STS

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CONTENTS

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"SCIENCE SUX": Don't take anyone's word for it

"School science can be so boring it puts young people off science for life", complained Ian Gibson MP, launching a parliamentary committee report (11 July 2002). Huh! If this is the case, then my finger of suspicion points directly at the government agencies that set what is taught in school science. Boring? Of course it is?

Perhaps we should teach science the way science is practised? Never introduce and use a concept unless there is supporting evidence is an ethical principle we could seek to uphold. Why ethical? Think about it! And how might it apply? By way of illustration consider the atomicity of matter – in Feymann's view, the single most useful concept in science. Much of the supporting evidence comes from chemistry – the laws of constant composition, multiple proportions and equal volumes. Before the word *atom* could be used, there should be weeks of experiments weighing substances before and after reactions and discussing the results. Pupils may well wonder what is this all about? Where is it leading? As patterns emerge, so ideas can be discussed. Perhaps the concepts of elements, compounds and atoms can be formulated? Then comes a degree of realization – the penny drops. What is science? Essentially it is observation, the collection of evidence, formulating concepts, making inferences, rejecting false ideas, sticking with the ones which hold. The next stage is one of anticipation; can these ideas be put to the test? Back to the bench for more experiments; this may result in satisfaction if the idea stands the test; we can now fairly talk about atoms.

But can we? Historically that was not the case. When the twentieth century began, the atomicity of matter was as then unestablished and contentious. What resolved the dispute was a very clever theory by Einstein – his explanation for Brownian motion. In his 1905 paper Einstein predicted that if matter were particulate and if its constituent particles were in random motion, then the average squared distance from the origin for particles undergoing Brownian motion will be proportional with time. The first experimentalist to confirm this prediction was Jean Perrin. Einstein's mathematical theory is beyond the scope of school science, but a simplified one-dimensional version by Tipler might be appropriate. Brownian motion itself can be studied with video microscopy. Therefore all this now lies within the scope of schools.

In my opinion school science should seek to teach the big ideas of science using as honestly as possible the methods of practising scientists. It must be based on observation so as to generate ideas for discussion. The formulation of concepts follow. These would be refined, tested, accepted or rejected following further experimentation. Adult science is a noble art. We should strive to infuse school science with its quintescence. The syllabuses and dependent practices need reforming.

"SCIENCE SUX", a quote from a recent *Big Issue*, typifies the anti-science prejudice common in much of the media. Knowing that just about everyone working in the media would have experienced some science lessons at school, we, as science teachers, have a collective responsibility for bringing about this bias. Is it because the science that is taught tends to be too dogmatic and unlike the spirit that infuses professional scientists? "Don't take anyone's word for it" is, in English translation, the motto (*Nullius in verba*) of the Royal Society. Would that it also infused the syllabuses we are required to teach?

Jim Jamieson

SSAC's vision for science

In November 2003 the Scottish Science Advisory Committee (SSAC), an independent committee set up to provide advice to Scottish Ministers on science strategy, published a report *Why science education matters*, subtitled *Supporting and improving science education in Scottish schools*. It is greatly to be welcomed that a public body speaks up for science education. Also to be welcomed are the additional allocations for science education in 2004–05 (Table 1) from the Scottish Executive; however, we will return to this later.

Despite Scotland having a distinctive education tradition and a culture where education is valued, the Committee believes "that there is an urgent need to improve science education in Scottish schools and that this must be regarded as a matter of high priority." As well as underpinning our knowledge economy and society as a whole, science education is also seen as crucial to education in its general sense – a point seldom made, but well worth the making. An arrest in the decline of the number of school and university students studying science is likely to be the government's target: it is a measurable quantity: the report, of course, does not hint at target-setting.

The recommendations are grouped under six headings: the curriculum; school science infrastructure; the teaching of technology and technical skills; connections and co-ordinations; teacher recruitment; and science education research. The recommendations are downloadable from

www.scottishscience.org.uk

Significantly, curriculum change is called for. This is seen as a mater of urgency. SEED and the examination bodies are called upon to set up a curriculum review group with the specific remit of producing a prioritised, less crowded, flexible set of curricula for all levels of science courses. There should be a *Science for Citizenship* course, in addition to which every science course should include some coverage of relevant ethical, environmental and social issues.

Regarding primary science, all primary schools should have a dedicated science room with peripatetic technician support and teachers with specialist training.

Recommendations on improving the science infrastructure in schools are:

- A rolling investment programme is required to ensure that all schools have modern well-equipped laboratories.
- Technical support in schools must be strengthened so that pupils can have the experience and stimulation of "hands-on" practical work.
- All secondary schools should have at least one dedicated science technician. Such staff members should be seen as an integral part of the science provision, having access to appropriate CPD and career enhancement opportunities.

On the teaching of technology and technical skills, because of the shortage in the supply of trained individuals with practical skills in such crucial areas as electrical installation, mechanical fabrication and electronic assembly, plumbing, carpentry, electronic work and metal work, the Committee recommend that FE colleges should be supported to deliver attractive technology courses; and schools encouraged to provide appropriate training for students to allow them to progress to technically skilled jobs.

Education Authority	*£'000s*
Aberdeen City	97.66
Aberdeenshire	175.98
Angus	72.50
Argyll and Bute	64.21
Clackmannanshire	28.56
Dumfries and Galloway	108.04
Dundee City	76.14
East Ayrshire	73.05
East Dunbartonshire	69.75
East Lothian	54.31
East Renfrewshire	58.44
Edinburgh, City of	185.44
Eilean Siar	24.44
Falkirk	79.75
Fife	203.76
Glasgow City	282.57
Highland	161.05
Inverclyde	47.92
Midlothian	50.29
Moray	58.91
North Ayrshire	82.63
North Lanarkshire	191.58
Orkney Islands	17.67
Perth and Kinross	84.56
Renfrewshire	99.98
Scottish Borders	74.29
Shetland Islands	21.63
South Ayrshire	66.68
South Lanarkshire	180.45
Stirling	54.48
West Dunbartonshire	55.93
West Lothian	97.37
Total	*3000.00*

Table 1 *Science Strategy Funding – Additional allocations for Science Education 2004-05*

Science Strategy Funding

The apportionment for additional funds from the Scottish Executive for school science in session 2004 – 05 is shown in Table 1 (opposite). The distribution will again be made through the Scottish Local Authorities.

New funding survey by Farmer

A second study by Stuart Farmer into the resourcing of physics departments in Scottish secondary schools indicates that Executive funding has, on average, had a negative impact on the normal funding of science (Table 1). Only about 36% of a typical state school's budget was spent on apparatus (Table 2). Farmer's 2003 survey drew responses from 68 of the 120 schools that had responded to his 2001 survey (see *Bulletin 203*). About 50% of the schools thought that LAs had passed on all allocated funds appropriately, but, in some of the others, there was evidence of a diversion of funds by either the LA or HT.

Discussing his results, Farmer writes, "In schools allocating per capita 'running costs', these do not seem to have been affected. It would appear however that additional bids for funds by science departments have not been entertained in many schools due to the existence of the Scottish Executive funds... This has resulted in a reduction in funds for science from other sources and a net reduction of funds overall over the period 2001 to 2003."

