SCOTTISH SCHOOLS SCIENCE EQUIPMENT RESEARCH CENTRE

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pH new guide
interfacing

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Walden Precision Apparatus (WPA) Ltd., The Old Station, Cambridge Road,
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INTRODUCTION

Planning Committee - new members

In accordance with the Committee's constitution three teacher members resigned after the summer meeting. At the time of writing three new members are about to attend their first meeting. The committee membership is now as below, with new members asterisked.

Chairman

Mr J.Wilson, (Science Adviser's nominee),Science Adviser, Dunbarton Division, Strathclyde.

Teacher members

Mr D.R.Carnie, P.T. Physics, Dingwall Academy
Mr R.Millar*, P.T. Biology, St.Saviours RC High School, Dundee
Mr J.C.Pattison, P.T. Biology, Eastwood High School, Newton Mearns.
Mr A.R.Taylor*, P.T. Physics, Bell Baxter High School, Cupar.
Mr G.Trensinger*, P.T. Chemistry, Craigshill High School, Livingston.
Mr G. Young, P.T. Chemistry, Bo'ness Academy.

Technician Member

Mr S.King, Chief Technician, Glasgow Division.

Central Committee on Science Nominee

Mr A.H.Sloss, Senior Curriculum Officer, SCDS, Dundee Centre.

CLEAPSE School Science Service

Mr D.Tawney, Director, CLEAPSE School Science Service.

Assessor

Mr H.MacLaren,HMI, SED.

Festive Season Closure

We hereby give warning that the Centre will close as from the end of business on Friday, 21st December, 1984 and re-open on the morning of Thursday, 3rd January, 1985. Some lucky SSSERC staff will be working, of course, making the annual raid over the border to the ASE Meeting, being held this year at Keele in deepest England.

Technicians and the "Bulletin"

Over the last year or so we have been running an increasing number of mini exhibitions and courses specifically for technicians. A perennial complaint at these events has been that many school technicians just never see a copy of the "Bulletin". Recently one technician expressed surprise at seeing a copy of a coloured card covered Bulletin 141. It turned out that she hadn't seen a copy since the old, flimsy white paper days. That means she had not had access to the Bulletin since at least issue No. 127, published in April, 1981!

The Planning Committee has asked us to stress the need for science teachers receiving copies of this publication to circulate it round their department. Such circulation, surely, must include technicians. They are often those needing the sort of safety, technical and source of supply information which we aim to provide. Technicians are key members of any Science Department staff and should not be subjected to the 'Mushroom'*  system of communication.

Footnote 

*Mushroom system of communication - where they keep you completely in the dark and throw manure on you twice a week!

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SSSERC pH publication

Bulletin 143 is something of a pH special. As well as having an article on pH measurement through software, we can also announce the availability of a major document on pH measurement. This is a technical guide entitled:

"School pH Meters & Probes - Advice on their use, maintenance and the diagnosis and remedying of faults"

Copyright-free masters will shortly be distributed to Regions and Islands Authorities. Additional copies will be available directly from SSSERC at £1.20 per copy (inc.p&p).

A separate document has also been prepared which outlines SSSERC Test Procedures for the evaluation of pH meters and probes. This is designed to accompany our test reports on individual pH meters. In co-operation with our English sister organisation, CLEAPSE School Science Service, we have recently carried out a large evaluation exercise. Having tested about 30 models we are presently updating our complete range of pH test reports. We hope to be in a position to publish a complete list of available reports in Bulletin 144.

SSSERC Software Service

Increasingly we are publishing articles on applications which utilise d-i-y computer programs. Often we haven't had the space to publish anything but the shortest listings of core routines. We have offered to supply longer listings on application to the Centre. The uptake for these has often been disappointing. We hope we understand the reason, and that this is the limited usefulness of listings to busy teachers who just don't have the time to sit down and key in large programs.

We have decided therefore to launch a pilot exercise in SSSERC software distribution. Initially this will involve interfacing or control programs for use on the 'Beeb'. A copyright free

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disc is being sent to Science Advisers (or nominated SSSERC/EA correspondents in those areas without a Science Adviser). The first disc, issued concurrently with this Bulletin, will contain core routines for certain specific applications. These are:

(i) acceleration histogram (see Bulletin 133)

(ii) pH measurement (this Bulletin)

(iii) servo motor control with the ZN409 i.c. (subject of separate notes announced in Bulletin 142).

Please Note

We must stress that we are only supplying core routines - the more tricky technical bits. We just don't have the man hours available at SSSERC to do a full front-ending job on any of these programs. It will be for end-users to decide whether or not to use the routines as they stand, just for simple instrumentation or control, or develop them into full-blown user friendly and pupil proof packages. Copies are also being sent to SMDP for possible upgrading and inclusion in their software library.

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SURPLUS EQUIPMENT OFFER

Precision potentiometers

It may have escaped the notice of readers of Bulletin 142 that we have announced the availability of a large and varied stock of these components. They were donated by Beckman via a school in Fife. Lack of space precludes a detailed listing here. Lack of computer time also precluded the drawing up of a printed stock list. However we can supply perfectly legible photocopies of our master stock list for these components. Many of them are precision made and some would cost many pounds each on the open market. We are offering them at nominal charges reflecting only SSSERC's costs incurred in handling and sorting.

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CLEAPSE Guides

We have recently received the following new or revised publications from our sister organisation "CLEAPSE School Science Service". Copies of these publications may be borrowed for up to one month by application to the Director of SSSERC:

L59a "Low Voltage Power Supplies - General Purpose Units"

L124 "Aquaria - Electrical Safety"

L145 "Laboratoryware - Plastics and Other Materials"

L171 "Simple Physiology Equipment"

L35 "pH Meters" [In co-operation with SSSERC, see "Introduction"].

In addition the following Repair & Maintenance Guides have been revised:

BAR "Restoring the vacuum in a Fortin barometer, d-i-y".

LEV "Lever arm balances, d-i-y".

PHE "Reactivation of pH electrodes, d-i-y".

VAC "Electrical rotary vacuum pumps, d-i-y".

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SAFETY NOTES

Dual-range ovens

We have been asked to draw again the attention of readers to the need for care in the use of these devices. Particular care is needed in the use of dual purpose oven/incubators. This is doubly important where the device has a "Hi/Lo" range switch.

The classic incident with this type of oven is where someone has used it as an incubator or drying oven on the ambient to ca.110^{o}C range. They have used a 0 to 100^{o}C mercury-in-glass thermometer to monitor the internal temperature. Later applications require the use of the high range. The range switch is activated but meantime everyone has forgotten about the thermometer. Result, a burst thermometer and a mercury contaminated oven. A reminder notice on the oven door, to encourage checking of the thermometer in use, is one possible precaution. However we are of the opinion that avoidance of mercury filled thermometers in ovens is a safer bet. For many applications the use of calibration charts attached to the oven and/or a rotary type bimetallic thermometer will suffice.

The siting of ovens and incubators needs some care and common sense. Teachers know their pupils best. It may present too much of a temptation if oven/incubators are sited in laboratories. In one recent incident pupils even over-rode a lockable type setting of the type normally requiring an Allen key for adjustment. This was particularly unfortunate in that there were microbiological cultures in the device at the time.

It has been suggested that ovens and incubators be clearly marked with information plates on siting. However it seems to us that this would be difficult to put into practice without causing undue discrimination against or alarm about the products of the complying manufacturers. There are a large number of firms making laboratory ovens and only a small proportion of their output finds its way onto the educational market. Also such a course of action does nothing about ovens and incubators already in the schools.

It seems to us that it is a little unfair to transfer to only some of these manufacturers, under Section 6 of the Health and Safety etc. at Work Act, a duty of care which more properly lies with employer's and management under Section 7. The general duty we have in mind is that concerned with the safe installation and use of equipment. It is more a matter for the common sense of science department managers in choosing suitably safe, yet convenient, sites for certain types of equipment.

Encapsulated mains power supplies

As a prefix to any article on electrical safety and U.K. based, school, science, laboratory equipment its worth bearing in mind the critical datum, in so far as our knowledge of events is true,

fatalities nil

This record should not however encourage us to be less than scrupulous on electrical safety. We perceive a slide in this particular context and we aim to stem it.

Our concern is specifically with the usage in schools of encapsulated mains to low voltage power supplies. They sometimes come in the form of mains adaptors; the 3 prong, 13 A plugs being an integral fitment to the device. Such devices are acquired by schools for a variety of reasons, the principal ones being

(1) Supplied by manufacturers of electronic equipment as the low voltage supply for that equipment; typical examples being laboratory instrumentation (GiPSI) and microcomputers (Spectrum).

(2) Deliberate purchase as an inexpensive, low voltage supply.

