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THE COSMICAL ABUNDANCE OF THE ELEMENTS[1]

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EIGHTY-EIGHT chemical elements are known—(not counting two whose isolation is still a matter of controversy, nor unstable isotopes of short life, produced artificially). For all these, methods of isolation and of qualitative and quantitative analysis have been developed in chemical and physical laboratories, so that it is only a matter of hard work for the analyst, presented with a sample of matter of any sort, to determine its composition with accuracy. The simplest definition of composition alone concerns us here—the relative abundance of the elements in our specimen. We may measure this by weight or by the numbers of atoms of different kinds. The chemist is likely to do the first, the astrophysicist the second. As one of the latter, it is not my place to-day to do more than mention the many methods by which the chemist separates the various elements, and avoids loss of them in the process. Suffice it to say that the separation is sometimes easy, sometimes very difficult (as for the rare earths). The best available tests are much more sensitive for some elements than for others, and it is peculiarly hard to detect the latter when they are present in but small proportion, say less than one ten-thousandth of the whole mass.

The physicist can at times come in to ease the situation. Radio-active tests are available for but a small number of the elements, but can detect these in excessively small amounts.

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[1] An address delivered at the symposium, September 26, 1941, in connection with the Fiftieth Anniversary Celebration of the University of Chicago.

Spectroscopic observations, in the romantic age of science, seventy years or so ago, led to the discovery of several of the rarer elements. For many years, this method, except for simple applications in qualitative analysis, was left to the astronomers. In recent times, however, it has been developed into a very rapid and fairly accurate analytical procedure, of considerable practical value. It has the great advantage that all the constituents which are present in the sample may be investigated at once, by a single process: but though the tests for some elements are of great delicacy, those for others are of such low sensitivity as to be substantially useless. Fortunately, the spectroscopic tests are often delicate when the chemical procedure is troublesome, and the two supplement each other.

To find, even roughly, the *cosmic* abundance of the elements is another thing. We can get a good determination of the *terrestrial* abundance provided that we define this adjective to mean the abundance within the thin superficial region on our planet extending a few miles above its surface and a mile or two below. The geologists can help us out by structural studies that extend the region in which the nature of the rocks may reasonably be inferred a few miles deeper.

But, even so, our knowledge is confined to a surface shell of our planet far thinner in proportion to its diameter than the skin of an orange or even an eggshell.

Making the best of what we have, and combining analyses of rocks of various kinds, of sea-water and of the air, in proportion to the total mass of each, we can get a very good idea of the composition of the earth's crust—that is, of everything that lies above some arbitrary depth such as ten miles below sea-level. We have here a solid mass of silicates of a few well-known metals, with a wash of water on its surface. Oxygen, whether by weight or by number of atoms, is the most abundant element. Silicon is next; and then come six metals, aluminium, iron, magnesium, calcium, sodium and potassium. These eight elements account for nearly 98 per cent. of the whole by weight. The hydrogen in the sea-water makes up but a part of the remaining 2 per cent.

But this surface layer is not likely to be a fair sample of the composition of our planet: and, indeed, we know that it is not. Measures of gravity on the earth's surface, and of its variation from equator to pole, show that the mean density is nearly twice that of the superficial rocks, and the central density much higher; and seismological studies reveal the existence of a central core nearly 4,000 miles in diameter, which appears to be liquid, and of at least one considerable discontinuity in density in the shell which overlies this.

We would be completely at loose ends, were it not that nature generously provides us with other samples, in the form of the meteorites which fall to the earth's surface from interplanetary space.

The larger ones, which get through the atmosphere and can be studied, show a considerable variety of composition. Some are masses of silicate rock; some are composed mainly of iron, alloyed with nickel; and some contain large quantities of metallic sulfides. V. M. Goldschmidt, the greatest authority on geochemistry, estimates that on the average there are ten parts by weight of stone, two of iron and one of sulfides. Taking an average on this basis, we may hope to have something more fairly representative of the cosmos than is the skin of our planet.

We must still be cautious. Accurate photographic observations of the trails of bright meteors, of which a good many have been secured in the last few years, show that almost all of them, before they hit the earth, were pursuing elliptical orbits of rather short periods, and were, in effect, tiny asteroids. They are samples of the solar system, perhaps, but not of the universe at large. The belief that most meteors have invaded our system from interstellar space has been greatly weakened by these new and much better observations —though it may well be true for the tiny shooting stars which are consumed in the upper air and never reach the ground.

