

# The Chemistry of Powder and Explosives

COMPLETE IN ONE VOLUME

BY

**TENNEY L. DAVIS, PH.D.**

*Emeritus Professor of Organic Chemistry  
Massachusetts Institute of Technology  
Director of Research and Development  
National Fireworks, Inc.*

## PREFACE

The present volume contains in one binding the whole contents of Volume I, first published in May, 1941, and the whole contents of Volume II which was published in March, 1943.

The book is primarily for chemists. The writing of it was commenced in order that a textbook might be available for the use of students in the course in powder and explosives which the author gave for about twenty years (nearly every year since the first World War) to fourth-year and graduate students of chemistry and of chemical engineering at the Massachusetts Institute of Technology. The writing of it has been completed while the nation is at war and while many chemists, not previously trained in powder and explosives, are at work preparing, studying, and testing these materials. The purpose of the book is to supply chemists with information concerning the modes of behavior of explosive substances and concerning the phenomena, both chemical and physical, which they exhibit. No effort has been made to describe the use of explosives in ammunition and in blasting beyond the minimum of description which is needed to make clear the modes of their behavior, and no account has been included of the chemical engineering aspects of their manufacture.

The book brings together much material which has never before been collected in one volume, and it sets down some of the facts in what are probably new relationships to one another, but it contains nothing which is not already known to those who are skilled either in chemistry or in the manufacture and use of explosives. It is elementary in the sense that it supplies a background of knowledge for the chemist who wishes to become an expert in any one of several technical branches.

The chapter on pyrotechnics has been made as full as possible. It contains much which will not be found in print elsewhere, but it limits its discussions to civil pyrotechnics—for several reasons. Civil pyrotechnics is a much broader subject than military pyrotechnics. Military pyrotechnic devices differ in no important respect from similar devices for civil and recreational

## PREFACE

purposes. Their varieties are few. Artifices which are not now used for military purposes may some day be applied to the uses of war, and a broad knowledge of civil pyrotechnics plus an acquaintance with the military necessities will determine the applications.

Workers with explosives will perhaps think that I have included in the chapter on pyrotechnics too much material on the construction of fireworks pieces, but chemists, interested in the manner in which their substances behave, will be tempted to try their hands at making the artifices, and the fireworks makers, aware of the importance of these details, will probably think that the account of them is too meager.

The chapter on aromatic nitro compounds deals with the chemistry of a large and important class of explosive substances, among which TNT stands as the most important of the military high explosives, with tetryl second in importance, while the whole class includes substances which are used, or may be used, in shells, bombs, grenades, and other devices of war. The precise manner in which they are loaded, the amounts which are used, the details of the construction of the devices, etc., are known to those who are concerned with such matters. But the practices change. The principles of the use of the materials and the physical and chemical properties of the substances upon which the principles depend do not change—and they are the proper subject matter of the present book.

The aim of the book has been to describe as clearly and interestingly as possible and as fully as seemed profitable the modes of behavior, both physical and chemical, of explosive substances, whether these modes find practical application or not. Historical material has been included where it was thought that it contributed to this end, and it has not been included elsewhere or for any other reason. It is a fact that a knowledge of the history of ideas, of persons, or of things produces something of the same sympathetic understanding of them that living with them and working with them does.

I am indebted to many friends to whom I wish to make grateful acknowledgment of information, of pictures, and of criticism. Dr. C. G. Storm has read the entire manuscript and has made many helpful suggestions. Dr. Walter O. Snelling has read the chapter on aromatic nitro compounds, has kindly prepared the specimen to illustrate the Munroe effect, and has made the photo-

## PREFACE

graphs from which the two figures are reproduced. Allen F. Clark of Bridgewater, Massachusetts, has read the chapter on pyrotechnics and has supplied many formulas and much other information. His brother, George J. J. Clark of Whitman, Massachusetts, has furnished several pictures of operations at the plant of the National Fireworks Company, while the *Boston Globe* with his consent has supplied others, and a third brother, Wallace Clark of Chicago, Illinois, has given information relative to the manufacture of Chinese firecrackers and has furnished the pictures which illustrate the process. George W. Weingart of New Orleans, Louisiana, has supplied information in his letters and has given permission to use material from his "Dictionary and Manual of Fireworks," and A. St. H. Brock of London, England, has given permission to quote from his "Pyrotechnics: The History and Art of Firework Making." I am indebted to Dr. E. Berl, to Dr. Émile Monnin Chamot, to the U. S. Bureau of Mines, to the Atlas Powder Company, to E. I. du Pont de Nemours and Company, Inc., to the Ensign-Bickford Company, to the Hercules Powder Company, to the Trojan Powder Company, and to the Western Cartridge Company for pictures; to the Williams and Wilkins Company of Baltimore for permission to cite and to quote from Symmes' translation of Naoum's "Nitroglycerine and Nitroglycerine Explosives"; to Sir Isaac Pitman & Sons, Limited, of London, for permission to cite and to quote from MacDonald's "Historical Papers on Modern Explosives," published originally by Whittaker & Co., whose business this firm later took over, and to the *Journal of the American Chemical Society*, to *Industrial and Engineering Chemistry*, to the *Journal of Chemical Education*, to the *Journal of the Franklin Institute*, to *Army Ordnance*, to the U. S. Bureau of Mines, and to the University of Pennsylvania Press for permission to cite and to quote from their publications. My thanks are also due to Professor Warren K. Lewis who has read the proof of Volume I and to Dr. Joseph Ackerman, Jr., who has read the proof of Volume II.

TENNEY L. DAVIS

NORWELL, MASSACHUSETTS  
7 March 1943



## CONTENTS

CHAPTER	PAGE
I PROPERTIES OF EXPLOSIVES.....	1
Definition.....	1
Classification of Explosives.....	2
A Complete Round of Ammunition.....	6
Propagation of Explosion.....	10
Detonating Fuse.....	11
Velocity of Detonation.....	14
Munroe Effect.....	18
Sensitivity Tests.....	21
Tests of Explosive Power and Brisance.....	23
II BLACK POWDER.....	28
Introduction.....	28
Berthold Schwarz.....	29
Boerhaave on Black Powder.....	29
Greek Fire.....	32
Marcus Graecus.....	34
Roger Bacon.....	35
Development of Black Powder.....	39
Burning of Black Powder.....	42
Uses of Black Powder.....	43
Manufacture.....	45
Analysis.....	47
Blasting Powder.....	48
Ammonpulver.....	49
Other Related Propellent Explosives.....	50
III PYROTECHNICS.....	52
Introduction.....	52
Development of Pyrotechnic Mixtures.....	53
Colored Lights.....	63
Railway Fusees.....	65
Scratch Mixture.....	66
Marine Signals.....	66
Parade Torches.....	67

## CONTENTS

CHAPTER	PAGE
Aluminum and Magnesium Flares.....	68
Lances.....	69
Picrate Compositions.....	70
Picrate Whistles.....	72
Non-Picrate Whistles.....	73
Rockets.....	73
Roman Candles.....	79
Stars.....	81
Gerbs.....	89
Fountains.....	90
Wheels.....	91
Saxons.....	92
Pinwheels.....	93
Mines.....	97
Comets and Meteors.....	98
Bombshells.....	100
Maroons.....	104
Toy Caps.....	105
Silver Torpedoes.....	106
Japanese Torpedoes.....	107
Globe Torpedoes.....	108
Railway Torpedoes.....	109
English Crackers or Grasshoppers.....	111
Chinese Firecrackers.....	112
Flash Cracker Composition.....	117
Sparklers.....	117
Wire Dips and Colored Fire Sticks.....	119
Pharaoh's Serpents.....	119
Black Non-Mercury Snakes.....	120
Smokes.....	122
IV AROMATIC NITRO COMPOUNDS.....	125
Introduction.....	125
Effect of Groups on Further Substitution.....	127
Utilization of Coal Tar.....	129
Effect of Substituents on Explosive Strength.....	132
Mono- and Di-nitrobenzene.....	133
Trinitrobenzene.....	134
Nitration of Chlorobenzene.....	140

