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THE CHEMISTRY OF THE FUTURE[1]

IT is interesting to speculate on what chemistry will be like fifty years from now. We may be sure that hydrochloric acid will neutralize sodium hydroxide just as it does now, and did half a century ago, and that the two will react in precisely the proportions that they have in the past. No doubt within fifty years the two isotopic hydrochloric acids will be available in small quantities in the pure state, but I am thinking now of the practical hydrochloric acid, the one that our fathers used before us and our grandchildren will continue to use in the laboratories and plants. By all this I mean, as you will understand, that the fundamental facts of chemistry will still be valid at the end of the next half century. Of course, that must be, for facts, defined as "the direct result of observation unmodified by any act of reason," are eternal. All our facts will be there but with what an enormous mass of new ones! Instead of a few hundred thousand compounds of carbon, we will have them literally by the millions. Inorganic chemistry will not be so bad, but with the extension of water, ammonia, sulphur dioxide, acetic acid, phosphorus oxychloride systems of acids, bases and salts and the natural development of the subject, the substances to be studied and facts to be learned about each will be enormously increased. Physical chemistry—my! and colloids, radioactivity, thermodynamics, phase rule and unborn nameless chemistries, each with a literature running into thousand upon thousand of pages. Pity! oh, pity, the poor student of fifty years from now and pity, too, the teacher.

How can all this be taught and learned? Well, the physicians are adding so rapidly to the average span of life that our grandsons can well afford to spend more time in preparation, particularly since the physiological chemists of that age will in a large part have solved the problem of prolonging our years of activity. The educational experts will doubtless contribute by shortening the period of preliminary training because it is inevitable that some good must come of all their feverish activity and to some of us seemingly wild unordered experimentation. But when students reach the university unable to use a dictionary because they were not taught the alphabet,

[1] Address of the retiring vice-president of Section C—Chemistry, American Association for the Advancement of Science—Philadelphia, Pa., December 28, 1926.

unable to multiply because the multiplication table was omitted, not knowing what a proportion is and thinking a ratio is something to eat, it can be easily seen that some of the present efforts are not in the right direction. Progress will be greater as pupils, parents and teachers learn that learning is proportional to the effort and that workless schooling will not work.

The chief reliance must, of course, be placed as in the past upon the most careful selection of fundamental facts and basic principles and their logical presentation and coordination with the aid of the best theories at hand. It is in the theories that we will probably find the greatest difference between the chemistry of to-day and that of the future. The facts remain, but their theoretical interpretation changes and with it comes change in language, so if we, in the turn of a hand, could go from here to a lecture on general chemistry in 1976, we would no doubt have great difficulty in understanding the speaker.

How are the theories going to change? We can only judge from the past. As you know we first have a chaos of apparently unrelated facts, then an inspired idea which, with the added hypotheses, reduces the confusion to comparatively simple unity, in which all the facts are naturally fitted and coordinated in such a way as to make their retention by the memory comparatively easy. The theory predicting new facts leads us on and on and frequently rewards us with new discoveries which almost fit the predictions but differ enough so that the theory clearly must be revised from time to time to make it agree with the stubborn facts. With these changes it always becomes more and more complex until at last it is really burdensome, although fully able to account for nearly all the facts very satisfactorily. Then some man with the genius of Copernicus appears and explains all the old and some of the new facts in a radically different and very much simpler manner. Many of our present theories are rapidly approaching the unwieldy stage. Take the atomic, for example, for a long time the model of simplicity. But now how complex! The perfectly elastic atom of our daddies transformed into a cosmos of protons and electrons revolving in a maze of actual and potential orbits, shooting from one orbit to another with the radiation of quanta of energy. Lucky dad, you did not have to worry about hv. Your element gave its spectral lines for the same reason that the hen ran in front of a car—because it did and that was the end of it. Good work, son, your idea is much better than our old awkward hv. Keep on, you are getting to the root of the matter now, but remember that your son is going to dig it all up and throw it away.

The atom of the physicist is very enticing with its marvelous accord of fact and fancy as guided by the quantum theory, electron theory, relativity theory, etc. The chemist of the present and much more of the future must be an able mathematician to take advantage of all this. Useful as this atom is in the physical laboratory, it is of but little service at present to the chemist, but perhaps it can be used to explain the puzzle of why a substance which undergoes a monomolecular reaction does not all change in an instant, instead of a perfectly definite fraction undergoing transformation per unit of time. We can picture to ourselves that the atom is perfectly stable until the electrons have dropped into some one definite set of orbits, when the atom immediately becomes reactive and undergoes the change. Perhaps also the same notion can be extended to cover the rapid increase in rates of reaction with rising temperature.