Moreover, the fiery ordeal which even a large meteorite undergoes by friction in the atmosphere may have a strongly selective effect in determining what gets through.

In the heads and tails of comets, the spectroscope reveals an abundance of gaseous compounds of carbon and nitrogen. It seems clear that these gases escape from solid particles in the comet's nucleus, when they are warmed by the sun. But ordinary meteorites are not rich in such compounds. It may quite possibly be that among the solid cometary particles, some are composed largely, if not entirely, of carbon compounds. Such a body, in its flight through our oxygenated atmosphere, would be utterly consumed. It would, in Billy Sunday's famous phrase, "have no more chance than a celluloid dog chasing an asbestos cat through Hell." So we can not be any too sure that we have a fair sample in the meteorites which are picked up. But, anyhow, we have the best there is.

The average composition of meteorites differs from that of the earth's crust significantly, but not very greatly. Iron and magnesium are more abundant, and nickel and sulfur rise from subordinate positions to places in the list of the first ten. Silicon, aluminium and the alkali metals, especially potassium, lose what the others gain.

The composition of the earth as a whole is probably much more similar to the meteorites than that of its "crust," which is substantially that of the granitic rocks which form the basement of all the continents, but extend to a depth averaging less than twenty miles. Granites are rich in aluminium and the alkalies, while the deeper and denser rocks are ferromagnesian. The known properties of the central core are entirely consistent with the assumption that it is composed of molten iron—though not enough to prove it. The generally accepted belief that it is composed of nickel-iron is based on the ubiquitous appearance of this alloy in metallic meteorites.

It is the earth's crust, then, and not the meteorites, which we may regard as peculiar in composition. Its distinctive characteristics follow from the reasonable hypothesis that it is a segregate from an originally molten magma which, being lighter, floated upon the main basaltic mass, while the dense molten metals sank to the center, and water-vapor and the permanent gases escaped to the surface.

In such a separation, certain elements tend to be concentrated in each phase. V. M. Goldschmidt, the principal authority on this subject, distinguishes the *siderophile* group of elements which dissolve preferentially in the molten iron, the *lithophile* group which go mainly into the silicate layer and the *atmophile* group which escape, as free gases or volatile compounds, and form the ocean and the atmosphere. Chemical considerations suggest the existence of a fourth *chalcophile* group, which would concentrate in the layer of metallic sulfides which would form if enough sulfur were present. Such a sulfide layer, in the earth, would lie just outside the metallic core (and be considerably denser than the superimposed silicates), but there is little seismological evidence in favor of its existence.

There are many interesting details. Rare elements with atoms or, more precisely, ions of about the average size tend to slip in here and there into the crystal-lattices of the minerals which compose the bulk of the rocks, and get lost—so that ordinary analysts have a hard job to find them. Those with unusually small ions, such as lithium, or large ones, such as the rare earths, remain in the residual fluid magma, and are concentrated in the granitic layer, and especially in the pegmatites, which solidify last.

We can escape from our planet and attempt a truly cosmic analysis, with the aid of the spectroscope alone —happily a very powerful aid.

The qualitative analysis of the sun and stars, which recognized in them the familiar elements, still presents the most impressive of all evidence of the uniformity of nature.

No technical prose can express its philosophic aspect as well as Stedman's stanza:

White orbs like angels pass
Before the triple glass
  That men may scan the record of each flame,
Of spectral line and line
The legendry divine
  Finding their mould the same, and aye the same,
The atoms that we knew before
Of which ourselves are made,—dust, and no more.

Returning from poetry to prose, we note that, at first glance, the stars, though revealing only known elements, appear to be very different in composition. Some show a host of lines of the metals, others relatively few, belonging to the permanent gases. Twenty years or so ago the riddle was solved, when Saha, applying the newly developed theory of ionization, showed that these differences were primarily to be attributed to temperature. This is too long and too well known a story to tell now. It may suffice to say that, in the cooler stars, the non-metals are not stirred up sufficiently to absorb lines in the rather narrow spectral regions which can be observed through our atmosphere, while in the hotter ones the metals, by repeated ionization, are put into a state where they absorb only in the inaccessible ultra-violet. Miss Payne's pioneer conclusion of 1925, that the general run of stars are very similar in composition, has been fully confirmed by subsequent investigations.

