Imperial College last November.

Fluorescence is one of the techniques most likely to provide quantitative data on the mixing of fuel and air in real engine environments. An assessment of the application of atomic fluorescence to combustion studies has been conducted by N H Wrobel of the Department of Aeronautics and Astronautics, Southampton University. Mr Wrobel described how the fluorescence of a trace species such as sodium, added to one of the reactants, may be strongly enhanced using a cw dye laser tuned to one of the Na D-lines. The sensitivity of the technique was dramatically demonstrated by colour slides of a 1 atm premixed $H_2/O_2/N_2$ flame on a flat-flame burner. Under these idealized conditions sodium number densities of about 10 ppb can readily be measured with a spatial and temporal resolution of $0{\cdot}2\ \mathrm{mm}^3$ and 1 MHz, respectively. The presence of carbon particles and fuel droplets seriously reduces the signal to noise ratio and poses major obstacles to the exploitation of the technique for many practical situations. Methods of overcoming these difficulties were discussed by the speaker.

J R Thomas (British Gas Corporation) described the application of photon correlation techniques to Raman spectroscopy. By forming the autocorrelation function of Raman light scattered from fluids, it is possible to derive information on the aerodynamic characters of gas jets, including rates of mixing, composition fluctuations and scale of turbulence. Experiments have been carried out on a turbulent, isothermal free jet of natural gas (Reynolds number about 13 500) and a more complicated flow arrangement consisting of a swirled air regime with tangential and radial gas injection.

Other important advances in applying Raman spectroscopy to combustion problems may come from further development of more complicated Raman processes such as resonant Raman and coherent Raman scattering. Professor I R Beattie (Southampton University) gave an illuminating account of coherent anti-Stokes Raman spectroscopy (CARS) through a brief outline of: the Raman effect (which is weak and essentially distributed over 4π steradians); the stimulated Raman effect (which usually involves selected pumping of one transition and further exhibits a threshold due to the appearance of an $\exp(gl)$ term where g is the gain in the medium and l the appropriate length); the inverse Raman effect (which exhibits no threshold but has the disadvantage that one is looking for absorption in the presence of high radiation densities).

Recent advances in infrared technology, particularly in the field of automatic signal retrieval and data processing, coupled with improved radiation models for hot gases, have greatly extended the information that can be obtained from measurements in this spectral region. An impressive example of the state of the art was described by J A Donovan and J M Ridout of the Ministry of Defence's Rocket Propulsion Establishment, who presented a paper on the infrared radiation from CO_2 and H_2O in rocket exhaust plumes. The main concern here was with the spectral and spatial irradiance of a hot, nonisotropic, nonhomogeneous medium as seen by a detector that is separated from the source by a cool, absorbing atmosphere.

A review of the state of equilibrium in flame gases was presented by Professor A G Gaydon (Imperial College) who also helped to organize the day's programme. Professor Gaydon's numerous contributions to the field of flame spectroscopy have earned him an international reputation in the subject and it was therefore fitting that he should agree to address the meeting. It was pointed out that spectroscopy is especially valuable for studying the more physical processes of energy release and rate of equipartition of energy following combustion. A proper appreciation of the extent of radiative and chemical disequilibria occurring in conventional flames is necessary not only for the combustion engineer, who is concerned with air pollution problems and more efficient uses of fuels, but also for the spectrochemical analyst who increasingly uses flames as a convenient form of high temperature heat bath.

Waves as catastrophes

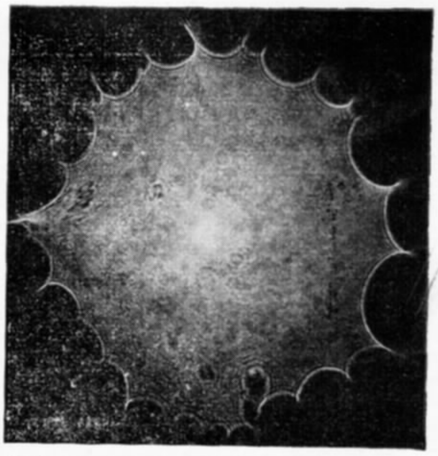
By Dr M Berry, M Inst P

It is becoming clear that the rapidly growing field of modern mathematics called 'catastrophe theory' has much to offer theoretical physicists in one of the oldest branches of their subject: the study of wave motion. In the limiting case when the wavelength is zero the proper way to describe wave fields is in terms of trajectories (rays in geometrical optics, particle paths in classical mechanics). However, when the wavelength is not zero but merely small the calculation of wave intensities becomes a difficult problem in asymptotic analysis. All the obvious methods fail: computer solution of wave equations is ruled out by the rapid oscillations of the wave functions, and eigenfunction expansions and perturbation series converge either slowly or not at all. Yet it is precisely for short waves that striking patterns of interference and focusing occur (see the accompanying illustrations). Catastrophe theory helps to explain and classify these patterns.