	State schools (n = 58)	Indep'nt schools (n = 8)
Mean physics department budget 2001	£4899	£5339
Mean physics department budget 2003	£4466	£6047
Mean physics department budget per pupil-hour 2001	15.5 p	22.6 p
Mean physics department budget per pupil-hour 2003	13.6 p	26.6 p

Table 1 *Comparison of budgets.*

Spending category	State (n = 58)	Indep'nt (n = 8)
Equipment - physics	36%	64%
Equipment - ICT	12%	10%
Photocopying, text-books and stationery	54%	26%

Table 2 *Physics spending breakdown (2003).*

Safety responsibilities and management

Safety in practical classes should be left to the subject specialists to manage.

We have taken several enquiries on who should manage work with radioactivity in schools where the post of principal teacher of physics has been abolished and where the teaching of physics is managed by a head of science, or faculty. At the root of this question is the inference that the person managing physics teachers may and generally will be a non-physicist.

The scope of the problem is really much broader. Who should be responsible for the safe running of a technical workshop when the person managing the staff is a home-economics teacher? Who should do the COSHH risk assessments when chemistry teachers are bossed by a botanist? Or who should risk assess microbiological practices when the person in charge knows his volts from his amps and never confuses the two with ohms?

The answers to these questions are obvious. Responsibility for health and safety in technical workshops must be in the hands of a technical teacher; in chemistry or biology labs, a chemistry or biology teacher respectively. Similarly, answering our enquiries, radioactivity should be managed by a physics teacher.

Control

The overriding legal requirement is that work in practical areas must be safe so far as reasonably practicable. Employers must make safety arrangements: they have a legal requirement to do so. They cannot take it on trust that teachers left to their own devices will somehow muddle through. If subject teaching is to be managed by a head of a collection of departments, then it is not unreasonable that the appointee should have responsibility for health and safety arrangements in the various subject areas under his or her control. But to attain working procedures that are reasonably safe while at the same time giving individual teachers the freedom to structure lessons as they wish, and make last-minute changes in what they teach, some delegation of health and safety duties must be placed on subject specialists. In any case, all teachers are responsible for classroom management and safety.

In conclusion, if practical subjects are to be managed by a group head rather than principal teachers of individual subjects, then the school management must not overlook the management of health and safety. In general, the organisation and supervision of safety arrangements should be tasks for school management whereas the details of safety in practical activities are best left to subject specialists to arrange and manage. This calls for a clear delegation of duties.

Wood dust and health surveillance

This note explains what health surveillance is and when there is a legal requirement for it. The note relates to staff working in a woodworking room who are habitually exposed to wood dust.

We have been asked about the need for health surveillance for those who handle wood. Often the answer will be 'No', but that depends on a number of factors, namely the particular woods used and the duration and magnitude of the exposure experienced in a particular school. Teachers and technicians working with wood in schools generally have only small exposures to wood dust – of shorter duration or smaller magnitude compared with those experienced by workers in the furniture and other woodworking industries. Thus the likelihood of occupational asthma and other wood-related diseases in schools will generally be very low and health surveillance may often be judged unnecessary.

There is a rare form of nasal cancer in the furniture industry. Among hardwoods oak and beech have been especially incriminated.

By using modern efficient local exhaust ventilation (LEV) on saws, sanders, planers, etc. in schools the dust levels will be kept low and health problems will be rare.

Two activities remain which can give rise to high dust levels, namely hand sanding and the emptying of full bags of dust collected in local exhaust ventilation systems (LEVs).

Health surveillance is carried out by looking for adverse health changes which could be caused by specific hazardous substances. Detection of any such indications at an early stage of a disease is clearly beneficial.

Health surveillance

This should be thought of as being part of the COSHH assessment process. If the assessment shows that there is likely to be a risk of sensitisation or other serious illness then it is the employer's responsibility to set up the arrangements for health surveillance and see that they are carried out.

Health surveillance is appropriate when there is a *clearly established link* between a particular wood dust and a *specific ill health*. Where no such clear connection exists it is unlikely that health surveillance will be needed. For a large number of woods there exists little or perhaps even no information on their hazards; for these and for any newly introduced, exotic wood it is not easy to assess the magnitude of any adverse health effect. Clearly a precautionary approach is advised in such circumstances.

The type and depth of health surveillance needed will of necessity depend on a number of factors. An outline of the possible arrangements taken by an employer to provide health surveillance is briefly outlined in Table 1 overleaf.

(A)	Initial surveillance by completing a questionnaire for employees about to start work with woods known to be (i) sensitisers, which includes several types of wood, or (ii) harmful, in the toxic sense [2].	This questionnaire is filled in by the responsible person [1]. This discovers the nature of previous employment and if the person has any symptoms of respiratory sensitivity, e.g. wheezing, chest tightness, runny eyes, nasal irritation. Employees should be told of the symptoms to look out for and that if they appear to report back to the responsible person.
(B)	On-going surveillance, again by questionnaire. The frequency might be annual, but will be determined by the employer's occupational health professional.	Again this is completed by the responsible person. The object here is to find out if any of these above listed symptoms have appeared since starting work. If warranted, the affected person might be referred to an occupational health nurse or doctor for further examination.
(C)	Situations where there is a high degree of hazard and risk.	In addition to the responsible person carrying out an interview and filling in a questionnaire, surveillance here may well include additional tests carried out by an occupational health professional as appropriate. These could include lung function and other medical tests.

Table 1 *Three possible types of health surveillance.*

Additional points to the above table:

If woods or other materials which are known to be potent sensitisers or of high toxicity are used, then it may be appropriate to move more rapidly to stage (C), e.g. use of two pot polyurethane paints, especially if applied by spraying.

1. ***The responsible person*** is an employee who has been trained by the occupational health doctor or nurse during the setting up of a health surveillance system. Responsible persons will collect information and may carry out simple observations of skin for dermatitis, but are not expected to make judgements on the causes of the symptoms.

2. ***Woods reported as causing particular diseases and disorders:***
   - ***Woods causing either decrease in lung function or asthma**:* alder, ash, boxwood, western red cedar, Douglas fir, ebony, hemlock, iroko, mahogany, maple, oak, obeche, pine, rosewood, spruce, teak.
   - ***Woods causing rhinitis(runny nose)* and *irritation of the mucous membranes***: alder, beech, cedars, Douglas fir, ebony, hemlock, mahogany, oak, obeche, poplar, sapele, walnut.
   - ***Woods causing cancer:*** hardwoods, particularly beech and oak, have caused a rarer type of nasal cancer.
   - ***Woods causing skin disorders***: birch, american cedar, western red cedar, Douglas fir, ebony, iroko, larch, mahogany, obeche , pine, rosewood, sapele, spruce, teak.
   - ***Woods which are poisonous***: box, greenheart, yew.

The adverse health effects caused by wood

Several different types of ill health can be caused by inhalation of wood dust, namely:

(1) respiratory diseases, mucous membrane irritation, rhinitis, allergic alveolitis (allergic inflammation of the alveoli producing flu-like symtoms), occupational asthma; (the last three named involve a sensitisation process).

(2) nasal cancer (the incidence of this is exceedingly low in the furniture industry).

(3) general ill health.

Contact with skin can lead to irritation or dermatitis.

Ingestion of wood dust is most unlikely and is not considered.

Which woods are worst?

Many hardwoods, especially oak and beech are regarded as nasal carcinogens and also as causes of asthma. The entries for hardwoods and softwoods are listed in the *Occupational Exposure Limits* (EH40/2002 with 2003 supplement) as being sensitisers (indicated by the appended '*Sen*' prefix) and with an MEL (maximum exposure limit) of 5 mg m^{-3}. Increasingly softwood dusts are also considered by some to be carcinogenic. The German equivalent of our (UK) EH40, called the *List of MAK and BAT values*, classifies:

- wood dusts in general as category 3B carcinogens[1];
- oak and beech as Category 1 carcinogens;
- nearly all woods as sensitisers of the skin; only obeche, western red cedar and limba are listed as sensitisers of the airways.

