# Contents

ţ.

Preface Acknowledgments	xiii Xv
Chapter One Chemical Thermodynamics	
<ul><li>A. Heats of Reaction and Formation</li><li>B. Free Energy, the Equilibrium Constant, and Flame Temperature Calculations References</li></ul>	1 5 15
Chapter Two Chemical Kinetics	
A. The Rates of Reactions and Their Temperature Dependency	16
B. Simultaneous Interdependent and Chain Reactions	20
C. Pseudo-First-Order Reactions	23
D. Pressure Effect in Fractional Conversion References	24 25
Chapter Three Explosive and General Oxidation	
Characteristics of Fuels	
A. The Criterion for Explosion	26
B. Explosion Limits and Oxidation Characteristics of Hydrogen	29
C. Explosion Limits and Oxidation Characteristics of Carbon Monoxide	34
D. Explosion Limits and Oxidation Characteristics of Hydrocarbons	37
1. Organic Nomenclature	38
2. Explosion Limits, Cool Flames, and General Mechanisms	41
3. Detailed Oxidation Mechanisms of Hydrocarbons	49
a. Methane	49
b. Aldehydes	51
c. Higner Paramn Hydrocarbons	52

d. Olefins e. Aromatics References	55 56 57
Chapter Four Flame Phenomena in Premixed Combustible Gases	
A. The Laminar Flame Speed	64
1. The Theory of Mallard and Le Chatelier	66
2. The Theory of Zeldovich, Frank-Kamenetskii, and Semenov	68
3. The Laminar Flame and the Energy Equation	75
4. Flame Speed Measurements	75
a. Bunsen Burner Method	79
b. Cylindrical Tube Method	80
c. Soap Bubble Method	81
d. Closed Spherical Bomb Method	82
e. Flat Flame Burner Method	82
5. Experimental Results and Physical and Chemical Effects	84
B. Stability Limits of Laminar Flames	87
1. Flammability Limits	87
a. Experimental Results and Physical and Chemical Effects	88

91

99

101

102

102

103

105

107

110

113

115

116

119

125

127

127

128

129

130

### 2. Determination of the Speed of Sound in the Burned Gases

1. Characterization of the Hugoniot Curve

2. Explosion, Deflagration, and Detonation

b. A Theoretical Approach

c. Analysis and Results

4. Stability Limits and Design

3. Flame Stabilization (Low Velocity)

1. Work of Damköhler and Schelkin

2. The Characteristic Time Approach

1. Premixed and Diffusion Flames

3. The Onset of Detonation

E. Flame Stabilization in High Velocity Streams

, 2. Quenching Distance

a. Flashback

D. Stirred Reactor Theory

Chapter Five Detonation

**B.** The Detonation Velocity

b. Blowoff

C. Turbulent Flames

References

A. Introduction

for Conditions above the Chapman-Jouguet Point

and the Uniqueness of the Chapman-Jouguet Point

a. Behavior of the Entropy along the Hugoniot Curve

3. Experimental Results and Physical and Chemical Effects

3. Calculation of the Detonation Velocity	
C. The Structure of the Detonation Wave	147
D. Comparison of Detonation Calculations with Experimental Results	150
E. Detonation Limits	153
References	157

## Chapter Six Diffusion Flames

А.	Gaseous Fuel Jets	158
	1. Appearance	159
	2. Structure	159
	3. Theoretical Considerations	161
	a. The Burke-Schumann Development	164
	b. Phenomenological Analysis and the Turbulent Fuel Jet	166
B.	Burning of Condensed Phases	168
	1. General Mass Burning Considerations and the Evaporation Coefficient	169
	2. Single Fuel Droplets in Quiescent Atmospheres	174
	a. Heat and Mass Transfer without Chemical	
	Reaction (Evaporation)—the Transfer Number B	176
	b. Heat and Mass Transfer with Chemical Reaction (Burning Rates)	181
C.	Burning in Convective Atmospheres	185
	1. The Stagnant Film Case	185
	2. The Longitudinally Burning Surface	187
	3. The Flowing Droplet Case	189
	4. Burning Rates of Plastics; The Small B Assumption and Radiation Effects	191
	References	102

#### Chapter Seven Ignition

А.	Concepts	194
B.	The Theory of Thermal Ignition	195
	1. The Stationary Solution—The Critical Mass and Spontaneous Ignition	
	Problems	196
	2. The Nonstationary Solution	1 <b>9</b> 8
	References	201

#### Chapter Eight Environmental Combustion Considerations

The Nature of Photochemical Smog	203
1. Primary and Secondary Pollutants	204
2. The Effect of $NO_x$	204
3. The Effect of $SO_x$	208
NO <sub>x</sub> Formation and Reduction	210
1. The Structure of the Nitrogen Oxides	211
2. The Effect of Flame Structure	211
3. Atmospheric Nitrogen Kinetics	213
4. Fuel-Bound Nitrogen Kinetics	219
	<ol> <li>The Nature of Photochemical Smog</li> <li>Primary and Secondary Pollutants</li> <li>The Effect of NO<sub>x</sub></li> <li>The Effect of SO<sub>x</sub></li> <li>NO<sub>x</sub> Formation and Reduction</li> <li>The Structure of the Nitrogen Oxides</li> <li>The Effect of Flame Structure</li> <li>Atmospheric Nitrogen Kinetics</li> <li>Fuel-Bound Nitrogen Kinetics</li> </ol>

	5. The Formation of NO <sub>2</sub>	223
	6. The Reduction of NO.	224
	7. The Partial Equilibrium Assumption	225
С.	SO, Emissions	227
	1. The Product Composition and Structure of Sulfur Compounds	228
	2. Oxidative Mechanisms of Sulfur Fuels	230
	a. H <sub>2</sub> S	231
	b. COS and CS <sub>2</sub>	233
	c. Elemental Sulfur	235
	d. Organic Sulfur Compounds	236
	e. Sulfur Trioxide and Sulfates	237
D.	Particulate Formation	240
	1. Characteristics of Soot	241
	2. Mechanisms of Soot Formation in Flames	243
	3. Influence of Physical and Chemical Parameters on Soot Formation	246
	4. Particulates from Liquid Hydrocarbon Pyrolysis	249
Е.	Stratospheric Ozone	249
	1. The HO, Catalytic Cycle	250
	2. The NO, Catalytic Cycle	251
	3. The CIO, Catalytic Cycle	254
	References	255

## Chapter Nine The Combustion of Coal

A. Diffusional Kinetics	258
B. The Burning Rate of Carbon	260
C. The Burning of Porous Chars	264
D. The Burning Rate of Ash-Forming Coal	267
References	260

Index