Unidirectional light passing through a substance with optical irregularities, for example, produces a field of waves moving forward in different directions. Where the trajectories (the normals to any wavefront in the short wave limit) are infinitely densely packed, the wave intensity will rise to very high values. Such generalized foci, called caustics, will form the significant structures of images on screens or photographic plates placed in the field. The most familiar caustic is the rainbow – a bright circle in direction space.

Caustics can be classified with the aid of a theorem due to Thom, which lies at the heart of catastrophe theory. 'Catastrophes' are 'singularities' of certain mappings of precisely the same type as the geometrical transformation from the incident wave to the space in which the wave is ultimately observed (for example the three-dimensional space near a focus, or the two-dimensional space of directions in the far field). Caustics, where the intensity on a trajectory picture would be infinite, are indeed the singularities of these mappings, i.e. the catastrophes. Thom's theorem concerns caustics that are 'structurally stable', that is those whose form is not changed by small perturbations (of, say, an initial wavefront).

1



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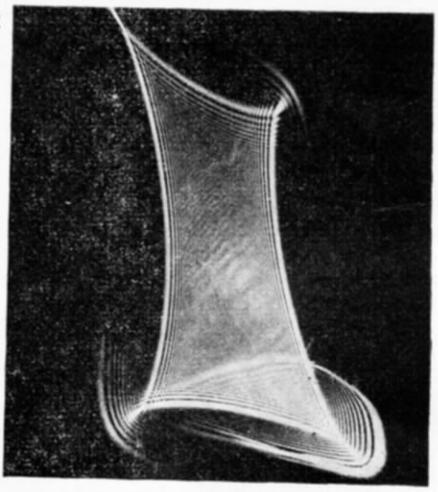

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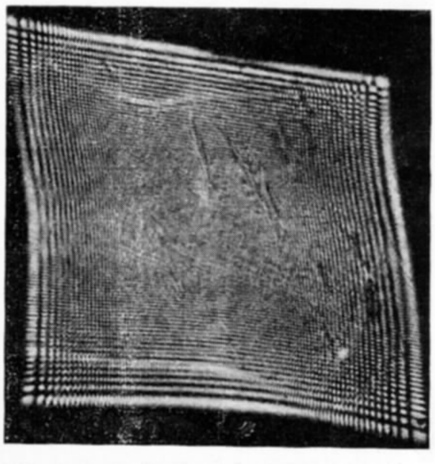
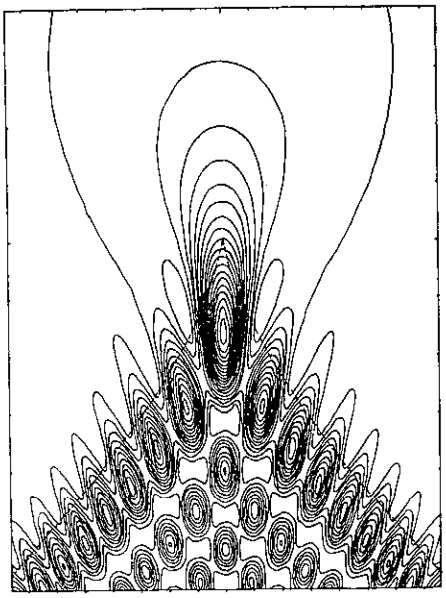


(*Photographs by George Keene*)

We would, therefore, expect to see families of caustics of the same form from similar, but not identical systems – representatives of such families are 'generic' caustics. Genericity is a topological con-



cept: Thom's theorem describes the forms of caustics, but not their precise coordinates. To see generic caustics, look at a distant point source of light through an irregular water droplet 'lens' on a dusty glass plate held close to the eye (figure 1) or shine a laser beam through irregular 'bathroom' glass on to a wall (figure 2).

It is remarkable that the number of different structurally stable singularities is finite. Thom's theorem consists of the enumeration of these fundamental caustic forms. These depend on the dimensionality of the space in which the caustics are observed. In two dimensions (screens, etc) the caustics are lines, usually smooth but possibly having singularities in the form of cusps (figure 1); corners and isolated points are not structurally stable. In three dimensions the caustics are surfaces, which are usually smooth but which may have cusped edges and higher singularities at three types of isolated point that Thom calls 'swallowtails', 'elliptic umbilics' and 'hyperbolic umbilics'. And so on, up to six dimensions where the present classification ends. ~~(Arnol'd has extended~~

Special circumstances can often produce nongeneric caustics, that is, caustics which do not fit into Thom's classification. For example, the focus of a lens is highly special on account of the cylindrical symmetry and breaks up into a variety of forms when that symmetry is broken. Again, the nongeneric corners on figure 3 are made by shining light successively through two panes of glass each of which has a one dimensional system of ridges, the two sets of ridges not being parallel. The 'exactly-solvable models' beloved by the theoretical physicist are often nongeneric. Thom's theorem can frequently be invoked to determine what will happen when the special circumstances are removed; this ability to predict the details of symmetry-breaking is a powerful feature of catastrophe theory. Each corner on figure 3, for example, can be shown to be a special section through the hyperbolic umbilic catastrophe, and splits into a cusped inner curve and a smooth outer curve (as on figure 2) in the generic case.

