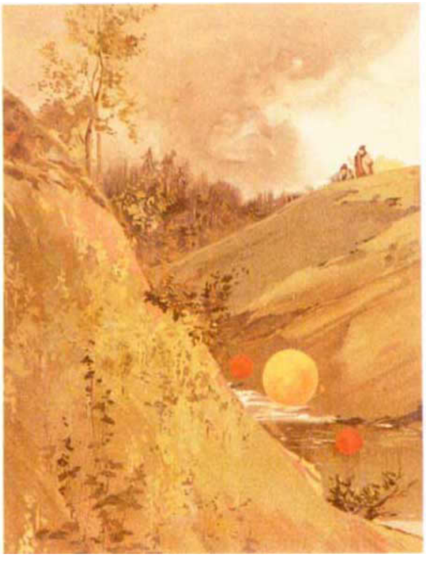
high velocity. Similarly, the plasma physicists B. M. Smirnov and E. Witalis have concluded independently that ball lightning cannot be a plasmoid. Smirnov is presently considering fractal combustion models with an aerogel structure[5].

Three types of fireball have been noted in laboratory experiments having qualitative resemblance to ball lightning. These laboratory fireballs are the globes formed in dilute mixtures of fuel gas in air, in some radiofrequency gas discharges and luminous spheres produced from metal wires by electric discharge. None of these is yet adequately understood. All show the possibility of a lifetime sufficient to account for that of ball lightning and, in some cases, have additional properties associated with ball lightning. In previous work, Ohtsuki and Ofuruton studied the ignition of dilute fuel gases. They failed to duplicate the previous results of investigators who produced long-lived fireballs in homogeneous gas mixtures. They found it necessary to add combustible aerosol particles for the formation of fireballs.

Now Ohtsuki and Ofuruton have turned their attention to radiofrequency discharges, as reported in this issue. The new results confirm the long lifetimes observed in previous studies. But more important is the observed motion of the fireball against the flow of air in their system (confirming one of Kapitza's predictions) and passage without damage through a ceramic surface placed in the experimental system. In reproducing these most unusual aspects of ball lightning, the new work represents a considerable advance over previous studies on radiofrequency discharges, including one by Tesla, which were largely limited to describing qualitative properties of lifetime, shape and colour.

In other recent theoretical work, analyses have been made of spherical fireballs containing internal electromagnetic radiation trapped by a surface plasma layer[6,7]. The trapped radiation provides the continuing energy needed to maintain the sphere for the observed long lifetime. This mechanism may be related to Kapitza's theory if the plasma ball is permitted to trap some of the radiation that leads to its formation, rather than expelling it. Also, an experimental paper[8] showed that a filamentary aerogel can form in a strong electric field through the aggregation of aerosol particles. This process was anticipated in the work of Cawood and Patterson[9] on the electrostatic coagulation of small dye crystals suspended in air. Very demanding experimental conditions are needed for the laboratory synthesis of aerogels which have been suggested as a structure of ball lightning. ☐



Mary Evans

Silent, vanishing balls of fire at Agé, near St Petersburg, 1888.

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PHOTOSYNTHESIS

Absorbing developments

M. C. W. Evans and J. H. A. Nugent

PHOTOSYNTHETIC organisms have two tasks in the early stages of photosynthesis. One is to operate an efficient process whereby solar energy is converted to chemical energy; the other is to capture photons with a high efficiency and at reasonable metabolic cost. Energy conversion is carried out by photosynthetic reaction centres, in which the initial solid-state photochemical reactions take place in picoseconds, and knowledge of the mechanisms involved has advanced rapidly as the result of a combination of spectroscopic and crystallographic work on the purple bacterial reaction centre[1,2]. Our understanding of light harvesting is less good. But as Kühlbrandt and Wang demonstrate on page 130 of this issue[3], here too rapid advances are being made using the electron crystallography techniques developed by Henderson with bacteriorhodopsin[4]. This technique allows detailed structures to be developed from the two-dimensional crystal arrays available for these proteins and has now resulted in the determination, to 6Å resolution, of the structure of a pea light-harvesting complex.

```
Helix A
                56                                 91
                 - -   + +- -  + +            -   +
                 DPETFAKNRELEVIHSRWAMLGALGCVFPELLSRNG
                  ............::::============:::::.

Helix B
               170                                 206
                 - -   - + +- +  +                 +
                 DPEAFAELKVKELKNGRLAMFSMFGFFVQAIVTGKGP
                  .............::::================:.

Helix C

                      117                        143
                           +                   - +
                      PSLVHAQSILAIWATQVILMGAVEGYR
                         ::=================::
```

