Contents

CHAPTER 1

Matter and Energy. The Interplay of Elementary Particles and Elementary Forces

1.1 An Attempt to Describe the Natural World Using the Smallest Number

	of Elementary Phenomena	1
1.2	General Foundations of the Physical Sciences	4
	1.2.1 Some principles	4
	1.2.2 Some properties of the elementary phenomena are governed by very	
	exact and strong laws of conservation	4
	1.2.3 Prohibitions	5
1.3	Elementary Forces and Particles	5
	1.3.1 Elementary forces	5
	1.3.2 Elementary particles	7
1.4	Elementary Particles	8
	1.4.1 "Bricks" and "mortar"	8
	1.4.2 Creation of the elementary particles	9
	1.4.3 "Life" and "death" of elementary particles	11
1.5	The Existence of Atomic Nuclei Is Due to the Forces of Attraction	
	Between Their Nucleons	12
	1.5.1 The weak force limits the number of stable hadrons	12
	1.5.2 Strong force binds the nucleons together	13
	1.5.3 Binding energy of a nucleon	14
1.6	Matter and Free Energy – The Intimate Connection	15
1.7	What Are the Conclusions for the Future Development of Mankind?	17
	Chapter 2	
	The Universe: How Is It Observed Here and Now? Its Past and Possible Future	
2.1	What Is the Universe?	19
		19
		19

2.2	Expansion of the Universe	21					
	2.2.1 The red shift	21					
	2.2.2 The five eras of the Universe	21					
2.3	What Is Known About the Universe Today?	21					
	2.3.1 The average composition of the Universe	21					
	2.3.2 Chemical composition of cosmic matter	24					
	2.3.3 Composition of photons	25					
2.4	The Universe as a Whole	26					
2.5	The Future of the Universe	28					
2.6	What Conclusions Can Be Drawn for the Future Development						
	of Mankind?	29					
	Chapter 3						
	The Origin and Nuclear Evolution of Matter						
	_						
3.1	The Creation of the Elementary Particles in the Very Early Universe 3.1.1 Unknown phase: Era of superunified force (Planckian Era or	30					
	Very Hot Era)	30					
	3.1.2 Era of grand unified force (Hot Era)	31					
	3.1.3 Era of unified force (Lukewarm Era)	31					
	3.1.4 Cold Era and Very Cold Era	32					
3.2	2 Evolution of the Elementary Particles. A Very Rapid Development						
	in the First Seconds of the Universe	33					
	3.2.1 Beginning of the Cold Era: Evolution in the "Hadron Epoch"	33					
	3.2.2 Production of hydrogen, deuterium, and helium: The Universe a	33					
	few seconds old; Lepton Epoch	36					
2.2		20					
3.3	The Beginning of the Present Very Cold Era: The "Stars Era".	27					
	The Evolution of Galaxies, Stars, and Life	37 37					
	3.3.1 The largest of the cosmic structures: The development of galaxies. 3.3.2 The evolution of stars; the nuclear and gravitational reactors	37					
	3.3.3 The protostar evolves from diffuse matter	39					
	3.3.4 The longest living stars, those of the Main Sequence	42					
	3.3.5 Red Giants: The cold stars with the hot interiors	43					
	3.3.6 Evolution towards hot dense stars	44					
	3.3.7 Explosion of a supernova: The most spectacular event in a galaxy.	45					
	3.3.8 Extremely dense stars: Neutron stars (pulsars) and black holes	45					
3 4	The Burning of Hydrogen – Nucleosynthesis in the Stars	46					
٥. ١	3.4.1 Deuterium: The fuel of protostars	46					
	3.4.2 The slow burning of hydrogen	47					
	3.4.3 The burning of hydrogen in a catalytic cycle assisted by carbon,						
	nitrogen, and oxygen	49					
3.5	Helium also Burns, but under More Extreme Conditions	49					
5	3.5.1 Production of carbon from the burning of helium	49					
	3.5.2 A very vital step: The production of oxygen	50					

