tion of magnesium sulphate in tetanus; (*b*) the possible danger of intravenous injection of magnesium sulphate; (*c*) The antagonistic and curative action of calcium salts in these cases, by S. J. Meltzer.

The Liberty field hospital ward. Designed on the unit construction plan. Portable. Adapted to American overseas summer and winter service (motion pictures), by Henry Fairfield Osborn.

The war and medical research (illustrated), by Simon Flexner.

Afternoon Session

Conformal geometry, by Edward Kasner.

Magnestism by rotation (illustrated), by S. J. Barnett (by invitation. Comstock prize recipient).

On the correction of optical surfaces, by A. A. Michelson.

Some recent observations of the brighter nebulæ (illustrated), by W. W. Campbell.

Physical researches for the war, by R. A. Millikan.

Evening Session

First William Ellery Hale Lecture, by John C. Merriam, professor of paleontology, University of California. Subject: The beginnings of human history from the geologic record. (Open to the public.)

TUESDAY, APRIL 23

Morning Session

Notes on isotopic lead, by F. W. Clarke.

The physico-chemical properties of gluten, by Lawrence J. Henderson (introduced by Raymond Pearl).

Correlation of the tertiary formations of the southeastern United States, Central America and the West Indies, by Thomas Wayland Vaughan (introduced by David White).

Coast survey charts and fringing reefs of the Philippine Islands (illustrated), by W. M. Davis.

Recent researches on the skeletal adaptations and modes of locomotion of the Sauropod Dinosaurs (illustrated), by Henry Fairfield Osborn and William K. Gregory.

Some additional data on the Cambrian Trilobites (illustrated), by Charles D. Walcott.

The development of governmental regulations during the world war, by C. R. Van Hise.

Afternoon Session

The big bears of North America, by C. Hart Merriam.

The growth of the Pribilof fur-seal herd between 1912 and 1917 (illustrated), by G. H. Parker.

A comparison of the growth changes in the nervous system of the rat with the corresponding changes in man (illustrated), by Henry H. Donaldson.

Measuring the mental strength of an army (illustrated), by Robert M. Yerkes (by invitation).

Second William Ellery Hale Lecture, by John C. Merriam, professor of paleontology, University of California. Subject: The beginnings of human history from the geologic record.

SPECIAL ARTICLES

A SIMPLE METHOD OF MEASURING PHOTOSYNTHESIS[1]

In collaboration with Loeb[2] one of us observed that certain marine algæ when exposed to sunlight cause the sea water to become more alkaline. Similar observations had been previously made by others[3] upon fresh-water plants in solutions containing bicarbonates.

It seemed to the writers that this procedure might be utilized in the study of photosynthesis. After investigating a number of marine plants it was found that *Ulva* (sea lettuce) is very satisfactory for such experiments. A piece of *Ulva* was placed in a beaker and covered with sea water to which a little phenolphthalein[4] had been added. It was then placed in direct sunlight. In the course of an hour the solution turned pink. The pink color grew steadily more pronounced and at the end of another hour was intense.

It seemed evident that by measuring the alkalinity which produced the change of color we might arrive at a simple and satisfactory method of studying photosynthesis.

In order to measure the degree of alkalinity produced by *Ulva,* a piece of the frond was placed in a tube of Pyrex glass[5] (about 12 mm. in diameter) in such a manner that it com-

1 Preliminary communication.

2 Loeb, J., "Dynamics of Living Matter," 1906, p. 98.

3 *Cf.* Czapek, F., "Biochemie der Pflanzen," 1913, 1: 519.

4 Ten drops of saturated alcoholic phenolphthalein was added to 1 liter of sea water. For class demonstration more may be added.

5 This glass was chosen because it does not give off measurable quantities of alkali during the period of the experiment.

pletely covered the inside of the tube for the greater portion of its length. Fronds were chosen which were sufficiently stiff so that their own elasticity caused them to remain closely and evenly pressed against the inner surface of the glass tube even when liquid was poured in and out or shaken back and fourth in the tube.

The glass tube was sealed off at one end, while at the other it was furnished with a short piece of rubber covered with paraffin.[6] The covering of paraffin was continuous and care was taken to renew it each time the tube was used.

After placing the frond in the tube, the latter was filled with sea water (at the temperature of the bath) and the rubber tube was clamped shut. In some cases a small bubble of air was left in the tube to act as a stirrer: in other cases the tube was completely filled with sea water and the stirring was effected by a small piece of paraffin or by a glass bead covered with paraffin.

The tube was then placed in a large water bath in direct sunlight. The tube was slanted so as to receive the sunlight nearly at right angles. The light passed through a sufficient amount of water to filter out most of the heat rays. Some light was reflected from the surface of the water but this was practically constant during any one experiment. The temperature of the bath was kept constant within 1° in most of the experiments.

In order to determine the degree of alkalinity produced by photosynthesis two methods were used. In the first the indicator was added to the sea water containing *Ulva* after a definite exposure to sunlight; in the second the indicator was added to the sea water before the exposure began. In the latter case there was a possibility that the presence of the indicator might affect the amount of photosynthesis, but it was found by control experiments that this was not the case with the concentrations employed in these experiments.

