CHEMICAL BONDS IN THE FIRST YEAR COURSE

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In earlier times the first course in college chemistry was based on inorganic chemistry. It was one of a series of courses designed to present the sweep of the field of chemistry to the student who persevered. The subject matter was largely descriptive. During the past fifty years ideas about the behavior of chemicals have become increasingly fruitful. No systematic study of chemistry can then ignore these devices for organizing our descriptive knowledge. These ideas include: molecular theory, atomic structure, equilibrium, reaction mechanisms, and relation of properties to structure. As a result the first year course has largely become an introduction to these ideas. With this introduction the serious student then moves into subsequent courses for more detailed study of the phenomena of chemistry.

By and large the first year course has, during the past twenty or thirty years, become an introductory physical chemistry course. Unfortunately, it has not proved possible to present a particularly sophisticated study of chemical theory in this course so that each part of the course is then taken up again in later years by the continuing student. Few students majoring in chemistry will, at the end of four years in college, have much to remember from their first year course. At the same time the average student in the first year course finds it a rapid survey of a vast amount of conceptual material often presented in a rather disjointed way. Whether it makes any significant contribution to the liberal education of the general student is at least a matter for disagreement.

It is my contention that chemistry instruction would be much better off if this survey course called "General Chemistry" were abandoned. As presently taught it is often too superficial to present any really effective picture of how chemists think or work. Instead it overwhelms the student with a mass of detail. With the growth of chemistry in modern times the basis for choosing details to be presented becomes increasingly arbitrary.

Even casual inspection of the chemical literature reveals a prodigious expansion in the publication of information. The problem of organizing and retrieving information has become a central concern. Conceptual schemes can be a most useful key to organization, and fortunately chemistry is now in possession of a small number of powerful conceptual schemes with great scope.

Why not, then, use these conceptual schemes as the basis for a series of courses in college chemistry? This has the advantage that the number of concepts is relatively small and comparable to the number of semesters in a four year college program. Even more important, once selected they offer a basis for choice among the expanding welter of descriptive chemistry available. And still more important the system of conceptual schemes is an open one. The student can expect with some confidence to fit in many new laboratory findings as they develop. After all, the atomic theory is over two thousand years old.

Some may object that this can only be a program for the chemistry majors. What of our responsibility to the students of other sciences or, perhaps even more important, what of our responsibility to the general student? It is proposed here to take a portion of chemistry for study during the first year chosen to illustrate a particular major theory. This procedure will, of necessity, fail to consider many important aspects of the science. But this procedure will have the advantage of developing much more carefully the relation of a few ideas to a variety of chemical systems. This should make it possible to discuss with something more than superficial understanding the implications of these ideas beyond

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chemistry. The general student should find it possible to get a clear understanding of how chemistry develops in a limited area. With this he should feel sufficient confidence to do whatever additional study his responsibilities may lead him into. It should be the aim of the course to give a real appreciation of the "tactics and strategy of science" of value not only to the major student but to the general student as well.

Chemistry is often defined as the study of the transformations of substances. It is concerned then with the properties of elements and compounds. Presumably, atomic theory should be used to account for properties. Atomic theory has been developed without assigning properties such as color, solubility, tensile strength, etc. to atoms directly. With the exception of mass, the properties of elements or of compounds are understood in terms of the bonds which hold the atoms together. Therefore, properties are thought about through consideration of bonds between atoms, and chemical reactions are thought about through consideration of the making and breaking of these bonds.

Earlham Chemistry Curriculum.—At Earlham we have conceived of the four year chemistry program divided into a series of courses each based on some major chemical theory. This works out fairly well into semester courses as indicated in the table.

Semester	*Main Concept*
First	Atomic Structure
Second	Covalent Bond
Third	Ions
Fourth	Chemical Energy
Fifth	Aromaticity and Resonance
Sixth	Kinetics and Reaction Mechanisms
Seventh	Advanced topics
Eighth	Advanced topics

The first two semesters, which take the place of a more conventional course called "General Chemistry," are limited primarily to a discussion of atomic structure, an introduction to the major types of bonds, and an extended treatment of the covalent bond. Throughout the course major emphasis is directed to the question of the relation of physical and chemical properties to bonds and the relation of bonds to atomic structure.

