history and traditions may have fostered divergent viewpoints, we are here dealing with a matter of the deepest interest to all nations. Moreover, the free and open access to information about all scientific and technical progress, which will be a basic condition for the efficiency of the control, will in itself go far towards promoting mutual knowledge and understanding of the cultural aspects of life in the various countries, without which respect and good-will between nations can hardly endure.

In all the circumstances it would appear that the possibility of producing devastating weapons, against which no defence may be feasible, should be regarded not merely as a new danger added to a perilous world, but rather as a forceful reminder of how closely the fate of all mankind is coupled together. Indeed, the crisis with which civilization is at present confronted should afford a unique opportunity to remove obstacles to peaceful collaboration between nations and to create such mutual confidence as will enable them jointly to benefit from the great promises, as regards human welfare, held out by the progress of science.

The attainment of this goal, which places upon our generation the gravest responsibility towards posterity, will of course depend on the attitude of all people. Valuable services, however, may be rendered by scientists all over the world in bringing about a genuine appreciation of what is at stake and in pointing out how the great development of our resources may contribute to progress for humanity. In a matter of such universal scope, help may also be found in the intimate connections between scientists, created by international cooperation which proved so fertile just in a domain of research that was to have such overwhelming consequences.

For meeting the challenge to civilization in the proper spirit it should be a most fortunate omen that we have to do with implications of pure scientific studies pursued with no other aim than to widen the borders of our knowledge and to deepen our understanding of that nature of which we ourselves are a part. Let us hope that science which, through the ages, has stood as a symbol of the progress to be obtained by common human striving, by its latest emphasis on the necessity of concord, may contribute decisively to a harmonious relationship between all nations.

THE ROLE OF BACTERIA IN THE FORMATION AND TRANSFORMATION OF PETROLEUM HYDROCARBONS[1,2]

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PETROLEUM is a complex mixture of gaseous, liquid and solid hydrocarbons. Besides the uncounted hundreds of hydrocarbons composing petroleum, there are numerous compounds of hydrogen and carbon which contain oxygen, nitrogen, phosphorus or sulfur. Petroleums from different oil fields differ widely in chemical composition and in physical properties. Some crude oils such as those from the Bradford, Pennsylvania, sands, for example, are clear amber-colored, free-flowing fluids, while others, exemplified by La Brea, California, crudes, are coal black, viscous tars. The density of petroleums ranges from a specific gravity of 0.65 (certain crudes from the Baku field in Russia) to somewhat more than 1.00 for oil from Athabaska (Alberta, Canada) tar sands. The range in the chemical composition of petroleums is as follows:

Carbon	82.2 to 87.1 per cent.
Hydrogen	11.7 to 14.7 " "
Sulfur	0.1 to 5.5 " "
Nitrogen	0.1 to 1.5 " "
Oxygen	0.1 to 4.5 " "
Minerals	0.1 to 1.2 " "

The hydrocarbons in various petroleums may consist predominantly of either (1) aliphatic compounds of the paraffin series, (2) aromatic compounds of the benzene series or (3) naphthenic compounds of the polymethylene or cyclo-paraffin series. Likewise, found in various crude oils are small quantities of fatty acids, phenols, naphthenic acids, resinous compounds, asphaltenes, mercaptans, thiophenes, sulfones, sulfoxides, sulfonic acids, organic sulfides, pyridines, quinolenes and other compounds. So complex are petroleums and so labile are some of their constituents that no crude oil has ever been completely analyzed.

In view of the ever-increasing importance of petroleum and its myriads of products to our mechanized and martialized civilization, it seems anomalous that our knowledge of what petroleum is and how it is formed is still so woefully wanting. Petroleum geologists have been so successful in finding subterranean

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[1] Annual William Conger Morgan Memorial Lecture delivered before Alpha Kappa Chapter of Phi Lambda Upsilon and the department of chemistry, University of California at Los Angeles, April 25, 1945.

[2] Contribution from the Scripps Institution of Oceanography, New Series No. 265. These investigations were supported in part by a grant from the American Petroleum Institute, Research Project 43A.

deposits and the industry has been so efficient in providing almost any required amount of amazingly low-cost petroleum products that no one has been too much concerned about what petroleum is or how it was formed. The time has arrived, though, when more knowledge of petroleum and better discovery methods are urgently needed to maintain the supply of low-cost oil. Detailed information on the origin of oil may provide clues to the location of undiscovered petroleum deposits, and such information may affect the economy of exploiting them.

