THERMODYNAMICS
FOR ENGINEERS

THERMODYNAMICS
FOR ENGINEERS

BY THE LATE

J. A. EWING, K.C.B.

SECOND EDITION

CAMBRIDGE
AT THE UNIVERSITY PRESS
1946

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107594760

First edition 1920
Second edition 1936
Reprinted by photo-lithography 1946
First paperback edition 2015

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-59476-0 Paperback

Additional resources for this publication at www.cambridge.org/9781107594760

PREFACE TO THE FIRST EDITION

ALTHOUGH written primarily for engineers, it is hoped that this book may be of service to students of physics and others who wish to acquire a working knowledge of elementary thermodynamics from the physical standpoint.

In presenting the fundamental notions of thermodynamics, the writer has adopted a method which his experience as a teacher encourages him to think useful. The notions are first introduced in a non-mathematical form; the reader is made familiar with them as physical realities, and learns to apply them to practical problems; then, and not till then, he studies the mathematical relations between them. This method appears to have two advantages: it prevents the non-mathematical student from becoming bewildered on the threshold, and it saves the mathematical student from any risk of failing to realize the meaning of the symbols with which he plays. When the non-mathematical student comes to face the mathematical relations, which he must do if he is to pass beyond the rudiments of the subject, he finds it comparatively easy to build on the foundation of physical concepts he has already laid: there is perhaps no better way to learn the meaning and use of partial differential coefficients than by applying them to thermodynamic ideas, once these ideas are clearly apprehended.

Accordingly the plan of the book is to begin with the elementary notions and their interpretation in practice, and to defer the study of general thermodynamic relations till near the end. Finally these relations are illustrated by applying them to characteristic equations of fluids, and in particular to steam, following Callendar's method.

The chapter on Internal-Combustion Engines gives occasion for introducing some results of experiments on the internal energy and specific heats of gases, and this matter is dealt with further in an appendix* which attempts an elementary account of the molecular theory.

In any exposition of the first principles of thermodynamics it is important to choose a way of dealing with temperature such that students may be led by simple and logical steps to understand the thermodynamic scale. The course followed here is first to imagine

* Now Chapter VII.

an ideal gas which serves as thermometric substance, and also as the working substance in a Carnot engine. This gives a perfect-gas scale by reference to which the efficiency of any Carnot cycle is provisionally expressed, and from that the step to the thermodynamic scale is easy.

The writer is indebted to Professor Callendar and his publisher, Mr Edward Arnold, for permission to include a much abbreviated version of his *Steam Tables*. By the recent publication of complete tables, Professor Callendar has added substantially to the many obligations under which he has put all students of thermodynamics. The writer would also thank Mr J. B. Peace, of the Cambridge University Press, for various suggestions and for the interest he has taken in bringing out the book; and also Dr E. M. Horsburgh, of the Mathematical Department of this University, for his great kindness in reading the proofs.

J. A. E.

THE UNIVERSITY, EDINBURGH
March 1920

NOTE TO THE SECOND EDITION

SIR ALFRED EWING died on January 7th, 1935: he was busy with the revision of this book till near his last days. He asked me to see the book through the press for him, a task gladly undertaken in tribute to his memory.

The revision was practically done: there remained steam tables to compile and proofs to revise. Had Sir Alfred been spared a little longer, he would have added a chapter on Radiation; apart from that, most of his plan of revision was complete. No attempt has been made to supply that chapter, so that the book may still be truly "Ewing's Thermodynamics."

Steam tables based on the latest 1934 International Steam-Table Conference values have been prepared to replace the tables in the former edition. Ewing realized that recent steam measurements were not in sufficiently good agreement with existing steam-table values and that the latter would eventually be superseded by tables in better agreement. He therefore wished that any provisional tables inserted in the Appendix to replace the former ones should be based on the most recent values. I am grateful to my collaborator, Mr G. S. Callendar, for the preparation of these tables.

Because he was not satisfied with the validity of the tables in the former edition, nor with that of the Callendar equations in the high-pressure regions, Ewing deleted the numerical examples in the text (Chapter III), which had been based on the figures in those tables, and he also shortened the sections (Chapter IX) dealing with the Callendar theory. I have put back the numerical examples, using the figures in the new tables, and feel sure this would have been in accordance with his wishes.

The chapters on the Steam-Engine and on Jets and Turbines were read by Mr H. L. Guy, and that on the Internal-Combustion Engine by Dr F. Ll. Smith. I have made a few small additions and alterations in accordance with their suggestions, for which I am very grateful. The last chapters are mainly taken by Ewing from his articles in the *Dictionary of Applied Physics*, and thanks are due to the publishers, Messrs Macmillan, for permission to use them.

Sir Alfred Ewing had very definite views as to the symbols for the thermodynamical quantities most used by engineers. The symbols he has adopted are in accord with those agreed by the

International Union of Pure and Applied Physics, except that ψ has been used for Free Energy and F for Electromotive Force, while G (Gibbs' Function) is taken as $-G$, the positive value $TS - I$ being more convenient for users of steam tables.

It will be noticed that the Centigrade scale is used throughout; almost the last words I had in conversation with Sir Alfred Ewing were in deprecation of the continued use of the Fahrenheit scale, which he hoped would rapidly go into disuse. Is it too much to hope that engineers will gradually adopt the metric system in their dealings with steam and oil?

A. EGERTON

OXFORD
May 1935

CONTENTS

CHAPTER I

FIRST PRINCIPLES

CHAPTER II

PROPERTIES OF FLUIDS

CHAPTER III

THEORY OF THE STEAM-ENGINE AND OTHER VAPOUR ENGINES

CHAPTER IV

THEORY OF REFRIGERATION

CHAPTER V

JETS AND TURBINES

CHAPTER VI

INTERNAL-COMBUSTION ENGINES AND PROPERTIES OF GASES

CHAPTER VII

MOLECULAR THEORY OF GASES

CHAPTER VIII

GENERAL THERMODYNAMIC RELATIONS

CHAPTER IX

APPLICATIONS TO PARTICULAR FLUIDS

* This map is available for download from www.cambridge.org/9781107594760