Principles of Soil Chemistry

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Principles of SOIL CHEMISTRY

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FOREWORD

Good college instruction consists primarily of a dedicated and knowledgeable instructor with organized information relevant to the subject. The rapid accumulation of knowledge and proliferation of interest in soil science by students not concentrating in agricultural studies could easily produce a teacher-student confrontation. A science course with little mention of soils or a provincial soils course without adequate science are always possibilities.

For a decade Dr. Tan has offered popular soils courses using available texts. However, students requested that a text be prepared to better complement the modern needs of students in understanding the complex nature of reactions in soils of importance in plant growth and crop production. Integrating pure science with the dynamics of soils is something Dr. Tan has accomplished in his research of fifteen years. He has now used the same procedure to write a solid textbook to teach a hard science to students of varied background. In the process he has balanced soil dynamics in a most interesting fashion. The text is scientific and the organization reinforcing, while the language is integrated and simple without being unnecessarily wordy. Not only has Dr. Tan written a book on soil chemistry, but he has written a book whose organization progresses in complexity from a conventional pure science to applied complex soil-plant relationships.

Elvis R. Beaty

The University of Georgia
Athens, Georgia

PREFACE

This book presents the adaptation of pure chemical science to the scientific study of soils and plants. The text provides comprehensive coverage of the fundamental topics in soil chemistry. Its unique approach, including a definite soils' flavor by the integration of organic and inorganic components in the dynamic processes in soils, important for continuation of life, is not currently available. In plain language, easy to comprehend by a wide range of scholars and students, but without sacrificing the scientific value, the book starts with a review of basic chemical principles and thermodynamics pertinent to the following topics on concepts and processes in and related to the soil solution: colloidal organic and inorganic components, their modern classification, and reactions and interactions affecting changes in the behavior of soils and plant growth. The book tells you everything that you want to know about humic acids. Separate chapters are included on the use of x-ray diffraction, infrared analysis, differential thermal analysis (DTA), and other methods for the identification of organic and inorganic soil constituents. Examples are given in interpretation of results using tables provided on diagnostic d spacings in x-ray analysis, wavenumbers in infrared spectroscopy, and peak temperatures in DTA. Crystal chemistry of inorganic compounds and surface chemistry of inorganic and organic colloids are explained in simple terms, showing their significance in the control of the many complex reactions in nature. The traditional adsorption, cation and anion exchange, soil acidity, and salinity theories are presented together with the current concepts. In the final two chapters, the principles of soil chemistry are applied in soil formation and in soil-organic matter interaction. Although the purpose of the book is to fill a need in soil science, that is, by bridging pure chemistry and soil science, the volume is equally useful in explaining the soil as a basic entity for related disciplines in agriculture and other sciences, for example, crop and plant sciences, irrigation, forestry, conservation, plant physiology, ecology, microbiology, geology, geochemistry, physics, chemistry, and botany.

Special recognition goes to Dr. Elvis R. Beaty, professor of agronomy, University of Georgia, for editing the book. My thanks are also due to Dr. Ralph A. Leonard, research leader, Southeast Watershed Research Program, USDA,-SEA, -AR, and to Dr. Robert A. McCreery, associate professor of agronomy, University of Georgia, for reading the manuscript for correct English usage and scientific value. Appreciation is extended to Dr. J.B. Jones, former director, Soil Testing Laboratory, Cooperative Extension Service, and former division chairman, Department of Horticulture, University of Georgia, for his valuable criticism, and to the unnamed people, who have assisted in the development of the book. Thanks are also extended to the various publishers, scientific societies, and fellow scientists, who gave permission to reproduce figures, photographs, and diagrams. Finally, the author wants to thank his wife, Yelli, and his son, Budi, who always stood by with great enthusiasm and a lot of encouragement.

Kim H. Tan

CONTENTS

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REVIEW OF BASIC CHEMICAL PRINCIPLES

1.1 ATOM AND ATOMIC STRUCTURE

An atom is the smallest particle of an element that can enter into a chemical combination. Atoms of the same elements are similar in composition, but one element differs from the other in size, position, and movement of its atoms. An element is a substance composed of atoms with the same atomic number, or nuclear charge. In solid matter, the atoms vibrate within the confines of very small spaces, whereas in gas the atoms exhibit a considerable range of movement.

The concept of atoms being the smallest particles of matter was first postulated by Democritus or Leucippus in approximately 425 B.C., but it was not before Dalton's atomic theory was formulated in the first decade of the nineteenth century that this idea became scientifically established. Since then Crookes, Thomson, and others, working on the conduction of electricity in rarefied gases, made revisions in the theory above and concluded that the atom was composed of still smaller particles. The structure of the atom became a subject of research interest, and by the end of the nineteenth century it became known that the atom had the following components:

1. Electrons, small negatively charged components of atoms of all substances
2. Protons, positively charged particles of much greater mass than electrons

With the advancement of science in the twentieth century, it became clear that atoms also contain neutrons. The neutrons have a mass number of 1, but have zero (0) charge. Less fundamental particles were also detected, the positrons. Positrons are particles with the mass of an electron and the charge of a proton. The fundamental particles of the atom recognized today are (1) electrons, (2) protons, and (3) neutrons.

