INTRODUCTION

The discovery of C_{60} Buckminsterfullerene, Fig 1, has its origins in a research programme involving synthetic chemistry, microwave spectroscopy and radioastronomy. In 1915, at Sussex (with David Walton), the long chain polyyne \text{H-C_xC-C_xC-C_xC-C_xN} was synthesised and studied by microwave spectroscopy. Subsequently, with Takeshi Oka and NRC(Ottawa) astronomers, the molecule was discovered in space, Fig 2, by radioastronomy using the laboratory microwave frequencies.

This discovery led on to the detection of the even longer carbon chain molecules \text{HCTN}, \text{HCgN} and \text{HCl}_{11}N in the space between the stars. Further work aimed at understanding the formation of the chains in space focussed attention on the possibility that they are produced at the same time as carbon dust in red giant stars. During experiments at Rice University in 1985 (with James Heath, Sean O'Brien, Robert Curl and Richard Smalley), designed to simulate the conditions in these stars and explore their capacity for carbon chain formation, the exciting discovery that C_{60} was remarkably stable was made. It was found that under conditions where almost all the atoms in a carbon plasma had nucleated to form microparticles the molecule C_{60} remained behind - together with some C_{70}. This result was, as is now well known, rationalised on the basis of the closed cage structure shown in Fig 1. It was proposed that the geodesic and aromatic factors inherent in such a structure could account for the stability of the molecule.

THE CIRCUMSTANTIAL EVIDENCE FOR THE EXISTENCE OF FULLERENES

Many subsequent experiments, carried out during the period 1985-90 provided compelling evidence for the exceptional stability of C_{60} whatever its structure might have been. For instance support for the structure had been obtained by showing that the mass spectrometric magic numbers observed in cluster experiments were consistent with the formation of a whole family of closed cages, the fullerenes Fig 3. Particularly convincing was the fact that the smallest cages, in which all the 12 pentagons needed for closure are isolated, are C_{60} and C_{70}.

To explain the spontaneous creation of such an unexpected species in a chaotic carbon plasma a simple refined nucleation mechanism was developed. It was also recognised that the mechanism could not only account for C_{60} but it also explained the detailed structure of carbon microparticles such as those that Iijima had observed (Fig 4a). In this scheme it is proposed that when carbon nucleates, curved and closing graphitic shells form (rather than flat sheets as has
traditionally been assumed) and these wrap up under epitaxial control. It predicts that the embryos involved in carbon particle growth are partially closed cages which grow into quasi-icosahedral graphite particles. This mechanism explains the formation of the fullerene cages, C60 in particular, as resulting from closure during the general carbon microparticle formation process. It is proposed that embryos that do not close grow directly into graphite microcrystals essentially consisting of imperfect, concentric quasi-icosahedral spirally interconnected shells. The mechanism is supported by simulated TEM images (Fig. 4b) derived for the structures predicted by the new scheme which show excellent agreement with the elegant electron microscope images of carbon microparticles obtained by Iijima in 1980, Fig 4a.

It was also recognised that there were significant similarities between the structures of the pure carbon particles and soot particles; both could be explained by essentially the same scheme (albeit in perturbed form for soot). This proposal has been criticised on various grounds, however detailed analysis of soot reveals that there are numerous serious gaps in our understanding of the formation process, indeed sufficient to show that the new scheme cannot be discounted readily. Harris and Weiner said, in 1985, that "...knowledge of the chemistry of soot formation has been totally absent," so there would appear to be some room for some fresh ideas on the chemistry involved. The new mechanism does appear able to explain many observations more simply than some previous models such as those involving liquid droplet formation in which it appears the substructure is thought to be held in place van der Waals forces. The mechanism predicts that C60 should be a by-product of the soot formation process. Interestingly Gerhardt, Löffler and Homann subsequently showed that C70 is the major ion in a sooting flame. Homann has however pointed out that this observation is not necessarily to be taken as support for the new scheme.

THE PRODUCTION AND CHARACTERISATION OF BUCKMINSTERFULLERENE

In August 1990 the scepticism which surrounded the original fullerene-60 proposal was finally laid to rest by the breakthrough made by two groups, Krätschmer, Lamb, Fostiropoulos and Huffman (Heidelberg/Tucson) and Taylor et al (Sussex). From the carbon deposit produced from arc processed graphite Krätschmer et al obtained a crystalline material. X-ray analysis showed it to consist of arrays of spherical C60 molecules of exactly the expected size. Mass spectrometric and infrared data were further confirmation. From similarly processed graphite Taylor et al also obtained mass spectrometric evidence for fullerene-60 and also extracted a red solution (in benzene) independently. Subsequently they chromatographically separated the material into two components C60 and C70. The 13C NMR analysis of the beautiful magenta solution of C60 yielded a single line resonance (Fig. 5) indicating that all the C atoms in the molecule are equivalent! A result perfectly commensurate with the proposed fullerene-both structure. Elegant support came from the spectrum of C70 which showed that it had five lines. (Fig 5b), again in perfect agreement with expectation. This result was also important as it showed that other members of the fullerene family existed.
Since this breakthrough was made in September 1990 the field has exploded and all aspects of the chemical and physical properties of the fullerenes are now being investigated in minute detail. The fact that this new, third form of carbon exists, is created spontaneously and has been under our noses since time immemorial is somewhat difficult to accept. Indeed fullerenes appear to make up some 10-30% of the material produced by the carbon arc and it has now been shown to reside in soot. Howard and co-workers who have found the fullerene content of soot from a benzene flame can be as high as 7% under certain conditions.

These observations have major implications; in particular for:

1) The composition of carbon vapour,
2) The mechanism of carbon nucleation,
3) The structure of graphitisable carbons,
4) Fluid carbon phases,
5) Soot formation,
6) The structure of interstellar and circumstellar grains,
7) Structure and synthesis of new polyaromatic hydrocarbons,
8) New metal-carbon complexes and intercalation compounds

New advances are made every day as the material becomes more and more accessible and a complete review of the material published on C\textsubscript{60} Buckminsterfullerene by the end of 1990 has been written\textsuperscript{4}.

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LITERATURE CITED

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12. H W Kroto (in preparation)
Fig 3  *Family of relatively stable Fullerenes*\(^5\)

Fig 4  *Comparison between TEM images of polyhedral graphite microparticles observed by Iijima*\(^9\)  a) and simulated images for a hypothetical icospiral microparticle (two different angles) b)
Fig. 1 $C_{60}$ Buckminsterfullerene.

Fig. 2 Radio line of $HC_3N$ observed in a giant molecular cloud SgrB2 near the center of the Galaxy.
Fig 5  $^{13}C$ NMR spectrum of Fullerene-60