ties, and in a brief address Dr Schuster pointed out the importance that this new calibration facility would have not only for UK but also for the European Community and other countries.

# Lasers solve problems

By M E Calcraft

A decade ago the cliché 'an answer in search of a problem' was applied to lasers. An interdisciplinary meeting on lasers in medicine held on 29 October 1975 exemplified the positive aspects of this cliché with laser and medical physicists reporting on the current state of laser technology and surgeons describing their requirements.

Professor O S Heavens (York) opened the meeting with a review of current laser technology applicable to medicine. He described how an argon laser with annular contact to the cornea through an optical fibre had been used for retinal holography using a focused power of $<0{\cdot}6\ \mathrm{W\,cm^{-2}}$ in an 18 ms exposure. Attention was given to the cw $CO_2$ (10·6 μm) laser, particularly the $He\text{–}N_2\text{–}CO_2$ laser with gas circulation to remove decomposition products. There was some indication that CO (5 μm) could replace $CO_2$ now that the former could be run at near room temperatures and a small transmitting fibre optic was feasible at 5 μm.

Dr W N Charman (UMIST) described the speckle pattern produced when a laser beam passed through a diverging lens to a diffusing surface. Viewed by an abnormal eye, the pattern was subject to parallax effects and appeared to move. Correcting lenses can be used to render the pattern stationary in two orthogonal directions and measure ocular refraction without relying on visual examination of the image on the retina or on culture-based tests demanding cooperation from the patient. Precision and accuracy were reasonable (within 0·3 dioptres) but the need to allow for accommodation, astigmatism and the dimensions of the eye meant that the system was not yet adequately refined as a routine screening procedure.

Dr E R Pike (RRE) and Professor D Hill (RCS) described the use of photon correlation techniques for the measurement of the velocity of retinal blood flow using a He–Ne laser attached to a Zeiss fundus camera with a 300 ms exposure. The method was inhibited by the low power needed to avoid retinal damage. Very sensitive methods of light detection amounting to the detection of photons were needed. The method produced results equivalent to cineangiograms, but was non-invasive and repeatable. Problems arose from nonuniform flow and heart beat surges.

An interesting series of electron micrographs of the layers of the retina were shown by Dr J Marshall (Institute of Opthalmology). They showed the difference between small, recoverable lesions and the explosive damage site due to severe thermal effects. Secondary damage to an overlying nerve affecting reception from otherwise undamaged areas was reported. The validity of extrapolating from monkey to human macular pigment was in doubt, but nevertheless understanding of levels of damage from which complete recovery was possible might lead to a new and higher safety level of $2{\cdot}5\ \mathrm{J\,cm^{-2}}$ at the cornea.

Dr D W Goodwin (York) and Dr J C Lawrence (MRC) described experiments to determine the exact damage mechanism using a cw laser (1·06 μm) on white and pigmented skin. It was particularly necessary to establish the mechanism since these effects were of interest to surgeons. Effects through denaturation to carbonization were studied *in vitro*, but again, extrapolation to *in vivo* was in some doubt as the body acted as a heat sink.

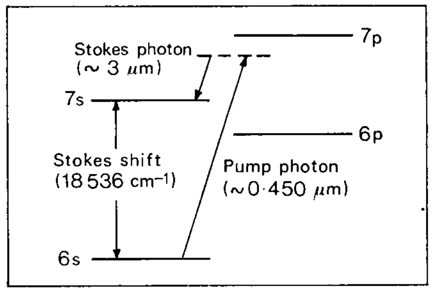
Mr R Hall (Newcastle General Hospital) spoke of the surgical application of lasers. A major advantage to surgeons was the inherent diathermy effect which reduced blood loss so markedly. Tissue treated by laser was destroyed *in situ* rather than excised, the cells being exploded by vaporization of cellular fluid. Use of lasers in endoscopic methods held promise, although at present these were limited by the size of apparatus which could be used in an operating theatre and the difficulties of power loss in transmission to the site. Mr Hall emphasized the need for portable lasers up to 100 W with fibre optic transmission to the site. In bladder endoscopy, for example, the preferred $CO_2$ laser was difficult to use as the bladder had to be filled with water. Use of a delivery tube resulted in power attenuation but a method of filling with $CO_2$ gas was possible. Some very precise surgery on polypae had been done by laser and laryngoscope and, not being traumatic, could be repeated frequently.

In the discussion which followed it became clear that the surgical requirements were reduced size and greater mobility. It was felt that for laser endoscopic surgery the $CO_2$ laser was limited without a transmitting fibre optic, that the CO laser showed promise provided a fibre optic endoscope could be produced and that more study was needed into the problems of the YAG laser for surgery. It was generally felt that more discussion between laser physicists, surgeons and administrators would prove valuable in enabling the UK to make a contribution to this field. While laser surgery might not be the revolutionary technique often claimed, it seemed to have considerable specialized uses.

