INTERNATIONAL CHEMICAL SERIES

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INORGANIC CHEMISTRY

PREFACE

Thirteen years ago the author of this book began to teach qualitative analysis from the standpoint of the law of mass action and the theory of electrolytic dissociation. The results were encouraging in spite of the difficulty that as yet no suitable text in general inorganic chemistry had been written to prepare the student for a course of this character. When a few years later Ostwald's masterly *Grundlinien* was translated into English, the need seemed to be met and the book was used as a text for a number of years at Kansas University.

Experience showed that Ostwald's fundamental idea was right; that inorganic chemistry can be most profitably taught from the standpoint of elementary physical chemistry; but because of its length, and of the presumption of maturity on the part of the reader, the book proved not well adapted to the average college student. In the meantime a number of other books appeared written along the same general lines, each with many excellent points, but none of which seemed to satisfy exactly the requirements. So with reluctance, which would have been greater if he had realized the magnitude of the task, the author undertook the preparation of this volume.

It has been through a number of mimeographed editions and has been used by six classes; consequently it represents several years of effort and experience. While aware that it is not perfect, the author is convinced that it is thoroughly teachable and adapted to students in the early part of their college course.

The general plan adopted was to avoid a long more or less theoretical introduction, but to develop the subject as logically as possible from the descriptive and experimental side, presenting each law or theory at the point best fitted both to the student and to the subject. This plan has met general approval during the past generation.

The order in which the non-metallic elements are discussed is that sanctioned by time and custom. When the metals are taken up, the subject has sufficiently advanced for the student to appreciate the Periodic System and thereafter the order is based upon this system except that for reasons which are obvious to every experienced teacher, copper, silver and gold are not treated until the student has become familiar with metals which are less exceptional in their properties.

The author believes that the more logically a subject is presented the easier it is to master. He has taken particular pains on this point, and also to see that the definitions and laws are as clearly and accurately worded as possible. After the introduction of a law, it is applied frequently so that the student may acquire a familiarity and working facility with the fundamental principles of chemistry.

Statements of fact have been carefully and repeatedly checked with the standard books of reference, and the original literature, and it is hoped that satisfactory accuracy has been attained. Where, as was often the case, the data were discordant, the author has used his judgment aided by the principle that, other things being equal, the lower boiling-points and higher freezing-points are those of the purer substances and hence the more accurate.

Throughout the preparation and revision of the book the author has been given loyal aid by his assistants Dr. H. C. Allen, Dr. Frank Rupert, Mrs. Florence Hedger Duke, Mr. Edward R. Weidlein and Mr. Paul V. Farragher. Especial acknowledgment should be given Dr. David F. McFarland, formerly of the University of Kansas but now Assistant Professor of Applied Chemistry in the University of Illinois, who wrote the sections on the metallurgy of lead, copper, silver and gold. In the final revision of these portions, considerable help was received from Mr. W. A. Whittaker, Associate Professor of Metallurgy. The author wishes to express his feeling of great indebtedness to Dr. H. P. Talbot and to Dr. F. B. Dains for their valuable suggestions—made by the one after reading the copy and the other the galley proof. He is especially grateful to his wife Stella C. Cady for most efficient assistance given throughout the work. The illustrations with the exception of the frontispiece and those on

the metallurgy of iron and steel were made by Mr. Charles Robinson. The copy for the frontispiece was prepared by Mr. Emil Grignard, while the cuts for the iron and steel were taken from Bradley-Stoughton's "Metallurgy of Iron and Steel."

HAMILTON P. CADY.

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INORGANIC CHEMISTRY

CHAPTER I

Chemistry is a branch of natural science and deals principally with the properties of substances, the changes which they undergo, and the natural laws which describe these changes.

It is a very difficult matter to convey thought from one person to another by means of words, and anything like accuracy can only be attained when the words have as nearly as possible the same meaning to each. For this reason it is necessary to discuss at some length the significance, in connection with chemistry, of some of the terms used in the opening statement.

Properties of Substances.—We are able to perceive objects around us. Each of these objects is called a body and the signs by which it makes its presence known to us are called the properties of the body. When we find ourselves surrounded by a number of different bodies we instinctively begin to arrange them into groups according to certain points of similarity in their properties. We may for example form a class of bodies called bottles and group together all objects having the general shape of bottles. When we come to examine the different members of the class, we find that they possess marked differences in properties, other than those of shape or size. Accordingly, we at once set up a number of sub-classes such as glass bottles, stoneware bottles, rubber bottles, etc., and say that these differ because they are made of different substances. Substances then, are the things of which bodies are made. As examples of substances we may give iron, salt, sugar, lead, etc.