There are almost as many theories regarding the origin of oil as there are students of the subject. Some few still recite the conditions whereby petroleum may have had an inorganic or cosmic origin, but most petroleum geologists hold that "rock" oil had an organic origin. Supporting the organic theory are the nitrogen content of oil, its optical activity, the presence of pigments of the porphyrin type, and the association of oil with marine sediments containing plant or animal fossils. There are widely divergent views regarding the mode of transformation of organic matter into crude oil, but it is generally agreed that (1) the temperature of formation was probably less than 150° C. and it may have been no higher than 30° to 80° C., (2) the pressure of formation was relatively low, (3) the oil was formed not far from the places where it is now found, and (4) it was formed primarily, if not exclusively, in marine environments. Either physical, chemical or biological agencies may have contributed to the formation of oil.

It is not the purpose of this paper to elaborate the theories of petroleum genesis, but rather to discuss the possible part played by bacteria in the formation and transformation of petroleum hydrocarbons. Assuming that the organic remains of plants and animals constitute the mother substance of petroleum, there are several ways in which the biochemical activities of bacteria and allied microorganisms could be instrumental in the conversion.

Field and laboratory observations during the last decade have established that a biochemically versatile bacterial flora is associated with marine sediments, both recent and ancient. These bacteria or their enzymes (organic catalysts) could be functional in geological environments simulating those in which oil is found and in environments where oil is believed to be formed. Large populations of living bacteria are found in bottom deposits from the floor of the ocean and in reservoir fluids from oil wells. Conclusive proof is still lacking that bacteria are physiologically active in subterranean deposits of brine or oil, but bacteria are unquestionably functional in recent marine sediments to the greatest depths sampled, around 25 feet. Thousands of viable bacteria per gram were recovered from bottom deposits collected at depths exceeding 20 feet below the sea floor. Extrapolating the curve for the vertical distribution of bacteria in recent marine sediments suggests that the lower limits of the biosphere in sedimentary materials would be limited primarily by increasing temperatures at greater depths.

The greatest depth from which samples of sedimentary material have been collected aseptically for bacteriological analysis is 1,560 feet. Cores of limestone impregnated with anhydrite, sulfur and traces of organic matter taken from this depth were found to contain living bacteria capable of propagation in such material. Numerous bacteria are often found in oil coming from depths of several thousand feet, but it is not known whether these are indigenous species or if they are adventitious species introduced after the well was drilled. Nevertheless, the recovery of numerous bacteria years after the well was drilled indicates that they are reproducing in the formation.

From petroliferous sediments have been recovered bacteria, some of which can grow at temperatures as low as 0° C. and others which are physiologically active at temperatures as high as 85° C. The bacteria are not injured by hydrostatic pressures up to 150,000 pounds per square inch, a pressure which is approximately ten times that occurring five miles below the surface of the earth. Some of the bacteria thrive in low salinity water while others grow well in salt-saturated brines. From these observations it is concluded that neither salinity, hydrostatic pressure nor temperatures up to at least 85° C. can be expected to prevent bacterial activity in petroliferous environments.

Most of the bacteria are facultative anaerobes. They attack nearly all kinds of organic matter. In highly reducing environments bacteria tend to convert the organic remains of plants and animals into substances which are more petroleum-like. This they do by splitting oxygen, nitrogen, sulfur and phosphorus from various organic compounds. This is illustrated by the data given in Table 1 on the average proximate chemical composition of the organic content of sediments of increasing antiquity.

TABLE 1

Type of material	Carbon Per cent.	Hydrogen Per cent.	Oxygen Per cent.	Nitrogen Per cent.
Marine sapropel	52	6	30	11
Recent sediments .	58	7	24	9
Ancient sediments ..	73	9	14	3
Crude oil	85	13	0.5	0.4

Sapropel consists largely of the recently deposited remains of marine plants and animals. A large part of it is decomposed prior to burial. The organic content of now exposed ancient sediment is less than the organic content of recent sediments. The lost organic matter has probably been oxidized to carbon dioxide and water. There is no proof that bacteria are responsible for the changes in the quantity and quality of the organic content of sedimentary material, but the occurrence of bacteria in the sediments which are potentially capable of such transformations is highly significant. Similar reductions in the total quantity and in the oxygen, nitrogen, sulfur and phosphorus content of organic matter incubated anaerobically for a few months have been observed in the laboratory where no such changes occurred in sterile controls. Several of the mechanisms are well known whereby bacteria deoxygenate certain kinds of organic matter (decarboxylation), reduce its nitrogen content (ammonification) or remove sulfur (hydrogen sulfide production).