		n, Oxygen, and Other Elements of Medium Mass Burn in a Flash.	50
		Energy production and energy required for nucleosynthesis	50
		Iron, the nuclear ash	50
		ysthesis of Heavy Elements: The Need for an External Energy	
Sou			51
		How can uranium be synthesised?	51
		The "s-process", the slow-process of neutron capture	52
		The "r-process", the rapid-process of neutron capture	53
		c Rays – A Strange Form of Matter	55
3.9	What	Are the Conclusions for the Future of Mankind?	56
		Chapter 4	
•	Chemi	cal Evolution and the Evolution of Life: The Cosmic Phenomena	
4.1	Chem	ical Evolution: Another Phase in the Evolution of Matter	58
	4.1.1	Special case of the electromagnetic force: The chemical force	58
		The actors in the chemical play	58
4.2		ical Synthesis Occurs in Cosmic Space	62
	4.2.1	,	62
	4.2.2		63
		Comets: Rare and strange, but formidable, chemical reactors	65
	4.2.4	Meteorites often consist of very "sophisticated" chemical compounds	66
	4.2.5	"Organic molecules" on the Moon and planets	67
4.3		Origin of the Planets	70
	4.3.1	Have the planets been formed "by chance"?	70
	4.3.2	The protoplanet, the first stage of evolution	71
	4.3.3	The chemical evolution of the Earth: A complex and dramatic	
		development	72
		All stable elements present in the Universe exist on Earth	75
	4.3.5	The history of the Earth has been influenced by the movement of	7.
	126	the continents	77
	4.3.6	The first phases of chemical evolution were driven by different	70
	a .1	energy sources and were influenced by a number of factors	78
4.4	•	esis of Complex Molecules on the Primitive Earth	82
	4.4.1		82
	442	hydrogen	83
	4.4.2 4.4.3	How were the large molecules, the polymers, produced?	84
4 ~			
4.3		Is Life? The Need for a General Definition	85
	4.5.1	Could life have originated spontaneously?	86
	4.5.2 4.5.3	What kind of elementary forces can play the role of energy carriers	00
	4.5.5	for living systems?	88
	454	What kind of elementary particles can play the role of carriers of life?	88

4.6	The Chemical Elements, Particularly the Light Elements,						
	Are the Carriers of Life						
	4.6.1	Why are the light elements best fitted for this role?	89				
	4.6.2	Why is hydrogen oxide – water – the unique medium for living	_				
		organisms?	91				
	4.6.3	The source of free energy for life: The stars of the Main Sequence.	92				
	4.6.4	The chemical composition of the living organism is similar to the					
		chemical composition of the Universe	94				
	4.6.5	Life is only possible in a Universe having the characteristics of our					
		type of Universe	96				
4.7	What	Can We Hope to Know About the Spontaneous Formation					
		rrestrial Life?	97				
	4.7.1	The problem: The uniqueness of life in our present state of					
	,	knowledge	97				
	4.7.2	The protobionts: The first living structures	98				
	4.7.3	The evolution of the living being occurred at the switch-over point	-0				
	4.7.5	from one energy source to the next	98				
4.0	T 1						
4.8		tion of Living Beings	101				
	4.8.1		101				
	4.8.2	The evolution of Man	102				
	4.8.3						
4.9	What	Are the Conclusions for the Future of Mankind?	104				
		Chapter 5					
		The Eternal Cycle of Matter on the Earth	-				
		•					
5.1	Matte	er on This Planet Is Almost Indestructible	105				
	5.1.1	How stable is terrestrial matter?	105				
	5.1.2	Terrestrial matter is isolated by the gravitational field; the amount					
		of matter is constant	106				
	5.1.3	Division of the Earth into five "spheres"	106				
5.2	The C	Gaseous Sphere Acts in the Exchange Between the Other Spheres	108				
	5.2.1	The main components of the atmosphere	108				
	5.2.2	The most active component, oxygen, a product of the biosphere.	110				
		Ozone: Modified oxygen which acts as a shield for the biosphere.	112				
	5.2.4	The carbon cycle, a chain directly related to the flow of energy in					
		the biosphere and technosphere	113				
	5.2.5	The "inert" nitrogen cycle, which controls the activity of the biosphere	116				
	5.2.6	The micro-components of the atmosphere, the troublesome "details"	117				
	5.2.7	Dust particles, a troublesome constituent of the atmosphere	119				
53		Hydrosphere – A Crucial Factor in the Existence of the Biosphere.	120				
	5.3.1	The cycling of water, the largest terrestrial material cycle	120				
	5.3.2	Quality of water, quality of life	122				

