ample, "liver," "lung," or "bone marrow" is suspect. It is further to be noted that specialized organ functions are conspicuously absent in almost all serially propagated dispersed cell cultures. It remains to be determined whether this reflects incorrect identification of the cells, an irreversible loss of their biosynthetic capacities, absence from the environment of necessary precursors or cofactors, or the fact that cellular organization and interaction are essential to those specialized functions.

References

1. H. Eagle, *Science* 122, 501 (1955); ———, V. I. Oyama, M. Levy, A. E. Freeman, *J. Biol. Chem.* 226, 191 (1957).
2. H. Eagle, V. I. Oyama, K. A. Piez, R. Fleischman, in preparation.
3. V. J. Evans, J. C. Bryant, M. C. Fioramonti, W. T. McQuilkin, K. K. Sanford, W. R. Earle, *Cancer Research* 16, 77 (1956); A. E. Pasieka, H. J. Morton, J. F. Morgan, *Can. J. Biochem. and Physiol.* 36, 771 (1958).
4. H. W. Fisher, T. T. Puck, G. Sato, *Proc. Natl. Acad. Sci. U.S.* 44, 4 (1958); I. Lieberman and P. Ove, *J. Biol. Chem.* 233, 637 (1958).
5. A. Meister, *Biochemistry of the Amino Acids* (Academic Press, New York, 1957).
6. W. D. McElroy and H. B. Glass, *Amino Acid Metabolism* (Johns Hopkins Press, Baltimore, 1955).
7. W. C. Rose, R. L. Wixom, H. B. Lockhart, G. F. Lambert, *J. Biol. Chem.* 217, 987 (1955).
8. H. Eagle, *J. Exptl. Med.* 102, 37 (1955); *J. Biol. Chem.* 214, 839 (1955).
9. ———, V. I. Oyama, M. Levy, *Arch. Biochem. Biophys.* 67, 432 (1957).
10. H. Eagle, *Proc. Soc. Exptl. Biol. Med.* 89, 96 (1955).
11. ———, K. A. Piez, V. I. Oyama, unpublished observations.
12. S. Barban, unpublished.
13. J. F. Morgan, H. J. Morton, A. E. Pasieka, *J. Biol. Chem.* 233, 664 (1958).
14. H. Eagle, A. E. Freeman, M. Levy, *J. Exptl. Med.* 107, 643 (1958).
15. C. Rappaport and J. L. Melnick, *Federation Proc.* 16, 429 (1957); A. A. Tytell, Y. Rader, D. L. Krumm, *ibid.* 17, 326 (1958).
16. H. Eagle, K. A. Piez, V. I. Oyama, unpublished observations.
17. H. Eagle, K. A. Piez, R. Fleischman, M. Levy, A. E. Freeman, unpublished observations.
18. L. Levintow, H. Eagle, K. A. Piez, *J. Biol. Chem.* 227, 929 (1957).
19. H. Eagle, V. I. Oyama, M. Levy, C. L. Horton, R. Fleischman, *ibid.* 218, 607 (1956).
20. R. Demars, *Biochim. et Biophys. Acta* 27, 435 (1958).
21. ———, unpublished.
22. ——— and H. Eagle, unpublished observations.
23. K. A. Piez and H. Eagle, *J. Biol. Chem.* 231, 533 (1958).
24. R. B. Roberts, P. H. Abelson, D. B. Cowie, E. T. Bolton, R. J. Britten, *Studies of Biosynthesis in Escherichia coli* (Carnegie Institution of Washington, Washington, D.C., 1955).
25. H. Eagle, K. A. Piez, R. Fleischman, *J. Biol. Chem.* 228, 847 (1957).
26. H. Eagle, K. A. Piez, E. P. Cohen, R. Fleischman, A. E. Freeman, M. Levy, unpublished observations.
27. L. Levintow, *Science* 126, 611 (1957).
28. N. P. Salzman, H. Eagle, E. D. Sebring, *J. Biol. Chem.* 230, 1001 (1958).
29. R. F. Haff, H. E. Swim, *Proc. Soc. Exptl. Biol. Med.* 94, 779 (1957).
30. L. Levintow, J. E. Darnell, Jr., H. Eagle, unpublished observations.
31. T. A. McCoy, M. Maxwell, R. E. Neumann, *Cancer Research* 16, 979 (1956).
32. R. F. Haff and H. E. Swim, *Federation Proc.* 15, 591 (1956).
33. T. T. Puck and H. W. Fisher, *J. Exptl. Med.* 104, 427 (1956).
34. R. Z. Lockhart, Jr., and H. Eagle, *Science*, 129, 252 (1959).
35. H. Eagle, K. A. Piez, R. Fleischman, V. I. Oyama, *J. Biol. Chem.* 234, 592 (1959).
36. J. Mandelstam, *Biochem. J.* 64, 55P (1956); *Nature* 179, 1179 (1957); *Biochem. J.* 69, 110 (1958).
37. H. Halvorson, *Biochim. et Biophys. Acta* 27, 255 (1958).
38. H. Eagle and K. Habel, *J. Exptl. Med.* 104, 271 (1956).
39. J. E. Darnell, Jr., and H. Eagle, *Federation Proc.* 17, 508 (1958); *J. Exptl. Med.*, in press.
40. L. Levintow and J. E. Darnell, Jr., *Federation Proc.* 18, 273 (1959).
41. J. E. Darnell, Jr., and H. Eagle, *Virology*, 6, 556 (1958).
42. H. Eagle, *Proc. Soc. Exptl. Biol. Med.* 89, 362 (1955); G. E. Foley and B. P. Drolet, *ibid.* 92, 347 (1956); L. Berman and C. S. Stulberg, *ibid.* 92, 730 (1955); E. P. Ruix and H. J. M. Morejon, *Rev. Biol. Med.* 1, 3 (1957).
43. W. F. McLimans, E. V. Davis, F. L. Glover, G. W. Rake, *J. Immunol.* 79, 428 (1957).
44. H. Eagle, *Proc. Soc. Exptl. Biol. Med.* 91, 358 (1956).
45. ———, S. Barban, M. Levy, H. Schulze, *J. Biol. Chem.* 233, 551 (1958).
46. H. Eagle, B. W. Agranoff, E. E. Snell, R. Fleischman, unpublished observations.
47. L. A. Herzenberg, unpublished observations.

