Another generally useful course which we would place next in importance for the pregeneralist is one in "intellectual techniques." This should supply the student with tools which would help him to ingest and digest a large amount of material in a limited time. It should include rapid and effective reading, quick ways of using a library, and what is known about efficient methods of study and learning. Such a course should come in the freshman year if possible. Some of us feel that introductory psychology is a good facsimile, others feel that it does not concentrate enough on the tool aspect to meet the need.

Installing the program. Before any new program can be introduced into an American college or university without objection it must be shown to fill certain needs. For the next decade colleges will ask: Does this program meet the distribution requirements? Does this program fit into the scheme of departmental concentration or majoring?

Distribution requirements vary from institution to institution, and are in the process of changing at many institutions. We have compared the proposed program with the distribution requirements at Harvard and at Princeton, since we are most familiar with these universities. There the distribution requirements would easily be met. It seems reasonable to conclude that this program would be consistent with the distribution requirements of a substantial number of institutions.

Next, there must be a home for the pregeneralist. Some department must be prepared to accept his widely distributed work as concentration in that department. Or a new interdepartmental program must be set up! Fnding a home may be difficult.

There will be difficulty with individual scientific departments wherever such a program is proposed; each such department has a natural desire to have these very good students concentrate in its department.

Finally, there will be objections from administrators about any program requiring students to take courses without the usual prerequisites.

These difficulties of installation, however, are merely details, and such a program can be started.

The point of view we have tried to expound might be summarized thus: Science is complex; yet it must become manageable. It can be managed better with the help of a few scientists with training in many sciences. A few such scientific generalists can be trained tomorrow with the courses at hand. To make science more manageable, we must perform a new and difficult synthesis on a higher level of organization.

Photoproduction of Molecular Hydrogen by *Rhodospirillum rubrum*

Howard Gest[1] and Martin D. Kamen

Mallinckrodt Institute of Radiology and *Department of Chemistry, Washington University*

THE PHOTOSYNTHETIC, nonsulfur purple bacterium, *Rhodospirillum rubrum* (strain SI)[2] will grow anaerobically upon illumination in a synthetic medium consisting of pure organic substrates, mineral salts including ammonium chloride, and a trace of biotin (*3*).[3] The organic substrate can be any of a large variety of compounds. Substrates more oxidized than carbohydrate are decomposed with a net production of CO_2 during growth. Aside from CO_2 and cell material, no other products have been observed in appreciable quantity. However, *R. rubrum* grown photosynthetically on certain oxidized substrates, with glutamate or aspartate instead of ammonia as a nitrogen source, exhibits in addition to CO_2 evolution a vigorous production of hydrogen.

In a preliminary survey, the only compounds so far found to be effective in evoking hydrogen production in growing cultures are malic, fumaric, and succinic acids. Of several dozen substrates tested at pH 6.6 with resting cells derived from hydrogen-producing cultures, only malic, fumaric, oxaloacetic, and pyruvic acids are effective. The magnitude of the hydrogen evolution from malic acid is of the order of one mole per mole of added substrate. Succinic acid has been tested with resting cells using pH values

[1] Predoctoral fellow of the American Cancer Society, recommended by the Committee on Growth of the National Research Council, 1947–1949. Present address, Department of Microbiology, Western Reserve University Medical School, Cleveland, Ohio.

[2] Original culture obtained through the courtesy of Prof. C. B. van Niel, Hopkins Marine Station, Pacific Grove. California.

[3] Hutner studied growth under aerobic conditions only. However, it appears that anaerobic growth requirements are similar.

varying from 5.7 to 8 because of the discrepancy in response of resting cells and of growing cells to this substance. Although extensive CO_2 evolution is observed over most of this range, no H_2 evolution is noted with succinic acid as substrate. This point is being investigated further.