a	•
Contents	X1
Contonts	Al

	5.3.3 Man's demand for water is gigantic	123
	5.3.4 Drinking water, where purity counts	124
	5.3.5 The erosion of the planetary surface	125
5.4	The Solid Earth, the Litosphere	125
	5.4.1 The main components of the Earth's crust	125
	5.4.2 The Earth's crust, the main source of materials for our civilisation	126
	5.4.3 Metals "prepared" by Nature, the most widely used	128
5.5	Ordered Matter and Entropy	130
	5.5.1 Concentration means increase of order and decrease of entropy	130
	5.5.2 Impact of substances in very small amounts: Poisons	131
	5.5.3 Material dissipation and waste formation increases entropy	132
5.6	What Are the Conclusions for Mankind's Future Development?	133
	Chapter 6	
	The Flow of Energy on the Earth	
		125
0.1	The Source of Free Energy on the Earth	135 135
	6.1.2 The elementary forms of energy	136
	6.1.3 How large is flux of energy?	137
62	The Energy Sources on the Earth	139
٠.2	6.2.1. Solar energy – The most important source	139
	6.2.2 Spectrum and albedo of solar light	140
6.3	Solar Energy and Climate	142
	6.3.1 The solar energy flux is not constant	142
	6.3.2 Solar energy is transformed into numerous forms and types of energy	145
	6.3.3 The past and future of the terrestrial climate	147
	6.3.4 The local climate depends on continental drift	148
6.4	Non-solar Terrestrial Energy Sources	150
	6.4.1 Other non-solar flows of energy play a small but not insignificant role	150
	6.4.2 The importance of the amount of stored energy	151
6.5	How Much Energy Does Man Need?	152
	6.5.1 Does man need energy at all?	152
	6.5.2 The sources of energy are changeable	154
6.6	The Indirect Use of Solar Energy	156
	6.6.1 The biosphere as Man's energy source for technology	156
	6.6.2 Transformation of solar into kinetic energy: Wind	157
	6.6.3 Transformed solar energy: The kinetic energy of falling water	158
	6.6.4 The "insignificant" form of solar energy: The heat of the oceans .	159
	6.6.5 The best forms of stored solar energy: Oil and coal	159
6.7	The Direct Technological Use of Solar Energy	163
	6.7.1 The simplest way: Space heating	163
	6.7.2 Solar energy converted into electricity on the Earth's surface	164
	6.7.3 The extraterrestrial conversion of solar into electrical energy	166

xii Contents

6.8	Technological Use of Non-solar (Nuclear) Energy	. 	167
	6.8.1 The heaviest elements: The gift of the supernova		167
	6.8.2 Geothermal energy results from the nuclear decay of radionuc	clides	168
	6.8.3 The fission of the heavy nuclides is one of the most abundant	t	
	terrestrial energy sources		169
	6.8.4 Fusion: The second coming of nuclear energy	:	174
6.9	Are There Other Sources of Energy?	:	177
6.10	Energy Production as a Source of Dangerous Waste and Environn	nental	
	Problems		179
	6.10.1 Energy production and nonradioactive waste materials		179
	6.10.2 Radioactive waste from nuclear energy		181
	6.10.3 Are fission reactors really dangerous?		182
	6.10.4 Radioactive waste and its management		183
	6.10.5 Fusion: The controlled thermonuclear reactor – Is this the		
	"clean" solution?		185
	6.10.6 Thermal waste, the local and global problem	'	186
	6.10.7 Surface waste in the production of energy		186
6.1	The Economics of Energy Production		188
	6.11.1 The energy cost of energy		188
	6.11.2 What is the price of energy?		189
6.1	2 What Are the Conclusions for the Future Development of Mankin	d?	190
	CHAPTER 7	.	
	The Biosphere: The Coupling of Matter and the Flow of Free	Lnergy	
7.1	The Biosphere: The Coupling of Matter and the Flow of Free Ener	gy	192
7.2	The Terrestrial Biosphere: Mass and Productivity		193
	7.2.1 The greatest component of the biosphere is, in terms of mass		
	the form of trees		193
	7.2.2 The biosphere's productivity does not match its pattern of distri		196
	7.2.3 The surprisingly simple chemical composition of the biosphere		198
7.3	The Magnitude of the Flow of Energy in the Biomass		199
	7.3.1 The direct net flux of energy in the biosphere is some 92 TW		199
	7.3.2 The total solar energy flux consumed by the biosphere `.		200
	7.3.3 The biosphere in the past		201
	7.3.4 The green plant is not only a synthesiser, it is also a water vap	ouriser	204
7.4	The Biosphere as a Source of Food for Mankind		206
	7.4.1 How much free energy in the form of food does Man need?.		206
	7.4.2 Man requires numerous structural materials for his body		206
	7.4.3 The winning of food from the biosphere		208
7.5	Agriculture, Source of Food for Humans		209
	7.5.1 Agricultural requirements of the average man		209
	7.5.2. Human food quality		211