Table 2 of the *HSE information sheet: Woodworking Sheet No 30* lists some fifty woods, their uses and their reported adverse health effects. The table in Appendix 1 (next page) contains a short selection.

Note that some of the layers of plywood are hardwood. The resins used to bond plywood, chipboard, MDF and blockboard may cause allergic reactions in those who are already sensitised. The types of wood used to make these composites vary, but softwoods predominate.

MDF dust

An HSE inspector informed us that high methanal (formaldehyde) levels were a problem in the manufacture of the MDF board, but not usually during sanding or routing unless an unusually high temperature was reached, and that was most unlikely. He also stated that below the level of 5 mg m^{-3}, the MEL for such dust, no ill effects have been demonstrated.

[1] Note that the German definitions of carcinogenic categories differ from those used by us in the UK. The German Category 1 has a definition similar to ours, i.e. can cause cancer in humans and can be assumed to make a significant contribution to the risk of cancer. For those in Category 3B there is evidence of carcinogenic effects in animals that is insufficient for classification of the substance in one of the other categories and that further studies are required before a final decision can be made.

Changing filters on LEVs on saws, sanders, etc

Wear the disposable respirator EN 149 FFP3 or filter to EN 143-P2 fitted to either a half mask to EN 140 or a full face mask to EN 136. **Do not empty the bag** in order to save money. Many types of bag are inexpensive; tie them up and seal them. Some LEVs have bags as part of a larger kit and the whole assembly must be disposed of; this type is more expensive.

Hand sanding

Limit the amount of hand sanding done and use a disposable dust mask to EN 149 FFP2. For hardwood or if the dust is very fine or abundant use disposable dust respirator EN 149 FFP3, or the same half and full face masks as used for changing filters.

Appendix 1

The table opposite has been extracted from Table 2 in *More common toxic woods* (*Toxic woods – Woodworking Sheet No 30*).

The HSE qualifies the information in their table as follows:

> "The inclusion of a wood in Table (3) does not automatically mean its use will result in adverse effects. Many timbers are used without apparent effect, but this depends on the species involved, the concentration and the extent of exposure, and the levels of toxic agent in the timber, as well as the sensitivity of the user to the wood."

Further reading

Preventing Asthma at work – how to control respiratory sensitisers, L55, (HSE), ISBN 0 7176 0661 9

Critical assessments of evidence for agents implicated in occupational asthma (HSE) – it lists several hardwoods and a few softwoods

Woodworking information sheet No 34, (HSE) *Health and safety priorities for the woodworking industry*

Woodworking information sheet No 33, (HSE) *Health surveillance and wood dust*

Timber	Use	Reported adverse health effects
Alder	Toys, brush handles	Dermatitis, rhinitis, bronchial effects
Ash	Joinery	Decrease in lung function
Beech	Furniture, tool handles	Carcinogen, decrease in lung function, eye irritation
Birch	Furniture	Dermatitis on sawing lumber
Cedar (American)	Joinery, boats	Allergic contact dermatitis
Cedar (Western red)	Planking, construction	Asthma, dermatitis, rhinitis, mucuous membrane irritation, central nervous system effects
Douglas fir	Joinery, veneers	Dermatitis, rhinitis, bronchial effects
Ebony	Musical instruments, tool handles	Mucuous membrane irritation, dermatitis, possibly a skin sensitiser
Gaboon	Blockboard, veneers	Asthma, cough, eye irritation, hands and eyelids
Greenheart	Axe handles, flooring	Severe throat irritation, cardiac and internal disorders, splinters go septic
Hemlock	Joinery, construction	Bronchial effects, rhinitis
Iroko	Bench tops, marine	Asthma, dermatitis, nettle rash
Larch	Construction, flooring	Nettle rash, dermatitis (possibly from bark lichens)
Mahogany	Furniture, cabinets, boats	Dermatitis, respiratory disorders, mucuous membrane irritation
Maple	Flooring, furniture	Decrease in lung function
Oak	Furniture, joinery	Asthma, sneezing, eye irritation
Obeche	Picture frames	Sneezing, wheezing, skin and respiratory tract irritation
Pine	Construction	Skin irritation (may be photosensitive), decrease in lung function
Poplar	Shelves, toys, matches	Sneezing, eye irritation
Rosewood (several species)	Furniture, musical goods	Dermatitis, respiratory disorders. Effects may arise from handling wood.
Sapele	Furniture, flooring, veneers	Skin irritation
Spruce	Construction, packing, pallets	Respiratory disorders, possible photosensitisation
Teak	Marine, furniture	Respiratory disorders, nettle rash, dermatitis
Walnut (not African)	Furniture, veneers	Sneezing, rhinitis
Yew	Cabinet making, turning	Headache, blood pressure drop, cardiac effects, systemic effects, e.g. headaches

Flicker and photosensitive epilepsy

A small section of the population is susceptible to epileptic fits induced by flickering optical sources including stroboscopes, TVs, computers and disco lights. Some control measures are suggested.

Photosensitive epilepsy (PSE) is a rare medical condition triggered by flickering lights. It can result in an epileptic fit. About 1 person in 10,000 is affected. The medical condition is due to a susceptibility to flickering lights. Persons who do not possess this particular susceptibility will not get PSE by looking at flickering lights. The condition is more common in females. Puberty is a stimulating influence because most cases appear between the ages of 10 and 14 years. There is evidence of some genetic component because it appears more frequently in some families.

Very few people will react adversely to flicker with a frequency below 3 Hz and above 60 Hz. All frequencies between these values are more or less capable of triggering PSE in susceptible individuals. The peak triggering frequencies are between 15 Hz and 20 Hz. However PSE will only affect those potentially affected persons when they are looking directly at the flashing source. Gazing away from the flashing source, be it a lamp or TV screen, will not trigger an epileptic response in the brain. Flicker with a red rather than any other coloration is more likely to trigger a fit. Viewing with one eye covered would reduce but not eliminate the risk for those individuals who are susceptible.

Controls

Pupils at risk: Schools should do all they can to identify children at risk. If a teacher has been forewarned that a child has PSE, then the following control measures should be put in place and the pupil with the condition warned not to look directly at the flickering light. Many would think it prudent taking precautions with all children since there is the possibility of having a child predisposed to PSE for whom the condition is yet to declare itself. If a child's first epileptic fit induced by flicker were to take place in school, it should be clear that the flickering source is the trigger of the condition declaring itself, not the cause of the condition. The purpose of control measures is to help those children known to have the condition from being exposed to types of flicker that might be capable of inducing seizures.

Figure 1 *Xenon stroboscope.*

Stroboscopes: The risk from using stroboscopes in laboratories can be controlled easily by setting up the apparatus in such a way that pupils only look at reflected light from the experiment. This would seem to be an adequate control. Therefore children should be sited behind or to the side of the lamp and kept at a distance from the strobed image. Children should not operate the stroboscope except under the direct supervision of a teacher. Experiments with stroboscopes should be demonstrated and not given to pupils to conduct by themselves.

