SCOTTISH SCHOOLS SCIENCE

EQUIPMENT RESEARCH

CENTRE

Bulletin No. 49. August, 1971.

Contents

Introduction

During last session we carried out a heavy programme of exhibitions, all except two of which were in the current year. The total attendance was over 1100, and geographically they were distributed as far apart as Dundee, Kirkcudbright and Stornoway. The year saw two extensions of our normal policy; the first of these was to hold exhibitions in three Colleges of Education for the benefit of graduate students in training. This has proved so successful that it will, with the Colleges' agreement, become an annual feature of our exhibition programme. In fact it has already been suggested that numbers are enough to justify two such exhibitions at Jordanhill, and we may also take an exhibition to Stirling University where there is a rapidly growing Education Department. The second was a highly successful exhibition of a week's duration which was set up in Dundee Teachers' Centre and left unattended. This meant that teachers in the area had more time to arrange a visit to suit their individual timetables, and is an arrangement which other Centres might consider in the future.

One aspect of such exhibitions is completely unpredictable - this is the extent to which the surplus equipment we take to them will be sold. At some exhibitions it is difficult to sell half-a-dozen bimetallic strips; at others almost the entire selection is sold. It is, and will continue to be our policy to take such material on future exhibitions. We believe that it is important that teachers who cannot readily come to Edinburgh should be able to examine what is available as well as their more fortunate colleagues. We would also repeat what has been said here on more than one occasion, that we will accept any method for payment, and will hold any items ordered until the teacher can arrange their collection, since it frequently happens that postage or freight charges amount to more than the cost of the items themselves. Finally it may be of interest to those who feel that the only department to benefit from surplus material is physics, to learn that we shall soon have on offer a quantity of glassware purchased from Dounreay.

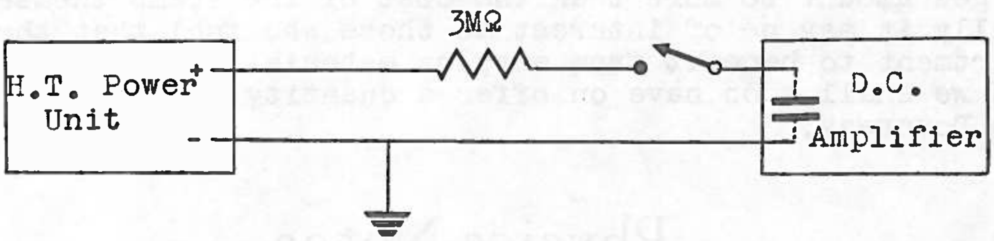
Physics Notes

One of the experiments suggested for Nuffield A level physics is the measurement of the velocity of sound in solids. In particular the physics organisers have suggested that this could be done by measuring the impact time of a metal rod free to move. If the end of such a rod is struck by a heavy hammer, or if the rod be dropped, for example on to an anvil, it rebounds after a time which is characteristic of the velocity of sound in the material, and is in fact the time for the compression wave to travel from the point of impact to the far end of the rod and back again. Measurement of this time interval will therefore enable us to calculate the velocity of sound in the solid.

Rough calculation shows that for metal rods 1m long, the times/

times to be expected are in the range $10^{-3} - 10^{-4}$s, which means that the standard scaler/timer counting to 1ms is inadequate. Two methods suggest themselves; use of the calibrated time base on the oscilloscope, and the linear charging of a capacitor. Since the Nuffield group are investigating the former method, we chose the latter.

If, during the time that the rod is in contact with the anvil or hammer, a current i is caused to flow into a capacitor C, then the time can be calculated from $t = (VC)/i$, where V is the final voltage across the capacitor. 100μA flowing into a 0.1μF capacitor will give 1 volt after 1ms; all these quantities are readily achievable. A D.C. amplifier, either the Unilab or the W.P.A. version will register the range 0 - 1 volt on its input. The latter has a built-in 0.1μF range, while a standard capacitor can be connected across the input of the Unilab amplifier. An H.T. power supply is used to give a constant charging current, by adjusting its output to give 100μA through an external, nominal 3MΩ resistance. The D.C. amplifier is adjusted in accordance with the manufacturer's instructions to register 1V full scale on its output meter. The components are then connected up as in the diagram below, the two sides of the switch being the rod and anvil. Contact to the rod was made by soldering a wire near one end; a similar contact on the anvil is obtained by scouring it with emery cloth and winding a length of tinned copper wire (connecting wire) several times round the cleaned area, taping this down with a complete turn of adhesive tape. We used ¼in dia. rod in various metals from the workshop materials store. To see if striking the rod, instead of bouncing it on the anvil made any difference, it was suspended horizontally with twine from two retort stands, and given a blow on one end from a 4lb hammer.