While it is not to be implied from the aforementioned laboratory experiments that bacteria produce petroleum from organic matter independent of other agencies, it is significant that the bacterial formation of hydrocarbons has been demonstrated. In a recent series of experiments 34 mgm of ether-soluble, unsaponifiable, oil-like material was recovered from a culture enriched with 1.2 grams of caproic acid as the only carbon source. Determinations of the refractive index, bi-refringence, optical activity and carbon and hydrogen content of this oil-like material indicated that it consisted largely of normal paraffins ranging from $C_{20}H_{42}$ to $C_{25}H_{52}$. In other extracts from bacterial cultures was found a material indistinguishable from the ceresin waxes of crude oil. Repetitions of the experiment have shown that certain sulfate-reducing bacteria isolated from petroliferous sediments produce small quantities of oil-like extracts from acetic, propionic, butyric, capric, stearic and lactic acids. Though not proposed as an answer to the origin of oil, these experiments establish that sulfate-reducing bacteria can convert certain kinds of naturally occurring organic matter into petroleum hydrocarbons under environmental conditions resembling those in which petroleum is believed to have been formed.

The evolution of methane during the bacterial fermentation of organic matter is common knowledge. Possibly ethane and propane in much smaller quantities are produced along with the methane. The bacterial production of carotene, leprotene, flavorhodin and other complex pigmented hydrocarbons has been reported. The liberation of benzene from the bacterial decomposition of the amino acid tyrosine has also been reported. Theoretically other aromatic hydrocarbons of the benzene series could result from bacterial decomposition of organic materials containing carbon-ring components.

Certain theories of petroleum formation require the copious evolution of hydrogen. As is pointed out, though, by a leading petroleum geologist late in 1942, "Because we have uniformly failed in the past to find the requisite hydrogen within the earth's crust, the theory remains unproved." Looking into the little explored microbiological realms for an explanation, we find that the anaerobic fermentation of organic matter may result in the liberation of appreciable quantities of hydrogen. In experiments conducted in the S.I.O. laboratories recently, it has been observed that as much as 60 per cent. of the gas (by volume) resulting from the fermentation of glycerol by marine anaerobes consisted of hydrogen. Large quantities of hydrogen are also liberated from cellulose and proteinaceous substrates. In the presence of other types of bacteria no free hydrogen may appear because (1) it may be activated to unite with carbon dioxide with the production of methane:

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

(2) certain bacteria may cause the hydrogen to reduce sulfates to hydrogen sulfide:

$$SO_4^{--} + 5H_2O = H_2S + 4H_2O$$

or (3) bacteria may actuate the hydrogenation of unsaturated organic compounds. All three reactions are known to be catalyzed by anaerobic bacteria which occur in marine sediments. Consequently, in such marine sediments one would expect to find the reduction products (methane, hydrogen sulfide or saturated hydrocarbons) rather than free hydrogen. It may be significant in this regard that unsaturated compounds are not found in petroleum.

Many kinds of bacteria provoke the direct transfer of hydrogen from one compound to another. Possibly it is by such a mechanism that lipoclastic anaerobes have demonstrated tendencies toward the reduction and the decarboxylation of fatty acids.

Hydrogen sulfide, which is produced in large quantities by sulfate-reducing and protein-decomposing bacteria, may play a role in the reduction of organic matter to hydrocarbons. The following is a hypothetical example of a reaction which is thermodynamically possible in a highly reducing environment:

$$C_6H_{12}O_6 + 7H_2S = C_6H_{14} + 6H_2O + 7S$$

Some such reaction may account for the observed diminution of the sulfide content in a closed system of anaerobes growing on carbohydrates and proteins. Bacterially produced hydrogen sulfide may favor petroleum formation by creating reducing conditions.

Reducing conditions promote the formation and favor the preservation of petroleum hydrocarbons. The oxidation-reduction potential of marine bottom deposits is as low as E_h -0.2 to -0.5 volts in areas where there is considerable deposition of organic matter. Measurements on profile series show that the sediments become more reducing from the surface downward to a depth of several feet, where the oxidation-reduction potential is uniformly low. Oil-bearing sediments are generally highly reducing, a condition for which bacterial activity may be largely responsible. It has been demonstrated in the laboratory that raw cultures of bacteria taken from marine sediments are able to create in simulated source sediments oxidation-reduction potentials more reducing than $E_h - 0.5$ volt.