There are of course many such devices on the market and we cannot say, even in general terms, that they are inherently unsafe. We have only examined a few, but this sample, small though it is, is the cause of our concern.

On what basis do we make a judgement on safety? To some extent it is opinionative. Not, however, a casual opinion, but an opinion based on professional work on electrical safety built up over the twenty years' lifespan of the Centre. The ground is partially covered by regulations, some national such as British Standards, some international such as from I.E.C. (International Electrotechnical Commission). Professional opinion depends upon interpretation of these regulations, wide experience of equipment design and construction, consultation with manufacturers and other professional bodies, and application of common sense.

What then are features we have found in mains encapsuated supplies, features that is, which, in our opinion, are second rate, or worse? We list them below.

(1) **Mains cable clamp** The mains cable should be securely clamped to equipment housings. We do not like the common practice of making use of the wedge action between the two halves of the housing.

(2) **Connections** Live conductors and earth leads should not be secured solely by solder joints. We have not observed any appliance of the type we are discussing which makes use of mechanical crimping.

(3) **Fusing** We think that the live conductor between input and step down transformer should be fused. This is particularly important if the device is a mains adaptor type. Many devices, mains adaptor type included, are not fused. However those which are not fused do appear to have a thermal cutout which in our view is only second best. The one device we found to be fused had neither an appropriate fuse nor had fuse rating and type marked on the casing.

(4) **Fixtures** It is usual to find components, including the mains transformer, mounted on printed circuit board and wedged in position by mouldings within the housing, but not bolted to the housing. In one device a wedge of paper prevented the transformer moving about. It is also common to find components birds nested; at the H.T. side the thermal cutout has been seen to be connected thus; at the L.T. side the rectifier and smoothing capacitor may be fixed thus. We could go further and condemn all devices inspected on grounds of birds' nesting; neither mains cable nor transformer being fixed to the housing. In one horrifying case the transformer could move such that its core

could come in contact with the live fuse.

(5) **Transformer** Transformers should be designed to the appropriate standards. Points we look for are (a) earth screen winding or double bobbin construction, and (b) earth conductor to yoke and core. In every case the transformer was of double bobbin construction, but in no case had the yoke and core been earthed.

(6) **Earthing and insulation** Some devices inspected carried the double insulation symbol. All inspected, indeed, have non conducting, moulded housings. However the integrity of an insulation system depends, amongst other factors, on the physical separation between a live conductor and non live conductor within the housing. We express concern at the integrity of any device in which conducting components are birds' nested.

(7) **Cable colour coding** We have seen devices in which the low voltage output cable is colour coded brown and blue. Neither these colours, nor green/yellow should be used for any purpose other than what one should expect by convention.

(8) **Low voltage output** Some supplies have male-type jacks, if you pardon the expression. (Why do so few women take up engineering?) Mains equipment should not have outlets of this kind; a modest, female-type, shrouded socket is better.

(9) **Adaptor pins** We express anxiety at the long term integrity of these fixtures depending, as they do, on contact adhesive between metal pin and moulded case.

These common features are the cause of our concern. We do not think it right that we should put up with double standards; one standard for conventional mains operated equipment such as a bench standing, low voltage, power supply; another standard for encapsulated mains supplies and adaptors.

A particular difficulty for us is the absence of a single recognised electrical safety standard for portable laboratory equipment. This was touched on in the opening section of this article. It results in the application of what are judged to be reasonable provisions culled from a number of other standards. The important point however, is that some of the encapsulated supplies we have examined do not even begin to meet any of these provisions. Some of them are downright sloppy and the waste bucket would be the proper place for them. Even the best of them are, in our view, second rate.

The concept of a convenient plug-in, mains to low voltage adaptor is not under attack here. Such supplies, properly designed and constructed can be extremely useful. What we are saying is that designs need to be markedly improved and the points made above attended to. In some cases this may prove difficult since the devices are imported items, many of far eastern origin. In the interim, our advice to schools is do not purchase an encapsulated supply in preference to a bench unit as a source of low voltage. Our advice to manufacturers is to improve their designs for such supplies if they are to continue offering equipment which incorporates them.

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Microscope spares - COC Models C & CA

The COC model C, was first recommended, for pupil use up to 'O' grade, with a SSSERC assessment of "A" (most suitable for use in Scottish schools) when the instrument cost only £19! Many teachers seem to have accepted or agreed with our assessment and the instrument is held in very large numbers by Scottish schools.

As far we can tell, the majority of these instruments are still giving good service. However, our early test report did make three recommendations which were, eventually, heeded by the Japanese manufacturers. The recommendations were:

- to fit a bottom focussing stop
- to fit a grub screw or similar mechanism to prevent loss/theft of the eyepiece
- to fit a similar preventative to the mirror shaft housing.

Unfortunately instruments were purchased by schools in fair numbers before these suggested design changes were implemented by the Carton Optical Company (COC). This has meant that eyepieces and mirrors on early models have exhibited high vapour pressures.* This has had an equally high nuisance value for many schools. Recently their problems have become even more acute because of the disappearance from the commercial scene of the sole British agents for certain COC models. We refer to the Parisian Opera & Field Glass Co.Ltd. who were merged with the firm of Newbold & Bulford Ltd. This latter concern took over Parisian Opera's stocks but eventually discontinued most of their range of models and spares. In any case the model C had already been discontinued before the merger, in favour of a more recent model - the CA.

Spare optics for both the model C and CA are not a serious problem. The eyepieces are of standard Royal Microscopical Society (RMS) external diameter, and objectives have RMS threads.
Any RMS threaded objective will fit the nosepiece. It may not however be parfocal with the other existing objectives, unless it had been designed with the same focal length/working distance as the original.

For example, checks on the sample models held in the Centre showed that a X10 Olympus objective from an HSC as well as x4,x10 & X20 objectives from badge engineered COC instruments, were adequate substitutes for the original objectives of model C and CA instruments. The "badge engineered" models in question were the Griffin Gamma 20 and the Opax NES 200X (T). Similarly, eyepieces were found to be freely interchangeable (so long as one loosened the grub screws first!).

A more serious problem is posed when spare mirrors are required. Mirrors from some earlier Opax models would fit straight into the model C mirror shaft housing. However recently there seems to have been a general tendency by most Japanese makers to use mirror shafts of slightly greater diameter. This may be to facilitate the fitting of locking grub screws in the mirror shaft holder. The only solution, it seems, is to buy whole spare mirror assemblies such as those for an Opax NES 200X (T) model and to drill out the model C mirror shaft aperture to take the new assembly made up of shaft, gimbal and mirror holder. We have already done this for one school which kindly allowed us to experiment on one of their instruments.

This simple modification involves unscrewing the mirror mount from the base of the limb. Use of a pillar drill is necessary and the workpiece has to be securely held and plumb, i.e. at right angles to the bit and drill table. For preference this means the use of a proper drill table vice or toolmaker's clamp. Only a very small amount of metal has to be removed and this requires the use of a 5.5mm diameter twist drill. Very little enlargement, ca. 0.5mm, is needed and the drill bit will go through very easily.

We also looked at the possibility of adding a grub screw in an attempt to more securely fix the shaft of the replacement mirror. However the slot on the new mirror shaft would make this very awkward and would require lathe work. Such a

* ∴ easily 'evaporating', disappearing into thin air.

modification would be unduly difficult for many schools and we decided not to proceed.

Spare mirror assemblies for the NES 200X (T) are available from Opax at the address on the inside cover. At the time of writing they cost £5.95 each.

Re-usable plastic Petri dishes

In Bulletin 134, February 1983, we reported on some in-house tests we had carried out on polycarbonate Petri dishes. These were claimed to be recyclable (horrible word!) being designed to withstand autoclaving at 121°C. The results of our own, somewhat artificial, tests were sufficiently encouraging for us to arrange field trials in a school as well as extending our own tests. The results of these further investigations have been to hand for some time, in a queue awaiting bulletin space.

Our further investigations addressed two major points:

a) Could the dishes, and contents if necessary, be reliably sterilised in a schools pressure cooker type autoclave?

b) Would they stand up to the rougher handling they would receive in a school without becoming unacceptably scuffed and damaged?

The answer to a), according to our tests, is probably not.

We used 'Thermalog S' steriliser indicator strips in a variety of autoclave runs. The germane results were those where a strip was placed inside a dish within a loosely closed, but unsealed, autoclave bag. A control strip was placed in a McCartney bottle with a loosened lid, in the same bag. In some runs with the standard 15 minutes full $15 lbin^{-2}$ above atmospheric pressure, the strip in the bottle indicated "safe" whilst that in the dish read "unsafe".

We have no explanation for these results other than the lack of any distortion in the polycarbonate base or lid. This of course is a plus point for recycling but may possibly prevent steam penetration/displacement of air. With polystyrene dishes this is not a problem. They distort grossly and freely admit the steam. This does little for their physical integrity and, although reliably sterile, they are hardly re-usable!

