PHYSICS

Introduction to Electromagnetic Theory

WITH LAB MANUAL

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by A. B. Bhattacharya, Atanu Nag
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FOREWORD

Engineering has played a very significant role in the progress and expansion of mankind and society for centuries. Engineering ideas that originated in the Indian subcontinent have had a thoughtful impact on the world.

All India Council for Technical Education (AICTE) had always been at the forefront of assisting Technical students in every possible manner since its inception in 1987. The goal of AICTE has been to promote quality Technical Education and thereby take the industry to a greater heights and ultimately turn our dear motherland India into a Modern Developed Nation. It will not be inept to mention here that Engineers are the backbone of the modern society - better the engineers, better the industry, and better the industry, better the country.

NEP 2020 envisages education in regional languages to all, thereby ensuring that each and every student becomes capable and competent enough and is in a position to contribute towards the national growth and development.

One of the spheres where AICTE had been relentlessly working from last few years was to provide high-quality moderately priced books of International standard prepared in various regional languages to all it's Engineering students. These books are not only prepared keeping in mind it's easy language, real life examples, rich contents and but also the industry needs in this everyday changing world. These books are as per AICTE Model Curriculum of Engineering & Technology – 2018.

Eminent Professors from all over India with great knowledge and experience have written these books for the benefit of academic fraternity. AICTE is confident that these books with their rich contents will help technical students master the subjects with greater ease and quality.

AICTE appreciates the hard work of the original authors, coordinators and the translators for their endeavour in making these Engineering subjects more lucid.

(**Anil D. Sahasrabudhe**)

Acknowledgement

The author(s) are grateful to AICTE for their meticulous planning and execution to publish the technical book for Engineering and Technology students.

We sincerely acknowledge the valuable contributions of the reviewer of the book Prof. R.P Dahiya, for making it students' friendly and giving a better shape in an artistic manner.

This book is an outcome of various suggestions of AICTE members, experts and authors who shared their opinion and thoughts to further develop the engineering education in our country.

It is also with great honour that we state that this book is aligned to the AICTE Model Curriculum and in line with the guidelines of National Education Policy (NEP) -2020. Towards promoting education in regional languages, this book is being translated in scheduled Indian regional languages.

Acknowledgements are due to the contributors and different workers in this field whose published books, review articles, papers, photographs, footnotes, references and other valuable information enriched us at the time of writing the book.

Finally, we like to express our sincere thanks to the publishing house, M/s. Khanna Book Publishing Company Private Limited, New Delhi, whose entire team was always ready to cooperate on all the aspects of publishing to make it a wonderful experience.

A. B. Bhattacharya, Atanu Nag

Preface

The book titled **"Physics - Introduction to Electromagnetic Theory"** is an outcome of the rich experience of our teaching of basic physics courses. The initiation of writing this book is to expose basic science to the engineering students to the fundamentals of physics as well as enable them to get an insight of the subject. Keeping in mind the purpose of wide coverage as well as to provide essential supplementary information, we have included the topics recommended by AICTE, in a very systematic and orderly manner throughout the book. Efforts have been made to explain the fundamental concepts of the subject in the simplest possible way.

During the process of preparation of the manuscript, we have considered the various standard text books and accordingly we have developed sections like critical questions, solved and supplementary problems etc. While preparing the different sections emphasis has also been laid on definitions and laws and also on comprehensive synopsis of formulae for a quick revision of the basic principles. The book covers all types of medium and advanced level problems and these have been presented in a very logical and systematic manner. The gradations of those problems have been tested over many years of teaching a wide variety of students.

Apart from illustrations and examples as required, we have enriched the book with numerous solved problems in every unit for proper understanding of the related topics. Under the common title "Physics" there is a set of four books covering different aspects and applications of physics in engineering. Out of those, the first one covers Introduction to Electromagnetic Theory, the second one is based on Introduction to Mechanics, the third one is related to Quantum Mechanics for Engineers and the fourth one is based on Oscillations, Waves and Optics. It is important to note that in all the books, we have included the relevant laboratory practical. In addition, besides some essential information for the users under the heading "Know More" we have clarified some essential basic information in the appendix and annexure section.

As far as the present book is concerned, "Physics - Introduction to Electromagnetic Theory" is meant to provide a thorough grounding in applied physics on the topics covered. This part of the physics book will prepare engineering students to apply the knowledge of Electromagnetic Theory to tackle 21st century and onward engineering challenges and address the related aroused questions. The subject matters are presented in a constructive manner so that an Engineering degree prepares students to work in different sectors or in national laboratories at the very forefront of technology.

We sincerely hope that the book will inspire the students to learn and discuss the ideas behind basic principles of engineering physics and will surely contribute to the development of a solid foundation of the subject. We would be thankful to all beneficial comments and suggestions which will contribute to the improvement of the future editions of the book. It gives us immense pleasure to place this book in the hands of the teachers and students. It was indeed a big pleasure to work on different aspects covering in the book.

A. B. Bhattacharya, Atanu Nag

Outcome Based Education

For the implementation of an outcome based education the first requirement is to develop an outcome based curriculum and incorporate an outcome based assessment in the education system. By going through outcome based assessments evaluators will be able to evaluate whether the students have achieved the outlined standard, specific and measurable outcomes. With the proper incorporation of outcome based education there will be a definite commitment to achieve a minimum standard for all learners without giving up at any level. At the end of the programme running with the aid of outcome based education, a students will be able to arrive at the following outcomes:

PO-1: **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO-2: **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO-3: **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO-4: **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO-5: **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO-6: **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO-7: **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO-8: **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO-9: **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO-10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO-11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO-12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Course Outcomes

After completion of the course the students will be able to:

CO-1: Describe different physical concepts of static electromagnetic fields.

