smaller than expected. This appears to suggest that the theory is basically correct, but that it requires further refinement. One possibility raised by the authors relates to what may happen when two vortex lines collide with each other at an angle (Fig.2*a*). They may cross each other, somehow reconnecting more or less as they were before the collision but with a few local wiggles caused by the mutual interaction of their flow fields, as in Fig.2*b*. Alternatively, they may 'topologically cross-connect', as shown in Fig.2*c*, so that what was the top end of one line joins to what was the bottom of the other and vice versa. The latter process gives rise to a more substantial curvature of the lines and thus, it can be shown, to a greater rate of line shrinkage, corresponding to a faster net decay of the line density. Thus, one possible interpretation of the present results would be that topological cross-connection processes are much rarer in comparison with line-crossing processes than had been assumed.

In any case, one may hope that further developments in both theory and experiment will now follow, leading eventually to a detailed understanding of the microscopic processes responsible for the decay of quantized vorticity in superfluid helium — something which many people had believed would remain forever a mystery. □

Polymers for solar energy

from Paul D. Calvert

IF silicon photovoltaic cells are to become widely used to generate power from sunlight they must become much cheaper to make, more rugged and longer-lived. This requires improvements not only in the photoactive material but also in the encapsulation, the packaging which will protect the silicon from the outside world. It seems sensible to use plastics in the encapsulation rather than expensive and heavy constructions of steel and glass. Unfortunately, many polymers degrade rapidly when exposed to bright sunlight or high temperatures (50°C and upwards), so there are great difficulties in finding suitable materials for solar cells. An American Chemical Society symposium in March brought out these problems. The preprints can be seen in *Polymer Preprints* Vol. 23, no.1.

Much of the work in this area is sponsored by the US Department of Energy, particularly through the 'Low Cost Solar Array' project at the Jet Propulsion Laboratory (JPL). The goal is to produce modules with an efficiency of 10 per cent and a 20 year lifetime for \$70 m^{-2}. Of this \$14 m^{-2} is allotted to the encapsulant system — a figure greatly exceeded by current systems which use aluminium, glass panels and silicone seals.

A particular problem is the pottant, a soft transparent polymer which serves to surround and protect the brittle silicon cell. Ethylene-vinyl acetate copolymers are favoured but it is doubtful whether they will last for 20 years without discolouration or embrittlement. To test stability conveniently it is necessary to accelerate ageing through the use of high temperatures or intensified natural or artificial light. ARCO Solar Inc. showed with such tests that the pottants degraded where they contacted the cells or the metal connections. Unfortunately, accelerated ageing tests are themselves notoriously unreliable. In the future, more reliable tests might be possible by using highly sensitive spectroscopic methods to follow the slow degradation process under natural conditions early in the life of the polymer. A JPL group is developing laser photoacoustic spectroscopy while at the Solar Energy Research Institute (SERI) a Fourier-transform IR spectrometer is

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Plant biology at the Carnegie Institution

from D.O. Hall

THE *Annual Reports of the Department of Plant Biology of the Carnegie Institution of Washington, University of Stanford, California* make compulsive reading — unlike most annual reports. The latest issue is a most useful summary of recent research and a reminder of how a small, well directed laboratory can produce world-renowned research.

Of particular interest are the reports covering desert plant survival under extreme conditions like those found in Death Valley where the temperature varies daily from 0 to 45°C. Much has been learnt about the photosynthetic carbon paths used, biochemical responses to changing temperature and how components of the membrane enable them to function at high temperatures. For example, *Camissonia* shows the highest photosynthetic capacity recorded to date; an attribute associated with exceptionally high levels of the CO_2-fixing enzyme ribulose-1,5-bisphospate carboxylase oxygenase (Rubisco). This attribute is common to a number of plants but, exceptionally, *Camissonia* has a Rubisco enzyme with a higher specific activity; it is thus both more abundant and more efficient.