In the original article we made the point that the economics of polycarbonate dishes, just like those of returnable glass bottles, hinge on journey numbers. Point b) poses the key question for school trials. On this aspect we can do no better than quote the teacher at Inverkeithing High, Fife, who kindly carried out the trials for us:

"We have evaluated the polycarbonate dishes and our findings are as follows:-

We used the Petri dishes for sixth year studies pupils only. The edge of each dish was marked each time it was used. These pupils used the pressure cooker (previously tested with spore sterilising indicator strips) in preference to the autoclave. They found that the dishes could only be used 3 or 4 times before a pattern of bubbles, resembling a network, appeared in the material. If the Petri dishes were allowed [accidentally] to come into contact with the metal this effect increased and there was distortion which was not rectified on cooling [The manufacturer warns of this, Ed.].

We also found it a nuisance to have to clean out/re-sterilise the dishes. In view of their short useful life, we probably would not consider buying them and having to do this."

There doesn't seem a lot of point in adding to that report. We are grateful to the biology department and pupils at Inverkeithing High for their assistance.

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pH probe/Beeb interface

Abstract

A description is given of the design, construction and performance of a home built pH meter comprising pH electrode, signal conditioning system and BBC microcomputer. Unlike conventional metery its hardware is kept very simple. Most of the signal conditioning is achieved by software; the hardware part consists of two elements only, a stable voltage reference and a very high impedance voltage follower.

Underlying principles

In order to understand the design of a pH meter it is necessary to start with the principles underlying pH measurement, or what one electronics textbook calls "the black art" of pH measurement. A pH probe acts like a cell with an emf of 0V in a neutral solution and an emf of around 60 mV per pH unit away from the neutral pH of 7.0. Acid solutions generate positive emf's, base solutions negative emf's. We see this relationship in the graph (Fig.1) which also reminds us that the probe emf is temperature dependent. The other key factor which has to be taken into account in meter design is the probe's internal resistance, which is typically 15 megohm upwards. This, for probes found in schools, is likely to lie between one hundred and five hundred megohms at room temperature, a figure which trebles if used at $0^{o}C$. For accurate measurement of probe emf a meter must have an input resistance which is many orders of magnitude greater than the probe's internal resistance (Fig.2). Three orders of magnitude difference produces a measurement which is 0.1% low.

The general rule which can be drawn from this analysis is one significant figure per order of magnitude difference.

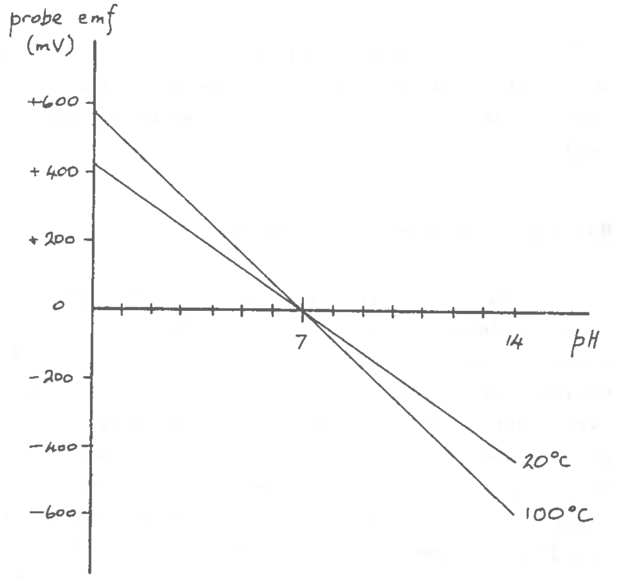
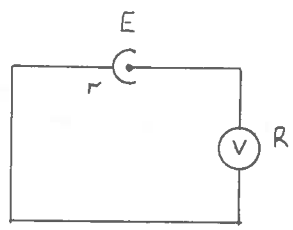


Fig. 1. Relationship between pH and probe emf.



r = internal resistance of probe
R = input resistance of voltmeter
E = emf of probe
V = voltmeter reading

r/R	(V/E)×100%
1/1	50%
1/10	91%
1/100	99%
1/1000	99.9%

Fig. 2. Meter reading as a percentage of probe's true emf.

This technical problem is met by inserting a very high impedance operational amplifier between the probe and meter. In our case this op amp is wired as a voltage follower which is a device whose output voltage matches precisely, and equals, its input voltage. The system behaves as an amplifier with a gain of 1 and can be described as a high impedance buffer (Fig.3).

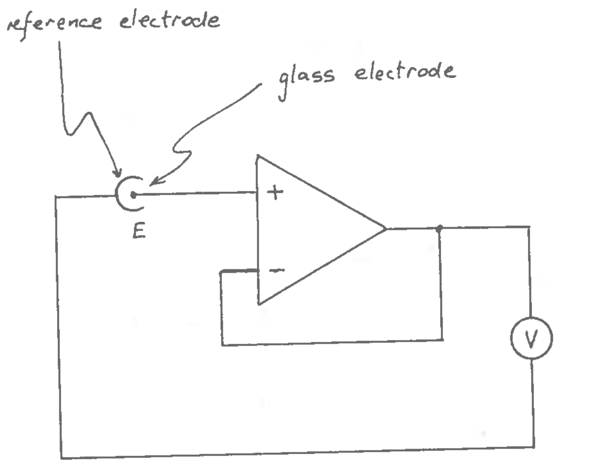


Fig. 3. Voltage follower between probe and voltmeter.

System design

The op amp we have chosen is a 7611 which is a C-MOS device with an input impedance of 10 teraohms (10 to the power 12), 3 to 4 orders of magnitude over the internal resistance of a typical probe. Its other two attractive features which we have taken advantage of in our home-brewed meter design is its extremely low operating voltage, which can be as low as ±0.5V, and its ability to drive the output to within a few millivolts of the supply voltage.

In this particular design we have had to allow for an input voltage range at room temperature of ±7x60 mV (±420 mV) giving a span of 840 mV. If working with solutions at higher temperatures this span would widen. For instance a solution at 100°C would widen the span by a factor of x1.3 to 1100 mV, setting a minimum reasonable supply voltage at ±0.6V.

Other factors which pH meter design has to take account of are

(1) temperature compensation,
(2) scaling factor, and
(3) offset zero.

Traditional pH meters deal with these factors by hardware contrivances, using variable gain amplifiers for (1) and (2) and a summing ampifier for (3). A scaling factor converts probe emf in millivolts into the pH scale of 0 to 14 and is 58.1 mV per pH unit at 20°C. This factor is usually determined empirically by the user (part of the calibration process) with standard buffer solutions and is achieved electronically by adjustment of an amplifier gain in the meter. The offset zero signal offsets the probe signal to its conventional pH readout. For example when a probe is in a neutral solution (pH 7) the signal from the probe is 0 mV and has an offset voltage added to it so that the meter reads 7.0; this process being traditionally performed by the operator during calibration who has to adjust a potentiometer that is part of the offset zero summing amplifier. Temperature compensation is achieved by means of a variable gain amplifier such that the signal amplitude from the probe is attenuated when the solution is warmer than 20°C, and vice versa.

All three factors can however be dealt with by software using an intelligent digital voltmeter or microcomputer. In our design with the BBC microcomputer, voltage sensing is achieved using the microcomputer's on board A to D converter accessed through the analogue port (ref. Bulletin 140). This port is designed to accept inputs in the range 0 to +1.8V and has a resolution of 1 part in 1024 in normal operation.

However the analogue port has one serious hardware defect which unless corrected would render this system worthless. All voltage measurements are made relative to an internal voltage standard which unfortunately drifts with temperature. The microcomputer, due to heat generated within it after power up, takes about three hours to attain a steady state temperature in a constant temperature environment. A 5% drift in internal voltage standard takes place during this warm up. Just suppose the analogue port is used unmodified, suppose the pH probe is in a neutral solution, and suppose the voltage from the op amp buffer is 600 mV during calibration at power up, then after three hour's usage the analogue port reading of neutral would have drifted off by 30 mV, 5% of 600 mV. The meter would be inaccurate.