Charging of the input capacitor through leakage can be a nuisance, and it pays to experiment with different arrangements of the circuit, e.g. interchanging the two sides of the switch. It is possible to get consistent results, and those quoted below are from an average of 10 or 12 measurements of the time interval. In case anyone calculates backwards from the results, our rods were not all 1m long, but were selected from off-cuts of about that length.

Material	Impact Time	Velocity ms^{-1}	True Value (Kaye and Labye)
Brass	990μs	3.1×10^{-3}	3.65
Copper	820μs	3.3×10^{-3}	3.97
Duralumin	530μs	3.6×10^{-3}	-
Mild steel	590μs	4.2×10^{-3}	4.7 - 5.2

An alternative method, also suggested by the Nuffield Advanced Physics group, is the ballistic use of a moving coil ammeter or mirror galvanometer. If a capacitance C, charged to a potential V, is discharged through the meter, resulting in a momentary deflection θ_1, the deflection is proportional to the charge passed through the meter, and the ballistic constant is given by

$$k\theta_1 = CV_1$$

If the same meter is used in place of the DC amplifier in the circuit given above, the power supply voltage and resistance being altered to give a suitable deflection θ_2, then the quantity of charge passed through the meter while the hammer and the rod are in contact is

$$it = \frac{V_2}{R} t = k\theta_2$$

It is possible to select values of R and C to give suitable deflections and use the same supply to provide V_1 and V_2, so that the two equations reduce to

$$t = CR \frac{\theta_2}{\theta_1}$$

Knowing that the times to be expected are between half and one millisecond, for θ_1 and θ_2 to be of the same order, the time constant CR requires to be 750ms (mean value) so that if C = 1μF, R = 750Ω. An important point emerges here. R is the total resistance in the circuit, and a meter of 100μA F.S.D. may well have a resistance of this order (and no additional resistance may be necessary). Hence one must either know or be able to measure accurately the internal resistance of the meter or one must abandon the convenience of having $V_1 = V_2$, use a much greater value for V_2 (a 300 HT power supply) in conjunction with a resistance of 100kΩ order, and assume that neglecting the internal resistance of the meter causes no appreciable error. Measuring the internal resistance of a meter without passing more than 100μA through it calls for some ingenuity, and pupils may well opt for the HT supply method. Even here there are snags; the voltage V_2 cannot be measured with the power unit off load because of the internal impedance of the power supply.

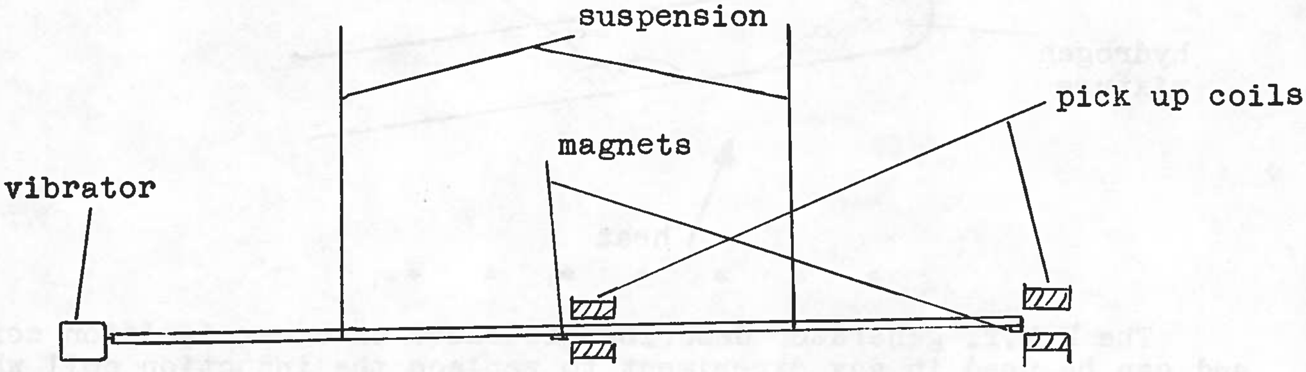
To give some indication of the results to be expected, we used a nominal 25V smoothed power supply from a low voltage power/

power pack, a 100 microammeter of resistance 700Ω, and a 1μF capacitor to get deflections of over half-scale. With a Pye Scalamp of resistance 1300Ω, the capacitance was reduced to 0.5μF. An advantage of the microammeter is that the investigation may then be made a class experiment; against this is the fact that deflections of a mechanical pointer are difficult to read accurately. The internal resistance of the mirror galvanometer may also be calculated from the specified sensitivities of the instrument, and for ballistic use its scale is much easier to read.

The foregoing account is given to show how a project investigation might be carried out by pupils with minimal guidance from the teacher. The experiment is open-ended; while the results of the ballistic method are consistent with those given in the table above, all give times about 20% too great. As we have a microsecond counter we were able to measure the contact time directly and accurately - e.g. for mild steel $t = 412 \pm 5\mu s$ - this discrepancy remains unexplained.