Perhaps one of the most important functions of bacteria in the origin of oil is the desorption or release of oil from sedimentary materials. There are several mechanisms by which bacteria liberate oil from oil-bearing sediments. One of the most obvious mechanisms is the dissolution of carbonates by carbonic and organic acids produced by bacteria. When limestone, dolomite or other calcareous materials are dissolved, the oil associated therewith is liberated, and at the same time void spaces or channels are formed which provide for the migration or accumulation of oil. Carbon dioxide produced by bacteria either as a normal product of respiration or from the dissolution of carbonates tends to decrease the viscosity of oil, thereby promoting the movement or flow of oil. By increasing the internal gas pressure, carbon dioxide produced by bacteria *in situ* tends to drive oil from dead-end pockets and through interstitial spaces.

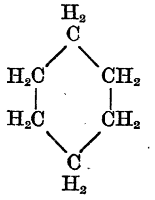
Certain thigmotactic bacteria release oil from noncalcareous sediments. By virtue of the affinity of such bacteria for solid surfaces on which they grow, oil is crowded off. Some of the bacteria produce detergents or surface-active substances which liberate oil from solid surfaces. "Light ends" released by any of the aforementioned mechanisms dissolve heavier hydrocarbons and promote the flow of oil. As will be elaborated below, some bacteria tend to decrease the density of crude oil, probably by splitting methane or other simple hydrocarbons from more complex molecules. It is believed that the action of bacteria in past geological ages has played an important part in the migration and accumulation of petroleum. Whether the oil is still locked in shales, tar sands or other oil-bearing materials or is in a fairly free-flowing state in subterranean structures, may have been determined largely by bacterial activity. The nature of the latter would be determined by the physiological types of bacteria which happened to be present and the prevailing environmental conditions.

The release of oil from plants is another function attributed to bacteria. Most plants synthesize hydrocarbons to some extent, and some, such as the rubber tree, guayule plant, Russian dandelion, candelilla plant and milkweed, produce appreciable amounts of hydrocarbons. The selective decomposition of the plant proteins and carbohydrates following the death of the plant may release the hydrocarbons for eventual accumulation in sediments. Of course, whether the hydrocarbons also will be destroyed by bacteria will depend upon the types of bacteria present and the environmental conditions.

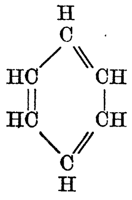
Although generally regarded as biologically inert, most kinds of petroleum hydrocarbons ranging from simple gases to complex solids are susceptible to oxidation by bacteria under certain conditions. Methane, petroleum ether, gasoline, kerosene, lubricating oil, paraffin wax, tars, benzene, xylene, anthracene, naphthalene, mineral oil and cyclohexane are among the common hydrocarbons which are attacked by bacteria. Half a hundred species of microorganisms representing more than a dozen different genera have been shown to utilize one or more kinds of hydrocarbons. Such microorganisms appear to be quite widely distributed in marine sediments. They are particularly abundant in the soil around tank farms, oil wells, leaky gas mains and elsewhere where petroleum or its products are spilled.

Evidence for the microbial utilization of hydrocarbons has been obtained by demonstrating the growth of bacteria in a medium which contains no carbon or energy source except pure hydrocarbons, by measuring oxygen consumption and carbon dioxide production in such a medium, and by observing changes in the hydrocarbons. Since most hydrocarbons are virtually insoluble in water, it is necessary to disperse them in order to provide for their ready attack by bacteria. Some degree of success has been enjoyed by emulsifying the hydrocarbons, but the best results have been obtained by dispersing the hydrocarbons adsorbed on solid surfaces such as asbestos fibers, glass wool, silica sand or diatomaceous earth. With the exception of one anaerobic organism, all known bacteria which oxidize hydrocarbons require free access to atmospheric oxygen. Representatives of the following genera have been credited with the ability to oxidize hydrocarbons: *Pseudomonas, Micrococcus, Mycobacterium, Actinomyces, Bacillus, Bacterium, Corynebacterium, Sarcina, Serratia, Spirillum, Aspergillus, Penicillium, Monilia* and *Micromonospora.*