Aided by the advance of atomic theory, astrophysics has identified almost every important spectral line which has been observed in extra-terrestrial sources. We find, in every once-perplexing case, familiar elements, shining under unusual conditions. In the nebulae, for example, the atoms are undisturbed by collisions long enough to allow them to emit lines which would normally be "forbidden." The last great riddle—the spectrum of the solar corona, has been interpreted by Edlèn in terms of forbidden lines of very highly ionized but familiar atoms of iron, calcium and nickel.

For a detailed analysis for many elements, we must have spectra of high dispersion, showing the fainter lines, and resolving close groups. In the sun, which gives us plenty of light, sixty elements have been identified. For almost all the rest, the strong lines are in inaccessible parts of the spectrum, and the observable lines should at best be very faint so that failure to find them is not surprising.

Spectra of the brighter stars, taken with great telescopes and spectrographs, show a wealth of detail. The most complete study so far, on Beta Pegasi, has identified more than forty elements.

Quantitative analysis is always more difficult than qualitative. It stands to reason that, the more atoms are at work producing a spectral line, the stronger the line will be. But the relation is complicated. Even with an absorbing layer of gas in the laboratory, of uniform pressure and temperature, the increase of strength of a line with the number of atoms is rapid for faint lines, slows up very much for those of moderate intensity, and increases again for strong lines, though to a less degree than at first.

In a stellar atmosphere, which has no sharp boundarise, but thins out gradually into space above, and becomes increasingly hazy below, the situation is more complicated, but the curve of growth which finally emerges from the analysis is of very similar form.

The exact shape of such a curve is influenced by the temperature of the atmosphere, turbulent motions within it, and by the influence of collisions between atoms in broadening the stronger lines. For any given star, it must be found by observation. With good spectra, it is fairly easy to measure the equivalent widths of the lines, which indicate how much light each one cuts out of the spectrum. The "number of atoms acting" to produce a line is a somewhat Pickwickian phrase. A given line of iron, for example, is absorbed only by those atoms which happen to be in a certain one of the hundreds of energy-states in which the atom can exist.

The fraction of all the neutral iron atoms which are in such a state depends upon the "weight" of the state and on the temperature. But atoms in this state can absorb many different lines. What proportion of them "works" on any one of these lines is fixed by the laws of spectral structure: but it can at present be calculated theoretically only for the simplest spectra, such as that of hydrogen. In complex spectra, however, there are numerous line-groups, known as multiplets, in which the relative numbers of atoms acting to produce the lines—the transition-probabilities—are given by fairly simple formulae. With the aid of these, and of extended groups called supermultiplets, it is possible to find the relative number of atoms which act to produce lines of known equivalent widths, and so by a process of successive approximation to draw the curve of growth and find the "excitation temperature" of the atmosphere as well. The multiplet formulae are approximations based on a simplified theory which overlooks numerous complications. It is probable, however, that the resulting errors average pretty well out when numerous multiplets are used.

The actual line-strengths may be found by laboratory measures. These are difficult, and great care must be taken to avoid systematic errors. Progress along this line is at present rapid, and we may hope to have, in a few years, measured intensities which remove the uncertainties just mentioned. The theory will doubtless advance too, but it is going to be very complicated.

The absolute number of atoms, per square centimeter of the sun's surface, is harder to determine. But this tells us about the *opacity* of the atmosphere —how far down we can see into the increasing incandescent fog—and not about its composition.

It is, however, important to know whether the atmosphere is equally opaque for light of different wave-lengths. Otherwise, we have to allow for the fact that we "see down" deeper, and through a greater quantity of gas, in some parts of the spectrum than in others. There is fortunately an independent test for this in the degree of darkening of the solar disk toward its edge. This shows that the differences in general opacity are small and no serious error is committed by ignoring them.

If the same curve of growth can be used for lines of all elements—which again is probably a tolerable approximation—we can find the numbers of atoms of various elements which are engaged in the production of lines in the observable part of the solar spectrum (from about 3,000 to 12,000 Ångstroms).

If we know the transition probabilities we can pass from the number of atoms "doing" a particular line to the whole number in the atomic state from which it is absorbed, and then the number of atoms in other states, and so to the whole number of atoms of the element.

Here we meet another complication. Neutral atoms, and those which have lost one, two or more electrons have entirely different spectra, which must be treated separately. In the sun only atoms which have lost one electron, or which retain them all, are important. In the stars, we have many which have lost two or three.

The percentage of atoms in these successive conditions depends of course on the energy necessary to pull the electrons off—the ionization potentials—and also on the temperature and the pressure of the gas. For several elements—calcium, titanium, etc.—the methods previously described give good determinations of the numbers of both neutral and singly ionized atoms. From these the pressure can be found (a suitable average representing the atmosphere as a whole). Thus, if we know for other elements the numbers of atoms in either the neutral or the ionized state we can calculate those in the other, and arrive at last at a complete census of the atoms of a given element.

