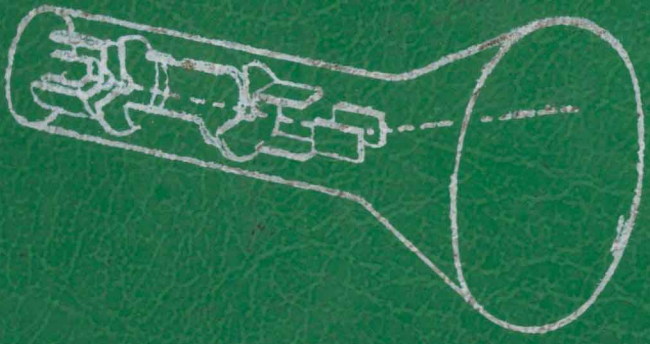
A COURSE IN

Electrical Measurements And Measuring Instruments

(FOURTH EDITION)



J.B. GUPTA

A COURSE IN

ELECTRICAL MEASUREMENTS AND MEASURING INSTRUMENTS

IN

S.I. UNITS

FOR

B.Sc. (Engineering) A.M.I.E. (India) Sec. B, Diploma and Other Equivalent Engineering Examinations

J.B. GUPTA

B. Sc. Elec. Engg. (B.H.U.) M.I E. (India)

Author of : A Course in Electrical Power, Utilization of Electric Power and Electric Traction, Theory & Performance of Electrical Machines, Elements of Electrical Engineering and Electronics, Fundamentals of Electrical Engineering, Electrical Installation Estimating and Costing, A Course in Electrical Technology.

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PREFACE TO THE FOURTH EDITION

The fourth edition has been extensively rewritten in S.I. units and enlarged in its scope and coverage. Whereas existing chapters have been revised and brought up-to-date, a chapter on "Measurement errors" has been added.

Some old blocks have been replaced to make the diagrams more illustrative and clear and inumerable new diagrams have been added. Most of the worked out examples, exercises and problems have been removed and replaced by new ones with thoroughly checked answers. Mistakes and misprints, as they were noticed, have been corrected.

The author is thankful to the students and teachers, who sent their valuable suggestions for the improvement of the book.

The author is most anxious to receive constructive criticism and suggestions from the readers for the improvement of the book.

5th. January, 1979 J.B. Gupta

PREFACE TO THE FIRST EDITION

The book has been written with the aim of presenting a short text-cum-help book covering the syllabii of A.M.I E Sec. B and Degree Examination of Indian Universities in the subject of **"Electrical Measurements and Measuring Instruments"**. Every effort has been made to deal with each and every topic and problem from the fundamental in easy and expressive language for the convenience and better understanding to the readers. While writing this book the difficulties and troubles which a common student faces and thirst of knowledge of an intelligent student have been kept in view.

The book comprises of 20 chapters covering entire syllabii on the subject prescribed by Institution of Engineers (India) and the Indian Universities for degree courses and provides exactly what is essential for them to have a thorough grasp of the subject. Most of the worked out examples, unsolved problems and exercises dealt in this book have been taken from examination paper of A.M.I.E. sec. B and various Indian Universities to give the idea to the examinees of what is usually asked in the examination. The solution to each and every problem is step by step and so clear that it helps the readers in understanding the basic theory and creates confidence in them.

Every care has been taken to eliminate omissions and errors but it is too much to expect that no inaccuracy has crept in and the author would be grateful if readers would bring any such error to his notice.

The author will consider his efforts amply rewarded if the book serves the purpose of the readers for whom it is meant.

Mr. D.D. Sharma deserves my special thanks for his drawing work.

My sincere thanks are due to all the Scientists, Engineers, Authors and Publishers whose works and text have been the source of enlightenment, inspiration and guidance to me in presenting this small book.

Lastly, but not the least I am very thankful to my publishers M/s B.D. Kataria and Sons for bringing out the book in such a short time and for pricing the book so moderatly despite heavy cost of paper and printing.

15th, January 1969. **J.B. Gupta**

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2. Aligarh
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J.B. Gupta

CONTENTS

1

Units, Dimensions and Standards

1.1. NATURE OF UNITS

In engineering quantities of different kinds are involved, including physical, chemical, mechanical, thermal, electrical and physiological ones. In order to record or to compare magnitude of quantities, some one magnitude of each kind must be taken as basis or unit. Each unit, either must be represented by a physical standard of some kind, natural or artificial or must be derived from a combination of other units represented by such standards.

1.2. FUNDAMENTAL AND DERIVED QUANTITIES

Experience shows that three basic ideas, concepts or dimensions are sufficient to describe quantitatively all the phenomena encountered in mechanical science. For three such concepts, those of length, mass and time are taken as fundamentals.

