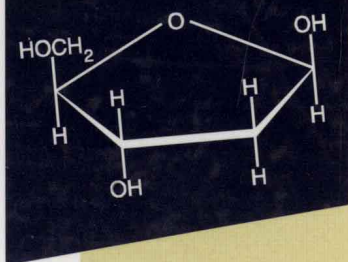
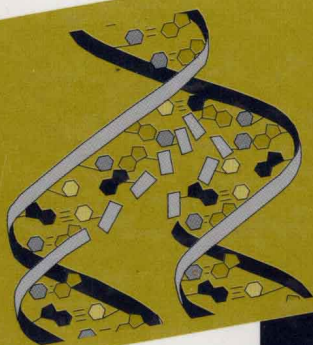


FUNDAMENTAL CONCEPTS OF ENVIRONMENTAL CHEMISTRY



G.S. SODHI



Alpha
Science

Fundamental Concepts of ENVIRONMENTAL CHEMISTRY

G.S. Sodhi



Alpha Science International Ltd.

G.S. Sodhi (M. Phil., Ph.D.)
Department of Chemistry, SGTB Khalsa College
University of Delhi, Delhi-110 007, India

Copyright © 2000

Alpha Science International Ltd.
P.O. Box 4067, Pangbourne RG8 8UT, UK

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the publishers.

ISBN 1-84265-012-2

Printed in India.

Preface

The term *Environmental Chemistry* has come to be regarded as synonymous with environmental pollution. Many conventional texts stick to this narrow definition and highlight only the problem of pollution resulting from the varied uses of chemicals. Yet it must be emphasised that environmental chemistry deals with a wider aspect of knowledge. The problem of pollution is just a small segment of this discipline.

A broader interpretation of the chemistry of the environment predates the pollution problem; it predates even the origin of universe. It initiates with the emergence of small atoms and molecules—the simplest chemical entities—and their organisation through various geochemical and geophysical processes into planets, including our earth. It then explains the evolution of earth's atmosphere and hydrosphere.

The hydrosphere provided a medium for the biochemical transformation of some of the simple chemical entities into molecules of life. With the emergence of life, each living species extracted a niche for itself. The habitat was gradually modified and thus emerged the biosphere.

Right from the time the man made the earth his home, he has tried to follow the hedonistic doctrine, that is, he has treated avoidance of pain and achievement of pleasure as the highest aim of mankind. In pursuit of this aim he developed a wide range of energy resources. The easy access to energy paved the way for modern methods of industrial and agricultural production.

The application of energy resources no doubt provided comfort and happiness to man, but it also started degrading his habitat. It was then that the problem of air and water pollution cropped up. It soon became apparent that the contamination of natural environment threatened the very existence of mankind. The hedonistic principle, therefore, demanded measures to check further ecological degradation so as to conserve the environment. Since then the philosophy of environmental conservation has come to stay with mankind.

It is in this broad perspective that this book is written.

G.S. SODHI

Acknowledgements

This text has been prepared under the Book Writing Scheme of the University Grants Commission (UGC), New Delhi (sanction letter No. F.10-11/93 (BP), dated August 12, 1993). Financial Assistance from the UGC is gratefully acknowledged.

It gives me immense pleasure to thank Dr. D.S. Claire, Principal, SGTB Khalsa College, University of Delhi, for his intellectual guidance, keen interest and important suggestions rendered during the tenure of my book writing scheme.

I feel complacent by placing on record my sincere thanks to Dr. S.S. Marwaha, Director, Punjab Council of Science and Technology, Chandigarh, for his perseverant help and cherishing attitude throughout the progress of the work embodied in this text.

I am obliged to Dr. R.S. Jolly, Scientist, Institute of Microbial Technology, Chandigarh and Dr. Gajendra Singh, Lecturer, Department of Pharmaceutical Sciences, Guru Nanak Dev University, Amritsar, for their assistance in literature survey.

Thanks are due to Dr. E.T. Eliasson, Geothermal Project Manager, National Energy Authority of Iceland, Reykjavik; Mr. Jurgen Dischoff, Director, Asia and Pacific Centre for Transfer of Technology, New Delhi; and Mr. B.B. Baliga, Editor-in-Chief, Indian Science News Association, Calcutta, for providing suitable reference materials and the permission to reproduce the same.