The unsatisfactory internal voltage standard within the BBC microcomputer is a chain of three series silicon diodes, showing incidentally how suitable these devices are as temperature sensors. It is possible, however, to override this reference standard by connecting an additional voltage reference device in parallel to the diodes and external to the analogue port (Fig.4). It is important that this external standard voltage is lower than the nominal 1.8V reference provided by the internal diodes. One suitable external reference device is the Ferranti bandgap diode, ZN423, whose output voltage lies in the range 1.20 to 1.32 volts, each individual bandgap having its own stable value somewhere within this range. Provided that the current conducted by the bandgap is fairly stable we find that the long term reference is maintained at better than 1 part in 2000, that is, a drift by as much as 500 microvolts has not been discerned by us (the manufacturer's data sheet specifies a drift no greater than 10 p.p.m./1000 hours). As the resolution of the A to D converter is 1 part in 1024 (as we use it, see below) the system is completely stable within its inherent precision. For proper operation the bandgap reference current should lie between 1.5 and 12 mA; control being achieved by choice of dropping resistor between the positive 5V supply rail and bandgap. As the 2K5 resistor within the microcomputer (Fig.4) sets the current at the lower limit we have boosted this bandgap current by adding a 2K2 resistor in parallel with the other. This also provides sufficient current for the op amp buffer.

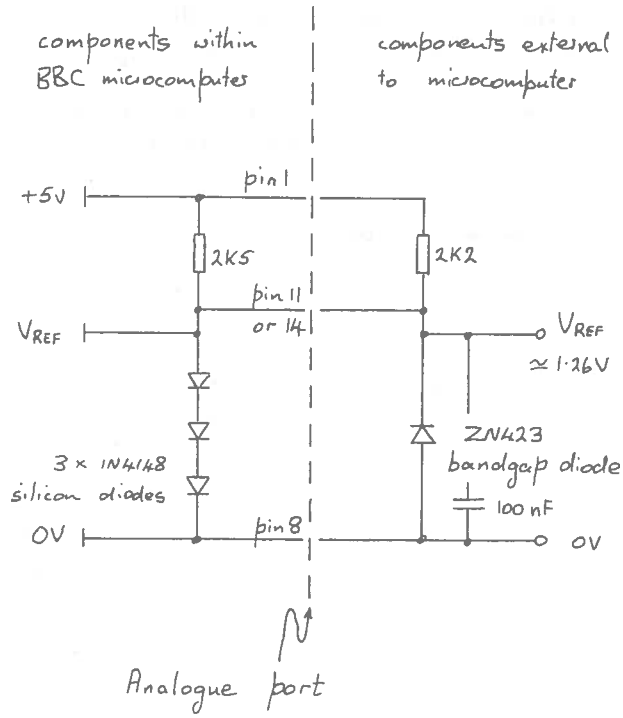


Fig. 4. Stable voltage standard for BBC analogue to digital converter.

— also stable power supply for pH probe. Power drawn from V_{REF}.

With this reference system the upper limit of the analogue port becomes the bandgap reference of about 1.26V. That is, the port has a resolution of about 1.2 mV. We can therefore use this port to measure the emf of a pH probe to a resolution of 1/50 th of a pH unit without amplification of the signal from the probe. With amplification we could achieve a finer resolution, but at the expense of range. In the program listing below each "reading" of pH is the average of 16 separate measurements and this has the effect of reducing the standard deviation of each reading to one quarter the standard deviation of a single measurement.

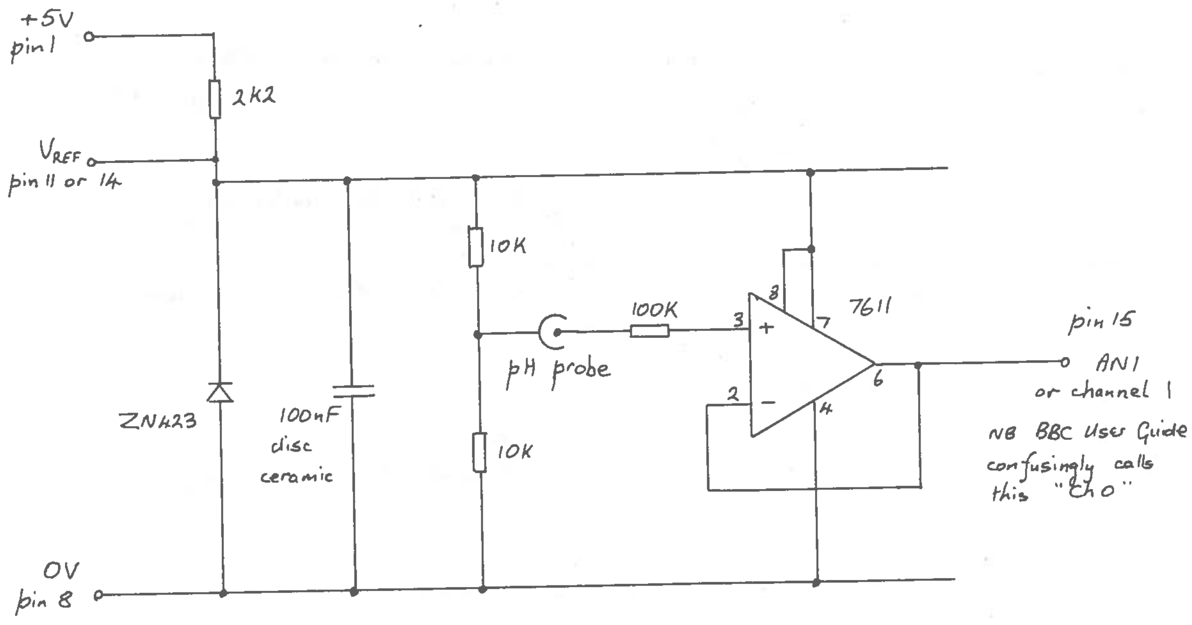


Fig. 6. Circuit diagram showing pH probe, signal conditioning system and BBC analogue port connections.

Therefore so far as the microcomputer side of the system is concerned the system has, theoretically, a resolution and stability of one hundredth a pH unit.

The actual circuit is shown in Figure 5. Power is drawn from the computer's internal +5V rail via the analogue port outlet, see above. It would seem instructive to discuss voltage levels as determined by our choice of components. The potential of the pH reference electrode is set at 0.63V by the two 10K potential divider resistors, this level being in the middle of the analogue port's input range (Fig.6). The output from the op amp neither requires amplifying, nor offsetting, but matches the analogue port's input specification with sufficient margin to spare.

Construction

The circuit should be assembled on 0.1 inch stripboard. A component layout plan is given (Fig.7). Take care that the leads to the two inputs of the op amp are as short as possible in order to lessen the chance of stray pick-up at these inputs; an effect which could happen on account of the extremely high input impedances. Copper strips to these inputs (pins 2 and 3) should therefore be cut back short. Again to help avoid pick-up it is advisable to insert the circuit in a small metal box. The input lead from the pH probe should be screened coax and should terminate with a 'bnc' type plug. There should be a matching 'bnc' type socket mounted on the metal housing.

In practice we have had no trouble at all from pick-up even though our prototype circuit was bird's nested, unshielded, in rough and ready fashion on breadboard.

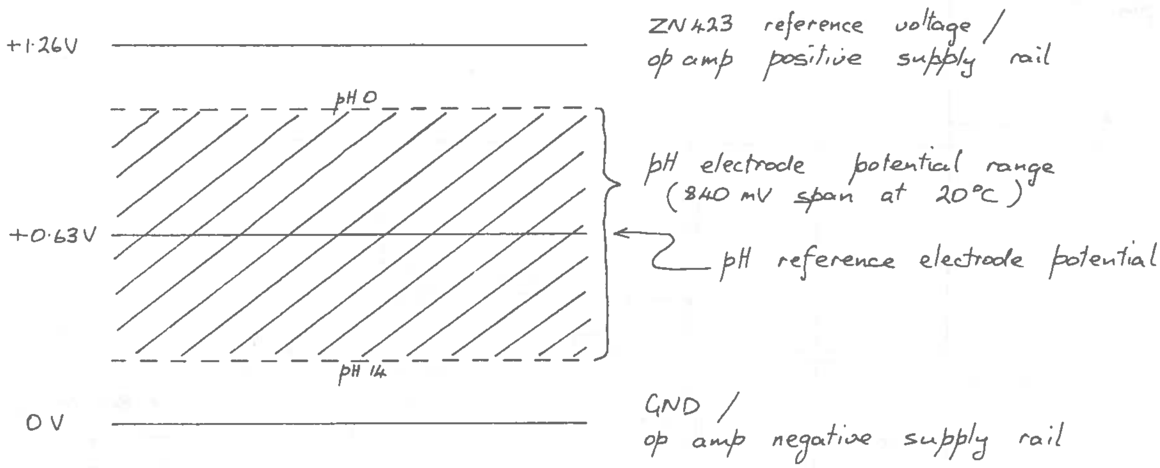


Fig. 6. Potentials on pH signal conditioning system.

