

ELECTRICAL ENGINEERING

BY E. E. KIMBERLY, PROFESSOR OF ELECTRICAL
ENGINEERING, THE OHIO STATE UNIVERSITY

THIRD EDITION

INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PENNSYLVANIA

COPYRIGHT, 1951, 1946, 1939, BY THE
INTERNATIONAL TEXTBOOK COMPANY
COPYRIGHT IN GREAT BRITAIN

PRINTED IN THE UNITED STATES OF AMERICA

*All rights reserved. This book, or parts thereof,
may not be reproduced in any form without
permission of the publishers.*

FIRST EDITION

First Printing June, 1939

Second Printing January, 1940

SECOND EDITION

First Printing July, 1946

Second Printing January, 1947

Third Printing March, 1948

THIRD EDITION

First Printing January, 1951

THE HADDON CRAFTSMEN, INC.
SCRANTON, PENNSYLVANIA

48705

Preface for Third Edition

This book is written especially for engineering college students who are not majoring in electrical engineering and also for those who are majoring in electrical communication.

The beginning portion contains enough single-phase, polyphase, and transient circuit analysis to enable the student to understand the more common types of industrial electrical machinery as described in the middle half and also to understand the more common elements of electronic industrial control described in the last portion. It is believed that the contents are sufficient to give a "non-electrical" engineer a good foundation or working knowledge of all electrical apparatus that he is likely to use. It should enable him to speak and understand the language of the electrical engineer.

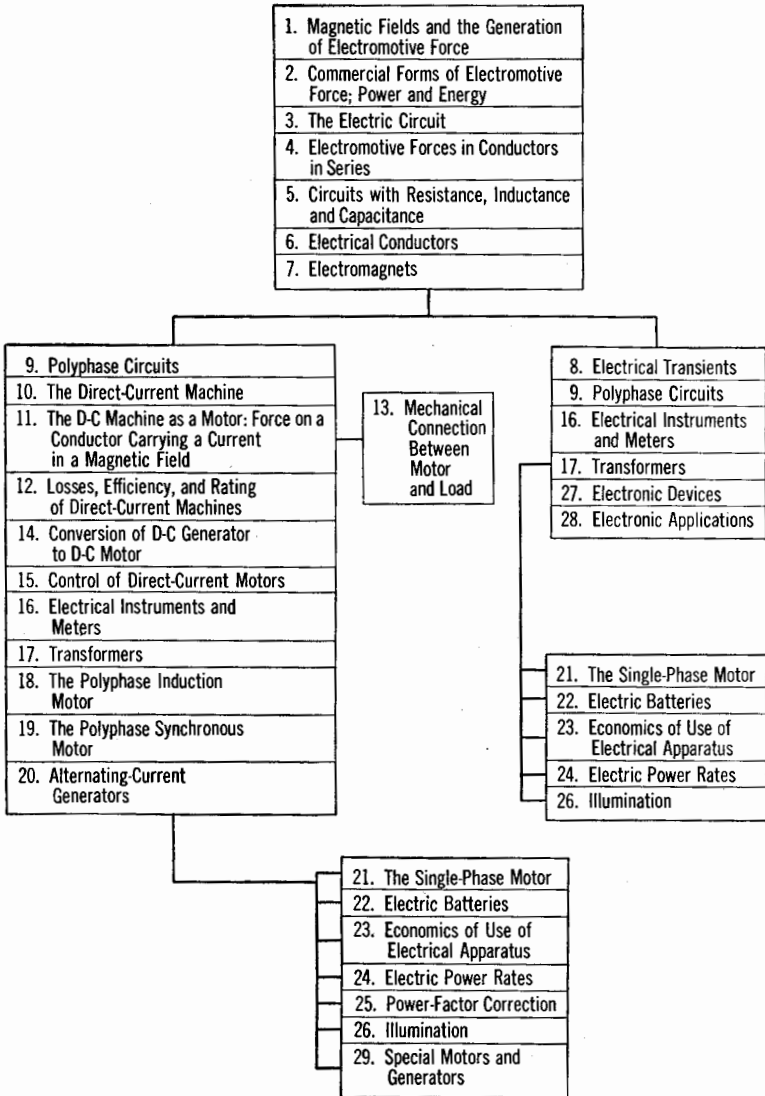
Furthermore it is believed that an electrical engineer whose major interest is communication will find about all of the working knowledge of power machinery that he is likely to need in his chosen specialty.

The choice of material is also intended to provide an introductory course for electrical engineers where that course will be followed by more detailed courses. The pace is set to enable the instructor to start laboratory assignments almost immediately after the first lecture.

Inasmuch as it may be desirable to omit some parts of the content to accommodate a foreshortened course, a flow sheet has been added to show chapters that must be studied in sequence and others that may be interspersed as laboratory progress permits.