The first attempt to analyze the sun's atmosphere in this way was made by the speaker twelve years ago. It was emphatically a reconnaissance in new territory. The theory of the curve of growth did not then exist; the equivalent widths had been measured for only a very few of the strongest lines, and only Rowland's estimates of intensity, on an arbitrary scale, were available for the rest; and there was no way of determining whether lines of the same intensity in different parts of the spectrum were produced by the same number of atoms.

It is remarkable that, with these handicaps, the results were as good as they were. When the old calibration is converted into a curve of growth, the agreement with the curve recently adopted by Menzel and now widely used is very close.

A similar analysis, using all modern refinements, is being made by Dr. Goldberg. Through his courtesy, I am able to present a preliminary comparison of the older results with his. After allowance for the difference in zero-points, and in the assumed temperature of the solar atmosphere, the average deviation between the two determinations of the logarithm of the number of atoms above the photosphere is ± 0.28 for 19 elements for which the data are good or fairly good. This corresponds to a factor of 1.9—small compared with the range in abundance among these elements, which is about 200,000-fold. The agreement for the weaker determinations is as good as could be expected, except for beryllium, where the results depend on two faint lines near the ultra-violet limit of the solar spectrum, where neither investigation had any observational test of an extrapolated calibration.

The actual numbers of atoms "above the photosphere" are smaller in Goldberg's list than in mine, by an average factor of about 30. This comes from his application of a correction for collisional broadening of the strong lines, which is undoubtedly sound, but was not so much as imagined twelve years ago.

Goldberg's calculations have not at present been extended to the rarer elements, whose presence is revealed in the sun only by weak lines, for which the equivalent widths have not yet been measured. For a comparison with Goldschmidt's data for meteorites, it is therefore still necessary to use the older analysis of the sun's atmosphere, which included 56 elements.

For the more abundant elements, which are not more than 100,000 times rarer than silicon or iron, the average discordance is ± 0.45 in the logarithm (a factor of 2.8) which, considering all the uncertainties of determination, does not indicate any definite difference of composition. For the rarer elements, Goldschmidt's values are greater than mine by a factor which ranges up to 20 or 30 for the rarest. These elements have to be determined from very faint Fraunhofer lines. For such lines the calibration at Harvard by Menzel, Goldberg and Cook (1940) gives a much larger number of effective atoms than the old one of 1929, and it is probable that the latter is at fault.

There is therefore no present reason to conclude that meteorites differ in composition from the sun's atmosphere, so far as the metals are concerned.

For the non-metallic elements, especially the lightest ones, the situation is radically different. It is not easy to determine their abundance in the sun. Carbon, oxygen and sulfur have fairly strong lines in the deep red, and nitrogen faint ones, from which the number of atoms in the excited states which absorb these lines can be fairly well determined. But these states are highly excited. The number of atoms of each element in the normal state is enormously greater, by a factor whose value changes rapidly with the temperature. We do not yet know the temperature of the region in the sun's atmosphere where these lines are absorbed accurately enough to enable us to calculate good values of these huge correction factors. But despite this uncertainty, it is evident that these elements, except perhaps sulfur, are at least as abundant as the most abundant metals, and may be much more so.

Hydrogen stands by itself. Its lines are peculiarly subject to broadening by many influences, so that they can not be used to determine its solar abundance, except to show that it must be very great.

There are, however, several indirect ways of estimating the abundance of hydrogen relative to other elements, in the sun and the stars. No less than six of these have been worked through by various investigators, and all agree that measured by the number of atoms, hydrogen is at least a thousand times more abundant than all the metals together. The separate determinations of this ratio run from 1,000 to 8,000. The large values appear to be the best, so that we may, for the present, adopt 5,000 as a round number.

The abundance of the inert gases—helium, neon, argon, etc.—can not be determined at all in the sun, for they show no absorption lines, and only helium appears in emission in the chromosphere.