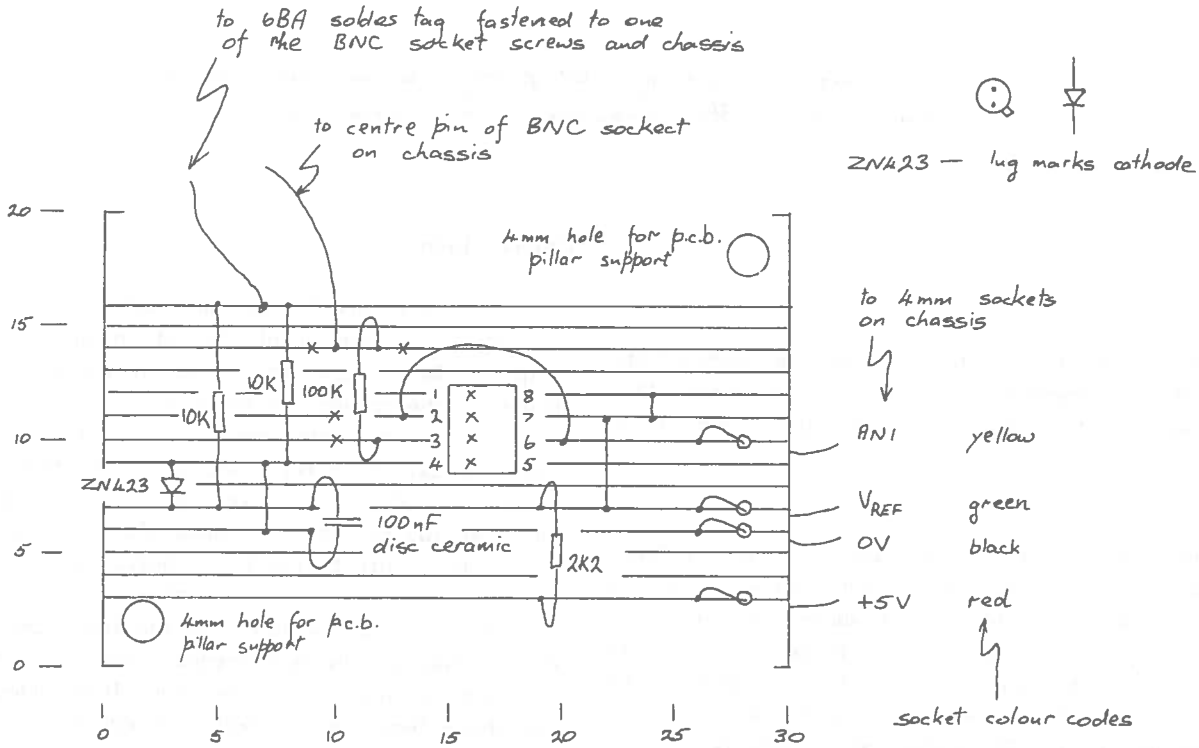


Fig. 7. Stripboard layout of components.

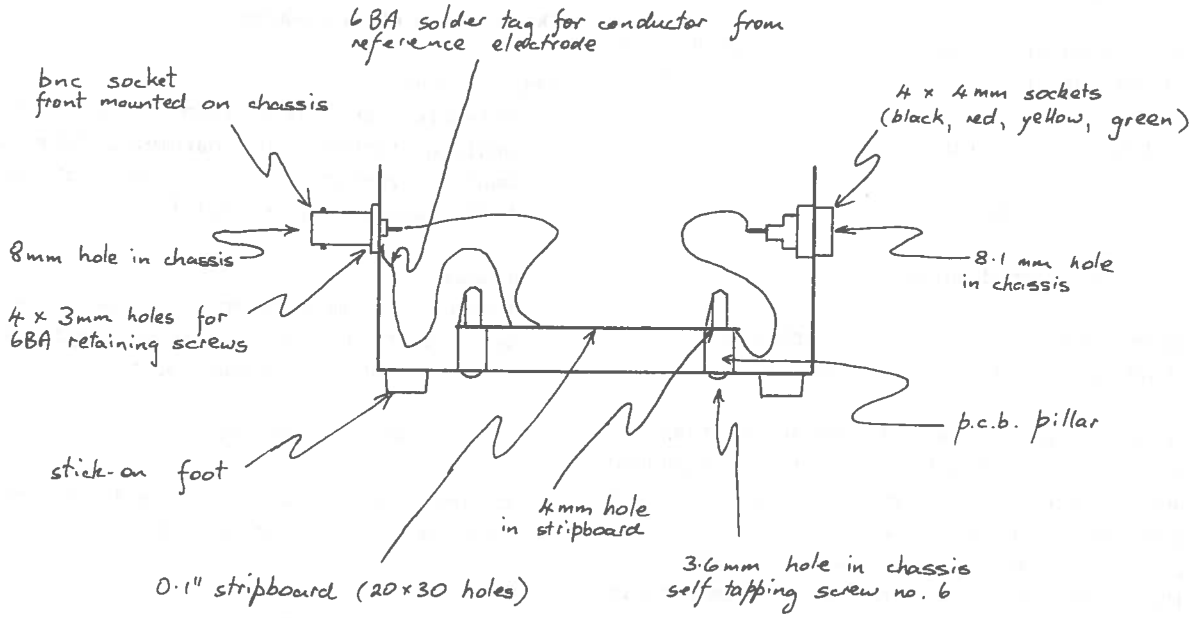


Fig. 8. Housing the circuit

Suitable components from the RS Components range are

308-887	op amp, 7611
283-233	bandgap diode, ZN423
124-178	disc ceramic capacitor, 100 nF
131-299	resistor, 2K2
131-378	resistor, 10K
131-491	resistor, 100K
455-624	'bnc' plug
455-810	'bnc' socket
402-759	d.i.l. socket, 8-way
509-989	aluminium alloy diecast box, 114x64x55 mm
444-618 etc.	4 mm sockets
433-826	stripboard, 0.1 inch
606-901	p.c.b. pillar
522-162	self tapping screw, no.6
532-541	solder tag, 6BA
543-327	'stick-on' feet

Notes on housing the circuit are given (Fig.8). An assembly order might be

(1) Cut stripboard with hacksaw, size 2x3 inches (20x30 holes). Smooth off cut edge.

(2) Drill two 4 mm holes, one each in opposite corners of the stripboard (4 mm drill, no.22).

(3) Place stripboard on bottom base of diecast box and use as the template for the position of these two holes. Drill two corresponding holes, diam. 3.6 mm, in the box base (3.5 mm drill, no.29). Fasten p.c.b. pillars at these two holes with no.6 self tapping screws. Check that stripboard fits securely to pillars.

(4) Front mount the 'bnc' socket at one end of box. First drill a pilot hole, then enlarge to diam. 8 mm (8 mm drill, no.0). Use socket flange as template and mark sites of 4 securing screws. Drill out 4 corresponding 3 mm diam. holes (3 mm drill, no.31) and fasten socket with 6BA screws.

(5) Mount 4x4 mm sockets on opposite end of box.

Begin with pilot holes and enlarge to 8.1 mm (8 mm drill, no.0). Code the sockets by colour

- black - ground
- red - +5V
- yellow - chl
- green - V_{ref}

and label accordingly.

(6) Solder components on to stripboard (Fig.7) starting with 8-way d.i.l. socket.

(7) Finally attach short flying leads (flexible stranded wire, 7/0.2 mm) to the stripboard and connect to the corresponding 4 mm sockets and 'bnc' socket; the lead from the signal pin of this socket going to the op amp via the 100K resistor; the lead from the mid point of the 10K potential divider chain being connected to the chassis at a 6BA solder tag fastened to one of the 'bnc' socket screws. Secure the stripboard within the box.

It will be ready for use after checking. Connection to the analogue port can be made with a system as described in Bulletin 140 (pages 6 and 7) except that an additional socket to the six shown (Fig.2, page 7, Bul.140) has to be provided giving access to V_{ref}, either pin 11 or 14.

Software

One short program listing is included, this program enabling the user to calibrate the system with buffer solutions and thereby obtain pH measurements of other solutions. A simple digital reading is displayed on the VDU screen.

There are two things to be aware of about calibration. (1) The first used buffer must be a neutral solution. (2) Both buffers should be at, or near to, 20°C. After calibration the system is ready for pH measurement. The number which appears on the screen during calibration and measurement is related to the probe voltage; the user should wait for this number to steady as a guide to equilibration. To recalibrate its necessary to press "ESCAPE" and type "RUN". To end the program, press "ESCAPE".

Description of procedures

PROCcalibration

This organises calibration by working out a scaling factor (the parameter "slopefactor") based on readings of electrode emf with two buffer solutions, neutral first.

PROCmeasure

Means 16 measurements of probe emf. The analogue to digital conversion instruction on channel 1 of the analogue port is

```
Y% = ADVAL(1) DIV 64
```

giving 10 bit resolution. The ADC buffer is not read until the ongoing conversion is complete. This is determined by

```
REPEAT UNTIL ADVAL(0) DIV256
```

and ensures that when we take the mean of a sample of voltage measurements we are meaning different actual measurements rather than meaning the content of the ADC register which retains the value of one conversion for about 10 ms. The sample number is 16. Note that the mean ADC reading is repeatedly displayed on screen as an aid to equilibration.

