STS

Scope includes Science, Technology and Safety

SSERC Bulletin

For those working in science or technology education

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CONTENTS

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Lets look through the square window today!

Today we are going to look through the square window and see what the toys are up to? Little Ted is looking into something too. What is he looking into? He is looking into a microscope. He is searching for wedge fringes. Look! He has plucked a hair out of his fur and placed it between two microscope slides. Big Ted told him to do this. He expects to see lots of parallel lines. These are called interference fringes. By making some simple measurements he should be able to find out how thick a single hair is.

If only it were so simple! Ideally, Big Ted's suggestion to use microscope slides is a good one. They are ubiquitous and of low cost. And if Little Teddy is careful, they can be returned to the box for others to work with. Sadly, the surfaces of microscope slides are seldom sufficiently flat to produce sets of collinear fringes. Certainly Ted will get fringes. Ellipsoidal, or hyperbolic, or ones resembling the contour lines of a topographical map of countryside covered with drumlins.

What Big Ted failed to point out is that the experiment really requires optical windows. These simply are pieces of plane glass machined flat to a specified optical tolerance. They come in various shapes: round, square, or rectangular. No arched ones, I'm afraid! No need, for this application. Depending on tolerance, prices run from £4 to £24. Perhaps that was why Big Ted refrained from mentioning them. They are rather expensive! We have all grown up doing laboratory experiments with string and sticky tape, or making things in the technology room with toilet roll holders and cornflakes' packets. The problem is, nothing ever really works.

Perhaps that is why, when Little Ted grows up, he will choose from arts, sports, business, law and media studies when he goes to university.

Now when Little Ted had been at PlaySchool, it was not unreasonable to expect him to play with empty cardboard boxes discarded from the kitchen or bathroom cupboard. But he was disappointed not to progress beyond these throwaway, valueless consumables on reaching secondary school - most especially in the Advanced Higher Class.

Little Ted could not be expected to know about departmental budget constraints. That his science department budgets had fallen because of the 1974 miners' strikes and then been slashed after the 1976 IMF bailout of the British economy, from which they had never recovered to former relative values. He would be unaware of the SSERC costings of last summer estimating an annual expenditure of £10k - not much relative to salary costs, but rather more than the £1k the department actually had been given (effectively reduced, after photocopying and buying stationary, to £300 for equipment). He would have been aware of the suites of computers in the Business and Computing Studies departments. And of course he could not fail to be enticed by the glamorous world of celebrities and the windows to that world via TV, radio, sport or journalism.

This is a window into Little Ted's world. He is in an Advanced Higher science laboratory where he is still using cheap replicas and getting no results. No wonder he won't go on to do engineering or science in higher education.

New cloots! Same fare!

With its changed format, we will continue to report on school science and technology within our usual ambit: equipment, health and safety, and practical work. With fewer pages, we want to tell it as it is, sharp and fast, here on paper, referring out to our website for fuller detail. We hope its new appearance will encourage us to report with freshness and vigour. Please let us know?

Equipment lists

Equipment lists for the three sciences have been placed on the SSERC website. The Biology and Chemistry lists cover equipment needed for Higher and Advanced Higher courses only. The Physics list covers all course work from S1 to S6. The last of these lists allows us to estimate how much it might cost to equip a school to teach a science subject and budget for its upkeep (Table 1).

In planning budgetary resources, items on the equipment lists have been split into capital assets and consumables. In any normal budgetary control, capital assets are given fixed lives. Thus we have assessed the working life of equipment in years of service and calculated their annual working costs. From this, we provide information to help you plan for depreciation.

One paradox in Little Ted's failed experiment (Editorial) is that while his school could not afford to buy a pair of optical windows at around £10 each, it was able to provide a travelling microscope. With these now costing about £1000 apiece, this may seem unreal. Although many schools do not hold one of these instruments, many others do. This fact shows that science budgets in the 1960s, when they would have been purchased, were relatively much more generous than they tend to be today.

If you are unable to visit our website and would like a paper copy, please ask for one.

Number of physics labs	Total cost £	Annual cost £
1	59000	7200
2	71000	9800
3	84000	12400
4	97000	15100

Table 1 *Budget estimates for equipping a suite of physics laboratories.*

Historical budget provision

Apparatus held by the school in which I taught in the 1970s included a vernier microscope (£1000), Edwards double stage rotary vacuum pump (£997), oil diffusion high vacuum pump (£869), interferometer (£593), Millikan's oil drop kit (£1671) and gravitational torsion balance (£1794). Considering that scale of provision, the inference that has to be drawn is that the funding of science and technology then was more generous than it often is now. It would be interesting to know what departmental budgets were lang syne, say before 1975? Are any readers able to recall these figures?

SSERC Website

One reason why the *Bulletin* has been downsized is that we are now placing information for schools on our website. Any teacher or technician from a subscribing school (this includes every Scottish council one) may access our site, but must register to do so. Registration is done on-line. To register, call up the SSERC website:

www.sserc.org.uk

Click on the underlined word in the box marked 'Members joining/rejoining SSERC'. This opens a registration form. On verification, you will get a return e-mail from SSERC, usually within a day, giving you a username and password. These let you enter the Members' area of the SSERC website.

At the time of writing, the SSERC site had members from about half of the secondary schools. About two thirds of the registered teachers were using their home e-mail addresses, showing up the lack of convenient on-line facilities in school departments.

HMI sciences' report

The Scottish Executive have issued a Standards and Quality report based on inspections of 325 biology, chemistry, physics and science departments. Amongst the bouquets, it is reassuring to find that the provision of resources is very good in 20% of departments and good in 70% of them. Brickbats are thrown at the general lack of modern equipment, noting even where scientific equipment appeared to be sufficient, some of it was outdated and some was inappropriate. Most departments were poorly supplied with equipment for ICT.

