A Fast Mobility Spectrometer for Atmospheric Ions

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by

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Frontispiece (Plate 3.71):

General View of the Experimental Site

See section 3.7 for details


COURTVILLE

A FAST MOBILITY SPECTROMETER FOR ATMOSPHERIC IONS

A B S T R A C T

The development of a mobility spectrometer which yields a complete spectrum every 25 seconds is described. The spectrometer uses a Differential Gerdien Chamber of the First Order with 8 collecting electrodes, giving a set of 8 "electrode charges" corresponding to each observed spectrum. A Least Squares iteration is used to fit the parameters of a function which describes the complete mobility spectrum. The spectrum function's parameters can be fitted reliably with standard deviations of 3% or better.

The spectrometer was used for observations of temporal variations in the atmospheric ion mobility spectrum at Auckland. These show a clear diurnal variation, and demonstrate that the spectrum can change significantly in an interval of 100 seconds. Atmospheric polar conductivities calculated from the mobility spectrum (which agreed well with independently measured conductivities) indicate that large ions can contribute as much as 40% of the total conductivity.

P R E F A C E

This thesis covers the development of a mobility spectrometer for atmospheric ions with time resolution significantly better than any other so far reported, and its use in studies of temporal variations of the atmospheric ion mobility spectrum at Auckland.

Relevant topics in Atmospheric Electricity are summarised in Chapter 1, which concludes with a complete statement of the aims of the investigation. Chapter 2 gives a detailed analysis of the ion currents collected by a generalised "Gerdien Chamber". Gerdien Chambers which are mechanically simple suffer the disadvantage that in computing a mobility spectrum the chamber's ion currents must be differentiated, with a consequent introduction of noise into the results. A new alternative method of spectrum computation is proposed, in which a "least squares" iteration is used to fit the parameters of a function which describes the spectrum. Although this lowers the mobility resolution available it greatly improves the accuracy with which the spectrum parameters may be determined. The chapter ends with a discussion of the design decisions required for the thesis spectrometer.

The spectrometer is a Differential Gerdien Chamber of the First Order, having eight collecting electrodes, each of which can be connected to a vibrating capacitor electrometer through a reed switch. Charges measured by the electrometer are punched onto paper tape at a maximum rate of one chamber electrode every 2.5 seconds. 5 seconds is allowed for synchronising information to be recorded so that all the electrodes are sampled (giving data for one complete spectrum) every 25 seconds. Practical details of the spectrometer are given in Chapter 3. Of particular interest here are the determination of the spectrometer's inter-electrode capacitances, the charges generated by the reed switches when they are opened, and the sequencing of the various spectrometer functions. The site where the spectrometer was installed is also described, together with the results of some preliminary experiments. Chapter 4 deals with the reduction of the large quantities of raw data produced by the spectrometer. A computer model of the spectrometer was developed, tested, and used in correcting the measured charges from the collecting electrodes for the effects of electrostatic interaction between them. "Leakage" currents to the electrodes, i.e. currents observed when in principle no ions could be collected, are discussed, together with the effect of resistive leakage of charge from the electrodes. In Chapter 5 a function is developed to represent the mobility spectrum. This has two parts : a delta function to represent the large ions, and a lognormal function to represent the small ions. Using the least-squares iteration mentioned above the parameters of this function can be fitted reliably with standard deviations of 3% or better.

Studies of temporal variations in the atmospheric ion mobility spectrum are discussed in chapter 6. These show that while the diurnal variation at Auckland is very similar to that at Glencree (Ireland) and Tokyo (Japan) the spectrum can change significantly in an interval of 100 seconds or less, indicating the clear demand for high time resolution in a spectrometer. Calculations of atmospheric polar conductivities (which compared well with independently measured conductivities) indicate that large ions can contribute as much as 40% of the total conductivity. This is surprising, for electrical conduction in the atmosphere is commonly assumed to involve only the small (i.e. high-mobility) ions. A preliminary investigation of the spectrum of ions produced in the laboratory by point discharge at a metal point gave results which are consistent with a simple description of the point discharge process. Chapter 7 considers the limitations of the present spectrometer and suggests some possible improvements to it.

Throughout the thesis convenient metric prefixes are used for units, hence the unit of mobility is $cm^2/Vsec$ rather than $x10^{-4}\ m^2/Vsec$. The prefix femto- is frequently used, particularly for currents : for example 2.7 fA means 2.7×10^{-15} A. All figures and tables have their section number as a prefix, so that fig. 6.32 is the second figure of section 6.3. Although the algorithms used in computer programs are fully discussed no program listings are given since they were written in a non-standard dialect of Fortran which was developed by the University Computer Centre and is no longer available.

Throughout this project my supervisor, Professor K.S. Kreielsheimer, has been tremendously helpful to me and it has been a real pleasure to work under him. Special thanks are due to Dr Murray Johns for our many valuable discussions, and particularly for his help in our joint development of the electrometer. I am indebted to the staff of the Physics Department Mechanical Workshop who built my spectrometer, and also to Miss June Magan who did all the typing for this thesis.

Since February 1971 I have been a lecturer in the University Computer Centre under its Director, Dr J.C.B. White, who has at all times been most understanding. Finally I must thank my family for their support and consideration over the past few years.

J.W. Brownlee
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