G.S. SODHI

Contents

<i>Preface</i>	v
<i>Acknowledgements</i>	vii

PART I: ABIOTIC ORIGIN **1-84**

1. Atoms and Molecules	3
Origin of the Universe	3
Nucleosynthesis	6
Interstellar Molecules	17
Inference	23
References	23
2. Solid Earth	25
Formation of the Earth	25
Zonal Structure of the Earth	28
Differentiation of Elements	33
References	35
3. Hydrosphere	36
Characteristics of the Hydrosphere	36
The Ocean	37
E Nino	49
Snow and Ice	52
The Fresh Water Systems	53
Water Vapours	54
References	55
4. Atmosphere	56
Origin of the Atmosphere	56
Composition of the Atmosphere	59
Structure of the Atmosphere	61
Temperature Inversion	63
Heat Balance of the Earth	64
References	65
5. Biosphere	66
Characteristics of the Biosphere	66
Biogeochemical Cycles	68
Soil	78
Inference	83
References	84

	PART II: BIOTIC ORIGIN	85–140
6. Life		87
Chemical Evolution and the Prebiotic Environment	87	
Stages of Chemical Evolution	90	
Inference	100	
References	102	
7. Cellular Environment		104
Origin of the Living Cell	104	
Chemical Constituents of the Cell	110	
Structure of the Cell	116	
How a Cell Functions	118	
References	119	
8. Cellular Alterations		120
Mutagenesis	120	
Teratogenesis	123	
Carcinogenesis	130	
References	138	
	PART III: ENERGY	141–214
9. Energy Flow		143
A Chemist's Perspective	143	
A Biologist's Perspective	145	
Energy Resources	148	
Energy Conservation	149	
References	151	
10. Fossil Fuels		153
Coal	153	
Petroleum	156	
Oil Spills	159	
Natural Gas	163	
Oil Shales	164	
Inference	166	
References	166	
11. Terrestrial Energy		168
Geothermal Energy	168	
Hydrogen-Based Economy	177	
Inference	181	
References	182	
12. Solar Energy		183
Utilization of Solar Energy	183	
Environmental Impacts of Solar Energy	190	
Inference	190	
References	191	

13. Nuclear Energy	192
Nuclear Power Generation	192
Nuclear Waste Disposal	199
Transmittance of Radioactivity to Humans	203
Effects of Radioactivity on Human Health	204
Risk Analysis of Nuclear Power Generation	206
Nuclear Catastrophes	208
Inference	213
References	214
PART IV: AIR POLLUTANTS	215–302
14. Sulfur Oxides	217
Sources of Sulfur Oxides	217
Fate of Sulfur Oxides in the Environment	219
Analysis of Sulfur Oxides	220
Effects of Sulfur Oxides	221
Control Measures for Sulfur Oxides	222
Acid Rain	224
References	228
15. Nitrogen Oxides	230
Sources of Nitrogen Oxides	230
Fate of Nitrogen Oxides in the Environment	230
Analysis of Nitrogen Oxides	231
Effects of Nitrogen Oxides	232
Control Measures for Nitrogen Oxides	233
References	239
16. Carbon Monoxide	240
Sources of Carbon Monoxide	240
Fate of Carbon Monoxide in the Environment	242
Analysis of Carbon Monoxide	244
Effects of Carbon Monoxide	245
Control Measures for Carbon Monoxide	246
References	246
17. Photochemical Smog	248
Formation of Photochemical Smog	248
Effects of Photochemical Smog	252
Control of Photochemical Smog	253
References	254
18. Greenhouse Gases	256
The Greenhouse Effect	256
Causes of Greenhouse Effect	256
Consequences of Greenhouse Effect	260
Abatement of Greenhouse Effect	263
Tie-in-Strategies	266

The Kyoto Protocol	267
References	268
19. Depletion of Stratospheric Ozone	270
Introduction	270
Mechanism of Ozone Depletion	272
Causes of Ozone Depletion	279
Consequences of Ozone Depletion	282
Abatement of Ozone Depletion	284
The Montreal Protocol	287
References	288
20. Suspended Matter	290
Types of Particulates	290
Sources of Particulates	293
Fate of Particulates in the Environment	296
Analysis of Particulates	296
Effect of Particulates	297
Control Measures for Particulate Pollution	301
References	302
PART V: WATER POLLUTANTS	
	303-368
21. Classification of Water Pollutants	305
Unique Characteristics of Water	305
The Different Types of Pollutants	307
Thermal Pollution	315
References	319
22. Heavy Metals	320
Mercury	320
Biomethylation of Mercury	321
Bioamplification of Mercury	322
Mercury Poisoning	323
Analytical Procedures for Estimation of Environmental Mercury	325
Antidotes to Mercury Poisoning	325
Abatement Procedures against Mercury Poisoning	326
Lead	327
Sources of Lead	327
Lead Poisoning	328
Analytical Procedures for Estimation of Environmental Lead	330
Antidotes to Lead Poisoning	330
Abatement Procedures against lead Poisoning	331
Inference	332
References	332
23. Soaps and Detergents	334
The Need	334
The Classification	335

