Use of the laser in the high school classroom : The LASE Project

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ABSTRACT

Laser Applications in Science Education (LASE) is an original, laser-based, hands-on and open-ended approach to the teaching of the principles and applications of modern optics at high school (14-19) level. LASE courses, supported by the National Science Foundation and the British Institute of Physics, have been presented in varying forms to numerous high school teachers. The LASE project includes a handbook for teachers, a newsletter and the continuing field testing development of courses and materials.

INTRODUCTION

The dominant innovative wave in information technology is a light wave. Optics and its applications are at the leading edge of the current technological front. This Conference itself reflects a recognition of the rapidly growing importance of optics in science education as a result of the demands of industry and commerce.

Predominantly, the engine which has provided the innovative drive is the laser and its many applications. In high school/secondary school (14-19), physics education however, there has been little reflection in curricula and approaches of the new types of optics - 'light' is still taught in a way which barely reflects any of the developments or excitement of the subject in the age of the laser. Yet low power (< 1mw) HeNe lasers are to be found in most school physics laboratories. But in our experience they are often regarded as esoteric, and perhaps dangerous, items of equipment to be brought out occasionally - usually to demonstrate diffraction - and then put away until next year.

The Laser Applications in Science Education (LASE) Project (and associated handbook*) arose as a result of a joint UK/USA initiative in 1988 when the authors set out to develop a course in which the full potential of the school laser could be exploited. Our aim was to design a course for *teachers* of physics, which would encourage this, by inducting and training them in what we believed to be a more fruitful approach to the teaching of optics ('light') and its application.

**Available from LASE (D), Department of Mathematical Sciences, Brighton Polytechnic, Brighton, BN2 4GJ at £10.95 (incl. p+p)*

or

LASE (D), Department of Physics, San Jose State University, 1 Washington Square, San Jose, California, USA at $19.95 (incl. p+p)

PRINCIPLES

Our principles in developing this approach were both pedagogic and practical.

Motivation: The laser together with the silicon chip, is generally portrayed as the epitome of the 'Hi-Tech' products of the technological revolution of the past 20-30 years. It is therefore likely to have a glamorous, ultra-modern image, enhanced (not entirely without penalty) by 'Star Wars' (cinematic as well as SDI) and by the spread of holography. We hoped that such an image would provide the motivation to learn - motivation which is often difficult to generate in the high school physics classroom. Hence, the laser is the central tool in our courses.

Real world relevance: A course on light must of course communicate effectively the principles of optics. But we also believe that students should become aware of and be motivated by some of the current applications of optics: e.g. bar-code scanners, laser range-finding, fibre optics, holography. The old principle of 'motivation through relevance' is still valid. LASE therefore includes many demonstrations and simple devices which illustrate some of these real-world applications.

'Hands-on' experience: Text book explanations, teacher and video demonstrations and set-piece 'experiments' have their place in physics education, but LASE puts emphasis on a 'hands-on', interactive, open-ended approach. It encourages genuine experimentation through 'extensions' of the core activities. Extendability is a major feature of our approach.

Economy: Schools - even in Silicon Valley - cannot be assumed to be able to purchase purpose-built optical and other expensive equipment. LASE is therefore based as far as possible on the use of simple but effective do-it-yourself, or commonly and cheaply available equipment.

User-friendliness: LASE 'documentation' is written in a conversational style and tries to avoid the somewhat arch and over-formal style adopted by many text-book writers. No previous knowledge of optics is assumed.

Skill development: LASE was developed with an awareness that optics education - like all science education - should provide a vehicle for the training of our students in the general skills of the scientist: for example, careful observation; acquisition of data; presentation and interpretation of graphs; analysis of results; formulation of hypotheses and models and the reporting of scientific work. A requirement to practice these skills is therefore a component of many LASE activities.

THE LASE CURRICULUM

LASE consists of a set of 'core' units, which we call '*stations*' for reasons we explain later. The content spans almost all the topics of conventional optics, and several important applications in addition. It also includes units or sub-units concerned with the properties of laser light itself. The course is designed primarily for *teachers* of 14-19 year old students. The explanatory notes therefore assume a certain level of awareness and knowledge of optical concepts. However, in the UK, LASE has been adapted for beginning undergraduate students and as a 'crash' course for students with little prior experience of physics. The level of treatment and the particular spread of stations that are used depends on the particular course concerned. We have space here only for a brief overview of each station. The brief description of each activity is taken from the course notes used in the latest version of the course recently presented in San Jose. The diagrams are taken from the "LASE Handbook". The reader will, therefore, require a feel for the style, content and presentation of a LASE workshop.

