SCOTTISH SCHOOLS SCIENCE

EQUIPMENT RESEARCH

CENTRE

Bulletin No. 9. November, 1966.

Contents

* * * * *

Introduction

Some confusion seems to have arisen over the decision of our Governing Body to exact an annual subscription of 5 guineas for the services which S.S.S.E.R.C. offers, including the Bulletins, from all organisations which heretofore had not contributed to our upkeep. We have received one indignant letter from a private school claiming that they should be placed on the same basis as Local Education Authority schools. This is precisely what the Governing Body has sought to do. L.E.A.s contribute to the upkeep of S.S.S.E.R.C. in proportion to their school population, and it has been calculated that this amounts to an average of 5 guineas per school.

Where this arrangement is in our view unfair and we have protested unsuccessfully, is in cases of schools or other institutions or individuals furth of Scotland, who cannot easily visit the Centre personally. Nor, by reason of legal technicalities, would it appear that they will be able to receive our reports on the testing of apparatus, although this point has not been definitely settled. We do all that we can to soften the blow by accepting under one subscription as many individuals on the staff as wish to have copies.

Opinion

Now that the Nuffield Biology Project texts and guide have been published, many teachers will be trying out the new ideas and experiments contained therein. Where the experiments are an improvement on traditional techniques, no teacher should feel that they will be unacceptable to the Scottish Certificate Examination Board, simply because they are unconventional, or use different reagents, as for example bicarbonate indicator in respiration and photosynthesis experiments. As the many teachers who have served as examiners or markers for the S.C.E. examinations will realise, any technique or experiment which will satisfactorily answer the question is acceptable. Particularly in chemistry, many hours have been spent examining on their merits unconventional methods dreamed up by candidates under examination stress.

Although it is probable that much of the Nuffield Biology work will be included in the coming syllabus in Biology, teachers should be warned against ordering expensive equipment or materials for unusual experiments, as these may eventually not find a place in their own syllabus.

Biology Notes

In consultation with our Development Committee, with H.M.I.s and others concerned in the teaching of Biology in Scottish Schools, the following specification of microscope requirements at various levels in the school has been drawn up. The standards referred to are those given in our Microscope Test procedure, published in Bulletin 7.

O Level.

a) Essential. One microscope between 2 pupils.
Magnification from x40 to x200.
Resolution E.M.T.'B'.
Safety stop to prevent damage to slides.
Two Stereomicroscopes per class such as the Baker "Stermag" or Prior "Stereomaster".

b) Desirable. Magnification to x300.
Resolution E.M.T.'A'.
Fine adjustment.
Mirror in preference to built-in illumination.
Adjustable safety stop.
One pointer eyepiece per class.
Facilities for phase contrast.

H Level.

a) Essential. One microscope between 2 pupils.
Magnification from x40 to x600.
Resolution E.M.T. 300 'A'.
Fine and coarse focussing.
Iris diaphragm.
Provision for fitting Abbe condenser and oil immersion objective.
One microscope per class fitted with these last two accessories.
Two stereomicroscopes per class as for O level.

b) Desirable. Mirror in preference to built-in illumination.
Safety spring loaded objectives.
One pointer eyepiece per class.
Facilities for phase contrast.

Post H Level.

a) Essential. One microscope to H Level specification per pupil, but with Abbe condenser and oil immersion objective fitted.
Two stereomicroscopes per class as for O Level.

b) Desirable. One pointer eyepiece per class.
Facilities for phase contrast.

* * * * * *

From a recent meeting of Biology teachers in Balweary School Kirkcaldy, came the following suggestions.

Measurement of individual reaction times. Hold a ½ metre or other stick of similar length vertically, with its lower end level with the subject's open hand which is ready to catch the stick when released. The distance fallen before being caught is a measure of the reaction time. (This can be marked in hundredths of seconds on the stick itself using the equation for free fall, $s = \frac{1}{2}gt^2$, or for those who wish it, we can send on loan a jig which will enable the teacher to rule off his own sticks with appropriate markings.

The use of a manometer attached to the top of the traditional "balloons in a bell jar" to show lung action helps to establish the sub-atmospheric pressure in the chest cavity.

The Millikan Experiment

The basic formulae for the experiment are derived in text-books and are quoted here for ease in reference. The symbols being used are:

- a = drop radius (cm)
- d = distance between cell plates (cm)
- e = electronic charge (e.s.u.)
- g = gravitational acceleration ($cm.s^{-2}$)
- n = number of electronic charges
- q = charge on a drop (e.s.u.)
- s = graticule spacing (cm)
- t = time of free fall of drops through distance s (s)
- V = potential applied to plates (e.s.u.)
- η = viscosity of air (poise)
- ρ = density of oil ($g.cm^{-3}$)
- σ = density of air ($g.cm^{-3}$)
- k, k' = constants of proportionality

The drop radius is given by $a^2 = \dfrac{9\eta s}{2t(\rho - \sigma)g}$ .. .. (1)

and the drop charge by $q = ne = \dfrac{6\pi a\eta sd}{tV}$ .. .. (2)

whence $q = \dfrac{18\pi d}{V}\cdot\sqrt{\left(\dfrac{\eta^3 s^3}{2t^3(\rho - \sigma)g}\right)}$ .. .. (3)

Here V is the balance voltage required to hold the drop stationary. Accumulating the constants gives for different drops:

$q = ne = \dfrac{ka}{tV}$ .. .. (4)

or for the same drop: $q = ne = \dfrac{k'}{V}$ .. .. (5)

If we wish to establish that charge is quantized and not a continuum, the possible error in a determination must be less than half a charge, so that if p = possible % error then

$np < 50$ .. .. (6)

It is therefore desirable to work with as small n as possible, e.g. n = 4 requires $p < 12\frac{1}{2}\%$. From eqn (4), small n requires that the drop radius a be small, and that t and V be large. a and t, however, are interdependent as will be seen from eqn (1), so that a small drop increases t and lowers the value of V.

Measurement of V presents the most serious problem. Using small drops, the movement of a drop under free fall is very slow, and the even slower movement of a nearly balanced drop becomes more difficult and takes much longer to detect. With extended observation it becomes uncertain whether any observed movement is due to Brownian drift, mains voltage fluctuation (power supplies are mains derived and unstabilized), convection drift, or a true rise or fall due to unbalance. There is also the very real difficulty of how to accommodate the experiment within the confines of a double period.

To show quantization of charge, which is the basic point of the experiment, the whole procedure has to be repeated several times on the same drop. This takes the experiment outside the scope of a Vth year pupil and places it amongst the VIth year projects, provided a lenient haedmaster has set aside an afternoon for VIth science practicals.

Our measurements indicate that a balance voltage is unlikely to be more exact than 3%, added to which we have a reading error of the voltmeter of some 1%, and a personal error of 2% within the instrument. This last is the quoted accuracy of the multi-range /

multi-range meter which we used in the tests. In all, then, the measurement of balance voltage gives rise to some 6% error.

If the charge on the drop changes by one unit, eqn (5) applied to both conditions will give on subtraction

$$e = k'\left(\frac{1}{V_{n+1}} - \frac{1}{V_n}\right), \text{ and since } \frac{e}{k'} = \frac{1}{nV_n} = \frac{1}{(n+1)V_{n+1}}$$

we get $V_n - V_{n+1} = \dfrac{V_n}{n+1}$.

The left hand side represents the smallest possible change in the balance voltage and must be large compared with any possible errors in individual measurement of V. If we take the previous figure of 6% accuracy then:

$$\frac{V_n - V_{n+1}}{V_n} > 12\% \text{ which leads to } n \leqslant 7.$$

Otherwise the balance voltage are not a series of discrete values, but run into a continuum and lose significance. To err on the safe side, we would suggest that if the balance voltage does not change by 15% or more on a rough estimate, the charge-changing technique ought to be repeated without wasting time on achieving an accurate balance. The advantage of the single drop method is that it eliminates apparatus error, the success of the experiment depending entirely on the accuracy with which various balance voltages can be set, read and measured.

The apparatus must be good enough to allow the charge on a drop to be changed readily, and to allow extended observation of a single drop for periods of up to an hour, during which time 4 to 6 charge changes should have been measured. It then becomes possible to establish that the product nV is a constant.

