Environmental Chemistry

The International System of Units (SI)

BASE AND IMPORTANT DERIVED UNITS

Quantity	Name of unit	Symbol	Definition
Length	meter	m	base unit
Mass	kilogram	kg	base unit
Time	second	s	base unit
Electric current	ampere	A	base unit
Thermodynamic temperature	kelvin	K	base unit
Luminous intensity	candela	cd	base unit
Amount of substance	mole	mol	base unit
Area	square meter	m^2	m^2
Volume	cubic meter	m^3	m^3
Force	newton	N	$kg\ m\ s^{-2}$
Pressure	pascal	Pa	$N\ m^{-2}$
Energy	joule	J	$kg\ m^2\ s^{-2}$
Power	watt	W	$J\ s^{-1}$
Electric charge	coulomb	C	A s
Electric potential difference	volt	V	$J\ A^{-1}\ s^{-1}$

SI PREFIXES

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

Often Used Conversion Factors*

	To convert from	To	Multiply by
Length	feet	meters	3.048×10^{-1}
	inches	centimeters	2.54
	miles (statute)	kilometers	1.609
Mass	pounds (avdp)	kilograms	4.536×10^{-1}
	tons (US short)	kilograms	9.072×10^{2}
	tons (US long)	kilograms	1.106×10^{3}
	tonnes (metric)	kilograms	1.000×10^{3}
Time	years (sidereal)	seconds	3.156×10^{7}
Area	hectares	square meters	1.000×10^{4}
	hectares	square kilometers	1.000×10^{-2}
	acres	square meters	4.047×10^{3}
	square miles	square kilometers	2.590
Volume	liters	cubic meters	1.000×10^{-3}
	liters	cubic decimeters	1.000
	gallons (US liquid)	cubic meters	3.785×10^{-3}
	barrels (US liquid)	cubic meters	1.192×10^{-1}
	barrels (US dry)	cubic meters	1.156×10^{-1}
	barrels (US petroleum)	cubic meters	1.590×10^{-1}
Force	dynes	newtons	1.000×10^{-5}
Pressure	atmospheres	pascals	1.013×10^{5}
	mm Hg (torr)	pascals	1.333×10^{2}
	pounds per square inch (psi)	pascals	6.893×10^{3}
Viscosity	poises	pascal seconds	1.000×10^{-1}
Energy	British thermal units (Btu)	joules	1.055×10^{3}
	ergs	joules	1.000×10^{-7}
	calories	joules	4.184
	Calories (nutritional)	joules	4.184×10^{3}
	kilowatt hours	joules	3.600×10^{6}
	Q (10^{18} Btu)	terajoules	1.055×10^{9}
Power	horsepower	watts	7.457×10^{2}

* The heat content of various fuels is given on the back endpaper.

Environmental Chemistry

（内部交流）

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Preface

Precisely what is meant by "environmental chemistry" is not especially easy to define, and there is really no consensus as to what should be included in this kind of textbook. Specific environmental problems such as photochemical smog, the degradation of stratospheric ozone, or mercury pollution of natural waters require the expertise of a variety of disciplines to determine appropriate approaches to their alleviation, but there is no doubt that chemistry and chemists must play a central role if successful approaches are to be found.

This book is predicated upon a rather broad interpretation of what is meant by environmental chemistry. Topics such as the origin and evolution of the environment, the energy crisis, mineral resources, solid wastes, recycling, and the effects of foreign substances on living systems have been added to the more conventional environmental chemistry relating to air and water pollution. An attempt has been made to apply chemical principles to all of these problems and to show the interrelationships among them. Often this has been done by choosing as examples specific problems of the type already mentioned and deriving from them general characteristics and principles.

One consequence of this approach is the inclusion of a large number of cross-references from one section of the text to another. Another is the numerous problems at the end of each chapter, many of which attempt to test the student's understanding of the applicability and interrelationships of the underlying general principles. Solutions to the problems have not been included, but when necessary information cannot be found within the text itself references have usually been given to outside sources for helpful facts or analysis. It is hoped that the interested reader will make extensive use of these references since other relevant information is also available in many of them.

