

PHYSICAL CHEMISTRY THROUGH PROBLEMS

S. K. DOGRA

Department of Chemistry
Indian Institute of Technology, Kanpur

AND

S. DOGRA

Department of Chemistry
Maitreyi College
University of Delhi, Delhi

JOHN WILEY & SONS

NEW YORK

CHICHESTER

BRISBANE

TORONTO

SINGAPORE

Copyright © 1984, WILEY EASTERN LIMITED
New Delhi

Published in the Western Hemisphere by
Halsted Press, a Division of
John Wiley & Sons, Inc., New York

Library of Congress Cataloging in Publication Data

Dogra, S. K.

Problems in physical chemistry.

1. Chemistry, Physical and theoretical—Problems,
exercises, etc. I. Dogra, S. II. Title.

QD456.D63 1984 541.3~~976~~ 83-12819

ISBN 0-470-27491-3

Printed in India at Prabhat Press, Meerut.

Preface

A proper understanding of the principles of physical chemistry is required for a study of pure, industrial and biological sciences. It is the authors opinion that these principles can be learnt properly only through their applications to solving problems and that the existing texts do not prepare a student sufficient in the diverse applications of the fundamental principles of physical chemistry. This book has been written to fill this gap.

The topics in this book have been put in the time tested arrangement of first structure, then dynamics and lastly synthesis. The first two fall in the domain of the physical chemistry proper and last in that of organic and inorganic chemistry. The first four chapters are devoted to the understanding of the elementary quantum mechanics and atomic and molecular structure. The care has been taken to give problems which illuminate the principles of atomic and molecular structures. So that the students can grasp the more involved details that follow. Chapter five illustrates the physical methods used in establishing the structures and parameters of molecules. Chapter six, seven and eight give the preliminary ideas about the three states of matter, i.e. solids, liquids and gases. Chapter nine serves as a bridge between the results of microsystems and their applications to the macrosystems, i.e. statistical mechanics. This chapter illustrates the methods of calculating the properties of bulk system from those of microsystems. Chapters 10 to 17 deal with the principles of thermodynamics and electrochemistry applicable to ideal systems. These help in determining whether particular process, physical or chemical, is feasible or not. Chapter 18 deals with quantities that measure the departure of real systems from ideal behaviour. The basic principles of chemical kinetics are dealt in Chapter 19. This helps in following the progress of a process.

Each section of a chapter starts with a short summary of the basic fundamentals to refresh the memory of the students and to place in perspective the results required for solving problems. This is followed by illustrations. At the end of each chapter there are number of unsolved problems, arranged in the order in which concepts have been introduced. The answers of these problems are given at the end. Care has been taken to provide all the data needed for a particular problem but a hand-book may be consulted wherever proper data has not been given.

The SI units have been used predominantly, though some non-SI units like those for pressure etc. have been used along side. This is because a large amount of information is still available in non-SI units

and the students should be familiar with both the systems.

A large number of problems enclosed in this book have been tested on first and second year students of the B. Tech. programme and on the M Sc. students, studying at I.I.T. Kanpur. The data needed in these problems have been taken from International critical tables, hand book for physics and chemistry, journals and physical chemistry text books. The authors acknowledge their debt. We also express our thanks to Mr. R.D. Singh and Mr. Anil Kumar for typing the manuscript and to Mr. B.S. Panesar for the preparation of drawings. The authors also acknowledge the financial grant from the curriculum development group of quality improvement programme at Indian Institute of Technology, Kanpur. Finally we would like to express our sincere thanks to Mr. S.N. Mahey (late) whose constant encouragement has made possible to complete this work.

