Preface

Transport of mobile ions in ionic conductors of many kinds is the key to performance in a wide variety of applications, including portable energy sources from primary and secondary batteries, chemical sensors, ionic switches, electrochromic displays, power generators, fuel cells, component in electronic devices, and electric car technology. These applications have become a major part of the world economy, and their advances in research and development in the future may shape the way of life of the present and future generations. Thus the field of research on ionic motions in ionic conductors has practical implications particularly in the search and discovery of materials with desired or optimal properties for applications in the bulk form and in the nanometer scale.

The dynamics of mobile ions leading to conductivity and diffusivity in various kinds of ionic conductors are interesting from the basic research perspective. In most ionic conductors, liquid and solid, the density of the mobile ions are considerable, and non-negligible is the effect of ion-ion interaction on the ion dynamics as well as interaction between the ions and the matrix in which the ions are embedded. Randomness and disorder in liquid and glassy ionic conductors may also complicate the dynamics. Brownian diffusion or random walk of particles without interaction is a well-known solved problem, but ceases to apply in most ionic conductors of interest. The presence of ion-ion interactions poses difficulty in visualizing the motion of the ions and in explaining the properties. This is because it requires the solution of a many-ion problem of irreversible process (conductivity or diffusion) in statistical mechanics, which does not exist at the present time. The nonexistence of a universally accepted solution to the problem is remarkable in view of the fact that more than a century has gone by since 1905 when Einstein solved the Brownian diffusion problem. Actually over the years very few attempts have been made just to attack the problem theoretically. This unique situation offers a fantastic opportunity at the present time for someone to make a great contribution in science by solving this fundamental problem.

However, an acceptable solution must be able to explain satisfactorily *all* known essential and critical experimental facts or at least be consistent with *all* of them.

By now many experimental techniques have been applied in the study of the ion dynamics over time scales ranging from microscopic times to macroscopic times and experimental data abound in the literature. They need to be collected, categorized, and summarized so the essentials can be brought out without neglecting any. This task is attempted by us in this book with the purpose of benefitting the research community engaged in solving this centuries-old problem in condensed matter physics. If a theory can account for the collection of properties of ionic conductors in general, it can be considered to be close to a final solution of the problem. Another purpose is to make those involved in applications aware of the properties and limitations of typical ionic conducting materials. This knowledge will help them in the search for new materials to suit the purpose of the application or for better performance.

By extracting the results from experiments and molecular dynamics simulations of ionic conductors with diverse chemical and physical structures (crystalline, liquid, and glassy), we are able to present overwhelming evidences of universal dynamics and properties of ions in many different ionic conductors. The universal properties found suggest they originate from some fundamental physics governing the motion of the ions. The universal behavior makes the problem more exciting and inspiring for others to solve the problem. Moreover, the universal dynamics of ions has analogs in the relaxation of structural units of glass-forming substances and systems. The analogy links the two research areas together, and it suggests that understanding the dynamics of ions can have impact on the research field of glass transition, which is currently also considered as an unsolved problem. Some of the ionic conductors are not glass-forming, and even the glass-forming ones have the ionic conductivity relaxation decoupled from the structural relaxation. Notwithstanding, the analogy continues to hold. This means that glass transition is just an effect with the cause being the universal dynamics shared with ionic conductivity relaxation in ionic conductors.

The authors of this book come from different backgrounds and have different but complementary expertise. Junko Habasaki is an expert and leader in molecular dynamics simulations of ionic conductors, ionic liquids, and porous ionic conductors. Carlos León has been engaged in experimental study of various ionically conducting materials for years and now leads a pioneering effort in nanoionics in his group. K.L. Ngai is a theoretician who works closely with experiments and simulations in the broad fields of relaxation and diffusion in complex systems. He is the originator of the Coupling Model, which has been applied with success to many different phenomena and materials in various research disciplines. In the book, we have combined our individual expertise in writing most of the chapters with participations to various degrees from all three of us. The chapters are linked to each other by their contents, which are either developments of the same subject in a different light or by a different technique, or specialization to a particular system. We deem that this book will be useful in various ways to readers with widely different interest ranging from physicists, chemists, materials scientists, and engineers, as well as for teaching a course of ionics in academic institutions. As far as we know, a book of this kind does not exist at the present time.

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Yokohama, Japan — Junko Habasaki
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