E. E. KIMBERLY

FLOW SHEET



Contents

	PAGE
Preface	v
Introduction	xiii
The Structure of Matter—Static Electricity—Dynamic Electricity—Conductors and Insulators—Sources of Electromotive Force.	
Chapter 1—Magnetic Fields and the Generation of Electromotive Force	1
Magnetic Field—Electromotive Force Produced by Motion—Fleming's Right-Hand Rule—Electromotive Force Produced by Change of Flux Linkages—Magnetic Field About a Conductor Carrying Current—The Ampere—Electrical Resistance—Ohm's Law.	
Chapter 2—Commercial Forms of Electromotive Force; Power and Energy	7
Instantaneous Values of Electromotive Force—Joule's Law—Power—Energy.	
Chapter 3—The Electric Circuit	12
Application of Ohm's Law—Voltage Rise and Voltage Drop—Comparison of Direct and Alternating Current—Alternating Currents in Resistive Circuits—Resistors in Series—Resistors in Parallel—Three-Wire Circuits—Kirchhoff's Laws—Network Solutions—Voltage Drop of Two-Wire and Three-Wire Systems—Effect of Fuse or Circuit Breaker in Middle Wire.	
Chapter 4—Electromotive Forces in Conductors in Series	22
Use of Vectors—Phase Displacement—Addition of Voltages With Phase Displacement—A More Convenient Notation—The Polar Form of Vector Representation—Exponential Form of Vector Representation.	
Chapter 5—Circuits With Resistance, Inductance, and Capacitance	29
Inductance—Mutual Inductance—Inductive Reactance—Circuits With Resistance and Inductive Reactance—Series Circuit of More Than One Part With Resistance and Inductance—Parallel Circuits With Resistance and Inductance—Conductance, Susceptance, and Admittance—Capacitance—Alternating Voltage Applied to a Condenser—Capacitive Reactance—Series Circuits With Resistance and Capacitance—Parallel Circuits With Resistance and Capacitance—Series Circuits With Resistance, Inductance, and Capacitance—Parallel Circuits With Resistance, Inductance, and Capacitance—Instantaneous and Average Power in a Circuit With Resistance Only—Power in a Circuit With Resistance and Inductance—Measurement of Power and Power Factor—The Kv-a Vector Diagram—Effective Resistance.	

	PAGE
Chapter 6—Electrical Conductors.....	53
Resistance of Conductor—Wire Gages—Change in Resistance With Change in Temperature—Economical Size of Wire.	
Chapter 7—Electromagnets.....	57
Magnetic Circuit—Magnetomotive Force—Permeability and Saturation of Iron—Series Magnetic Circuits—Parallel Magnetic Circuits—Hysteresis—Permanent Magnets—Eddy Currents—Energy Stored in a Magnetic Field—Application of Magnets—Pull of Magnets and Solenoids—The Shading Coil.	
Chapter 8—Electrical Transients.....	73
Direct-Current Transients—Current Transient in a Purely Inductive Circuit—Current Transient When <i>RL</i> Circuit Is Closed—Time Constant of the <i>RL</i> Circuit—Storage of Electromagnetic Energy—Transient in an <i>RC</i> Circuit—Energy Stored in a Condenser—Discharge of a Condenser in an <i>RC</i> Circuit—Transients in Alternating-Current Circuits—Circuit With Resistance Only—Circuit Containing Inductance Only—Circuit With Inductance and Resistance Only—Circuit With Capacitance Only—Circuit With Resistance and Capacitance Only.	
Chapter 9—Polyphase Circuits.....	88
Classes of Circuits—The Use of the Double Subscript—Three-Phase Circuits—Phase Sequence—Electromotive Forces in a Delta-Connected System—The Balanced Three-Phase Wye-Connected Load—The Balanced Three-Phase Delta-Connected Load—Combined Delta and Wye Loads—Power in Three-Phase Circuit by Three-Wattmeter Method—Measurement of Three-Phase Power by Two-Wattmeter Method—Interpretation of Wattmeter Readings in Two-Wattmeter Method—Phase Sequence Indicator—Three-Phase <i>Kv-a</i> and Power Factor—The Three-Phase, Four-Wire System—Choice of Methods of Measuring Three-Phase Power.	
Chapter 10—The Direct-Current Machine.....	104
Types of Direct-Current Machines—Armature of Direct-Current Generator—The Commutator—The Elementary Generator—Brushes—Windings—Lap Winding—Wave Winding—Field Structure—Field Excitation of Shunt Generator—Building up Voltage of a Self-Excited Generator—Calculation of Electromotive Force in a Generator—Performance of a Shunt Generator—Other Limits of Power Output—Voltage Regulation—Operation at Voltages Above or Below Rated Voltage—Operation at Speeds Above or Below Rated Speed—The Compound Generator—The Series Generator—Armature Reaction—Calculation of Armature Reaction—Interpoles—Change in Characteristics—Parallel Operation of Compound Generators—Calculation of Series-Field Turns for Compounding a Shunt Generator—Effect of Brush Shift—Commutator Wear.	
Chapter 11—The D-C Machine as a Motor: Force on a Conductor Carrying a Current in a Magnetic Field.....	128
Lenz's Law—Simultaneous Application of Faraday's Law and Lenz's Law—The Shunt Motor—Interpole Connections in Motor—Calculation of Torque in a Motor—Characteristics of Shunt Motors—Speed Control of a Shunt	

