integrate devices in a second stage.

A search for new functionalities and new types of processes, and not just improvements in known devices, might provide the innovative thinking required. There is an increasing, worldwide effort. At the National Institute of Advanced Interdisciplinary Research in Japan, for instance, the Atom Technology Project has its sights set on the ultimate manipulation of atoms and molecules, as described above in hydrogen bonding to silicon surfaces. Somehow, industrial manufacturing and synthetic chemistry will merge on the nanometre scale; this is the idea behind designed self-assembly. As H. Rohrer of IBM Zürich put it in the final discussion, we should remember that "tomorrow is not an extrapolation of today". □

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INTERSTELLAR MEDIUM

Fullerene's faint fingerprint?

Harold Kroto

HISTORY has shown that astronomical observations can lead to some of the greatest advances in scientific understanding, from Newton's discovery of the colours of the Sun's spectrum, through the discovery of helium in the Sun to our understanding of the origin of the chemical elements as the products of nucleosynthesis in stars. Today, few more fascinating puzzles exist than the identities of the carriers of the diffuse interstellar bands (DIBs), a set of absorption bands seen in the spectra of stars observed through dusty regions of the Galaxy. On page 296 of this issue, Foing and Ehrenfreund[1] point to a possible culprit.

For sixty or so years it has been recognized that the DIBs are not associated with the stars themselves but with tenuous material in the space between the stars — the interstellar medium (ISM). Herbig[2] carried out a definitive and valuable overview of the characteristics of these features in 1975; since then the number of known DIBs has quadrupled from about 50 to about 200, largely because of advances in astronomical instrumentation.

The features are almost certainly caused by electronic transitions, but they are too broad to be due to free atoms. In recent years the consensus has been (arguably) that the carriers are moderate to large molecules, containing at least 6–10 atoms, where the breadth is due to unresolved fine (rotational) structure. But other suggestions, for example that they are small molecules whose spectral lines are broadened by predissociation, or atomic ions trapped in solid ice or other particles where the broadening is caused by interactions between the ions and the lattice, still cannot be ruled out completely.

Recently, however, the combination of advances in astrophysical spectroscopy, ingenious technical developments in the laboratory and some serendipitous discoveries has offered hope that the identities of these shadowy characters which lurk in the dusty highways and byways of the Milky Way may be on the verge of being revealed. Over the years countless guesses have been made, but a handful of laboratory and astronomical observations that are truly worthy of the problem have at last appeared.

For one, Krelowski and Walker[3] have obtained important 'family' correlations among the stronger features and thus shown unequivocally that there must be several carriers. Another considerable advance came when Sarre[4] and Fossey[5] recognized that one of the sets of related features was observable in emission (rather than absorption) from a planetary nebula. The most elegant and convincing experimental contribution to the whole story so far came from Maier's group last year[6]: they provided compelling evidence that some of the DIB features are due to highly unsaturated carbon chain molecules, C_nH_m, with $n = 6, 8 \ldots$ and $m = 1, 2$ (that is, molecules such as $C{=}C{=}C{=}C{=}C{=}CH_2$). Now, Foing and Ehrenfreund publish data on some new DIB features that they have discovered, which are tantalizingly consistent with laboratory measurements on the buckminsterfullerene positive ion, C_{60}^+.

These studies[1,3–6] stand apart from many previous contributions because in addition to containing reliable data they satisfy, perhaps for the first time in the long-drawn-out history of the DIBs, the essential criteria for good science: the results provide a clear basis for further investigation, and the proposed explanations are susceptible to verification or falsification by techniques that are accessible *now* — or nearly so.

In 1985, when C_{60} was first discovered, an immediate conjecture was that as the species was produced spontaneously under the same conditions as carbon chains and carbon soot — both known to be associated with the DIBs — it might in some way be responsible for some of the DIBs[7]. Indeed, one of the principal motives of the experiments that uncovered the existence of C_{60} (described in detail in ref. 8) was to probe the hypothesis made by Douglas[9] in 1977 that carbon chains might explain some of the DIBs. Ever since Klemperer's ingenious hunch[10] that a particular unidentified radio line might be the ion HCO^+, it has been clear that complex molecular ions are very abundant in the ISM and likely to give rise to prominent interstellar spectra. Such arguments led to the original proposal that the ion C_{60}^+ might be more abundant than the neutral species in the ISM[11] and to suggestions that other C_{60} analogues might be important in space[12].

The successful 'mass production' of C_{60} by Krätschmer and co-workers[13] was the key step that enabled laboratory spectra of the ion to be obtained by the groups of Schatz[14] and Maier[15]. Foing and Ehrenfreund have carefully searched the regions of astronomical spectra where these laboratory data suggest C_{60}^+ features should lie and have found bands which lie within the expected range. A note of caution is warranted, however: the spectra have, as yet, only been obtained in cold argon and neon matrices and are thus subject to matrix shifts from the gas-phase frequencies.

These new observations are undeniably exciting, although the final, definitive identification can only be made by fitting the astronomical features to those of the cold, isolated molecule. Nevertheless, Foing and Ehrenfreund have made a considerable step forward in carrying out this careful observation and analysis programme, and present a well argued case for the existence of C_{60}^+ in space. They clearly identify the final step: it is the measurement of gas-phase ion spectra in the laboratory. A formidable challenge, but not an impossible one, given the tremendous advances in molecular ion spectroscopy in recent years. I have every hope that very soon we will be able to say that C_{60} is indeed a "celestial sphere"[8]. □

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