The observation time can be reduced by changing the technique to that which Millikan himself used. Instead of attempting to obtain a balance voltage which is time consuming, a fixed voltage V' greater than balance is applied to raise the drop at a steady speed. If the upward transit time across the graticule is t_1 and the time of free fall t_2 then the balance voltage is given by:

$$V = \frac{V't_1}{t_1 + t_2} .$$

Deduction of this equation should not be beyond the powers of a VIth year pupil. The technique calls for considerably greater skill since the drop is at no time stationary and must be 'caught' after each timing. Timing error is introduced into the measurement, but this is more than offset by the accuracy with which V' can be obtained. Being constant throughout the experiment and provided that the manufacturer's design does not call for voltages in the region of kilovolts, V' can be supplied from batteries, thus avoiding errors due to mains fluctuation. Also it can be measured by potentiometric methods. CLEAPSE claim that balance voltages found by this method are more consistent than those obtained by direct balancing. For this reason, and also as a general principle we regard the provision of a special power supply with Millikan's apparatus as an unnecessary expense.

Taking single measurements on different drops means going one step further than the above, and attempting to determine the electronic charge e. The proportionality constants of eqns (4) or (5) must therefore be determined and the apparatus error so introduced may double that obtained by the single drop method.

Air viscosity varies with temperature, the value quoted in tables (Kaye and Laby) being at 23°C. If the cell is at a different temperature the error in assuming the 23° value will amount to 0·4% per deg.C. If means are available, e.g. a thermocouple for measuring cell temperature, this correction should be applied.

Where the teacher or pupil is required to measure the oil density allowance must be made for the possibility of temperature

/

temperature change during the experiment. The adjusted type of specific gravity bottle usually found in school laboratories has an accuracy of just under 1% for the 25 ml size. As manufacturers possess bulk quantities of the oil which makes it easy to measure density it is preferable that oil should be supplied with the apparatus with its density and limits of measurement specified.

With a 0·1 mm scale, obtainable from Proops it is possible to measure the width over the whole graticule with a 1% accuracy. This gives - see eqn (3) - a 1½% error in q, and assumes that the scale is accurate.

Longer times, which mean small drops lead to increased accuracy in timing free fall. Unfortunately this also increases the uncertainty with which the balance voltage can be determined. A 0·1s stop-watch or even Venner clock or electronic scaler should be used for timing, although the latter two will illustrate that it is sometimes possible to use instruments too good for the task in hand, in view of the personal error of the operator. With these precautions it is unlikely that timing will contribute more than 2% to the error in q.

The plate separation d introduces an error which is usually much greater than that of any other factor. It is desirable to have the cell manufactured so that the plates can be easily removed for cleaning, and also to show pupils how the cell is constructed. Once the plates have been taken out, however, it is unlikely that they can be replaced so that they are exactly parallel, or at their previous separation. One reason for this difficulty is abrasion of the material separating the plates, which must be an insulator, and is usually plastic. On two models which have been examined, one by CLEAPSE and one by ourselves, assuming the plate separation given by the manufacturer would have given errors of 5 and 6%. With a plate separation of 5 mm it is not difficult to be this far out. On balance it is better to have a cell where the plates are immobile and have their spacing measured, and its limits specified, by the manufacturer. Cleaning and cell inspection can then be done through ports in the plastic material. If the spacing can be checked by the pupils by travelling microscope so much the better.

For the reasons given above it is unlikely that the determination of e from various drops will be obtained to better than 10%, and 15 or even 20% is more likely in practice with pupil experiments. This limits n to three charges or less, and a quick method of selecting these drops is desirable. A nomogram which has been prepared by CLEAPSE and which we have copied will allow this calculation to be carried out quickly, once the basic technique has been learned. A copy will be sent to any school free of charge upon request. To reason out the modus operandi of the nomogram is in itself a good exercise for the pupil.

We hope we have convinced the teacher that at O or H level the most the pupil could achieve would be observation of drops, controlling their vertical motion by means of an applied P.D., roughly balancing a drop and then upsetting the balance by a radio-active source (handled by the teacher). Any quantitative work must, we believe, be left to class VI.