Motor by Field Adjustment—Effect of Shifting Brushes From Neutral—Speed Regulation—Stabilizing Windings—Compensating Windings—The Compound Motor—The Series Motor—Mathematical Comparison of Characteristics.

- Chapter 12—Losses, Efficiency, and Rating of Direct-Current Machines 144
 Types of Losses—Loss in Shunt-Field Circuit of D-C Generator—Loss in the Armature Circuit—Losses by Windage and Other Friction (Mechanical Losses)—Stray Load Loss—Armature-Iron Loss—Efficiency—No-Load Losses From “Running Light” Test—Efficiency of D-C Motors—Ratings and Standards—Permissible Temperatures for Insulation—Rating of Enclosed Motors—Explosion-Resisting Motors—Totally Enclosed Fan-Cooled Motors—Full-Load Currents.
- Chapter 13—Mechanical Connection Between Motor and Load 152
 Direct Drive and Gear-Head Motors—Belt Drives—Gear Drives—Calculation of Accelerating Time.
- Chapter 14—Conversion of D-C Generator to D-C Motor 157
 Similarity of Motor to Generator—Conversion of Shunt Machine—Conversion of Compound Interpole Type Machine.
- Chapter 15—Control of Direct-Current Motors 160
 Starting of D-C Motors—Drum Controllers—Automatic Starters—Types of Automatic Motor Starters—Counter-emf Starters—Series-Relay Starters—Series-Lockout Starters—Definite-Time-Interval Starters—Overload Protection of D-C Motors—Low-Voltage Release and Low-Voltage Protection—Miscellaneous Starting Devices—Reversal of Direct-Current Motors.
- Chapter 16—Electrical Instruments and Meters 173
 Types of Instruments—Direct-Current Voltmeters (D’Arsonval Type)—Direct-Current Ammeter—Alternating-Current Dynamometer-Type Voltmeters and Ammeters—Iron-Vane Voltmeters and Ammeters—Electronic Voltmeters—The Single-Phase Wattmeter—Use of Wattmeter—The Compensated Wattmeter—Polyphase Wattmeters—Potential Transformers—Current Transformers—Proof of Connections When Instrument Transformers Are Used—Burdens of Current and Potential Transformers—Power-Factor Meters—Reactive-Factor Meters—Frequency Meters—Rectifier-Type Meters—Thermocouple Meters—Graphic Instruments—Watt-Hour Meters—The Oscillograph—The Stroboscope.
- Chapter 17—Transformers 191
 Uses of Transformers—Theory of Operation—Voltage Transformation Ratio—Current Transformation Ratio—The Equivalent Circuit of a Transformer—Determination of Equivalent R , X , and Z of a Transformer by Test—Vector Diagrams and Voltage Regulation—Construction—Losses and Efficiency—Voltage Regulation—Operation at Other Than Rated Voltages and Frequen-

