methods of ORGANIC ELEMENTAL MICROANALYSIS

G. Ingram A.R.I.C.

Methods of
Organic Elemental
Microanalysis

G. Ingram
A.R.I.C.
Research Laboratory
Courtaulds Limited
Maidenhead

Chapman & Hall
London: 1962

First published 1962

Chapman & Hall Ltd
37 Essex Street
London W.C.2

Catalogue No. 4/675

Printed in Great Britain by
The Whitefriars Press Ltd

Preface

The subject of microchemistry now represents a vast field for study that continues to expand as the scope of application widens. In the case of organic microanalysis considerable advances in technique and in methods have been made, since Pregl in 1912 initiated organic microanalysis by his development of methods for the determination of major elements in organic compounds. By reason of the present-day demands for economy of materials and of time, these methods or their modern counterpart have been adopted in both academic and industrial laboratories. It is generally acknowledged that micro methods have now superseded the classical macro procedures. In fact, the research worker, whether chemist or biochemist, utilises small-scale procedures for the isolation, purification and identification of organic substances. Microchemical instruction is now almost prevalent in university and technical colleges concerned with the teaching of chemistry.

In consequence of this wide following a vast amount of information has appeared, and continues to appear in the chemical literature appertaining to the field of organic microanalysis. While several excellent texts have been written on the subject, a point has been reached where textbooks can no longer deal extensively with it unless a book of a voluminous nature is contemplated. Comprehensive surveys of the literature, and particularly appreciations of methods, are equally as important to the beginner as to the analyst having a knowledge of microchemistry. Existing textbooks deal authoritatively with methods that are essentially those of Pregl or preferred modifications of established methods. Few books provide sufficient detail to enable the analyst, and more particularly the beginner, to appreciate fully the merits of a method of analysis.

It has been possible in this book to give a broad survey of the work in the field of elemental analysis by limiting it to this aspect of analysis. Description of milligram-balance weighing technique, determination of physical constants such as molecular weight, and functional group determination have been generally omitted. Adequate information concerned with micro-balance weighing and physical constants already exist. Full appreciation of functional group determination can only be realised by a text devoted entirely to the subject.

The book is intended as an appendage to existing authoritative works on organic microanalysis. It has been written for the practising analyst and others engaged in research work in the field of organic chemistry, who by resolve or necessity turn to microchemical methods of analysis. It is felt by the writer that such a book outlining the status of elemental microanalysis, now approaching its fifth decade of development, might also be helpful to the student who must gain knowledge of microchemical technique. Full working details of methods are given in the text, together with modifications where they exist. Alternative methods are described and discussed, with emphasis on those which represent improvements over older methods. It has not been possible to include every method, neither to discuss all aspects of the subject. There are some omissions; this is unavoidable, owing to the extent of the literature pertaining to the branch of organic microanalysis under discussion.

Some of the methods described for certain elements have been developed in the writer's laboratory. Others originate from the Birmingham University Analytical School under the direction of my friend and colleague, Professor R. Belcher. Yet other methods have been taken from the literature, particularly those which have been examined by other workers and proven reliable. It is now a certainty that the original Pregl methods in their entirety, like the former classical procedures of Liebig, have become classical methods. In the main the Pregl methods have been greatly modified, and in some cases have taken second place to alternatives that offer advantages concurrent with present-day demands of analytical speed and manipulative simplicity. Many of the methods described in the book are therefore comparatively new, but have been well tried out in academic and industrial laboratories.

The rapid combustion procedures described for the determination of carbon and hydrogen, sulphur and halogens are examples of the newer methods. In Great Britain the rapid method in particular has almost replaced the Pregl carbon and hydrogen method because of its speed and great simplicity of manipulation. The combustion tube used is comparatively expensive; however, this is insignificant compared to the great life of the tube which, if properly cared for, will last for 3,000 combustions. Other methods for the determination of carbon and hydrogen, sulphur and halogens are presented and discussed, for no method is universally applicable for every type of sample. For this reason carbon and hydrogen cannot be determined in an extremely volatile or a gaseous compound by the rapid combustion procedure. Likewise, the Dumas and Kjeldahl methods are not applicable to all classes of compound. Whereas two decades ago variations were few and far between, much work has been carried out during the latter part of the period, and procedures of greater simplicity and range of application have been advanced. The determination of oxygen on a routine basis has also been established during this period. In recent years our knowledge of the chemistry of fluorine compounds has increased tremendously, accompanied by the problem of fluorine analysis. Many methods have thus appeared in the literature for the determination of fluorine and of other elements in fluorine-containing compounds and are described in the text.