TOPIC 1: 'Straight to the point: Measuring with a laser beam

> "To a very good approximation a laser beam can be considered as a 'pencil' of intense collimated light which can run over large distances without diverging very much, and so can be used very effectively as a lightweight 'pointer'. (In fact you might have seen one used this way by a lecturer to point to things on a screen). We shall use this property of a laser beam in a surveying exercise to measure the height of the room. This can be extended to measuring the height of a building - or anything."

This activity can be enjoyed comfortably during a single class period and involves, in addition to measurements which have to be taken, the use of some amusing mathematical 'tools'

Also associated with this topic is the measurement of laser beam divergence, by noting the beam diameter after it has travelled the length of the room, and then when it has been reflected back to the laser. The laser is placed on the floor for this measurement. This is also an opportunity to point out laser speckle and its dependence on the acuity of the eye.

TOPIC 2: The law of reflection, the optical lever, and double mirrors

> "Many people have noticed that when light reflects off a surface ***the angle of reflection is equal to the angle of incidence*** (the law of reflection), that a reflected beam swings through twice the angle turned by the mirror from which it reflects, and that two mirrors at right angles to each other act as a "retroreflector". Historically, these things have been observed using a 'conventional' light source or just observing where images of objects placed in front of the surfaces, are located. We shall, of course, use a laser beam to verify these findings."

The laser beam in both this and the next topic is made visible by passing the beam through a rectangular tank containing water 'doped' with a small amount of either 'Ludox' (a colloidal suspension of ~10 nm silica particles, and manufactured by Dupont) or white emulsion paint, which contains Ludox. (see Fig. 1). This produces a very uniform scattering. Mirrors, glass or plastic blocks, and solid or hollow prisms can then be immersed in the water to deflect the beam.

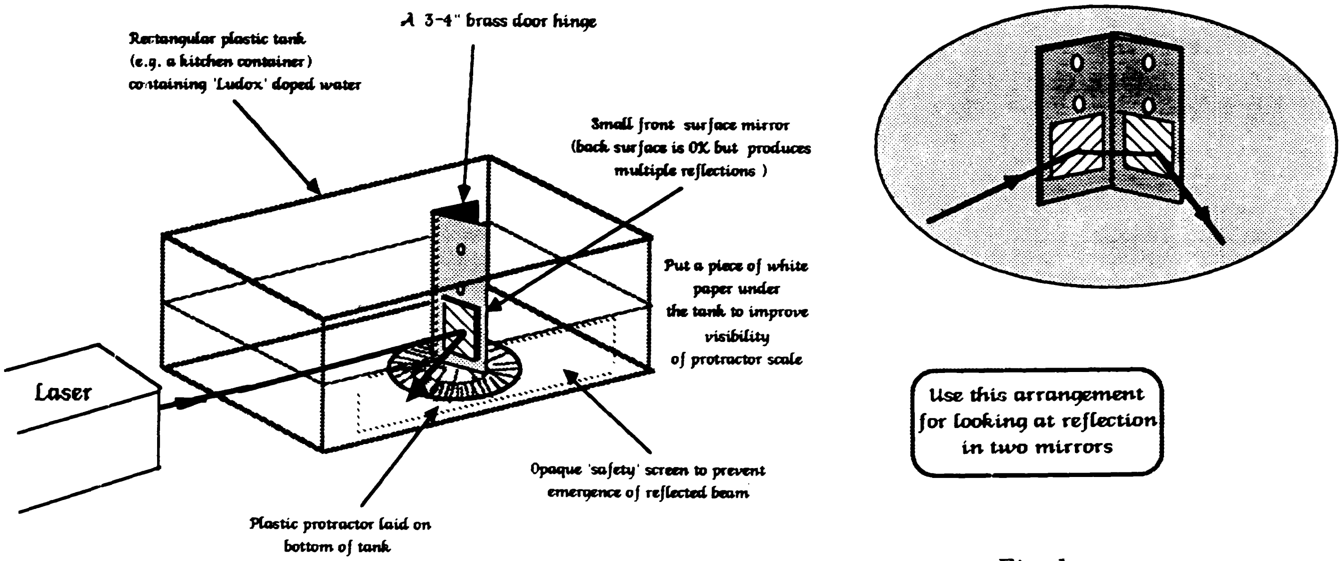

Fig. 1

TOPIC 2B: Constructing a photodetector

"In general, semi-conductor material are light sensitive. In particular, photodiodes and phototransistors when placed in the right circuit, show a linear response to the light falling on them; if the irradiance doubles, the circuit voltage doubles. Some details concerning a suitable circuit and linearity are to be found in the Handbook. Notice that the Optometer is only linearly sensitive below a certain irradiance. As a general rule, if the beam is reduced to about 0.3 mW, then you are in the linear range. Above this value is becomes saturated, still useful as an on/off detector, but not good for detailed studies.