For teachers who like to wear braces with a belt, flicker frequencies within those values (between 3 Hz and 60 Hz) that can cause PSE should be avoided unless there were to be an educational purpose. The direction in ASE guidance *Safeguards in the School Laboratory* to keep the flicker frequency below 4 Hz is misleading; it holds only for experiments where pupils are looking directly at the stroboscope and fails to acknowledge the absence of risk above 60 Hz.

Disco lights: If discotheque stroboscopic lights are set up such that they can be directly gazed at, then the flicker frequency should be kept to below 5 Hz[1]. However indirect illumination of the eyes from flickering lights at an angle to the line of sight is not a trigger for PSE.

[1] This guidance has been issued by HSE to local authorities. Applying the 5 Hz limit ensures that only 5% of the flicker sensitive population will remain at risk of an attack.

TVs and computer displays: Whereas with stroboscopic lights a flicker-sensitive person can avoid an attack by not gazing at the lights, this control does not apply for TVs, or computer displays. The mechanisms that might generate dangerous flicker are (1) electrical, mainly the screen refresh rate, and (2) programmed rapidly repeating images. The latter is not currently a problem in the UK because the producers' guidelines issued by television companies prohibit programme content with flashing or flickering images.

With computer CRT monitors, the number of times a second the electron beam scans the screen is known as the refresh rate. This usually lies between 40 Hz and 80 Hz, and is partly within the range of frequencies that can cause a PSE seizure. The optimum refresh rate is a compromise between keeping the value sufficiently high to avoid the risk of harm to persons with PSE, but not so high as to impair the resolution of the image. Modern CRT monitors tend mostly to have a refresh rate set at 60 Hz or 72 Hz, putting them just outwith the range that can trigger an attack. Some older monitors had a lower refresh rate and were a cause of harm.

A whole TV picture is generated in 1/25th of a second. The picture is built up from two scans of the raster, each of which take 1/50th of a second, using a technique called interlacing. Thus although the whole picture is refreshed once every 25th of a second, the flicker frequency is effectively doubled to 50 Hz. This is inside the range of frequencies that can trigger an attack, but is far above the peak triggering frequencies. Persons with PSE are at risk of a seizure if they watch TV. The risk can be minimized by:

- keeping the room well lit, and
- ensuring that the person at risk sits sufficiently far from the screen that the individual line resolution cannot be seen.

Acknowledgement

Guidance was obtained from the Employment Medical Advisory Service of the HSE.

Colour mixing

Demonstrations of colour mixing can be vastly improved by replacing traditional sources of radiation with new, powerful LEDs, called lumileds.

Last year (2003) new families of light-emitting diodes (LEDs), far more powerful than any earlier products, were devised and produced by Lumileds, a joint venture company of Agilent Technologies (Hewlett Packard) and Philips Lighting. The trade-mark name of these new products is *Luxeon*, and, just as the *hoover* is a generic name for a domestic appliance, these super-powerful LEDs, some conducting 1 A of current, have become known as *lumileds*.

Laying technicalities to one side for the present, have a look it how lumileds perform. In the classic experiment, if three circular spots of red, green and blue (RGB) radiation partially superpose, then white should result from all three colours mixing in correct proportion, and yellow, cyan and magenta from combinations of two only. Here is the evidence (Fig. 1). The result is very effective.

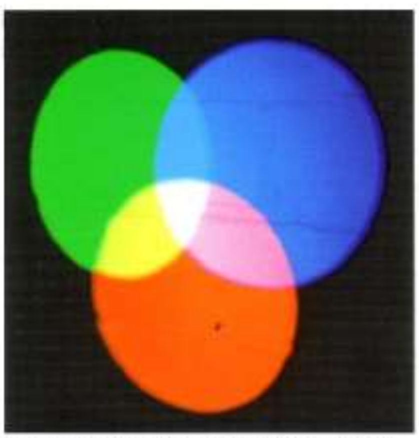

Figure 1 *The classic demonstration: partial superposition of radiation from red, green and blue lumileds.*

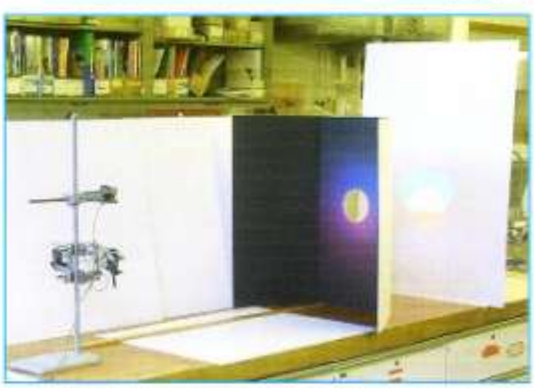

Figure 2 *Apparatus for the colour mixing display shown in Figure 1.*

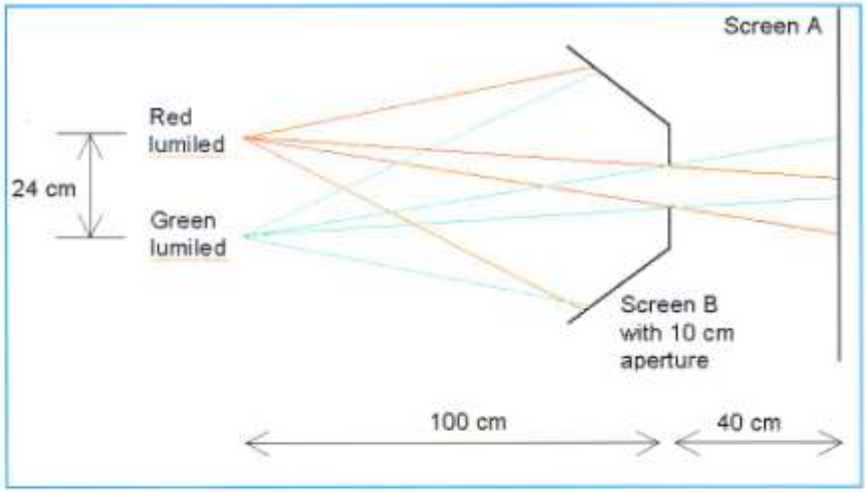

Figure 3 *Schematic plan of apparatus for colour mixing display in Figure 1.*

For this demonstration, three coloured lumileds – red, green and blue – were held in clamps on a single stand and directed from a distance of 1.4 m at a white, A1-sized, card screen (*A*) (Fig. 2). The lumileds were arranged so that each was at the point of an imaginary equilateral triangle with 24 cm sides. The mid-point of this triangle was 30 cm above the bench. A second sheet (*B*) of A1-sized card, black in colour, with a circular hole 10 cm in diameter and centred 30 cm above the bottom edge of the card, was placed 40 cm in front of the white screen *A*. By directing each of the lumileds at this aperture, the coloured beams partially overlapped on screen *A* behind.

To prevent the display on screen *A* being hidden from view, screen *B* had two 30 cm folds, intercepting all of the radiation not falling on the aperture (Figures 2 and 3).

Optical properties

Luxeon LEDs (or lumileds) are very high intensity, high efficiency sources of optical radiation.

Coloured lumileds, in common with LEDs in general, have narrow emission bands and for some purposes such as colour mixing experiments their radiations can be considered to be pure colours, or effectively monochromatic (Table 1).

