



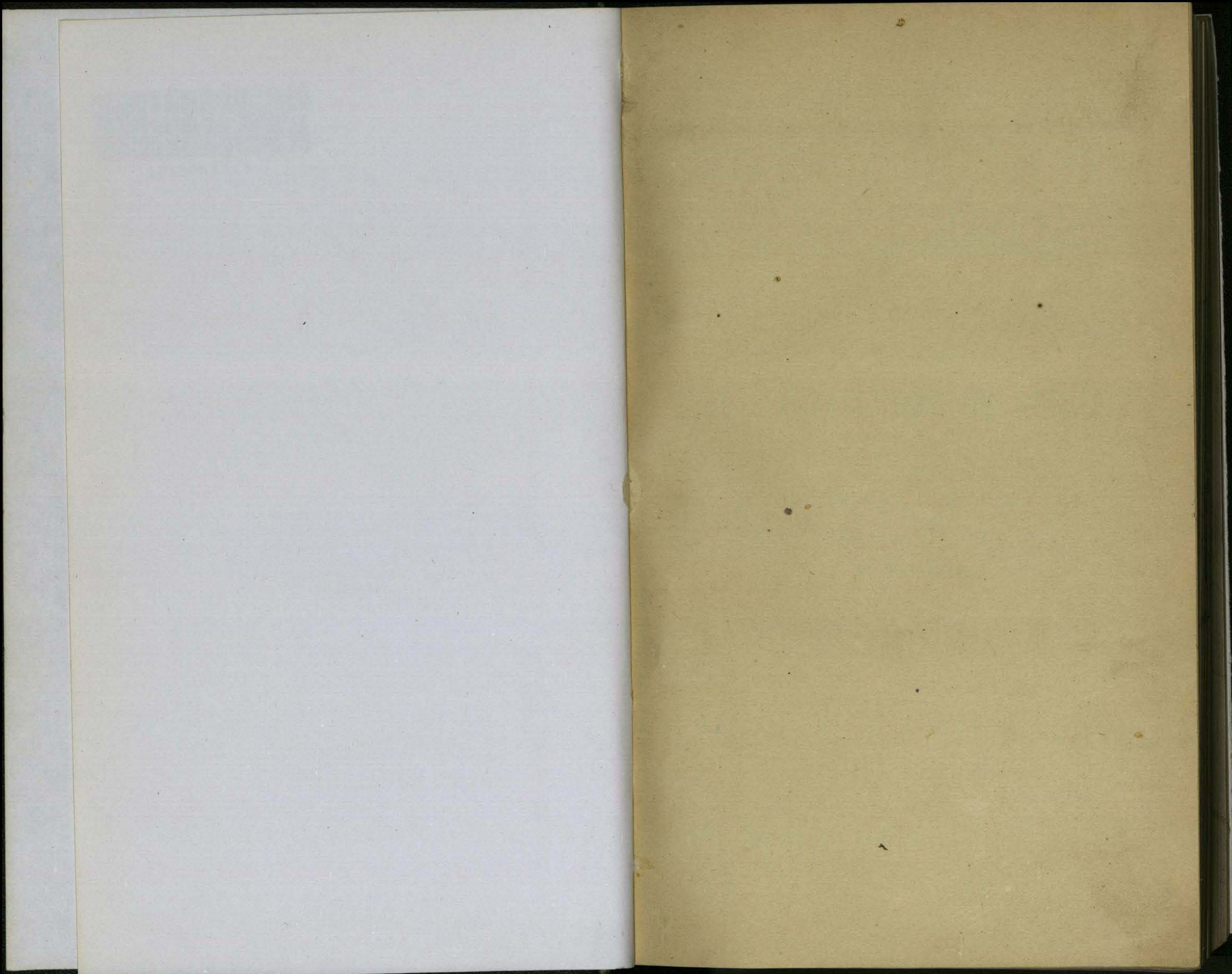
Harbord

THE METALLURGY
OF STEEL

TN730
H26
1916
v. 1



1020061217 /





THE METALLURGY OF STEEL.

VOLUME I.—METALLURGY.

BY

F. W. HARBORD.

NET BOOK.—This book is supplied to the Trade on terms which will not allow of Discount to the Public.

CHARLES GRIFFIN & COMPANY, LTD.

GRIFFIN'S METALLURGICAL SERIES.