The Characteristics	336	
Environmental Impacts of Soaps and Detergents	339	
Abatement Procedures for Soaps and Detergents Pollution	341	
References	343	
24. Paper Mills		344
Paper Manufacture	344	
Environmental Implications of Paper Mills	348	
Abatement of Paper Mill Pollution	349	
References	351	
25. Water Treatment		352
Water Purification	352	
Criteria of Water Purity	364	
References	366	
PART VI: POLLUTANTS FROM INDUSTRY		369–402
26. Polymers and Plastics		371
The Need	371	
The Classification	372	
The Characteristics	373	
Environmental Implications of Polymers and Plastics	376	
Abatement Procedures for Polymer and Plastic Pollution	378	
References	380	
27. Asbestos		381
Structural Characteristics of Asbestos	381	
Applications of Asbestos	382	
Sources of Asbestos in the Environment	384	
Analysis of Asbestos	384	
Effects of Asbestos Pollution	385	
Mitigation of Asbestos Pollution	387	
References	388	
28. Food Additives		389
The Need	389	
The Classification	390	
Risk Analysis of Some Specific Food Additives	395	
Inference	401	
References	402	
PART VII: POLLUTANTS FROM AGRICULTURE		403–440
29. Fertilizers		405
The Need	405	
The Classification	406	
Environmental Implications of Fertilizers	407	
Abatement Procedures for Fertilizer Pollution	409	

Eutrophication	409	
References	413	
30. Insecticides		414
The Need	414	
The Classification	415	
The Characteristics	415	
Environmental Implications of Insecticides	418	
Abatement Procedures for Insecticide Pollution	420	
Bhopal Episode	423	
References	426	
31. Fungicides and Herbicides		428
The Need	428	
The Classification	430	
The Characteristics	433	
Environmental Implications of Fungicides and Herbicides	434	
Abatement Procedures for Fungicide and Herbicide Pollution	438	
References	440	
PART VIII: ENVIRONMENTAL RESTORATION	441–456	
32. Is It Possible?		443
Structural-Functional Approach	443	
Noise Pollution	448	
References	450	
33. India's Efforts		451
National Committee on Environmental Planning and Coordination	451	
The Tiwari Committee	452	
Department of Environment	452	
Environment (Protection) Act, 1986	453	
Some Voluntary Agencies Working for Environmental Conservation	455	
References	456	
INDEX		457

Part I

Abiotic Origin

CHAPTER 1

Atoms and Molecules

Believe it or not, all naturally occurring elements which are the building blocks for all forms of matter, both the living and the nonliving, originated in the cores of stars. The study of the origin and build-up of these elements in the stars is called *nucleosynthesis*. The interstellar space was also the site where the first series of molecules were formed. Therefore, these molecules are referred to as *interstellar molecules*. To know more about nucleosynthesis and interstellar molecules, we have to know a great deal more about the origin of the universe.

Origin of the Universe

There are two theories pertaining to the origin of the universe: Static (or the steady state) theory and the evolutionary (or the big-bang) theory. The steady state theory (or the continuous creation hypothesis as is often called) propounds that the universe did not have a beginning in time and that matter is being created on a continuous basis. The big-bang theory, on the other hand, supports the idea that the universe had a beginning in time. It advocates that the universe was created at time t_0 , about 10^{10} years ago, when a hyperdense sphere of matter packed into a volume roughly that of our solar system, with extremely high density and temperature, exploded in a 'big-bang' at or near the velocity of light.

How can these two patently divergent views be reconciled? Which of the two theories is more accurate? We do not know; perhaps we shall never know. However, the astronomical evidence is biased in favour of the big-bang hypothesis. We shall, therefore, choose the 'big-bang' as the starting point of our discussion on the origin of the universe.

The Three Eras

The big-bang model divides the history of universe into three eras—radiation era, matter era and the life era. Each era is subdivided into a number of epochs; each epoch corresponds to a specific period in the build-up of the universe. Fig. 1.1 shows the time scale delineation of the three eras and the corresponding epochs.