The determination of metallic elements and non-metals are never given the attention they warrant in textbooks. Description is confined to the simple fusion procedure with consequent restriction in the range of application. Some importance is now attached to the determination of metals in organic compounds as organo-metallic compounds are being prepared on an increasing scale for industrial, medical and other uses. This aspect is adequately treated in the book, and techniques associated with the analytical methods, such as precipitation and separation, are described.

In recent years great interest has arisen in the determination of elements using less than a milligram of sample. Remarkable progress has been made in the development of methods on this, the microgram scale, using but 50 micrograms of sample. A section of the book is devoted to this branch of analysis. Until the advent of atomic energy, application of these extremely small-scale procedures was restricted to simple inorganic qualitative analysis. The development of balances capable of determining microgram differences with the accuracy required has created a precedence and the field is being actively explored.

The book is set out in three sections. Part 1 is devoted to methods for the determination of the common elements in organic compounds. Part 2 is concerned with metallic and non-metallic elements and the micro techniques involved in their determination. In Part 3 are described the techniques of microgram weighing, the treatment of samples, reagent transference, titrimetry and the methods of analysis on the microgram scale. In three appendices are collected in Appendix 1, special details for the preparation of samples which include sampling, drying techniques, purification of samples and the determination of water. The preparation of standard solutions are described in Appendix 2, while in Appendix 3 are given suitable compounds for use as reference substances.

G. I.

Acknowledgments

My thanks are due to the various colleagues who have helped in their different ways in compiling the manuscript and providing material for the book: Professor R. Belcher for details of many of the microgram methods and valuable suggestions; Mr. G. S. Crouch for his interest and help during the initial preparation of material; Mr. M. Lonsdale for reading through the manuscript during the various stages of its preparation; Mr. D. Taylor for some of the photographs of apparatus; Messrs. Baird and Tatlock (London) Ltd. for the photographs of the rapid combustion apparatus for the determination of carbon and hydrogen, and sulphur and the halogens; Messrs. L. Oertling Ltd. for the illustrations of the microgram balance; Mr. G. R. Ingram for preparing some of the drawings; Dr. D. D. Van Slyke for permission to reproduce the table of factors for the calculation of carbon in the wet oxidation method; Mrs. S. P. Taylor for typing during various stages in the preparation of the manuscript; Dr. B. E. Bailey for the onerous task of proof-reading.

G. I.

Contents

Appendices

Part 1

The Elements Carbon and Hydrogen, Oxygen, Nitrogen the Halogens and Sulphur

Introduction

Since Pregl introduced microchemical elemental analysis some notable advances in methods and techniques have been made, and one may safely say that present day practice has in the main departed from Pregl's original procedures. Other methods offering a wider application, greater rapidity, and imposing less manipulative strain on the part of the analyst have been evolved. The literature, particularly during the past two decades, deals with a vast amount of matter appertaining to elemental organic analysis, and there is a host of methods from which to choose.

A large proportion of this literature is concerned with the determination of carbon and hydrogen covering, for example, improvements of the Pregl method; automatic combustion of the sample; innovations such as the use of absorption tubes constructed of metal;[1] replacement of the conventional lead dioxide filling with a more reliable reagent used externally; and the use of fast streams of oxygen instead of the usual 4 ml. per minute speed. In spite of these developments, it is surprising that no major change in the method of determination has been advanced. Carbon and hydrogen are determined by a procedure established by Gay-Lussac and Thenard more than a century ago, and progress has been one of technique development, which applies generally also for the other elements determined in organic substances. Another outstanding fact is that the method of determining the combustion products of carbon and hydrogen has not undergone a radical change, although suggestions of other ways of determining the carbon dioxide and water have been made from time to time. Their collection by absorption with dry reagents and subsequent weight determination is still preferred because it affords the most simple means after combustion of the sample. Nevertheless, it would appear that new ideas on this aspect of the determination are required to enable the rapid estimation of the elements without any loss in accuracy. The ideal approach would be the development of an extremely fast oxidation process coupled with determination of the carbon dioxide and water produced by an instrumental procedure. Progress towards this end has been made by the use of the vapour-phase chromatography technique to determine the products following combustion of the substance in the conventional manner.

