METHODS OF
Experimental Physics

VOLUME 4 - PART B

Atomic and Electron Physics

FREE ATOMS

Volume 4

Atomic and Electron Physics

PART B

Free Atoms

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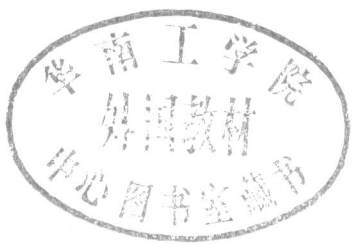

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Methods of Experimental Physics

VOLUME 4

ATOMIC AND ELECTRON PHYSICS

PART B

FREE ATOMS

METHODS OF EXPERIMENTAL PHYSICS:

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FOREWORD

After an interval, which somewhat exceeded our expectations, Volumes 4A and 4B are presented herewith to the scientific community. To a great extent the delay was due to the wealth of material; critical examination of the subject required repeated revision of the original schedule. In my foreword to Volume 2 of this treatise I mentioned the need to split the material into Volumes 4 and 7. I announced at that time that Professors Benjamin Bederson and Wade Fite have taken over the editorship of Volume 7 and we expected that this reorganization would be sufficient for a compact presentation of the single particle aspects of atomic and electron physics. We were too optimistic; the amount of material which had to be included in Volume 4 exceeded the bounds of a single volume and forced us into reorganizing it into the two halves presented here.

A consequence of this growth is that our "Methods of Experimental Physics" acquires more and more the character of an encyclopedia. While the organization and format differ from the conventional its contents comprise a reasonably complete presentation of the majority of the methods required by an experimental physicist. I say "the majority"; I am aware of certain methods not being presented adequately or at all, but it is our endeavor to fill these gaps, either in forthcoming volumes or in new editions of the existing ones.

I wish to thank Professors Vernon W. Hughes and Howard L. Schultz for their unflagging devotion and interest to the problem of producing such a book. They succeeded in gathering a remarkably good group of contributors; the results of their cooperation with the volume editors is offered here for the benevolent criticisms of the experimental physicists.

L. MARTON

April, 1967

PREFACE TO VOLUME 4

Volumes 4 and 7 of the "Methods of Experimental Physics" cover the field of atomic and electron physics. Volume 4 is restricted primarily to a treatment of the methods of experimental physics applicable to the study of individual particles as opposed to the study of the interaction of particles with one another. Due to the thoroughness and diligence of the authors of Volume 4, the amount of material exceeds a reasonable length for a single book, and therefore the volume appears in two parts as Volumes 4A and 4B. Volume 4A treats the topics of sources and detectors of particles. Volume 4B treats the methods for experimental studies of free electrons, positrons, atoms, and ions, organized according to the property under investigation, and also includes a chapter on basic techniques of ultra-high vacuum and gas purity.

These volumes are directed toward the research worker and graduate student in experimental atomic and electron physics. A major objective of the volumes has been to bring together a comprehensive treatment of all aspects of the subject of the methods of experimentation in atomic and electron physics. Leading experts contributing in their specialties to the volumes have made every effort to treat their topics with a high degree of completeness. Not only have they presented the most recent techniques but they have also given introductory background and theory useful to the student not intimately familiar with the subject. Usually, general methods, their advantages and limitations, are emphasized rather than detailed descriptions. Some parts of the volume treat highly specialized techniques not easily found in the literature.

Some overlap between Volume 4 and other volumes of this treatise, notably those dealing with Electronic Methods (Volume 2) and Nuclear Physics (Volume 5) exists. The amount of overlap present is unavoidable, even desirable, in the interest of completeness, and in a sense, it complements the presentations in other volumes. The overlap in nuclear physics technique is minimized as a result of the natural division on the basis of the energy of detected particles and radiations.

We wish to express deep appreciation to the contributors for their painstaking efforts and cooperation throughout this long venture, and to extend our thanks to the publisher, and especially to Dr. L. Marton, the Editor-in-Chief, for his constant help and encouragement.