It now remains to distinguish between the properties of bodies and those of substances. This distinction may be brought out by considering what we do in forming the sub-class glass bottles. In grouping the glass bottles together, we pay slight attention to the properties of shape and size, but look to other characteristics which we say are the properties of the substance glass. Every part of a glass bottle presents the properties of the substance glass, and to precisely the same degree as every other part; further, if the bottle be broken into pieces that body will cease to exist and in its place there will be a collection of bodies called pieces of glass. If we neglect shape and size, the properties of all these bodies are alike and identical with those of the glass bottle from which they were formed. The properties of bodies, then, aside from those of shape and size are the properties of the substance from which the bodies are made. The properties of the body, as such, are those of shape and size. A given body cannot be a barrel unless it has a certain shape and is of a definite size; if it is larger it is a hogshead; if smaller a keg.

Changes.—Experience shows us that the properties of substances can be altered in various ways.

Every alteration constitutes a change, and for purposes of convenience, changes are arbitrarily divided into two classes, physical and chemical.

A physical change is one which alters only a very few of the properties of a substance. The moving about of a body or the heating of a piece of iron are examples of physical changes.

A chemical change is one which alters all or nearly all of the properties of a substance. In fact, after a substance has undergone a chemical change, we are unable to recognize the presence of the original substance, and in its place we find one or more new substances with different properties. The burning of wood or the rusting of iron are familiar examples of chemical changes.

From these definitions it would seem to be an easy matter to decide whether a given change is physical or chemical. And so it is in most cases. However, there are all gradations in the number of properties altered in the change, and in many cases it becomes really impossible to decide definitively to which class they belong. This is due to the fact that there is no real difference between the two changes; we having simply arbitrarily drawn a distinction as a matter of convenience in our general scheme of classification. The freezing of water is an example of a change which it is difficult to classify. So many of the properties of ice are different from those of water that one is inclined to call freezing a chemical change, but on the other hand the transformation takes place so easily, simply upon changing the temperature, that probably the majority of people consider it a physical change.

In most cases there is no difficulty. For example, a piece of rubber when rubbed with woolen acquires the property of attracting bits of paper, but is not otherwise altered. Without question this is a physical change. If the rubber be brought in contact with a flame, it will take fire and burn with a smoky flame and continue to do so until all the rubber has disappeared. Soon after the rubber begins to burn a very strong odor will be noticed which must be due to something produced from the rubber. Since we have in this case the complete disappearance of the properties of rubber and the appearance of the properties of a new substance this is a chemical change.

Natural Laws.—Having discussed the properties of substances and the changes which they undergo, we may now turn to the natural laws which describe these changes.

Experience tells us that under like conditions events repeat themselves in a very large measure, and that the more nearly the conditions are reproduced the more closely are the events duplicated. So generally is this the result of our experience shat we finally become convinced that if it were possible to reproduce the conditions exactly, the events would be exactly duplicated. This however we know to be impossible; for if every other condition were duplicated, the time of the taking place of the two events would be different since otherwise the two would be one event. As a result then of our experience we are able to say, after repeated trials, just what takes place under certain conditions. Such a statement is a law of nature. A law of nature differs then essentially from a law of man in that it is simply a statement of what does happen and has in it no element of compulsion. Man is so insignificant a part of nature that he cannot presume to dictate to her but can only observe, and learn to make the condition such that the operations of nature shall be as favorable to himself as possible. A law of nature is a statement of the way nature works and should be so worded that it describes as large a number as possible of single phenomena and gives us the maximum amount of information concerning each.

As an illustration of a law of nature, we may select the law of falling bodies. We know as a matter of common experience that heavy bodies if unsupported fall to the earth, and a statement to this effect is a law of nature. It would be much more useful if it gave us the results of our experience as to the velocity of the bodies after falling for given times and in addition the space passed over during certain times of fall. The law might then be worded as follows: "All heavy bodies fall toward the earth with a velocity which is equal to the force of gravity times the time that the body has been falling and the space passed over is equal to one-half the force of gravity times the square of the time of fall."

Obviously from what has been said the wider our knowledge of the laws of nature the better equipped we are for life. They are all directly or indirectly the results of experience and their formulation is one of the most important works of science.

The Fundamental Law of Chemistry.—We find upon examining the properties of different bodies composed of the same substance that they agree exactly in all their essential properties, that is, the properties of the substance in distinction from those of the bodies. We find too that other substances have radically different properties and that the change from one to another is sudden, leaving gaps which are not filled in by gradual alterations in the properties. We have then as many absolutely distinct sets of unvarying properties as there are substances.

Bodies may be arranged in classes such that the different members of each class agree exactly with each other in all their essential properties. The different members of each class are the bodies composed of the same substance. The law just given is known as the law of the definiteness of properties and is often called the fundamental law of chemistry.