We then decided to see whether sound vibrations could be set up and detected in the rod. The classical method of doing this is the Kundt's tube experiment, but we thought that a more permanent vibration was called for. Accordingly the end 5mm of a rod was drilled and tapped 2BA so that it could be screwed directly to the stem of a <u>Linstead</u> vibrator - those with an <u>Advance</u> vibrator will require to make this a 4BA tap. At the other end of the rod we cemented a small magnet, salvaged from a broken MR38P meter. The rod was suspended horizontally from two strings and the vibrator clamped in line with it so that the two could be screwed together without stressing the vibrator. At the far end a pick up coil, consisting of a 4oz reel of D.C.C. copper wire was lined up coaxially with the rod so that the end of the magnet just penetrated the coil bobbin. The pick-up coil was connected to the pre-amplifier described in Bulletin 44, and thence to the oscilloscope.

Tuning the signal generator through the audio range gives a number of resonances which are readily detectable, aurally as well as visually. The problem is to determine whether these are true resonances of the rod alone, or of the whole system, vibrator plus rod. To sort this one out we taped another of the same magnets to the mid-point of the rod and pushed a second similar pick-up coil on to the rod, clamping it in the same position relative to the magnet so that the rod did not touch the inside of the bobbin. The two coils were connected through a change-over switch to the pre-amplifier so that either coil could be sampled at will. Although the results were often inconclusive we were able to establish that a 1m length of copper rod gave a fundamental resonance at 1920 Hz, with the induced emf in the middle coil dropping as that in the end coil increased through the resonance point. This gives a value of $3.84 \times 10^3 ms^{-1}$ for the velocity of sound in copper.



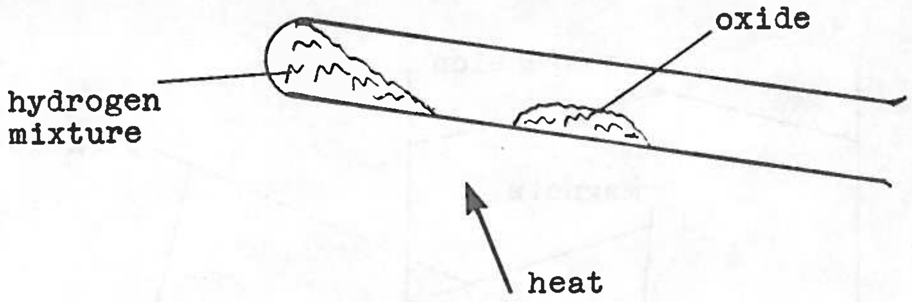
Chemistry Notes

In the supplement to this bulletin we give a summary of the Chandos A47 pH meter, wherein it will be noted that the cost of a battery replacement is £2.95. Since the report was prepared, this battery gave out on us, and we opened up the plastic case and removed the wax packing. The battery was found to consist of two Mallory cells and a PP3, and tests showed that it was the last which had worn out. A new PP3 was bought - cost 14p - soldered in, and the whole replaced in its casing together with the wax removed. The meter now functions as well as ever, and we recommend teachers who have a Chandos meter to consider the saving which this allows them to make, before sending to the manufacturer for a replacement battery. We have no means of knowing how long the Mallory cells will last, of course, but it will not require to be very long in order to effect a saving.

* * * * * * *

In Bulletin 42 while discussing the performance of natural gas burners, we reported that copper (II) oxide could be reduced using the gas, but not lead oxides. Since more and more schools are being converted to natural gas, and some new schools are being built to work on propane/butane mixtures such as calor gas, we think it worth while to give a reduction technique which uses hydrogen but does not have associated with it the dangers that hydrogen from cylinders or even the more conventional gas generators carries.

The hydrogen is generated by heating a mixture, in approximately theorètical proportions of zinc powder and calcium hydroxide at the far end of an open test-tube which also contains the oxide to be reduced. The sketch below shows the arrangement. The oxide is heated first, then the burner is tilted so that both oxide and mixture are heated. Calcium hydroxide is used in preference to soda lime, potassium or sodium hydroxide since it forms an intimate mixture with the zinc powder. If necessary, the hydrogen may be ignited at the mouth of the tube to prove its presence. There is no danger since an open tube is used.