This serious gap in our knowledge has been filled by an investigation by Unsöld based on measures of line-widths in spectra of the star Tau Scorpii, taken at the McDonald Observatory. This star is so hot that the atoms of helium and neon are got into condition to absorb spectral lines. By a very ingenious method Unsöld has avoided the difficulties presented by the high temperature, and determined what appear to be reliable values for the abundances of the light elements, and also of magnesium, aluminium and silicon. He finds that, for every atom of magnesium or silicon (which are almost equally abundant) there are approximately 3 of carbon, 6 of nitrogen, 16 of oxygen, 18 of neon, 3,000 of helium and 16,000 of hydrogen. The enormous preponderance of hydrogen is again confirmed, and helium turns out to be a rather good second.

It is to be hoped that these results, which are much the best so far obtained, will soon be confirmed by similar studies of other stars, and that it may be possible to find in the same way the abundance of fluorine, sulfur, phosphorus and argon.

A large field for such studies is already available in the high-dispersion spectra of bright stars which exist at Mount Wilson, McDonald and some other observatories. Pending such precise studies, only large differences of composition among the stars can be detected by more obvious methods. In a number of important cases, these certainly exist. The most notable example is furnished by the stars of classes R and N, whose spectra show enormously strong bands due to carbon molecules and carbon compounds. Here there is no doubt that, as the late R. H. Curtiss first suggested, we have to deal with reducing atmospheres in the ordinary chemical sense, containing more carbon than oxygen, while the great majority of the cooler stars have oxidizing atmospheres, the excess of oxygen permitting the formation of the metallic oxides, which show in their spectra. Why a few of these stars show strong bands of zirconium oxide and most of them those of titanium oxide is not known.

At higher temperatures, where compounds are dissociated, differences in composition are spectroscopically less conspicuous. One star of about the sun's temperature, R Coronae Borealis, has been found by Berman to contain carbon in great excess and little hydrogen; and another, Upsilon Sagittarii, analyzed by Greenstein, shows helium in great preponderance and hydrogen almost absent.

There are many minor peculiarities—stars with strong lines of silicon or strontium or barium—which when fully analyzed may yield results of great interest. There is enough here to do to keep the greatest telescopes, and more astronomers than are likely to work at it, busy for years to come.

Outside the stars the opportunities of spectroscopic investigation are few, but of great interest.

In the gaseous nebulae, and in the envelopes which surround novae, atoms thinly strewn in space, near very hot stars, are set shining either by the direct effects of their radiation, or by radiation emitted by other atoms in the nebula, or by collision with electrons ejected from such atoms. These special conditions favor very strongly the emission of forbidden lines, and elements which have such lines in the observable region have much the best chance of detection. The light elements—nitrogen, oxygen, fluorine and neon—have this advantage, and are frequently found, as are sulfur, chlorine and argon. Hydrogen and helium, though possessing no forbidden lines, are very much in evidence, and must be here, as everywhere, overwhelmingly preponderant. The metals are here at a spectroscopic disadvantage, but faint lines of several of them have been found, and it appears that, allowing for the very different conditions of excitation, there is left remarkably little evidence of difference in composition.

Still more thinly strewn are the isolated atoms and molecules which are to be found in interstellar space. These reveal their presence only by absorbing the light from distant stars.

Once again they represent a peculiar state of matter, in which the atoms, as a result of long periods of complete isolation, unload any excess of energy which they may have contained, and all settle down in the ground state. In this condition the lines are greatly reduced in number. Of the thousands of iron lines, a dozen or so are left—of which only the strongest has been observed, while the great and complex cyanogen band reduces to a single line. Many abundant elements, for example, magnesium and silicon, are thus removed from our observation, since their remaining lines lie in the far ultraviolet, and are cut off by the ozone in our atmosphere. The few which have been detected are common elements—sodium, potassium, calcium, titanium and iron—with the compounds CH and CN. Hydrogen is not directly observable, but the presence of lines of both neutral and ionized calcium makes it possible to estimate the number of free electrons in space. This is far greater than the whole number of metallic atoms, and can be explained only by the presence of hydrogen, as usual, in great superabundance.

The relative rarity of hydrogen on earth, and its practically complete absence from meteorites, is simply explained as a gravitational effect. Meteorites —and, for that matter, asteroids—have much too small a gravitational attraction to keep the fast-moving molecules of hydrogen from flying off into space. The earth, in its present cool condition, can retain an atmosphere, but, if it had ever been really hot on the surface, it must have lost all its hydrogen and most of the other atmospheric gases. Meteorites and the earth have both just the composition which might be expected in solid bodies segregated by condensation from an incandescent mass of composition similar to the stars. Only those constituents which could condense into, or be absorbed by a molten magma would remain; the atmophile elements would escape. The meteorites have lost these wholly; the oceans and most of the air may well have come out of the solidifying interior of the earth after the surface had cooled considerably.