- SCIENCE AND INDUSTRY: THEIR CO-OPERATION. By S. R. ILLINGWORTH, A.R.C.Sc., &c. In Pocket Size, Cloth, - 1s 0d
- AN INTRODUCTION TO METALLURGY. By Sir W. C. ROBERTS-AUSTEN, K.C.B., F.R.S., A.R.S.M. SIXTH EDITION, by F. W. HARBORD, A.R.S.M. net. 18s 0d
- THE METALLURGY OF GOLD. By Sir T. KIRKE ROSE, D.Sc., Chemist and Assayer to the Royal Mint. SIXTH EDITION, Revised and re-written, - net. 22s 6d
- THE METALLURGY OF SILVER. By H. F. COLLINS, Assoc.R.S.M., M.Inst.M.M. SECOND EDITION, - *In Preparation.*
- THE METALLURGY OF LEAD. An Exhaustive Treatise on the Manufacture of Lead. By H. F. COLLINS, Assoc.R.S.M., M.Inst.M.M. SECOND EDITION, Revised, - net. 21s 0d
- THE METALLURGY OF THE NON-FERROUS METALS. By WM. GOWLAND, F.R.S., Prof. of Metallurgy, Royal School of Mines, - net. 18s 0d
- THE METALLURGY OF STEEL. By F. W. HARBORD, Assoc.R.S.M., F.I.C., and J. W. HALL, A.M.Inst.C.E. FIFTH EDITION. In two volumes.
- THE METALLURGY OF IRON. By THOMAS TURNER, Assoc.R.S.M., F.I.C., Prof. of Met., Birmingham Univ. FOURTH EDITION, Revised and Enlarged. net. 16s 0d
- ALLOYS, AND THEIR INDUSTRIAL APPLICATIONS. By EDWARD F. LAW, A.R.S.M. SECOND EDITION, Revised, - net. 12s 6d
- SAMPLING AND ASSAY OF THE PRECIOUS METALS. By E. A. SMITH, A.R.S.M., - net. 15s 0d
- ANTIMONY: Its History, Chemistry, Mineralogy, Geology, Metallurgy, Preparation, &c. By C. Y. WANG. In Large Svo. Cloth, Illustrated, net. 12s 6d
- ROBERTS-AUSTEN: Addresses and Scientific Papers. By S. W. SMITH, - net. 21s 0d
- THE METALLURGY OF COPPER. By T. C. CLOUD, A.R.S.M. *In Preparation.*

OTHER METALLURGICAL WORKS.

- RAND METALLURGICAL PRACTICE. In Two Volumes.
Vol. I.—SECOND EDITION, net. 21s. Vol. II, - net. 21s 0d
- RESEARCHES ON SPECIAL STEELS. By Sir ROBERT HADFIELD. *In the Press.*
- PHYSICO-CHEMICAL PROPERTIES OF STEEL. By C. A. EDWARDS, M.Sc. *In the Press.*
- MODERN COPPER SMELTING. LECTURES ON. By D. M. LEVY, - net. 10s 6d
- CAST IRON IN THE LIGHT OF RECENT RESEARCH. By W. H. HATFIELD, B.Met. Profusely Illustrated, - net. 10s 6d
- CYANIDING GOLD AND SILVER ORES. By H. FORBES JULIAN and EDGAR SMART, A.M.Inst.C.E. SECOND EDITION, - net. 21s 0d
- THE CYANIDE PROCESS OF GOLD EXTRACTION. By Prof. JAMES PARK, F.G.S. FIFTH ENGLISH EDITION, - net. 8s 6d
- TEXT-BOOK OF ASSAYING. By J. J. BERINGER, F.I.C., F.C.S., and C. BERINGER, F.C.S. THIRTEENTH EDITION. Illustrated, - net. 10s 6d
- METALLURGICAL ANALYSIS AND ASSAYING. A Three Years' Course. By W. A. MACLEOD, B.A., B.Sc., and CHAS. WALKER, F.C.S., - net. 12s 6d
- MINERALOGY OF THE RARER METALS. By E. CAHEN and W. O. WOOTTON, - net. 6s 0d
- MICROSCOPIC ANALYSIS OF METALS. By FLORIS OSMOND and J. E. STEAD, F.R.S. SECOND EDITION. By L. P. SIDNEY, - net. 8s 6d
- METALLIC ALLOYS: Their Structure and Constitution. By G. H. GULLIVER, B.Sc., F.R.S.E. SECOND EDITION, Thoroughly Revised, - net. 10s 6d
- INTRODUCTION TO PRACTICAL METALLURGY. By Prof. T. TURNER, net. 3s 0d
- ELEMENTARY METALLURGY. By A. H. SEXTON, F.I.C. FOURTH EDN., - net. 6s 0d
- LECTURES ON IRONFOUNDING. By Prof. T. TURNER. SECOND EDITION, net. 3s 6d
- GENERAL FOUNDRY PRACTICE. By A. McWILLIAM, A.R.S.M., and PERRY LONGMUIR. In Medium Svo. SECOND EDITION, Revised, - net. 15s 0d
- NOTES ON FOUNDRY PRACTICE. By J. J. MORGAN, F.C.S., - net. 2s 6d
- BLAST FURNACE PRACTICE. By J. J. MORGAN, F.C.S., - net. 1s 6d
- ELECTRIC SMELTING AND REFINING. By Dr. W. BORCHERS and W. G. McMILLAN. SECOND EDITION, - net. 21s 0d
- TREATISE ON ELECTRO-METALLURGY. By W. G. McMILLAN and W. R. COOPER. THIRD EDITION, Revised, - net. 12s 6d
- THE VALUE OF SCIENCE IN SMITHY AND FORGE. By W. H. CATHCART. Prof. Notes by Dr. J. E. Stead and Dr. R. Barr, - net. 4s 0d

LONDON: CHARLES GRIFFIN & CO., LTD., EXETER STREET, STRAND.