Lumiled colour	Dominant wavelength			Spectral half-width
	Min.	Typ.	Max.	
	(nm)	(nm)	(nm)	(nm)
Blue	460	470	490	25
Green	520	530	550	35
Red	620	625	645	20

Table 1 *Lumiled emission spectra. The* spectral half-width *is the spectral width at greater than ½ of the peak intensity.*

The form we are using here is fitted with a collimating lens, resulting in a broad-area source with an effective diameter of 16 mm. The radiation is imperfectly collimated. Rather, it is a narrow beam with a small amount of divergence. The centre of the beam casts a uniform, non-variegated swathe of light on a screen. This is surrounded by an aureole of radiation of lower intensity (Fig. 4).

In our first colour-mixing demonstration, described above, the optical radiation required no enhancement. The radiation was used just as the lumiled produced it. The beam's central bright cone had diverged at 1 m, where screen *B* had been positioned, such that its diameter had spread to a little more than 10 cm, completely filling the aperture with uniform radiation.

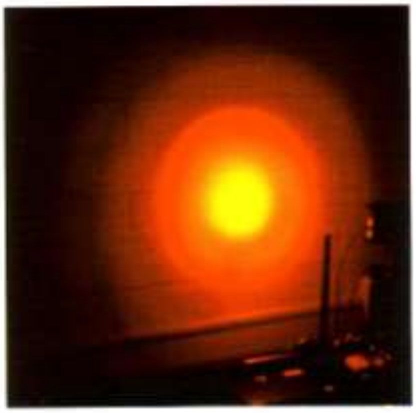

Figure 4 *Beam quality from a lumiled with optic (type: Luxeon 1W Star with Optic (Low Dome Batwing)). Note the central core with high, uniform power density surrounded by aureoles of lower power density.*

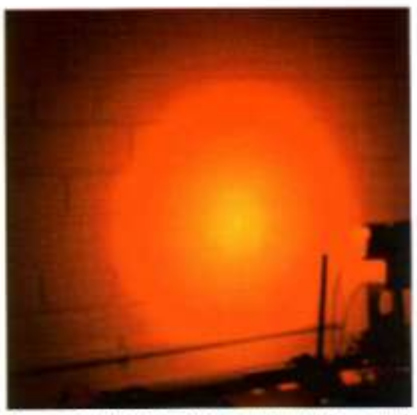

Figure 5 *Effect on beam quality with ground glass diffuser fitted in front of lumiled.*

In other applications where the entire beam is used – both the central cone and its outer aureole – a ground glass screen should be placed directly in front of the lumiled to diffuse the radiation. Compare the unaltered radiation shown in Figure 4 with radiation that has been transmitted through a diffuser (Fig. 5). The unaltered beam is generally unsuitable for colour mixing unless only its central region were to be used, as in Figure 1, but for many applications the use of a diffuser is necessary. The drawback, however, is that the radiation intensity of the main beam is reduced because some of the light is scattered away to the side.

Product description

The product range includes white[1] and coloured LEDs. Luxeon LEDs are supplied by RS Components and Farnell. The type being used in our experiments (Table 2) is known as a 'Luxeon 1W Star with Optic (Low Dome Batwing)'. The *low dome batwing* description alludes to the type of lens that has been fitted to the LED, one whose design produces a beam of uniform cross-sectional intensity when used with a collimating lens.

Colour	Luxeon product code	RS stock number	Price
Blue	LED Blue LXH-NM98	449-1905	£11.79
Green	LED Green LXH-NM98	449-1882	£11.79
Red	LED Red LXH-NM98	449-1927	£9.65
White	LED White LXH-NM98	449-1876	£11.79

Table 2 *Lumiled products and supplier's stock numbers referred to in text. Lumiled type: Luxeon 1W Star with Optic (Low Dome Batwing).*

At a maximum running current of 350 mA, these lumileds have an input power of 1 W. A lumiled should be supplied from a voltage-regulated source through fixed-value resistors of suitable power and resistance. Current should not be allowed to drop below 100 mA. The maximum brightness should be set by your choice of resistor. With the values of series resistor shown in Table 3, lumileds can be run safely at about 75% maximum brightness when sourced with a 5 V supply.

Lumileds can be damaged by static. A simple preventive measure is a 1 Mohm resistor connected in parallel across the LED.

Colour	Resistor network in series with lumiled	Resistor power
Blue	15 ohm in parallel with 22 ohm	3 W
Green	15 ohm in parallel with 15 ohm	3 W
Red	10 ohm	3 W
White	10 ohm in parallel with 22 ohm	3 W

Table 3 *Resistor networks for setting the lumiled current at 250-300 mA with 5 V regulated supply.*

The brightness level should be controlled by pulse-width modulation. A suitable frame-rate frequency of this digital pulse is 1 kHz. Such a controller can be designed with two 555 timers, one to generate the 1 kHz frame rate, and the other to alter the mark-to-space ratio of the output signal. The LED is then driven by a MOSFET. The circuit diagram can be downloaded off the SSERC website.

Lumileds should be mounted on heatsinks, fastening with screws and nuts. The twisted-vane heatsinks on which we have mounted our LEDs are designed for T03-type transistors and have a thermal resistance of 7°/W (RS 402-967). Although a smaller heatsink would suffice, we went for this one because, by enclosing the LED, it protects the delicate connections from stresses and allows the assembly, including series resistors, to be held securely in a clamp (Fig. 6).

Figure 6 *Lumiled (type: Luxeon 1W Star with Optic (Low Dome Batwing)) fastened to heatsink and with series resistors.*

Anode marked with copper dot (not shown).

Complementary demonstration

Instead of directing RGB radiation at an opaque screen with circular aperture, radiation can be directed at a transparent screen with circular, opaque mask. The RGB shadows from the mask superpose, resulting in a complementary display (Fig. 7) to the one first described (Fig. 1).

In this complementary demonstration, a sheet of Perspex served as the transparent screen, while the mask was a compact disk, centred 30 cm above the bench. Because the entire radiation beam is utilized, diffusers had to be fitted in front of each lumiled. Several diffusing materials were tried. Some of the cheap ones – tracing and tissue paper, and translucent polythene – all

[1] Applications of white lumileds will be published in another *Bulletin* issue.

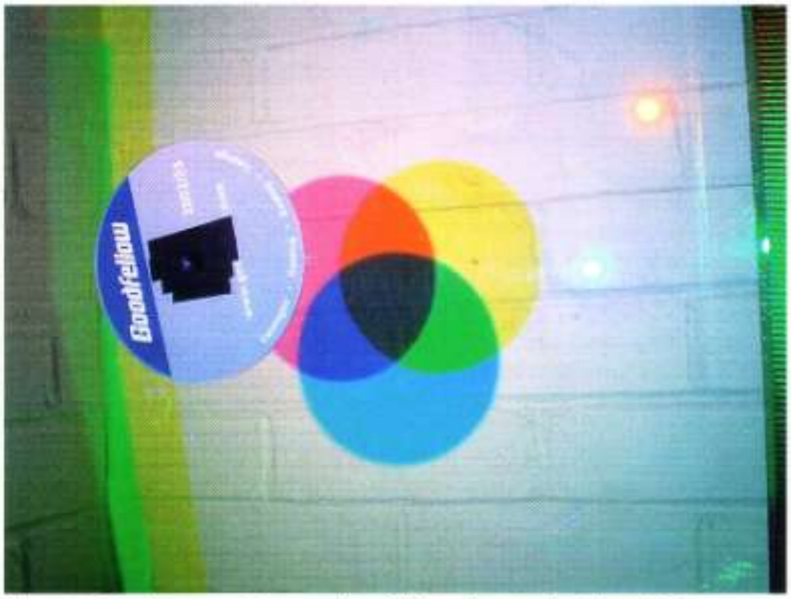

Figure 7 *Complementary demonstration. Display photographed through Perspex screen. Circular shadow mask shown on left.*