1. The radiation era

The hyperdense sphere of matter which caused the big-bang was a giant neutron ball consisting of 10^{78} to 10^{79} neutrons. This neutron ball is often referred to as

4 Fundamental Concepts of Environmental Chemistry

primordial matter or "Ylem". The temperature of the "Ylem" was about 10^{30} K. The first epoch, the *chaos epoch*, lasted for just 10^{-27} second, during which time the neutrons of the "Ylem" remained stable. Thereafter, the disintegration of neutrons into protons and mesons initiated, and lasted upto about 10^{-3} second. This stage is referred to as the *hadron epoch*. The neutrons, protons and mesons (collectively called hardons) collided with one another and were converted to high energy photons, thus creating a brilliant fireball of radiation. The temperature during the hadron epoch dropped to about 10^{12} K.

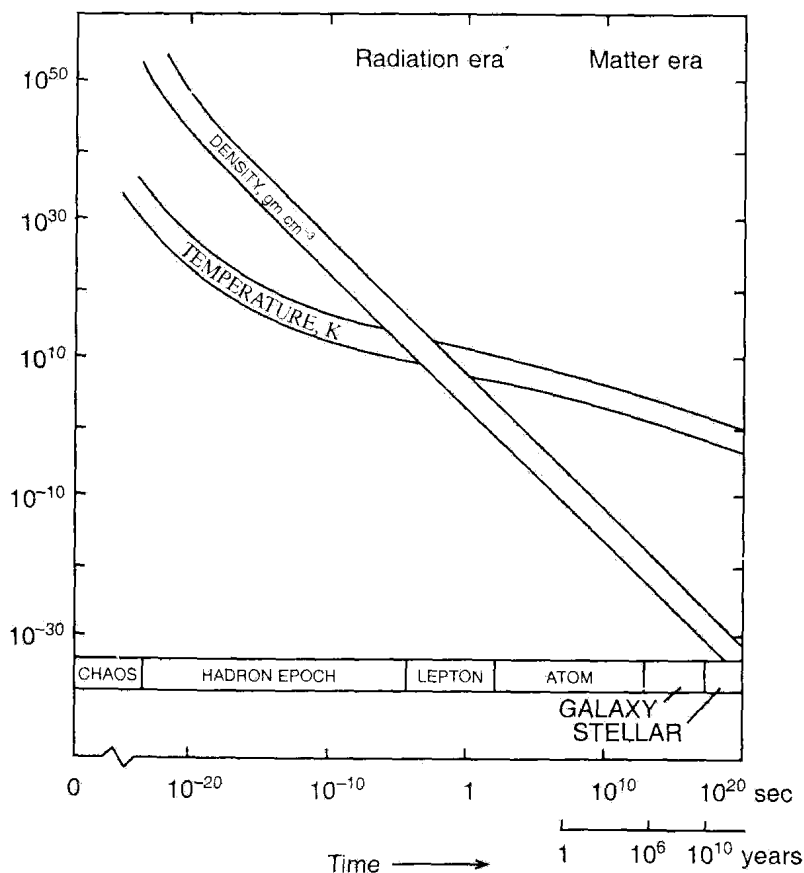


Fig. 1.1 Variation of temperature and density following the big-bang

As the universe expanded, its contents cooled. The average temperature during the third epoch, called the *lepton epoch*, dropped to about 10^{10} K. During this epoch, the lighter elementary particles, such as electrons, neutrinos and muons (collectively called leptons), began to emerge. However, like the hardons, these too were transformed into photons. The lepton epoch lasted upto a few hundred seconds after the big-bang.

During the first three epochs, the radiation density exceeded the matter density by a large amount. Photons of radiation outnumbered particles of matter. As soon as the elementary particles of matter had begun to coagulate, fierce radiation destroyed them. For this reason, the first three epochs are collectively referred to

as the radiation era. Whatever matter existed was merely an inconspicuous precipitate suspended in a sea of dense, brilliant radiation.

2. The matter era

The fourth epoch, called the *atom epoch* extended in time from about a few hundred seconds to about a million years after the big-bang. Midway through this epoch, the average temperature had fallen to about 10^6 K. Towards the beginning of the atom epoch, radiation still dominated the matter and the universe remained flooded with photons. However, as the universe expanded the photon density decreased. The early dominance of radiation thus also diminished. Sometime between a few minutes and a million years after the big-bang, the charged elementary particles of matter were able to coagulate electromagnetically without being broken apart by radiation. Henceforth, matter would dominate radiation as the principal constituent of the universe.

The influence of radiation had grown so weak that it could no longer prohibit the combination of those leptons and hadrons which had not been transformed into photons. As a result of this combination atoms began to appear. The first to be formed was hydrogen, since it required only a combination of a single electron to a single proton. Significant amounts of hydrogen atoms were synthesized in the early universe.

So long as the temperature of the universe exceeded 10^7 K, fusion of hydrogen atoms resulted in the formation of helium atoms. However, as the temperature dropped below the critical value of 10^7 K, the synthesis of helium, as well as of the higher atomic number elements, ceased. In contrast to the rapid cooling of the early universe, the dense interior of the stars were (and are) suitable for the generation of hotter temperatures and thus of heavier elements. The core of the stars were where the heavier elements were created—and where they are still being created. We shall discuss the plausible mechanisms for the synthesis of these heavy elements in the section on nucleosynthesis.

By the end of the atom epoch, matter was in firm control. During the fifth epoch, the *galaxy epoch*, gravity began to pull some of this matter together into enormous clumps. Galaxies were beginning to form; hot gases, intense radiation and turbulence of the clumps were conducive to galaxy formation. By the middle of the galaxy epoch, the average temperature of the universe had decreased to about 3000 K. The universe was becoming thinner, colder and darker.

The next epoch is the present *stellar epoch*. The dominant episode of this epoch was the formation of stars. As now, the universe has an average density of 10^{-30} g cm⁻³ and an average temperature of 3 K. Under these conditions, the formation of new galaxies is an impossibility. Nevertheless, stars are being formed within the existing galaxies.

The atom epoch, the galaxy epoch and the stellar epoch are collectively termed as the matter era. During this era the matter prevailed, while the radiation subsided. The epochs in the radiation era were spread over a few minutes; the epochs of the matter era were spread over millions of years. The reason being that when the universe was extremely hot, events occurred at a rapid pace; once it cooled, the pace of events slowed down. For example, the formation of stars

and their life cycles cover millions and millions of years. During these eons heavy elements have been, and are being, synthesized at a slow pace.

3. The life era

The atoms formed in the universe combined to give molecules. Since these molecules were formed in space, they were termed interstellar molecules. Initially, the interstellar molecules were simple in composition. Gradually, more complex molecules were formed. The increasing complexity of the interstellar molecules with the passage of time is called *chemical evolution*. The chemical evolution finally led to the formation of amino acids and proteins—the molecular building blocks of life.

The life era covers not only the emergence of life on earth, but also the emergence of technologically intelligent life. Technology enables life to control matter, much as matter grew to dominance over radiation, billions of years ago. Matter is now losing its total dominance, at least at those isolated locations where technologically intelligent life persists. The transformation from matter era to life era was not instantaneous. It took millions of years for the matter to dominate over radiation; it took an even greater time for life to dominate over matter. And the transformation is not yet complete—at least when we strive for a more advanced, technologically intelligent life. Hence we name this epoch as the *future epoch*.

Nucleosynthesis

During the atom epoch, the combination of a proton and an electron produced a hydrogen atom. The heavier elements were produced by a series of nuclear reactions which occurred in the cores of stars. The build-up of the elements in the cores of stars is called nucleosynthesis. In order to discuss the role that stars played in the nucleosynthesis, we shall have to describe, qualitatively, the formation and structure of stars.

Life Cycle of a Star

A star is not a static heavenly body. It changes, evolves and dies. The younger stars, such as our sun, are called *Population I stars*, while the older ones are referred to as *Population II stars*. An earlier Population II star was obviously formed when the universe was rich in hydrogen and had small amounts of some lighter atoms like deuterium, helium and lithium. As the condensation of these atoms into the star proceeded, the gravitational potential energy of the atoms was converted into kinetic energy. As a result, a great diffuse mass of gas agglomerated at an accelerated pace, becoming progressively smaller, denser and hotter. Over the next millions of years, the star became compact and spherical and continued to consume hydrogen in various nuclear reactions. When hydrogen was exhausted in the core of the star, the star began to lose energy. To make up for the energy deficit, it contracted under the influence of gravitational forces and became hotter and denser. For the next millenia, the star became optically opaque and began to emit infrared radiation. It continued to lose energy and contract; the density and temperature continued to rise till the star exploded into