THE METALLURGY OF STEEL.

BY

F. W. HARBORD, Assoc.R.S.M., F.I.C.,

FORMERLY CONSULTING METALLURGICAL AND ANALYTICAL CHEMIST TO THE INDIAN GOVERNMENT,
ROYAL INDIAN ENGINEERING COLLEGE, COOPERS HILL;

AND

J. W. HALL, Assoc.M.Inst.C.E.,

CONSULTING ENGINEER, BIRMINGHAM.

Fifth Edition, Enlarged and Revised.

With 54 Folding Plates, comprising 115 Figures, over 500 Illustrations in the Text, and nearly 80 Photo-micrographs of Steel Sections.

A VOLUME OF
GRIFFIN'S METALLURGICAL SERIES.



LONDON:
CHARLES GRIFFIN & COMPANY, LIMITED;
EXETER STREET, STRAND.

1916.

[All Rights Reserved.]

27433

86
669.16
H.
TU730
H26
1916
V.1



127457

PREFACE TO FIFTH EDITION.

SINCE the last edition appeared there has been no special development in the Manufacture of Iron and Steel which has had far reaching results on the industry, but there has been steady progress in details of practice. As far as possible these advances have been dealt with, and amongst them may be mentioned the Production of what is a very near approach to Chemically Pure Iron in the Basic Open-Hearth Furnace from Phosphoric Pig-Iron, and several methods for producing Sound Ingots and for decreasing Segregation.

The Chapter on Armour Plate Manufacture has been largely rewritten, and also the Chapter on the Theory of Hardening of Steel. In this last chapter Professor Carpenter has very kindly contributed a short summary of the various Stress Theories which have been advanced, with his own views on this subject. Constitutional Diagrams have been added for Special Steels.

In the second volume on the Mechanical Treatment of Steel, by Mr. J. W. Hall, little alteration has been necessary, as in the last edition a great deal was rewritten, and new chapters added dealing with all the more recent developments.

We have to thank Mr. C. O. Bannister, A.R.S.M., for reading the proofs of the first volume, for preparing the Index, and for seeing it to press.

TABLE OF CONTENTS.

VOLUME I.

§ I. THE MANUFACTURE OF STEEL.

INTRODUCTION, PAGES
1-3

CHAPTER I.

THE BESSEMER PROCESS.

The Converter—General Description of Process—The Modern Converter—
Rotating the Converter—Lining of the Vessel—Details of Bottom Section
—Replacing a Bottom Section—Repairing "Plug"—Materials for Lining
of Converters—Cupola Furnace—Position of Cupola—The Metal Mixer or
Receiver—Supply of Metal to Converter—Tipping Ladles—Blast for
the Converter—The Casting Ladle—The Casting Crane—Ingot Moulds—
Bottom Casting *versus* Top Casting—Ingot Cranes—Stripping the Ingots
—The "Ingot Stripper"—Stripping the Pit—Arrangement of Bessemer
Shop—Repouring Metal before Casting—Car Casting—Detailed Descrip-
tion of Process—Scrapping the Charge—Finishing the Charge—Casting—
Running Stoppers, 3-57

CHAPTER II.

THE BASIC PROCESS.

Introduction—The Thomas-Gilchrist Experiments—Basic Bessemer Plant—
The Lining of the Converter—Preparation of the Basic Material—Brick
Linings—Ramming the Linings—The Bottom Section and Plug—Dis-
position of Plant—Removal of Slag—Description of the Process—Sampling
the Metal—Addition of Ferro, Spiegel, &c., 58-68

CHAPTER III.

MANUFACTURE OF STEEL IN SMALL CONVERTERS.

Survival of the Small Converter—The Swedish Bessemer Process—The Clapp-
Griffiths Converter—The Robert Converter—The Walrand Legénisel
Process—Tropenas Process—The Stock Converter—Small Converters
considered generally, 68-79

CHAPTER IV.

CHEMISTRY OF THE ACID BESSEMER PROCESS.

General Considerations—Three Stages Involved—Production of Fume—Mass
Action in the Converter—The Function of the Slag—Composition of Pig
Iron—Low Silicon and High Manganese Pig Iron—Low Silicon and Low
Manganese Pig Iron—High Silicon and Low Manganese Pig Iron—High
Silicon and High Manganese Pig Iron, 79-91

CHAPTER V.

CHEMISTRY OF THE BASIC BESSEMER PROCESS.

	PAGES
Acid and Basic Process Contrasted—Pig-Iron Requirements for Basic Practice—Purity of the Lime—Oxidation of Impurities—Silicon and Manganese—Sulphur and its Elimination—Phosphorus—Rephosphorisation of Metal on Addition of Spiegel, etc.—Re-carburisation in the Basic Bessemer Process—Effect of Oxide Additions—Thermo-Chemistry of the Acid and Basic Bessemer Processes,	92-111

CHAPTER VI.

GAS PRODUCERS.