Your first task will be to construct the circuit shown, and to measure its output first with a voltmeter (suitable for constant or slowly varying irradiances)."

TOPIC 3: Refracting a laser beam

"When light travels from one medium to another it either speeds up or slows down. This causes wavefronts to change direction as they cross the boundary separating the two media (unless the angle of incidence is zero, in which case the angle of refraction is also zero). The angles of incidence and refraction are shown in the figure on page 20 of the LASE Handbook. (see Fig.2) Even though that figure shows the 'top' medium as air, it does not have to be. Also, with some media combinations, the beam will bend the other way. The vertical line in the diagram is again called the *normal* (the perpendicular to the surface) and we say the refracted ray is bent either towards or away from the normal. As the angle of incidence increases, so too does the angle of refraction (which can also be called the transmission angle, if you prefer). However, the relation is not a linear one. ***Rather, the sine of one angle bears a linear relation to the sine of the other.*** We shall use the small tank used in Topic 2 to measure the speed of light in gelatin".

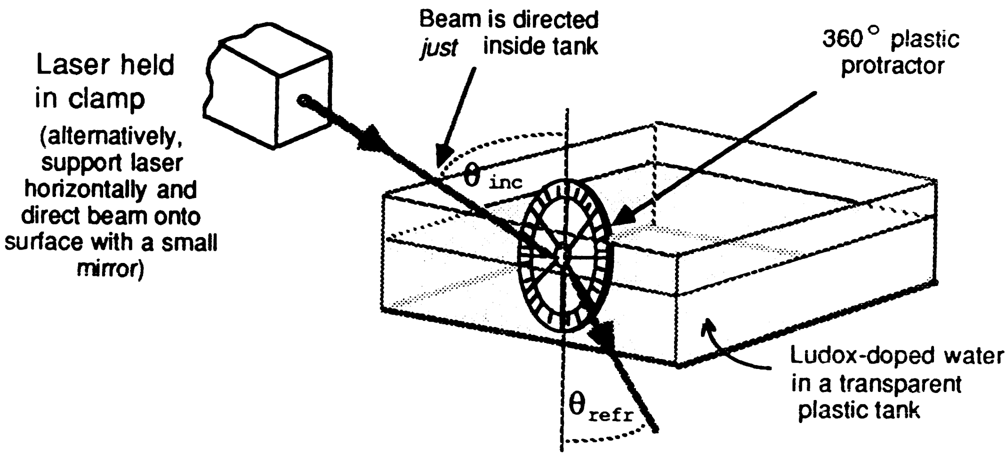

Fig. 2

TOPIC 4: Getting things into focus

"We shall use the wobbler, described on page 65 of the LASE Handbook (see Fig. 3), to 'present a positive (converging) lens with a cone of light. It will focus it to a point. The cone originates at the wobbler (object point) and spreads out to the lens at which point is is converged back to the (image) point. The lens equation will give the focal length of the lens. The diagram on page 28 is useful to visualise this. Different lenses and lens systems can be investigated this way".

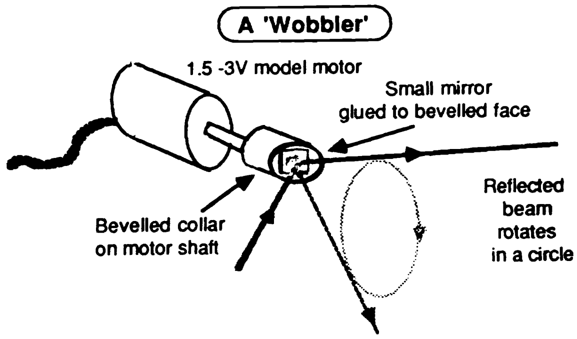

Fig. 3

We have also used a different approach, the 'fanscanner', with which it is possible to produce a linear scan (see Fig. 4).