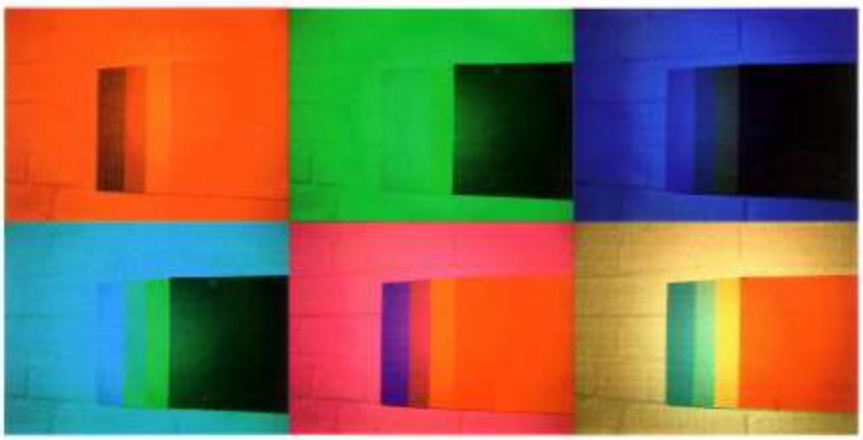

Figure 8 *What are the colours of the cards? Montage of 4 cards illuminated with red, green, or blue radiation. The top 3 images were created with one lumiled source; the bottom set with combinations of two lumiled sources.*

reduced the light overmuch. Micro-cellular bubble wrap and bleached greaseproof paper can be recommended for some applications, but for best results try a ground glass diffuser, such as one from Edmund Optics[1].

Colours assumed by surfaces

Four strongly-coloured, matt cards – red, yellow, green and blue – were attached to a white screen and illuminated with radiation from coloured lumileds set up 50 cm distant from the screen. Diffusers were fitted in front of the lumileds. The colours assumed by each surface depended not only on the pigment of the card, but also on the colour of the radiation (Fig. 8). In some of the images, the card matches the background – a white-painted wall.

Figure 9 shows the appearance under a mixture of red, green and blue.

Colour mixing with wee LEDs

Small scale versions of the above demonstrations can be carried out with medium intensity LEDs. Details will be posted on our website.

Because the image cast by a wee LED is highly irregular, it is essential to place a diffuser in the radiation, and since this reduces the radiant power density, blackout conditions are needed. Despite this, colour effects with wee LEDs are markedly superior to that which can be produced with a raybox, or similar apparatus (Fig. 10). Costs are low. The blue-light eye risk is lower than with a lumiled. Brightness is easily controlled by pots. A nice set of pupil experiments could be set up that would be easy to budget for while giving the youngsters scope to find out by their own efforts.

Figure 9 *The 4 cards seen under a mixture of red, green and blue.*

Figure 10

A convincing yellow created by two wee LEDs – a red and green – and a diffuser. The radiation is interrupted by a 35 mm diameter disk on an acetate sheet suspended in space.

NOTE: Figures 1, 4, 5, 7, 8, 9 and 10 were produced under darkroom conditions.

[1] Ground glass diffuser: 25 mm dia., X43-723, £6.72; 50 mm x 50 mm, X43-724, £9.18; 102 mm x 127 mm, X02-148, £10.88 (Edmund Optics).

Theory of colour

It may be useful to classify colours as subjective or objective with Goethe's classification from his early-nineteenth century Theory of Colour. Taking the red, green and blue lumiled emissions to be more or less monochromatic, they can be thought of as objective colours, whereas the others are subjective colours, that is they appear unexpectedly because of processes in the mind.

Yellowness resulted from the superposition of narrow band red and green radiations. The yellows that appear in Figures 1, 7 and 10 are illusory. Yellow is a subjective colour, to use Goethe's terminology, or a "sensation of the mind" according to Feynmann.

Both yellow and cyan can have physical reality because radiations can be produced at intermediate wavelengths giving these colours. Magenta is entirely an illusion of the mind: it doesn't have any physical reality.

Risk assessment

The scope of this risk assessment relates only to Luxeon 1W Star with Optic (Low Dome Batwing) lumileds. The assessment is provisional; if we alter it, we will let you know.

The main forms of protection are natural aversion responses. Any responsible person getting the direct beam in the eye would blink, or turn away. However natural aversion responses can be overridden intentionally by deliberately staring into the beam, and can also be influenced by the use of alcohol or drugs.

Because the area of the emitting surface is quite large (16 mm diameter, or about 2 cm^2), the image formed by radiation, were a lumiled to be viewed either directly or through a magnifier, is extended rather than concentrated. This prevents the retina being harmed by a dangerously-high power density. Therefore there would seem to be little risk of a retinal burn.

The main risk to the retina is over-exposure to blue-light radiation, resulting in photochemical damage. Radiation contributing to this effect extends from the visible-UV junction at 400 nm through to the green part of the visible spectrum at 550 nm. The effect peaks at 440 nm, where the colour of the radiation is blue. This blue-light risk increases with cumulative exposures and depends on the mean power density per exposure.

Blue lumileds we have been supplied with by RS have accompanying warning marks saying "Class 2 laser product". We understand that this is because of the blue-light radiation hazard from this LED.

Safety control measures

Apply roughly similar rules with Luxeon LEDs (or lumileds) as you would do for working with a Class 2 laser.

- Do not look directly at a Luxeon LED from close range.
- Do not stare at a Luxeon LED source.
- Place a screen at the end of the working area preventing the source being stared at from a distance.
- A source must be clamped before being powered up. It must not be used hand-held.
- Do not direct radiation from a Luxeon LED at the head of another person.
- When setting up the beam, the position of the radiation shall be found with the aid of a white paper screen.
- The power source shall be a voltage-regulated supply set such that it cannot supply an overvoltage.
- Junior pupils (below S3) should not be allowed to work with Luxeon LEDs. However junior pupils may be shown demonstration experiments utilizing Luxeon LEDs.
- Mid-secondary pupils (S3-S5) may work with Luxeon LEDs provided they have been instructed in safe working practices and are supervised continuously.

Auroral displays

There were several fine auroral displays over Scotland in October and November 2003 (Fig. 1). By good fortune, they occurred during moonless nights when the sky was relatively free of cloud: they were therefore easily visible. Tips for seeing auroral displays are:

- Night sky must be moonless and clear.
- Don't look at the night sky until at least 2 hours after sunset.
- Wait outdoors at least 5 minutes for your eyes to adapt to the darkness.
- Avoid areas with street lights.
- If you see press reports of large sunspots, or solar flares, make a point of looking at the night sky.
- Luminous structures to look for include an arc across the NW sky, folded band, rays directed at zenith, and corona in zenith.
- Look for changes in brightness (e.g. flickering), shape, structure and colour – normally too pale to see any colour.

Figure 1 *Auroral display over Peeblesshire on 20th November 2003. Photographed by Bob Kibble, Edinburgh University, with an SLR camera and 30 s exposure.*

Blue Bottle – now low hazard

By replacing the strong alkali with a dilute acid, the Blue Bottle experiment can be made less hazardous and more suitable for use by young pupils.