Robert Emerson, Investigator of Photosynthesis

At the present state of knowledge of biology the experimental approach, designed to establish empirical relations between relevant variables, usually turns up unexpected effects and thus serves as the starting point for the development of entirely new concepts. Robert Emerson was particularly adept at this type of exploratory measurement uncommitted to any particular theory. His life was spent on experimental investigation of the mode of action of pigments in green plant photosynthesis. The effect of his career, directly on the field of photosynthesis and indirectly on related aspects of biology, is of particular value not only because of his own discoveries but also because he established unusually high standards of performance and critical self-evaluation of experimental measurements.

Born in 1903 to Haven Emerson (later to be public health commissioner for New York City as well as professor of public health at Columbia University) and a Philadelphia Quaker mother, he grew up in New York, attended the Ethical Culture School, and spent his summers in rural Long Island. He graduated from Harvard in 1925 and received his doctorate in 1927 from the University of Berlin; his work for the doctorate was based on studies of *Chlorella* respiration, made in collaboration with Otto Warburg. At this time he isolated the "Emerson strain" of *Chlorella pyrenoidosa,* which became the standard plant for photosynthesis research. He returned to Harvard for two years as a National Research Council fellow, and there he taught a course on photosynthesis and experimented with the effects of light intensity, temperature, and chlorophyll content on photosynthesis of *Chlorella.* In his lectures be made experimental data speak for themselves —a powerful technique that he developed to a high level of effectiveness.

In 1929 he married Claire Garrison and moved to California Institute of Technology. There, with the assistance of William Arnold, he investigated the effects of flashing light on photosynthesis. These experiments are the basis for the concept of the "photosynthetic unit" —a group of chlorophyll molecules functioning together as a single entity. This concept turned out to be very fruitful and continues to provide incentive for many new experiments and discussions.

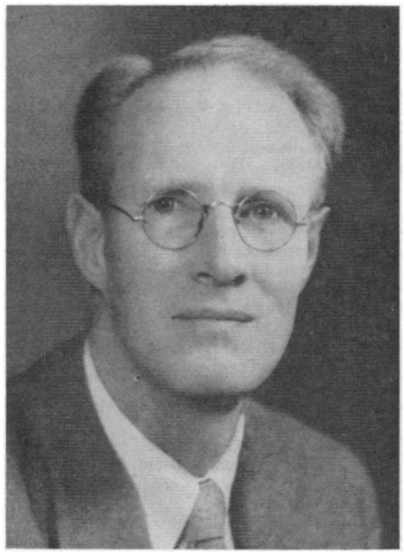
Emerson's scientific work reflected his extraordinarily forceful character. Two characteristics that influenced the course of his research and left a vivid impression on his students and colleagues were his strong moral sense and his outrage at sloppy performance of any sort. His desire to do everything with excellence resulted in clear-cut, definitive scientific results. No relevant details of experimentation were too minor to be set right, and his research was characterized by unusual care and thoughtful effort. He once made the comment that personal satisfaction in scientific research comes more from thorough and reliable work than from a larger output of lesser quality.

