PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Concluding Remarks

G. B. Benedek

Phil. Trans. R. Soc. Lond. A 1979 **293**, 469-471
doi: 10.1098/rsta.1979.0113

Phil. Trans. R. Soc. Lond. A **293**, 469–471 (1979)
Printed in Great Britain

Concluding remarks

By G. B. Benedek

The papers presented at this conference have demonstrated the extraordinary range of information that can be deduced from experimental studies of the spectrum and the intensity of light scattered by matter. Indeed, these experiments provide detailed information on the energy level structure, dynamical motion and spatial structure of atoms, molecules, solids, fluids and synthetic and biological macromolecules. Each of the participants in this conference has given us the detailed analysis of his experimental studies on these various systems. I see it as my function to remind you, in the briefest way, of those physical findings which stand out most clearly in my own mind, without an effort to be complete.

When considering atoms, the work of Dr Svanberg on resonance scattering provides detailed knowledge of the energy level structure of the electronic multiplets. Dr Cohen-Tannoudji has discussed the possibility of, and the theoretical basis for, an understanding of the precise dynamics of the radiation process using 'antibunching' experiments.

For molecules, experimental studies of the Raman effect, and measurements of molecular polarizability by Dr Jones, Dr Madden, Dr Knaap and Professor Buckingham have provided accurate information on the moments of inertia and interatomic distances in molecules, the lifetimes of rotational and vibrational states and the electronic charge distribution through the polarizability.

For solids, Dr Patel has shown how the Landau levels in indium antimonide can be used to produce a laser light source with great monochromaticity and high power. By combining this 'spin-flip' Raman laser with the sensitive detection techniques of opto-acoustic spectroscopy he has been able to measure the temporal variation in the very low concentration of NO and NO_2 in the atmosphere and the stratosphere. Dr Cummins has shown how Raman and Brillouin scattering experiments in ferroelectric crystals can provide knowledge on structural phase transitions by detecting the softening of specific normal modes of the lattice vibrations as the transition is approached. Dr Pusey has created a uniquely interesting 'solid' made up of highly charged polystyrene latex spheres. By studying the spectrum and angular dependence of the intensity of light scattered from this system as a function of the degree of order, he can observe the development of the diffusive motion and the time average pair correlation function as the system of spheres evolves from a solution to a solid lattice.

For fluids, Dr Vinen has explained how his work and that of Dr Greytak on the spectrum of light scattered from liquid helium provides information on the rich variety of elementary excitation such as phonons, rotons (including a roton bound state), and second sound in this fascinating quantum fluid. Dr Pike has shown how optical mixing, or photon correlation spectroscopy of the Doppler shift in the light scattered from macroscopic motion in a fluid can be used to provide information on velocity profiles and turbulent motion in fluids. These methods are applied to systems as diverse as chimney stacks, vortices behind jet aircraft on takeoff and landing, and flames. In addition he uses these techniques to observe blood flow in the retinal microcirculation in the living eye as was first demonstrated by Dr Riva and his

collaborators. At the conclusion of his talk he showed some vivid, beautiful moving pictures of light scattered from a variety of dynamical fluid motions.

In the case of macromolecules, Dr de Gennes presented his theoretical predictions and the experimental findings of Adam & Delsanti on the radius of flexible polymer chains as a function of the number of monomers in dilute solution for both 'good' and 'poor' solvents. Following this, he presented scaling law arguments to describe the dynamical motion of entangled chains in concentrated polymer solutions. The application of scaling law ideas from the theory of critical phenomena to entangled polymer solutions and gels promises to provide a deeper understanding of these systems and their analogues, the biological gels such as the vitrous of the eye, synovial fluid and perhaps the cell cytoplasm itself. Dr Eisenberg presented his current findings on the interesting interactions between plasmid DNA molecules (from *E. coli*) and the histone proteins.The DNA molecules alone are monodisperse and undergo a variety of conformational changes as a function of the nature and condition of the solvent. Furthermore, the interaction between the DNA and the histone protein produces chromatin like chains whose dynamical behaviour can be studied by measuring the scattered line width as a function of the scattering angle. Dr Lewis and Dr Rentzepis presented their independent spectroscopic and picosecond pulse Raman scattering investigations of the primary photochemical changes involved in the absorption of light by rhodopsin. These investigations are leading the way to an understanding of the conformational and dynamical changes occurring in this important chromophore directly following the absorption of a photon.

As a number of participants have provided us with historical insight into the origins of light-scattering studies, I am encouraged to draw your attention to a brilliant insight made by Lord Rayleigh which relates closely to our discussions. In 1892, the *Philosophical Magazine* published in volume XXXIV, pp. 407–411, a letter from Lord Rayleigh to Professor A. Michelson entitled 'On the interference bands of approximately homogeneous light'. Michelson had inquired of Lord Rayleigh as to the mechanism for the width of spectral lines. In this letter, Rayleigh describes briefly each of the mechanisms with which we are now familiar, e.g. radiation damping, the effect of collisions ('encounters between neighbours'), and the Doppler broadening. Rayleigh further realized that 'there is another, perhaps more important, consequence of molecular motion, which does not appear to have been remarked', 'besides the motion of translation there is the motion of rotation to be reckoned with'. He then goes on to point out that (in modern language) the amplitude of the scattered field is modulated by the rotation of the molecule and considers a special case. 'Suppose for example that the axis of rotation is perpendicular to the axis of vibration,† and consider the radiation in a direction perpendicular to the former axis.' 'If ω be the angular velocity [of rotation and n the angular velocity of the incident field] then the vibration may be represented by

$$2\cos\omega t\cos nt = \cos(n+\omega)t+\cos(n-\omega)t.$$

The spectrum would thus show a double line whose components are separated by a distance proportional to ω.' Thus Rayleigh saw already in 1892 that the interaction of the exciting radiation with the molecular rotation would produce in the scattered light, sidebands at the vibration frequency of the molecule. In fact, in that letter he predicted the Raman effect 36 years before its discovery in 1928.

† By 'vibration' he means the direction of polarization of the exciting field.

As I have listened to each of the presentations at this meeting, I have been continuously impressed by the quantity and the quality of information which is now available for the characterization of the structure and the dynamics of atomic and molecular systems in the gaseous, liquid and solid states. This information is the result of most careful mathematical analysis of a variety of ingenious and delicate experiments. As physicists, we share a deep appreciation of this kind of precise, well founded knowledge, generally accepted and understood by a broad range of colleagues, bound together with a consistent theoretical framework and rooted in the fundamental laws of physics. When one thinks of the wide range of fundamental problems in fields such as immunology, in enzymology, in cellular biology and in organ or receptor physiology, it becomes very apparent that these rich subjects, now being explored largely with the best methods of biochemistry, can benefit greatly from the theoretical and experimental rigour and diversity which we have seen expressed in these discussions. And so, may I be a bit evangelical and encourage some few of you to study these borderline fields and then to use your analytical and experimental methods to contribute to them. I believe that you will find this a worthy and fruitful challenge.

Finally, I believe I speak for all the participants when I express my heartfelt thanks to the organizers: Professor A. D. Buckingham, F.R.S., Professor G. W. Series, F.R.S., Dr E. R. Pike and Professor J. G. Powles, and the Royal Society Staff, particularly Miss C. A. Johnson, for making it possible for us to come from many distant places to join together in these splendid rooms to meet and to talk about science together.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES