MODERN PYROTECHNICS

Fundamentals of Applied Physical Pyrochemistry

Dr. Herbert Ellern

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FOREWORD AND ACKNOWLEDGMENTS

The idea of writing a book on pyrotechnics was conceived in 1954. Four years of work in the newly revived armament field (not counting the war years 1942–45) showed me how difficult it was to acquaint young (and older) chemists and other personnel with the field of military pyrotechnics.

Until the publication of this book, there was no comprehensive text available west of the Iron Curtain. There were only some applicable details in books on chemistry, fireworks, and explosives. The reports and other literature written during World War II and the Korean conflict were buried in arsenals and government laboratories—they still are. To make things even more difficult, a secrecy label was often affixed to rather innocuous formulas or devices when there were tactical implications which mainly concerned the end use.

The lack of specific information is aggravated by the lack of chemical knowledge of reactions (dry or wet) and of practical chemistry. This may not be the place to discuss the theories of teaching chemistry and the value of "broad understanding" against the despised memorization of "masses of unconnected facts," but the statement must be made that the man who knows the applicable facts will be the better pyrochemist.

While this book was designed for the practical worker in the field, it attempts to give a broader view of exothermic dry reaction chemistry and physics than would be achieved by describing devices, their manufacture, and other strictly technological or tactical aspects of pyrotechnics. Perhaps this approach will please neither the scientist nor the practitioner. However, it seemed to me that this is the only way a comprehensive, basic primer could be written on this subject at the present "state of the art."

A great many people have contributed to this book indirectly. In the first place, credit is due to Theodore Tsvetkov, former Chief Chemist of Universal Match Corporation, who taught me just about

all that is to be known about matches and a great deal about military pyrotechnics. Only a few days before his death in the spring of 1960, Tsvetkov translated for me from the Russian a chapter of *Osnovy Pirotekhniki*—the only other comprehensive textbook on pyrotechnics in existence.

Numerous valuable pieces of information have come out of informal discussions with the scientific and technical personnel at government installations, especially at Picatinny Arsenal, the Naval Ordnance Laboratory, the Army Chemical Center, and the Diamond Ordnance Fuze Laboratory. I wish to single out only one person—Dr. David Hart of Picatinny Arsenal—whose untimely death in 1958 deprived the country of one of its leaders in the field.

The preparation of the manuscript would have been impossible without the tolerant understanding of the company with which I have been connected for more than twenty years, Universal Match Corporation of St. Louis, Missouri. Greatest praise must go to my secretary, Mrs. Ruth Levine, whose untiring effort in several rewritings of the manuscript got it to the publisher exactly at the deadline. Mrs. Levine was assisted by Mrs. Margaret Thomas, "our girl Friday" of the Pyrochemical Laboratory.

About 99% of this book was written on Saturdays, Sundays and during vacations. Therefore, a great deal of "silent" partnership goes to Edna Linn, Jim and Elizabeth—wife, son and daughter of the author. Jim, a student of chemistry at the University of Illinois has, between semester end and NROTC cruise, eliminated numerous errors of style and diction from the manuscript. Others who endeavored to rid the manuscript of Germanisms and ponderous phrases are I. Kowarsky and E. R. Lake, colleagues and friends for many years.

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PART I

GENERAL OUTLINE

CHAPTER 1

SCOPE AND PURPOSE

This book is a comprehensive survey of pyrotechnics. It treats the basic concepts and the materials for achieving certain effects rather than describing formulas, devices, and techniques. Although this book is based on scientific principles and requires a knowledge of chemistry and physics, it is an empirical rather than a scientific treatment of pyrotechnics. This limitation is due to the fact that the chemical reactions and many of the accompanying physical phenomena have not been sufficiently explored. The study of pyrochemical reactions and pyrophysical phenomena, on which modern pyrotechnics is based, may eventually become a separate branch of chemistry allied to the physical chemistry of solids.

The material published about pyrotechnics has been fragmentary, widely scattered in the literature and is often out of date. The author feels, therefore, that there is a real need for a comprehensive study that presents fundamentals rather than details, such as formulas, methods, and devices. The omission of detailed descriptions of applications is also deliberate. The author could have presented a mass of details and many tricks of the trade—especially in those phases of this subject of wide scope to which he has devoted years of practical study, but he did not consider this necessary.

This book should be of help to the ever-increasing number of chemists, physicists, and engineers, employed in government arsenals, research institutes, universities, industrial plants, and laboratories, who are engaged in work on light and sound signals, power sources, photographic illumination, training weapons, as well as accessories to rockets, guided missiles, and other applications of pyrotechnics. The book should also be useful to teachers and students of chemistry on every level and to everyone interested in this least-known and least-understood offspring of chemistry which, in the form of the ordinary safety match, is utilized by all of us every day.

Instead of crowding each chapter with a series of footnotes, the author has endeavored to make the text more fluid and readable

by an informal presentation of footnote material at the end of the chapters. Literature references are discussed or at least mentioned in these Notes, and then listed at the end of the book. Additional subordinate material which would have interrupted the major lines of thought and discussion is also presented in the "Notes" to the individual chapters.

In selecting references, the author has relied as much as possible on the readily available books, articles, patents, and abstracts. In areas of specific interest, the original literature was studied and evaluated. Otherwise, the abstracts of the original articles, as published in the *Chemical Abstracts,* etc., and general publications on chemistry have been used as reference material. Russian literature on pyrotechnics will be discussed in the next chapter.

The problem of security restrictions has been less bothersome than the author originally feared. An overcautious attitude in "classifying" formulas and devices is fortunately waning and only in a few instances was the author compelled to treat an interesting application or a "new" material in general terms or not at all.

However, military literature, such as reports from government laboratories and arsenals, specifications and formulas of ordnance items, and reports on the activities of private contractors represent a "gray area" which the author has approached with caution even if it bore no stamp of being "confidential" or "secret" information. The technical worker who has access to such material will read the specific literature if he is interested in more detail, while the general reader will find sufficient information in this book.

One would expect that World War II might have brought forth at least one comprehensive treatment of modern pyrotechnics, accessible to the English speaking world. No such book has appeared in Europe or in the Americas. This is the only book of its kind in the English language.

The author has spent twenty-four years in the match industry and the greater part of this time, during World War II, and especially during the last decade, in many phases of military pyrotechnics. In addition to his personal experiences, the author studied all available published material and drew from it to give a well-rounded picture of the present status of pyrotechnics.

The author is aware that his daily preoccupation with practical problems of pyrotechnical development or production has slanted his approach toward empirical facts rather than toward a more

scientific attitude. The application of theories of solid-state reactions on pyrotechnics will undoubtedly play an important role in the future. However, at this time, it would be hard to deny that pyrotechnics is still rather an art than a science. It will take the efforts of a whole generation to make a science of pyrotechny emerge from the present state of transition and to create a comprehensive theoretical foundation for the exothermic interaction of solids and the associated physical phenomena.

CHAPTER 2

DEFINITION OF PYROTECHNICS AND SURVEY OF ITS LITERATURE

Pyrotechnics is, verbally, the art of fire, from the Greek *pyr,* fire, and *techne,* an art. According to all the major dictionaries, it is the "art of making fireworks."

More specifically, it has been said that "the art of fireworks making comprises the preparation and application of mixtures capable of burning independently of the oxygen of the atmosphere" (Brock). A more elaborate definition is the following: "Fireworks, pyrotechnics, or artificial fireworks as they were formerly called, are contrivances that by the agency of fire produce audible, visible, mechanical, and thermal effects useful for industrial or military purposes or for entertainment. Fireworks produce noise, heat, smoke, motion, and light of various colors, forms, and appearances, and also a great variety of combinations of these phenomena" (Davis).

Pyrotechnics deals with flame or glow, caused by the heat development within a system independent of outside energy sources. The heat is the result of chemical reactions between at least two substances. With few exceptions, these substances are finely powdered solids which are mixed and compacted into a self-contained unit. Once initiated, such a unit completes its main reaction in a few seconds or minutes. The heat of reaction can be utilized as such, either directly for igniting or as a destructive fire starter, or indirectly for heat transfer in the manner of a hot plate or an immersion heater. The conditions prevailing in pyrotechnic reactions are apt to create very high temperatures, causing incandescence. This property makes pyrotechnical devices suitable for use as fireworks, signal flares, and flash powders. Other secondary phenomena of pyrochemical reactions are smoke (used for signaling and obscuration) and gas release (used for energy transfer). Sudden or rhythmic gas release is used to create noise or whistling sounds. In addition, gas production falls in the domain of pyrotechnics insofar as small forces and minor rocketry are concerned. The field of propellants, on the whole, and the field of explosives for destructive purposes are outside the scope of this book.

The chemical products of pyrotechnical reactions are often too complex to be known in detail. However, there is a small but interesting group of reactions which are characteristically pyrotechnical, but which yield useful products of known composition, for example, a chemically pure gas, such as oxygen, a pure metal, or an alloy that is difficult to obtain by other means.

Application of modern pyrotechnics to numerous civilian and military uses has greatly enlarged the scope of pyrotechnics beyond the art of making fireworks. For this reason, those concerned with the advancement of military pyrotechnics have often wished that a more distinctive term could be found to distinguish between fireworks making and the more important uses of pyrotechnics. The frequent use of the words *pyrochemical* and *pyrophysical* and of the corresponding nouns in this book is an attempt to employ less often the term pyrotechnics, though this word itself has not been replaced by a more distinctive term.

It is not easy to find factual information on modern pyrotechnics in the general literature. Aside from chapters on pyrotechnics and fireworks, the encyclopedias contain information under headings such as "Chemical Warfare," "Aluminothermics," "Thermit," and "Matches."

Books on inorganic chemistry, while mostly rather casual when dealing with specific exothermic reactions between solids or with spontaneous ignition, are a source of information on properties of materials. They are better sources when they are descriptive rather than general and theoretical. Such books are, of course, indispensable to the student who is interested in expressing chemical reactions in the form of equations, or is looking for information on stoichiometry, molecular and equivalent weights, exothermic and endothermic reactions, etc. However, these chemical fundamentals are not treated in detail in this book. The same applies to physics. The reader is advised to refer to the appropriate books for information on gas laws, the laws of radiation, etc.

Much information on properties of pyrochemically interesting substances is found in the so-called German "handbooks" and texts. It should be noted that a *Handbuch* may be a set of bulky volumes to be kept "at hand" rather than in the hand.

In the specialized literature, the emphasis is mostly on fireworks, propellants, and explosives. The books on fireworks for pleasure contain a few modern military items. It is significant that the writer