The broad approach to environmental chemistry employed has evolved from the syllabus of a course first taught at Eastern Michigan University during the summer of 1972. The minimum prerequisite was one year of general chemistry, and students were strongly advised to complete quantitative analysis and/or a semester of organic chemistry prior to enrollment. Since no textbooks were available in this "intermediate" environmental chemistry category at the time the syllabus was developed, handouts of lecture notes were provided, and considerable reliance was placed on assigned readings in advanced treatises.

Because of its popularity among chemistry, biology, and other science majors, ranging from sophomore to graduate levels, the course has been taught at least once a year since 1972. Each such offering has provided further opportunities to refine the presentation of the material and to obtain feedback from students regarding the usefulness to them of including a broad range of topics. The requirement of a general chemistry prerequisite and recommendation of analytical and organic courses has allowed the subject matter to be treated in sufficient depth to bridge the gap between the often superficial texts intended for nonscience majors and the highly specialized treatises found on the bookshelves of professional chemists who are attacking environmental problems. Despite the breadth of coverage, many seniors and graduate students were challenged by the course because it included aspects of applied chemistry that they had not become aware of through the conventional undergraduate curriculum. A very important aspect of this text is its attempt to provide such students with a broad overview of the applications of chemical facts and principles. It is hoped that this will prove useful when choices relating to specialized areas for research and/or employment opportunities must be made.

Two other important threads which bind the book together are evolution (chemical, geological, and biological) and an attempt to develop what economist Kenneth Boulding has called "generalized eyes and ears." To this latter might be added "pens" since the discoverer of new knowledge has some obligation to disseminate it in ways that are accessible to others who might use it. Many environmental problems have had their genesis in the failure of decision-makers to consider all aspects of a problem and the failure of specialists with relevant information to make it available or understandable. The need for improved communication and broadened perspectives are obvious when environmental problems are studied. These aspects of the course have been discussed in more detail elsewhere [see John W. Moore, *J. Coll. Sci. Teaching* **4**(5), 319–321 (May 1975)].

The Suggested Reading lists at the ends of Parts I through VII should prove extremely useful to both students and teachers. The literature of environmental chemistry is diverse, and much important information is to be found in government documents and research reports which are less accessible than the journals familiar to most chemical researchers. We have attempted to collect the most useful references from all sources and to indicate their level and contents as accurately and as briefly as possible. For those who wish to delve further we suggest a study of the Appendix which surveys sources available in the environmental literature.

The International System (SI) of units, as described by Martin A. Paul, *J. Chem. Doc.* **11**, 3–8 (1971), has been adopted throughout the text. A summary of SI units and conversion factors appears on the front endpapers. This uniform and consistent set of units is especially helpful in the discussions of energy (Part II). The nomenclature *dioxygen* has been used throughout to distinguish gaseous O_2 from atomic or other forms of the element, and the prefix di has been attached in the case of other diatomic molecules as well. In many cases this aids in avoiding ambiguity, and we hope it will not appear unusual to our readers.

We firmly believe that many of the problems, techniques, and approaches to solutions discussed are of profound importance to both chemists and other scientists, as well as to the public at large. We hope that our readers will agree, and that they will give serious consideration to what contributions they can make toward the solution or abatement of particular environmental problems.

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A number of persons have made contributions to this book. Ronald W. Collins, Clark G. Spike, and K. Rengan, as well as other colleagues in the Department of Chemistry at Eastern Michigan University have provided valuable support and information. Mrs. Margaret Schultz cheerfully typed much of the manuscript on stencils and ran off copies for student use. Professors Henry A. Bent, John Hayes, Henry Foth, Margaret F. Fels, Roger Minear, and Dr. George L. Waldbott read and provided useful comments on portions of the manuscript. Professors Amos Turk and Barry Huebert each provided a more extensive review. Mr. Mark Riddle read and commented on an early version of the manuscript, and many of his suggestions were incorporated in its final form. Students who have used the materials in Eastern Michigan classrooms since 1972 have corrected errors and helped us clarify our prose.