Standards and quality in secondary schools 1995-2000: The sciences Scottish Executive 2000 ISBN 1 84268 417 5

Summer schools

Plans are underway for summer schools in biotechnology, chemistry and physics to be held concurrently at the University of Edinburgh from Monday 26 June to Friday 30 June. Details have been, or are about to be, circulated to schools. Application for a place on the biotechnology school should be made through LT Scotland. For a place on one of the other two, please contact the university (addresses on page 12).

Enlist! Your country needs you!

The UK requires 115,000 extra engineering professionals by 2009 compared with the numbers employed in 1998. Also there will be 370,000 new job openings within this period in the engineering manufacturing sector according to a report by the Department for Employment and Engineering (DfEE).

Although engineering manufacturing has been in a long-term decline in the past three decades, the report indicates that there continues to be a strong demand for engineering skills in the UK economy, particularly in the fast-growing electronics and telecommunications industries.

There would seem to be a shortage of people with relevant skills and experience. A number of engineering employers find vacancies difficult to fill.

The statistics from higher education are gloomy. The annual UK output of first degree engineering graduates is around 22,000. The output declined by 10% between 1994/95 and 1997/98 while the average output from HE increased by 10% and the output from popular subjects increased by more than 20%. The main reason for the decline is viewed as being the unattractiveness of engineering as a subject to study and as a career.

Commenting on UCAS data for entrants to electronics engineering in September 2000, Electronics Times commented, "The rapid expansion plans of large electronics companies in the UK means that a single company such as BAE Systems or Lucent Technologies could take the country's entire graduating population of engineers in one go and probably still need more staff".

An assessment of skill needs in engineering DfEE 2000 ISBN 1 84185 400 X

Nae biology

We are sorry for the lack of biology in this issue. Our biologist is taking a break to visit family overseas.

Electrical accident

A physics teacher received an electric shock while using an aged Philip Harris Transformer and Discharge Lamp. Several versions of this lamp were produced by Harris between the 1960s and 1980s. The one in the accident resembles the version shown in that company's 1977 catalogue and is illustrated below (Fig. 1) (stock item P41250/3).

As can been seen from the illustration, the lamp is supplied from the transformer through a flying lead with detachable connector. The three-pin plug on this lead has round pins, the largest of which is the protective earth conductor. Through natural ageing, or wear and tear, this plug had lost its polarity uniqueness and could then be inserted in any position into the transformer's socket.

The accident occurred after the last class of the day had left the laboratory. Finding that the lamp had failed to operate during a lesson and powering up the transformer to investigate, the teacher touched the supposedly earthed metal cage enclosing the transformer and got a shock, his body forming a current path from live a.c. to earth. This dangerous current was switched off automatically by a residual current circuit breaker protecting the room's supply.

The direct cause of the accident had been the mating of the plug's earth pin with the socket outlet's live terminal. Clearly If you have an aged spectral lamp and transformer you are advised to inspect it and judge whether it suffers, or may do so, from this fault condition. Any other aged equipment that may also be at risk should be inspected also.

What else can we learn from this accident? There was one feature that helped to prevent the accident being serious, but other factors that may have contributed to it.

1. *RCD protection* : Electrical accidents occur infrequently, but when they do they can be fatal. One reason why they are uncommon is that electrical systems are engineered to have at least two layers of protection. Usually in school laboratories this will be protective earthing and insulation. Belts and braces! But why stop at two protective barriers? We argued in this journal some years ago that school laboratories should have RCD protection also [1], a third protective system. Thereafter we were contacted by the chief inspector of the National Inspecting Council for Electrical Installation Contracting (NICEIC), the body responsible for checking the work of electrical contractors. He told us that he could not find anything about our case to disagree with, and could he issue our article to his inspectors. This teacher was saved from serious injury by RCD protection. The reasons for having it are sound.

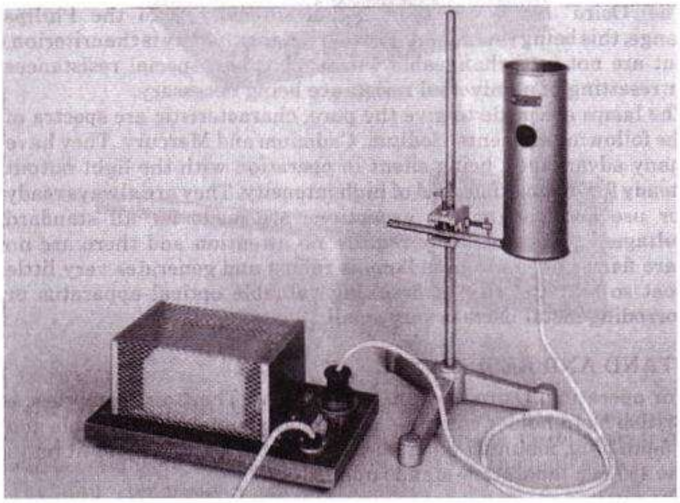

Figure 1 *Philip Harris Lamphouse and transformer P41250/3.*

2. *Routine inspections* : The majority of electrical accidents could have been prevented had someone looked at the system before using it. Fault conditions are often obvious. You just have to look for them! PAT testing may uncover some defects, possibly hidden, but most others can be spotted by eye. The cause of this accident could have been so found. Who should do the looking? The technician laying out the apparatus for use, the teacher using it and the technician putting it away after the lesson. The law requires that electrical apparatus shall be maintained so as to prevent, so far as is reasonably practicable, danger. Any maintenance system of formal inspections and tests should be backed up by informal checks by users [2].
3. *Training* : Any safety system depends on the competence of staff. Competence is not assured by training, but training may help staff towards becoming competent in carrying out informal checks on electrical equipment. Generally most councils provide training for technicians on electrical safety. Really though physics and technology teachers should also be so trained because much of their work is with electricity. In the school with the accident, neither the physics teachers nor the laboratory technician had attended an electrical safety course.
4. *Aged equipment*: The apparatus in this accident is thought to be about 25 years old. Who of us at home continue running refrigerators, televisions or washing machines as old as that! For many reasons there has been neither a political nor professional will to see that aged laboratory apparatus is disposed of and replaced. In any normal commercial undertaking, capital assets would be given fixed lives and thereafter written off. For reasons of safety, electrical equipment should be managed with a formal system of planned preventive and condition-based maintenance [3]. The planned preventive part of such a maintenance system might have written into it a requirement to assess equipment after 10 or 20 years with a view to replacing before safety-critical parts failed.