S K DOGRA

S DOGRA

January, 1984

Contents

<i>Preface</i>	vii
1 SI Units	1
1.1 Introduction	1
1.2 Special Notes on the Use of SI Units	2
1.3 Basic Units	3
1.4 Derived Units	3
1.5 Prefixes	3
1.6 Equations of Electromagnetism from cgs to SI	3
<i>Problems</i>	12
2 Elementary Quantum Mechanics	14
2.1 Dual Nature of Radiation	14
2.2 Concept of Quantum in Energy	15
2.3 Rydberg Equation	17
2.4 Bohr's Theory of Atomic Structure	17
2.5 Particles and Waves	19
2.6 Heisenberg Uncertainty Principle	19
2.7 Wave Mechanics	20
2.8 Operator	24
2.9 The Expectation or Average Value	27
2.10 Schrödinger Wave Equation	29
2.11 Particle in a Box	30
2.12 Bohr's Correspondence Principle	31
2.13 Approximate Methods	32
<i>Problems</i>	34
3 Atomic Structure	43
3.1 System Description	43
3.2 Angular Functions	44
3.3 The Radial Function	47
3.4 Energy Value	50
3.5 Electron Position	50
3.6 Multi-Electronic Atoms	52
3.7 Atomic Term Symbols and Russell-Saunders Coupling for Two Electrons	55
3.8 Term Symbols for Poly-Electronic Atoms	56
3.9 Hund's Rules	62

- 3.10 Spectrum of Polyelectronic Atoms 64
 Problems 67

4 Molecular Structure

72

- 4.1 Introduction 72
4.2 Ionic Bond 72
4.3 Covalent Bond 75
4.4 Molecular Orbitals 81
4.5 Shapes of Molecular Orbitals 82
4.6 Relative Energy Levels of the Molecular Orbitals 83
4.7 Molecular Electronic Configurations 85
4.8 Molecular Term Symbols 85
4.9 Bond Order and Bond Energy 88
4.10 Electronegativity 89
4.11 Dipole Moment 90
4.12 Ionic Character 90
4.13 Polyatomic Molecules 93
4.14 Bond Angles in Hybrid Orbitals 97
4.15 Geometrical Shapes of the Molecules 97
4.16 Conjugated Molecules 105
4.17 Bond Order and Bond Length 112
4.18 Coordination Compounds 116
 Problems 121

5 Spectroscopy of Diatomic and Polyatomic Molecules

129

- 5.1 Born-Oppenheimer Approximation 129
5.2 Rotational Spectra of Diatomic Molecules 130
5.3 Vibrational Spectra of Diatomic Molecules 132
5.4 Rotational-Vibrational Spectra 136
5.5 Vibrational Spectra of Polyatomic Molecules 143
5.6 Raman Effect 145
5.7 Effect of Temperature on the Intensities of Rotational
 Vibrational Spectra (Thermal Distribution of Quantum
 States) 148
5.8 Electronic Transitions 150
5.9 Nuclear Magnetic Resonance 153
5.10 Electron Spin Resonance 159
5.11 Calculation of Dissociation Energy 161
 Problems 164

6 Solids

174

- 6.1 Different Types of Solids 174
6.2 Lattice Energy 176
6.3 Bonding in Metals 179
6.4 Space Lattice 182

6.5	The Unit Cell	183	
6.6	Unit Cell Content	183	
6.7	Unit Cell Coordinates	184	
6.8	Coordination Number	185	
6.9	Ideal Density of Crystal	186	
6.10	Crystal Radii	187	
	<i>Problems</i>	189	
7	Liquids		194
7.1	Heat of Vaporisation and Intermolecular Forces	194	
7.2	Viscosity	196	
7.3	Measurement of Viscosity	197	
7.4	Temperature Dependence	198	
7.5	Surface Tension	200	
7.6	Surface Tension and Vapour Pressure of Small Droplets	200	
7.7	Contact Angle	201	
	<i>Problems</i>	201	
8	Gases		204
8.1	Pressure	204	
8.2	Temperature Scale	206	
8.3	Laws of Ideal Gases	206	
8.4	Real Gases	215	
8.5	Kinetic Theory of Gases	225	
	<i>Problems</i>	234	
9	Statistical Mechanics		242
9.1	Definitions	242	
9.2	Combinatory Rules	242	
9.3	Probability and Most Probable Distribution	244	
9.4	Distribution of Non-Distinguishable Particles	245	
9.5	Stirling's Theorem	246	
9.6	Maxwell-Boltzmann Statistics	246	
9.7	Partition Functions	251	
9.8	Calculation of Partition Functions	251	
9.9	Thermodynamic Properties	258	
9.10	Thermodynamic Properties of Ideal Gases	259	
9.11	Molar Heat Capacity	264	
9.12	Equilibrium Constant	267	
	<i>Problems</i>	271	
10	First Law of Thermodynamics		276
10.1	Work	276	
10.2	Heat	278	
10.3	Energy	278	