Theory of the Gas Producer—Description of Producer—Chemical Reactions in the Producer—Classification of Producers—The Siemens Original Producer—Modern Producers—The Siemens Producer (Modern Type)—Wilson Producer—Dawson Producer—Duff Producer—Mond Producer—Mechanical Producers—Talbot Producer—Hughes Producer—Kerpely Producer—Rehmann Producer—Fuel for Producers—Charging Fuel in Producers—Efficiency of Producers—Calorific Power of Gases—Taking Samples—Water Gas—Natural Gas,	112-140
---	---------

CHAPTER VII.

THE OPEN HEARTH OR SIEMENS PROCESS.

General Description of Furnace—The Furnace—The Maerz Port—The Regenerators—Dust Catchers—The Tilting Furnace—The Campbell Furnace—The Wellman Furnace—Valves—The Chimney—Position of Producer—Drying the Furnace—The Furnace Lining—The Acid Open Hearth Process—Making Hearth and Tapping-Hole—Charging and Starting the Furnace—Mechanical Chargers—The Wellman Charging Machine—Broadbent Overhead Charging Machine—Working the Charge for Dead Soft Steel—Tapping the Charge—Precautions to be observed—The Ladle—Cranes for Ingot Stripping—Repairing the Bottom—Reactions in the Acid Siemens Process—Elimination of Impurities—Composition of Slag—Sulphur in Producer Gas—Axle, Tire, Spring Steel, etc.,	140a-180
---	----------

CHAPTER VIII.

BASIC SIEMENS PROCESS.

Early Practice—The Batho Furnace—Lining the Furnace—Preparing the Hearth—Details of Working—Pig-Iron and Scrap—Considerations respecting Slag—Manufacture of High Carbon Steel in Basic Siemens Furnace—Darby Recarburising Process—The Elimination of Sulphur—The Saniter Process—Hematite and Low Phosphorus Pig-Iron—Production of Pure Iron in Basic Open Hearth from Phosphoric Iron—The Talbot Washing Process—Krupp's Dephosphorising Process—Modifications of Open Hearth Practice—Bertrand-Thiel Process—The Talbot Continuous Process—The Twynam Process—The Monell Process—Duplex Process—Heat Developed by Oxidation of Metalloids in Siemens and Allied Processes—General Arrangement of Open Hearth Melting Shop—Comparison of Bessemer and Open Hearth Processes—Quality of Metal Produced—Yield of Metal—Cost of Acid and Basic Processes—Comparison as to Cost—Dr. Schuster's Conclusions—Selection of Process—Tables illustrating Reactions occurring under Different Conditions of Basic Open Hearth Practice and in the Bertrand-Thiel and Talbot Processes—Analyses of Pig-Irons suitable for Manufacture of Steel by the Bessemer and Open Hearth Processes—Typical Analyses of Steels from Bessemer and Open Hearth Processes—Analyses of Refractory Materials used for Bessemer Converters and Siemens Furnaces—Materials for Siemens Furnaces—Basic Materials,	180-233
---	---------

CHAPTER IX.

THE PRODUCTION OF STEEL CASTINGS.

	PAGES
Steel Employed—Description of Moulds—"Green Sand" Moulds—"Dry Sand" Moulds—Internal Stresses in Castings—Annealing the Castings,	233-240

CHAPTER X.

THE PRODUCTION OF SHEAR AND CRUCIBLE STEEL.

The Cementation Process—Grades of Cement Bars—Micro-structure of Cement Bars—Aired Bars—The Origin of the Blisters—The Diffusion of the Carbon—Spring Steel—Shear Steel—Case-Hardening—Cast or Crucible Steel—Pot Melting—Methods of Manufacture—Melting the Steel—Treatment of Ingots—Temper of Cast Steel—Chemistry of the Process—Gas-fired Crucible Furnaces,	241-260
---	---------

CHAPTER XI.

ELECTRIC SMELTING OF STEEL.

The Induction Furnace—The Kjellin Furnace—The Röchling-Rodenhauser Furnace—The Arc-Resistance Furnace—The Héroult Process—The Keller Process—The Girod Furnace—The Grönwal Furnace—The Ruthenburg Furnace—The Gin Furnace—The Giffre Furnace—The Stassano Furnace—The Removal of Phosphorus and Sulphur—Manufacture of Steel in Different Furnaces—General Conclusions,	261-283
---	---------

CHAPTER XII.

ARMOUR PLATE MANUFACTURE.

Varieties of Armour Plate—Krupp-Harveyised Plates—Cast Armour Plate—Materials Employed—Wilson's Compound Armour Plates,	284-290
---	---------

CHAPTER XIII.

DIRECT PROCESSES OF STEEL MANUFACTURE.

Difficulties Involved—Native Forge or Bloomery Processes—Wootz or Indian Steel—Puddled Steel—The Catalan Process—The American Bloomery Process—Stückenof (The Old High Bloomery)—Chenot's Process—Blair's Process—Eames Process (Carbon Iron Company's Process)—Siemens Process,	291-295
--	---------

§II. FINISHED STEEL.

CHAPTER XIV.

MECHANICAL TESTING OF MATERIALS.