As a final comment, the reader may think that we are placing over much responsibility on the shoulders of school staff. Under health and safety legislation, each employee has a duty of care towards himself and others. He also has to comply with his employer's safety system, which may delegate responsibilities on him. However the prime responsibility rests with the employer (see next story). He has the duty for setting up safe systems of work, including maintenance systems, supervision and training. He also has to ensure that such systems are adequate for the purpose and work effectively. Had this accident been worse, it would have been on the employer's door that the inspector would have come knocking.

References

1 *RCD protection* Bulletin 185 SSERC 1995

2 *Portable appliance inspecting* Bulletin 184 SSERC 1995

3 *Safe use of work equipment Provision and use of work equipment regulations 1998* Approved code of practice and guidance HSC 1998 ISBN 0 7176 1626 6

Prosecution

A school was recently successfully prosecuted by the Health and Safety Executive after an accident in which a piece of wood flew off from a pedestal drill injuring a pupil on the temple. Following emergency treatment for a blood clot, the pupil has fully recovered.

During the court proceedings the prosecution pointed out that clamps to fix the piece of wood being worked as well as false tables to raise the working pedestal drill table were available within the Design Technology area but were not being used at the time. The school had information from British Standards documents and HSE guidance notes stating that work on pedestal drills should be clamped.

The prosecution went on to point out that the education authority had advised the school on how to perform risk assessments. The school had been provided with sufficient information for them to undertake risk assessments not only on the pedestal drill but on all other areas of the school as well. HSE were of the opinion that the school had decided not to take this advice on board. Because other risks in the school had not been assessed, or not fully so, the HSE had issued the school with an improvement notice insisting that risk assessments were completed.

The school governors were fined £1,250 for breaches of Section 3(1) of the Health and Safety at Work etc. Act 1974. Under this section of the act an employer must exercise a duty of care, as far as reasonably practicable, towards persons not in his employment. The scope of Section 3(1) includes school pupils working with pedestal drills. The governors were also fined the maximum fine of £5,000 for not having carried out the risk assessment in contravention of Regulation 3(1) of the Management of Health and Safety at Work Regulations 1992.

Compensation for damages is being pursued by the injured boy's parents through the civil courts.

The number of prosecutions in the UK within the education sector arising from action by the HSE lies between four and six annually. This court decision shows that arrangements for health and safety must be in place and be seen to be effective. This includes being managed.

3M OHPs emitting asbestos

We have had a report from a council informing us that the asbestos heat shield, measuring 2" square, of an obsolete 3M overhead projector can break up due to age and heat. Dust from this shield can then be emitted to the atmosphere by the cooling fan. The model is a 3M type 299 AHB 500 watt. We understand from 3M that this is the only 3M model to be so affected. 3M ceased manufacturing the model in 1975. Responding to the risk, 3M contacted customers in 1984 recalling the product to remove the heat shield. Modified machines were then returned to customers for further use.

The story has recently resurfaced after a technician carrying out a routine electrical safety check found some white dust in the base of a machine. Further checks have resulted in a further five unmodified OHPs in that council's schools. It would seem likely that if one council has this problem, others will have it too.

If you have any of these models, check whether the heat shield is present, or has disintegrated into dust. If so, withdraw them from use and inform either the chief technician at your council's technician repair centre, or your council safety officer for advice on what to do. You may find the you are not permitted to dispose of these OHPs as ordinary refuse. They may have to be got rid of as special waste.

Unilab product recall

Unilab have found that mains cable clamps fitted to its mains-powered products between August 1999 and October 2000 are unreliable. There is a risk that the mains cord is insecure. Were the mains cord to be pulled through the clamp, someone might get an electric shock.

In October Unilab sent recall letters to the heads of science in schools that had purchased mains-powered equipment in that period. The defective cable clamp has a hexagonal plastic head around where the cable enters the apparatus.

The type of clamp fitted before August 1999 has a round plastic sleeve where the cable enters the apparatus and an adjacent crosshead screw. It is reliable. Apparatus so fitted should not be returned.

Design and Technology code of practice

The British Standard for design and technology in schools has been revised.

The British Standards Institution (BSI) has revised and republished BS 4163 [1], its specific guidance on health and safety for design and technology in schools and similar establishments. We reported on this in our last issue, but what we didn't know then is that this document is available at a discount price from the Design & Technology Association (DATA) at £12 for DATA members, or £18 for non-members.

The introductory section on health and safety management distinguishes between hazard and risk, explains how to make a risk assessment and make health and safety arrangements. All the buzz words are there, with up-to-date interpretations.

The following section offers advice on how to plan and design a work area. It has information on the storage of bulk materials, flammable liquids and compressed gases. There is advice on the working area environment including heating, lighting, floors, ventilation and noise, giving a rule of thumb that, 'if persons about 2 m apart are required to shout to be heard and have difficulty in understanding each other, there could be a noise hazard'.

The bulk of BS 4163 is contained within Section 4, on teaching areas, equipment, tools and processes. It is split into sub-sections on related items. For illustration, the sub-section on woodworking machinery outlines the generic hazards and safety arrangements. That is followed by information on specific machines (mortising machine, moulding machine, etc.), listing the hazards and recommending the risk control measures.

Thereafter, there is a much shorter section on materials, similarly structured with generic information followed by specific details. The standard then finishes on definitions and references.

Although its scope includes home economics, the document mostly relates to technology of a nuts and bolts type!