One of us (JWM) is grateful for a fellowship in the Eastern Michigan University Center for the Study of Contemporary Issues during 1974–1975 which allowed additional time for writing and permitted numerous contacts with others in the environmental field. We gratefully acknowledge the library sources of Eastern Michigan University and the University of Michigan upon which we heavily relied for references and reports.

Special thanks are due Professor Theodor Benfey, editor of *Chemistry*, for permission to reproduce in its entirety the poem "Necessary Ethic" by Henry A. Bent which appears at the beginning of Part VII. Parts of Section 17.6 in expanded form have also appeared in *Chemistry* [**48**(6), June 1975] under the title "The Vinyl Chloride Story." We are also grateful for the permissions granted by other publishers to reproduce several of the figures and tables. Each of these is indicated in the text.

Finally, we wish to thank the staff of Academic Press for making our first attempt at textbook authorship proceed so smoothly.

By acknowledging contributions of others we do not intend to shift responsibility for any errors or omissions which remain. We are aware that in such a rapidly developing field no textbook can hope to be completely up-to-date. We hope that readers who detect errors or misstatements will be good enough to inform us of them so that they can be corrected in future printings.

Contents

I

Origins

What's past is prologue.

Shakespeare

The Present is the living sum total of the whole Past.

Thomas Carlyle

THE THREE CHAPTERS THAT CONSTITUTE PART I of this book are concerned with the application of a number of chemical subdivisions—nuclear chemistry, spectroscopy, acid-base theory, electrochemistry, thermodynamics, and biochemistry—to the understanding of the truly ancient history of the chemical elements, the earth, and the biosphere. At first glance such material may seem irrelevant, since environmental chemists are primarily concerned with today's problems and their effects on the future. On closer examination, however, many of the facts and principles contained in these three chapters are intimately related to more specific environmental problems which will be dealt with later on.

Chemistry can be applied fruitfully to many more than just those carefully defined problems encountered in the laboratory, and indeed it must be so applied if environmental problems are to be attacked successfully. The reader of this part of the book should constantly bear in mind that the techniques and philosophy of those chemists who have studied the origins of the earth and of life are highly useful in the evaluation of environmental threats. In both cases a broad knowledge is required to devise plausible scenarios or hypotheses which can be tested by application of scientific facts and logic.

Finally, it is the purpose of these three chapters to evoke an appreciation of the slow evolutionary development of the biosphere and its myriad, interconnected components. Only recently has any species achieved the levels of population and technology which today enable mankind to alter this evolutionary process significantly, rapidly, and on a global scale.

1

Origin of the Elements and Interstellar Molecules

We are brothers to the wind, the sun, the stars—and perhaps to more.

St.-John Perse

There is considerable (but far from conclusive[1]) evidence that the universe originated in a giant fireball which emerged from an infinitely dense collection of neutrons between ten and twenty billion years ago. This so-called "big bang" resulted in the formation of hydrogen and some helium nuclei from which galaxies and stars eventually evolved. It also is assumed to be responsible for the observation that the universe seems continually to be expanding and for the presence of background microwave radiation in outer space. The big bang began a process of evolution which continues to this day and seems capable of going on many billions of years into the future. The origin of the earth and its biosphere represent only a minor part of this universal evolution, but one which it is useful for us to examine in some detail.

1.1 NUCLEOSYNTHESIS OF THE ELEMENTS

Ninety chemical elements (those up through $_{92}$U excepting $_{43}$Tc and $_{61}$Pm) have been discovered in the substances that make up the crust and

[1] D. W. Sciama, "Modern Cosmology." Cambridge Univ. Press, London and New York, 1971.