10.4	First Law of Thermodynamics	279
10.5	Reversible and Irreversible Process	280
10.6	Process at Constant Volume	280
10.7	Enthalpy and Process at Constant Pressure	281
10.8	Relation between Enthalpy and Energy	281
10.9	Heat Capacity	282
10.10	Applications of First Law to Ideal Gases	289
10.11	Real Gases	296
	<i>Problems</i>	299
11	Thermochemistry	307
11.1	Heat of Reaction	307
11.2	Measurements of Heat of Reactions	308
11.3	Relationship between ΔH and ΔE	309
11.4	Temperature Dependence of Heat of Reaction (Kirchhoff Relation)	310
11.5	Hess's Law	311
11.6	Heat of Formation	312
11.7	Heat of Combustion	313
11.8	Bond Energy	314
11.9	Heat of Neutralisation	315
11.10	Heat of Solution	316
	<i>Problems</i>	318
12	Second and Third Laws of Thermodynamics	323
12.1	Definition of Second Law of Thermodynamics	323
12.2	Carnot Cycle	323
12.3	Efficiency of Heat Engines	324
12.4	Heat Pump and Refrigerator	328
12.5	Entropy	329
12.6	Calculation of ΔS for Various Reversible Processes	330
12.7	Change in Entropy for Isothermal Mixing	337
12.8	Standard State for the Entropy of Ideal Gas	338
12.9	The Third Law of Thermodynamics	339
12.10	Thermodynamic Properties at Absolute Zero	340
12.11	Calculation of Entropy at any Temperature	341
12.12	ΔS_T^0 for a Chemical Reaction and Its Dependence on Temperature	343
	<i>Problems</i>	344
13	Free Energy and Chemical Equilibrium	354
13.1	Free energy functions (Definitions)	354
13.2	Coupled Reactions	358
13.3	Criteria for Equilibrium and Spontaneity	359
13.4	Calculation of Free Energy	360

13.5	Properties of Helmholtz Free Energy	362
13.6	Properties of Gibbs' Free Energy	363
13.7	Some Mathematical Results	370
13.8	The Fundamental Equations of Thermodynamics and Maxwell's Relations	373
13.9	Systems of Variable Composition	376
13.10	The Free Energy of Mixture	377
13.11	Chemical Equilibrium in a Mixture	382
13.12	Different Forms of Equilibrium Constants	385
13.13	Temperature Dependence of Equilibrium Constant	386
13.14	The Lechatelier Principle	387
13.15	Effect of Addition Inert Gas	388
13.16	Calculations of K and Concentration of Species at Equilibrium for Ideal Gases	388
13.17	Heterogeneous System	390
13.18	Real Gases	391
13.19	Calculation of Fugacity of Real Gases	392
13.20	Mixture of Real Gases and Certain Relations	400
13.21	Equilibrium Constants for Reactions Involving Real Gases	400
	<i>Problems</i>	402
14	Phase Equilibria and Phase Diagrams	419
14.1	Equilibrium Condition	419
14.2	The Clapeyron Equation	420
14.3	Integration of Clapeyron Equation	421
14.4	Effect of Pressure on the Vapour Pressure	425
14.5	Phase Rule	426
14.6	Phase Diagrams for One-component System	428
14.7	The Component System	431
14.8	Three-component System	444
	<i>Problems</i>	447
15	Electrochemistry	459
15.1	Definitions	458
15.2	Kohlrausch's Law	460
15.3	The Arrhenius Law of Dissociation	461
15.4	Electrolysis and Electrode Reactions	463
15.5	Ionic Mobilities	464
15.6	Transport Number	465
15.7	Ionic Conductances	470
15.8	Colligative Properties of Electrolytes	472
15.9	Applications of Conductance Measurements	473
	<i>Problems</i>	474