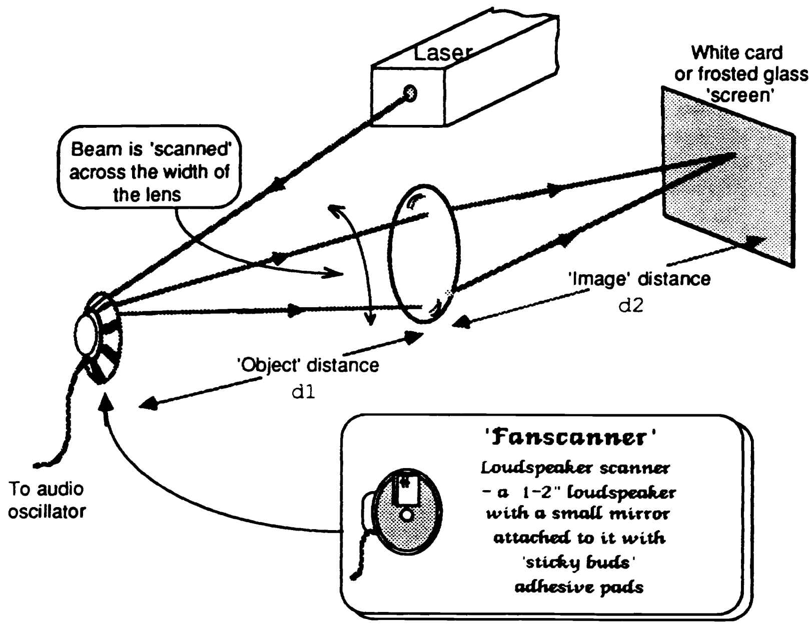

Fig. 4

TOPIC 5: Beam choppers and pattern recognition

"The same motor we used in the lens experiment can be used here. This time a card with a slot cut out of it is attached to the shaft, and to see the effect on the beam of rapidly rotating the card, we shall use an oscilloscope connected to the photodetector. We shall also use a transparent disc with an opaque letter on it. A brief primer on the use of the oscilloscope will be given first, and a list of interesting things to do will follow. This is going to be quite a long activity, but we hope you'll find it to be one of the more interesting ones."

TOPIC 6: Bar-code reading

"As opposed to topic 5, where the beam was held steady and the pattern being 'read' was moved, in this activity we shall scan a stationary target with a moving beam. Use the 'wobbler' to do this. The figure on page 62 of the LASE Handbook (Fig. 5) shows how the scanning will be achieved, although you should notice that today we shall not be using the linear scan fanscanner, but the circular scan wobbler instead. Notice the cunning use of the lens to 'collect' the sweeping beam to bring it to a stationary point where the photodetector is then located".

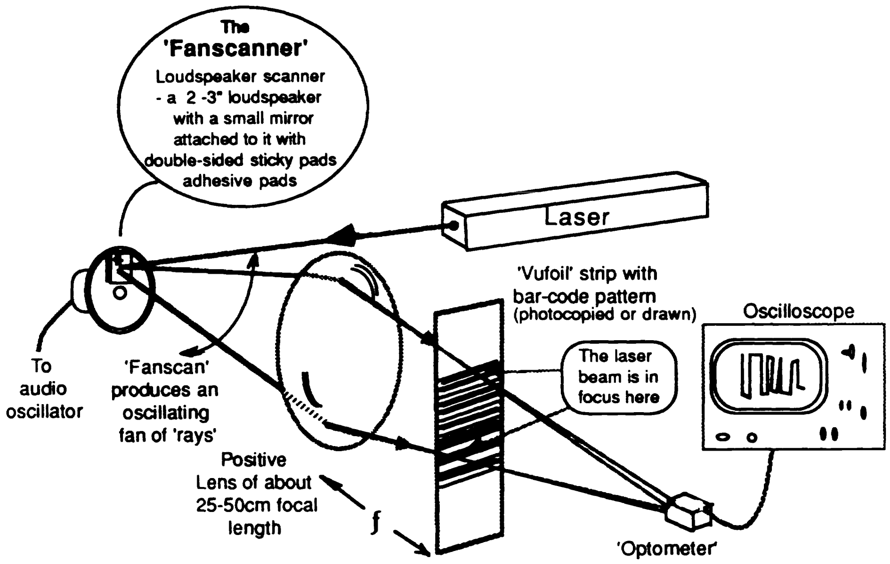

Fig. 5

TOPIC 7: POLARISATION

"The lasers we use all have beams of plane linearly polarised light. If your laser is unpolarised, you will need to place a polaroid sheet in it to make it plane polarised for the rest of this experiment. We shall spin a polaroid sheet in this beam and observe the sinusoidal variation of irradiance imposed on the beam by doing this. This fluctuation can be transposed into a voltage signal, via our photodetectors, and observed on an oscilloscope.