In conclusion, this is an indispensible compendium of health and safety advice. And for the moment it is bang up to date!

Reference

1 BS 4163:2000 *Health and safety for design and technology in schools and similar establishments - Code of practice* BSI.

Essential science safety references

The third edition of ASE's reference book 'Topics in Safety', with its health and safety-related essays, has just been published.

Mainstays of the health and safety literature for science education are the two books from the Association for Science Education (ASE): *'Safeguards in the school laboratory'* (1996) and *'Topics in safety'* (2001).

'Safeguards', which ASE call a booklet, gives a brief account of the main safety problems in science. One purpose behind it is to give new teachers an overview of science safety. It is sufficiently short to be read easily in one evening, but, running to 123 pages, by calling it a booklet is to mislead and downplay its importance. It also is a comprehensive guide. A book of first resort for any teacher, experienced or not, in search of advice. It is an essential reference for every departmental library.

'Topics' in contrast sets out to be a more reflective book for the experienced science teacher. It aims to be a reference book comprising of "a collection of health and safety-related essays on issues which are important, current, complex and perhaps contentious". Although it does not try to give comprehensive coverage, it does in fact deal with most of the significant issues.

The editorial team for both *'Safeguards'* and *'Topics'* comprised members of the ASE's Safeguards in Science Committee, on which SSERC and CLEAPSS are represented. The text of both publications has been checked, and in some parts written, by CLEAPSS or SSERC staff. We recommend that teachers turn to *'Topics'* on a routine basis as their second port of call when searching for advice.

Looking for 'model steam engines' in the indices gave three references in *'Safeguards'*, but none in *'Topics'*. The text in the former refers out to SSERC *'Bulletin 182'* for further information, illustrating the point that the former is a comprehensive guide, whereas the latter is not. Nor does it purport to be. It does however have intelligent, discursive comment on the main safety issues: using chemicals, assessing carcinogenic hazards, allergies and asthma, living organisms, microbiology and biotechnology, and working with DNA.

It's good to find topics on science technicians and manual handling. Staff are at greater risk of injury than pupils. The evidence tells us so. Another new topic deals with laboratory design - a useful reference for anyone planning not just teaching areas, but preperation and storage rooms also.

'Topics in safety' costs £18, including post and packing, from ASE Booksales (less 10% for ASE members). SSERC has made a bulk purchase and is able to supply SSERC members at £15 if collected from the Centre, or £16.50 if dispatched.

Safeguards in the school laboratory 10th edition ASE 1996
ISBN 0 86357 250 2

DiVA spectrophotometer

This computer-based instrument from Nicholl Education has applications across the three sciences

DiVA operates with a PC to produce spectral graphs of:

- optical radiation from discharge lamps, lasers, LEDs and other sources;
- sunlight and skylight;
- transmission through colour filters, solutions and other translucent materials such as polymers, leaves, or dyes;
- reflection from surfaces such as fabrics, paints, or metals;
- luminescent or fluorescent materials.

Only the first of these applications has been tested. The results form the basis of our report.

Radiation enters the spectrophotometer through an optical fibre which is protected within a reinforced, articulating, steel sheath. The analyser and detector consists of a Microparts VIS spectrometer. This monolithic device is bonded to a Hamamatsu linear photodiode array of 256 elements. The Microparts specification quotes a range of 380 to 780 nm. Because it is sensitive beyond these limits, *DiVA* has a displayed wavelength range of 340 to 900 nm. Sensitivity drops off at either end of the range. From this information, the resolution cannot be better than 2.2 nm.

The spectrophotometer connects with a PC via its serial port. The operating program is still under development. Users may obtain updates by downloading off Nicholl's website.

The helium spectrum from a Geissler tube was used in the tests because its spectrum consists of a small number of discrete, isolated lines. The apparent gaussian spread exhibited by each emission line is characteristic of *DiVA's* display (Fig. 1). By measuring the standard deviations of these distributions, the mean value for random uncertainty works out to be ± 6 nm. The emission lines systematically register high by 4 ± 1 nm. Nicholl have informed us that this is down to a software error and will be corrected. The sensitivity dependence on wavelength is evident from the relative heights of the 389 nm and 588 nm lines. Both lines should have the same intensity, showing that *DiVA* has a peak sensitivity around the visible red part of the spectrum.

Because its effective resolution is 6 nm, *DiVA* fails to resolve complex spectra such as from a neon source consisting of bands of discrete emission lines (Fig. 2). This failure can be put to good use because it shows how instruments can sometimes mislead.

The time taken to make a reading varies from a few seconds to quarter of an hour depending on the intensity of the source. We were disappointed to find that *DiVA* was unable to show clearly the atomic hydrogen emission line spectrum from a hydrogen filled Geissler tube, the emissions being too faint to detect. On the one ocassion