CO-2: Explain the principles of electrostatics and magnetostatics to describe boundary conditions for electric fields and potentials.

CO-3: Discuss the concepts related to Faraday's law of electromagnetic induction.

CO-4: Apply the Maxwell's equations to solve problems relating to propagation of waves in electromagnetic field theory.

CO-5: Analyze different properties of magnetic materials.

CO-6: Analyze the propagation of electromagnetic waves in different media.

Course Outcomes	Expected Mapping with Programme Outcomes *(1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)*											
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12
CO-1	3	1	1	-	-	-	-	-	-	-	-	-
CO-2	3	1	2	1	1	-	-	-	-	-	-	-
CO-3	3	2	1	1	-	-	-	-	-	-	-	-
CO-4	3	3	2	1	1	-	-	-	-	-	-	-
CO-5	3	1	3	1	2	-	-	-	-	-	-	-
CO-6	3	3	3	1	1	-	-	-	-	-	-	-

Abbreviations and Symbols

List of Abbreviations

General Terms			
Abbreviations	**Full form**	**Abbreviations**	**Full form**
AC	Alternating Current	*emf*	electromotive force
BW	Band Width	Ge	Germanium
CO	Course Outcome	LCR	Inductor-Capacitor-Resistor
CRO	Cathode Ray Oscilloscope	*mmf*	magnetomotive force
CRT	Cathode Ray Tube	PO	Programme Outcome
DC	Direct Current	Q-factor	Quality factor
EM	electromagnetic	UO	Unit Outcome
Units Used			
Abbreviations	**Full form**	**Abbreviations**	**Full form**
A	ampere	nF	nano farad
C	coulomb	Oe	oersted
G	gauss	T	tesla
GHz	Gigahertz	V	volt
Hz	hertz	W	watt
kHz	kilohertz	Wb	weber
mH	milli henry	μA	micro ampere
nA	nano ampere	μC	micro coulomb
nC	nano coulomb	μF	microfarad

List of Symbols

Symbols	Description	Symbols	Description
A	Magnetic vector potential	J	Current density
B	Magnetic induction	J_d	Displacement current density
C	Capacitance of a capacitor	K	Co-efficient of coupling
D	Electric displacement	L	Self-inductance
e	Electronic charge	M	Mutual inductance
E	Electric field intensity	M_s	Saturation magnetization
f_{res}	Resonant frequency	P	Poynting vector
g	Gyromagnetic ratio	p_{eff}	Effective number of Bohr magneton
H	Magnetic intensity		
I_d	Displacement current	r	Reflection coefficient

Symbols	Description	Symbols	Description
R_H	Hall coefficient	ε_0	Permittivity of free space
S	Reluctance	ε_r, k	Relative permittivity
t	Transmission coefficient	λ	Linear charge density
T_N	Neel temperature	μ_0	Permeability of free space
U	Electromagnetic energy density	ρ	Volume charge density
V_H	Hall voltage	σ	Surface charge density
Z	Impedance of a medium	φ	Electric flux
α	Attenuation constant	φ_m	Magnetic scalar potential
β	Phase constant	ψ	Wave function
γ	Propagation constant	ω_{L}	Larmor frequency
δ	Skin depth	χ	Electromagnetic susceptibility

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Unit 1 Electrostatics in Vacuum

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Unit 6 Maxwell's Equations

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Guidelines for Teachers

To implement Outcome Based Education (OBE) knowledge level and skill set of the students should be enhanced. Teachers should take a major responsibility for the proper implementation of OBE. Some of the responsibilities (not limited to) for the teachers in OBE system may be as follows:

- Within reasonable constraint, they should manoeuvre time to the best advantage of all students.
- They should assess the students only upon certain defined criterion without considering any other potential ineligibility to discriminate them.
- They should try to grow the learning abilities of the students to a certain level before they leave the institute.
- They should try to ensure that all the students are equipped with the quality knowledge as well as competence after they finish their education.
- They should always encourage the students to develop their ultimate performance capabilities.
- They should facilitate and encourage group work and team work to consolidate newer approach.
- They should follow Blooms taxonomy in every part of the assessment.

Bloom's Taxonomy

Level	Teacher should Check	Student should be able to	Possible Mode of Assessment
Create	Students ability to create	Design or Create	Mini project
Evaluate	Students ability to Justify	Argue or Defend	Assignment
Analyse	Students ability to distinguish	Differentiate or Distinguish	Project/Lab Methodology
Apply	Students ability to use information	Operate or Demonstrate	Technical Presentation/ Demonstration
Understand	Students ability to explain the ideas	Explain or Classify	Presentation/Seminar
Remember	Students ability to recall (or remember)	Define or Recall	Quiz

Guidelines for Students

Students should take equal responsibility for implementing the OBE. Some of the responsibilities (not limited to) for the students in OBE system are as follows:

- Students should be well aware of each UO before the start of a unit in each and every course.
- Students should be well aware of each CO before the start of the course.
- Students should be well aware of each PO before the start of the programme.
- Students should think critically and reasonably with proper reflection and action.
- Learning of the students should be connected and integrated with practical and real life consequences.
- Students should be well aware of their competency at every level of OBE.

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