He enjoyed building things, particularly laboratory devices. The equipment he made was always solid, stable, and finished with a craftsmanship far beyond the ordinary in laboratory practice.

On leave from California Institute of Technology, he spent the years 1937 through 1940 as research associate in the Carnegie Institution's Division of Plant Biology, at Stanford, where he had the understanding support of Herman A. Spoehr. There, with the assistance of Charlton Lewis, he measured the effectiveness of different wavelengths of light for photosynthesis in *Chlorella* and *Chroococcus*. For this purpose they built an excellent grating monochromator with a high energy output. These measurements are basic to our present knowledge about participation in photosynthesis by the accessory pigments—carotenoids and phycobilins. Emerson and Lewis also discovered that light on the long-wave side of the red chlorophyll *a* absorption band is used very inefficiently. The carotenoids were found to be only partially effective, while the phycobilins contributed all their absorbed energy to photosynthesis.

Following up these experiments, Emerson and Lewis redetermined the efficiency of photosynthesis in *Chlorella* —a classical experiment of his former teacher, Otto Warburg, for whom he had deep admiration and respect. The results of the new measurements gave an efficiency about one-third to one-half the previous value of four quanta required to reduce a molecule of CO_2. This disagreement led to a long search for possible errors in both sets of measurements. Unfortunately, and quite unnecessarily, this disagreement developed into a bitter controversy, eventually involving several laboratories on both sides of the question. For Emerson it became a moral crusade of truth against error.

In 1946, after six more years at the California Institute of Technology, he was appointed research professor of botany at the University of Illinois, where he remained. There he and Eugene Rabinowitch developed a leading center of photosynthesis study. The quantum-yield crusade continued for many difficult years until it was established to his



Robert Emerson

own satisfaction that the results he obtained were incontestable. He then published a series of articles written with remarkable detachment from the controversy. He made it possible for Otto Warburg to come as a visiting professor to Urbana in order that the discrepancies could be amicably settled. At the present time each of the opposing groups of investigators considers the problem satisfactorily settled in their favor, which means that they still disagree as strongly as ever about the efficiency of photosynthesis.

Emerson's last years were the most productive of all as he again took up the mode of action of the different plant pigments concerned with photosynthesis. The low efficiency of long-wavelength red light previously discovered with Lewis had been on his mind during the intervening years. It had remained a puzzle whose solution he instinctively felt would mean important progress in understanding that step of the photosynthetic process in which the conversion of light to chemical energy takes place. He returned to this problem with the discovery that the efficiency of long-wave red light can be dramatically raised by simultaneous irradiation at shorter wavelengths. The stimulating effect of simultaneous light activation of other pigments as well as of chlorophyll *a* on photosynthesis was the subject of his work at the time of his death [R. Emerson and R. V. Chalmers, *Phycol Soc. Am. News Bull.* **11**, 51 (1959)]. These studies, of great current interest, have raised serious doubts about the concept that all photosynthetic pigments of plants act only by transferring their energy to chlorophyll *a*.

A remark which circulated among his friends was: "Bob considers the world a moral gymnasium in which he is at liberty to exercise his conscience daily." He was active in civil liberties organizations and was particularly concerned about discrimination against minority groups. The imprisonment of the American citizens of Japanese ancestry during World War II aroused his moral indignation. He worked hard to reduce the suffering of these people, both on the personal level and in educating government officials to pursue a more civilized policy. His professional knowledge of plant physiology and his friendship with highly skilled Japanese gardeners and technicians contributed to his effectiveness in a guayule culture research program for rubber production during the war.

He was a practising follower of his philosopher great uncle's cult of "plain living and high thinking." He raised his own chickens and vegetables, enjoyed homemade bread, shaved with an old-fashioned straight razor, and for relaxation made wood carvings.

In spite of his well-known scientific achievements and of honors such as the Stephen Hales award of the American Society of Plant Physiologists, the 50th Anniversary award of the American Botanical Society, and membership in the National Academy of Sciences, he never seemed to be aware of his high status, both as a scientist and as a man, nor did he ever seem to realize how greatly he was esteemed by everyone who either worked with him or argued against him.

Before World War II Emerson belonged to the small group of scientists who had chosen photosynthesis as their main scientific problem. Ten years later, after research with radioactive tracer carbon had become fashionable, the number of people working on photosynthesis expanded rapidly, and the number of published papers in this field has grown accordingly. But Emerson's death in an airplane accident at La Guardia field on 3 February 1959 suddenly makes us aware that there are still only a very few scientists in the entire world capable of approaching the core of the problem with his technical ingenuity, his special knowledge, and the extraordinary care he took to ensure the reliability of the data that he published.

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