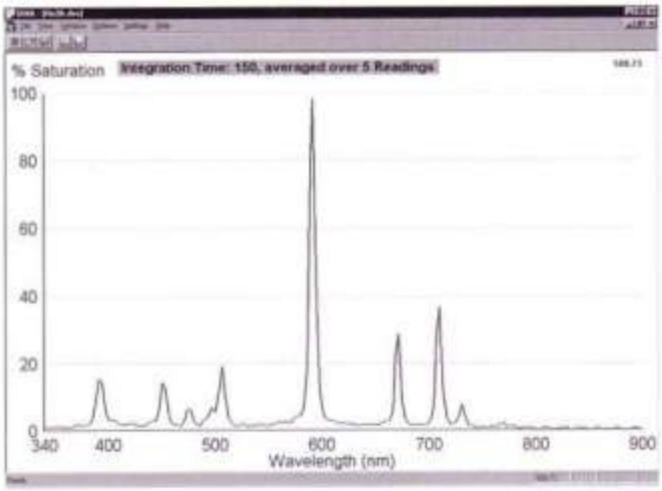

Figure 1 *Emission spectrum from a Geissler spectrum tube filled with helium.*

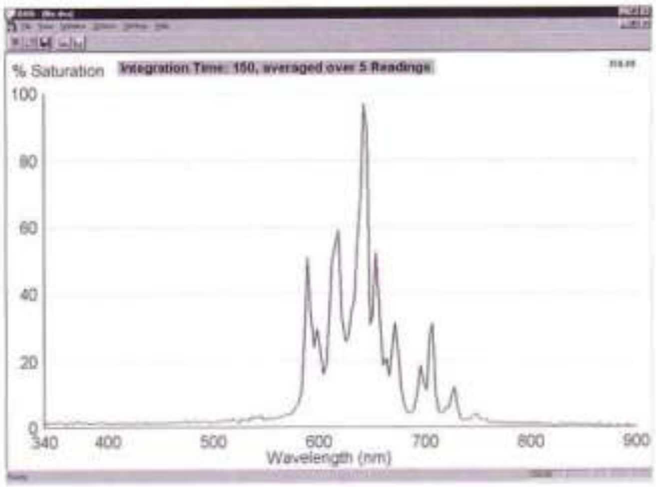

Figure 2 *Emission spectrum from a Geissler spectrum tube filled with neon.*

when *DiVA* failed to operate properly it was being used with laser radiation. Either the photodiode array or charge sensitive amplifier had became saturated. The fault sorted itself after a night's rest.

The software has an icon bar with pull-down menus. Although quite easy to use, the program could do with being improved.

Despite some deficiencies, *DiVA* is well worth buying. There are many applications for spectrophotometry in all three sciences. If used in conjunction with a hand spectroscope, one shows up the limitations of the other, but both together give a fuller picture than either on its own can achieve.

Further performance details can be found on the SSERC website.

Laser radiation sensor

The sensor is based on a planar photodiode whose surface area is sufficiently large to accommodate all of the radiation within a laser beam.

In any application where comparative measurements of laser radiation intensity are to be made the entire beam should fit within the bounds of a planar photodiode. The beam cross-sectional diameter is typically 3-5 mm. What's then required is a planar photodiode whose dimensions are sufficiently great to accommodate the beam. Such devices are now stocked by Farnell. Of the eight sizes in the range, the one we chose for testing is 10.2 mm square. This photodiode comes with two types of connection. SLCD-61N5 (order code 316-8165, £5.58) is a chip with legs for soldering to stripboard. SLSD-71N5 (order code 316-8244, £7.14) is fitted with 130 mm flying leads. The former would be our preferred choice, being less fragile once soldered in place.

The reverse leakage current generated by the photodiode is proportional to the intensity of radiation. In the circuit (Fig. 1), this current establishes a potential difference across the 10 kΩ feedback resistor. The op-amp's output voltage is therefore proportional to intensity.

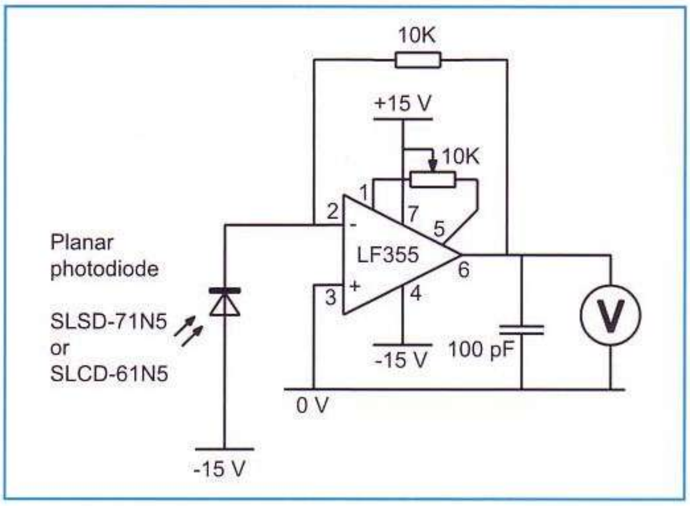

Figure 1 *Circuit to measure the intensity of laser radiation.*

Polarisation experiments

Because the radiation from a laser diode is plane polarised with the polarisation vector being in stable alignment, these devices are excellent sources for polarisation experiments.

Generally the polarisation vector of radiation from an educational HeNe laser rotates slowly with time. The period of rotation can vary from 25 s to 10 min at switch-on, depending on type, and typically lengthens to perhaps 30 min after two hour's operation once the device has fully warmed up. These lasers are unsuitable for polarisation experiments. An exception is the last HeNe laser model sold by Griffin (XFV-540-010V), which has a stable plane of polarisation.

In contrast the radiation from all of the laser diode modules we have tested has been found to have a stable plane of polarization. These then are excellent radiation sources in experiments or applications on polarization. The radiation intensity should be measured with the sensor described above.

The graph shown opposite (Fig. 1) is a demonstration of Malus's Law. Radiation from a laser diode module was directed at the planar photodiode. The radiation was transmitted through a single sheet of polarising film, which acted as the analyser. This was rotated through 360° to produce the effect shown. The technique may also be applied to investigate polarisation by reflection, from which a value for Brewster's angle may be found.

Polarising laminated film is supplied by Edmund Scientific (order code E43-781 at £5.06 for a pair of 2" squares). Details on how to construct a simple polarising mount for 360° rotation will be sent to you on application to SSERC. A commercial polariser holder is made by PASCO (order code OS-8533) at £96.