Bulletin 204 described a modification of the traditional method (which we will call *Method A*), originally described in the *Standard Grade Chemistry Practical Guide Vol 1*, in which 0.1M sodium hydroxide was used in place of the 0.5M solution of alkali. This decrease of hazard was welcome, as there was always the danger of the alkali accidentally being splashed if the bung came off when the flask was shaken.

This article points to a variation on the traditional Blue Bottle (*A*), seen in a recent article in the *Journal of Chemical Education*[1], dispensing altogether with the sodium hydroxide. Two modifications of this variation given in the article are described here; they use ascorbic acid as the reducing agent in place of glucose, and either have no alkali at all, or the much less corrosive carbonate or hydrogen carbonate. Thus these two versions of the demonstration (which we will call *Methods B* and *C*) are very suitable for use by young pupils.

The colour changes resulting from two redox reactions are represented schematically below. In the presence of ascorbic acid, methylene blue in solution will exist as its reduced or leuco form, which is colourless, but on shaking the solution with air it is oxidised back to methylene blue.

$$MBH_2^+ \underset{\text{Stand}}{\overset{\text{Shake}}{\rightleftharpoons}} 2e^- + 2H^+ + MB^+$$

(Reduced leucoform) (Colourless) — (Blue)

On allowing the flask to stand the ascorbic acid continues to work, but, without the competing oxidation, the colourless reduced form is restored. Copper(II) ions act as a catalyst and chloride ions presumably as a ligand to copper.

The simple method, *B*, is described here and a brief comparison of it and the "Fast modification", *C*, is given in Table 3.

[1] Wellman, Whitney E Noble, Mark E and Healy, Tom *J. Chem. Educ.* **2003**, 80, 536-540

Simple method (*B*)

The *Journal of Chememical Education* article gives the quantities here in terms of "kitchen measures", i.e. a 2 litre bottle, two thirds full, or a level teaspoonful, etc. These have been roughly translated in Table 1 to grammes and cm³.

Large Scale	*Small Scale*
Clear, colourless plastic bottle, 2 litre	500 cm³ bottle
3.5 g ascorbic acid	1 g ascorbic acid
2 g table salt	0.25 g table salt
1400 cm³ tap water	340 cm³ tap water
16 drops of 1% methylene blue solution	4 drops 1% methylene blue solution
12 cm³ 0.1M copper(II) sulphate	12 cm³ 0.1M copper(II) sulphate

Table 1 *List of reagents in Method* B *(large and small scale versions).*

Vitamin C powder and tablets can be used instead of the ascorbic acid but the solutions are cloudy and the colour takes longer to disappear.

Method

To the required volume of water in the bottle add the ascorbic acid and shake until dissolved. Add the table salt and shake until dissolved. Add the methylene blue and copper sulphate and shake the bottle. Close the top tightly and leave to stand until required.

In the resting state the methylene blue is in its colourless reduced form. Giving it a shoogle introduces air into the solution, which converts the methylene blue to its blue oxidised form.

Hazards of materials

A dilute aqueous solution of methylene blue poses negligible risk. During preparation of the solution it is easy for the teacher or technician to avoid the raising of dust as the quantities needed are very small. Alternatively the commercially prepared solutions, typically 1%, may be in school as a microscope stain. Wear eye protection and gloves.

Substance	Hazards
Copper(II) sulphate	Harmful by ingestion or by inhalation of dust; moderately severe eye irritant. Label any solution 1M and above as 'Harmful'
Methylene blue	Harmful - avoid skin contact and inhalation of dust during preparation of solution.

Table 2 *Hazards and control measures.*

Differences between methods

Glucose was the reductant in potassium or sodium hydroxide in the original method, *A*, and in ascorbic acid in the revised methods, *B* and *C*.

(i) Colours

The blue oxidised colour produced by *B* and *C* (Fig. 1) is not as dark as that obtained in the original method (sodium hydroxide and glucose) (*A*). It tends to be on the green side rather than on the purple side of blue; this greenish tinge is noticeable during the fading of the blue colour when the bottle is left to rest. A

Figure 1 *Blue Bottle effect with Method* B.

deeper blue can be obtained by increasing the amount of methylene blue, but this will result in a longer time being taken for the reduction to the decolourised form. Using less ascorbic acid has a similar effect on both the colour depth and on its rate of removal.

At rest both versions will often show the thin layer of blue at the water/air interface.

(ii) Rates of change

One other noticeable difference is that on shaking the solutions the blue colour forms faster in the original method, *A*. In the simple version, *B*, the blue seems to continue gradually forming for some 15 to 20 seconds after the shaking has stopped.

The "fast modification", *C*, (Table 3) differs from the simple method, *B*, in that it contains sodium hydrogencarbonate and a higher concentration of ascorbic acid. It goes through its cycle in two minutes compared to just over three minutes for *B*.

(iii) Useful life

Even without use, the traditional method, *A*, loses its activity on standing. This is caused by the glucose being degraded by the strong alkali to a dark yellow product. The original Blue Bottle, *A*, really needs to be made up not more than a few hours before use. The ascorbic acid versions *B* and *C* seem to remain reasonably active on standing for more than a week.

Clearly, with a lot of use, both versions will run short of their respective reducing agents and, of course, also oxygen if the stopper or top isn't occasionally removed.

The colour change is much sharper in the original method, *A*, which used glucose and sodium hydroxide, and there is no reason why this cannot be used as a more striking "magic" trick by the teacher. However variations *B* and *C* are useful in that they are suitable for younger pupils. Moreover they have a longer shelf life.

An interesting observation is often made if a plastic bottle is used: it eventually starts to collapse as the oxygen in the airspace above the solution is used up. Loosening the top of the bottle to let more air in can reverse this. Is there an opening for a wee investigation into the removal of oxygen from the air by ascorbic acid using methylene blue as the intermediate carrier? Other experiments could seek to show if the reaction is reasonably quantitative and, if so, to develop a volumetric method for the determination of dissolved oxygen by titration with ascorbic acid.

Ingredients	Simple revised method (B)	"Fast modification" (C)
ascorbic acid	1 g	4.8 g
methylene blue 1%	4 drops 1%	3.6 mg
copper(II) sulphate	3 cm³ 0.1M	45 mg (or 18 cm³ 0.01M)
sodium hydrogencarbonate	nil	150 mg
sodium chloride	0.3 g	1.0 g
water	600 cm³	600 cm³
Time for complete cycle when fresh	Just over three minutes	Just over 2 minutes

Table 3 *Recipes for Methods B (the revised simple method) and C (the fast variant on B) and comparison of cycle times.*

Magical Mushrooms

Full instructions for the following protocol can be found at: http://www.ncbe.reading.ac.uk/NCBE/PROTOCOLS/PRACBIOTECH/oystercap.html

Who could fail to be impressed by the sight shown in the photograph (Fig. 1)? These are oyster cap mushrooms and yes... they are growing on a (bog-standard?) toilet roll.

The fresh oyster cap mushrooms now readily available in the 'fruit and veg' section of supermarkets are generally farmed on short lengths of tree trunk. They can, however, be cultivated very easily in schools or at home on toilet rolls. In addition to the starter culture *Pleurotus ostreatus* (available from the National Centre for Biotechnology Education, Reading), the only materials required are: a kettle for boiling water; a saucer; a soft paper (unbleached) toilet roll; cling film or a large plastic bag; access to a refrigerator; and three weeks' worth of patience.