PROCbuffer

Organises the use of buffer solutions during calibration and assumes a working temperature of buffer solutions of 20°C.

PROCsample

Organises determination of pH of sample under investigation. Displays pH reading to 2 decimal places.

PROCequilibrate

System repeatedly measures pH probe voltage and waits for user to decide when equilibrated. Figure on screen is related to probe reading.

PROCtemperature

Derives temperature factor.

```
10 REM pH meter, Program 1
20 REM features digital readout of pH
30 REM copyright Scottish Schools Science Equipment Research Centre
40 MODE7
50
60 REM sample channel 1 (analogue port) only
70 *FX16,1
80
90 REM calibrate meter with 2 buffer solutions
100 PROCcalibration
110
120 REPEAT
130   REM measure unknown pH of sample
140   PROCsample
150   REM end program by pressing ESCAPE
160   UNTIL FALSE
170 END
180
190 DEFPROCcalibration
200 REM organise calibration of meter
210 PROCbuffer("neutral (pH=7)")
220 firstpH=7: calread1=mean
230 PROCbuffer("second")
240 secondpH=pH: calread2=mean
250 slopefactor=(firstpH-secondpH)/(calread1-calread2)
260 ENDPROC
270
280 DEFPROCmeasure
290 REM take mean value of 16 readings of voltage applied to channel 1
300 T%=0
310 FOR N%=1TO16
320   REPEAT UNTIL ADVAL(0) DIV256
330   Y%=ADVAL(1) DIV 64
340   T%=T%+Y%
350   NEXT N%
360 mean=T% DIV 16
370 PRINT TAB(18,9);"         "
380 PRINT TAB(18,9);mean
390 ENDPROC
400
410 DEFPROCbuffer(order$)
420 REM organisation of use of buffers in calibration
430 CLS:PRINT TAB(0,5);"Place pH probe in ";order$;" buffer"
440 IF order$ = "second" THEN PRINT "and key in pH of buffer": INPUT pH
450 PROCequilibrate
460 ENDPROC
470
>
```

```
480 DEFPROCsample
490 REM measurement of unknown pH of sample, giving digital readout
500 PROCtemperature
510 PRINT TAB(0,6);"Place probe in sample"
520 PROCequilibrate
530 samplepH=firstpH-(calreadl-mean)*slopefactor*tempfactor
540 @%=&20209:PRINT TAB(10,9);"Sample pH = ";samplepH:@%=&10
550 PRINT TAB(3,18);"Press SPACE BAR for another reading"
560 REPEAT:A$=INKEY$(100):UNTIL A$=" "
570 ENDPROC
580
590 DEFPROCequilibrate
600 REM pause for user to decide when equilibrated - takes measurement
610 PRINT "Press SPACE BAR when probe equilibrated"
620 REPEAT
630   PROCmeasure
640   A$=INKEY$(100)
650   UNTIL A$=" "
660 ENDPROC
670
680 DEFPROCtemperature
690 REM determination of temperature factor
700 CLS:INPUT TAB(0,5) "Key in sample temperature (C) " temp
710 tempfactor=(273+20)/(273+temp)
720 ENDPROC
>
```

Further development

We do not have room in the Bulletin to outline or list lengthier software, but this listing, Program 1, can be developed by that process which is known as "frontending", taking the bones of a software system and fleshing it out into a system which is comprehensively useful, robust and user friendly. We have done a little frontending to Program 1 ourselves and our second version, Program 2, lets the user plot pH versus time, obtain a screen dump on an Epson printer with use of Printmaster, and save data on disk. Program 2 is available on request as a listing. This software is also being distributed on disk into Scottish Regional and Island Authorities who are to receive one copyright free copy (see Introduction to this Bulletin).

May we briefly mention other possibilities which exist for the enthusiast.

(1) The slope of a probe is not linear over the whole pH range. Consequently for accurate work any meter should be calibrated (i.e. slope control fitted) and standardised at a pH bracketing or very close to that being measured. The software could be amended so that the probe is calibrated over several ranges and the software arranged so that it will 'switch in' the appropriate value for the slope.

(2) Closed loop control engineering is well within the scope of able pupils. At a simple level this might consist of a system to control the rate of flow of titrant.

Evaluation

The system was subjected to the same test procedures used by the Centre for evaluating commercial pH meters. Because of the intrinsic nature of some features of this system, certain of the tests required to be modified.

(a) General description

1.The meter has a scale of 0-14 X 0.01pH and has manual temperature compensation facilities. Clearly it has an output which is fed to the micro' and which may be displayed on the monitor or reproduced on a printer.

The whole system is housed in a small box requiring only a BNC socket for the probe input at one end and four 4mm sockets at the other end to provide connections to the BBC.

(b)Performance

2. wide range error
The instrument was calibrated using buffers pH7 and 4 and moved successively with rinsing between buffer solutions of pH 2,4,5,6,8 and 10. The errors found were:
at 2, zero
at 10, -0.24 (i.e. a shortfall of 0.24)

3.short range error
(i) The errors found were:
at 6, -0.09
at 2, +0.02
(ii) the system was then recalibrated using buffers pH7 and 9 and moved successively between buffers of pH 8,6,10 and 8. The errors found were:
at 8, -0.14
at10, -0.11

4.error of scales
Multiples of 58.1mV were applied to simulate a probe with an ideal Nernstian response at 20°C.
+7X58.1mV applied, error = -0.01pH
-7X58.1mV applied, error = -0.01pH

millivolt scales--N/A

5.temperature compensation
(a) wet test.(meter + probe)
The probe is 'buffered' at pH4,7 and 9 at 20°C and in each case the temperature of the waterbath is changed in intervals of 10°C from 10 to 50°C. The meter reading is noted and the manual temperature compensation applied. the errors found were:

at pH4,	zero	at 50°C,	0.04 low at 10°C
at pH7,	0.05 high	,	0.04 low
at pH9	0.02 high	,	0.12 low

(b)dry test.(meter only)
There was fed into the meter the expected ideal output from a probe immersed in a buffer solution of pH3 at 40°C and at 70°C. The reading was noted with the temperature compensation set at 20°C and at the stated temperature. the read-outs after application of corrections were:
at simulated 40°C, 3.14
at simulated 70°C, 3.12
(3.16 expected in both cases)

6.drift -- zero over a period of 3 hours. This was measured with the micro' switched on from cold and the probe placed in a buffer solution kept at a constant temperature in a thermostatically controlled water bath.

7.battery check N/A

8.stability of power supply -- not tested

9.probe recovery -- not tested

10.output -- this is available via the BBC to VDU or printer.

11.input impedance -- 9 X 10^{11} ohms. Though not as high as expected ,probe response was found to be adequately rapid even at low temperatures (3.5°C was used)

(c) Ease of use

12. The digital display on the screen is of the normal print size and as the software stands the display is more suited for individual use than for demonstration purposes. The graphical display

(pH/time) is very suitable for demonstrating titration curves if a burette with a constant flow device is available. Such a device is described elsewhere in this bulletin. If desired subsequent graphs may be superimposed on earlier traces.

13. <u>controls</u> -- are entirely by software and hence in the process of calibration the output of a probe can be assigned any exact value.

14. <u>other devices</u> -- none

15. <u>slope control</u> -- the accomodation is made available by software and is therefore infinite.

16. the device is at low voltage, being powered by the 5V supply available from the BBC's analogue port.

17. <u>instructions</u>. -- once the software has been loaded the instructions appear on the screen at the appropriate stage of the procedure.

Summary

The graphing facilities mentioned in 12 are very useful for showing rapidly the shapes of titration curves for weak and strong acids and bases. The device as it stands does lack a millivolt measurement facility and is not very portable. On the other hand this digital meter, unlike the majority of commercially available digital meters, does have an output. The performance is more than adequate for most purposes in schools.

**

The constant flow burette

A common way of producing a trace of the pH of a solution against the volume of titrant added to it has been simply to plot pH against time and hope that the rate of addition is fairly constant. This may be approximately true for the addition of the first 10-15 cm^3 delivered from a full burette.

An additional point to be considered in plotting titration curves is the time needed for a pH probe to respond to changes in pH. Thus if the titrant is added very rapidly the read-out will always be lagging behind the pH of the solution at that instant. Slowing down the flow rate should reduce this defect, though it may not matter if one is simply concerned with the shape of the curves.

Various Emmett-like contraptions have been employed to keep a constant head of liquid in the burette, but one of the simplest devices we have seen is a modification of a method published in the School Science Review. Our thanks are due to Mr.Mclean of Dunoon Grammar School for bringing this modification to our attention.