If there is anything to this idea the system should radiate energy way down in the infra red because the electron changes are probably in the very outlying orbits. In the case of the radioactive elements which follow the monomolecular type of change the sensitizing electron shift must lie within the nucleus because it is evident that the nucleus is the seat of the alpha, beta and gamma rays. This difference in the location of the orbits may perhaps account for the indifference of radioactive changes to alteration in temperature. Electron shifts between orbits lying within the nucleus should give rise to radiations of very high frequency and this may perhaps account for the gamma rays. No doubt some of the attempts which are being made to reconcile the Bohr-Sommerfeld atom of the physicist with the Lewis-Langmuir cubical atom of the chemist will soon succeed and give us an atom suitable to the needs of each. This atom may perhaps be tetragonal instead of cubical. The basis of this suggestion is the result of a recent conversation with our crystallographer, Dr. Knight. He found difficulty in finding crystals of the cubic system with the necessary development of faces to give corners for the electrons in the positions demanded by some of the elements of high atomic weights. But we found that the requirements can be easily met in the tetragonal system. Now when you come to think about it, the two electrons in the K position will naturally lie along some one axis and should make this different from the others, leading almost inevitably to a tetragonal system.

By the time we get these atoms working satisfactorily to all concerned and have taken care of the growing idea that both electrons and protons are complex we will have a truly marvelous universe in miniature. I am very sure that you will agree with me that simplicity and not complexity is evidence of genius and I for one can not believe that the supreme Genius, the Deity, would make anything as complex as a Bohr-Sommerfeld-Lewis-Langmuir atom would be. Some say that these are not complex, being made up of simple electrons and nuclei, but a glance at Sommerfeld's picture of the xenon atom shows it to be incredibly complex, so we may confidently expect that some young man will play the part of Copernicus and give us an entirely new, beautifully simple theory in place of our creaking atomic theory and all its attendant fancies. Then for a while our children's children may have an easy time until this theory has lost its beautiful smoothness from the lumps raised by its hard knocks on unyielding facts.

The advent of such a theory would doubtless be followed by a renaissance of chemistry similar to that which recently changed the physicists from placid seekers for the fourth decimal into eager pioneers straining every nerve to reach some portion of the fertile field of knowledge which the recent theories laid open to their astonished view.

Radioactivity having established that elements change spontaneously into other elements, it is, of course, inevitable that we shall find out how to do the trick. Perhaps some of the reports of transmutation such as those of mercury and gold may prove to be correct. The reported change of hydrogen into helium is more credible than some of the others because it should take place with the evolution of energy. Such transmutations may be taught as a matter of routine in general chemistry within the next few years, let alone the half century, being illustrated in lecture demonstration in which the process is carried out in a few moments' time under the very eyes of the class, and while it is going on some budding engineer or premedic will go to sleep, considering it not spectacular enough to be interesting. Of course, the production of hydrogen nuclei from aluminum is now commonplace and may be demonstrated to the eye or ear of a large audience.

Physical chemistry will doubtless be very different; for one thing we must turn our attention to concentrated solutions, to the things that we actually use. Intensive study of these must yield results the reaction of which will be far reaching. These investigations will call for all the aid which thermodynamics, mathematics and physics can give the chemist. Of course, great advance will be made in other lines also and we will soon have more and better data on all the important physical constants of our almost innumerable substances. The new theories will certainly open up many lines for investigation.

I am sure we all expect that within the next few years catalysis will so far yield its secret as to lead us to a good working hypothesis which will enable us to make predictions with reasonable assurance of their fulfilment.

Will colloid chemistry be supreme fifty years from now, as some of its advocates seem to think, or will it be merely a very important part of chemistry, as the most of us believe? I am willing to see colloids in the soup, the salad, the jello with the whipped cream of dessert, but I am going to insist that the mineral water is a "true" solution.

The good old phase rule, famed for its simplicity and because of its freedom from assumptions concerning the molecular state of its working substances, is now showing signs of maturity because some of the old standard one component systems are behaving in such a way as to indicate that they have to be considered pseudo binary or ternary systems with all the attendant complications. Even so the more intensive study of alloys which is now beginning will, largely under the direction of the phase rule, so expand our knowledge that we will doubtless be able, in a very great measure, to predict the properties of alloys and to produce metallic materials having almost any desired properties.