Although there is a high degree of specificity in the types of hydrocarbons attacked by individual microbial species, certain tentative generalizations can be made. These generalizations are based upon observations on the behavior of enrichment cultures grown in the presence of about a hundred pure hydrocarbons and a score of "narrow cuts" or refinery products. As a rule, aliphatic or paraffinic compounds are oxidized more readily than corresponding aromatic or naphthenic compounds. Long-chain hydrocarbons are more susceptible to bacterial oxidation than those of shorter chain length. For example, when similarly dispersed in mineral solutions, paraffin wax is utilized more readily than lubricating oil. Then follows kerosene, gasoline, low-boiling-point petroleum ether and natural gas. There are relatively few organisms which can oxidize methane (CH_4), and it only with difficulty. Oxidized with progressively increasing ease are propane (C_3H_8), hexane (C_6H_{14}), octane (C_8H_{18}), decane ($C_{10}H_{22}$), hexadecane ($C_{16}H_{34}$) and dicetyl ($C_{32}H_{66}$). Branched chain hydrocarbons or iso-compounds are oxidized by bacteria more readily than normal or straight chain homologs. Unsaturated compounds containing double bonds are oxidized more readily than the corresponding saturated compounds in the aliphatic series. However, cyclohexane, which has no double bonds, is more susceptible to bacterial oxidation than benzene:



Cyclohexane



Benzene

It may be of interest to point out in passing that rubber hydrocarbons, both natural and synthetic, are attacked by a large number of microorganisms. Pure natural rubber or caoutchouc, which has the composition $(C_5H_8)_n$, is more susceptible to microbial oxidation than compounded rubber products. In the absence of inhibitors, buna-N, buna-S and butyl rubbers are all readily attacked by bacteria when dispersed in appropriate mineral solutions. Thiokols A, B and FA, which differ markedly in chemical composition from other synthetic rubbers, are relatively resistant to microbial attack.

Hydrocarbon-oxidizing bacteria may be of considerable importance in the petroleum picture: (1) Such organisms may prevent the accumulation of oil in any environment except where conditions are inimical to their activity. Thus in seeking the origin of oil we should look for factors which inhibit the activity of hydrocarbon-oxidizing microorganisms. Some of the factors which are known to be inhibitory are hydrogen sulfide, low oxidation-reduction potentials and certain heavy metals.

(2) There is some evidence that hydrocarbon-oxidizing bacteria may alter the properties of crude oil by attacking preferentially long chains or branched chains, by splitting methane and perhaps other simple hydrocarbons from more complex compounds, or by attacking preferentially compounds containing oxygen, nitrogen or sulfur. A decrease in the density of a small sample of crude tar from 1.02 to 0.94 during six months' incubation has been shown to be due to the action of bacteria.

(3) The rapid disappearance of oil pollution in waterways, around refineries, pipe-line leaks, oil seepages, along beaches where there is drilling, and elsewhere where oil is spilled in water or on the soil is believed to be due largely to the activity of hydrocarbon-oxidizing bacteria. This seems to be Nature's way of "pulling the chain" for the disposal of oil which otherwise would pollute fields and waterways.

(4) Hydrocarbon-oxidizing bacteria may contribute to the formation of "paraffin earth" which is quite commonly found in surface soil overlying subterranean deposits of petroleum. Certain samples of so-called "paraffin earth" have been found to contain large numbers of hydrocarbon-oxidizing bacteria or their refractory remains.

(5) Large numbers of bacteria which oxidize volatile hydrocarbons, including ethane, propane and butane, are found in surface soil surrounding or overlying oil fields. The demonstration of these bacteria or their fossil remains in surface soil in definite distribution patterns is the basis of so-called "geomicrobiological" prospecting methods. Although nature generally hides her treasures well, she usually leaves a clue, which in this case may be the fossil remains of hydrocarbon-oxidizing bacteria. The perfection of a technique for the rapid identification of such fossils in the field may provide another tool to aid in the search for oil.

(6) The whimsical behavior of hydrocarbon-oxidizing bacteria sometimes results in confusion in the search for oil by "soil analysis" methods of prospecting. Volatile hydrocarbons in soil samples collected for analysis may be destroyed quantitatively within a few hours by bacteria, if conditions are conducive to the activity of such bacteria, resulting in negative or anomalous findings. The failure of various workers to find petroleum hydrocarbons in recent sediments may be due to the increased activity of hydrocarbon-oxidizing bacteria following the collection, transportation and storage of the samples.

