

Contents

1	The Solar System and the Heliosphere	1
1.1	Properties of the Solar System	1
1.2	Dynamo Processes and Magnetic Properties	3
1.3	The Sun's Influence on the Heliosphere	5
1.4	On the Study of Heliospheric Space Weather	6
	Further Reading	10
2	Exploring the Sun and Heliosphere.	11
2.1	Brief History of Magnetic Phenomena and Processes in the Solar System	12
2.2	Observatories in Space and on the Earth	14
2.2.1	Brief History of Space Missions	14
2.2.2	Ground-Based, Balloon-Borne and Rocket-Observing Solar Telescopes.	20
2.3	People and Their Research Methods	24
2.4	Some Measuring Instruments and Techniques.	25
2.4.1	General Remarks	25
2.4.2	Measurements of Particles	26
2.4.3	Field Measurements	29
2.4.4	Photon Measurements	31
2.5	Analytical Modelling and Numerical Simulation	33
	Further Reading	35
3	The Active Magnetic Sun	37
3.1	Magnetic Solar Phenomena	39
3.2	The Inner Structure and the Atmospheric Layers of the Sun.	40
3.2.1	A Look into the Interior of the Sun	40
3.2.2	Solar Phenomena in the Atmospheric Layers	42
3.2.3	Sunspots and Faculae Regions in the Photospheric Network	45
3.2.4	Chromospheric Network and Corona Above the Sunspots	47

3.2.5	About the Origin of Sunspots	47
3.2.6	Evolution of Sunspot Number and Magnetic Flux Densities over the 11- and 22-Year Activity Cycles	52
3.2.7	The Passive and Active Sun	55
3.3	Generation of Solar Magnetic Fields in Dynamo Processes	55
3.3.1	The Dynamo-Electric Principle of Werner von Siemens	57
3.3.2	On the Realisation of Cosmic Dynamo Processes	57
3.3.3	How the Solar Dynamo Works	58
3.3.4	The α - Ω Dynamo Model	60
3.3.5	The Flux Transport Dynamo Model	62
3.4	Chromospheric Network, Spicules and Tornadoes	65
3.4.1	Chromospheric Spicules	67
3.4.2	Atmospheric Heating by Chromospheric Tornadoes	68
3.4.3	Solar Gas Clouds over the Solar Limb	70
3.5	Prominences and Coronal Magnetic Field Structures	71
3.5.1	Prominences and Filaments	72
3.5.2	Field Structure Developments in Prominences	72
3.5.3	The Unstable “Grand Daddy” Hedge Prominence	74
3.6	Flares, Solar Eruptions and Coronal Mass Ejections	75
3.6.1	Release of Magnetic Energies in Flare Processes	76
3.6.2	Eruptions of Solar Prominences	80
3.6.3	Coronal Mass Ejections	81
3.7	About the Heating of the Solar Atmospheric Layers	84
	Further Reading	88
4	The Solar Wind in Space	91
4.1	Historical Remarks	91
4.2	Solar Wind and Heliosphere	93
4.2.1	Regions of the Heliosphere	93
4.2.2	At the Edge of the Heliosphere and Solar System	95
4.3	Properties of the Solar Wind and Their Variations During the Solar Cycle	98
4.3.1	Fundamental Parameters	98
4.3.2	Spatial Variations	99
4.3.3	Temporal Variations with the Solar Cycle	101
4.4	Sources of the Solar Wind in the Solar Corona	102
4.4.1	Large-Scale Sources in the Corona	103
4.4.2	Small-Scale Sources in the Chromospheric Network	106
4.4.3	Short Summary	109
4.5	Heating of the Corona and Acceleration of the Solar Wind	110
4.5.1	Temperatures and the Heating Problem of the Solar Atmosphere	110
4.5.2	On the Acceleration of the Solar Wind	112
4.5.3	Coronal Mass Ejections	116
4.5.4	On the Heating of the Solar Corona	118

