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# Introduction to Combustion Phenomena

*(for Fire, Incineration, Pollution, and Energy Applications)*

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E7961421



GORDON AND BREACH SCIENCE PUBLISHERS  
New York                      Paris                      London

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Gordon and Breach, Science Publishers, Inc.  
One Park Avenue  
New York, N.Y. 10016

*Editorial office for the United Kingdom*

Gordon and Breach Science Publishers, Ltd.  
42 William IV Street  
London WC2N 4DF

*Editorial office for France*

Gordon & Breach  
7-9 rue Emile Dubois  
Paris 75014

First Published September 1975  
Second Printing with corrections May 1977

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# Introduction to Combustion Phenomena

**Combustion Science and Technology Book Series**

**Editor**

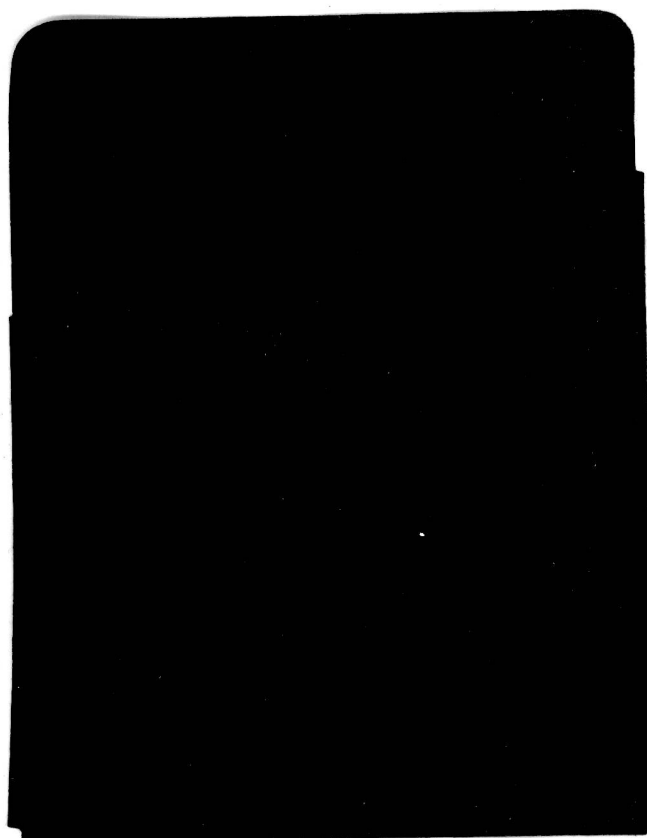
**Irvin Glassman, *Guggenheim Laboratories, Princeton University***

**VOLUME 1 Gasdynamic Theory of Detonation**

***Heinz D. Gruschka and Franz Wecken***

**VOLUME 2 Introduction to Combustion Phenomena**

***A. Murty Kanury***



*Dedicated to*  
my Mother—Punnamma  
and  
my Wife—Kathleen  
for the life and love they have given me

“Everything that happens is due to the flow and transformation of energy. . . . . Control fire and you control everything. The discovery of fire . . . . . lifted man from the level of the beast and gave him dominion over the Earth”.

Morton Mott-Smith in his  
Introduction to Heat and its Workings.  
D. Appleton & Co. (1933)

# Preface

This book is written with the belief that a need exists for it as a textbook in the academic community to introduce combustion to students in physical sciences and as a reference book in the research community to present a broad but coherent background in combustion to scientists involved in the study of destructive fires, of incineration and of efficient and harmless extraction of energy from conventional fuels.

As a textbook, this work finds its origin in the days of my teaching a senior level undergraduate combustion course at the University of Minnesota in the late Sixties. Aimed at students from Mechanical, Aero and Chemical engineering schools, this course has the objective, among others, of introducing to the student how the science of combustion is composed of complex interactions between several disciplines including thermodynamics, chemical kinetics, chemical mechanisms, fluid mechanics, heat and mass transfer and, to some extent, mathematics. In spite of the availability of a number of exemplary treatises both on these component pure disciplines and on combustion, I found it considerably difficult to prescribe a single textbook for my course. I was not willing to prescribe a chapter in one book and a chapter in another for the fear of fragmented styles, concerns, notions, notations and levels of treatment. Being a student myself, in not too distant a past, I was also concerned about the budgetary considerations of an average student.

