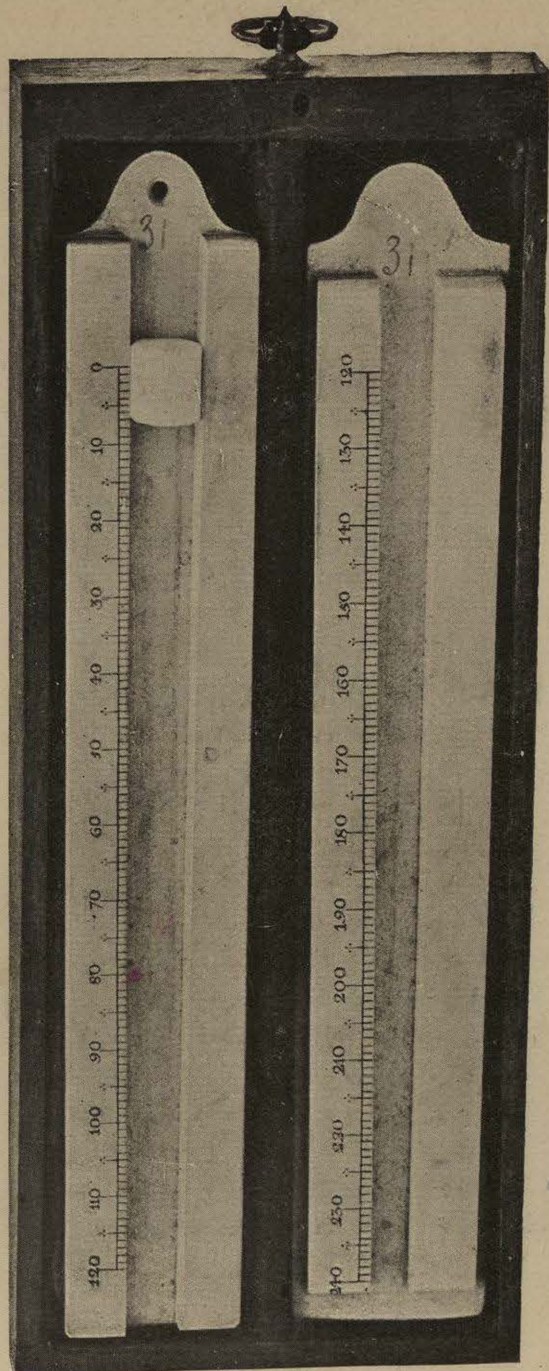
MEASUREMENT
OF
HIGH
TEMPERATURES

BURGESS

LE CHATELIER



Wedgwood's Pyroscope. *Frontispiece.*

The Measurement of High Temperatures

BY

G. K. BURGESS

BUREAU OF STANDARDS

AND

H. LE CHATELIER

MEMBRE DE L'INSTITUT

THIRD EDITION. REWRITTEN AND ENLARGED

UNIVERSIDAD DE NUEVO LEON
BIBLIOTECA UNIVERSITARIA
"ALFONSO REYES"
MONTERREY, MEXICO

NEW YORK
JOHN WILEY & SONS
LONDON: CHAPMAN & HALL, LIMITED

Stanhope Press
F. H. GILSON COMPANY
BOSTON, U.S.A.

PREFACE I.

THE main purpose of this preface is to recall the origin of the volume Mr. Burgess and I present to the reader. For a long time, all precise, scientific investigations at high temperatures were made impossible by the absence of suitable methods for the measurement of these temperatures. Wedgwood, more than a century ago, had already insisted on the capital importance of the carrying out of high-temperature investigations, and devised for this purpose his pyrometer, which is but an arbitrary-comparison apparatus. The question was taken up later by many scientists, but with little success, until I called attention definitely to the precision to be obtained by the judicious use of thermoelectric couples.

Pouillet about 1830, and afterwards Edmond Becquerel, had made some measurements with the gas thermometer provided with a platinum bulb. This method, however, was completely discredited following the discovery, by Henry Sainte-Claire Deville, of the permeability of platinum to hydrogen; and it is only since the very recent employment of platinum-wound electric resistance furnaces, free from all combustible material, that it has been possible to obtain accurate measurements with the platinum-bulb gas thermometer; but its complexity and the difficulty of manipulation limit its use to the standardization of other measuring apparatus.

Henry Becquerel, later his son Edmond, and also Pouillet, advocated the employment of thermoelectric couples; but their use did not spread, and Regnault emphatically condemned them after finding serious irregularities in their behavior. These anomalies, the cause of which he did not then recognize, were due, as I showed later, to the use of iron as one of the metals of the couple, and to imperfections in the methods of electrical measurements.

Violle, following Regnault and Sir William Siemens, proposed the calorimetric method with platinum as the heated substance, instead of iron used by Regnault and copper by Siemens, in their industrial pyrometers. This complicated method, of delicate and slow manipulation, did not come into general use.

Mention should also be made of other isolated and even more restricted attempts, the application of which hardly exceeded a series of observations by a single experimenter. Sir William Siemens proposed the electrical resistance pyrometer; before this, Edmond Becquerel had suggested a radiation pyrometer; finally, several observers sought to apply to determinations of the sun's temperature certain heat-radiation methods.