Amino-acid sequences (single-letter code) of the transmembrane helices of a pea light-harvesting complex. Helices are labelled A, B, and C, as by Kühlbrandt and Wang[3]. The hydrophobic core of the membrane is approximately 30Å or 20 helical amino-acids wide. Structure prediction indicates that helices A and B extend beyond the membrane and that the lipid phase may contain charged amino acids. The uncharged core of the predicted membrane span is shown as [=], residues near the edge of the membrane span as [:] and the possible helical extension at the N termini of helices A and B as [.] Helix C forms a 'classic' transmembrane helix with a stretch of about 20 uncharged amino acids spanning the lipid bilayer.

Reaction centres and their associated electron-transport chains are complex structures that are metabolically expensive to make. The photochemical energy-conserving reaction takes place in a pair of chlorophyll molecules in a special environment. But even in bright sunlight individual chlorophyll molecules will be hit by a photon only about once a second. The problem of providing effective light absorption and rates of energy transfer to the reaction centre at low metabolic cost has been overcome by surrounding the reaction centre by a bed of pigment molecules — the light-harvesting or antenna complex — which must be organized to provide efficient energy transfer. Following the absorption of a photon, the excited state generated can migrate to other chlorophylls very rapidly by one of two routes (delocalized exciton coupling or Förster transfer). The excitation follows a random path through the pigment bed but is effectively spiralling down an energy gradient to reach the chlorophyll in the reaction centre, which absorbs longer wavelengths and therefore lower energies. In practice, plant reaction centres may therefore turnover more than 100 times per second and operate at maximum efficiencies at low light intensities.

The structure and efficiency of the pigment bed supplying the reaction centre must be optimized by specific positioning of pigments within pigment protein complexes of the photosynthetic membrane. In higher plants the main components of the pigment bed are the chlorophyll *a/b* binding (CAB) proteins. From secondary structure analysis CAB polypeptides are predicted to have two to four membrane-spanning helices, although a three-helix model is widely accepted[5]. Kühlbrandt and Wang identify three helices. But this highlights a problem with some of the putative membrane-spanning helices in CAB proteins, namely that it is impossible to model three helices without including charged residues in the membrane (see figure). The CAB helices are also interesting in that two are considerably longer than expected or required simply to cross the hydrophobic part of the membrane, and are longer than those found in the reaction centre or bacteriorhodopsin, which may indicate some anchoring or binding function outside the membrane.

Another question which must be answered for light-harvesting complexes has to do with where the chlorophylls are bound. Crystals of bacterial light-harvesting proteins contain only 18 chlorophylls in an oligomer of relative molecular mass 84,000 (M_r 84K)[6], whereas the CAB proteins contain 15 in a polypeptide of M_r only 25K. Chlorophyll appears to be associated with specific residues within reaction centres, the 'traditional' residues being histidine, glutamine and asparagine. But there are not enough highly conserved residues among the family of CAB proteins to bind the associated chlorophylls. Unless there are specific residues in each type of CAB, this implies that there is some other form of liganding through water molecules of backbone carbonyls. In the structure determined by Kühlbrandt and Wang, the chlorophylls are arranged on the outside of the protein, which may perhaps facilitate energy transfer to the reaction centre or between CAB molecules. Combination of the results from further refinements of the present structure, with results from X-ray analysis of three-dimensional crystals of the light-harvesting protein from purple photosynthetic bacteria[6], will allow the development of a full model of light-harvesting structures.

As is only to be expected, the partial resolution of a protein structure poses many more questions than it answers. Inevitably we must ask for even greater resolution and detail, and we need to distinguish the chlorophyll *a* and *b* molecules and define their absorption wavelengths. From the present structure it would seem that there is heterogeneity between the parts of the protein in each leaflet of the lipid bilayer. Does this mean that there is a particular pathway in or out of the monomeric complex to other similar complexes or to the reaction centre? Each plant species contains a number of CAB proteins, and although the structure determined by Kühlbrandt and Wang seems to offer a general model there must be small but important differences between them. The most important question will be how these proteins interact with the reaction centre to provide effective energy transfer. ☐