Protons and neutrons are located in a small central portion of the atom called the *nucleus*. The nucleus is of high specific weight and contains most of the mass of the entire atom. The various groups of electrons are placed in concentric shells around the nucleus. The shells may be composed again of subshells or cells. Neglecting the presence of subshells, the shells may contain one electron, as is the case with a hydrogen atom, or two electrons, as is the case with a helium atom, or more (Figure 1.1). The first shell adjacent to the nucleus is called the *K shell*, while the shell next to it is designated as the *L shell*, and so on. The largest atom is the uranium atom (^{238}U) with 92 electrons distributed around the nucleus in K, L, M, N, O, P, and Q shells. The diameter of the nucleus is between 1×10^{-13} and 1×10^{-12} cm. While the nucleus carries an integral number of positive charges, or integral number of protons, each of 1.6×10^{-19} C, each electron carries one negative charge of 1.6×10^{-19} C.

The electrons in the inner shells are tightly bound to the nucleus. This inner structure can be altered by high-energy particles (α rays, x-rays). With most atoms, it is the arrangement of energy in the outer shells that undergoes changes during chemical reactions. These outer shell electrons are responsible for the chemical properties of the element. During these changes, the role of the nucleus is usually a passive one. The hydrogen atom is perhaps an exception since it has only one shell and one bare proton.

An atom which loses one or more electrons from the outer shell is called a *cation* (Faraday), since such an atom assumes a net positive charge. When an atom has excess electrons, not balanced by the

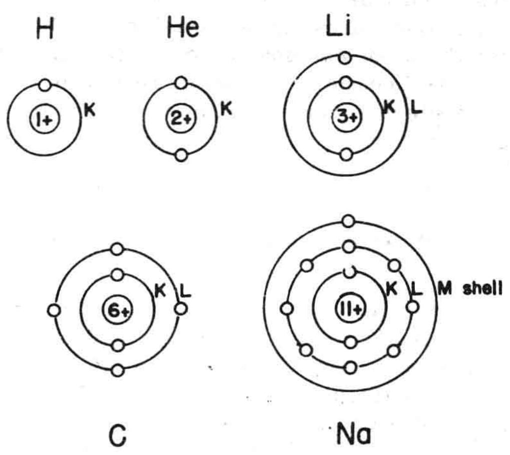

Figure 1.1 Atomic structure showing the K, L, and M electron shells.

positive charges of the nucleus, it assumes a net negative charge and is called an *anion*.

1.2 ATOMIC MASSES AND WEIGHTS

The atomic mass number is the sum of the masses of the protons and neutrons. Masses of electrons are neglected since they are very small and are considered to form an insignificant portion of the total mass of an atom. The atomic mass can be expressed on a chemical or a physical scale. In general, masses on the chemical scale are smaller than a weighted average physical mass by a factor of 0.99973. On a chemical scale the element oxygen is arbitrarily assigned the mass 16, nitrogen the mass 14, hydrogen the mass 1, and so forth. For a pure isotope the atomic weight gives the total number of nucleons (protons + neutrons).

Strictly speaking, atomic weights are not weights at all. They are reference numbers which indicate the relative weights of the different kinds of atoms, and no reference is made to absolute weights. Hydrogen was originally assigned a relative weight of 1, since it was considered the fundamental particle and the lightest of all atoms. The heaviest of any of the naturally occurring atoms is uranium with an atomic weight of 238. When we say that the element oxygen has an atomic weight of 16, we simply indicate that the oxygen atom is 16 times heavier than the hydrogen atom. Therefore, no weight units have been assigned to the numbers.

Atomic weights apply only to elements. Compounds have molecular weights, which equal the sum of the atomic weights of all elements making up the compounds.

The initial selection of hydrogen as a standard base for comparative assessment of other atomic weights was later changed in favor of oxygen, which is assigned an arbitrary mass of 16.0000. The atomic weight of hydrogen changed consequently to 1.0080. To comply with suggestions from atomic physicists, this oxygen base was revised again in 1961, and atomic weights (AW) are currently based on the assigned relative mass of ^{12}C (AW 12.0000). However, the consequent changes in atomic weights of the other elements are very small.

1.3 AVOGADRO'S NUMBER

The number of atoms in 1 gram atomic weight of any element is

$$6 \times 10^{23}$$

This number is known as the *Avogadro's number* (See Table 1.1).

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Table 1.1 Absolute Weights of One Atom (or One Molecule) of Selected Elements

Substance	Mole	AW or MW	Grams	Number of particles or atoms	Weight of one atom
H^+ ion	1	1	1	6×10^{23}	1.67×10^{-24}
Carbon	1	12	12	6×10^{23}	2.0×10^{-23}
Na	1	23	23	6×10^{23}	3.83×10^{-23}
K	1	39	39	6×10^{23}	6.50×10^{-23}
Ca	1	40	40	6×10^{23}	6.67×10^{-23}
NaCl	1	58	58	6×10^{23}	9.67×10^{-23}
KCl	1	74	74	6×10^{23}	1.23×10^{-22}
$CaCO_3$	1	100	100	6×10^{23}	1.67×10^{-22}
$C_6H_{12}O_6$ (glucose)	1	180	180	6×10^{23}	3.00×10^{-22}