# Tuning into infrared

By Dr D C Hanna, MInstP

Tunable infrared lasers have proved more difficult to develop than tunable visible lasers such as dye lasers. Although various approaches have been successful in generating tunable infrared, they have involved considerable complexity and expense. Recent work however in the Electronics Department at Southampton University has shown that stimulated Raman scattering in alkali metal vapours can offer a simple method for converting the beam from a tunable dye laser into an intense, coherent beam of tunable infrared radiation (see *Physics Bulletin* November 1975 p482 by Dr G H C New).




Energy level scheme for one of the Raman transitions used in caesium vapour

In its most familiar form, Raman scattering is a spontaneous scattering process in which a photon incident on an atom or molecule is annihilated and a scattered photon of lower energy (Stokes photon) is produced, the atom being left in an excited state (see diagram). The energy difference, known as the Stokes shift, between the incident (pump) photon and scattered photon is therefore equal to the fixed energy difference between the initial and final states of the atom or molecule. If the frequency of the incident photons is changed, the frequency of the scattered photons must change in exactly the same way, thus offering the possibility of converting a frequency-tunable source of incident photons (eg a dye laser) into a tunable source at longer wavelength.

This only becomes an attractive proposition if the scattering process is efficient and typically the efficiency for spontaneous Raman scattering is very low, perhaps 1 in $10^{-6}$ of incident photons being scattered. However, if the pump intensity is of the order of $\mathrm{MW\,cm^{-2}}$ (an intensity easily obtained from a modest dye laser of a few kW power) the process of *stimulated* Raman scattering becomes important. The relationship between stimulated Raman scattering and ordinary (spontaneous) Raman scattering is analogous to the relationship between the stimulated and spontaneous emission processes occurring in a laser. In a laser a spontaneously emitted photon can interact with an atom in the upper laser level and stimulate it to emit an identical photon. In the stimulated Raman process the scattering of a Stokes photon is stimulated by the presence of a Stokes photon originally produced by spontaneous Raman scattering. This *stimulated* Stokes photon has the same frequency and propagates in the same direction as the original Stokes photon. These two Stokes photons in turn give rise to further stimulated scattering and so on in an avalanche process thus leading to very efficient scattering with essentially all of the pump photons being converted to Stokes photons. The stimulated Raman beam is collinear with the pump beam and shows the highly directional properties characteristic of a laser beam.

Stimulated Raman scattering was first observed in various organic molecules, the Stokes shift being typically $1000\,cm^{-1}$ since this shift corresponds to the excitation of a quantum of vibrational energy of the molecule. Raman scattering in atoms can provide a much greater Stokes shift ($20\,000\,cm^{-1}$ or more) since the atom is left in an excited electronic state. With such a large Stokes shift, radiation from a dye laser pump (at $25\,000\,cm^{-1}$ say) can be directly converted into infrared radiation. The infrared wavelength can then be tuned simply by tuning the dye laser, by tilting a diffraction grating for example.

In the work at Southampton two different dye laser systems have been used; a medium power laser (powers of 10–20 kW) pumped by a nitrogen laser, and a high power laser (up to $\sim 1$ MW power) pumped by the second harmonic of a ruby laser. So far two alkali metal vapours have been studied; potassium and caesium. The metal vapour is confined in a heat-pipe oven of about 30 cm length with a visible window at one end to allow the dye laser beam in, and an IR window at the other end to transmit the generated infrared beam. Using the nitrogen pumped dye laser and potassium vapour, a Raman tuning range of 2·6–3·5 μm was covered using a single dye laser and Raman powers of up to 1 kW were obtained.

This IR source was used to take an absorption spectrum of $CO_2$ gas and the observed spectral resolution indicated that the Raman source had a linewidth of less than $0{\cdot}4\,cm^{-1}$. Using the high power dye laser and caesium vapour, a much wider tuning range has been obtained with considerably higher power. The Raman output has been tuned over the ranges 2·5–4·75 μm, 5·67–8·65 μm and 11·7–15 μm with maximum powers of 25 kW, 7 kW and 2 kW respectively.

These preliminary results suggest that the technique of stimulated electronic Raman scattering holds considerable promise. Since the heat-pipe can easily be scaled up and much higher dye laser powers can be produced it should be possible to achieve much higher infrared powers than those reported here. Further work to extend the tuning range and improve the frequency resolution is now under way at Southampton University.