All other mechanical quantities can be expressed in terms of these three fundamental quantities and are known as *derived quantities*. The various powers (positive or negative) of the fundamental quantities represent the dimensions of these derived units.

Thus velocity, $[v] = \frac{[\text{Length}]}{[\text{Time}]} = \frac{[L]}{[T]} = [LT^{-1}]$

Acceleration, $[\alpha] = \frac{[\text{Velocity}]}{[\text{Time}]} = \frac{[LT^{-1}]}{[T]} = [LT^{-2}]$

Force, $[F] = [\text{Mass}] \times [\text{Acceleration}] = [M]\,[LT^{-2}] = [MLT^{-2}]$

Work, $[W] = [\text{Force}] \times [\text{Length}] = [MLT^{-2}]\,[L] = [ML^2\,T^{-2}]$

Power, $[P] = \frac{[\text{Work}]}{[\text{Time}]} = \frac{[ML^2T^{-2}]}{[T]} = [ML^2T^{-3}]$

$[\text{Surface Tension}] = \frac{[\text{Force}]}{[\text{Length}]} = \frac{[MLT^{-2}]}{[L]} = [MT^{-2}]$

Such expressions indicate the nature of derived quantities in terms of fundamental dimensions [L], [M] and [T] and are known as *dimensional equations.*

The dimensional equations help (*i*) in conversion from one system of units to another one (*ii*) in derivation of equations for physical quantities and (*iii*) in checking the accuracy of an equation.

1.3. SYSTEMS OF MECHANICAL UNITS

There are four general systems of mechanical units used in engineering, Foot-pound-second system, the English system, Centimetre-gram-second system and Metre-kilogram-second system. In F.P.S. system the units of fundamental quantities, length, mass and time are foot, pound and second respectively. In English system the corresponding units are foot, slug and second. In C.G.S system the units of fundamental quantities length, mass and time are centimetre, gram and second respectively. In M.K.S. system the respective fundamental units of length, mass and time are metre, kilogram and second, defined below.

The Metre : The metre is a distance at 15°C between two marks on a platinum bar kept at International Bureau of weights and measures at Sevres in France.

The kilogram : The kilogram is the mass of a block of platinum kept at Sevres.

The Second : The second is the mean solar second *i.e.* $\frac{1}{86,400}$ of a mean solar day.

The relation between some of the principal mechanical units in M.K.S., C.G.S. and F.P.S. systems are given below.

Quantity	M.K.S. Units	C.G.S. equivalent units	F.P.S. equivalent units
Length	1 metre	100 cm	3·281 ft
Mass	1 kg	1,000 gm	2·205 lbs
Velocity	1 metre/second	100 cm/second	3·281 ft/second
Acceleration	1 metre/second^2	100 cm/second^2	3·281 ft/second^2
Force	1 Newton	100,000 dynes	7·23 poundals
Energy or work	1 Joules or Nw-m	10^7 ergs	23·76 ft-poundals
Power	1 Joule/second	10^7 ergs/second	23·76 ft-poundals/second

1.4. ABSOLUTE UNITS

An Absolute system of units may be defined as a system in which the various units may be expressed in terms of a small number of fundamental units. The word "absolute" does not imply any special standard of accuracy ; it merely indicates that such derived or absolute units are, in theory, capable of being established from the primary units through experiments implied by defining equations rather than by relative measurements against arbitrary standard of the same kind.

1.5. SYSTEMS OF ELECTRICAL UNITS

Where as, three basic concepts and three fundamental units are sufficient for description and measurement in mechanical science, experience shows that, in electrical science, four concepts or dimensions and four arbitrarily defined fundamental units are necessary to obtain a complete system of dimensions and units. At least one of these four units must be electrical in character.

Amongst the various electrical unit systems used are :

(*a*) *The C.G.S. Electrostatic System of Units* (*C.G.S.E.S.U.*)

It is an absolute system based on the centimetre, gram and second as the fundamental mechanical units and permittivity (ϵ) of the media as fourth fundamental unit. The unit of permittivity (ϵ) is of such a size that the measure number of permittivity for free space is unity *i.e.* $\epsilon_0 = 1$. These units are commonly designated by using the prefix stat with the name of corresponding practical units *e.g. stat volt.*

(*b*) *The C.G.S. Electromagnetic System of Units C.G.S.E.M.U.*)

It is another absolute system based on the centimetre, gram and second as the fundamental mechanical units and permeability (μ) of the media as fourth fundamental unit. The unit of permeability is of such a size that the measure number of permeability for free space is unity *i.e.* $\mu_0 = 1$. These units are commonly designated by using *ab* with the name of the corresponding practical units *e.g. ab volt.*

The electro-magnetic system is more convenient from the point of view of most electrical measurements, and is, therefore, much more generally used than the electrostatic system.