We have to acknowledge our indebtedness to our sister organisation CLEAPSE for making available a very comprehensive report on the Millikan apparatus, and on which much of the above article is based.

Laboratory Workshop Equipment

The list of machines, tools etc. below has been prepared in collaboration with science teachers and with a supervisor in technical subjects. Prices are a recent quotation from an Edinburgh firm of ironmongers, John Wilkinson, and may vary throughout the country. Catalogue numbers where given refer to the manufacturer's catalogue and are not those of the Edinburgh firm. Teachers are also referred to a very informative article on the Science Laboratory Workshop in Appendix 2, the Science Master's Book, Series IV, Part I, published for the A.S.E. by John Murray.

Cat. No.	Description	£.	s.	d.
10/005	Myford Super 7 3½" Centre Lathe	109.	10.	-
60/005	½HP Motor, single phase, OR	11.	-.	-
60/006	½HP Motor, three phase	8.	12.	-
20/040	Cabinet stand with reversing switch and starter	34.	10.	-
40/001	G.S. Burnerd 4" three jaw chuck	11.	7.	6.
40/011	Independent Burnerd 6" 4 jaw chuck	13.	-	-
1478	Set of 12 H.S.S. Slide Rest Tools, 5/16" square	3.	4.	-
1410	Four tool turret	4.	17.	6.
85	Set of lathe carriers, ½" - 1"	1.	-	3.
41/001	0 - 3/8" Drill chuck, No. 2 M.T.	2.	6.	9.
169	Fluted Centre, No. 2 M.T.		14.	-
1031	Patent Collets No. 2 M.T., 1/8" - ¼"	1.	9.	-
1484	Collet Case		19.	-
1435	Tailstock Dieholder, No. 2 M.T., 13/16"	1.	9.	6
33/025	GMT Rotating Centre, Type CM2, No. 2 M.T.	5.	-	-
1412	Fixed Steady	4.	3.	-
1413	Travelling Steady	2.	11.	-
1468	Rear Tool Post	2.	12.	6.
633S	Eclipse parting toolholder	1.	16.	6.
	* * * * * * * *			
D820	Black and Decker 3/8" two speed Drill	11.	19.	6.
GB80	Bench Stand drill clamp	5.	5.	-
D988	Sanding attachment	5.	9.	6.
	* * * * * * * *			
GPG6	Wolf Bench Grinder	18.	19.	6.
ABDF	Flamemaster hand torch	8.	16.	9.
RBF1	Compressor/Vacuum pump, Edwards	21.	5.	-
K3	Keetona hand lever guilletine	7.	12.	-
	Bench blowtorch	16.	8.	-
	Set glassblower's tools	3.	5.	-
	Electrical soldering iron, 25W Antex	1.	15.	-
887	Electrical soldering iron, 125W Selen	2.	9.	6.
	Micrometer screw gauge, 0 - 1" by 0·001"	3.	4.	-
	Round nose pliers, 6"		7.	9.
	Flat nose pliers, 6"		7.	9.
	Cutting nippers		10.	
	Long chain nose pliers		12.	10.
	Gilbow tinman's snips, 10"		12.	-
	Cabinet screwdrivers, 4", 6", and 8", Stanley No. 25C	1.	1.	10.
	Screwdriver Stanley handyman No. 133H		18.	-
	Electrician's screwdriver, Gordon 6"		3.	10.
	Philips pattern screwdriver, No. 1		6.	-
	Ball pein hammer, ½lb, Stanley No. 308		9.	8.
	Ball pein hammer, 1lb, Stanley No. 310		11.	11.
	Carpenter's mallet, Marples No. 4		7.	3.
	Set double-ended spanners, 1/8" - ¼" B.S.W. Gedore No. 12/6W		14.	5.
	Set spanners, Terry 1069A, B.A. sizes		3.	-