We can 'move' the twisted nematic molecules of a liquid crystal display cell (LCD) by applying a varying voltage to it - either from the photodetector in the experiment above, or from a signal generator. We shall discover (we hope!) that the molecules will only be able to 'keep up' with the voltage variations if they are slow enough".

TOPIC 8: Interference (or the superposition of waves reflected off various surfaces or unlimited wavefront superposition irradiance patterns)

"The necessary and sufficient condition for interference fringes is the presence of two coherent waves of the same wavelength impinging upon each other. The two waves are invariably produced from an original single wave. In this way the two are replicas of the original and so are replicas of each other. We say they are coherent with each other. (Interference and diffraction are very similar in that they are both caused by waves impinging on each other. In general we can say that many waves are impinging upon each other in the case of diffraction while only a small number (frequently only two) do so in interference).

Using a laser as the original light source with its high irradiance and great purity of colour, the two replica beams, when they combine, give very visible non-localised fringes. The beams are produced from the original by reflecting off surfaces. Any movement of any of these surfaces causes the fringes to move. By studying the fringe movement, the surface movement can be studied.

In this topic, we shall reflect light off a glass microscope slide and off a glass cover slip and observe the difference in the patterns. Heating the glass with a soldering iron in each case will cause the patterns to change and the use of this as a temperature change indicator can be observed and discussed."

TOPIC 9: Diffraction by screens or the superposition of waves after passing through screens

"When obstacles are placed in a beam of light we have the condition for diffraction. 'Neat' diffraction patterns (caused by the superposition of many secondary light beams) are obtained only for simple obstacles - the simplest being a periodic structure such as a diffraction grating. We shall study gratings in some depth today. After first measuring the spacing of the lines of the grating by 'probing' it with laser light, we shall use our results to measure the wavelengths of the light emitted by a helium discharge lamp and compare our results with those quoted in tables found in a Handbook of Physical constants. We shall finish by observing the patterns formed by passing a laser beam through more complicated diffracting screens."

An alternative approach we also use is the well-known measuring of the wavelength of light with a ruler, using a steel ruler at grazing incidence as a diffraction grating (Fig. 6). A Compact-Disc also makes a cheap and excellent diffraction grating. Here though, we suggest that the wavelength of the laser light is used to work out the spacing of the CD tracks.

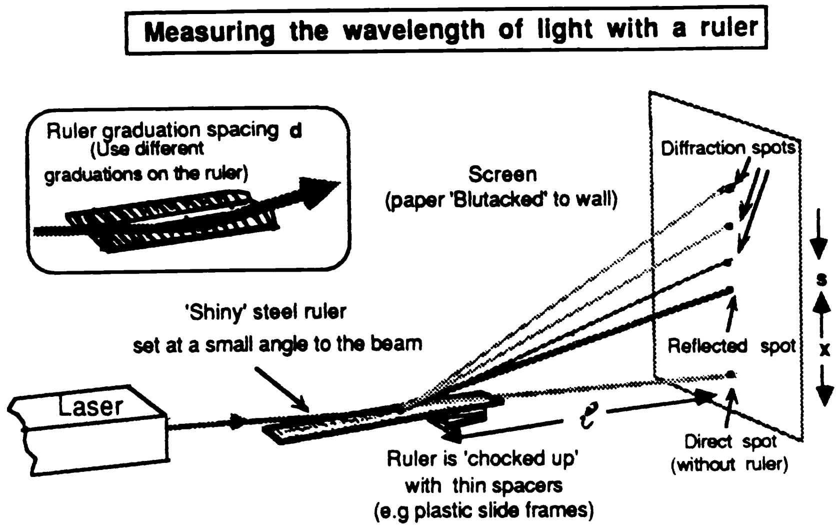

Fig. 6

TOPIC 10: The profile of a laser beam

"The most straightforward way of plotting the beam profile is to measure the output of our photodetector as it is moved across the beam at a distance of about 5 m down-beam. It should show a Gaussian shape and the diameter, defined as the distance between the $1/e^2$ points, can be accurately measured."

TOPIC 11: Absorption of a laser beam

"In general, when a laser beam travels through a medium, some of the energy is absorbed. The amount depends on how much medium it travels through and the absorbing ability of the medium (Fig. 7). Insert one, then two, then three, and so on, light absorbing sheets in the beam and measure the corresponding voltages on your photodetector. You should get a characteristic *exponentially* decreasing curve. (If the medium had 'gain', then you would get an exponentially increasing curve!)".