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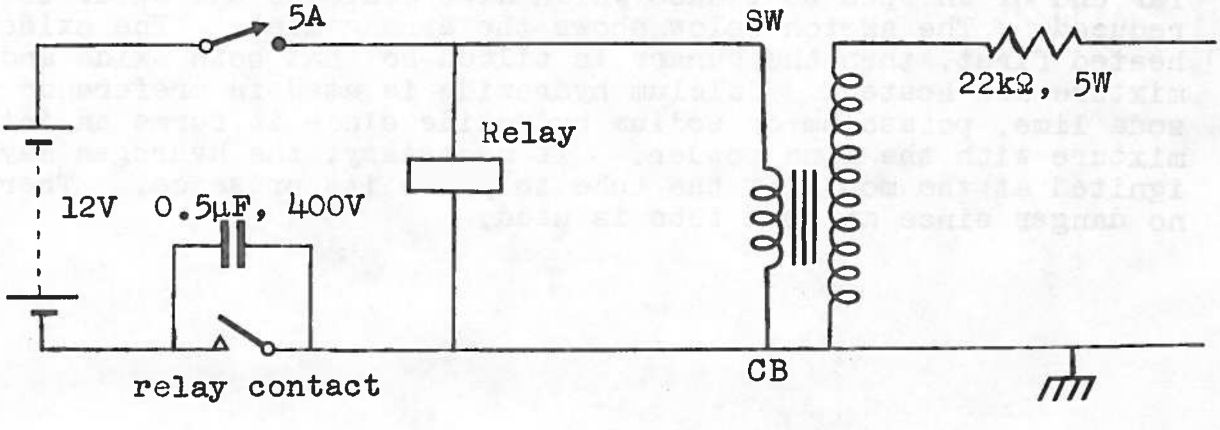
The E.H.T. generator described is based on a car ignition coil, and can be used in any experiment to replace the induction coil which is now prohibitively expensive, besides being frowned on as an unwitting source of x-rays, or the piezo-electric generator which cannot conveniently be used to produce continuous sparking. The principle is the same as that used in the induction coil, a post office relay being used to interrupt the current.

The circuit diagram is given below. Our type 3000 relay has a 200Ω coil, and one heavy duty, normally closed contact. The latter requirement is essential, as the contact has to break 5 amperes or more. When the supply is switched on, the relay is energised and breaks its own contact, thus cutting off the current. This "electric bell" type action continues, so that current into the primary of the ignition coil is continually interrupted, and the inductive effect gives a large e.m.f. at the secondary. The capacitor across the relay contact reduces sparking and consequent wear, and also reduces radiation of radio frequency interference. For the same reason a resistor is included in the output lead.

We have not given details of the layout of the components since these are not critical. If built in an enclosed box it will be necessary to provide high insulation for the E.H.T. output. In our case the components were secured to a wooden baseboard with straps made from aluminium sheet, and a length of cable of the type used in the car electrical system was used from the coil output. The 'earth' connection shown is to the can of the ignition coil, made through the strap referred to above. The on/off switch was similarly mounted on an aluminium bracket.

A battery, rather than a mains derived supply, is the better source of power as it produces less R.F. interference. With the former, interference can be picked up on medium and long waves only within 10m of the apparatus. Using a low voltage power unit, we could get interference at twice this distance and it is possible that it could travel further by feedback through the mains.



In The Workshop

When we explained in Bulletin 38 that we could not devise a system of aquarium aeration which would operate off 12V, we did not realise that we had already had half the solution at hand. At that time we were looking for a 12V D.C. motor which would run continuously without wearing out for over 1000 hours. Despite several suggestions we haven't found such a motor, but what we did not appreciate was that the pump we were using did not have to operate at the high speed produced by a motor in order to generate a high enough pressure to operate a diffuser in 30cm of water. The pump works adequately, and aerates efficiently, at speeds of one stroke per second or less, and we were therefore able to use an entirely different method of driving the pump.

What is done is to use current in a solenoid to raise a soft iron plunger by about 1cm, and then allow it to fall on the pump diaphragm in the manner of a pile driver. This is the active stroke which generates the necessary pressure. When the plunger is raised, a weak spring inside the pump stretches the diaphragm sufficiently to open the inlet valve and admit more air from the atmosphere. In a closed system the pump will build up a maximum pressure of 180mb, which is equivalent to slightly more than 1.8m of water and is adequate to operate any normal aquarium through a diffuser most of which require a pressure of 60-100mb to operate them.

The construction of the pump, which is based on a design by Mr. R.G. Cawthorne of the City of Portsmouth College of Education is shown in the diagrams below. The various sections of the pump, and the solenoid which operates the plunger, are bolted together with four 4BA bolts 60cm long, which are countersunk into the pump base plate. The four perspex discs and the solenoid former should be clamped and drilled together for these bolts so that they fit properly when the time comes to assemble the parts. A notch cut on one side of each disc acts as a locating mark to ensure that the discs are correctly orientated when assembling. We have indicated the orientation by spotting (*) one of the anchor holes in each diagram.