Cat. No.	Description	£.	s.	d.
	Engineer's scriber, Eclipse No. 222		3.	-
	Sliding bevel, 7½", Stanley No. 25		19.	-
	Set Allen keys, 1/16" - 3/8"		8.	-
	Set figure punches, ¼"		18.	-
	Set letter punches, ¼"	2.	13.	-
	Record fitter's vice, No. 23	6.	4.	-
	Record wood vice, No. 52E	3.	14.	-
	Record machine vice, No. 643	6.	16.	-
	Set drills H.S.S. Dormer No. 18, 1/64" - ½" by 1/64"	6.	16.	6.
	Set drills H.S.S. Dormer No. 12, 1 - 60 gauge	4.	19.	-
	Drill stand Dormer 1/16" - ½"		7.	6.
	Drill stand Dormer 1 - 60 gauge		7.	6.
	Set dies B.A. Nos. 1 - 8, 13/16" dia.	2.	2.	4.
	Circular die stock for 13/16" dies		8.	-
	Stanley hand drill No. 803	1.	14.	8.
	Imperial standard wire gauge, 1 - 36	1.	11.	10.
	Standard drill gauge, 1 - 60, Moore and Wright	2.	2.	3.
	Outside spring calipers, 3", M. and W. No.52		8.	-
	Spring dividers, 3", M. and W. No. 50		8.	-
	Inside spring calipers, 3", M. and W. No. 51		8.	-
	Calipgage vernier caliper No. 333P		8.	1.
	Monodex sheet metal cutters	1.	19.	6.
	Eclipse automatic centre punch, No. 171		13.	-
	Marking gauge Stanley No. 5061		6.	9.
	Rose head countersink No. 852		8.	-
	Set Ridgway flat bits, 3/8" - 1", No. 355	1.	13.	3.
	Stanley try square, 6"		15.	-
	Eclipse hacksaw frame, No. 20T		15.	4.
	Blades for above, 12" x ½", per dozen	1.	-	-
	Eclipse junior saw, No. 14J		2.	3.
	Blades for above, per dozen		2.	6.
	Eclipse fretsaw		9.	3.
	Spearior hand saw, 20", No. 88	2.	2.	9.
	Sandvik tenon saw, 10", No. 318	1.	2.	6.
	Stanley smoothing plane, No. 4	2.	2.	6.
	Stanley bevel edge firmer chisels, ¼", ½", and 1"	1.	7.	6.
	Bradawl, 1"		1.	6.
	Abraframe		2.	9.
	Abrafiles, 8", Nos. 150 - 152, per pkt of 3		7.	-
	Abrafile No. 154			6.
	Bastard files, 8", flat, hand, round, half-round and square		15.	4.
	Second cut files, 8", flat, hand, round, half-round and square		14.	11.
	Smooth files, 8", flat, hand, round, half-round and square		17.	8.
	File handles, 4", per dozen		2.	6.
	Dreadnought milling file, 12" flat		10.	-
	Set six assorted needle files, Stubbs No. 319		14.	6.
	Centre drills Nos. 1, 2, and 3		8.	4.
	Record G cramps, 3" and 6", No. 120	1.	1.	5.
	Toolmaker's clamps, 2½"	1.	5.	-
	Rabone-Chesterman spring rule, 10 ft		15.	9.
	Combination stone, carborundum, 8" x 2" x 1"		10.	6.
	Wesco oil can, No. 20		10.	6.
	56 lb all-steel anvil	5.	9.	-

Physics Notes

Following our comment on the g by free fall experiment, we give below a note from Mr. John Emery of Trinity College, Glenalmond who is the designer of the Griffin and George free fall apparatus, L22-850.

"As the designer of the Venner clock and associated free fall equipment, I feel that I should call the attention of all concerned to the Venner brochure ESC/1, in particular to p.8, para. 1 and p.9, paras 2 and 4."

"The equipment was designed to carry out a specific function which it does well within the specification limits. The delay in release from a bare mu-metal pole piece is just observable in a sample of a hundred successive drops from a height of 64 cm, and the single coating of Selotape suggested really does help. There is no measurable rebound if the impact switch is adjusted as explained in the instructions, when it will open with the weight of a 3/8" ball".

"Criticism of equipment is always justifiable when it fails to meet specification, but it seems a little hard that it should be based on an incorrect application and on neglect of the maker's instructions. One does not criticise a metre rule for being unable to measure the thickness of a single sheet of paper."