VERNON W. HUGHES
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May, 1967

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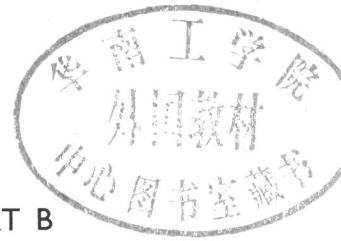
Methods of Experimental Physics

VOLUME 4

ATOMIC AND ELECTRON PHYSICS

PART B

FREE ATOMS



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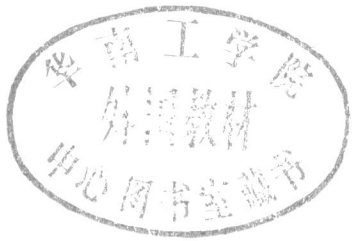

3. PROPERTIES OF FREE ELECTRONS AND POSITRONS*

3.1. Introduction and Summary

This chapter is concerned with our current empirical knowledge of the intrinsic properties of free electrons and positrons. The experiments upon which this knowledge is based are described and, when appropriate, discussed in some detail. Theory is mentioned only when the experimental result has some important bearing on the structure or justification of the theory. In keeping with the basic philosophy of this series, experiments of only historical importance are not discussed; however, an effort has been made to provide a route to these experiments through the references. Generally, the emphasis here is on the more modern experiments and techniques which give information about the properties of free electrons and positrons. A summary of the current state of affairs is given in Table I.

The word "free" is used here to mean "not bound into an atomic system." However, experiments on bound systems which advance our knowledge of the properties of the free particles are not excluded from this chapter. Some particle properties, such as the electron-proton charge difference, must necessarily be measured with bound systems but, generally, free particle experiments, when possible, are more precise. This is due mainly to the more complicated interactions of the bound particle which often make interpretation of the results, in terms of free particle properties, more difficult and more ambiguous.

The apparent overemphasis of experiments on the electron at the expense of the positron is unfortunate, but unavoidable. The fact is that, in comparison to the electron, the properties of the positron have not been precisely measured. There are probably two reasons for this lack of experimental work on the positron's properties; first, source and lifetime problems limit the scope of possible experiments, and second, theory strongly suggests the identity (except for charge) of electrons and positrons and a high precision experiment, as well as a certain amount of audacity, is required to challenge a well-founded theory. An effort has been made, usually at the end of each section, to examine what independent evidence there is concerning positron properties.

Finally, methods for measuring the states of free electrons are not

* Part 3 is by David T. Wilkinson.

discussed in this chapter. Readers are referred to Volume 5 of "Methods of Experimental Physics" for discussions of the measurement of momentum, energy, and polarization of electrons and positrons.

TABLE I. Summary of the Experimental Values of the Properties of Electrons and Positrons as of January, 1966

Property	Value	References
Electron charge, e	$(4.802\,98 \pm 0.000\,20) \times 10^{-10}$ esu	[a]
Electron–proton charge difference	$<10^{-21}e$	[b]
Electron–positron charge difference	$<2 \times 10^{-15}e$	[c]
Electron mass, m	$(9.1091 \pm 0.0004) \times 10^{-28}$ gm	[a]
Electron–positron mass difference	$<3 \times 10^{-5}m$	[d]
Electron e/m	$(1.758\,796 \pm 0.000\,019) \times 10^{7}$ emu/gm	[a]
Electron magnetic moment	$\frac{\mu_e}{\mu_0} = 1 + \frac{\alpha}{2\pi} - (0.327 \pm 0.005)\frac{\alpha^2}{\pi^2}$	[e]
Positron magnetic moment	$\frac{\mu_{pos}}{\mu_0} = 1 + (1.0 \pm 0.1)\frac{\alpha}{2\pi}$	[f]
Electron electric dipole moment	$<2 \times 10^{-21}$ cm $\times e$	[g]
Positron electric dipole moment	$<8 \times 10^{-13}$ cm $\times e$	[h]

[a] "New Values for the Physical Constants," *Phys. Today* **17**, 48 (1964); E. R. Cohen, *in* "Methods of Experimental Physics" (I. Estermann, ed.), Vol. I, pp. 35–52. Academic Press, New York, 1959.

[b] J. G. King, *Phys. Rev. Letters* **5**, 562 (1960).

[c] Section 3.2.3.

[d] Section 3.3.2.

[e] D. T. Wilkinson and H. R. Crane, *Phys. Rev.* **130**, 852 (1963).

[f] Arthur Rich and H. R. Crane, *Bull. Am. Phys. Soc.* **11**, 121 (1965); *Phys. Rev. Letters* **17**, 271 (1966).

[g] P. G. H. Sandars and E. Lipworth, *Phys. Rev. Letters* **13**, 718 (1964).

[h] E. E. Salpeter, *Phys. Rev.* **112**, 1642 (1958); Section 3.6.4.

3.2. The Electron Charge, e

3.2.1. Summary of Experimental Methods

3.2.1.1. Cloud and Drop Methods. The first measurement of the electron charge, e, was reported by J. S. Townsend in 1897—the same year