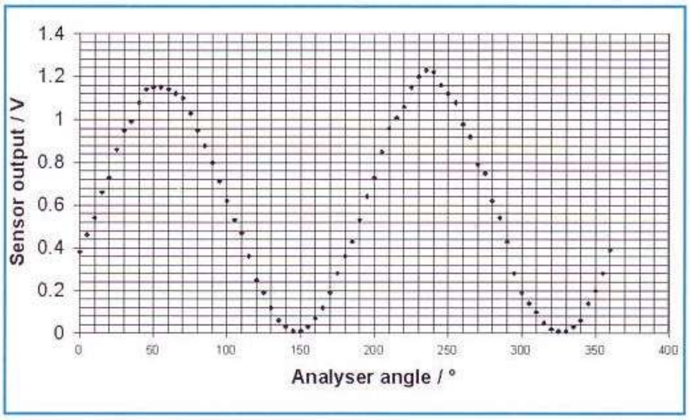

Figure 1 *Demonstration of Malus's law.*

If working with lasers, please follow the standard safety guidance [1].

Reference

1 *Guidance on the use of lasers in laboratory work in schools and colleges, and in non-advanced work in further education establishments* Circular No. 7/95 SEED 1995

Photoelectric effect kits

The photoelectric effect should be introduced by reviewing the experimental evidence, where possible from classroom experiments. Inferences which can thereafter be drawn lead into the quantization of radiation and photon concepts. A test report on the available kits is presented here.

Before reporting on apparatus for showing the photoelectric effect, it is important to be clear about the underlying science and its historical beginnings. The story is sometimes reduced to a list of end results with the "how do we know .....?" questions avoided. Most of the original experimental work was down to Philipp Lenard (1902). His apparatus should be familiar. It would seem to be essential to provide students with a description of it to give them an insight into what was being measured before presenting the results.

There is not space here to describe the results in full, but see Table 1 for an outline. The paradoxes are:

- the maximum kinetic energy of the photoelectrons is unaffected by the light intensity (Fig. 1);
- the saturation current is directly proportional to the light intensity with no evidence of a threshold below which there is no photoemission (Fig. 1);
- the maximum kinetic energy of the photoelectrons increases with a rise in frequency of the incident light.

The main part of Einstein's famous paper proposing the photon concept (1905) was a rederivation of the black body spectrum. In the original quantum theory, Planck had proposed that the energies of atomic and molecular oscillations were quantized. In his reinterpretation, Einstein put forward the idea of the quantization of radiation. The photoelectric effect was brought in as further support when he showed that the photon concept is capable of resolving the photoelectric paradoxes.

The third listed paradox relating the maximum kinetic energy of the photoelectrons, or the stopping voltage, with the frequency of incident light had been known only qualitatively in 1905, and the linear relationship was then unknown. It was Einstein in his 1905 paper who predicted it with:

$$e\Delta V_s = h\nu - W_0$$

Experimental support appeared some years later from Richardson and Compton (1912), Hughes (1913) and, definitively, Millikan (1916). The experiment is therefore called Millikan's photoelectric experiment.

As we will now see, the purpose underlying the two new photoelectric effect kits from Unilab and PASCO is performing Millikan's experiment. Neither is capable of demonstrating Lenard's original set of experiments upon whose results the photon concept can be inferred (Table 1).

It would seem that the most plausible route open to teachers is to introduce photoemission with a gold leaf electroscope demonstration, describe Lenard's results with a lot of hand waving, make the inferences which lead to the photon concept, derive Einstein's prediction that the stopping p.d. and frequency have a linear dependence, and confirm by doing Millikan's experiment.

Experimental result	Gold leaf electro-scope	Unilab PE2 Photo-electric Unit	Unilab PE3 Photo-electric Unit	Unilab Planck's Constant Apparatus	PASCO h/e Apparatus
Photoelectron emission; emission of negative charge when metal surface illuminated with light	Yes	Not clearly	Not clearly	Not clearly	Qualified yes
Photocurrent increases as the electrodes are moved closer together, but levels off at a certain minimum separation	Perhaps	No	No	No	No
Maximum (saturation) photocurrent under an accelerating p.d. is directly proportional to the light intensity	No	Perhaps Untested	Perhaps Untested	No	No
The above effect extends down to extremely ow intensities (6 orders of magnitude)	No	No	No	No	No
For retarding p.d.s the photocurrent does not drop instantly to zero, but decreases gradually to a limiting value ΔV_s	No	Yes, but effect obscured	Yes, but effect obscured	Yes Clearly	Qualified yes
For retarding p.d.s the cut-off value ΔV_s is unaffected by light intensity	No	Perhaps	Obscure	Yes Clearly	Yes Clearly
For retarding p.d.s the cut-off value ΔV_s depends on frequency of light	No	Yes	Yes	Yes	Yes
For retarding p.d.s the cut-off value ΔV_s is directly proportional to the frequency of light A value of Planck's Constant can be derived	No	Yes Difficult to establish	Yes Difficult to establish	Yes Clearly	Yes Very clear

Table 1 *List of experimental results underpinning the photoelectric effect. Lenard and Thomson (1899) had shown that the emitted negative ions had the same e/m value as any other electrons. All these results, except for the last one, were known by Einstein in 1905. The other columns show which experiments can be performed with the various photoelectric kits.*

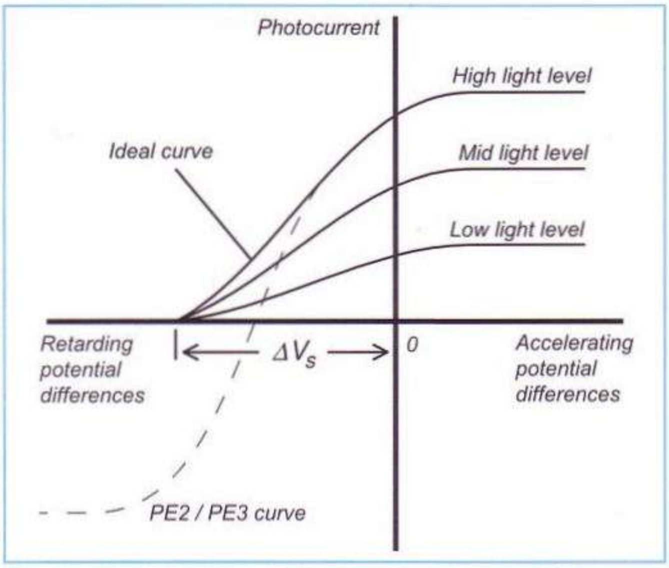

Figure 1 *Idealized curves (solid) for three different intensities of the same wavelength of light. The pecked line shows an actual curve with either PE2 or PE3 caused by photoemission from both electrodes.*

Here is a run-down on the apparatus (Table 2). Both of the obsolete Unilab kits are included because a fair number will be in circulation still. Their performance merits a mention.