A piece of capillary tubing approximately equal in length to the burette is fitted as shown in Fig.1.

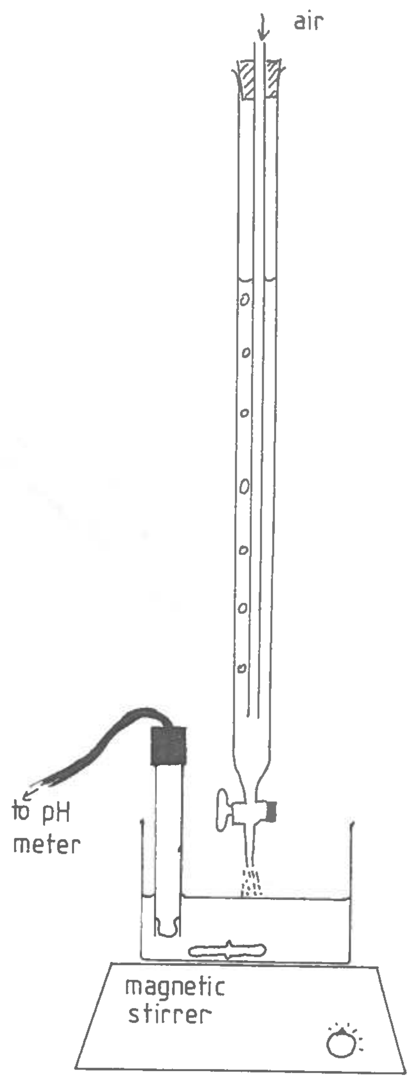
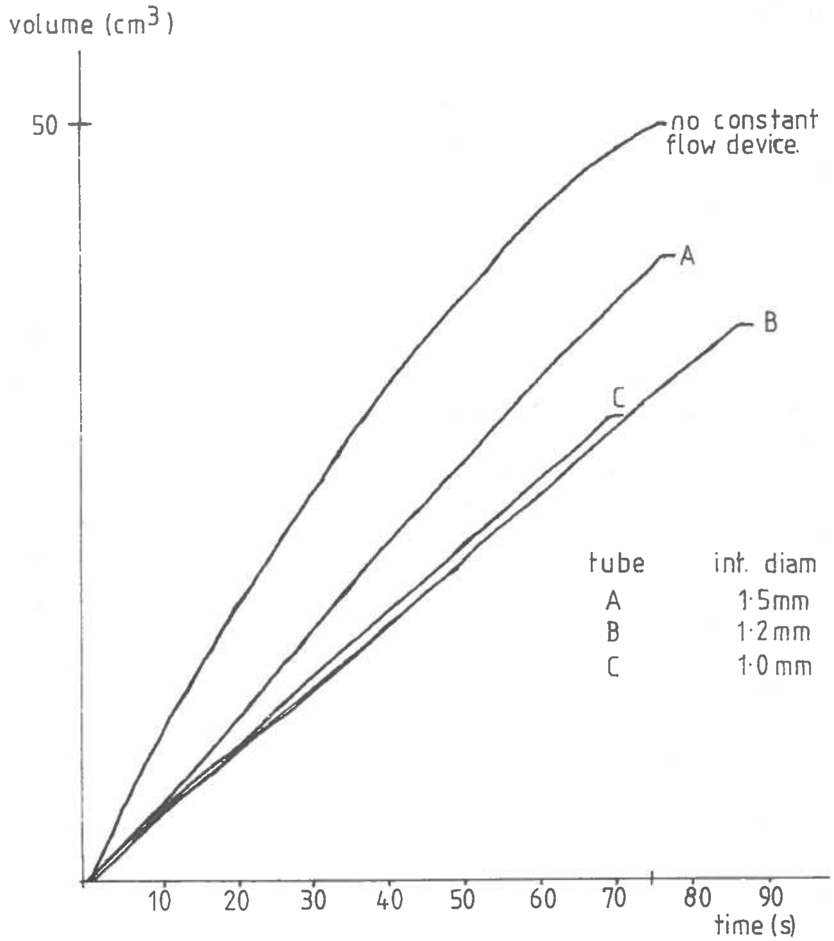


Fig. 1.

We tried out this method with tubing of different bores by weighing the water delivered from the burette on an electronic TP balance. The traces shown in Fig.2 were made on a chart-recorder fed from the analogue output fitted on the Oertling HC22. The method is indeed satisfactory as can be seen from the traces in Fig.2, but it should be remembered that owing to the volume taken up by the tubing itself that the volume markings on the burette now give an overestimate. This error is greatest for thinner bore tubing which has stouter walls. The print-out for the neutralisation of phosphoric(V) acid is shown in Fig.3.

As an aside there may be some scope here for a CSYS Physics project bringing in surface tension, viscosity, fluid flow and pressure.

Fig. 2.


volume (cm3)
50
no constant flow device.
A
B
C
tube
int. diam
A
1·5mm
B
1·2mm
C
1·0mm
10
20
30
40
50
60
70
80
90
time (s)

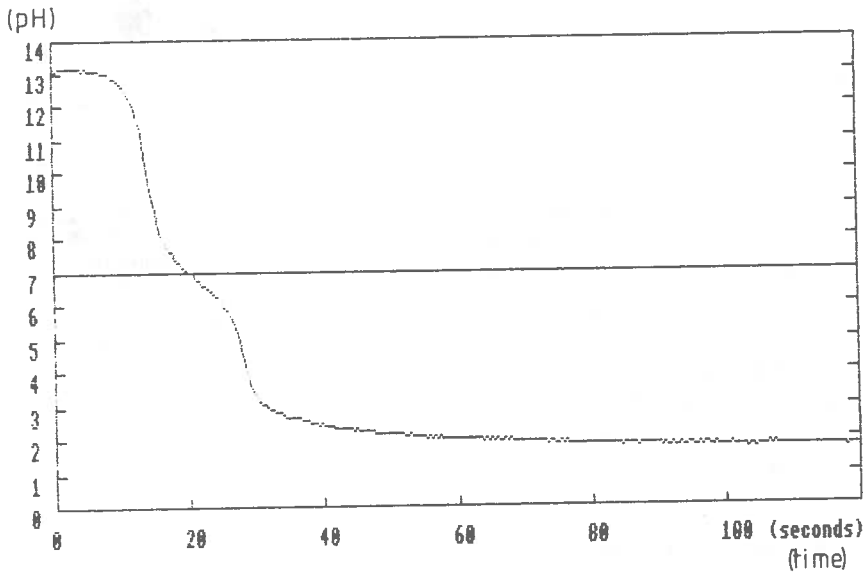

(pH)
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100 (seconds)
(time)

Fig. 3.

Measurement of gravitational acceleration with VELA, GiPSI or other timers

This is readily achieved with electronic timers, including VELA and GiPSI, using the traditional method of dropping a ball bearing through a height s and measuring the time interval of fall t; acceleration being calculated in the usual way from

$$s = 1/2\ at^2$$

The experimenter arranges the switching circuit such that on release the timer is started and on impact on a microswitch the timer is stopped. Nothing unusual. All part of the normal experimental repertoire.

How then can free fall acceleration be determined by the rate of change of velocity? There are timers with memory specifically designed to tackle this task. However a simple idea, novel to us, has been supplied by Sandy Pirie, Tayside science adviser, which overcomes the requirement to store data electronically. A mask (Fig.1) is fashioned out of sheet aluminium. This is arranged to fall from a fixed marker through a light gate to obtain repeated measurements of time through sections AB, CD and EF. Acceleration can be calculated in the usual way from

$$a = (v-u)/t$$

Care should be taken that the mask is correctly positioned and held steady before release. In particular it should be gripped above its centre of gravity such that its long axis is vertical. These little points may seem simple, but at our exhibitions many users do not put them into practice.

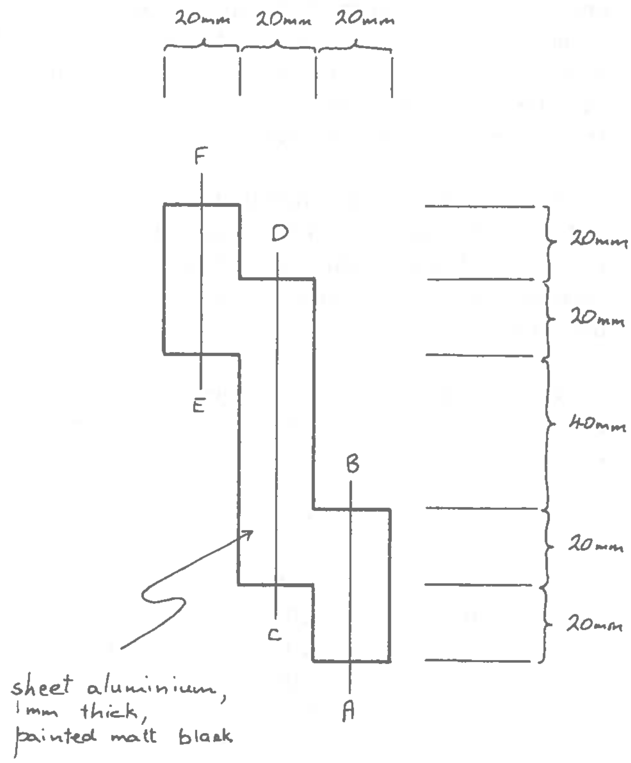


Fig. 1. Accelerating mask.