Tensile Strength—Elastic Limit—Modulus of Elasticity (Young's Modulus)—Elongation—Reduction of Area—Yield Point—Stress Diagrams—Testing Machines—Wicksteed Testing Machine—Adamson Machine—Calibrating Testing Machine—The Test Piece—The Shape and Form of Test Piece—Gauging the Test Piece—Testing the Specimen—Extensometers—The Measurement of Specimens after Fracture—Compression Tests—Ordinary Transverse and Shearing Tests—Variation in Strength of Specimens from	
---	--

	PAGES
same Plate, Bar, etc.—Hardness Tests—Impact Tests—Alternate Bending and Impact Testing—Arnold Alternating Test Machine—Sankey Testing Machine—Working the Machine—Calibration—Test for Welding and Hot Working—Testing Rails, Axles, etc.—Tire Testing—Springs,	297-340

CHAPTER XV.

CARBON AND IRON.

The Direct Combination of Iron and Carbon—Limits to the Amount of Carbon taken up by Iron—Conditions of Carbon in Iron—Graphitic Carbon—Cement Carbon—Hardening Carbon—Temper Carbon—Influence on Physical Properties—Influence on Tensile Strength—Influence of Carbon on Hardening—Influence on Magnetic Properties—Constitution of Steel—The Solution Theory—The Allotropic Theory—The Carbon and Sub-Carbide Theories—Stress Theories,	341-365
--	---------

CHAPTER XVI.

THE INFLUENCE OF SI, S, P, Mn, As, Cu, Sn, Sb, &c., ON THE PHYSICAL PROPERTIES OF STEEL.

Silicon and Mild or Low Carbon Steel—Silicon and Medium and High Carbon Steels—The Influence of Sulphur—The Influence of Phosphorus—The Influence of Manganese—The Influence of Arsenic—The Influence of Copper—The Influence of other Elements—Antimony—Bismuth—Calcium—Tin—Zinc—Segregation—Occlusion of Gases by Iron and Steel—Prevention of Blowholes, Pipes and Cracks in Ingots—The Hadfield Method of Producing Sound Ingots—The Talbot Method of Producing Sound Steel, . 365a-393	365a-393
---	----------

CHAPTER XVII.

SPECIAL STEELS OR STEEL ALLOYS.

Aluminium Steel—Boron Steel—Chromium Steel—Cobalt Steels—Manganese Steel—Molybdenum Steel—Nickel Steel—Nickel and Chromium Steel—Tantalum Steel—Titanium Steel—Tungsten Steel—Uranium Steel—Vanadium Steel—High-Speed Tool Steel,	393-426
---	---------

CHAPTER XVIII.

HEAT TREATMENT OF STEEL.

Annealing—Hardening—Tempering—Changes of Structure brought about by Heat Treatment—Pyrometers,	428-448
--	---------

CHAPTER XIX.

MICROSCOPICAL EXAMINATION OF STEEL.

Preparation of Samples—Sorby's Method—Osmond's Method—Roberts-Austen's Method—Arnold's Method—Martens' Method—Stead's Method—Ewing and Rosenhain's Methods—H. le Chatelier's Methods—Sauveur's Method—The Author's Method—Development of Structure—Nitric Acid Etching—Iodine Etching—Etching with Picric Acid—Other Methods of Etching—Microscopic Apparatus—Microscopic Accessories—Microscopic Examination—Examination for Mechanical Defects—Examination for Size of Grain—Examination to Determine Microstructures—Ferrite—Cementite—Pearlite—Martensite—Sorbite—Troostite—Osmondite—Austenite—Sampling for Micro-Examination,	449-469
---	---------

	PAGES
TYPICAL STEEL PLANTS,	470
PHOTO-MICROGRAPHS,	471-490

APPENDICES.

I. SPECIFICATIONS:—American Standard Specifications—Railway—Bridge Material—Castings, &c.—British Standard Specifications—Rails—Axles—Tires—Tables giving Summary of Various British Standard Specifications,	491-515
II. TABLE SHOWING RELATION OF PERCENTAGE OF CARBON TO TENSILE STRESS,	516
III. TONS AND LBS. PER SQUARE INCH COMPARED WITH KILOGRAMMES PER SQUARE MILLIMETRE,	517-521
IV. RAPID DETERMINATION OF PHOSPHORUS AND MANGANESE,	522
INDEX,	i-xxix

LIST OF PLATES AND ILLUSTRATIONS.

VOLUME I.