The various types of stress that interact to limit photosynthetic processes — the damaging effects of extreme temperatures, limitations in CO_2 availability and water stresses, in combination with high and low light intensities — can be described by the catch-all term of photoinhibition. Photoinhibition is well defined as the "damage to photosynthetic capacity occurring when more light is absorbed by a leaf than can be used by normal photosynthetic reactions . . . it can be induced by any factor restricting utilization of the reducing power generated by light-driven electron transport". Since photoinhibition is widespread and results in decreased photosynthetic capacity, this pioneering work relates closely to optimizing potential yields from photosynthesis. Specific studies using higher plants and algae and a variety of techniques all point to the conclusion that degradation of the oxygen-evolving reaction (photosystem II) is the main manifestation of photoinhibition under stress regimes. If excess light energy can be dissipated the plant is able to survive.

The ratio of photosystems I to II in the chlorophyll membrane need not be unity, as is often assumed, but can vary depending on the light regime under which the plants are grown. Shady environments or incandescent lights, for example, both of which have more infrared, result in more photosystem II reaction centres and more granal membranes synthesized. Work is also reported on the role of the chloroplasts of the guard cells of stomata which do not show photosynthetic CO_2 fixation but whose movements are strictly controlled by light. Chloroplasts can now for the first time be isolated from guard cells; they catalyse both photosystems I and II and can make ATP which is consumed when CO_2 is present — by an as yet unknown mechanism.

Finally, the reports from the molecular biology group show how much progress they have made since they were established five years ago. The use of three new pea clones, for example, enables the fine structural organization of repetitive DNA to be documented, which also demonstrates the elegant fine tuning and organizational properties of specific fragments of this DNA. A new emphasis is emerging which will use molecular biological approaches to study the problems identified by physiological research as being so important to plant productivity.

The reports will all probably be published but to have them summarized and documented in detail in a short book is an annual pleasure. Winslow Briggs, the Director, need not be modest in claiming that "they represent a fine record of high-caliber productivity". □

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being developed to allow measurements to be made while polymers degrade in the instrument under controlled conditions.

The pottant must be protected from solar UV by an absorbing material on the sunside surface. Glass could be used but it is heavy and fragile. A polymer film would be highly suitable but must be very resistant to degradation. Very few clear polymer films will remain tough for long in bright sunlight. Of a great range tested by Boeing in concentrated Arizona sunshine (and for hail resistance with an intriguing iceball throwing machine!) only two fluorocarbons — polyvinyl fluoride and polyvinylidene fluoride (trade names Tedlar and Kynar) — stood up to 10 (accelerated) years without embrittlement or discolouration. Various other points must be kept in mind. The fluorocarbons are not cheap materials and polyvinylfluoride also has the drawback that it is very difficult to process. The stability of the fluorocarbons is thought to be due to the strength of the carbon–fluorine bond but little work has been done on oxidation of these materials and it is not clear how this protects the normally vulnerable C–H bonds in the molecule. Dust tends to stick to the surfaces of polymer films and reduce the transmitted light intensity. Fluorocarbon films, however, seem to be self-cleaning, probably because a surface film forms and washes off with the dust when it rains.

Films are also needed as covers for heated water solar collectors and, when metallized, have been used as 'inflatable' mirrors. There is thus a real requirement for a cheap, transparent photostable film. A group at Brookhaven National Laboratory has designed a solar collector for roof mounting which is made from all thin film materials stretched on a steel frame and estimates that it can thus achieve a tenfold reduction in weight and a fivefold reduction in cost.

As well as passive uses, the symposium provided examples of polymers in the active role, replacing the silicon in photovoltaic cells. Preliminary studies were reported on polymeric phthalocyanines from Xerox of Canada, on heat-treated polyacrylonitrile and on polyacetylene. These materials offer the potential of cheap photocells using powders or thin films as opposed to expensive silicon single crystals. Amorphous silicon already represents a move in this direction. However, these relatively disordered systems are characterized by a high density of defects so that few of the freed electrons manage to travel from the point where light is absorbed to the electrode. Thus pure single crystal silicon reaches efficiencies above ten per cent, amorphous silicon is cheaper to produce but reaches an efficiency of two to three per cent while the organic films are only producing fractions of one per cent in efficiency. Hence the prospect of solar power from polymer painted on the roof of a house is a long way off. □

Tree rings and archaeology: dating Roman oaks

from J.M. Fletcher

THE recent discovery of the wooden foundations for a Roman bridge across the Rhine at Koblenz has provided an exciting opportunity for European dendrochronology to prove its worth to archaeology. The dating of the bridge was one of the topics discussed at the recent workshop organized by the European Science Foundation which brought dendrochronologists and archaeologists together at the Wood Biology Institute of the University of Hamburg.