The diaphragm, Part b, is cut from surgical rubber bandage, obtainable from Boots or other pharmacists and the anchor holes are cut with a cork borer, or with scissors since they do not require to be round. The spring shown in Fig. 2 was coiled on a much smaller diameter rod from 26 SWG piano wire using the lathe, and coiling a much larger number of turns so that 2 - 3 turns in the middle of the coil would be evenly wound. These were cut out, and the beehive shape of the final spring formed by bending in the top turns with pliers, little by little. A final sharp bend is given to each end to turn it in towards the centre, and also slightly towards the middle of the spring, since it is important that the sharp ends of the wire should not be in contact with the diaphragm which might then be pierced by them. The inlet valve, Part e, is formed from a 25mm dia. disc of the same rubber bandage, with a 3mm dia. hole in its centre. The outside turn of the spring referred to above rests on the rim of this disc. Two tubes of brass, turned and drilled on the lathe from solid rod to the dimensions given in Fig. 3, and sealed with Perspex cement into the thicker/

thicker perspex discs, form inlet and outlet ports for the pump.

The outlet valve, Part g, is a disc cut from a toy balloon; the anchor holes in this can be cut with scissors. Another small hole, about 3mm diameter is cut in this disc to coincide with the hole for the outlet in the bottom perspex disc. In the bottom disc, two depressions are drilled to approximately half the disc thickness, one 5mm dia in the centre of the disc, the other, which connects with the outlet port, and which is 2mm dia, at a point 10mm from the centre. On the top side of the disc a shallow channel is cut between these two holes, using the 5mm drill. This is done by securing the pillar drill at the correct height to cut a 2mm deep channel in the perspex, positioning it over the centre hole and then pushing the disc sideways against the drill. The channel need be only deep enough to allow the balloon rubber under pressure from the diaphragm to expand into it, thus allowing air to travel from the centre of the pump to the outlet.

The bottom disc of the pump, Part h, is fixed to a plywood baseplate measuring 80 x 110 x 10mm with 2 countersunk screws. Holes for the screws in the perspex are cut to tapping size, so that the screws cut their own thread. Before bolting the disc to the baseplate the four anchor bolts are fitted to the disc. Each disc is thinly coated with silicon grease before assembling the next part in place and in particular the piece of balloon rubber should be smoothed out flat before the next disc is added. When the pump parts have been assembled, and before the nuts have been screwed on, the performance of the pump can be tested by connecting the outlet to a simple manometer and repeatedly tapping the diaphragm with the finger. Each tap should raise the pressure slightly and there should be no reduction in pressure before the next tap. On our version, after pumping up to full pressure, the leak was less than 10% in a period of 10 minutes. If the pump is working satisfactorily the nuts may be tightened up; if not it must be dismantled when it will be found that the balloon rubber has wrinkled over the channel, allowing air to leak back.

Details of the solenoid and plunger are given in Fig. 4. The coil consists of approximately 2500 turns of 30 SWG enamelled copper wire; the completed coil has a resistance of 28Ω and an inductance, with the plunger and core in position, of 62mH. Plunger and core are turned from mild steel rod; the bottom of the plunger requires smoothing off with a file and emery cloth in case any rough edges damage the diaphragm. In our version after 2000 hours use the diaphragm shows no sign of wear apart from surface marking. Our coil former was machined from Tufnol, but a suitably sized wooden bobbin would serve equally well. The coil ends are soldered to tags fixed to short lengths of 6 BA screwed rod, tapped into the top of the coil former. The rubber washer on the plunger serves only to reduce the noise when the pump is working. The mass of our plunger was 82g. The core is a push fit into the top of the coil former; its presence increases the magnetic force on the plunger, and a second simple way of helping a sluggish plunger into a proper stroke, and one which is easier to apply than adjusting the solenoid position, is to lay on Arnold's disc magnet on top of the core.

The anchor bolts on the pump are large enough to allow the height/

height of the solenoid above the pump to be adjusted through 1-2cm; the higher the solenoid, the greater the stroke of the plunger and the greater will be the maximum pressure achieved. If the solenoid is raised too high however, the current in it may be insufficient to raise the plunger fully. As there is no particular merit in having a high pressure in the present application, and as it will increase wear in the diaphragm, the solenoid should be adjusted to give a plunger stroke of about 10mm which we have found to be sufficient.

Screwed to one end of the wooden baseboard is an aluminium panel 50 x 80mm which has bolted to it two 4mm sockets for the 12V power supply, a Radiospares midget 10kΩ volume control which is the pump speed control and a piece of Veroboard measuring 7 x 7 holes which carries the control circuit. The latter is given in Fig. 5, and all components except the variable resistor and the coil itself are mounted on the Veroboard using the technique described in Bulletin 18. The speed control varies the period between 0.5 and 1.3s. Measurements show that the solenoid current is about 450mA, and as this is "on" for approximately 1/3 of the period, the average drain from the power supply is 150mA. This is also the mean current through the 2N697 power transistor, so that it can be used without a heat sink. The system will operate off a 12V D.C. power supply such as a car battery, but will not work off a Nuffield type low voltage power unit unless this has some degree of smoothing, say 1000μF or more, across its output. As we have on two occasions ruined transistors by careless connection to the supply, a warning should be given that the circuit must be connected with the correct polarity of supply.