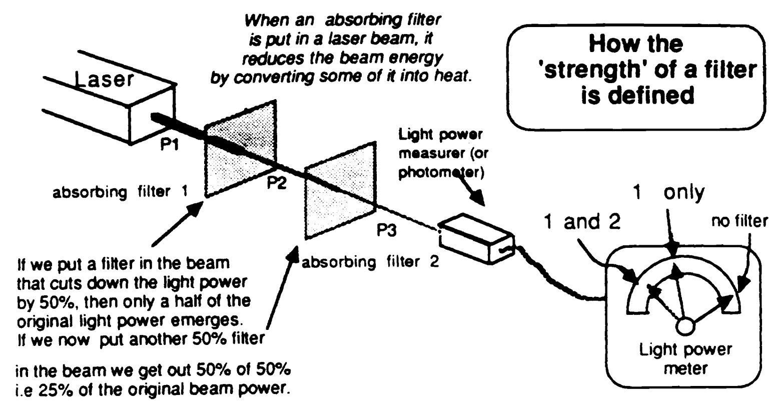

Fig. 7

Some versions of the LASE workshops, and the LASE Handbook, also include substantial sections on fibre optic principles; in particular, demonstrations of the bending of a laser beam in a graded index medium. A very simple set up which shows this is sketched in Fig. 8, but more sophisticated three-layer simulations of graded-index fibres have been successfully demonstrated by us.

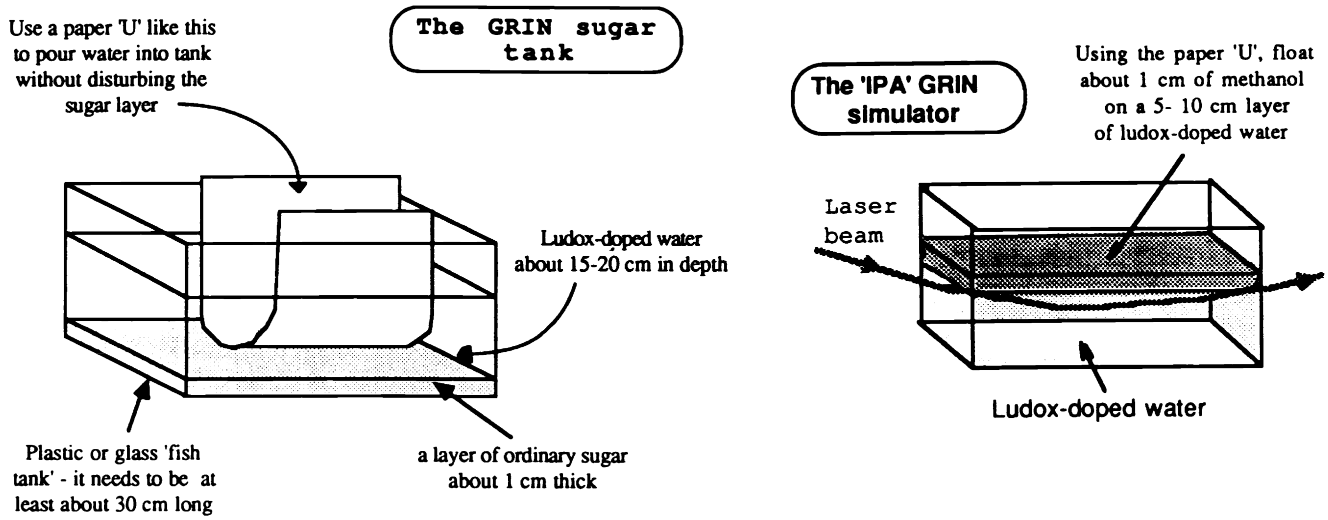

Fig. 8

In the LASE workshops held in UK, the culmination of the courses has often been the production of a hologram by participants themselves. The set-up is a very basic Denisyuk arrangement as shown in Fig. 9; *no* special vibration isolation has been necessary. As a result of these courses, many British schools now use this simple arrangement.