It was also necessary to ascertain whether the degree of alkalinity produced was a reliable measure of the amount of photosynthesis. This was done by making simultaneous determinations of the degree of alkalinity and the amount of oxygen evolved (by Winkler's method). The results show that the amount of photosynthesis, as indicated by the evolution of oxygen, is approximately a linear function (in this range) of the change in the PH value of the sea water. This being so we can measure the amount of photosynthesis by determining the change in PH value regardless of any possible complications such excretion of alkali by the plant.

Since the plants produce CO_2 by respiration this must be taken into consideration. Experiments conducted under precisely the same conditions except that light was excluded showed that the respiration was practically constant. It is, therefore, easy to make a correction for it.

In order to ascertain how much photosynthesis had taken place after a definite time the pink color produced by the *Ulva* was matched against the colors of a series of tubes (of the same size) containing the same concentration of indicator in a series of buffer solutions of known alkalinity.[7] The matching was done under a "Daylight" lamp, which is invaluable for this purpose.

In this way the degree of alkalinity produced may be easily ascertained and since this corresponds to the amount of oxygen evolved it gives us a direct measure of photosynthesis, provided we know the amount of CO_2 or of O_2 corresponding to the observed changes in alkalinity. These may be determined in various ways which can not be discussed here.

[6] It is necessary to use paraffin which will not give off measurable quantities of acid during the time of the experiment. For this purpose paraffin of a high melting point is usually advantageous. Rubber should be used which gives off the minimum amount of acid; the rubber used in these experiments was repeatedly boiled before using.

[7] For buffer solutions see: Sörensen, *Biochem. Zeit.*, 21: 131, 1909; *Ergeb. d. Physiol.*, 12: 392, 1912. Höber, R., *Physik. Chem. d. Zelle u. d. Gewebe*, 4te Aufl., 1914, S. 169. Bayliss, W. M., "Principles of General Physiology," 1915, p. 203.

For the PH values needed in these investigations mixtures of .05 *M* borax and 0.2 *M* boric acid (to each liter of boric acid 2.925 gm. NaCl is added) are useful. The following table gives the

In order to study the effects of temperature, light intensity, etc., it is not necessary to know the amount of CO_2 abstracted; it is sufficient to compare the time required to produce the same change in the color of the indicator under different conditions. This gives much more accurate results than comparison of the amounts of CO_2 abstracted in equal times. In case anything is added to the solution which changes its buffer value due allowance must be made for this.

It is evident that the method is accurate, simple, rapid and convenient, permitting us to measure minute amounts of photosynthesis at frequent intervals.

It may be added that aquatic plants are greatly to be preferred to land plants for quantitative studies of photosynthesis because in the latter the temperature can not be satisfactorily controlled while with the former the fluctuations can be confined within one degree, or less.

PH values of a series of mixtures (Palitzsch, S., *Bioch. Zeit.*, 70: 333, 1915. *Compt. rend. lab. Carlsberg*, 11: 199, 1916). *Cf.* McClendon, J. F., Gault, C. C., Mulholland, S., Pub. 251 Carnegie Inst., 1917, pp. 21–69.

0.2 *M* Boric Acid, c.c.	.05 *M* Borax, c.c.	PH
0	10	9.24
1.0	9.0	9.11
2.0	8.0	8.98
3.0	7.0	8.84
4.0	6.0	8.69
4.5	5.5	8.60
5.0	5.0	8.51
5.5	4.5	8.41
6.0	4.0	8.31
6.5	3.5	8.20
7.0	3.0	8.08
7.5	2.5	7.94
7.7	2.3	7.88
8.0	2.0	7.78
8.5	1.5	7.60
9.0	1.0	7.36
9.4	0.6	7.09
9.7	0.3	6.77

By plotting the c.c. of borax as ordinates and the PH values as abscissae a curve is obtained from which intermediate values can be obtained by graphic interpolation.

From the PH values found in sea water 0.21 must be subtracted on account of the "salt error."

Similar experiments were made with a variety of fresh-water plants, including *Spirogyra, Hydrodictyon* and *Potamogeton.* The results were very satisfactory. The usual procedure was as follows: A gallon bottle was filled with the water in which the plants were growing, a little phenolphthalein was added and a solution of sodium bicarbonate was then added, drop by drop, until a pink color was produced.[8] On pouring this into the tubes used in the experiments the pink color was not perceptible since the layer of liquid was not sufficiently thick.

When the algæ were placed in these tubes in sunlight a pink color appeared in a short time. If the tubes were placed in the dark the color disappeared as the result of respiration. In many cases the algæ lived for several days in these tubes and made considerable growth, showing that they were not injured.

The method is well adapted to class work. For ordinary laboratory demonstrations Pyrex glass is not necessary since any good glass[9] will answer. It will be found that some algæ (particularly blue-green and unicellular green algæ) will operate satisfactorily in diffused daylight. It is important, however, that the plants be in active condition. Aquatics are apt to prove unsatisfactory in fall and winter while in spring and summer the same species may be very active.

SUMMARY

Minute amounts of photosynthesis can be accurately measured by placing aquatic plants in solutions containing bicarbonates, with a little phenolphthalein, and observing changes in the color of the indicator.

The convenience, simplicity and rapidity of the method make it as useful for class-room demonstration as for quantitative investigations.

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[8] This solution should be freshly made each day.

[9] Open bottles, test-tubes, beakers or tumblers may be employed.