient solution and of keeping it circulating. Figure 3 shows such a basic system. The reservoir tank is a commercial plant trough ca.2'9". The growing channel is the tray in which more normally the trough would stand. Both were purchased from the gardening section of a d-i-y store. The basic construction is very simple and Fig.3 is hopefully self-explanatory. The only tricky bit is to set up the correct slope, and the necessary number and sizes of drainage holes to match the circulation rate. Pairs of holes in each side of the trough lip will permit the fitting of a transverse bar on which the top tray may rest. Altering the position of this bar will allow adjustment of the tray slope.

Circulation

We chose air-lift as the nutrient circulation method. Such a method avoids contact of mildy corrosive solutions with pump parts, uses a reliable aquarium pump designed for continuous operation and removes any need for additional aeration. Air-lift is a technique worthy of introduction in any case. This is because of its potential as a non-shearing agitation technique in fermenters, particulary with plant cell cultures. Our NFT air-lift mechanism is identical to that employed in our tidal aquarium design [1]. The one-way valve is not strictly necessary but helps to prevent blow-back breaking the syphon from the reservoir. An alternative is a longer loop of tubing which will have the same effect resisting the entry of air bubbles into the syphon.

Heating

Circulating aqueous solutions and proximity of mains electricity are to be avoided if possible. The careful use of mains heaters and thermostats designed for aquarium usage, clearly, would be acceptable. We considered that route and would be pleased to give advice on suitable, safe wiring methods. We finally decided on low-voltage circuitry. This was not solely from considerations of safety but because we were looking at NFT as a vehicle for multi-disciplinary technology projects. In addition to biological experi -mentation the system lends itself to development of control techniques both hardware and software engineered. Mains driven devices are technically difficult to control with safety. That may make for expense unacceptable at school level.

We chose a 12 V, 5 A, nominal 50 W, miniature immersion heater of the type used in physics departments for heating block calorimeters (e.g Irwin Desman EA0274 £10.75). This we initially controlled with a home built precision circuit. Reliability problems with the diode sensor drove us back to a simple thermostat (SSSERC Item 380 £1.25) originally intended for refrigeration applications. Trials showed that our nutrient reservoir could be kept adequately heated to 25 °C even when ambient night temperatures had dropped to single figures. Even with the cruder thermostat control was achieved to within ±2 °C. The maximum temperature which could be achieved with our size of trough and one 12 V heater in continuous operation was just over 28 °C.

Topping up

Clearly with heated solutions and numbers of growing plants, water losses through evaporation and transpiration may be considerable. The simplest course is daily visual inspection of the reservoir, topping up manually as necessary. For the more ambitious a number of automatic top-up mechanisms are possible. These range from ball-cock type mechanical systems through to electronic level sensors and pumps. We have developed a simple system of the latter type. Lack of bulletin space precludes description of that system but we would be pleased to supply details on request. A description may also appear in a future issue.

Biological applications

The system is itself an interesting example of applied biology and commercial hydroponics. In our early trials, the bottom heat it provided was useful for routine tasks such as rooting cuttings. It may prove worth having in the laboratory merely as a focus for discussion. Despite claims to the contrary from some educational researchers, a little technical complexity may be worth exhibiting for its own sake. In working with similar devices such as trout hatcheries and tidal aquaria, the author's experience has been that pupil interest has been much stimulated. If that interest be kept alive what matter if relative complexity interfere with the teaching of some dry, academic point?

With two or more systems, some real experimentation becomes possible. Different temperature conditions may be arranged for the nutrient solutions bathing the plant roots and the effects on both root and stem growth observed. One system may be run as a control with a 'complete' nutrient solution and another as a experimental without some major or trace element. Sach's formulations suggest themselves for such applications. Changes in pH or oxygen content could be monitored by means of spot testing or continuous logging.

Further developments

In parallel with work on fermenters the potential for development of control and data logging techniques is very great. The controls described herein are relatively unsophisticated all being hard-wired. However many opportunities exist for both control and data gathering by means of software engineered techniques. These could use a microcomputer although that would perhaps unnecessarily tie up expensive equipment. Alternatives would include the use of other microprocessor-based devices as data logger and controller. Automated level maintenance, solution composition, pH and temperature control all may be feasible as a series of further multi-disciplinary projects.