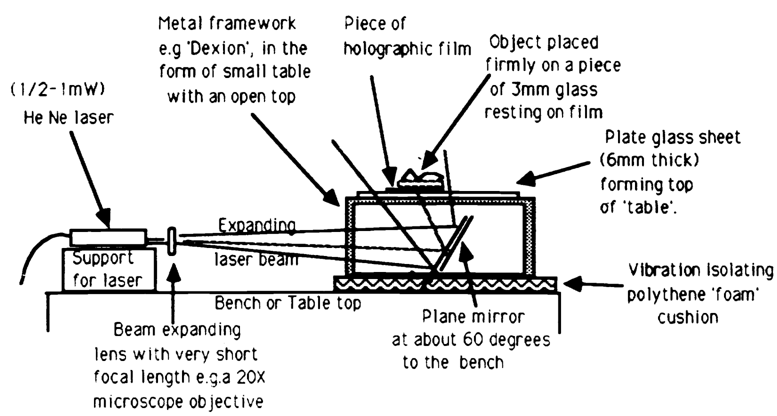

Fig. 9

In short workshop courses, a white light reflection hologram has been made as a demonstration, with this set-up. We have found it possible to produce very acceptable holograms with a considerable background level of illumination (a shaded desk lamp in a corner of the room at floor level). In a recent course, a 13 year old girl twice produced successful holograms in front of a large group of teachers whilst a total of 8 flash photographs were taken of successive stages of the process! (Fig.10)

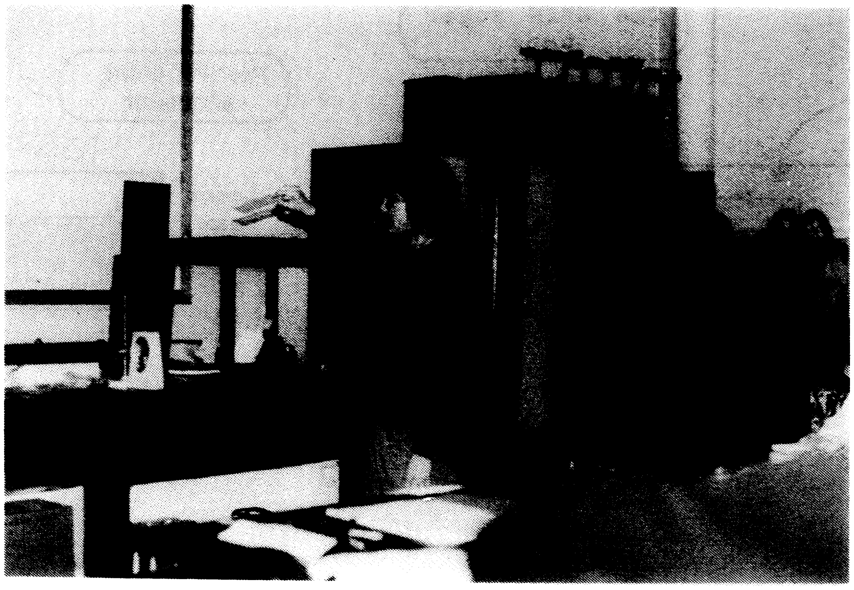

Fig.10 Janine Cornwall (13) placing a piece of holographic film on the 'holocamera' table, while demonstrating the making of a Denisyuk hologram in dim ambient white light. (Flash photograph)

ORGANISATION OF LASE WORKSHOPS

LASE courses are presented as 'workshops' during which participants stop for a time at a series of 'stations' based on the topics listed above. Some workshops occupy only 3 hours during which only about 3 or 4 of the 'stations' are visited, whilst larger courses of a week or more cover virtually all the topics.

Workshop courses usually start with an introductory overview, emphasising the aims of the course, the safe handling of lasers and an overview of the activities. Participants, in pairs, then spend between 20 minutes (or much longer in a week's course), at each station moving on cue to the next station. With almost 20 participants per course duplicate sets of stations are usually necessary, and strict control of the timing of the moves between stations is necessary. In the most recent workshops multiple copies of each station were provided, so that participants move through the stations in a less regimented way. Guidance notes for each station are intended to be read in advance and are designed to be self-contained, because of the arbitrary order in which stations will, usually, be sequenced. The documentation contains a reminder of the basic optical principles involved, a 'what to do' section, and a series of suggested 'extensions' ideas and questions intended to be thought about and tried out within the school classroom.

Some teachers (and their students) initially approach the laser with apprehension having absorbed images, derived from both the SDI and cinematic versions of 'Star Wars', of the less benign applications (or imagined applications) of lasers. More recently, the use of laser based weapons in the Gulf War has reinforced this misleading image. We emphasise that the <1mW HeNe laser if correctly handled is as safe as an oscilloscope - both our courses and our book start with a presentation of a 'code of practice' for safe handling, and reassurances to participants that a school laser is safe, if common-sense precautions are taken.

