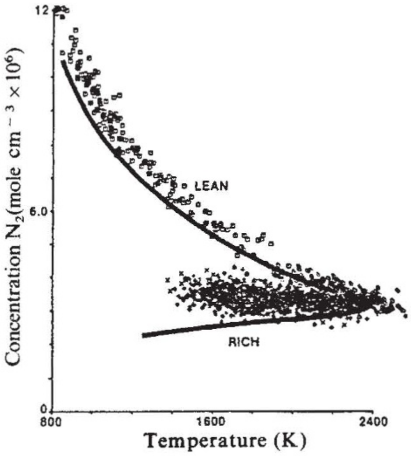

Fig. 3 Comparison of simultaneously acquired N_2 concentration and temperature data with a theoretical curve for a hydrogen air flame (taken from ref.9).

spectrum of nitrogen, Taran's work also demonstrated the possibility of CO_2 detection down to an estimated 1,000 p.p.m. and the measurement of CF_4 at around one per cent. The latter was injected into the combustion flow for short periods of time to infer residence times.

This approach of obtaining a spectrum by scanning the frequency of ω_s is satisfactory for demonstration experiments and laboratory gas samples, but it can lead to errors in determining mean values of temperature and concentration in fluctuating or turbulent conditions. Because the Raman spectrum is a non-linear function of temperature (it is a function of the Boltzman distribution of population of energy states), averaging varying spectra does not lead to a true mean temperature. In order to freeze these fluctuations in time, short-pulsed lasers are used (pulse length $\sim 10^{-8}$ s) and the complete spectrum is obtained in one shot. In conventional Raman this is simple since all of the spectrum is generated simultaneously, but for CARS to achieve the same result it is necessary to use a 'broad-band' laser at ω_s so that a complete section of a Raman spectrum is generated at the CARS signal frequency ω_{as}.

This approach has been very successfully developed by Eckbreth and co-workers[7] who have demonstrated single-shot broad-band CARS measurements in a variety of flames. In particular, they have measured temperature in a Pratt and Whitney JT-12 combustion can burning Jet 'A' fuel. Similar studies have recently been completed in this country on a Rolls-Royce 'Gem' combustion can fuelled with gas[8]. A typical 'single-shot' flame and a room temperature nitrogen spectra are shown in Fig.2, together with least-square fits of theoretical spectra. These spectra clearly show a large variation with temperature. In this study a sufficiently large number of 'single-shot' spectra from each geometric point was obtained to allow an estimation of both the mean and the r.m.s. of the temperature. Statistical information of this type is used to validate the aerodynamic type of mathematical model discussed earlier.

The above examples clearly demonstrate the potential for CARS spectroscopy for physical and chemical measurements in practical combustion devices, and suggest that CARS might replace conventional Raman as the preferred technique for combustion analysis. Complete replacement is unlikely since CARS is both financially and technically more demanding than conventional Raman, and the latter remains well suited to combustion measurements where signal strength and fluorescence rejection are not paramount. Indeed, fundamental combustion studies have clearly illustrated the wide-ranging ability of conventional Raman. Of particular interest is the work of Lapp and co-workers[9] where data have been collected simultaneously for temperature and nitrogen, hydrogen and water concentrations for each laser shot in a hydrogen air diffusion flame. Correlated data of this type can be very usefully compared with theoretical models. Such a comparison for a temperature–nitrogen concentration correlation is shown in Fig.3. Models of this type assume fast chemistry with the consequence that the combustion process is dominated by fuel air mixing. Although results show good

NATURE

100 YEARS AGO

THOUGHT-READING

THE public mind has of late been somewhat agitated by the doings of a Mr Bishop, who has come before the world of London society in a capacity no less startling than that of a professed reader of thought. He has not only taken by storm the general public and daily press, but also succeeded in convening an assembly of scientific men to witness his performance, while still more recently he has had the honour of exhibiting his powers before the Heir Apparent to the Crown. It seemed to Prof. Croom Robertson worth while to make a careful trial of Mr Bishop's powers, and he therefore invited Mr Francis Galton, Prof. E.R. Lankester, and myself to join him in an investigation.

First, Mr Bishop was taken out of the room by me to the hall down stairs, where I blindfolded him with a handkerchief; and, in order to do so securely, I thrust pieces of cotton-wool beneath the handkerchief below the eyes. While I was doing this, Mr Sidgwick was hiding a small object beneath one of the several rugs in the drawing-room; it having been previously arranged that he was to choose any object he liked for this purpose, and to conceal it in any part of the drawing-room which his fancy might select. I then led Mr Bishop up stairs, and handed him over to Mr Sidgwick. Mr Bishop then took the left hand of Mr Sidgwick, placed it on his (Mr Bishop's) forehead, and requested him to think continuously of the place where the object was concealed. After standing motionless for about ten seconds Mr Bishop suddenly faced round, walked briskly with Mr Sidgwick in a direct line to the rug, stooped down, raised the corner of the rug, and picked up the object.

It was soon found that Mr Bishop succeeded much better with some of us than with others; so at a second meeting, in order to make a numerical comparison, he was requested to try two experiments with each of the four persons who were present. With Mr Galton, Prof. Robertson, and Prof. Lankester he failed utterly, while with myself he succeeded once perfectly and the second time approximately. For on the first occasion I concealed a pocket-matchbox upon the top of a book behind the leather lap of a book-shelf. After feeling along the rows of books for some time he drew out the one on which the matchbox was lying. In the second experiment I placed a visiting-card on the key-board of a grand piano and closed the cover. After going about the room in various directions for a considerable time he eventually localised the piano, and brought his finger to rest upon its upper surface about six inches from the place where the card was lying. It has also to be mentioned that in one of the experiments which he tried with Prof. Robertson the evening before, he was, after a good deal of feeling about, successful in localising a particular spot on an ordinary chair which Prof. Robertson had selected as the spot to be found. From this it will be seen that it made no difference whether a particular article or a particular spot was thought of; for if the subject thought of was a certain square inch of surface upon any table, chair, or other object in the room, Mr Bishop, in his successful experiments, would place his finger upon that spot. Neither did it make any difference whether the article or place thought of was at a high or a low elevation. Thus, for instance, in one of the experiments I placed a small pencil-case high up in the chandelier of one of the drawing-rooms. While feeling over the surface of a table in the other drawing-room, and not far from the corresponding chandelier, Mr Bishop suddely pointed at arm's length vertically to the ceiling. He remained motionless in this position for a few seconds, and then set off at a brisk pace in a straight line to the other drawing-room, until he came beneath the other chandelier.

From this brief summary it will be seen that on the whole his power of localising objects or places thought of by a person whose hand he clasps is unquestionably very striking. Of course the hypothesis which immediately suggests itself to explain the *modus operandi* is that Mr Bishop is guided by the indications unconsciously given through the muscles of his subject. He describes his own feelings as those of a dreamy abstraction or "reverie," and his finding a concealed object, etc., as due to an "impression borne in" upon him. But however this may be all our experiments have gone to show that Mr Bishop owes his success entirely to a process of interpreting, whether consciously or unconsciously, the indications involuntarily and unwittingly supplied to him by the muscles of his subjects.

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