Reference

1. SSSERC "Bulletin", No.133,p.8.

* * * * * * * *

Lamp frame

Introduction

The idea of a simple lamp frame, to provide supplementary lighting and so extend the school season for plant physiology experiments, is not really new. For a number of years we exhibited such a frame. Although it aroused a deal of interest we doubt whether any biology teacher had one built. This was not least because of the size and complexity of our beast. It contained no fewer than twelve fluorescent tubes with all their control gear!

The much simpler two-tube frame, used with the NFT system shown in "Biology Notes", is based on a design sent in some time ago by John Pickering, P.T. Biology, Wallace High School, Stirling. This is smaller than our original version but still exploits our weight saving device in the lamp housing by separating the heavy control gear from the lamps.

Construction

As shown in Figure 2, the unit has four basic sub-assemblies:

the main frame or carcass **A**

the lamp housing **B**

the plant chamber cladding **C**

the control gear housing **D**

A cutting list for these units is given towards the end of this article.

Frame and plant chamber

500 and 250 mm lengths of 25 x 25 mm dressed softwood are screwed and glued to the 4 mm plywood side panels. Allow to set preferably overnight. Using these small battens as guides, fit 1260 x 25 x 25 mm spars to the base and back panels. Glue and screw sides, back and base together. Affix the remaining 1260 mm spar to the box front using four small corner pieces of 4 mm ply as shown in Fig.1.

Control gear housing

Consult the cutting list part D and construct as above. Two rectangular shaped cut-outs will be required in the end wall of D for the fitting of louvred vents. Given the lack of any load on this unit, oval brads and glue will suffice for fixing back and sides.

When the glue has set, mount the chokes on the aluminium heat sink and attach to the 6 mm back-board using nuts and bolts and leaving at least a 12 mm space between heatsink and wooden back-board.

Cut a clearance hole in this housing, at what will become the back of the lamp frame assembly, for an IEC chassis socket mains input. Fit this to a metal or plastic backplate and attach with No.6 woodscrews.

Lamp housing

Consult the cutting list part B and construct the housing in a similar manner to that described for the plant chamber.

Two 600 mm "Gro-Lux" tubes are used. These are held in Terry clips with the holders for the starters screwed to the underside of the housing top, between the ends of the lamps. Fit the wiring (see diagram in figure 3 and parts list). Drill a suitable hole for the leads from the chokes and wire to the terminal block as indicated.

With the lamp housing in place on top of the plant chamber mark the position of, and then fit, the piano hinge. An added refinement is a lid-stay to hold up the lid when changing the tubes. Required, in the interests of electrical safety , is a sheet of perspex fitted below the lamps. This is to protect them from splashing water - something which is difficult to avoid when growing plants.

Finishing

When the whole lamp frame is completed, sand, fill, prime and give two coats of white gloss. An alternative finish to increase the reflectance of the inside walls of the plant chamber is to glue or otherwise affix to them sheets of aluminium kitchen foil.

Cutting list

Note: sizes given are for guidance only in the sense that dimensions may be increased proportionately for a larger chamber and thus use of longer fluorescent tubes.

A. Carcass or framing

25 x 25 mm dressed softwood

4 pcs. 250 mm

4 pcs. 500 mm

4 pcs. 1260 mm

B. Lamp housing

1 off 70 x 25 x 25 mm dressed

2 off 1140 mm long as above

2 off 250 mm long as above

1 off 300 x 1102 x 4 mm plywood

C. Plant chamber cladding

All 4 mm plywood.

2 off 300 x 500 mm (sides)

1 off 1350 x 300 mm (base)

1 off 1350 x 500 mm (back)

1 off 80 x 300 mm (top fillet left)

1 off 90 x 300 mm (top fillet right)

D. Control gear housing

1 off 70 x 500 x 12 mm

1 off 70 x 276 x 12 mm

1 off 500 x 300 x 6 mm

1 off 500 x 300 x 4 mm

Components list

Probable local purchase

Glue, e.g. Evostick 'Resin W'

1 off piano hinge, 250 x 12 mm

2 off plastic louvre vents 270 x 170 mm

2 off 900 mm (3') 'Gro-lux' fluorescent tubes with end-caps, chokes and starters.

1 off sheet aluminium heat sink sized to mount chokes.

2 off 'Terry' clips (80/3 for 'Gro-lux' type tubes)

1" oval brads and No.6 three-quarter woodscrews

double, one way, mains light switch

surface mounting pattress for above

1 off sheet of perspex to 'glaze' underside of lamp housing.