16 Electrochemical Cells	481
16.1 Introduction	481
16.2 Electrodes	483
16.3 Nature of Electrodes	484
16.4 Electrode Potential	486
16.5 Convention for Electrochemical Cells and Electrode Reactions	487
16.6 Dependence of e.m.f. of a Cell on Activities of Reaction Species, i.e. Nernst Equation	489
16.7 Concentration Cells	492
16.8 Thermodynamics of the Cells	496
16.9 Applications	497
<i>Problems</i>	502
17 Ideal Dilute Solutions	510
17.1 Ideal Solutions	510
17.2 Vapour Pressure of Mixture of Volatile Components	511
17.3 Gibbs' Duhem Equation	512
17.4 Ideal Dilute Solutions	514
17.5 Colligative Properties	519
17.6 Osmotic Pressure	524
17.7 Equilibrium in Solution	526
<i>Problems</i>	535
18 Non-Ideal Solutions	546
18.1 Introduction	546
18.2 Partial Molal Properties	546
18.3 Calculation of Partial Molal Quantities	547
18.4 Activity and Activity Coefficient	557
18.5 Choice of Standard State	
18.6 Methods of Finding Activity and Activity Coefficients	560
18.7 Distribution Law	569
18.8 Mean Activity and Activity Coefficients of Electrolytes	569
18.9 Relations between Activity, Mean Activity, Activity Coefficient, Mean Activity Coefficient etc. of Ions in Electrolyte	572
18.10 Debye-Hückel Limiting Law	573
18.11 Effect of Ionic Strength on Dissociation Constant and Solubility Product	576
<i>Problems</i>	578
19 Chemical Kinetics	587
19.1 Definitions	587
19.2 Zero-order Reactions	590
19.3 First-order Reactions	590

19.4	Second-order Reactions	592
19.5	Third-order Reactions	594
19.6	Pseudo-order Reactions	596
19.7	Half-life	596
19.8	Methods of Determining Rate Constant and Order of Reaction	598
19.9	Complex Reactions	604
19.10	Steady State Hypothesis	612
19.11	Effect of Temperature on Rate Constant	614
19.12	Simple Collision Theory	616
19.13	Activated Complex or Transition State Theory	618
19.14	Thermodynamic Formulation of Rate Constant	619
19.15	Primary Salt Effect	621
	<i>Problems</i>	622

Answers

635

Index

663

SI Units

1.1 Introduction

In normal day-to-day life, although variety of units have been used but in scientific world mainly two systems of units are commonly used. One is F.P.S. (Foot, Pound and Second), originated in U.K. and other cgs. (Centimetre, Gram and Second) originated in France. As the definitions stand today, foot or cm is a distance between the two fixed marks on a specific kind of metal, pound is a weight of a certain mass of metal whereas a gm used to be (originally specified) as a mass of one cubic centimetre of water at 0°C . The kilogram was later specified as being the mass of a particular piece of metal.

For a common man units of measure do not matter much and he will prefer to use the same units which he is using for centuries. But in the scientific world, if there is no common language it is not easy to understand the discoveries or an achievement of scientists of different countries, since the knowledge of science does not remain in domain of one person or of one country. The other major disadvantage of the present system of units is that they are not in any way derivable from the scientific formulas or natural constants. So the need was felt to arrive at a common system of units. The meeting was held under the auspicious of Conference Generale des Poids et Mesures (C.G.P.M.) and agreed to adopt common units of measurements known as Systeme Internationale d' Units or the International System of Units, the abbreviation of which is SI. Many countries have adopted this system of units.

According to SI, the unit for distance is 'metre (m)', defined as the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom. The SI unit of area is the square metre (m^2). Land is often measured by the hectare (10000 m^2 or approximately 2.5 acres). The SI unit of volume is the cubic metre (m^3). Fluid volume is often measured by the litre (0.001 m^3 or dm^3).

The unit of time is second(s), defined as the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom. The SI unit for frequency is the hertz (Hz) which equals one cycle per second.

The standard unit of mass, the kilogram (kg) is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures

at Paris. It is important to note that unit of mass is not defined in terms of physical constants and is quite possible that the base unit of mass now known as kg will be renamed as giorgi, symbol G. The SI unit of force is newton (N), which is the force when applied for one second will give to a 1 kg mass a speed of 1 m per second. One newton equals nearly 0.2 lb of force. The SI unit for work and any kind of energy is the Joule (J), $1\text{ J} = 1\text{ N.m}$. The SI unit for power of any kind is the Watt (W), $1\text{ W} = 1\text{ J s}^{-1}$.

The Kelvin or thermodynamic scale of temperature used in SI has its origin or zero point at absolute zero and has a fixed point at the triple point of water defined as 273.16 K. The triple point defined on Celsius scale is 0.01°C and on Fahrenheit scale as 32.02°F .