The site of the bridge had been identified when waterway engineers, searching in a large bell for underwater objects which might be a danger to shipping, found stumps protruding from the silt. They appeared to be remains from 600–700 piles which had supported pillars that carried the bridge. For each pillar the Romans had inserted into the river bed, on a regular grid, 25 oak piles estimated to have been 10–15 m long. They were the trunks, about 50 cm wide, of slow-grown trees about 250 years old when felled. From the widths of the rings on stumps extracted from the river bed B. Schmidt (University of Cologne) was able to date construction of the bridge accurately to AD 49 — an achievement possible because of the tree ring chronology built up for central Germany and because some of the stumps retained all their sapwood. Schmidt also concluded that to provide the straightness necessary for being driven into the ground, the oaks were *Quercus petraea* rather than *Q. robur*, and that the level of the Rhine at the time was about 1.5 m higher than at present.

Other applications described at the workshop ranged over several millenia and illustrated the magnitude of the research. Oak, as for the Roman bridge, was the wood used in the numerous Neolithic and Bronze Age settlements by the side of Swiss and other lakes formed as a result of the Ice Age around the Alps. Thousands of samples excavated from more easily available sites are enabling U. Ruoff (University of Zurich) and H. Egger (University of Neuchatel) to place the settlements in a chronological pattern.

Further north, B. Becker (University of Hohenheim, Stuttgart) and others in Germany have extracted hundreds of oaks from the gravels which mark the ancient course of rivers, such as the Danube, Rhine and Main. The widths of their annual rings have enabled a long oak chronology going back many millenia to be constructed for central Europe. It almost rivals in length the chronology derived from conifers, including bristlecone pine, which grew in the western part of the US. This European work is of great importance to archaeology for it allows the calibration of radiocarbon results. There has been concern that the American chronology, on which calibration has hitherto been based, may not apply to Europe and other areas. In fact the two calibration curves agree closely in spite of being based on different species, growing in different geographical locations and at different altitudes. Furthermore, by confirming the secular oscillations, or 'wiggles', the European work opens the way to their use as indicators of climatic variations in the distant past.

Another application, to the archaeology of classical, Byzantine and medieval times in the Near East, comes to many as a surprise. Few believed that enough timber had survived in that region to make tree-ring dating a viable technique. In fact, P. Kuniholm (Cornell University), with the enthusiasm and persistence of an explorer, has established chronologies for conifers from Greek and Turkish samples obtained from tombs below ground, and temples and churches above ground. Even the Parthenon and similar temples have contributed to the project, as a small block of wood, known as an *empolion*, was inserted at the interface of each cylindrical 'drum' that built up a column. Small though they were, these pieces often had more than 100 rings of annual growth. The slowness of the growth of the Near East conifers, like that of those in the arid south-west of the US, is a help to the dendrochronologist: a millenium can be covered by relatively few samples while the growth pattern of such slow-grown trees is distinctive and provides reliable matching. As with oaks in north-western Europe, the patterns from trees with narrow rings often match even when grown far apart.

There remains, however, scope for replacing obsolete methodology and for improving the quality of oak chronologies in north-west Europe, since D. Eckstein and S. Wrobel (University of Hamburg) reported that success with dating in the North German plain sometimes amounted to only 50–60 per cent for archaeological samples. This may partly reflect the failure to make use of *weisejahre*, the years in which the change in growth (an increase or decrease in ring-width) is sufficiently consistent among the many samples which form a chronology to act as indicators. These have proved helpful in the more maritime and temperate parts of Europe in matching and thereby dating the fast grown samples of oak, with relatively few annual rings, that form a substantial proportion of building timber.

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