The mask as designed introduces an error in the measurement of time interval between initial and final velocities; interval CD should run from mid-times, not mid-points, of AB and EF. We don't think the error matters too much in this case. Besides it gives teachers the opportunity of raising the point with pupils. For a fuller discussion of experimental error please refer back to the article in Bulletin 133.

cont./

Some notes and measurements follow on the application of this technique with VELA. The light gate we used provides logic 1 on make and 0 on break. With program 05 on eprom 1 we worked with parameter 1 such that timing starts on break and stops on make. Conveniently, repeated measurements can be made automatically. Recourse to pressing the keyboard is unnecessary.

To our surprise TTL signals from our light gate did not trigger the Pulse Input on VELA. However routing to Pulse Trigger via Channel 1 on gain x1 worked; it would seem our signal required power boosting.

The mask was held 16 cm above the light beam before release. Measurements of time intervals, in seconds, are shown

t_{AB}	t_{CD}	t_{EF}
0.035	0.057	0.022
0.034	0.056	0.023
0.034	0.056	0.024
0.034	0.056	0.023
0.034	0.056	0.022

from these times we obtained

$$u = 1.17 \text{ ms}^{-1}$$
$$v = 1.76 \text{ ms}^{-1}$$
$$a = 10.5 \text{ ms}^{-2}$$

Another approach, with VELA, to acceleration is the usage of multiple inputs to the Digital Input under control of program 06. However this would involve using two or more light gates. The method outlined above gets by with one.

*   *   *   *   *   *

TRADE NEWS

Change of address

It would seem that a number of folk are still using an old address for Walden Precision Apparatus (WPA). The attention of readers is drawn to the up-to-date address on the inside cover of this issue.

Bioshirtology

Groans, stage left! We have recently received updated information on "Gee Tee Shirts", available from G.T. Woods(see inside front cover for address). We first mentioned their periodic table designs in Bulletin 139, having seen them at the Exeter ASE meeting. The periodic table tee shirt is still available with a choice of three different background colours and up to five size ranges.

More recently available is a heart design so that the biologists don't feel left out of things. The heart design is a sectional drawing of the human heart and associated blood vessels. Red and blue colourways are used, both in the design and labelling, to distinquish oxygenated and deoxygenated blood. The design is almost life-size and placed on the left-hand side of the chest. The labelling uses initials to challenge the wearer or onlooker to complete it. Two ground colours are available, white and sky blue, in four sizes.

The shirts cost £4 each (including p&p, UK only, overseas add 10%). Terms are cash with order, cheques payable to P.J. Woods. Bulk discounts are available on orders for 10 or more shirts.

Microscope Servicing

Some time ago we received details of the services offered by the Glasgow firm - Microscope Sales & Servicing Ltd.(see address list). This firm wrote to us offering special rates to schools of approximately £12 per hour (usually £15). They claimed that this would mean an average charge of £4-£7 for servicing a typical schools microscope. Travelling charges are extra at the same hourly rate or slightly less. The firm is willing to quote fixed charges on receipt of information regarding numbers, type and makes.

They also supply new and used instruments and buy in, offering part exchange. They supply the following makes:

Swift (Pyser)	Russian(TOE)	Chinese
Meiji	Olympus(stereo)	Gillet & Sibert

Also supplied are most microscope lamps (i.e. spare bulbs) but with a minimum order of 10 bulbs if a surcharge is to be avoided.

Molecular models

The "Allyn and Bacon Molecular Model Set", formerly only obtainable from W.W.Baird (Publishers) and a limited number of booksellers, is now also available from IMS.

This set falls somewhere between the long familiar Molymod Introductory Set 001 (Harris Cat.No. C51320/1) and the Molymod Organic Set 003 (Harris Cat.No. C51360/2). The atom centres and linkages are very similar in size and design to the Molymod type. They enable the construction of models of most simple organic compounds - alcohols, esters and aromatic hydrocarbons. The availability of two linkage types enables either the more realistic space-filling type of model building or open constructions with scales of 17mm and 28mm to 0.10mm.

As with the Molymod sets stereoisomerism and conformational analysis may be demonstrated. Priced at £12, the Allen & Bacon set contains 66 atom centres and 92 linkages. It is comparable with the Molymod sets in terms of price and content. The two Molymod sets contain:

Set 001	48 centres	74 linkages
Set 003	97 centres	140 linkages

These sets sell at £10.27 and £20.97 respectively.

Does it lose its flavour?

Science staff, especially the chemists, are aye being asked about solvents to remove this or that stain and various other unmentionable pollutants. One perennial request is for a magic potion to remove offending chewing gum deposits. Scientists like to feel wanted, especially these days, but a role as chief chuggy consultant can lose its savour. One way to circumvent these unwanted calls on valuable professional time would be to persuade the upper layers of school management, i.e. the "Janny", to lay in a stock of G.H.Woods "Cleancare" chewing gum remover. This is sold in Scotland by G.H.Woods agents -Wilson Watson McVinnie Ltd.

The current price of the remover is £27.95 per box of six, 500ml tins.

Low cost safety tapes

Now available from CP Laboratories,agents for New England Biolabs, are lost cost, self adhesive, printed warning tapes. The tapes all conform to DHSS, BS and international standards and mostly deal with biohazards. However two are of more general application viz. "Caution Radioactive Material"(25mm width) and "Danger Broken Glass"(50mm). All rolls are 66m long. Most come in 25mm widths, a few in 50mm and one ("Sterile") in 12mm. The 50mm wide tapes cost £5.75 per roll, all others are priced at £3.00, with discounts for quantity.

Bespoke glassware service

Glassware will be built or modified to order by Thomas P.Young of Bridge of Allan. One-offs can be dealt with but obviously prices are lower where a quantity of glassware is involved. One example of a quote, received by a school recently, was for 20 conductivity flasks at £3.50 per flask. The flasks in question were conicals, with entries on opposite sides for bungs each carrying a carbon rod electrode. This price per tailored flask compares favourably with that normally asked for off-the-peg, single entry, conductivity flasks.

'Poly bag' sealer

We have recently discovered the delights of Lakeland Plastics catalogue. This is a source of reasonably priced lay-flat tubing as well as for a heat sealer at £17.95. This latter device is used to turn the tubing into bags of various dimensions to suit different applications. The catalogue contains a range of other goodies, such as sealable plastic containers, which may find a ready use in the science department.

Oscilloscopes

A sign of the times, perhaps, Scopex who stopped trading last year have recommenced business in association with Bridage Scientific Instruments to whose address enquiries should be made. Of interest to the school market is model 4S6, £225, a single trace 'scope with 10cm screen and 4mm sockets. Time base sensitivity is 1 μscm^{-1} to $100mscm^{-1}$ in 15 steps; voltage sensitivity is $10mVcm^{-1}$ to $50Vcm^{-1}$ in 11 steps. A repair service on older Scopex models is also offered.

Meanwhile their trading partners, Bridage, themselves manufacture two models for the school market

dual trace oscilloscope, DB242	£225
single trace oscilloscope, SB121	£195

Bridage models are more basic than the Scopex item mentioned above, but have calibrated voltage-time scales, sensitivities being $1\mu scm^{-1}$ to $10mscm^{-1}$ (4 steps) and 0.05 to $50Vcm^{-1}$ (9 steps). Other features are 7cm screen and 4mm sockets.

Power supplies

A comprehensive range of mains to low voltage power supplies is manufactured by Educational Electronic Equipment to whom application should be made for a catalogue. Model TL51 seems good value for money if looking for voltage regulated power units for practical work in electronics; mains input and four regulated outputs rated +5V, -5V, +15V and -15V, all at 1A. The price £27.50, you can't grumble at that!

Linear air-track

Unilab have introduced a linear air-track to their range, model 432.100, price £170. Unlike their usual practice this item is not manufactured by themselves, but imported from Denmark. Described as a 'quality' air-track Unilab tell us that if you are looking for something better than at the 'bright and cheerfull' end of the market their product should be considered. They also supply an up-market blower, item 432.101, price £85, which we have been invited to listen to at the ASE exhibition at Keele. Claimed to be 'amazingly quiet' watch this space for our evaluation.

* * * * * *

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

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