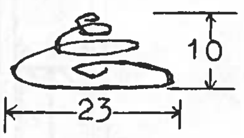


Fig. 2. Spring, Part d, piano wire.

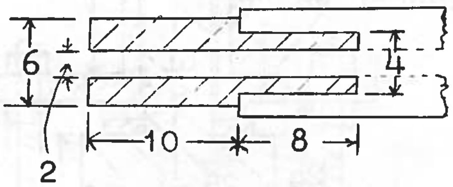
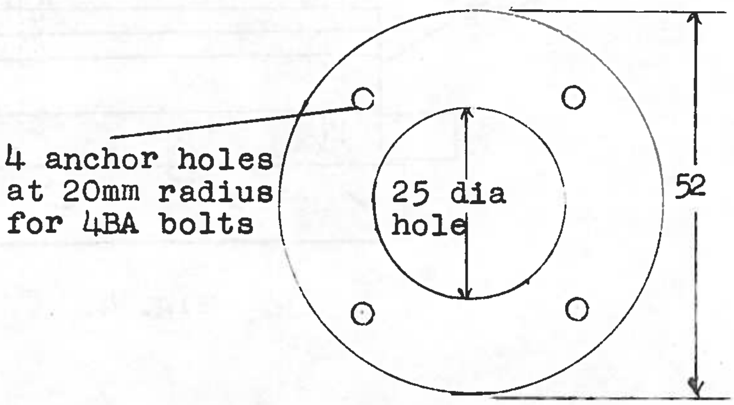


Fig. 3. Inlet and outlet ports.



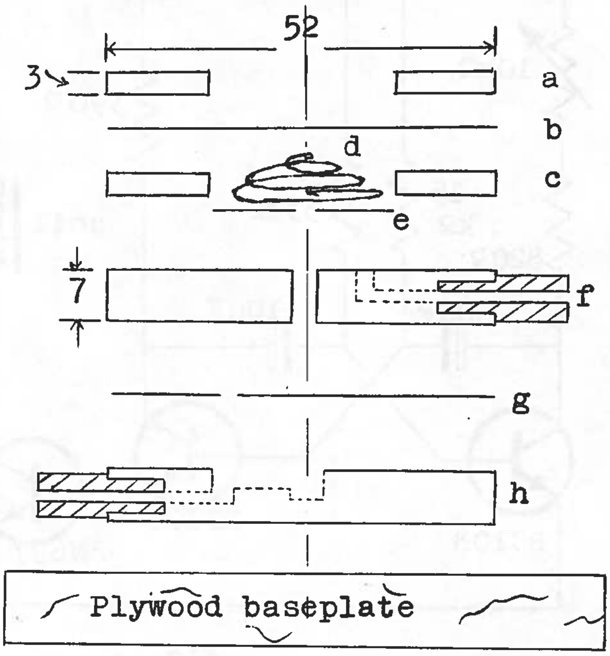
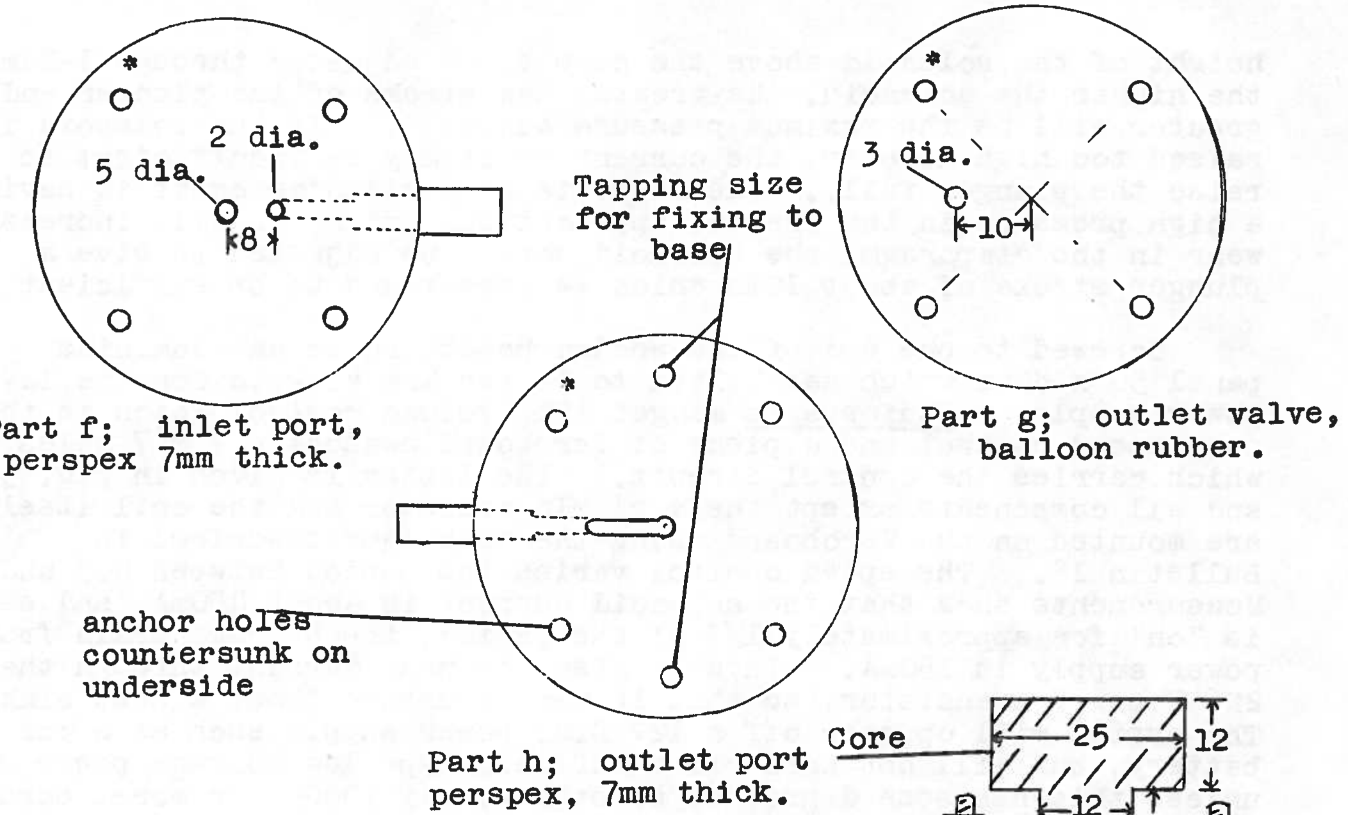