The changes in organic chemistry will probably lie in a great increase in the number of compounds of our familiar types with a comparatively small increase in compounds of new types, although this latter statement is subject to revision. There will certainly be a great extension of applications of physical chemistry to organic chemistry, with advantages to each. X-ray analysis will, of course, be largely used as a guide to structure. Electron theory of valence and other valence theories will be of great assistance. Along this same line the study of the potentials of voltaic cells with organic active materials will yield important information. Organic syntheses of essential industrial materials, such as rubber, oil, etc., are growing now, as every one knows, by leaps and bounds and must make us in the future at least partially independent of the natural processes and stores of such substances. Parallel to this will come the discovery of means to improve the natural processes for the production of such substances through better agriculture and more efficient handling. Most of this is interlocked with the development of our knowledge of catalysis. Some one is going to bring about the frequently announced photosynthesis of carbon compounds. You have probably been impressed by the fact that each worker in this field is doubtful of the success of others. The fact that compounds of nitrogen, phosphorus, etc., are essential to the life of living plants suggests that perhaps the first step is the production of compounds containing some of these elements and carbon, say of the type HCN, with their subsequent reaction with water and polymerization to form carbohydrates. If this view is correct, the addition of proper compounds of these elements to a carbon dioxide water system should catalyze the photosynthesis of carbohydrates.

We are all looking forward to most spectacular advances in the overlapping fields of organic chemistry, physiological chemistry and medicine. Modern miracles are happening every day. I suspect that most of us could find in our immediate families or among our close friends individuals alive and in good health who a short twenty-five years ago must have taken the long journey in spite of all the aid which even the best of science could have given them. We may be certain that in our own time man's years of comfortable, happy, useful life will be greatly increased, and what more can we ask of chemistry than an enlarged opportunity to be of service to our fellows?

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SHORELINE INVESTIGATIONS ON THE ATLANTIC COAST

In the course of researches on the supposed progressive subsidence of the Atlantic coast it has been discovered that many of the apparent changes of level were in fact caused by local fluctuations of the high tide surface due to changes in the form of the shoreline. As low tide levels are likewise known to vary with variations in the form of the shore, but as a given shore change does not necessarily produce equal or equivalent changes in the high tide and low tide levels, the question arises as to whether mean sea level itself may not change with changes in the form of the shore. It has generally been assumed that mean sea level, when determined by accurate observations extending over a long period of years, is essentially a constant plane; and differences of mean sea level as determined at different periods have been held to prove progressive submergence of the coast; while differences determined at different localities at the same time have been ascribed to errors in tide gauge readings or computations, or to errors in levelling. It seems possible that these observed differences of mean sea level may have been correctly determined and represent merely the fluctuations of an irregular surface, the inequalities of which vary, both from time to time and from place to place, with variations in the form of the shore.

The importance of determining whether mean sea level is locally an irregular surface (aside from the broader inequalities known to exist due to gravitative attraction of mountain masses, direction of ocean currents and other causes previously studied,) and whether it may change to an appreciable degree and with rapidity consequent upon changes in the form of the shore, is obviously very great. Many of the supposed proofs of a recent and continued subsidence of the Atlantic coast of North America can be interpreted as due to local fluctuations of high tide level amounting in cases to as much as several feet. Proof of subsidence, if it exists at all, must be based on a comparison of mean sea level observations made at different periods; and it is clear that the necessary evidence can be regarded as reliable only as it be demonstrated that changes in shore form do not affect the position of mean sea level. At present all arguments for changes in the relative level of land and sea based on observed changes of mean sea level are open to suspicion.

The altitudes of the official benchmarks throughout the country referred to mean sea level are calculated on the basis of tide-gauge records obtained in localities many of which are apparently favorable to local fluctuation of the high and low tide surfaces, and hence possibly of the mean sea level surface. This results from the fact that tide gauges are most conveniently located in bays, harbors or other protected re-entrants in the coast, the very places most subject to fluctuations of tidal levels. If neither accurate tide-gauge observations extending over long periods of years nor the most precise levelling from gauge to permanent benchmarks gives results of permanent value because a gauge is unfortunately located, this fact should be known.

It is not alone the scientific investigator, the surveyor and the geodesist who have a vital interest in this question. Every owner of property bordering the sea has an actual or potential interest of no mean importance. Where waves are attacking the coast, the value of property may in considerable measure be determined by the probable future rate of coast erosion, and the consequent nature and expense of the protective engineering works required to check the inroads of the sea. Even the title to ownership of property may hinge in part on rates of erosion in the past, as has been demonstrated in recent cases in litigation. In all such cases the question of possible changes of sea level needs to be taken into account; for if this coast is subsiding at the rate of one or two feet per century, as many geologists have believed, the erosion will be much more vigorous than if the coast is stable. Other cases have arisen in which title to valuable property has depended directly on whether or not the land has subsided.

The aspects of the case briefly outlined above could readily be developed at greater length, but enough has been said to indicate both the scientific importance and the practical value of the results to be obtained