It has become necessary in recent years as the progress of organic chemistry advances, to be able to analyse substances containing elements capable of interfering with a normal course of combustion. Thus, a standard method has been developed for determining carbon and hydrogen in fluorine-containing compounds; this type of substance causes trouble because of the formation of fluorine-containing combustion products which are not retained in the normal way, but pass on into the absorption tubes. It is now of some interest to be able to determine the elements in volatile and gaseous substances, and for these a satisfactory micro method has been devised. With the advent of the rapid combustion procedure (pp. 20–51) the micro determination of carbon and hydrogen in normal substances has been simplified as never before. One more step is needed to bring the determination of these elements to a final state of perfection as outlined above. Titrimetric determination may be the answer, but the technique as it stands at present is by no means quicker for routine work than weighing, and certainly not as accurate unless conditions are very carefully controlled. The gravimetric finish can be completed in 15 minutes, permitting, with a rapid combustion, one determination per half hour. A titrimetric finish with slow combustion considerably lengthens the determination. A longer sweeping period is generally necessary to ensure the complete removal of the products from the combustion tube, and their quantitative reaction with the reagents employed. This applies particularly to the water reaction (production of hydrochloric acid (p. 51): reaction with Karl Fischer reagent[2]), and there is the possibility of high or variable blank values effecting the accuracy.

One notable contribution to this branch of analytical chemistry made by Unterzaucher has been his work on the micro determination of oxygen in organic compounds. Before this period, some attempt was made to establish a reliable method for this element, but the earlier methods proposed were never satisfactory. Some workers have not been able to repeat Unterzaucher's results when determining amounts of oxygen in the region of 1 per cent. The method is undoubtedly passing through a proving period, and causes of blank errors, which make the trace determination unreliable, will eventually be eliminated altogether.

Nitrogen is determined by methods established many years ago which have not changed a great deal since they were brought to micro scale proportions. Only in very recent years has any attempt been made to modify them, or to develop alternative methods in which different principles are involved.

The halogens, with the exception of fluorine, have for many decades been determined by a Carius oxidation followed by precipitation and weighing of the silver halides. Pregl used a combustion method for oxidation of the sample, but also employed the gravimetric finish. Carius' treatment is often considered too time-consuming, and combustion is preferred. Other decomposition treatments have been evolved which are even more rapid than combustion, such as oxidation achieved by burning the sample in a flask filled with oxygen (p. 179), and titrimetric finishes are now used in preference to gravimetric finishes. Fluorine in organic compounds has never been an easy determination, and the position is aggravated when the analysis involves only a milligram or so of the element. Following the sudden interest in fluorine compounds, considerable work has been carried out recently to establish a reliable micro method. Several methods have been proposed, but they leave much to be desired as regards accuracy and reproducibility. It seems that the problem of decomposition has been overcome, but the methods available for finishing the determination are tedious, and very exacting to obtain the desired degree of accuracy.

Sulphur, in organic compounds, has proved one of the most difficult elements to determine. While the test substance may readily be broken down, there have been few methods of finish until recently to surpass the classical barium sulphate precipitation. Many other gravimetric and titrimetric methods have been proposed, but these have not become as widely used as the conventional gravimetric method. A new reagent for sulphate has been developed (p. 254), but which unfortunately is not readily available as it is in the class of carcinogenic compounds. It has been used as a precipitant for the micro determination of sulphur in organic compounds, the determination being subsequently completed by a titration.

In the following chapters of this section will be found many of these newer methods. They are presented not as an historical account, but as an appreciation. Full working details are given of those methods which are considered important because of their advantages over the older established methods.

References

1 Kuck, J. A. and Arnold, M. *Mikrochemie* 1951 **38** 521
2 Johansson, A. *Analyt. Chem.* 1954 **26** 1183

Chapter 1

Determination of Carbon and Hydrogen

The micro determination of carbon and hydrogen closely follows that of the classical Liebig method in which the substance is decomposed in a current of oxygen in the presence of an oxidising agent. Carbon dioxide and water resulting from the combustion are collected in weighed tubes containing appropriate absorbents. Pregl,[1] in transferring these principles to the micro scale, encountered innumerable difficulties which involved changes not only in apparatus design but also in manipulative technique. The principal changes were concerned: (1) with the oxidising medium in the combustion tube, which had to be modified to provide a suitable packing able to cope with almost any type of organic compound; (2) with the speed and pressure of the oxygen flow through the combustion tube; and (3) with the technique of collecting and weighing the carbon dioxide and water.

In the subsequent rapid and widespread use of the method, it has been subjected to exhaustive investigation with the object of simplifying the procedure and of minimising the possible sources of error. Thus, some changes were introduced and other methods suggested which differed fundamentally, or only in some small degree, from Pregl's method. Some of the modifications achieved their object of simplifying the procedure or of reducing the inherent sources of error in the determination.

In recent years the need has arisen for a rapid method of determining carbon and hydrogen which has promoted the search for alternative methods. Certain methods have been advanced which combine both rapidity and simplicity and these are described in the following pages.

The Pregl Method

Before discussing the various merits or disadvantages of other methods for the determination of carbon and hydrogen, it is necessary to refer briefly to the notable method of Pregl. In this procedure the organic substance is vaporised and decomposed in a slow stream of oxygen in the presence