The basic unit of electric current is ampere (A), defined as the magnitude of the current that, when flowing through each of two long parallel wires separated by 1 m in free space, results in a force between the two wires (due to these magnetic fields) of $2 \times 10^{-7}\text{ N}$ for each metre of length. The SI unit of voltage is volt (V), which is defined $1\text{ V} = 1\text{ W A}^{-1}$. The SI unit of electrical resistance is the ohm (Ω) which is defined $1\Omega = 1\text{ V A}^{-1}$.

It is good if the standard units are used every where. Certain units, e.g. minute, hour, day, litre, degree Celsius, degree (angle), minute (angle) etc. will be used simultaneously along with SI units for some times though these units have no place in scientific world. Of course units like scurie, electron volt, gauss, bar and barn will be used along with SI units but we hope that with time they will be phased out.

In the following pages the usages of SI units will be discussed by taking certain examples. It will be shown that SI units are much better and one does not need to remember the units of many quantities.

1.2 Special Notes on the Use of SI Units

1. Only the singular form of units is to be used, e.g. km and not kms.
2. Full stop at the end of abbreviations is to be omitted, e.g. km not km.
3. The decimal sign is to be a point or a comma on the line, e.g. 2.5 or 2, 5 not 2.5.
4. Digits should be grouped in threes about the decimal point in order to facilitate the reading of long numbers. Commas should not be used to space digits in numbers, e.g. 16 543 121.133 45 and not 16, 543, 121.133, 45.
5. The degree sign is to be omitted when the Kelvin scale is employed, e.g. 273 K and not 273°K .
6. The solidus is not to be encouraged, but where used, no more than one should be employed, e.g. $\text{J kg}^{-1}\text{K}^{-1}$ or J/kg K but not $/\text{Kg/K}$.

1.3 Basic Units

The basic units of the SI system are shown in Table 1.1.

TABLE 1.1 Base Units

Physical quantity	Unit	symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity of light	Candela	Cd
Plane angle	radian	rad
Solid angle	Steradian	srn

The mol has been recommended by the ISO (International Organisation for Standardisation) as a basic unit but this remains to be accepted by the CGPM.

1.4 Derived Units

Derived units with special names are given in Table 1.2.

1.5 Prefixes

It is recommended that prefixes to be used should differ from a unit in steps of 10^3 (Table 1.3).

Units to be eventually abandoned are listed in Table 1.4.

1.6 Equations of Electromagnetism from cgs to SI

Table 1.5 gives the conversion factors for converting the equations representing the electromagnetic quantities from cgs to SI units, i.e. for each electromagnetic quantity expressed in cgs units, substitute the required value and rearrangement gives the desired quantities in SI units (see exercises 1.9 and 1.10).

TABLE 1.2 Symbols for Certain SI Derived Units

Physical quantity	Name of SI Unit	Symbol of SI Unit	Definition of SI Unit
Force	newton	N	kg m s^{-2}
Pressure*	pascal	Pa	$\text{kg m}^{-1} \text{s}^{-2} (= \text{N m}^{-2})$
Energy	joule	J	$\text{kg m}^2 \text{s}^{-2}$
Power	watt	W	$\text{kg m}^2 \text{s}^{-3} (\text{J s}^{-1})$
Electric charge	Coulomb	C	A s
Electric potential difference	volt	V	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-1} (= \text{J A}^{-1} \text{s}^{-1})$
Electric resistance	ohm	Ω	$\text{kg m}^2 \text{s}^{-3} \text{A}^{-2} (= \text{V A}^{-1})$
Electric conductance*	Seimens	s	$\text{kg}^{-1} \text{m}^{-2} \text{s}^3 \text{A}^2 (= \text{A V}^{-1} = \Omega^{-1})$
Electric capacitance	farad	F	$\text{A}^2 \text{s}^2 \text{kg}^{-1} \text{m}^{-2} (= \text{A s V}^{-1})$
Magnetic flux	Weber	Wb	$\text{kg m}^2 \text{s}^{-2} \text{A}^{-1} (= \text{V s})$
Inductance	henry	H	$\text{kg m}^2 \text{s}^{-2} \text{A}^{-2} (= \text{V A}^{-1} \text{s})$
Magnetic flux density	Tesla	T	$\text{kg s}^{-2} \text{A}^{-1} (= \text{V.s m}^{-2})$
Luminous flux	lumen	Lm	Cd sr
Illumination	lux	lx	Cd sr m^{-2}
Frequency	hertz	Hz	s^{-1}

a. recommended by CIPM.