In 1885, when I attacked the problem of the measurement of high temperatures, it is fair to say there existed nothing definite available on this important question; we possessed only qualitative observations for temperatures above 500° C. Engaged at that time in industrial studies relative to the manufacture of cement, I sought a method which above all would be rapid and simple, and decided on the use of thermoelectric couples, intending to determine the order of magnitude of the sources of error noticed by Regnault. The readings of even a crude galvanometer might be very useful in technical work, provided the limitations of its accuracy were appreciated. I soon recognized that the errors attributed to this method could easily be eliminated by discarding in the construction of the couples certain metals, such as iron, nickel, and palladium, which give rise to singular anomalies; and indicated a simple test for recognizing the suitable metals. One takes a stretched wire of the metal, the ends of which are connected to the terminals of a sufficiently sensitive galvanometer, indicating at least $\frac{1}{10000}$ volt, and the wire is then heated from point to point with a Bunsen flame, which is carried back and forth beneath the wire, when no electric currents should be produced. Now, iron and palladium, the two metals advocated by Becquerel and Pouillet, give rise to large and variable parasite currents which diminish the accuracy of the measurements. Among the different metals and alloys studied, pure platinum and the alloy of platinum and rhodium which are still used to-day, gave the most satisfactory results.

Finally, I called attention to the importance, overlooked by Regnault, of employing only galvanometers of high resistance, to avoid the influence of variations in resistance of the wires of the couple when heated. I recommended also the calibration of the couples, not against the air thermometer directly, as Becquerel had tried to do, but in terms of the fixed points of boiling or fusion of certain pure substances, in such a way that, when these temperatures should be known more exactly, as is the case since my earlier researches, the results could be corrected with certainty.

Some months later, at the request of Sir Robert Hadfield, director of the Hecla Steel Works, I developed an optical pyrometer, and calibrated it by comparison with the thermoelectric couple. By means of these two instruments, I determined a large number of temperatures, in the laboratory and in the industries, and rectified, often by several hundred degrees, the numbers previously admitted in terms of fantastic estimations.

From this date, the measurement of high temperatures came rapidly into general use in the laboratory as well as in the industries. A few years later, in a course of lectures delivered during the year 1898 at the Collège de France, I thought it useful to give a summary of the progress accomplished. These lectures, gathered into book form with the aid of my assistant, Mr. Boudouard, formed the first edition of this work. Mr. Burgess, who had followed my lectures, took the trouble to translate it into English; but, while there was little demand for the French edition, the English translation was soon exhausted. Mr. Burgess wrote a second edition, considerably improved and enlarged by him; this is again exhausted. This time Mr. Burgess has rewritten anew the whole book, so that it is no longer a translation but an original work which we present to the reader.

For several years past, my studies have taken me into other fields of investigation, and I have been unable to follow the considerable progress realized in the measurement of temperatures. Mr. Burgess, on the contrary, has been actively interested in these new researches and to him is due an important part in the more recent advances. Consequently, this book is much more his work than mine, which enables me to praise it as it deserves, and state that this publication will render great service both to investigators and engineers.

H. Le CHATELIER.

PARIS, *February 15, 1911.*

PREFACE II.

SINCE the appearance in 1900 of *Mesure des Températures Elevées* by Messrs. Le Chatelier and Boudouard, the theory and practice of pyrometry have grown greatly, and methods which at that time were in a tentative stage of development have been improved in accuracy and convenience, and adapted by means of new instruments both to technical and scientific requirements.

In gas pyrometry, accurate measurements may be said to have been initiated at the Reichsanstalt by the publication in 1900 of a series of metal freezing points, by Holborn and Day, constituting what is still known as the Reichsanstalt temperature scale.

Again, it is only since 1900 that the significance of the application of the laws of radiation to pyrometry has been appreciated. The theoretical work of Wien, Planck, and others closely contemporaneous with the experimental verifications of Paschen, Lummer and Pringsheim, and many others, was soon followed by the optical and radiation pyrometers of Wanner, Féry, Morse, and Holborn and Kurlbaum, and by many applications to technical and scientific uses.

In thermoelectric and electric resistance pyrometry there has been in recent years an unparalleled improvement in the design of electric measuring instruments, millivoltmeters, potentiometers, galvanometers, Wheatstone bridges and the like, suitable for use in temperature measurements, either in the works or in the laboratory. There have also been executed since 1900 several exact experimental investigations in pyrometry with such apparatus, notably at the several national laboratories and at the Geophysical Laboratory of Washington. Furthermore, the subject of automatic temperature recording has received a great deal of attention, resulting in many new instruments.

In so far as practicable in the following pages, we have dwelt less upon particular types of instrument than on the principles underlying them. We have, however, consulted nearly all the manufacturers of pyrometers as to their practice, and have drawn very freely on the material they have been so kind as to put at our disposal, — material that in several instances is otherwise unpublished, and for which we express our obligation.

We have kept in mind three classes of readers: the student, to whom the historical aspect and fundamental principles are of prime interest; the engineer, who is interested mainly in adapting some method or instrument to his particular technical operation; and the investigator, who has an intensive interest in accurate methods of measurement and their adaptability to his needs. We realize that one book cannot meet satisfactorily all these requirements. If the wants of the investigator have been somewhat neglected, he has ready access to the literature, a summary of which is given in the Bibliography.

We are indebted to Dr. C. W. Waidner for many suggestions; to Dr. R. B. Sosman for reading the chapters on Gas and Thermoelectric Pyrometry; and especially to Dr. A. L. Day, from whose criticisms of the manuscript we have been able to profit greatly.

GEORGE K. BURGESS.

WASHINGTON, *August 24, 1911.*

CONTENTS.

INTRODUCTION.