	PAGE
Fig. 1. Original Bessemer Converter,	4
" 2, 3. Early Types of Converter,	4
" 4-6. " " " "	5
" 7-10. Modern Converters,	PLATE I., to face 6
" 11. Hydraulic Racking Gear for Converter,	7
" 12. Converter Ready for Ramming,	8
" 13. Core for Ramming Converter,	9
" 14. Bottom Section of Converter,	10
" 15. Bottom Plate of Converter,	10
" 16, 17. Twyer Brick for Bottom of Converter,	10
" 18. Method of Inserting Plug in Bottom Section,	11
" 19. " Holding " "	12
" 20. Modern Cupola,	14
" 21. " with Wellman Charging Machine,	15
" 22. Metal Mixer,	16
" 23-26. Plan, Section, and Elevation of Metal Mixer,	17, 18
" 27-29. " Hot Metal Ladle,	22, 23
" 30-32. Details of Casting Ladle,	24, 25
" 33, 34. Details of Sleeves and Nozzle for Casting Ladle,	26
" 35. Details of 40-ton Casting Ladle,	27
" 36. Hydraulic Centre Casting Crane,	29
" 37, 37a. Teeming Steel into Ingot Moulds,	30
" 38-41. Details of Ingot Moulds,	30-34
" 42. Bottom Casting,	35
" 43. Closed Top Ingot Mould,	36
" 44-48. Turner's Method of Casting Small Ingots,	PLATE II., to face 36
" 49. Bottom-supported Ingot Crane,	38
" 50, 51. Top-supported Ingot Crane,	39, 40
" 52-54. Plan and Elevations of Evans Ingot Stripper,	42, 43
" 55. Wellman's Electric Ingot Stripper,	45
" 56, 57. Stripping Attachment,	46
" 58. Guided Ingot Stripper,	47
" 59. Details of Guided Ingot Stripper,	48
" 60. Old Arrangement of Bessemer Casting Pit,	49
" 61, 62. General Arrangement of Bessemer Plant,	PLATE III., to face 50
" 63. Plan of Basic Bessemer Shop,	51
" 64. Section through Cambria Bessemer Shop,	51
" 65, 66. Plan and Elevations of Car Pusher,	53, 54
" 67, 68. Barrow Bessemer Shop,	PLATE IV., to face 54
" 69. Iron Mould for Basic Bricks,	61

LIST OF PLATES AND ILLUSTRATIONS.

xiii

	PAGE
Fig. 70, 71. Details of Casing, &c., for Basic Plug,	63
" 72. Method of Inserting Basic Plug in Bottom Section of Converter,	64
" 73. Hatton Fixed Converter,	72
" 74. Robert Converter,	73
" 75. Walrand Legénisiel Converter,	75
" 76, 77. Tropenas Converter,	77
" 78. Diagram showing Removal of Impurities during Acid Bessemer Blow,	80
" 79. " Composition of Gases at Different Periods,	80
" 80-85. Diagrams illustrating Removal of Impurities during Acid Bessemer Blow under Different Conditions of Working,	84-91
" 86. Diagram showing Removal of Impurities during Basic Blow,	94
" 87. " " Phosphorus during Basic Blow,	100
" 88. Original Siemens Producer,	116
" 89. Modern Siemens Producer,	117
" 90-92. Wilson Producer,	118, 119
" 93. Section through Air Distributor and Water Bottom, Wilson Producer,	120
" 94. Mechanical Feed for Producer,	120
" 95-100. Dawson Gas Producer,	PLATE V., to face 121
" 101-103. Duff Gas Producer,	PLATE VI., to face 121
" 104. Mond Gas Producer,	122
" 105. " with Ammonia Recovery Plant,	123
" 106. Talbot Producer,	125
" 107. Hughes Producer,	126
" 108. Kerpely Producer,	128
" 109. Rehmann Producer,	128
" 110. Bildt Automatic Feed for Gas Producer,	130
" 111. Diagram showing Variations in Temperature of Producer Gas,	136
" 112. Dellwik-Fleischer Water-Gas Plant,	138
" 113. Old Form, Siemens Furnace,	141
" 114. Sketch showing Position of Gas and Air Ports in Open Hearth Furnace,	141
" 115-120. Siemens Regenerative Furnace,	PLATE VII., to face 142
" 121, 122. Sketches showing Position of Gas and Air Ports in Open Hearth Furnace,	142, 143
" 122a. Open Hearth Furnace "Block,"	144
" 122b. The Maerz Port,	145
" 123-126. Basic Open Hearth Furnace,	PLATE VIII., to face 146
" 127-130. Modern 40-ton Basic Open Hearth Furnace,	PLATE IX., to face 147
" 131. Campbell Tilting Furnace in Normal Position,	148
" 132. " " Position when Pouring,	149
" 133, 134. 50-Ton Wellman Furnace,	PLATE X., to face 150
" 135, 135a. Sketch illustrating Butterfly Reversing Valve,	150
" 136, 136a. Plan and Section of Butterfly Reversing Valve,	151
" 137, 138. Details of Kirkham Valve,	152
" 139. Hollow Disc Reversing Valve,	152
" 140. Hall Reversing Valve,	153
" 141. Wailes Siphon Reversing Valve,	154
" 142. " Water-Seal Reversing Valve,	155
" 143. Mills Water-cooled Reversing Valve,	156
" 144. Section through Hearth of Acid Siemens Furnace,	159
" 145, 146. Peels for Siemens Furnace,	160
" 147. Wellman Charging Machine,	161