Fig. 1. Pump assembly

Dimensions in mm.

Parts a and c, perspex, 3mm thick.


2 dia.
5 dia.
8
Part f; inlet port,
perspex 7mm thick.
Tapping size
for fixing to
base
3 dia.
10
Part g; outlet valve,
balloon rubber.
anchor holes
countersunk on
underside
Part h; outlet port
perspex, 7mm thick.

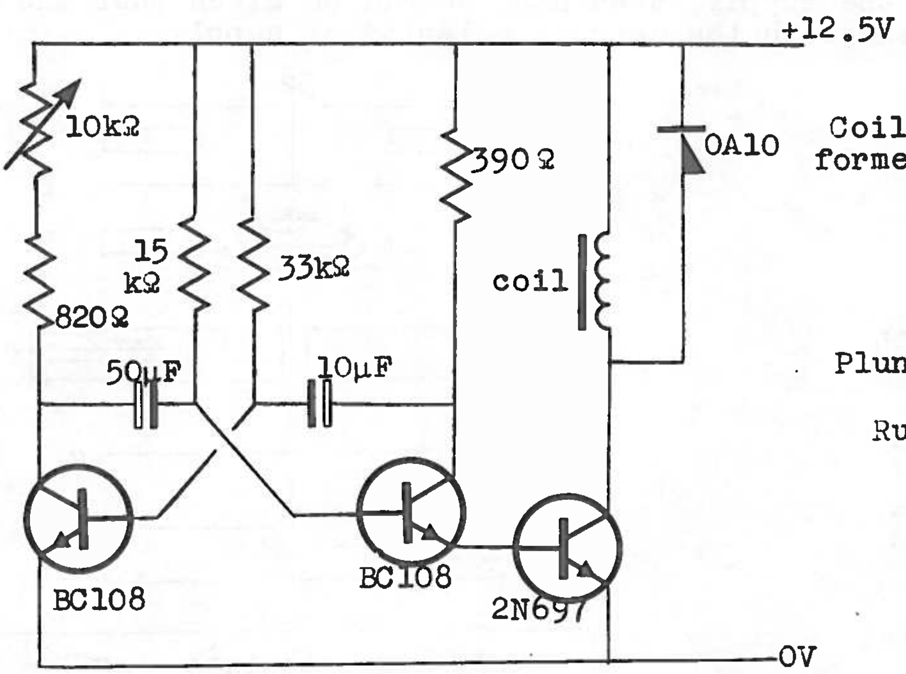

+12.5V
10kΩ
820Ω
15
kΩ
33kΩ
390Ω
OA10
coil
50μF
10μF
BC108
BC108
2N697
OV

Fig. 5.