Our first workshop for teachers was presented successfully in 1988 at Brighton Polytechnic, UK, and was followed by similar courses at San Jose State University, California. Successful experience of these courses encouraged one of us (GTW) to submit a proposal for a National Science Foundation (NSF) award and to seek other support. As a result, financial and material assistance from NSF, the Optical Society of Northern California and the Electro-Optics Manufacturers Association in the USA enabled a two-week LASE course to be held in 1990 and two one-week courses in 1991. These courses required teacher-participants to implement LASE activities in the school classroom during the following school year, and to report on their experiences.

In the UK, as well as half-day courses for teachers, short LASE courses are held annually for beginning physics and engineering students at Brighton Polytechnic, and the Institute of Physics has in 1991 introduced very successful LASE workshops for about 50 participants in its twice-yearly residential 'update' courses for teachers. In addition to the activities organised by the authors, it is gratifying that LASE-type activities have been promoted at their own initiative by teachers in schools in the USA and in the UK.

THE LASE PROJECT

The central strand of the LASE project is the workshop courses. However, the external funding in the USA since 1990 has provided the opportunity to extend the LASE initiative into schools themselves (as mentioned above). Teacher participants in the workshop course were encouraged and supported in introducing LASE activities into their laboratory teaching. A total of 17 schools in the San Jose area were involved, in 1990, and many more in 1991.

To stimulate and initiate student and teacher involvement, a monthly newsletter, LASE LOG, has been desk-top published since October 1990. Its stated purpose is "to facilitate the introduction of laser applications in science education". It has published articles from high school physics students and their teachers, and laser-related items of interest to them. They range from the basic to the quite advanced: titles in the first four issues include - 'Spatial Character Recognition'; 'Characterisation of the index of refraction versus concentration for aqueus sugar solutions'; 'The Sounds of Light';'The Index of refraction of Jell-O'; 'Detecting laser light using a PV cell'; 'Holograms'; 'Laser Light pattern at low temperatures'; 'A home-made Michelson interferometer'. 'LASE LOG' is distributed free to many schools, universities and companies mainly in Northern California.

In 1991, "*LASE: A Handbook for Teachers*" was published. (see footnote on first page) This collects together many of the ideas developed since 1988, and provides numerous ideas for 'extensions' of each LASE topic.

LASE - THE FUTURE

The LASE approach offers ample scope for expansion. One 'extension' of LASE carried out as a project by one of our students has been to investigate the feasibility of using a collimated visible semi-conductor (S.C.) laser as a substitute for the 'HeNe'. Many LASE activities prove equally practicable with this compact, relatively inexpensive and low voltage source (including the production of a Denisyuk hologram). Unfortunately, most currently available S.C. lasers have wavelengths of around 670 nm at which the eye has a sensitivity of only about one-sixth that at 633 nm. To attain comparable brightness therefore requires powers of the order 2-3 mW which puts the laser into safety Class 3, and makes it unsuitable for general use in the open teaching laboratory. In addition, the large intrinsic divergence of a S.C laser means that the collimated beam is of the order of 3-5 nm in diameter, and is less 'ray like' than the 633 nm laser beam. There seems little doubt that S.C lasers will come down considerably in both wavelength and price in the next few years. The development of cheap S.C lasers at different wavelengths would open up yet more opportunities for LASE-type experiments and demonstrations. In particular, topics which are absent in our course, because of our current single-wavelength limitation (notably, dispersion and aspects of colour vision), would become practicable. (Of course green, yellow and orange HeNe lasers are available, and we have used a green HeNe for demonstrations, but the cost is prohibitive for schools).

A further undergraduate project in the UK will shortly investigate the development of an 'advanced' LASE workshop, The demonstration of scattering and polarisation phenomena, of optical information processing, and of 'traditional', holographic and speckle interferometry, has already been shown to be feasible with simple equipment. Conversion of these demonstrations to LASE-style activities will involve even simpler and cheaper set ups.

The laser, as a teaching tool, has proved to be remarkably prolific. Our experiences over the last 3 years have demonstrated that the principles of optics and an insight into some of its current applications can very effectively be communicated using one of the more 'glamorous' of its offspring - the HeNe laser. Responses of participants in LASE workshops have been quite enthusiastic. We have found that teachers themselves are grateful for the opportunity to refresh and update their knowledge of optics, even if through practical constraints they are unable to introduce more than a minor change in their practical teaching.

In both the USA and the UK there is a crisis in physics education, related among other factors, to a gross shortage of qualified physics teachers, to inadequacy in per capita expenditure on resources and, in the UK, to a perceived devaluing of the status of physics within secondary education as a result of the introduction of new core-curricula, and a more utilitarian perception by Government of the purpose and goals of education at both school and in Higher Education. The LASE project may to a small extent help to alleviate some of the impact of these changes.