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John Allen looks at research casting new light on how plants convert the Sun's energy

Unravelling a green mystery

ACROSS the country, the British are trying to tame the most important biological process on earth. The familiar ritual of extracting lawnmowers from their winter hibernation and distracting the quiet of suburban weekends is prompted by the unruly spring growth of grass. For most people this is the most obvious sign of the power of photosynthesis: the ability of green plants (and other living cells) to harness the energy of the sun's light.

Without exception, everything that happens in the living world needs energy to make it run. All this energy ultimately comes from the Sun, where hydrogen atoms fuse at very high temperatures to make helium and radiant energy, including light. Yet many of the details of how photosynthesis works are still unclear. The 1988 Nobel prize for chemistry went to three German biochemists who worked out the structure that cells have built up to convert sunlight into useful energy.

The energy in our food was converted from radiant energy recently, when the plants that we eat used sunlight for their growth. So the wheels of a bicycle are driven by nuclear fusion that happened a few years ago in a reactor at the safe distance of 93 million miles. The wheels of a car go

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round for the same reason, but in that case the energy was converted long ago, when 100 million years of sunlight was compressed into the coal, oil and gas on which our style of civilisation can briefly depend.

Photosynthesis has come a long way in the 3,000 million years or so of evolution, but we can still glimpse its essential features in the membranes of the cells of green plants, algae and photosynthetic bacteria. In all cases, a network of "light harvesting" pigments collects light and channels it to the "reaction centre" where energy conversion occurs.

The detailed structure of the molecular machine — the reaction centre — that carries out this crucial, early event of photosynthesis was revealed by Johann Deisenhofer, Hartmut Michel and Robert Huber of the Max Planck Institute for Biochemistry at Martinsried near Munich, in their 1985 report on the research that won them the Nobel prize.

In a technical *tour de force*, they made X-ray diffraction studies of crystals obtained from the photosynthetic membranes of purple bacteria. Though protein crystallography has been done for some time, their studies were the first of a membrane protein, which is intrinsically more difficult to crystallise than water-soluble proteins like haemoglobin. The studies revealed the structure that underpins processes scientists felt had been going on inside the photosynthetic reaction centre.

The reaction centre converts the energy of sunlight into electrical energy when the green pigment, chlorophyll, loses an electron to a neighbouring molecule of the closely related substance, called phaeophytin. The phaeophytin must hand the electron on to a quinone molecule, and a series of other molecules in turn play "pass the electron". In the final part of the game, the energy is transformed again — from electrical into chemical energy stored in a molecule known as ATP.

The studies revealed a structure that fits the Identikit picture of a reaction centre that had been put together from indirect evidence. It shows four chlorophyll molecules, two phaeophytin molecules, a quinone molecule and an iron atom held in a very precise symmetrical arrangement by three large protein molecules. These proteins are plugged through the cell membrane and folded around and between the other molecules, even including a quinone-shaped hole for a second quinone molecule. The relative positions and orientations of these molecules reflect the individual steps of electron transfer in the reaction centre.

So the first and fundamental step of energy conversion in photosynthesis is the movement of an electron from one of the four chlorophylls to the adjacent phaeophytin. This takes several millionths of a millionth of a second. The electron moves to one quinone in just less than a millionth of a second and on to the second quinone in just less than a thousandth of a second.

The photosynthetic membrane of a cell also contains an array of light-harvesting units to collect light in the way that a satellite-dish antenna collects radio waves. For light must be harvested by this array of chlorophyll molecules before the reaction centre can work. Whatever its structure, there are things we already know about the antenna of chlorophylls and proteins that harvests light. For example, the antenna must be large and operate at high efficiency when sunlight is in short supply — but a sudden, bright shaft of light will then dangerously overload the energy converting, reaction centre unit if there is no way of regulating the supply of energy.

Green plants can regulate the way light-harvesting and reaction centre units work together by subtly modifying the chemistry of their protein molecules. This chemical modification, *phosphorylation*, was discovered by John Bennett at Warwick University in the late Seventies. The effect is to disconnect a part of the light-harvesting unit from its neighbouring reaction centre, and so decrease the amount of energy that is presented to the reaction centre for conversion.

But what does the detached, phosphorylated light-harvesting unit do with the light it has absorbed, but cannot pass on for conversion? Some groups believe that the energy is converted wastefully to heat, while others believe it is redirected to a different kind of reaction centre, in which case it may be saved.

We will be able to understand the process only when molecular structures are available for the phosphorylated and unphosphorylated proteins. But a subtle modification of existing proteins is not enough to explain the great differences between plants or cells grown in sunny and shady environments. Here at Leeds University, we think that the switch that controls phosyphorylation also controls the activity of the genes that give rise to the light-harvesting and reaction centre components. We need to know how these genes can be turned on and off by light.

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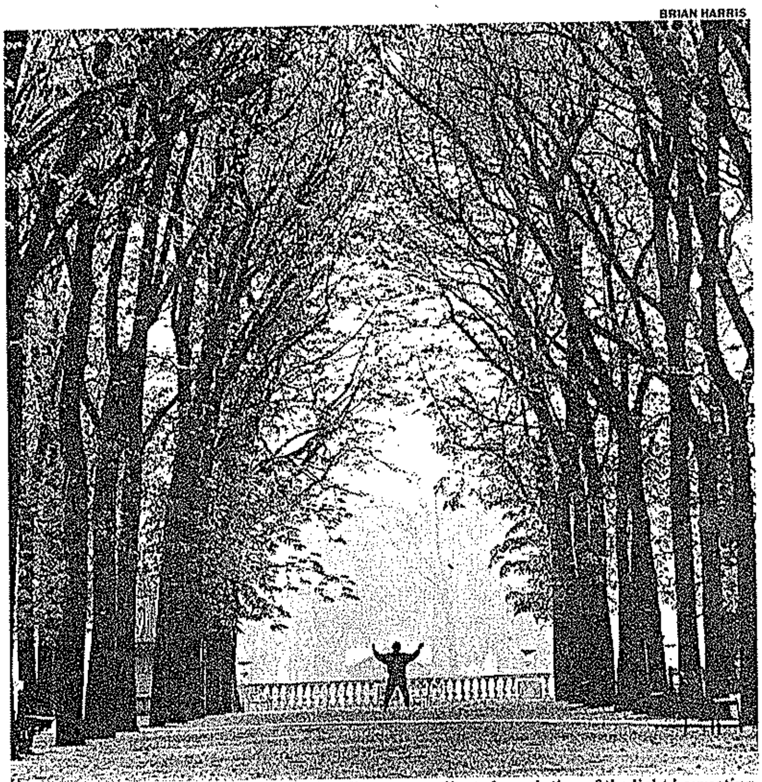
We need to know the structure of light-harvesting complexes in order to understand how they fit together with reaction centres. Then we will begin to understand how the green machine of photosynthesis works and adapts. We also need to know how photosynthesis is able to switch genes for its own components on and off.

The answers should tell us not just about photosynthesis, but more generally about how proteins interact with each other in any cell membrane. This in turn should help to provide an understanding of other important activities in biology, including vision, smell, hormone action, and nerve signal transmission.



BRIAN HARRIS

The tremendous power of photosynthesis relies on complicated regulation of the light harvesting

The author is lecturer in Pure and Applied Biology at Leeds University