Figure 1 *Mushrooms growing on toilet roll.*

The (clean and unused) toilet roll is firstly soaked with boiling water and allowed to cool. This serves the functions of facilitating easy removal of the cardboard tube, partially sterilising the paper and providing the appropriate damp conditions required for growth. Some starter culture is then poured into the hole in the middle of the toilet roll, the whole lot covered with clingfilm or a polythene bag to prevent it drying out and left in a warm, dark place for about two weeks, during which time fungal mycelium (threads) will grow throughout the paper and over the surface. The covered toilet roll is then placed in a refrigerator at ~ 4 °C for 2 – 3 days in order to shock the fungus and thus trigger production of the mushrooms.

The mushrooms are the fruiting bodies of the fungus which produce spores. The toilet roll is then unwrapped, left in a

Continued on page 16

Index to Bulletins 201 to 210

Index

Continued from page 12

Magical mushrooms

cool place and kept moist by spraying. In 12 – 17 days, oyster mushrooms will start to appear (Fig. 2).

As well as being fun to carry out, this practical activity can be used to raise a number of questions. What is the food supply for the fungus? What process do fungi such as *Pleurotus* carry out in the wild? Can you think of illustrations where such fungi can be a nuisance and others where they can be beneficial? In this case, the *Pleurotus* is decomposing the toilet roll by using the cellulose as an energy source and the fruiting bodies are a source of delicious food. Growing oyster cap mushrooms on toilet rolls is an activity suitable for supporting several parts of the science curricula: e.g. 5 – 14 microbiology; Intermediate 1 and Standard Grade Biology; Intermediate 2 and Higher Biotechnology.

Safety notes

(1) By using a large inoculum of *Pleurotus ostreatus*, the risk of growth of contaminants is reduced. Note that a single pack of *Pleurotus ostreatus* bought from NCBE contains enough starter culture for ten toilet rolls.

(2) The mushrooms are edible but should be eaten only if grown in a clean and safe area (not a laboratory).

(3) The mushrooms should be picked before they start to produce many spores as some people are allergic to fungal spores.

Figure 2 *Mushrooms growing on a toilet roll – indicating the scale and whole appearance.*

Trade news

Safety alert

Soda Lime for use with a spirometer should be *medical grade*, also called *BP grade*. Scientific and Chemical Supplies can supply soda lime for use with the spirometer which is BP grade. Philip Harris Education are currently seeking a supplier. The Soda Lime supplied by Griffin Education is not medical/BP grade.

Microwave and UHF apparatus

Philip Harris (and Unilab) regret to announce the withdrawal of two popular kits from their product range, including items:

2.8 CM Wave Transmitter	H30300
2.8 CM Wave Receiver	H30324
Probe Detector	H30312
UHF Apparatus 1GHZ	H30294

on account of a diode in this equipment being obsolescent. They hope to redevelop these items.

Film graticule strip

Shaw Scientific are able to supply *film graticule strip*, produced on *Estar film*, which is 0.18 mm thick. Each strip of 12 x 1.5 inches contains 7 images of a 10 mm scale in 0.1 mm divisions. Strips are priced £15 each; the catalogue number is B404000. Because each strip can be cut to supply 7 graticules, this should be an inexpensive source of these devices for microscopy.

Pestles

A pestle is normally sold with a mortar as a pair – inconvenient, since it is the pestle that is more readily broken. Griffin and George, and Scientific and Chemical Supplies now supply pestles separately.

Freshford Ltd, mentioned in *Bulletin 205* for service and repair of gas regulators, have a new address and telephone number.

Electronic projects from Rapid

Rapid Electronics have devised a set of nifty-looking designs for simple-to-build electronic devices – moisture tester, timer, AM radio, logic alarm, audio amp... Each comes with a printed set of student notes, which can either be downloaded from the website, or ordered in paper version. Component kits are supplied in multiples of 5; each comprises electronic, electrical and mechanical components; pcb packs of 5 are additional. Prices are very low – about £8 and £3 respectively.

Visual Accelerometer

PASCO have produced an accelerometer (PS-2128, £154) providing a visual display with a set of 10 LEDs of either a single-axis acceleration, or the vector component of the gravitational field. The accelerometer fits on top of PASCO's range of dynamics' carts. A zero control nulls the field when sat on an inclined plane. The device is suitable for both demonstrations and pupil experiments. Because the concept of *acceleration* is difficult to grasp, users are liable to find the interptretation of the signals initially hard to fathom. This is not a detriment: the *Visual Accelerometer* does shed light (literally, too) on this phenomenon; it forces, provocatively, the student to think about has been observed and is an aid for seeing further than conventional methods provide.

The *Visual Accelerometer* can also be used with computer equipment with a *PASPORT* connector and *EZscreen* or *DataStudio* software.

Addresses

Edmund Optics Ltd., 1 Tudor House, Lysander Close, Clifton Moor, York, YO30 4XB. Tel: 01904 691 469, Fax: 01904 691 569, Web site: www.edmundoptics.co.uk

Farnell, Canal Road, Leeds, LS12 2TU. Tel: 0870 1200 200, Fax: 0870 1200 201, Website: www.farnell.com/uk

Freshford Ltd, Unit 1, Progressive Business Park, Gorby Road, Audenshaw, Manchester, M34 5HT. Tel: 0161 371 0000, Fax: 0161 371 8555, Email: info@freshfordltd.co.uk Web: www.freshfordltd.co.uk

Griffin & George, Bishop Meadow Road, Loughborough, Leicestershire, LE11 5RG. Tel: 01509 233344, Fax: 01509 231893, Email: griffin@fisher.co.uk

Philip Harris Education, Findel House, Excelsior Road, Ashby Business Park, Ashby-de-la-Zouch, Leicestershire, LE65 1NG. Tel: 0845 120 4520, Fax: 01530 419 492, Website: www.philipharris.co.uk/education

HSE Books, PO Box 1999, Sudbury, Suffolk, CO10 2WA. Tel: 01787 881165, Fax: 01787 313995.

Instruments Direct Limited, Unit 14, Worton Road, Isleworth, Middlesex, TW7 6ER. Tel: 0208 560 5678, Fax: 0208 232 8669, Website: www.science4schools.com

NCBE, Whiteknights, PO Box 228, Reading, RG6 6AJ. Tel: 0118 987 3743, Fax: 0118 975 0140, Website: www.reading.ac.uk/NCBE

PASCO Scientific, 10101 Foothills Blvd., Roseville, California 95747, USA. Tel: (+1) 916 786 3800, Fax: (+1) 916 786 8905, Website: www.pasco.com (UK representatives: Instruments Direct)

Rapid Electronics Ltd., Severals Lane, Colchester, Essex, CO4 5JS. Tel: 01206 751166, Fax: 01206 751188, Website: www.rapideducation.co.uk

RS Components Ltd., Birchington Road, Corby, Northants. NN17 9RS. Tel: 01536 201201, Fax: 01536 201501, Website: http://rswww.com

Scientific & Chemical Supplies Ltd., Carlton House, Livingston Road, Bilston, West Midlands, W14 0QZ. Tel: 01902 402402, Fax: 01902 402343, Website: www.scichem.co.uk

Scottish Science Advisory Committee, 22-26 George Street, Edinburgh, EH2 2PQ. Tel: 0131 240 5014, Fax: 0131 240 5034, Website: www.scottishscience.org.uk

Shaw Scientific Education (UK) Ltd., PO Box 404, Aylesbury, Bucks. HP19 9WD. Tel: 0870 241 6938, Fax: 0870 241 6939, E-mail: sales@shaweducation.co.uk