# Measuring IR spectra

A simple way to measure the spectrum of a pulsed infrared laser is to split the laser beam in two and make a laser hologram. At wavelengths in the 3 μm infrared range, conventional metal films used for holography at 10 μm, are either insensitive or do not show a linear response to varying light intensity. W Braun from the Max Planck Institut für Plasmaphysik, Munich has found that gelatine dissolved in water and spread on a simple glass plate is suitable as an area detector in the infrared for recording interference patterns between the two split laser beams.

A pulsed electric discharge through a $SF_6$–$H_2$ mixture produces chemical laser action from excited HF molecules. The time dependence of the laser pulse, integrated over all wavelengths, can be observed using an InAs detector. To look at the pulse spectrum, a time resolving detector and various optical components can be used to give a time resolved spectrum of the laser emission at a particular point of the beam cross section. This in effect gives a time resolved, space integrated spectrum.

In *Optical Engineering* 1975 **14** 208, Dr Braun has suggested a way of looking at a time integrated, space resolved spectrum using holographic techniques. The HF laser beam has to be split into two beams of small divergence, each including all the spectral output. Both beams are directed onto a gelatine layer keeping the path difference between the two as small as possible and taking care to adjust the beam cross sections exactly one on top of the other. An interference pattern or phase hologram is formed by a modulation of the optical thickness of the gelatine. If a He–Ne laser (0·6328 μm) is shone through the hologram the distribution of the focused light intensity in the first order of diffraction gives directly the spectrum of the original HF laser radiation.

A conventional HF laser was used for the experiment. A high voltage, low inductance Marx generator bank was used to excite about 2000 pin discharges, resistively decoupled by a $CuSo_4$ solution. The filling gas was 5–30 Torr $H_2$ and 50–120 Torr $SF_6$ and a gold coated spherical mirror and a plane quartz plate were used for the laser resonator. The hologram method of looking at laser spectra should however be applicable to measuring all spectra in the $1\,J\,cm^{-2}$ range and their dependence on the filling gas pressures.

# Burning bad fuels well

For almost half a million years, mankind has known how to burn good fuel badly. Until the past decade he has always assumed that good fuels are in plentiful supply and has spent little time researching into better methods of burning low grade fuel and extracting the maximum energy from combustion processes. With the growing awareness that conventional fuel supplies are limited, research into better ways of using chemical fuels has begun; some of it is being done under the auspices of Professor F J Weinberg at Imperial College.

In an article published in *Nature* 1975 **257** 367, Professor Weinberg and S A Lloyd described the methods they used to investigate the constraints which control the stable burning of very low grade fuels. The fuel they started off with was 3·7% methane in air: a mixture well below the normal flammability limit for burning in air of 5·3% methane. The burner they used was a Swiss roll one, so called because the air/fuel mixture travels along a rolled pipe to the combustion point at the centre. The combustion products travel along a parallel rolled pipe in the opposite direction out to the open air. During their experiments to find the leanest mixture which could be burnt, no heat was removed from the system and the width, number of turns of the spiral and insulation were altered to minimize the heat losses as leaner fuel mixtures were used. Thermocouples sealed into five points of the spiral recorded temperatures at different stages of the process.

A plot of the leanest fuel concentration which could be burnt in a Swiss roll with a certain number of turns, against that number of turns resulted in curves approximating to rectangular hyperbolae. This showed that increasing the number of turns of the spiral allowed leaner fuel mixtures to be burnt up to a limiting point when sideways heat losses were no longer negligible. However, increasing insulation and the width of the strip at this stage allowed even leaner mixtures to be burnt, with no apparent limit.

Weinberg and Lloyd did not experiment on mixtures leaner than 10% methane in air. They had already found an interesting feature of the mixture burning process: the temperature in the reaction zone, that is, where the burning was taking place, remained constant within the limits of experimental error no matter what fuel concentration was used. The limiting reaction rate is thought to be constant and more dependent on temperature than on the composition of the fuel. As the activation energy has to be increased as the fuel concentration is decreased, rises in temperature do occur as the mixture becomes leaner, but these are only slight. Weinberg and Lloyd have estimated on the activation energy argument that a 0·22% methane in air mixture would have to be used before the temperature of reaction became so high as to damage the construction material of the Swiss roll.

Such a configuration has assumed that no heat is extracted from the system, although it could be used where heat extraction is not required at the maximum temperature, for example for room heating, humidifying and sterilizing hospital atmospheres or burning waste gases and pollutants. If heat is needed at the maximum temperature, Weinberg and Lloyd have concluded that even with prime fuels, a higher conversion of energy can be achieved if the fuel is first diluted with a great excess of air.

They have calculated that the most efficient means of heat exchange would be to use two Stirling engines having their hot ends connected to the Swiss roll and their cold ends exposed either to the outside or fed back into the reactant pipe. The efficiency of the heat conversion increases as the temperature of the reaction zone increases and Weinberg and Lloyd have come to the conclusion that the only con-