Photoelectric Kit Types *PE 2* and *PE 3* : Unilab

The photocells in these kits can be biased with an external p.d. to plot the photocurrent under accelerating and retarding fields. The currents are tiny and require amplification. Typically the range is 100 pA. The meter should be able to resolve to 1 pA. The obsolete Unilab DC Amplifier 003.813 with a 10^{11} Ω input resistor is suitable. In principle most of Lenard's experiments can be shown with these kits. However they perform poorly because there is photoemission from both electrodes. Analysing a set of characteristic curves to determine the cut-off p.d.s is not a simple matter (Fig. 1). Methods have been given in journals. But neither kit is capable of showing clearly the results and paradoxes from which useful inferences can be drawn. Rather it's the other way round. Only once you have a clear grasp of the photo-electric effect can you then set about unravelling the experimental data which these kits provide. The message is: avoid them both.

Planck's Constant Apparatus : Unilab

The photocell can be backed off with a retarding p.d. from an internal PP3 battery and multiturn pot. Because a changeover switch has not been provided, it is not possible (or not convenient) to investigate how the photocurrent behaves under an accelerating field. In consequence one of Lenard's paradoxes cannot be uncovered. The others are clearly shown. There is no evidence of photoemission from the other electrode. Thus the characteristic *I-V* curves come fairly cleanly to the voltage axis. However because the method depends on detecting where the current falls to zero, determining the cut-off p.d. is rather inexact. (Current is measured with a *Picoammeter*, Unilab, C50491.)

The photocell has a spectral response between 185 and 650 nm. Suitable sources of radiation include skylight, tungsten filament lamp and mercury vapour lamp. Sets of filters are provided. For optimum results, use a mercury vapour lamp in a blacked out laboratory. The intensity should be varied by shifting the lamp away from the kit. Millikan's experiment can be carried out with any of these suggested sources. In every case the result for Planck's constant was around 5 x 10^{-34} J s.

The h/e Apparatus : PASCO

The *Photoelectric Head* AP-9368 has been designed to measure the stopping voltage only. When the capacitance on the photocell reaches the backing-off potential of the photoelectrons, the current drops to zero and the cell voltage stabilizes. The electrical output shows a rising voltage, which steadies after a few seconds. The steady state value is the stopping voltage for the highest frequency of light on the photocell.

The preferred radiation source is PASCO's *Mercury Vapour Lamp* OS-9286-220. The *Optics and Alignment Kit* AP-9369 includes a blazed grating and lens which disperses the mercury spectrum such that five discrete emission lines, one by one, hit the photocell. A set of readings of stopping voltage against frequency can be made in about a minute. When graphed, the 5 points are seen to be collinear, confirming Einstein's prediction, from which Planck's constant works out at 6.7 ± 0.2 x 10^{-34} J s.

The *Photoelectric Head* can also be used with a Philips mercury vapour lamp and other optics to disperse the light. However *The Complete h/e System* AP-9370 is simpler to work with.

Verdict

For Millikan's experiment, PASCO's h/e apparatus is outstandingly good. Unilab's *Planck's Constant Apparatus* is satisfactory. There is no apparatus with which to show the complete set of Lenard's experiments, but two of the three paradoxes can be shown with Unilab's *Planck's Constant* kit. Avoid using Unilab's earlier kits *PE 2* or *PE 3*.

Acknowledgement

Material for the historical introduction was drawn from '*Teaching Introductory Physics*', Arnold B Arons, 1997, John Wiley & Sons, New York, ISBN 0 471 13707 3.

Apparatus	Manufac-turer	Order code	Price £
Photoelectric Unit Type PE2	Unilab	073.722	Obsolete
Photoelectric Unit Type PE3	Unilab	073.723	Obsolete
Planck's Constant Apparatus	Unilab	C51203 (073.733)	£459
The Complete h/e System	PASCO	AP-9370	£1635
Photoelectric Head		AP-9368	£818
Optics and Alignment Kit		AP-9369	£498
Mercury Vapour Light Source		OS-9286-220	£707

Table 2 *Apparatus for photoelectric effect experiments.*

Quantitative determination of reducing sugars with Benedict's solution

The principle of the method is that of running the sugar solution of unknown concentration from a burette into a known quantity of boiling Benedict's solution until the copper(II) (blue colour) is reduced to colourless copper(I) by the sugar.

We have been asked several times for the details of this method and it is worth outlining it. The stoichiometry of the reaction is not known, but since 1 mole of glucose always reacts with close to 6.5 mole of copper(II) the concentration of glucose can be calculated. (Strangely for Fehling's, which is a more alkaline medium, the ratio is 1 mole of glucose to 5 moles of copper(II) [1].)

There are several variations of the recipe. All contain the same concentration of Cu^{2+}, but differ slightly in the amounts of sodium carbonate and the complexing agent (citrate). The method tried out and tested as below was largely based on that kindly supplied by Geoff Smith at Fisher Scientific.

The solution

The quantitative version can be either purchased or prepared according to the recipe below:

188 g l^{-1}	trisodium citrate
75 g l^{-1}	sodium carbonate, anhydrous
125 g l^{-1}	potassium thiocyanate
0.25 g l^{-1}	potassium hexacyanoferrate(II) (pot ferrocyanate)
18 g l^{-1}	copper sulphate-5-water

The reagent was very slightly cloudy as prepared. Filtering it gives a clear solution, but sometimes on cooling a small amount of whitish precipitate settles out overnight. Before dispensing 25 cm^3 the bottle was given a good shake to get the material in suspension.