	PAGE
Fig. 148. Low Ground Wellman-Seaver Charging Machine,	162
" 149. Overhead Wellman-Seaver Charging Machine,	162
" 150. Broadbent Overhead Charging Machine,	PLATE Xa., to face 162
" 151, 152. Casting Ladle for Siemens Furnace,	165
" 153, 153a. Electric Overhead Crane,	PLATE XI., to face 166
" 154. Travelling Crane for Steel Works,	166
" 155. Sketches of Tools used at Siemens Furnace,	167
" 156. Ingot Moulds for Tire Blanks,	178
" 157. Bottom Plate for Tire Ingot Moulds,	179
" 158, 159. Batho Furnace,	181
" 160-163. Sketches illustrating Lining of Basic Open Hearth Furnaces,	182, 183
" 164. Darby Recarburising Apparatus,	190
" 165-168. Bertrand-Thiel Plant,	PLATE XII., to face 200a
" 169. 250-Ton Talbot Furnace,	PLATE XIIa., to face 202
" 170-173. Tilting Furnace adapted for Talbot Process,	PLATE XIII., to face 202
" 174-175. Talbot 200-Ton Plant,	PLATE XIV., to face 202
" 176. General Arrangement of Homestead Siemens Melting Shop, 1890,	208
" 177. " Pencoyd Siemens Melting Shop,	209
" 178. Wellman Furnace with Casting Ladle,	209
" 179, 180. Homestead Plant,	PLATE XV., to face 210
" 181. Sectional Elevation of New Plant at Bethlen-Falva Works,	211
" 182. Transverse Sectional Elevation of Georgsmarienhutte Open Hearth Plant,	212
" 182a. Elevation of Scrap, Melting, and Casting Shops at the New Works at Witkowitz,	PLATE XVa., to face 212
" 182b. Longitudinal Section and Elevation of 200-ton Talbot Furnace erected at Witkowitz,	PLATE XVb., to face 216
" 182c. Cross-section of the 200-ton Talbot Furnace erected at Witkowitz,	PLATE XVc., to face 216
" 183, 184. Cementation or Converting Furnace,	241, 242
" 185. Crucible Steel Furnace,	251
" 186. Sketches illustrating Manufacture of Crucibles,	253
" 187. Crucibles as used in Sheffield,	253
" 188. Dawson, Robinson, and Pope Gas Crucible Steel Furnace,	259
" 189-191. New Form Siemens Crucible Furnace,	PLATE XVd., to face 260
" 192, 193. Kjellin Furnace,	262
" 194-196. Röchling-Rodenhauer Furnace,	265, 266
" 197. Héroult Furnace,	267
" 198. Keller Furnace,	270
" 199. Girod Furnace,	272
" 200-203. Grönwal Furnace,	273, 274
" 204. Ruthenburg Furnace,	275
" 205. Stassano Furnace,	278
" 206-209. Carburising Furnace for Armour Plates,	285, 287
" 210. Stress-Strain Diagram Curve,	301
" 211. Sketch illustrating the Principles of the Wicksteed Testing Machine,	303
" 212. Wicksteed Testing Machine (Bradford College),	304
" 213, 214. Compression Tests in Wicksteed Testing Machine,	306
" 215. Adamson Lever Testing Machine,	308
" 216. Gripping-Box in Adamson Lever Testing Machine,	309
" 217. Different Shapes of Test Bars,	311
" 218. Sketches of Kirkaldy's Test Pieces,	312

	PAGE
Fig. 219. Screw Micrometer Gauge,	313
" 220, 221. Test Bars before and after Fracture,	314, 315
" 222-224. Compression Tests,	317
" 225. Shearing Test,	318
" 226. Brinell Testing Machine,	320
" 227, 228. Arnold Alternating Test Machine,	324, 325
" 229, 230. Sankey Alternate Bending Machine,	326
" 231. Welding and Drifting Tests,	328
" 232. Plating-out Test for Red-shortness,	328
" 233, 234. Drop Testing Apparatus for Axles,	330
" 235, 236. Testing of Axles,	332
" 237. Tire after Drop Testing,	332
" 238-240. Drop Testing Machine for Tires,	334, 335
" 241. Spring Scragging Machine,	337
" 242-246. Springs before and after Testing,	338
" 247. Spring Testing Machine,	338
" 248. Diagrams showing the Influence of Carbon on Tenacity of Steels,	347
" 249. Diagram showing the Influence of Carbon on Ductility of Steels,	348
" 250. Freezing Curve of Solution of Common Salt,	354
" 251. " Copper-Silver Alloys,	356
" 252. Curve showing Separation of Iron and Carbide during the Cooling of Carbon Steels,	357
" 253-258. Microstructure of Copper-Silver and Iron Carbide Alloys,	PLATE XVI., to face 358
" 258a. Apparatus employed by Hadfield for producing Sound Ingots,	388
" 258b. Ingots made by Hadfield System and in Ordinary Manner,	389
" 258c. Illustrating Hadfield Method of Casting,	389
" 258d. Sections of Ingots illustrating Talbot Method of producing Sound Steel,	391
" 258e. Section of Rail made by Talbot Method,	392
" 258f. Constitutional Diagram of Chromium Steels,	397
" 258g. " " Manganese Steels,	400
" 258h. " " Nickel Steels,	408
" 259. Changes of Microstructure brought about in Steel by Heat Treatment,	PLATE XVII., to face 432
" 260. Baird and Tatlock Pyrometer,	442
" 261. Photographic Curve from Baird and Tatlock Pyrometer,	443
" 262. Iron Tube containing Thermo-couple for Baird and Tatlock Pyrometer,	443
" 263. Diagram indicating Arrangements for obtaining Differential Curves,	444
" 264. Féry Radiation Pyrometer Telescope,	446
" 265. Féry Radiation Pyrometer,	447
" 266, 267. Stead's Polishing Apparatus,	452
" 268-270. Sorby-Beck Reflector,	457
" 271. Stead's Illuminator,	458
" 272, 273. Beck's Illuminator,	458
" 274, 275. Zeiss Illuminator,	458
" 276. Photo-micrographic Plant,	459
" 277. Photo-micrograph of Ferrite,	461
" 278-280. " Cementite,	462
" 281. " Pearlite,	463
" 282. " Martensite,	463