Properties of a Substance and the Substance.—We have defined properties as the signs through which objects manifest themselves to us and have spoken of them as though they belonged to substances, and of the substances as though they in some way possessed the properties. Indeed the original meanings of the words would convey these ideas, and it is very hard to get away from them. However, when we come to consider just what there is about a substace which is not a property of that substance and which might be that which possessed the properties we are completely at a loss. Everything that we know about a substance is a property of that substance and if by experimentation we find out anything more, that will also be a property; farther than this it seems to be impossible for us to conceive of anything concerning a substance that is not a property of that substance. One can be readily convinced of this by trying to think of anything about a familiar substance that is not a property of that substance. A realization of this fact does not make our conceptions of the substance any the less definite because these properties are the real things, about the substance, which we can know and measure. In fact our idea of the substance is simply the sum of all these properties which we know. For us then a substance is simply *a specific group of essential properties which always occur together and to an unvarying degree under given conditions.* This may be used as a working definition of a substance. If there is anything more to a substance than its properties we can know nothing of it. We cannot even imagine anything about it. So we will leave the question of the actual existence of a possessor of properties to speculative philosophy, and in matter of fact chemistry when we say substance we will mean properties.

Every known substance has a name which in a way stands for the properties of the substance. These names can mean to us only as much as we know of the properties of the substances. So in studying chemistry we must take care that we do not merely learn the names of the various substances with which we deal, but also that we make these names mean something to us by learning the more important properties of the substances. Some of the properties of substances, as for example color, can be ascertained by simple inspection, while others require more or less elaborate experiments to bring them to light. The constant aim is to represent these properties by numbers. To do this a unit must be decided upon and the property carefully measured in terms of this unit. Almost all of the units used in scientific work are derived directly or indirectly from three fundamental units, the centimeter, the gram, and the second, and the whole scheme of units is called the C. G. S. system. The second is the unit of time. It is in use in daily life and is familiar to everyone. The centimeter is the unit of length and is the one hundredth part of the length of a certain bar of platinum carefully preserved in Paris, which is called the "Standard Meter." This standard meter was intended to be the 1/10,000,000 of the earth's quadrant measured on the meridian of Paris, but afterward turned out to be something different from this owing to an error in the measurement. An inch is equal to a little more than 2.5 cm. The gram is the unit of mass and will be defined in the next chapter.

Physical and Chemical Properties.—It is convenient to divide properties into two classes—physical and chemical. A physical property is one which can be detected and measured without causing the substance to undergo more than a physical change. As examples we might give color, density, conductivity for heat or electricity, etc.

A chemical property is one which is only revealed when the substance is transformed into something else and consequently undergoes a chemical change. One of the properties of sulfur is that it burns with a pale blue flame, and finally all disappears, leaving behind something which is invisible but which has a very strong smell. Since this property is shown only when the sulfur is transformed into a new substance, this is, therefore, a chemical property.

Of course there is no real difference between physical and chemical changes, and thus there is none between the two sets of properties, but nevertheless, it is convenient to make the arbitrary distinction.

Identification of Substances.—The chemist is very often confronted with the problem of deciding as to whether two different bodies are composed of the same or of different substances. The decision rests upon the answer to the question, Do the bodies have exactly the same essential properties? If they do, they are composed of the same substance; if they do not, of different substances. Evidently the question can only be answered after carefully investigating the properties. To be perfectly sure, it would seem to be necessary to compare all of the properties because two substances might agree in most of their properties and yet differ enough in some to make them different substances. The labor required for the comparison of all of the essential properties is so great that it is never done. The chemist compares some of the essential properties, and if these agree exactly he decides that the two bodies are composed of the same substance. In doing this he takes advantage of a law which states that if two bodies agree exactly in some few of their essential properties they will agree exactly in all and are composed of the same substance.

The Characterization of a Substance.—The properties chosen for investigation in order to characterize a substance vary with the case, but naturally they are, in general, those which can be most readily observed and measured, or else they are the ones in which the substance differs most from other substances.

The impressions produced upon our sense of sight, taste, and smell can be very easily determined, and are but rarely omitted. The physical state (solid, liquid, or gaseous) of the substance at ordinary temperature and pressure and the conditions under which it changes from one state to another are easily determined and important properties. The solubility of a substance in water is another valuable characteristic. A few words concerning some of these frequently studied properties would seem to be in order here.

Color.—A substance has color because it has the power of absorbing some of the light with which we view it, while it allows the rest of it to pass on to our eye, thereby giving us the impression of the kind of light which is not absorbed. In general it is only light of a definite color which is absorbed so we get the sensation of the complementary color. Complementary colors are any two colors which together will produce the sensation of white. The following are complementary colors:

red	green
orange	blue
yellow	violet

If a substance absorbs one of these colors, the color of that substance will be the complement of the color absorbed. For example if yellow is absorbed the substance will appear violet, or if violet is absorbed the substance will appear yellow. Red paint then absorbs green light. The amount of light taken up, and consequently the depth of color will depend upon the thickness of the layer of the substance through which the light