R.S. or similar

terminal block, 12 way,e.g. R.S. 423-166

IEC chassis plug e.g. R.S. 488-191

fuse holder e.g. R.S. 412-661

or

IEC fitting with fuse e.g. R.S. 489-122

IEC cable socket e.g. R.S. 488-185

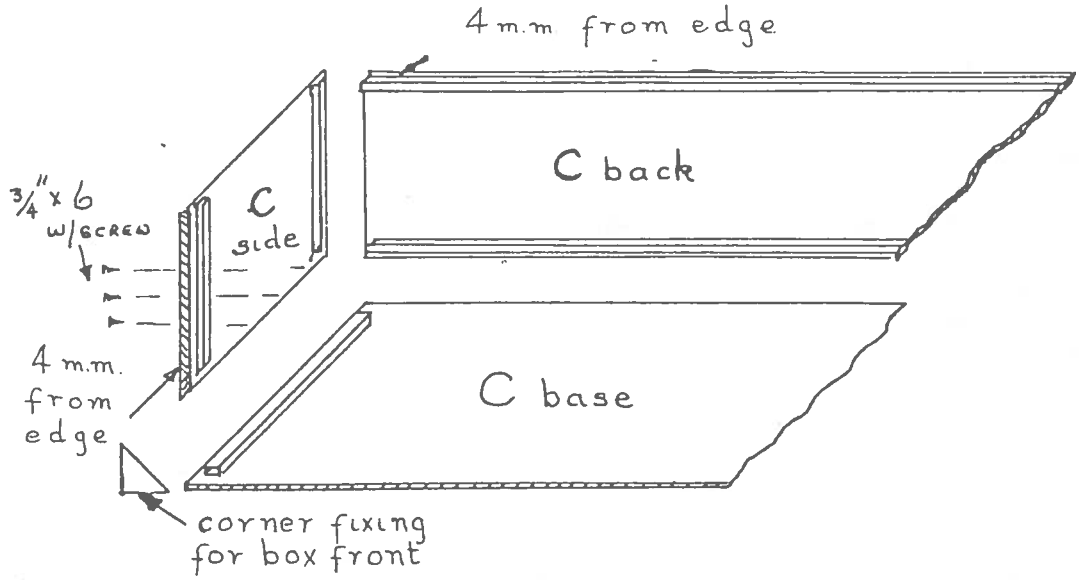

Fig.1

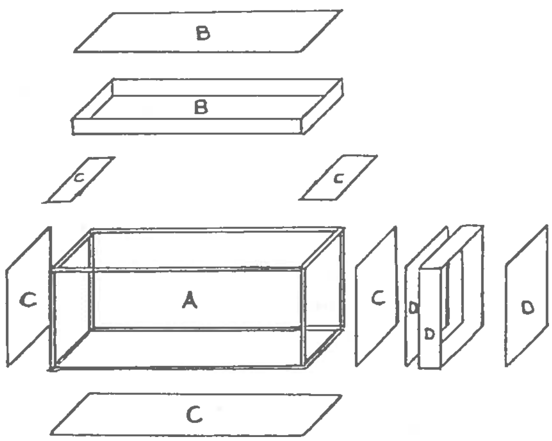

Fig.2

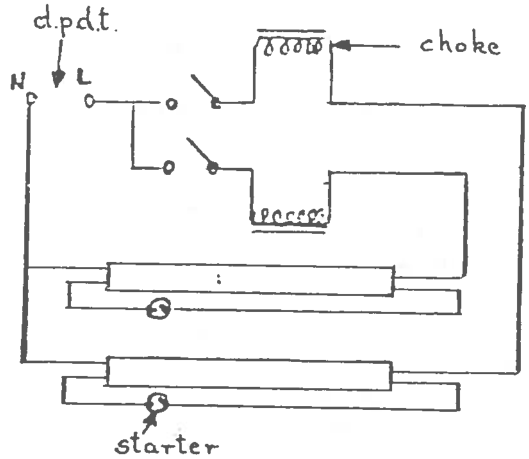

Fig.3 - wiring diagram

Microscopes

PZO microscopes from Poland have had a chequered marketing history in the UK. We did test a few models some years ago and found them to perform satisfactorily. They were also reasonably priced. However they never seemed to be coming from the same firm for very long. This we suspected was caused by their entry to the market as a result of back-to-back trade agreements. Consequently we were reluctant to publicise them too strongly. We had doubts about long term back-up for repairs and spare parts.

