RS•C

Mass Spectrometry

A Foundation Course

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RS•C
advancing the chemical sciences

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To Craig

"The occasional fineness of line, the masterly distribution of masses"

(from The Master (1895) by Israel Zangwill (1864–1926))

Preface

This book presents a broad coverage of the theory and application of mass spectrometry to provide the reader with an appreciation and understanding of the importance of mass spectrometry across a range of scientific disciplines. It is uniquely organised to enable a course or unit in mass spectrometry to be constructed at either the undergraduate or postgraduate level for students of a range of backgrounds and educational experiences where no single course can be deemed suitable for students of the physical, chemical, environmental, biological and medical sciences.

It is published at a time when most available textbooks present an introduction to mass spectrometry, a broader treatise devoid of much detail or one that is focused on a particular area of the field. A large number of multiple author collections describing specialised disciplines, often inspired by a conference or workshop, together with new encyclopedic series have provided readers with up-to-date descriptions of mass spectrometry research and applications though usually in a less cohesive and accessible format. This has left a new scholar with some difficulty in comprehending the foundations, role and capabilities of mass spectrometry.

This has motivated the construction of a new book on mass spectrometry that presents a broad treatise of the field across a wide range of scientific disciplines in a single accessible and affordable volume. Sufficient depth is presented throughout the book to enable students to understand the principles behind and the reasons for particular experiments, together with ample representations of mass spectral data and applications. Importantly, the book provides a reference text around which a series of university level courses can be constructed for the education of students with varied backgrounds, experiences and interests.

The unique design of the book achieves this through the presentation of core sections that are common to all mass spectrometry experiments. These sections are coupled to content from other optional sections and specialised chapters dependent upon a student's educational level, specialisation and interests. Recommended course structures are presented

in the front of the book. At the same time, the organisation of the book is designed to present the field of mass spectrometry in a logical manner regardless of the course undertaken. Specialised chapters are included on organic mass spectrometry, ion chemistry, biological mass spectrometry featuring proteomics, mass spectrometry in medical research, the environmental and surface sciences and accelerator mass spectrometry.

Large numbers of mathematical equations and derivations have been avoided and the theoretical description of mass spectrometry based experiments has been kept to a minimum. The absence of a large number of citations to the enormous body of published research on mass spectrometry was also deliberate, not so as to ignore the important work contributed by many scientists throughout the world, but rather to prevent the reader from being distracted by extensive annotations and references throughout the course of the text. Each chapter concludes with a list of key references and recommending reading material providing a springboard to further study.

The author hopes that this book will assist with the teaching of mass spectrometry to the field's future pioneers. Certainly, mass spectrometry education will remain an important exercise given the important, and in some cases essential, role that mass spectrometry plays in scientific discovery.

Kevin M. Downard

Guide to a Foundation Course in Mass Spectrometry

	Chemistry	*Physics*	*Biology*	*Medicine*	*Environmental Sciences*
Undergraduate Core	1.2.2 1.3 2.1 2.2.1 2.3–2.5 3.1 3.2.1–3.2.3 3.2.5 3.26 3.2.8 – 3.2.10 3.3 3.3.1 3.3.2 4.1 5.3 5.4	Ch 1 2.1 3.1 3.2.1 4.1 6.2 6.3 9.4–9.6 Ch 10	2.1 2.3–2.5 3.1 3.2.6–3.2.9 3.2.10 3.2.11 4.1 7.1 7.2.1–7.2.3	2.1 2.3–2.5 3.1 3.2.1–3.2.3 3.2.6 3.2.8 3.2.9 Ch 8	2.1 2.2.1 2.3–2.5 3.1 3.2.1–3.2.3 3.2.5 9.1–9.3 9.6 10.1 10.3 10.4
Undergraduate Optional*	1.1 1.2.1 3.3.3 4.2.1 4.2.2 5.1 5.2 Ch 6	2.2–2.5 3.3–3.6 4.2 6.1	3.2.4 3.3 4.2 7.2.4–7.2.6 7.3 7.4	3.2.7 3.2.10 4.1 5.3 7.1 7.2.1–7.2.3 10.1 10.3 10.5	4.1 5.3 10.2
Graduate/ postgraduate Supplement**	2.2.2–2.2.5 3.4–3.6 4.2–4.7	3.2 4.3–4.7 6.2 6.3	2.2 Ch 8	2.2 3.2.11 4.2.1–4.2.3 7.2.4–7.2.6 7.3–7.4	2.2 9.4 9.5

All sections listed represent the entire section (with sub-sections). All subsections listed represent the entire subsection only.

*optional sections and subsections should be added to the core material in the order that they appear in the text, not the order they appear in this table. ** postgraduate material should be taught in addition to, or as a supplement for, the undergraduate material dependent on the exposure of students to this subject matter at the undergraduate level.

Acknowledgements

I owe a particular gratitude to John Bowie for introducing me to the exciting field of mass spectrometry and for his support throughout my career. John's internationally recognised research in gas phase ion chemistry instilled in me an early appreciation of the positive aspects of negative ion mass spectrometry beyond the analytical.

I am grateful to many colleagues and students past and present, too numerous to mention here, in both the mass spectrometry community and further afield who have contributed to my own education and challenged my teaching of mass spectrometry. I also thank my wife and family for their love and support.

Finally, it has been my pleasure to work with Janet Freshwater, Robert Eagling, Tim Fishlock and the entire editorial and publication team at the Royal Society of Chemistry. My thanks also go to Edward Abel, former president of the society, who catalysed this interaction. Their belief in, and support of, this project has made the book possible.

Kevin M. Downard

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CHAPTER 1

Mass Spectrometry's Beginnings

1.1 A BRIEF HISTORY

1.1.1 Early Pioneers and Cathode Rays

Mass spectrometry had its beginnings in experiments performed over a century ago. Scientists in the late 19th century began conducting experiments within evacuated glass tubes in order to gain some understanding of the nature of electricity.

George Johnstone Stoney was the first to report that electricity has its basis in a particle, or an "atom of electricity" that he referred to as an electron. Stoney measured the charge of the electron in 1894 but it was left to Joseph John (J.J.) Thomson to measure the charge-to-mass ratio (*e*/*m*) of the electron and estimate its mass at a thousand times less than that of a hydrogen atom. Thomson had developed an interest in the electron while investigating the passage of electricity through gases in his laboratory in Cambridge. Thomson believed that the stream of rays emitted from a negatively-charged cathode, known as *cathode rays*, consisted of these particles. He also proposed that the particles (which Thomson preferred to call *corpuscles*) were one of the bricks from which all atoms were built – a controversial theory at the time. Thomson went on to describe his case in the book *Corpuscular Theory of Matter* published in 1907.

1.1.2 Positive Rays

Some time earlier Eugen Goldstein, a scientist in Germany who had given the name to cathode rays and studied them for several decades, discovered that the presence of gases in *cathode ray tubes* also gave rise to rays that behaved very differently from cathode rays (Figure 1.1). Wilhelm Wein in 1898 was able to deflect these rays in the opposite direction to cathode rays using magnetic and electrical fields. He