cies—Additive and Subtractive Polarity—Transformer Single-Phase Connections—Parallel Operation—Grouping of Single-Phase Transformers for Three-Phase Operation—Three-Phase Transformers—Auto-Transformers—The Scott, or T, Connection.	
Chapter 18—The Polyphase Induction Motor	212
Characteristics of Polyphase Induction Motor—Principle of Operation—The Squirrel-Cage Rotor—The Rotating Magnetic Field—Speed of an Induction Motor—Torque at Standstill—The Constant-Speed Induction Motor—Multi-Speed Motors—Wound-Rotor (Slip-Ring) Motors—Determination of Performance of Polyphase Induction Motor Without Loading—The Simplified Circle Diagram—Starting of Polyphase Induction Motors—Regenerative Braking of Induction Motors—Single-Phase Operation of a Polyphase Induction Motor—Operation at Other Than Rated Voltage and Frequency.	
Chapter 19—The Polyphase Synchronous Motor	234
General Characteristics of the Synchronous Motor—Starting of Synchronous Motors—Running Conditions—Vector Diagram of the Synchronous Motor—Synchronous Impedance—Effect of Varying Field Excitation When the Load Is Constant—The Synchronous Condenser—Starting Procedure for Synchronous Motors—Synchronous-Motor Applications.	
Chapter 20—Alternating-Current Generators	244
Types of Alternating-Current Generators—Voltage Regulation—Effects of Armature Reaction—Voltage Control of A-C Generators—Rating—Parallel Operation—Significance of Phase Sequence—Synchronizing Current—Division of Load Between Two Alternators—Effect of Change in Field Excitation—Synchronizing Devices—Hunting of Alternators.	
Chapter 21—The Single-Phase Motor	256
Need for Small Motors—The Single-Phase Induction Motor—The Shaded-Pole Induction Motor—The Split-Phase Induction Motor—The Capacitor Motor—The Repulsion Motor—The Repulsion-Induction Motor—The Series A-C Motor (Universal Motor).	
Chapter 22—Electric Batteries	266
Primary Batteries—Secondary (Storage) Batteries—The Lead-Acid Storage Battery—Change in Voltage During Charge and Discharge—Charging Rates—Charging Methods—Equalizing Charge—Discharge Rates—Effect of High and Low Temperature—Gas—Care of Lead-Acid Battery—The Nickel-Iron-Alkaline Storage Battery—Charge and Discharge Characteristics—Care of Nickel-Iron-Alkaline Storage Battery—Comparison of Lead-Acid and Nickel-Iron-Alkaline Batteries.	
Chapter 23—Economics of Use of Electrical Apparatus	274
Types of Problems Involved—Purchase of Industrial Machinery—The Calculation of PW_D —Calculation of PW_o —Calculation of PW_i —Choice of Size of Apparatus—Group Drive vs. Individual Drive—Operating Costs of Group Drive and Individual Drive—Most Economical Size of Cable.	

	PAGE
Chapter 24—Electric Power Rates	284
Power Charges—Energy Charge—Demand Charge—Power-Factor Charges —Minimum Charges—Restricted Service Rates—Sample Rate Structures— Hours Use of Demand.	
Chapter 25—Power-Factor Correction	291
Importance of Power Factor—Economic Limits of Power-Factor Correction —Power-Factor Correction by Resistive Load—Power-Factor Correction by Static Condensers—Power-Factor Correction by Synchronous Motors.	
Chapter 26—Illumination	297
Factors Affecting Vision—Intensity of Illumination; The Foot-Candle— Light Flux—Light Sources—Fluorescent Lamps—Lamp Life—Comparison of Efficiency—Light Control—Selection of Industrial Lighting Units.	
Chapter 27—Electronic Devices	307
Thermionic Emission—Electron Affinity—Oxide-Coated Cathodes—Direct and Indirect Heating of Cathodes—The Diode—The Diode as a Rectifier— The Gas-Filled Diode—Metering of Rectified Current—The Half-Wave Recti- fier With Capacitance Load—The Half-Wave Rectifier With Inductive Load —The Full-Wave Rectifier With Inductive Load—Comparison of <i>RC</i> and <i>RL</i> Loads—Magnitude of Ripple in the Output Voltage of <i>RC</i> Load—Peak Inverse Voltage—The Triode—Transfer and Plate Characteristics of a Triode —The Load Line and Dynamic Characteristic—Plate Resistance—Voltage Gain of a Tube—Amplification Factor, Plate Resistance, and Transconduct- ance—Amplification of Alternating Voltage—The Alternating-Current Equiv- alent Circuit—Application of the Equivalent Circuit in Measuring μ —Appli- cation of the Equivalent Circuit in Measuring g_m —The Resistance-Capaci- tance-Coupled Amplifier—The Impedance-Coupled Amplifier—The Transfor- mer-Coupled Amplifier—The Triode as a Detector—Tetrodes—Pentodes— The Beam Power Tube—The Triode as a High-Frequency Generator—Gas- Filled Triodes—The Grid-Glow Tube—The Thyatron—The Ignitron— Ignitron Circuits—The Mercury-Vapor Rectifier—The Copper-Oxide Recti- fier—Photoelectric Cells—The Gas-Type Phototube.	
Chapter 28—Electronic Applications	348
Circuits for Electronic Applications—High-Frequency Oscillators—Relaxation Oscillators—Filter Circuits—Saturable Reactors—Peaking Transformers— Phase-Shifting Devices—Phase of Voltage Obtained From <i>RL</i> Phase-Shifter— Direct-Current-Motor Control—The Mot-O-Trol (Westinghouse)—The Elec- tronic (Light-Sensitive) Relay—The Cathode-Ray Oscilloscope—Industrial X-Rays—Vacuum-Tube Voltmeters.	
Chapter 29—Special Motors and Generators	370
The Arc-Welding Generator—The Third-Brush Generator—The Synchronous Converter (Rotary)—Operating Characteristics—Balancer Sets—The Three- Wire Generator—Adjustable-Speed Drives—The Amplidyne (General Elec- tric Company).	
Appendix	379
Index	391