“Green matter”: It tripped Priestley up, but more than a century later became a key to understanding photosynthesis

By Jane F. Hill

In 1771, Joseph Priestley discovered that plants and animals exist in an inter-relationship mediated by gases: Animals kept in confined spaces make air “bad,” so that candles cannot burn in it and the animals cannot breathe it and eventually die. Green plants restore the air so that it is once again breathable and supports combustion. The discovery of this interdependence of plant and animal life was a major insight into how life on earth works. It was an achievement of the first rank. Another breakthrough by Priestley that proved highly important for the understanding of the role of gases in life was his discovery, in 1774, of “dephlogisticated air” (oxygen), which makes air breathable and supports combustion. These two discoveries by Priestley were major milestones on the path to understanding photosynthesis, the process by which plants take carbon dioxide from the atmosphere and water from the soil and, using energy from sunlight, form carbohydrates, with the liberation of oxygen gas.

After discovering the interdependence of plant and animal life, based on gas exchange, Priestley abandoned plant research for a number of years. Then, in the summer of 1778, he resumed it, but had difficulty duplicating his earlier results showing the production of dephlogisticated air by plants. His major problem was that he did not understand that plants need light in order to produce dephlogisticated air. Further complicating his efforts was a mysterious “green matter” that developed in the containers of standing pump water in which he grew his plants. He noticed that the green matter yielded dephlogisticated air in the sunlight. At first he thought that the green matter was a “vegetable,” but he soon changed his mind because he could not discern any microscopic living form in the substance. He decided that the dephlogisticated air was emanating, instead, from the water itself. In early 1779, he reported his results on plants and the green matter, including his changing interpretations of the nature of green matter, in his book (preface dated March 1, 1779) *Experiments and Observations relating to various Branches of Natural philosophy, with a Continuation of the Observations on Air*, Vol. I (see especially pp. 338-351). We now know that the green matter was not a plant but a microscopic green alga, a member of the Chlorophyta algal group, but, since algae, like plants, photosynthesize, he would have discovered photosynthesis had he recognized that the green matter was alive and that it was the source of the dephlogisticated air released from the pump water in sunlight.

The summer after publication of this book, Priestley continued to study the green matter. In letters to friends between June 20, 1779, and September 27, 1779, he wrote that he had concluded that the green matter was, after all, the source of the dephlogisticated air released from the pump water and that it was a “vegetable.” (Until relatively recently, algae were considered plants; microscopic spores of algae are present in water and in the atmosphere, and thus can readily enter, or already be present in, containers of standing water, and can propagate there.) He also wrote to friends that he had discovered that ordinary plants, growing in water, need light in order to produce dephlogisticated air. Unfortunately for Priestley, however, he did not formally publish these findings about light.

Meanwhile, during that same summer of 1779, Dutch physician Jan Ingen-Housz studied photosynthesis intensively. In a book published that fall, he presented strong evidence that plants require light to produce dephlogisticated air, and he identified the green matter as a plant. His dedication of the book, to Sir John Pringle, is dated October 12, 1779, which was after Priestley had reported his correct conclusions in letters to friends. Because Ingen-Housz formally published first, however, Ingen-Housz and not Priestley is credited with the discovery of photosynthesis.

Ingen-Housz also introduced the use of isolated leaves as experimental subjects (Priestley had used only whole plants). Plants and leaves continued to be the major experimental subjects for photosynthesis research until 1920, when German biochemist and cell physiologist Otto Heinrich Warburg introduced a new experimental organism—a unicellular green alga (a member of the Chlorophyta) called *Chlorella pyrenoidosa*. He also introduced new laboratory techniques for studying photosynthesis in these tiny bodies. In very thick suspensions of unicellular algae, nearly all the incident light is absorbed, whereas in leaves, much more of the light is scattered. Therefore, algal suspensions are better than leaves for studying the conversion of light energy to chemical energy. *Chlorella pyrenoidosa* and certain other unicellular green algae quickly became the major experimental subjects for photosynthesis research, and remained so for the rest of the 20^{th} century. This alga is still used today.

During the 1930s through 1960s, studies of *Chlorella pyrenoidosa* led to ground-breaking advances in knowledge, including the understanding that there are two major sets of reactions in photosynthesis—the "light" reactions and the "dark" reactions. The light reactions convert sunlight that is absorbed by the pigment chlorophyll (and by other, "accessory" pigments, which transfer the light energy they absorb to chlorophyll) into chemical energy, with the release, to the atmosphere, of oxygen gas derived from water. In the subsequent dark reactions, the plant uses the chemical energy produced in the light reactions to fix carbon dioxide into carbohydrate, which in turn is converted by the plant into proteins, fats, nucleic acids, and all the other molecules essential to life. Outstanding contributions were made by Robert Emerson, among others, to understanding the role of light, and Andrew Benson and Melvin Calvin worked out the basics of the dark reactions—all using *Chlorella pyrenoidosa*.

It is ironic that an alga akin to the "green matter" that had thrown Priestley off track was to prove, some 150-190 years later, the laboratory workhorse that led to such spectacular achievements in unraveling the details of photosynthesis, the process that sustains almost all life on earth and the process that Priestley had taken major, early strides towards elucidating.

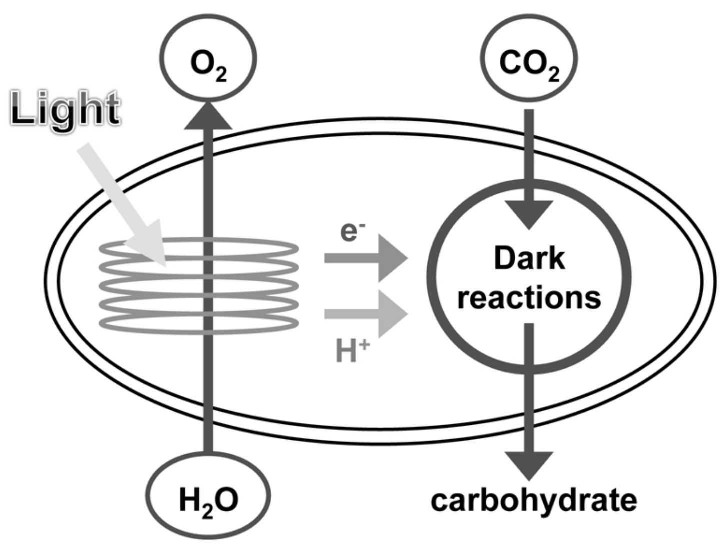

Diagram showing dark and light reactions of photosynthesis.
Figure provided by Govindjee and A. Stirbet.