(7) Microorganisms which attack hydrocarbons are sometimes instrumental in causing undesirable changes in petroleum products stored over water. The discoloration of refinery products and the formation of gummy substances have been traced to the activity of hydrocarbon-oxidizing bacteria. This also applies to observed decreases in the octane rating of aviation gasolines which in certain emergencies and experimentally have been stored over water.

The action on aviation gasolines is threefold: (a) Branched-chain hydrocarbons which have the highest anti-knock characteristic are preferentially attacked with the liberation of some methane, (b) microbially produced sulfides precipitate tetraethyl lead, and (c) peroxides produced by the bacteria catalyze the deterioration of tetraethyl lead.

(8) There is a report in the literature which ascribes an explosion of a kerosene tank to the production of a mixture of methane and hydrogen from the bacterial decomposition of kerosene in water storage.

(9) The growth of hydrocarbon-oxidizing bacteria in medicinal and pharmaceutical preparations having hydrocarbon bases has resulted in discolored and otherwise altered products. Allergies have been traced to the use of such products. Cooling oils have also been unfavorably affected by the profuse growth of hydrocarbon-oxidizing bacteria.

Little is known regarding the end-products which result from the bacterial utilization of hydrocarbons, except that carbon dioxide and bacterial protoplasm are always produced. There are reports in the literature on the production of methane, hydrogen, ketones, aldehydes, alcohols and organic acids. The products of metabolism will depend upon the bacterial species, the hydrocarbons and the experimental conditions. The observation that fatty acids result from the bacterial oxidation of petroleum hydrocarbons suggests exploring the possibilities of using microbial catalysts to convert hydrocarbons into much needed edible fatty acids. More extensive and intensive studies on the products of hydrocarbon utilization can be expected to yield interesting information on bacterial physiology.

In conclusion and to clarify my own views on the subject, it should be emphasized that while bacteria probably play an important role in the formation and transformation of petroleum, geological, geophysical and geochemical factors are also believed to be of importance in the origin of oil. The bacterial synthesis of certain petroleum hydrocarbons has been demonstrated, but it seems doubtful if it will ever be practical to produce by bacteria any hydrocarbons except methane on a commercial scale. The fondest hope for the future now entertained is that intensified microbiological studies coupled with other investigations on the origin of oil may eventually provide information which will aid in the discovery of existing pools of petroleum. Geomicrobiological prospecting and refined methods of "soil analysis" may prove to be a step in this direction. Microbiological processes may find practical applications in the petroleum industry, the most promising of which appears to be the use of bacteria in the recovery of petroleum from oil-bearing materials, in certain refinery processes and in the disposal of various waste products. Wherever petroleum or its products are stored in contact with water, the possible effects of hydrocarbon-oxidizing microorganisms must be taken into account. The multiple effects of bacteria on the formation and transformation of petroleum hydrocarbons is a new frontier of learning which presents a challenge to the petroleum industry and to the microbiologist.

OBITUARY

EDMUND BURKE DELABARRE

Edmund Burke Delabarre, one of the pioneers of American psychology in the days when it was transforming itself into an experimental science, died in Providence on March 16, 1945. He was born in Maine in 1863. His influential teachers were Garman at Amherst, James at Harvard and Münsterberg at Freiburg, where he obtained the Ph.D. in 1891. He established the psychological laboratory of Brown University in 1892 and remained there as active professor for forty years and as emeritus (but still active) for the remaining years of his long life. His investigations were principally concerned with vision and with muscular movement and the sensations of such movement. An ingenious apparatus man, he designed pieces for continuous registration of respiratory and circulatory movements (as in emotion) and of automatic hand movements. He was the first, in 1898, to obtain an objective record of eye movements, and his method of mechanical registration, though soon superseded by photographic methods, gave accurate and important results. He attacked the difficult problem of explaining how the visual field can be transformed from a mere aggregate of color patches into a well-organized field of objects in space, and showed that a fairly comprehensive theory could be based on sensations of tension in the eyeball muscles. His work on this problem and others has not been fully published. As an avocation he did much intensive work in New England archeology and is especially noted for his decipherment of the famous "Dighton Rock." Dr. Delabarre was a man of sparkling eyes and cheerful disposition and of wide interests, a man whom it was always a pleasure to encounter.

R. S. Woodworth

FRANK W. COLLIER

Dr. Frank W. Collier, formerly dean and professor of philosophy at the Graduate School, American