On small scales, where the phase differences between contributing trajectories are of order π, each caustic has a characteristic diffraction fine structure. Thom's classification can be used to find the analytical form of each such wave pattern; this gives a new set of 'standard functions' which can be computed once for all. For example, the cusped caustic singularity is, on a fine scale, clothed with the function whose contours are shown on figure 4 (previously computed by Pearcey). In terms of these patterns, the full shortwave asymptotic form of any wave function can be calculated once the caustics of the corresponding trajectories are known.

The concept of genericity implies a methodology to which experimental physicists are somewhat unaccustomed. Instead of setting up a tightly structured situation and asking nature a precise question one tries as far as possible, by avoiding all special circumstances, to get her to display all structurally stable caustic forms. Searching for 'specimens' of catastrophe has more in common with botany than physics – the four hyperbolic umbilics on figure 2 are not congruent like four Ford cars but topologically equivalent like four roses. ~~(Report by R. Herman)~~

Heating plasmas

When hydrogen atoms combine to form helium, excess energy is released as kinetic energy of particles. One of the objects of fusion research is to devise a viable system in which this process could take place in such a way that the excess energy can be extracted and used. The rate of fusion depends on the energy spectrum of the particles involved, and is a maximum at temperature of about 10^8 K. At such high temperatures the atoms dissociate into a plasma of ions and electrons.

How can such high temperatures be produced and maintained? This problem was the subject of an Institute of Physics meeting held on 7 January 1976 at Imperial College, London.

The first paper discussed heating by injecting an energetic neutral beam into the plasma. Dr J G Cordey of Culham Laboratory described the theory of energy transfer from the incoming particles to the plasma. When the particles get into the plasma, charge exchange or direct ionization through collisions with the plasma particles leads to the production of fast ions and electrons. Since the ions are much heavier they carry most of the energy.

The slowing down of the ions is described by the Fokker–Planck equation. Dr Cordey showed that results calculated from the equation using a series of simplifying assumptions compared well with experimental figures. He went on to describe the heat transfer achieved in a number of different experiments worldwide, and also pointed out possible future refinement to theory. Dr E Thompson, also of Culham, completed the treatment by describing new methods of producing very energetic neutral beams. It is important that the beam should be energetic enough to penetrate well into the plasma so heating can occur throughout a large volume. A new focusing system for the beam using four electrodes (equivalent to a convex and concave lens) combines low beam divergence with high current density.

Professor A Offenberger of the University of Alberta described some exciting experiments using CO_2 lasers to heat the plasma. A number of problems have to be overcome: how to generate and confine a long slender plasma column, how to effectively couple the laser beam with the end of the plasma column, how to propagate the beam, how to confine the beam radially, and how to overcome all the other mechanisms for energy loss such as Brillouin backscatter. He reported that magnetohydrodynamic modelling of the problem gave encouraging results, although no totally selfconsistent solution was available. Experiments with a 1 m linear plasma in a solenoidal field showed that 85% of the laser energy went into plasma production and laser heating. Professor Offenberger felt that this was a promising new avenue for fusion research, and investigations would continue.

Professor Miklos Porkolab of Princeton University described theoretical investigations into the propagation of hybrid waves of wavelengths short compared with the plasma scale length, and their heating effects.

Results of experiments on the Tokamak ATC fusion reactor at Princeton agree with theory and show that this can be an efficient method of energy transfer.

Yet another heating method – injection of high current relativistic electron beams – was described by Dr A E Dangor of Imperial College. The problems of injecting these beams have not yet been solved. The EMFs induced by the current entering the plasma establish a return current which clearly reduces the net current passed into the plasma. If enough power can be concentrated in the beam to generate a significant net current this method could be used for heating plasmas. But experiments using the technique did produce larger net currents than predicted by theory.

One of the most exciting recent developments in fusion physics comes from the 'Alcator' experiment at MIT. Equipment there achieved a record value of 10^{19} s m^{-3} for the Lawson number $n\tau$, where n is particle density and τ is reaction time for fusion. It is generally believed that an $n\tau$ of 10^{20} s m^{-3} is the minimum value for an energetically self sufficient plasma. The new value is greater by a factor of five than has been achieved previously.

Burning bad fuels well

On page 14 of the January issue of *Physics Bulletin* an error was made in the last paragraph of the middle column. It should read 'Weinberg and Lloyd did not experiment on mixtures leaner than 1% methane in air'.