4.5.5	On the Acceleration of Heavy Ions	120
4.6	The Dynamic Heliosphere	121
4.6.1	Turbulence and Waves in the Solar Wind	121
4.6.2	Shock Waves and Discontinuities in the Solar Wind	127
4.7	Microscopic Processes in the Solar Wind	131
4.7.1	General Considerations	131
4.7.2	Velocity Distributions and Fundamental Concepts	134
4.7.3	Characteristic Lengths and Times in the Solar Wind	136
4.7.4	Distribution Functions of Electrons	138
4.7.5	Distribution Functions of Protons	140
4.7.6	Plasma Microinstabilities	142
4.7.7	Heavy Ions in the Solar Wind	145
	Further Reading	147
5	Parker Solar Probe and Solar Orbiter	149
5.1	New Epoch in the Exploration of the Inner Heliosphere	149
5.2	Scientific Goals and Instruments of Parker Solar Probe	151
5.2.1	Scientific Questions	151
5.2.2	Scientific Instruments	154
5.3	Scientific Goals and Instruments of Solar Orbiter	154
5.3.1	Scientific Questions	154
5.3.2	Scientific Instruments	156
5.4	First Results of the Missions	158
5.4.1	Images of the Solar Wind from WISPR	158
5.4.2	Waves and Turbulence in the Solar Wind	159
5.4.3	Magnetic Field Reversals	159
5.4.4	Campfire in Ultraviolet Light	163
5.4.5	Ultraviolet Line Spectrum of the Solar Atmosphere	163
5.4.6	Determining the Speed of the Solar Wind	165
5.4.7	News from PSP and SO	167
	Further Reading	169
6	Obstacles in the Solar Wind	171
6.1	Bow Shock Waves in Front of Magnetic Obstacles	172
6.2	Magnetospheres and Ionospheres of the Planets and Moons as Obstacles	174
6.3	Asteroids and Comets as Obstacles	177
6.4	Interstellar Particles as Obstacles	178
	Further Reading	179
7	Comets and Their Tails	181
7.1	Formation of the Comet Coma	182
7.2	Comet Tails in Near Proximity to the Sun	185
7.3	Fragmentation of the Comet Nucleus and Tail Fractures	187
7.4	Activities in the Comet Nucleus	188
	Further Reading	190

8	Magnetospheres, Ionospheres and Auroras	193
8.1	Historical Facts	193
8.2	The Planets with Dynamo-generated Magnetospheres	197
8.3	The Earth in the Solar Wind.	202
8.3.1	Generation of the Earth’s Magnetospheric Fields	204
8.3.2	Functional Principle of the Geodynamo	206
8.3.3	Excursions and Polarity Reversals of the Earth’s Magnetic Field.	208
8.3.4	Structures and Current Systems of the Earth’s Magnetosphere.	212
8.3.5	About the Origin of the Aurora Borealis	214
8.3.6	Geomagnetic Substorms	218
8.4	Magnetic Field Properties of Other Planets.	219
8.4.1	Mercury’s Magnetic Field in Near Proximity to the Sun	220
8.4.2	The Induced Magnetosphere of Venus.	222
8.4.3	The Crustal Magnetic Field of the Earth’s Moon	224
8.4.4	Electric Currents and Magnetic Fields on Mars	225
8.4.5	Dynamo Processes Inside Jupiter.	226
8.4.6	Influence of Magnetic Fields on Saturn’s Ring Structures.	228
8.5	Radiation Belts and Auroras of Other Planets	229
8.5.1	Jupiter’s Radiation Belt and Auroras	230
8.5.2	Polar Lights of Saturn	231
8.5.3	Radiation Belts and Auroras Through or on the Moons of the Gas Planets.	233
8.5.4	The Auroras of the Ice Planets.	236
8.6	Importance of the Exploration of Planetary Magnetospheres and Ionospheres	237
8.6.1	Why the Magnetospheres Are Being Explored	237
8.6.2	On the Importance of the Ionospheres.	239
	Further Reading	240
9	Exploring Space Weather	243
9.1	Space Weather in the Heliosphere and Earth’s Environment.	243
9.1.1	Weather and Climate in Space and on Earth	243
9.1.2	Factors Determining Space Weather	244
9.2	Presentation of Exemplary Space Weather Events	246
9.2.1	Coronal Mass Ejections	246
9.2.2	Solar Energetic Particles	247
9.2.3	Cosmic Radiation in the Heliosphere	250
9.3	Space Weather and Earth’s Magnetosphere.	252
9.3.1	Geomagnetic Storms	252
9.3.2	Radiation Exposure in the Van Allen Belts	254

9.4	Effects of Space Weather	256
9.4.1	Effects on the Earth System	256
9.4.2	Consequences of Space Weather for Our Technical Environment.	256
9.4.3	Direct Consequences of Space Weather for Us Humans	259
9.5	Tasks and Specific Work of the Space Weather Prediction Centres	260
9.5.1	Forecasts on the Development of the Space Weather	260
9.5.2	Raising Awareness of the State of Our Space Environment.	261
9.5.3	Numerical Simulations of Space Weather	263
9.5.4	Some Protective Measures Against the Effects of Space Weather	264
9.6	Manned Space Flight and the Effects of Space Weather on the Moon and Mars	265
9.6.1	Protective Precautions for Astronauts on Space Flights.	265
9.6.2	Hazards from Space Weather on the Moon	266
9.7	About the Possible Influence of Space Weather on Human Health	268
	Further Reading	270
10	Epilogue	273
	References.	276
	On the History of the Discovery of Solar and Heliospheric Processes. . . .	277
	Further Reading	305
	Glossary	307
	Index.	319