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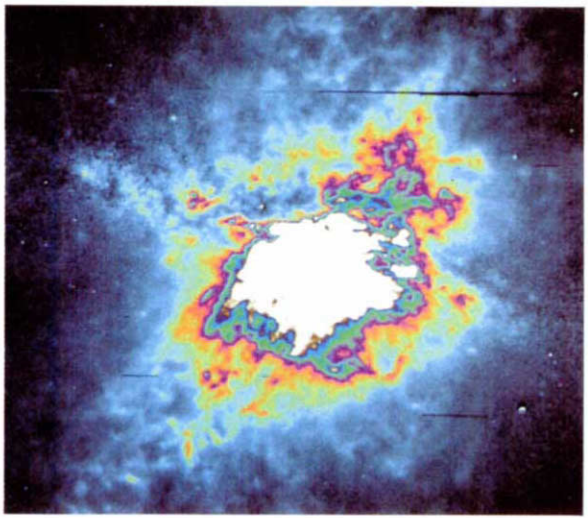
MILKY WAY

Not with a whimper

Leo Blitz

THE centre of the Milky Way appears to be primed to explode in a profusion of star formations leading to the explusion of vast amounts of matter from our Galaxy. This is the conclusion of A. Stark and colleagues, based on an analysis of radioastronomical observations of the central regions of the Milky Way and reported in the *Monthly Notices of the Royal Astronomical Society* (**248**, 14p – 17p; 1991). This starburst will occur 10–100 million years hence, they suggest, a time very short compared to the age of either the Milky Way or the Solar System.



The prototypical starburst galaxy, M82. The image shows an extensive system of filaments extending several kiloparsecs above and below the starbursting disk. The kinematics and other physical properties show that gas is flowing out in a large-scale bipolar patter, probably driven by the starburst. The colours in this false-colour image indicate the intensity of line emission (Balmer–α) from atomic hydrogen. (Courtesy of T. Heckman and L. Armus.)

The Milky Way has been known for some time to harbour massive clouds of gas and dust in its central regions. Similar but smaller clouds occur throughout the disk of the Galaxy, and are the material from which new stars form. Known as giant molecular clouds, these objects are composed primarily of molecular rather than atomic hydrogen, and are typically a hundred to a thousand times denser than the mean for interstellar gas. In our part of the Galaxy, about half way out in the disk, giant molecular clouds typically have enough material to form about 100,000 stars with a mass like that of the Sun. The efficiency is known to be low, however, and only a few per cent of the gas is actually turned into stars.

Occasionally, a few stars form, known as O stars, that are so bright that the radiation from their surfaces accelerates a wind of ions at velocities up to about 1 per cent of the speed of light. The Sun also generates a wind of ions, but at rate as much as 10^{10} times weaker than the O star. The ultraviolet radiation from the O stars is so intense that it destroys (by dissociation and ionization) the molecular clouds out of which they are born in a sort of cosmic matricide. Finally spent in the relatively short time of 3 million years, an O star suffers a cataclysmic explosion visible as a supernova which leaves a remnant neutron star or black hole.

In our region of the Milky Way, giant molecular clouds typically form fewer than 10 O stars at any one time, and although the phenomena associated with these stars are quite spectacular, their small numbers ensure that their effects are limited to a relatively small volume near the stars themselves. In the centres of some galaxies, however, the star formation is so vigorous that as many as a million O stars are formed almost simultaneously. The collective effects of these stars can produce a brilliant galactic nucleus and give rise to spectacular ejections of matter from stellar winds and supernova explosions. These rare galaxies, known as starburst galaxies, contain unusually large concentrations of molecular gas at their centre. The nearest example of a starburst, shown in the photograph, is the galaxy M82. The bright nucleus is hidden by the intervening dust, but the disturbed appearance testifies to the enormously energetic activity going on at the centre. In spite of its spectacular appearance, as starbursts go, M82 is rather wimpy.

It has been known since the 1970s that the nucleus of the Milky Way contains a vast reservoir of molecular gas — enough to make more than 10 million O stars if all of the gas could be converted this way. But until recently, there was no reason for supposing that this gas could not maintain itself in stable orbits around the centre, or at worst spiral slowly and harmlessly into the centre owing to the viscosity of the gas. What Stark *et al.* have shown is that the molecular gas that is collected into the largest discrete clouds, which are a substantial fraction of the total, will inevitably spiral into the nucleus in a time no more than about 1 per cent of the age of the Milky Way, and perhaps considerably less.

The reason for this is dynamical friction, a gravitational analogue of what happens if one suddenly shuts off the motor of a boat ploughing through the water. Most of the stars in the nucleus of the Milky Way are part of the central bulge which contains stars ro-