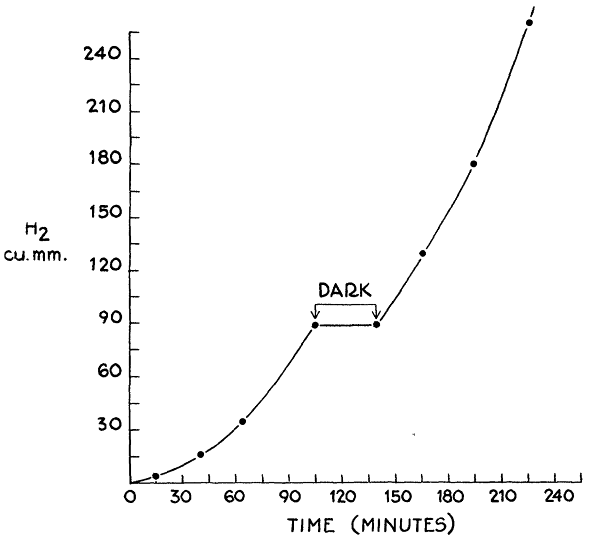

FIG. 1. Photochemical production of H_2 by *Rhodospirillum rubrum* (SI): 50 mm^3 of washed cells was suspended in 2 ml M/20 phosphate buffer (pH 6.6) and 5 mg of D,L-malate was tipped in at zero time. The center well contained 0.2 ml of 10% KOH; the gas space was filled with 100% helium.

When the gas phase in resting cell experiments is helium, argon, or hydrogen, a vigorous photoproduction of molecular H_2 is observed. A typical experiment is shown in Fig. 1, which demonstrates the results obtained with conditions as noted in the legend. In the presence of nitrogen there is no evolution of H_2. The possibility that a slight oxygen contamination of the nitrogen is responsible for the inhibition has been eliminated in three ways. First, a gas mixture consisting of 1 percent oxygen plus 99 percent helium fails to repress H_2 production. Second, nitrogen completely freed of oxygen (99.99 percent N_2) inhibits H_2 evolution. Third, a mixture of pure nitrogen (0.1 atmosphere) and helium (0.9 atmosphere) inhibits H_2 production. In addition it has been found that ammonia abolishes H_2 production under helium or hydrogen. Thus H_2 production is not observed if ammonium salts or molecular nitrogen are present. This effect of ammonia brings to mind nitrogen-fixing organisms, in which combined nitrogen inhibits production and activity of hydrogenase (*4*). The possibility exists that there may also be a hitherto unsuspected nitrogenase system in *R. rubrum*. This is now being investigated, using molecular nitrogen labeled isotopically.

The production of hydrogen during normal photosynthesis by either growing or resting cells of *R. rubrum* is unusual in that there is always present a large amount of CO_2 which can be reduced with hydrogen photochemically by these organisms, as can be demonstrated with resting cells.

Hydrogen evolution is dependent on exogenous substrate, is not inhibited at high light intensity, and does not require a prolonged adaptation period. Thus, photoproduction of hydrogen by *R. rubrum* differs from the only instance of photoproduction of hydrogen reported previously. Gaffron and Rubin (*2*) observed that in the green alga, *Scenedesmus*, an endogenous production of hydrogen of low magnitude occurred at low light intensity after long anaerobic incubation of these ordinarily aerobic organisms in the absence of CO_2, or in the presence of CO_2 when dinitrophenol was added. There is also to be remarked as a point of difference the unexpected effect of molecular nitrogen in inhibiting the H_2 evolution noted in *R. rubrum*.

Attempts to link hydrogen evolution to a formic hydrogenlyase system have failed. Growth in the presence of formate produces organisms which will evolve hydrogen in the dark with formate as substrate and with N_2 as the gas phase. However, no photoproduction of H_2 has been observed with formate. It may be recalled that fermentative production of H_2 by microorganisms is ordinarily inhibited by H_2 (*1*), whereas this is not the case with *R. rubrum*.

The data at hand do not permit of a decision as to the source of the photohydrogen. As a working hypothesis, it may be assumed that the substrate employed is the source, on the basis of the substrate specificity observed. The possibility of testing this hypothesis using labeled hydrogen is remote but is being considered.

In conclusion, it appears that *Rhodospirillum rubrum* under the influence of light and in the presence of a single organic substrate can liberate hydrogen as a photosynthetic product. This hydrogen evolution is linked to nitrogen metabolism and perhaps even to a nitrogenase system. It is hoped that further work now in progress with labeled nitrogen, hydrogen, and carbon will clarify the mechanisms involved in this production of molecular hydrogen during hydrogen transfer in photosynthesis.

References

1. CARDON, B. P. and BARKER, H. A. *Arch. Biochem.*, 1947, **12**, 165.
2. GAFFRON, H. and RUBIN, J. *J. gen. Physiol.*, 1942, **26**, 219.
3. HUTNER, S. H. *J. Bact.*, 1946, **52**, 213.
4. LEE, S. B. and WILSON, P. W. *J. biol. Chem.*, 1943, **151**, 377.