Recently we were contacted by AICO International who claim to have negotiated such long term UK marketing rights for the PZO range of instruments. They have set up a separate division - AICO MICRO - to handle distribution, servicing and spare parts back-up for these instruments. A very wide range of student microscopes is available but space allows for but one illustrative example. A model meeting our 'H' grade specification, with 3 objectives; built-in mains illumination; Abbe condenser all mounted on a modern stage focusing stand and in a hardwood cabinet costs £226.00. With a 25% educational discount against an official order this means a delivered price of £169-50.

Another market place development has led to changes in the distribution of instruments and spares for **Olympus** microscopes. Previously the main UK importers and agents were Gallenkamp. Hence the marketing of Olympus models to schools by Griffin and George and the supply of spares through G & G by Gallenkamp. Both firms of course are part of the Fisons group of companies.

Now Olympus Optical Co.(UK) have set up their own microscope division. This will market directly the Olympus microscope range in the U.K. They also claim to offer a full back-up service on Olympus microscopes and their accessories. The division has a representative in Scotland. However we are informed that he is best contacted through the main London office address or telephone number given on the inside cover of this bulletin.

New to us

We are grateful to technician staff in the Robertson Centre, Paisley and in Moray House College respectively, for bringing to our attention two sources of supply previously outwith our ken.

In Bulletin 145 we provided a review and test summary of a range of heart-rate monitors or pulse meters. Since then we have been sent details of another specialist medical electronics company. This is Cranlea & Co. who offer a range of interesting devices some of which are within school price levels. This range includes the usual pulse/heart rate and blood pressure meters including examples by Philips, Monark and Tunturi as well as Cranlea models. Prices for pulse monitors start at £39. A wide range of more sophisticated health and fitness monitoring equipment is also available. However, as you might expect, the prices increase in step with the sophistication offered.

A cheap and cheerful stand-alone digital thermometer, the ST100, is available from Solex. This has both a built in 'environment' sensor and a remote probe. The range covered is -40 to +120 Celsius at a claimed precision of plus or minus one degree. At the one-off price of £28 or £25 each for ten or more, these thermometers deserve further attention. We intend obtaining evaluation samples but meantime would appreciate hearing reports from anyone who has used them in a school.

Digital deluge?

Solex are also a source of reasonably priced electronic stopwatches and count-down timers, but then who isn't? These days almost as many firms sell digital thermometers. Another like Solex with models starting at very reasonable prices is Scientific & Medical. Their bottom of the range model is the 'Mini Therm' at £29-50 (Fig.2). This has a range identical to that of the Solex ST100 and uses a single semi-conductor sensor in a probe.

* * * * *

SSSERC MEMO 1

Constructional Techniques

breadboard stripboard
wire wrap printed circuits

SSSERC MEMO 2

Data Logging Applications

Bicycle Speed Logger

hardware & software removable memory
BBC, PET, Spectrum computer replay

SSSERC MEMO 3

Analogue Application

temperature logging A-D converter
hardware & software BBC, PET, Spectrum

Logic Families

TTL metal gate CMOS
silicon gate CMOS interconnecting

SSSERC MEMO 4

Instructional Techniques

methodology hardware choice
diy approach future trends

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

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

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

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

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

Harris Electronics (London), 138 Gray's Inn Road, London WC1X 8AX

JPR Electronics, Unit M, Kingsway Industrial Estate, Kingsway, Luton, Beds. LU1 1LP Tel. 0582 410055.

Maplin Professional Supplies, PO Box 777, Rayleigh, Essex SS6 8LU Tel. 0702 552961

Nutriculture Ltd., Sandy Lane, Mawdesley, Ormskirk, Lancs. Tel. 0704 822536.

Olympus Optical Co.(UK) Ltd., 2-8, Honduras Street, London EC1Y 0TX Tel. 01 253 2772.

RS Components Ltd., PO Box 99, Corby, Northants. NN17 9RS Tel. 0536 201201

SCDS, Dundee Centre, College of Education, Gardyne Road, Broughty Ferry, Dundee DD5 1NY; Tel. 0382 201201.

Scientific & Medical Products Ltd., c/o Shirley Institute, Didsbury, Manchester M20 8RX Tel. 061 434 3466 or 061 445 2434

Solex International, 44 Main Street, Broughton Astley, Leicestershire LE9 6RD Tel. 0455 283486.

Tait Components Ltd., 973 Sauchiehall Street, Glasgow G3 7TQ Tel.041 339 9959

Unilab Ltd., Clarendon Road, Blackburn, Lancs. BB1 9TA Tel.0254 57643

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

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