	PAGE
Fig. 283. Photo-micrograph of Austenite,	464
" 284. Diagrammatic Illustration of Microstructure,	PLATE XVIII., to face 464
" 285, 286. Photo-Micrographs of "Burnt Steel,"	468
" 287. Plan of North-Eastern Basic Bessemer Steel Plant,	PLATE XIX., to face 470
" 288. Plan of Frodingham Basic Open Hearth Steel Works,	PLATE XX., to face 470
" 289. Plan of the New Gary Steel Plant,	PLATE XXI., to face 470
" 289a. Plan of the Normanby Park Steel Works,	PLATE XXIa., to face 470

PHOTO-MICROGRAPHS.

Nos. 1-5. .16 per cent. Carbon Steel \times 100,	472
" 6-10. .16 " " \times 1,000,	473
" 11-15. .47 " " \times 100,	474
" 16-20. .47 " " \times 1,000,	475
" 21-25. .89 " " \times 100,	476
" 26-30. .89 " " \times 1,000,	477
" 31-35. 1.12 " " \times 100,	478
" 36-40. 1.12 " " \times 1,000,	479
" 41. 1.50 " " as cast \times 100,	480
" 42-43. 1.50 " " annealed \times 1,000,	480
" 44. Steel Casting, as cast \times 100,	481
" 45. " annealed \times 100,	481
" 46. .328 per cent. Carbon Steel, as cast \times 100,	482
" 47. .328 " " annealed \times 100,	483
" 48-53. Effect of Heat Treatment,	484, 485
" 54-57. Influence of Prolonged Heating on Size of Grains,	486, 487
" 58-60. Oil-tempered Axles,	488
" 61-64. Effect of Finishing Temperature on Size of Grains,	489
" 65-66. Sections from Steel Rails,	490
" 67. Cement Bar, showing Pearlite and Cementite,	490

THE METALLURGY OF STEEL.

SECTION I.

INTRODUCTION.

DURING the last sixty years the introduction of the Bessemer and Open Hearth processes have not only revolutionised the steel manufacture of the world, but have compelled us to revise our definition of steel. Before 1856, the year in which Bessemer first published the particulars of his great discovery, there were practically only two varieties of steel in the market—viz., crucible or cast steel, and shear steel—although small quantities of puddled steel and steel made direct from the ore were produced.

Crucible or cast steel was made by melting blister steel bars containing different percentages of Carbon, according to the grade required, with small percentages of steel scrap in crucibles, and casting the fluid metal into small iron moulds, the ingots thus obtained being afterwards forged down to the required size and shape. The percentage of Carbon in such steels usually varied from .25 to 1.75, although sometimes it was higher. Shear steel was made by piling and welding together plated, cemented, or blister bars into what was known as a "faggot," and afterwards forging and rolling this faggot down into thin strips, suitable for the manufacture of cutlery.

The distinguishing features of these classes of steels were, that by rapid cooling from a red heat by quenching in water, they became extremely hard and more or less brittle, and that by re-heating to different temperatures, or "tempering," this hardness could be modified, the brittleness removed, and great elasticity, combined with varying degrees of hardness conferred upon the steel. The maximum degree of hardness which each steel was capable of taking depended upon the Carbon content, the higher the percentage of Carbon, the greater the hardening power of the steel; and the use of crucible and shear steel was practically confined to the manufacture of cutlery, tools, etc., and some special parts of machines which required a material which could be hardened after it had been forged or machined into shape. For structural purposes wrought iron and cast iron were the materials almost, if not quite, exclusively employed, the former possessing properties which enabled it to be wrought or forged into any required shape, and the latter being moulded into different forms by pouring it, while in a molten condition, into moulds of the required shape. The chief distinction between wrought iron and steel was that the former was not hardened by rapid cooling in water from a red heat, and contained always less than 0.20 per cent. of Carbon, and generally less than 0.10. Cast iron, on the other hand, contained from 2.5 to 4.0 per cent. of Carbon, and was distinguished from both steel and wrought iron by being brittle at a red heat, and incapable of being wrought or forged, and by having a comparatively low melting point of from 1,075° to 1,276° C., against 1,500° C., or higher, for wrought