TABLE 1.3 Prefixes for Fractions and Multiples of SI Units

Prefix	Symbol	Factor	Prefix	Symbol	Factor
tera	T	10^{12}	*centi	c	10^{-2}
giga	G	10^9	milli	m	10^{-3}
mega	M	10^6	micro	μ	10^{-6}
kilo	k	10^3	nano	n	10^{-9}
*hecto	h	10^2	pico	p	10^{-12}
*deca	da	10	femto	f	10^{-15}
*deci	d	10^{-1}	atto	a	10^{-18}

*An asterisk indicates that the use of these prefixes is limited to occasions where recommended prefixes are inconvenient.

TABLE 1.4

Physical quantity	Unit	SI equivalent
Length	*Ångstrom (Å)	10^{-10} m
	*Inch (in)	0.0254 m
	mile	1.60934 km
	*nautical mile international	1.852 km
Area	*barn (b)	10^{-28} m ²
	*square inch (in ²)	645.16 mm ²
Volume	cubic inch	1.63871×10^{-5} m ³
Mass	*pound (lb)	0.453 592 37 kg
Force	*dyne (dyn)	10^{-5} N
	poundal	0.138 255 N
	pound force	4.448 22 N
Pressure	*atmosphere (atm)	101.325 kN.m ⁻²
	*bar (bar)	105 N m ⁻²
	torr (torr)	133.322 N.m ⁻²
	p.s.i.	6 894.76 N m ⁻²
Energy	*calorie international	4.1868 J
	calorie 15°C (cal _{IT})	4.1855 J
	*calorie thermochemical (cal _{th})	4.184 J
	B.t.u.	1055.06 J
	electron volt (eV)	1.6021×10^{-19} J
	*erg (erg)	10^{-7} J
Power	horse power	745.700 W
Radioactivity	*curie (Ci)	3.7×10^{10} s ⁻¹
Exposure	roentgen (R)	2.5×10^{-4} C.kg ⁻¹
Magnetic flux density	*gauss (G)	10^{-4} T
Kinematic viscosity	*stoke (St)	10^{-4} m ² s ⁻¹
Dynamic viscosity	poise (P)	10^{-1} kg m ⁻¹ s ⁻¹

*An asterisk indicates that the conversions are exact.

TABLE 1.5 Expressions for Physical Quantities

Physical quantity	cgs symbol	SI symbol	Physical quantity	cgs symbol	SI symbol
Electric charge	Q	$(4\pi\epsilon_0)^{-1/2} Q$	Resistivity	ρ	$4\pi\epsilon_0 \rho$
			Conductance	G	$G/4\pi\epsilon_0$
Charge density	ρ	$(4\pi\epsilon_0)^{-1/2} \rho$	Conductivity	K	$K/4\pi\epsilon_0$
Surface charge density	σ	$(4\pi\epsilon_0)^{1/2} \sigma$	Impedance	Z	$4\pi\epsilon_0 Z$
			Self-impedance	L	$4\pi\epsilon_0 L$
Electric dipole moment	p	$(4\pi\epsilon_0)^{-1/2} p$	Capacitance	C	$C/4\pi\epsilon_0$
			Speed of light	c	$(\mu_0\epsilon_0)^{-1/2}$
Electric current	i	$(4\pi\epsilon_0)^{-1/2} i$	Magnetic induction	B	$(4\pi\mu_0)^{1/2} B$
Electric current density	j	$(4\pi\epsilon_0)^{-1/2} j$	Magnetic field strength	H	$(4\pi\mu_0)^{1/2} H$
Electric field strength	E	$(4\pi\epsilon_0)^{1/2} E$	Magnetisation	M	$(\mu_0/4\pi)^{1/2} M$
			Electromagnetic moment	m	$(\mu_0/4\pi)^{1/2} m$
Electric displacement	D	$(4\pi\epsilon_0)^{1/2} D$	Relative permeability	μ	μ/μ_0
Dielectric polarisation	P	$(4\pi\epsilon_0)^{-1/2} P$	Magnetic susceptibility	χ	$\chi/4\pi$
Electric potential	V	$(4\pi\epsilon_0)^{1/2} V$			
Relative permittivity	ϵ	ϵ/ϵ_0			
(Dielectric constant)	D				
Electric polarisability	α	$\alpha/4\pi\epsilon_0$			
Resistance	R	$4\pi\epsilon_0 R$			