Jupiter and the other great planets have sufficient gravitational attraction to retain atmospheres, even if they were very hot. Their atmospheres actually contain great amounts of hydrogen compounds, and their mean densities are low.

Only a very small portion of the known matter in the universe is in the atmospheres of the stars. An overwhelmingly large portion is deep in the interior of the stars, inaccessible to observation. Even here, however, atomic theory can follow it and find the elements divided into two groups—hydrogen and helium on the one side, and all the heavier ones on the other. The amount of heat radiated by a star depends mainly upon its mass, rather little upon its size or internal distribution of density, but a good deal upon the relative proportion in its interior of these two groups of elements. Many investigators, from Eddington to Strömgren, agree in finding that the observed data for stars as different as the Sun, Sirius and Capella, indicate that, if there is no helium, the interior contains 35 per cent. (by weight) of hydrogen, with the rest heavier elements. Counting by number, the hydrogen atoms would be fully ten times more abundant than all the rest (depending on the average weight of the heavy atoms).

If helium is present, the proportions of hydrogen and heavy atoms both diminish, but the numerical preponderance of hydrogen persists. Hydrogen is not only the simplest atom: it is the one whose transformation into other elements liberates by far the most energy and is irreversible. The great and almost invariable preponderance of hydrogen may therefore be taken as strong evidence that our universe is still young.

OBITUARY

HUGH McCORMICK SMITH

Early in the morning of September 28, 1941, Dr. Hugh McCormick Smith died suddenly of a heart attack after an illness of a few hours. He was seventy-five years of age.

Dr. Smith was born on November 21, 1865, in Washington, D. C., son of Thomas Croggon and Cornelia Hazard Smith. He began his natural history studies when a small boy, owing largely to his father's interest in birds and other small animals on his farm in Virginia. He attended Central High School, D. C., was first president of its Natural History Society, graduating in 1884. In 1888 he graduated in medicine with a perfect record in all oral and written examinations from Georgetown University Medical School and was a member of its staff from 1888 to 1905.

On March 12, 1889, Dr. Smith married Emma Hanford. Their daughters are Mrs. Edmund Vincent Cowdry of St. Louis and Mrs. Carl Harry Claudy, Jr., of Washington.

Dr. Smith's interest in science was guided while he was in high school by Professor Spencer F. Baird, the latter giving him the opportunity to work in the National Museum in 1884–85. He entered the service of the U. S. Fish Commission under Commissioner Baird in 1886, and during the next six years had six promotions. From 1893–1897 he was assistant in charge, division of statistics and methods of the fisheries of the U. S. Fish Commission and during the next five years Smith was assistant in charge, division of inquiry respecting food fishes and the fishing grounds.

From 1903 to 1913 Dr. Smith was deputy commissioner of the Bureau of Fisheries, a position especially created by Congress and from 1913 to 1922 he was the Commissioner of Fisheries. In 1900 he was named to represent the United States at the First International Fishery Congress, Paris; and again in 1905, the Third International Fishery Congress at Vienna. He was secretary-general at the Fourth International Fishery Congress, Washington, in 1908.

Smith held several positions of honor such as secretary, National Fishery Congress, 1898; chairman, International Jury on Fish Culture, Louisiana Purchase Exposition, 1904; expert adviser of the Food and Drugs Board and of the Bureau of Chemistry in fishery cases arising under the Pure Food and Drugs Act of 1906–1913; expert special assistant of the United States Counsel at the Arbitration of the North Atlantic Fisheries Dispute at The Hague, 1910; United States Government representative of the International Commission for Adjudication of Fishery Disputes with Canada and Newfoundland arising under the award of The Hague arbitration tribunal, 1910; representative of the United States on the Permanent International Council for the Exploration of the Sea, 1912; member of the research committee and associate editor, National Geographic Society, 1909–1919; commissioner on behalf of the United States on International Fishery Commission for regulation of fisheries in boundary waters of the United States and Canada, 1914.

Dr. Smith was director of the Marine Biological Laboratory of the U. S. Bureau of Fisheries, Woods Hole, Mass., 1901–1902, and director of the *Albatross* expedition for investigation of fisheries and aquatic resources of the Philippine Islands, 1907–1910.

From 1900 to 1934 he studied the aquatic resources and the fisheries, as well as inspected methods of fish culture, some of the laboratories, biological investigations and fishery administrations in 22 foreign countries in Europe, South America and Asia. The exten-