In discussing atomic structure we have found it useful to take the student into a treatment not only of shells and subshells but also into orbitals and the application of the Pauli exclusion principle to the pairing of electrons. With these considerations of theory the student is led to consider the periodic arrangement of the elements and to see how such properties as melting points, boiling points, hardness, and chemical reactivity are related to atomic numbers. Fruitful discussion is possible not only for the representative elements but also for the transition elements and for the inner transition elements.

To discuss systematically with students the relation between physical and chemical properties and atomic structure we have chosen to introduce various types of bonds. In fact we would argue that in a certain sense it is the bonds which possess the properties. Thus, the solubility of compounds containing chlorine is dependent for its explanation on the particular type of bond which unites the chlorine to the other atoms in the compound. Clearly the type of bond is determined ultimately by the kind of atoms involved but for simplicity of discussion, it seems necessary at this point in the development of chemical theory to make use of the bond concept.

Three prototype bonds are described: ionic, covalent, and metallic. These are presented as bonds produced by electrostatic attraction between charged atoms where the atoms do not overlap, bonds where electrons are shared in pairs, and bonds between atoms where many electrons are shared among many atoms, respectively. In addition covalent bonds are discussed for cases where the electron sharing is equal and for cases where it is unequal, so that polar bonds can be described and the idea developed that ionic bonds and covalent bonds can be considered as extreme types of polar bonds. It is quite appropriate then to mention the distinctive role of hydrogen bonds, with this also tied to the concept of the polar covalent bond.

The general approach can perhaps be illustrated here by considering the properties of metallic sodium, gaseous chlorine, and their reaction product sodium chloride.

	Sodium	*Chlorine*	*Sodium Chloride*
Melting point, °C	97.5	−102.1	800.4
Boiling point, °C	892.	−34.7	1413.
Heat of dissociation, kcal/mole	(25.1)[a]	56.9	101.
Heat of vaporization, kcal/mole	25.1	4.4	40.2[b]
Water Solubility, moles/lit	reacts	0.09	6.1[b]
Color	silver	Greenish-yellow	Colorless

[a] It is assumed that all the sodium atoms dissociate during vaporization. Actually the vapor contains a small fraction of diatomic molecules.

[b] Formula weights are meant rather than moles.

Some comments on the reaction of sodium and chlorine to form sodium chloride may serve to show the method of presentation. A few properties of these substances are given above. Considerable point is made of the fact that the properties of sodium chloride are not, outside of weight, the sum of the properties of sodium and of chlorine separately. This dramatic and discontinuous change in properties that characterizes the reaction indicates that the two different elements are not behaving independently in their compound. An important chemical problem is to understand what it is about sodium and chlorine that does play a role in determining the properties of sodium chloride.

The values for sodium are rather typical of a number of metals and can be accounted for at least qualitatively in terms of metallic bonds between the metal atoms. Perhaps the most characteristic features are the color and the large difference between melting and boiling temperatures. The large value for the heat of vaporization plus the softness of the metal demonstrate the large forces that operate between atoms in the solid while at the same time the atoms can move around rather readily, so long as they do not move away from each other. Chlorine represents a quite different system which is understood in terms of discrete molecules formed from atoms joined in pairs through the sharing of electrons. These molecules or units, however, have relatively small forces between them and so the material is a gas at room temperature and with only a small interval between melting and boiling temperatures. This state of affairs is still further reflected by the small value for the heat of vaporization which requires separating only the molecules and the large value for the heat of dissociation which requires separating atoms. Thus, when sodium atoms with loosely held electrons and chlorine atoms with great attraction for electrons come together, the result is the formation of ions which then arrange themselves into a material with the properties listed under sodium chloride. The attractive forces possessed by the ions are large but nondirectional. This is reflected in the fact that the solid melts and boils only at quite high temperatures with a considerable range of temperature between melting and boiling while in addition the heat of vaporization is large. Further information is also introduced to indicate that the sodium chloride crystal is an ordered array of sodium and chloride ions whose gross shape is determined primarily by the geometrical problems involved in packing spherical ions together compactly.

It is hoped that this type of course will give the student insight into an important part of the logic of chemistry. This course cannot present the whole of the logic of chemistry but it can present that part which is concerned with the dependence of physical and chemical properties upon bond types within chemical substances. Our first year of experience with the course has been reasonably satisfactory. Student response has been good and students express particular interest in the question of the interrelations of the properties of chemical elements and their compounds.