

Contents

Preface to the First Edition	<i>IX</i>
Preface	<i>XI</i>
Acknowledgments to the First Edition	<i>XIII</i>
Acknowledgments	<i>XV</i>

1	Introduction	<i>1</i>
1.1	Basics of Fusion	<i>1</i>
1.2	Magnetic Confinement	<i>3</i>
1.2.1	Closed Toroidal Confinement Systems	<i>4</i>
1.2.2	Open (Mirror) Confinement Systems	<i>6</i>
1.3	Feasibility of Fusion	<i>8</i>
1.3.1	Scientific Feasibility	<i>8</i>
1.3.2	Engineering Feasibility	<i>10</i>
1.3.3	Practical Feasibility	<i>11</i>
1.3.4	Economic Feasibility and Fuel Resources	<i>11</i>
2	Basic Properties	<i>13</i>
2.1	Plasma	<i>13</i>
2.2	Electric and Magnetic Fields	<i>14</i>
2.3	Plasma Frequency	<i>17</i>
2.4	Coulomb Scattering	<i>18</i>
2.5	Characteristic Times	<i>22</i>
2.6	Resistivity	<i>23</i>
2.7	Gyromotion	<i>24</i>
2.8	Drifts	<i>25</i>
3	Equilibrium and Transport	<i>29</i>
3.1	Equilibrium and Pressure Balance	<i>29</i>
3.2	Classical Transport	<i>31</i>

3.3	Neoclassical Transport	34
3.4	Fluctuation-Driven Transport	35
4	Confinement Concepts	37
4.1	Magnetic Mirrors	37
4.1.1	Simple Mirrors	37
4.1.2	Minimum- B Mirrors	39
4.1.3	Tandem Mirrors	41
4.1.4	Current Mirror Research	44
4.2	Tokamaks	44
4.2.1	Confinement Principles	44
4.2.2	Stability	49
4.2.3	Density Limit	52
4.2.4	MHD Instability Limits	52
4.2.5	Scaling of Experimental Energy Confinement Times	54
4.2.5.1	Ohmic Confinement	54
4.2.5.2	L-Mode Confinement	55
4.2.5.3	H-Mode Confinement	55
4.3	Alternative Confinement Concepts	56
4.3.1	Stellarator	57
4.3.2	Spherical Torus	59
4.3.3	Reversed-Field Pinch	59
5	Plasma Heating	63
5.1	Ohmic Heating	63
5.2	Neutral Beam Injection (NBI)	64
5.3	Wave Heating	68
5.3.1	Wave Phenomena in Plasmas	68
5.3.2	Waveguides	70
5.3.3	Launching an Electromagnetic Wave into a Plasma	73
5.3.4	Radio-Frequency Heating	74
5.4	Compression	76
5.5	Fusion Alpha Heating	77
5.6	Non-Inductive Current Drive	77
5.7	ITER Plasma Heating and Current Drive Systems	78
6	Plasma–Wall Interaction	81
6.1	Surface Erosion	81
6.2	Impurity Radiation	83
6.3	Impurity Control	87
7	Magnetics	93
7.1	Magnetic Fields and Forces	93
7.1.1	Long Straight Conductors	93
7.1.2	Coaxial Loop Conductors	95

7.1.3	Ideal Torus	96
7.1.4	Solenoid	99
7.2	Conductors	101
7.2.1	Normal Conductors	101
7.2.2	Superconductors	104
7.2.3	Stability and Quench Protection	105
7.3	Tokamak Magnet Systems	107
7.3.1	Poloidal Field Coils	107
7.3.2	Toroidal Field Coils	110
7.3.3	Coil Interactions	112
7.4	Structural Design Criteria	114
7.5	ITER Magnet System	115
8	Transient Electromagnetics	119
8.1	Inductance	119
8.2	Elementary Electric Circuit Theory	121
8.3	Coupled Electromagnetic Circuits	123
8.4	Tokamak Transient Electromagnetics	124
8.5	Energy Storage Systems	125
8.5.1	Inertial Energy Storage and Transfer	126
8.5.2	Capacitive Energy Storage and Transfer	130
8.5.3	Inductive Energy Storage and Transfer	130
9	Interaction of Radiation with Matter	135
9.1	Radiation Transport	135
9.2	Neutron Multiplication	139
9.3	Nuclear Heating	140
9.4	Neutron Radiation Damage	142
9.4.1	Displacement and Transmutation	142
9.4.2	Material Property Changes	146
9.5	Radioactivity	151
9.6	Radiation Shielding	155
10	Primary Energy Conversion and Tritium Breeding Blanket	159
10.1	Tritium Breeding	159
10.2	Blanket Coolants and Structural Materials	166
10.3	Heat Removal, Hydraulics, and Stress	174
10.4	Plasma Facing Components	181
10.5	ITER Blanket Test Modules	185
10.6	Fissile Production	187
10.7	Transmutation of Nuclear Waste	190
11	Tritium and Vacuum	193
11.1	Vacuum System	193
11.1.1	Vacuum Pumping	193

11.1.2	Vacuum Chamber Topology	197
11.2	Tritium Fuel Cycle Processing	199
11.3	Tritium Permeation	202
11.4	Tritium Retention in Plasma-Facing Components	204
11.5	Tritium Breeding and Inventory	207
12	Fusion Reactors	211
12.1	Plasma Physics and Engineering Constraints	211
12.1.1	Confinement	211
12.1.2	Density Limit	213
12.1.3	Beta Limit	213
12.1.4	Kink Stability Limit	214
12.1.5	Startup Inductive Volt-seconds	215
12.1.6	Non-Inductive Current Drive	216
12.1.7	Bootstrap Current	216
12.1.8	Toroidal Field Magnets	216
12.1.9	Blanket and Shield	217
12.1.10	Plasma Facing Component Heat Fluxes	218
12.1.10.1	Heat Fluxes	218
12.1.10.2	Stress Limits	218
12.1.10.3	Temperature Limit	219
12.1.10.4	Fatigue Limit	220
12.1.10.5	Heat Flux Limit	220
12.1.11	Radiation Damage to Plasma Facing Components	220
12.2	International Tokamak Program	221
12.3	The International Thermonuclear Experimental Reactor (ITER)	221
12.4	Future Tokamak Reactors	226
12.5	Tokamak Demo Reactor	229
12.6	Tokamak Neutron Source	230
12.7	Future Stellarator Reactors	231
12.8	Future Spherical Torus Reactor	233
12.9	Future Reversed Field Pinch Reactor	234
	Appendix A: Frequently Used Physical Constants	237
	Appendix B: Energy Conversion Factors	239
	Appendix C: Engineering Conversion Factors	241
	Index	243