And then, to pick an existing book on combustion I ran into somewhat related but different deliberations. If one looks around, one immediately finds out that most of the combustion books are written as reference books for a specialist rather than as textbooks for a student. Furthermore, some of them concentrate exclusively on experimental aspects of combustion, and others deal exclusively with theory. Some of them emphasize the chemical aspects of combustion while others stress the physical features. Some of them describe the mechanical “nuts and bolts” aspects of combustion equipment and others present the science.

Evolved out of these thoughts is the first generation version of the present manuscript. Its explicit goal is to elucidate the workings of different types



of combustion phenomena and to balance in this elucidation, theory with experiment, chemistry with physics and engineering with science.

Not to divert attention from the principal topic of the book but to make available the prerequisite knowledge in a consistent framework, thermodynamics, thermochemistry and equilibria of reactive mixtures are presented in the first three appendices. With the conviction that it is a highly specialized aspect of combustion and that its exclusion does not hurt the well-roundedness of the present work, I deliberately limited here the scope of discussion of detonative combustion.

The Minnesota course covered much of the material presented here in a series of 30 hour-long lectures of roughly three hours for each of the ten topics: thermodynamics of mixtures, thermochemistry and equilibrium in combustion systems, chemistry and physics of combustion, ignition/extinction, burning of solids, liquids and jets and finally, premixed flames. Note that Appendix E presents some problems for use in pedagogy.

Revision, updating and finalizing my lecture notes into the present form was done with intentions of rendering combustion a scope broader than of interest merely to a specialist involved in research and development, mostly of power and propulsion equipment. These are precisely the intentions which, I hope, make this book a valuable reference to scientists and engineers involved in various combustion-related researches. Let me elaborate on this hope.

Although combustion is one of the oldest scientific disciplines, the greatest strides of progress occurred only in the past two decades, mainly due to the impetus given by aero- and space-propulsion. Having conquered space by means of combustion, man has recently turned his scientific attention to the earthly problems such as: (a) prevention and reduction of hostile fires which in the U.S. alone annually kill over twelve thousand people and leave many thousands more with life-long physical and psychological scars; (b) reduction of the harmful effluents which are slowly but surely snuffing out the very civilization that grew to depend on combustion; (c) design of efficient and safe incinerators to dispose wastes; (d) improvement of the efficiency with which our dwindling chemical energy resources are burned; and (e) innovation of methods to extract energy from sources which were, hitherto, considered uneconomical. All too often solution to one of these problems may offer solutions to others.

Especially in the energy and fire problem areas, almost orders of magnitude increase in the interest, concern and activity occurred just in the most recent months and years. The influx of scientists into these two areas from various, sometimes remotely, related fields is so phenomenal that technical progress is tortuous and slow. Vividly clear is the lack of a thorough and uniform background in the fundamental physical and chemical implications

of various combustion processes. Even though a scientist's contributions in his specialty are exceptionally superior in caliber, noticeable lack of the overall perspectives of combustion taints his vision. The need for an intelligible and coherent account of combustion phenomena is obvious.

To the student who is opening up his wings and to the researcher who is expanding his horizons, I hope the topical arrangement of this book is appealing and logical. The various combustion phenomena are sorted into three distinct but conceptually related groups—those in which physical mixing and flow exert control, those in which chemical kinetics and mechanisms exert control and the rest in which both physics and chemistry come into play with more or less equal importance. Upon becoming conversant with the thermodynamic concepts of the first three appendices, one can delve into the main text of the book. Chapters two and three deal respectively with the chemistry and physics of combustion. Chapter 4 deals with combustion phenomena in which chemistry dominates, whereas Chapters 5–7 deal with those in which physical processes of flow and mixing dominate. Chapter 8, finally, deals with premixed flames in which careful consideration of both the chemistry and physics is needed.

Visible throughout this book is the special spirit of my teacher Perry Blackshear who taught me much on combustion and much more on life itself. While I hold him not responsible for any disasters, I do hope that this book befits the high caliber and clarity which he always insisted upon. Special thanks are due to Professor Irvin Glassman of Princeton University for his constant encouragement during the preparation of this book and for his technical review. Professor A. M. Mellor of Purdue has read the manuscript and suggested many improvements. My colleagues at Stanford Research Institute, especially Stan Martin and Norm Alvares provided me with much encouragement when I needed it. And finally, my wife Kathleen whose patience, understanding and love far exceed her typing abilities did, in fact, type the final version of the manuscript. To these people, I am much indebted.

Palo Alto

Anjaneya Murty Kanury

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