"The Wallace Hall Academy design closely resembles one of the many tried and rejected by me in the early stages of the clock project. Not only is it cumbersome, expensive with mercury at £3 per pound, potentially dangerous (scattering mercury vapour around the room) and slow to reset, but with a moment of inertia well over ten times that of my final design, and with a variable factor in the depth of immersion of the prong in the mercury, it could give very erratic results."

* * * * * *

We apologise to teachers for an omission in the article on the direct vision spectroscope in the last bulletin. The diffraction grating replica is obtainable from Proops, price 10s. for a 10" x 8" sheet. Ask for the transmission grating, as there is a similar reflection grating which is unsuitable for this application.

* * * * * *

When we gave in the last bulletin the lengths of copper wire required to shunt the Japanese MR38P 1 mA meter, we based our calculations on the resistance of meter coils which we had in the Centre, all of which were within 1% of 60Ω. Several teachers have written in to say that their own meters had resistances widely different from ours so that the shunt values were useless. We therefore arranged to test nearly 100 such meters, all with a "Shinohara" label - our own were labelled "Eagle Products". The results were not encouraging.

33 meters had resistances grouped round 109Ω, but ranging from 102 to 116Ω. 50% of this group had resistance within 108 - 110Ω, which in effect means that the meter readings using the same length of shunt would be within 1% of the true value. The other group totalling 62 meters had resistances ranging from 168 to 200Ω. 26% of these had resistances within 1% of 171Ω, and 40% were within 2% of this value.

Apparently, therefore, the best that one can do apart from tailoring each shunt individually would be to make up a number of lengths of wire to fit the 109Ω and 171Ω values, and reject any meter the tolerance of which is outside the values the teacher is prepared to accept. This problem only arises when the teacher is attempting to make up a class set of meters with interchangeable shunts; otherwise individual tailoring of shunts, although time consuming, is the best answer, e.g. if one is making a switched multi-range meter. In making individual shunts and having calculated the length of wire needed for say 109Ω coil resistance, lengths for other coils are in proportion to the resistance.

Bulletin Supplement

The versions of Millikan's apparatus listed below have been tested and individual reports can be had on loan from the Centre. The equipment has been placed into one of three grades, viz; A - most suitable; B - satisfactory; C - unsatisfactory.

Cat. No.	Maker	Grade	Max. Plate Voltage	Light Source	Plate separation	Graticule separation	Price
N7/2463 N7/1533	W. B. Nicolson	B	1,300v	12v, 2.2w	4.5 mm	2.8 mm	£42.16s.6d. 13. 2s.6d.
L89-960	Griffin and George	B	300v	3.7v 0.3A	5.0 mm	2.5 mm	£36.15s.
P7988C P7988RS P7970A P7851	Philip Harris	A	2,000v	12v, 24w	6.3 mm	2.0 mm	£19.10s. 6. 5s. 3.15s. 11.15s.

The W. B. Nicolson version consists of cell apparatus and power unit, sold separately. The Philip Harris version consists of cell, reversing switch, lamphouse and low power microscope, all sold separately, of which the reversing switch was not tested. The Griffin and George and Philip Harris versions require a power unit for lamp and electrostatic field.

* * * * * *

The Griffin and George conductivity apparatus, S75-690-694, price £16. 10s. has been tested and given grading A. Copies of the test report will be available shortly on loan from the Centre.

S.S.S.E.R.C., 103 Broughton Street, Edinburgh, 1. Tel. WAV 2184

C.L.E.A.P.S.E. Development Group, Wyvil School, Wyvil Road,
London S.W.8.

Griffin and George Ltd., Braeview Place, Nerston, East Kilbride.

Philip Harris Ltd., Ludgate Hill, Birmingham, 3.

W. B. Nicolson Ltd., Thornliebank Industrial Estate, Glasgow.

(Proops) Sound and Science Ltd., 3-5 Eden Grove, Holloway, London, N.7.

Venner Electronics Ltd., Kingston By-Pass, New Malden, Surrey.

John Wilkinson Ltd., 310 Leith Walk, Edinburgh, 6.