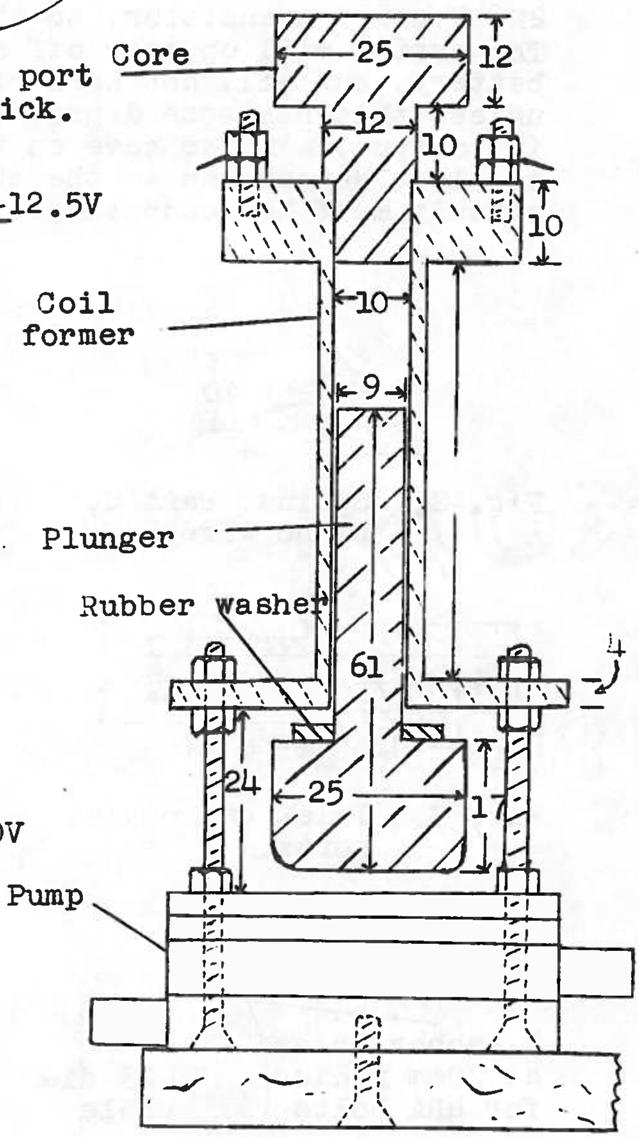

Core
25
12
12
10
10
Coil
former
10
9
Plunger
Rubber washer
61
4
24
25
17
Pump

Fig. 4.

Bulletin Supplement

Below is a summary of tests carried out on a selection of pH meters; others will be given in a future Bulletin. Individual reports on these meters can be borrowed by writing to the Director. The classifications used are: A - most suitable for school use; B - satisfactory for school use; C - unsatisfactory.

Model		A47	C5	C10
Manufacturer		Chandos Inter-continental	Walden Precision Apparatus	Walden Precision Apparatus
Price*		£26.25	£27.50	£33.90
Electrode	type	X27	B17D	B17D
	cost	£10.50	£6.50	£6.50
Battery	type	Special	2x DT9	2x DT9
	cost	£2.95	60p	60p
Range(s)		0 - 14pH	0 - 14pH	0 - 14pH 0 - 1.4V 0 - 2.8V
Sensitivity: 1 div =		0.2pH	0.2pH	0.2pH
Readability: division separation =		1.0mm	1.6mm	1.6mm
Accuracy: wide range max. error		0.2pH at pH2 and 10	0.1pH at pH2 and 9	0.1pH at pH5
Short range max. error		0.2pH at pH10	None	None
Temperature range		10 - 70°C	10 - 70°C	10 - 70°C
Temperature compensation: max. error		None	0.2pH at 70°C	0.2pH at 70°C
Amplifier		10% error	Satisfactory	1% error
Drift		Satisfactory	Satisfactory	Satisfactory
Classification		B	A	A

Notes *Price includes the electrode. With W.P.A. models the electrode must be ordered separately.

In Bulletin 36 we reported that we had tested the Chandos A53 and A54 meters. We had considerable trouble with these tests, not all of it the manufacturer's fault - one model was irreparably smashed in transit by post - and when the reports had been drafted the firm announced that they were discontinuing production and no further action was taken.

SSERC 24 BERNARD TERRACE EDINBURGH EH8 9NX TEL. 031-668 4421

Advance Electronics Ltd., Roebuck Road, Hainault, Ilford, Essex.

E.J. Arnold and Son Ltd., Butterley Street, Leeds, 10.

Chandos Intercontinental Ltd., Chandos Works, High Street, New Mills, Stockport.

Linstead Electronics Ltd., Roslyn Road, Near Braemar Road, London, N.15.

Radiospares Ltd., P.O. Box 427, 13-17 Epworth Street, London, E.C.2.

Unilab Science Teaching Equipment Ltd., Clarendon Road, Blackburn, Lancs.

Walden Precision Apparatus Ltd., Shire Hill, Saffron Walden, Essex.