It does contain a large concentration of chemicals and a smaller volume can be prepared. (As stated in the method each determination will use 25 cm^3.)

Method

1 Pipette 25 cm^3 of Benedict's solution into a 250 cm^3 conical flask, add approximately 100 cm^3 distilled water. Add anti bump granules, warm and gradually add 10 g of anhydrous sodium carbonate and bring up to boiling. Boil the mixture vigorously until the salt has dissolved. In some ways, though slower, a hotplate is preferred to a tripod and gauze as the boiling solution is lower. If a bunsen and tripod are used, secure the flask by clamping (Fig. 1).

2 Fill the burette with the sugar solution (diluted if necessary to contain < 0.5% glucose) and run it into the boiling reagent, rapidly at first and then dropwise at intervals of 10-20 seconds until the blue colour disappears, the precipitated copper(I) thiocyanate being white or pale green. The solution should be kept boiling and water added, if necessary, to compensate for evaporative losses.

Some may prefer to add a few drops of methylene blue, but our experience is that the end point is quite easily detected without this redox indicator; the disappearance of the blue colour of copper(II) being easily seen.

3 Once the approximate titre is known from the first titration, in the second titration run in quickly about 1 cm^3 less of the sugar solution than that needed on the first run. Thereafter finish the titration dropwise, pausing for a few seconds after each addition as the reaction is slow at this stage.

Calculation

25 cm^3 of this Benedict's solution reacts with 50 mg of glucose or 53 mg of fructose and this quantity is contained in the volume of sugar solution required.

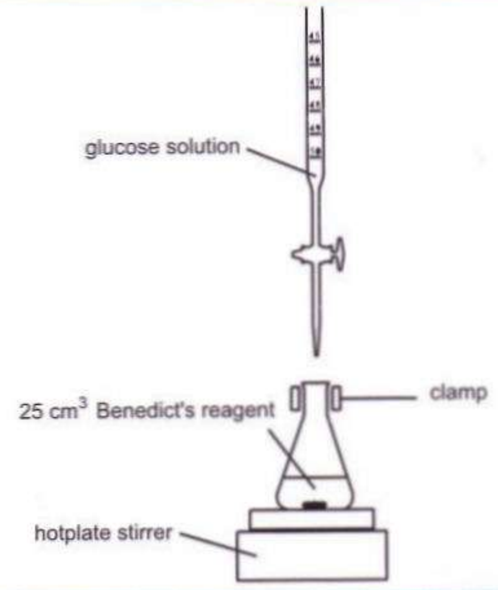

Figure 1 *Apparatus described in method.*

Other points

1 An interesting effect - if you let the solution remaining in the flask at the end of the titration cool down and then give it a shake, it turns blue again. This emphasises the need for keeping the air out during the titration; boiling does this effectively.

2 It is good practice to carry out a standardisation on the Benedict's solution, whether purchased ready made or prepared in school, rather than accept the given 50 mg per 25 cm^3.

3 There is no reason why the whole method cannot be scaled down using 10 or even 5 cm^3 of the solution. The accuracy of the method will suffer a little unless the sugar solution happens to be weak. One way of reducing the scale is to dilute the glucose solution by a known amount, determine its concentration and multiply up by the dilution factor:

With the recommended 25 cm^3 of reagent, 12.5 cm^3 of a 0.4% solution of glucose are required. 5 cm^3 of reagent would give a reasonable titre reading (10 cm^3) of the glucose solution if it were first diluted fourfold.

4 The method can be extended for other sugars, 25 cm^3 of reagent reacting with 0.053 g fructose or with sucrose following the hydrolysis of the latter.

Safety

Hazards associated with the substances are tabulated opposite.

Wear eye protection when preparing the reagent and when boiling it during the determination. The hazards of the substances listed above are those of the solids and will be greatly lessened in the solution.

Clamp the flask during the titration. (Some methods recommend using an open porcelain dish, but this is less stable and will not contain splashes from the boiling solution.)

Substance	Hazard
trisodium citrate	May irritate eyes.
sodium carbonate, anhydrous	Irritating to the eyes.
potassium thiocyanate	Harmful if swallowed in quantity.
potassium hexacyanoferrate(II)	Irritating to eyes and skin. Low oral toxicity. Reacts with hot acids to yield very toxic hydrogen cyanide.
copper sulphate-5-water	Harmful by ingestion and if inhaled as dust. Irritating to eyes and skin.

Quantitative Fehling's solution

There is an analogous method using Fehling's solution, which works very well and there is no reason why it should not be used. Fehling's solution, made by mixing equal volumes of Fehling's solutions No 1 and No 2, contains approximately 1.9 M sodium hydroxide (*CORROSIVE*). However, in this quantitative method, this is usually diluted sixfold leaving the diluted solution, which has to be boiled, at approximately 0.3 M (*IRRITANT*).

Reference

1 *Problems with Benedict's* Bulletin 196 SSERC 1999

LENS OFFER

Would you like to be able to set up a large scale demonstration of circular interference fringes for a whole class to view simultaneously? Fed up asking kids to peer into a microscope saying, "Do you see the fringes?"! This demonstration is plain for all to see. Since first describing the method in Bulletin 191 the convex meniscus lenses on which the method depends have been taken off the market. SSERC has therefore sought and obtained a generous grant from the Engineering and Physical Sciences Research Council (EPSRC) to underwrite most of the manufacturing costs of these special lenses. They have been made for us by Coherent Ealing, a leading lens maker. We offer them to schools at a greatly discounted price of just £7 each, not including post and packing.

The demonstration is simple to show. Set up the lens one metre in front of the laser and direct the radiation at the lens. This should give two reflected spots (reflections off front and rear surfaces). These should be viewed on a screen placed one or two metres behind the laser. Adjust the lens until the spots overlap giving circular interference fringes.