(*c*) *The Practical System of Units* : Since neither C.G.S. electrostatic units nor C.G.S. electro-magnetic units were of convenient size for the purpose of practical work, therefore, a practical system of units in which unit current (ampere) $= \frac{1}{10}$ c.g.s.e.m.u. of current and unit of potential difference (volt) $= 10^8$ c.g s.e.m.u. of potential difference was employed. Though the practical system is sufficiently extensive to deal with the various proportion of every day calculations of electrical engineering, but it has got following defficiencies.

(*i*) The absence of recognized units for magnetic and electrostatic relations, therefore, some or all the magnetic units used to be expressed in c.g.s.e.m.u. system.

(*ii*) The practical units are related by conversion factors to those systems of units (c.g.s.e.m.u. and c.g.s.e.s.u.) in which theoretical relations of the science have been commonly developed in the past.

(*d*) *The M.K.S. System of Electrical Units* : It is an absolute system based on the metre, kg and second as fundamental mechanical units and permeability of the media as fourth unit. The unit of permeability is of such a size that measure number of permeability for free space is 10^{-7}.

Its great advantage is that its units are identical with those of practical system and are the same whether built up from the electro-magnetic or electrostatic theory.

The value of permittivity for free space, ϵ_0 in m.k.s. (unrationalized) system can be determined from the relation

$$\frac{1}{\sqrt{\mu_0 \epsilon_0}} = C, \text{ velocity of light}$$

$$\text{or} \quad \epsilon_0 = \frac{1}{\mu_0 C^2} = \frac{1}{10^{-7} \times (2{\cdot}998 \times 10^8)^2} = 1{\cdot}113 \times 10^{-10}$$

(*e*) *Rationalized M.K.S. System of Units* : The above unrationalized system has been further rationalized by assigning different values to μ_0 and ϵ_0. Rationalization means the removal of quantity π from the places, where its appearance is unnatural, irrational and geometrically unjustified to places where

it properly belongs. By doing so, most of the equations and formulaes in electrical engineering have become simple and logical. In R.M.K.S. system, the permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H/metre and the permittivity of free space, $\epsilon_0 = 8{\cdot}854 \times 10^{-12}$ F/metre.

The change in the values of μ_0 and ϵ_0 does not change the values of electrical units but does change the units of m.m.f., magnetizing force etc.

It was Prof. G. Giorgi, who first of all, suggested this system in 1901. After the name of Prof. Giorgi, it is also known is Giorgi system of units.

The important characteristics of this system are given below :

1. A single set of units covers all electrical and magnetic quantities and is applicable to both electromagnetic and electrostatic effects.

2. The values of units used in circuit theory are identical with the units of 'practical' system described above.

3. A unit magnetic pole emits a unit magnetic flux and not 4π units of flux.

4. In c.g.s. systems, described above, the numerical values of magnetizing force H and flux density B are equal in vacuum, but in r.m.k.s. system the values of B and H in a vacuum are not equal but are linked through a constant μ_0.

$$B = \mu_0 H$$

where μ_0 is named as permeability of free space and its value has been apparently chosen as $4\pi \times 10^{-7}$.

In magnetic materials $B = \mu_0 \mu_r H$ where μ_r is the relative permeability of the material and is equal to permeability value in c.g.s. system.

5. Similarly in a dielectric, flux density $D = \epsilon_0 \epsilon_r E$ (field strength) where ϵ_0 and ϵ_r are the permittivity of free space and relative permittivity of the medium.

6. The relation $\frac{1}{\sqrt{\mu_0 \epsilon_0}}$ = velocity of light holds good numerically as well as dimensionally.

(*f*) *The Rationalized M.K.S.A. System of Units* : Since these properties (permeability and permittivity of free space) although eminently suitable as physical reference standards, are less easily comprehended than such concepts as ampere, charge, potential difference or resistance, therefore, it has been agreed to make, ampere defined from its magnetic effect as fourth fundamental quantity and the system developed so *i.e.* employing metre, kilogram, second and ampere as fundamental units is called as R.M.K.S.A. system.

1.6. INTRODUCTION TO S.I. SYSTEM OF UNITS

S I is the latest form of metric system and absorbs in it the rationalized M.K.S.A. system. S I stands for "Systeme International d' Unites" in French. This abbreviation is now adopted by the International Standardising Organisation as the abbreviated name of this new system of units in all languages.

The S I system is, in fact, simply the R.M.K.S.A. system expanded by adding the degree Kelvin and Candela as basic units of temperature and luminous intensity respectively. The S I system is a comprehensive, logical and coherent system, designed for use in all branches of science, engineering and technology.