Contents	xiii

7.6	Constraints on the Further Development of Agricultural Production	213
	7.6.1 Can the area under cultivation be increased?	213
	7.6.2 Can agricultural production be doubled over the next 50 years?	215
7.7	The Ocean. A Source of Human Food?	216
	7.7.1 How productive is the ocean?	216
	7.7.2 The ocean is an important source of proteins	219
7.8	Food Production Needs a Large Energy Input	220
	7.8.1 Solar and technological energy input to agriculture	220
	7.8.2 Single-Cell protein – A new food source	222
7.9	The Biosphere Is More than a Source of Food	223
7.10	0 What Conclusions Can Be Drawn for Mankind's Future Development? .	223
	Chapter 8	
	Is the Future Development of Mankind on This Planet Possible?	
8.1	Is It Possible to Consider the Future?	226
8.2	The Main Problem: The Increase of the World Population	226
	8.2.1 Is it wrong to consider mankind as part of the biosphere?	226
	8.2.2 The growth of world population in the past	227
	8.2.3 The reference case used in this chapter – A stable world population	
	of 8 billion	228
8.3	Problem No. 2: A Place on the Earth for Everyone	229
	8.3.1 How much space will each inhabitant have in the future?	229
	8.3.2 Organisation of space and transport: The energy lost	231
	Problem No. 3: Food for Everyone	231
8.5	Problem No. 4: Material Resources for Everyone	233
	8.5.1 Maximum recycling and minimum use	233
	8.5.2 Material recycling and energy	236
8.6	The Ultimate Problem for the Future of Mankind: The Flow of Free Energy	
	8.6.1 Why energy?	
	8.6.2 The prognosis for energy consumption	237
	8.6.3 How much energy is needed to produce the technological energy	220
	used by Man?	
	8.6.4 The future source of free energy	
07	8.6.5 Not only the free energy sources are important but also the sinks! .	
ŏ./	The Future Climate of This Planet	
00	1	
	The Quality of Life	243
8.9	What Conclusions Can Be Drawn Concerning the Future Development of Mankind?	244
	OL WATERIO /	/44

Chapter 9

The	Distant	Future	Λf	Mankind	- T	errestrial	or	Cosmic?
THE	Distant	Lutuic	uı	Dimanta	_ 1	CIICSUIAI	v.	COSHIEC

9.2 The Future Development of the Universe	. 249
9.3 The Future of the Galaxy and the Sun	
9.3.1 The stability of galaxies	
9.3.2 How stable is the cosmic neighbourhood of the Solar system?	. 252
9.3.3 How stable, how predictable is the Sun?	. 254
9.4 The Future of the Planet Earth	. 256
9.4.1 The stability of the planet	. 256
9.4.2 The fall of small cosmic objects and earthquakes	
9.4.3 The future terrestrial climate	. 258
9.5 The Possibilities for Mankind: Self-destruction, Self-isolation, Expansion	259
9.6 Human Colonies in Space – Possibility or Nonsense?	. 261
9.7 The Existence of Other Planetary Systems with Intelligent Life	
9.7.1 How many stars have planetary systems?	
9.7.2 How many planets having intelligent life could exist?	
9.8 The Extraterrestrial Exchange of Information	. 265
9.9 Summary of the Limits of World Population Growth	. 267
9.10 Human Galactic Expansion and the Drake Limit	
9.10.1 The expansion velocity	
9.10.2 The energy need for cosmic journeys	. 270
9.11 Is It Really Impossible to Colonise the Galaxies?	. 272
9.12 The Very Distant Future; Mankind on This Planet	. 273
9.13 What Are the Conclusions Concerning the Distant Future of Mankind	273
7011 I	055
Bibliography	. 275
Index	. 281