Life: The Science of Biology, **Ninth Edition**
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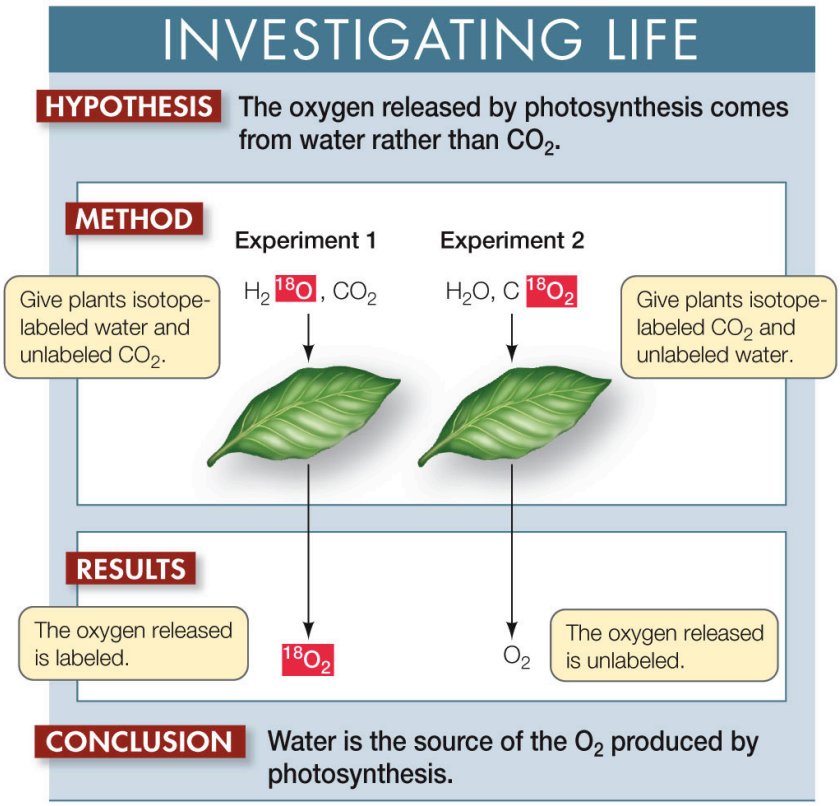
Working with Data

Water Is the Source of the Oxygen Produced by Photosynthesis

(Textbook Figure 10.2)

Introduction



In the 1930s, Cornelius van Niel (1897–1985), then a graduate student at Stanford University, was the first to propose that the oxygen released during photosynthesis is not actually derived from carbon dioxide, but rather from the water molecules consumed in the reaction. This hypothesis was formed on the basis of the discovery that purple sulfur bacteria do not release oxygen during photosynthesis. Instead, these organisms convert hydrogen sulfide (H_2S) into elemental sulfur in their photosynthetic pathway, which is represented as follows: $12\ H_2S + 6\ CO_2 + \text{light} \rightarrow C_6H_{12}O_6 + 6\ H_2O + 12\ S$. Given the similarities between this photosynthetic process and that performed by green plants, van Niel proposed that during the generalized process of photosynthesis, hydrogen is extracted from water and incorporated into glucose, leaving the oxygen to be released as elemental oxygen. This hypothesis was later confirmed by Samuel Ruben and Martin Kamen, who utilized radioisotopes to trace the flow of oxygen in plants. Specifically, they allowed two groups of plants to undergo photosynthesis. The first group of plants was given radioactively-labeled water and unlabeled carbon dioxide. By comparison, the second group of plants was given radioactively-labeled carbon dioxide and unlabeled water. Results showed that the oxygen released from the first group of plants was radioactive, confirming that water is the source of the oxygen produced by photosynthesis. While seemingly simple, later studies went on to demonstrate that photosynthesis is a combination of two separate processes, each involving multiple steps.

Original Paper

Ruben, S., M. Randall, M. D. Kamen, and J. L. Hyde. 1941. Heavy oxygen (O^{18}) as a tracer in the study of photosynthesis. *Journal of the American Chemical Society* 63(3): 877–879.
http://pubs.acs.org/doi/pdf/10.1021/ja01848a512

Links

Arizona State University: College of Liberal Arts and Sciences: Center for Bioenergy and Photosynthesis: What is Photosynthesis?
http://photoscience.la.asu.edu/photosyn/education/learn.html

University of Illinois at Urbana-Champaign: The Photosynthetic Process
http://www.life.uiuc.edu/govindjee/paper/gov.html#20

University of Hamburg: Botany Online: Photosynthesis
http://www.biologie.uni-hamburg.de/b-online/e24/24.htm

Wikipedia: Cornelius van Niel
http://en.wikipedia.org/wiki/Cornelius_Van_Niel

WebElements: Oxygen: the essentials
http://www.webelements.com/webelements/elements/text/O/isot.html

Analyze the Data

As part of the expanding research on radioisotopes during World War II, the U.S. government set up a radiation laboratory at the University of California, Berkeley. Out of this lab came key experiments that described the light-dependent and light-independent pathways of photosynthesis. In this set of experiment, *Chlorella* algal cells were exposed to water and CO_2, the latter coming from bicarbonate ($–HCO_3^-$, which dissolved in water to form CO_2. In Experiment 1, the oxygen was labeled in water (H_2O^{18} and CO_2^{16}), while in Experiment 2, the oxygen was labeled in CO_2 (H_2O^{16} and CO_2^{18}). A mass spectrometer was used to measure the isotopic content of the reactants and O_2 produced in terms of the isotopic ratio (O^{18}/O^{16}). The data are shown in Table 1.

TABLE I

ISOTOPIC RATIO IN OXYGEN EVOLVED IN PHOTOSYNTHESIS BY *Chlorella*[a]

Expt.	Substrate	Time between dissolving $KHCO_3$ + K_2CO_3 and start of O_2 collection, minutes	Time at end of O_2 collection, minutes	Percent. O^{18} in H_2O	Percent. O^{18} in HCO_3^- + $CO_3^=$	Percent. O^{18} in O_2
1	0.09 *M*	0		0.85	0.20	..
	$KHCO_3$	45	110	.85	.41[b]	0.84
	+0.09 *M*	110	225	.85	.55[b]	.85
	K_2CO_3	225	350	.85	.61	.86
2	0.14 *M*	0		.20		..
	$KHCO_3$	40	110	.20	.50	.20
	+0.06 *M*	110	185	.20	.40	.20
	K_2CO_3					

Question 1
In Experiment 1, was the isotopic ratio of O_2 similar to H_2O or CO_2? What about Experiment 2?

Question 2
What can you conclude from these data?