## CONTENTS

CHAPTER	PAGE
Trinitrotoluene . . . . .	141
Trinitroxylene . . . . .	153
Nitro Derivatives of Naphthalene . . . . .	154
Hexanitrobiphenyl . . . . .	158
Picric Acid . . . . .	159
Ammonium Picrate . . . . .	167
Guanidine Picrate . . . . .	168
Trinitrocresol . . . . .	169
Trinitroresorcinol . . . . .	169
Trinitroanisol and Trinitrophenetol . . . . .	169
Trinitroaniline . . . . .	173
Tetranitroaniline . . . . .	173
Tetryl . . . . .	175
Ethyl Tetryl . . . . .	183
Butyl Tetryl . . . . .	183
Hexanitrodiphenylamine . . . . .	184
Hexanitrodiphenyl Sulfide . . . . .	187
Hexanitrodiphenyl Sulfone . . . . .	187
Hexanitro-oxanilide . . . . .	188
Hexanitrocarbanilide . . . . .	188
Hexanitroazobenzene . . . . .	189
 V NITRIC ESTERS . . . . .	 191
Methyl Nitrate . . . . .	192
Other Alkyl Nitrates . . . . .	194
Nitroglycerin . . . . .	195
Dinitroglycerin . . . . .	214
Mononitroglycerin . . . . .	218
Nitroglycide . . . . .	218
Dinitrochlorohydrin . . . . .	220
Tetranitrodiglycerin . . . . .	222
Nitroglycol . . . . .	223
Dinitrodiglycol . . . . .	226
Trinitrophenoxyethyl Nitrate . . . . .	227
Nitration of Ethylene . . . . .	228
Pentryl . . . . .	229
Hexanitrodiphenylaminoethyl Nitrate . . . . .	232
Trimethylene Glycol Dinitrate . . . . .	233
Propylene Glycol Dinitrate . . . . .	234



## CONTENTS

CHAPTER	PAGE
Butylene Glycol Dinitrate.....	235
Nitroerythrite.....	235
Nitromannite.....	236
Nitrodulcite.....	238
Nitrosorbite.....	238
Nitrated Sugar Mixtures.....	238
Nitroarabinose.....	240
Nitroglucose.....	241
Nitromannose.....	241
Nitromaltose.....	241
Nitrolactose.....	241
Nitrosucrose.....	242
Other Nitrosugars.....	242
Early History of Nitrated Carbohydrates.....	244
Nitrocellulose.....	256
Determination of Nitrogen.....	269
Nitrostarch.....	273
Utilization of Formaldehyde.....	276
Pentaerythrite Tetranitrate.....	278
Dipentaerythrite Hexanitrate.....	281
Trimethylolnitromethane Trinitrate.....	283
Nitropentanone and Related Substances.....	285
 VI SMOKELESS POWDER.....	 287
Bulk Powder.....	287
Early History of Colloided Powders.....	292
Classification of Colloided Nitrocellulose Powders..	297
Manufacture of Single-Base Powder.....	299
Stabilizers.....	307
Transformations of Diphenylamine During Aging of Powder.....	311
Absorption of Moisture.....	313
Control of Rate of Burning.....	317
Gelatinizing Agents.....	320
Flashless Charges and Flashless Powder.....	322
Ball-Grain Powder.....	328
 VII DYNAMITE AND OTHER HIGH EXPLOSIVES.....	 331
Invention of Dynamite.....	331

## CONTENTS

CHAPTER	PAGE
Invention of Ammonium Nitrate Explosives. . . . .	335
Guhr Dynamite. . . . .	336
Straight Dynamite. . . . .	338
Blasting Gelatin. . . . .	343
Gelatin Dynamite. . . . .	344
Permissible Explosives. . . . .	346
Sprengel Explosives. . . . .	353
Liquid Oxygen Explosives. . . . .	355
Chlorate and Perchlorate Explosives. . . . .	357
Ammonium Nitrate Military Explosives. . . . .	367
VIII NITROAMINES AND RELATED SUBSTANCES. . . . .	369
Nitroamide. . . . .	369
Methylnitramine. . . . .	371
Urea Nitrate. . . . .	372
Nitrourea. . . . .	373
Guanidine Nitrate. . . . .	374
Nitroguanidine. . . . .	380
Nitrosoguanidine. . . . .	391
Ethylenedinitramine. . . . .	393
Dinitrodimethyloxamide. . . . .	394
Dinitrodimethylsulfamide. . . . .	395
Cyclotrimethylenetrinitramine. . . . .	396
IX PRIMARY EXPLOSIVES, DETONATORS, AND PRIMERS. . . . .	400
Discovery of Fulminating Compounds. . . . .	400
Mercury Fulminate. . . . .	405
Silver Fulminate. . . . .	412
Detonators. . . . .	413
Testing of Detonators. . . . .	421
Lead Azide. . . . .	424
Silver Azide. . . . .	430
Cyanuric Triazide. . . . .	432
Trinitrotriazidobenzene. . . . .	436
Nitrogen Sulfide. . . . .	438
Lead Styphnate. . . . .	440
Diazonium Salts. . . . .	441
Diazodinitrophenol. . . . .	443
Tetracene. . . . .	446

## CONTENTS

CHAPTER	PAGE
Hexamethylenetriperoxidediamine.....	451
Friction Primers.....	453
Percussion Primers.....	454
INDEX OF NAMES.....	459
INDEX OF SUBJECTS.....	465

FIRST PRINTED IN 1943