

Contents

1	Fundamentals of Special Relativity	1
1.1	Introduction	1
1.2	The Principle of Relativity	2
1.3	★Groups: The Galilei Group	5
1.4	Galileian Law of Addition of Velocities	8
1.5	The Lesson from Electromagnetism	8
1.5.1	The Ether	10
1.5.2	The Michelson–Morley Experiment	11
1.6	The Postulates of Special Relativity	13
1.6.1	The Role of the Speed of Light	14
1.7	Consequences of the Postulates	16
1.7.1	Relativity of Simultaneity	16
1.7.2	Time Dilation	17
1.7.3	The Twin “Paradox”	23
1.7.4	Length Contraction	23
1.8	Conclusion	26
	References	28
2	The Lorentz Transformation	29
2.1	Introduction	29
2.2	The Lorentz Transformation	29
2.3	Derivation of the Lorentz Transformation	31
2.4	Mathematical Properties of the Lorentz Transformation	33
2.5	Absolute Speed Limit and Causality	36
2.6	Length Contraction from the Lorentz Transformation	39
2.7	Time Dilation from the Lorentz Transformation	40
2.8	Transformation of Velocities and Accelerations in Special Relativity	41
2.8.1	Relative Velocity of Two Particles	43
2.8.2	Relativistic Transformation Law of Accelerations	45
2.9	Matrix Representation of the Lorentz Transformation	46

2.10	★The Lorentz Group	48
2.11	The Lorentz Transformation as a Rotation by an Imaginary Angle with Imaginary Time.	51
2.12	★The GPS System	53
2.13	Conclusion.	55
	References	56
3	The 4-Dimensional World View	59
3.1	Introduction	59
3.2	The 4-Dimensional World	60
3.3	Spacetime Diagrams	63
3.4	Conclusion.	68
	References	70
4	The Formalism of Tensors	71
4.1	Introduction	71
4.2	Vectors and Tensors	71
4.2.1	Coordinate Transformations	74
4.2.2	Einstein Convention	75
4.3	Contravariant and Covariant Vectors.	76
4.4	Contravariant and Covariant Tensors	79
4.4.1	Tensor Symmetries	83
4.5	Tensor Algebra	85
4.6	Tensor Fields	87
4.7	★Index-Free Description of Tensors	90
4.8	The Metric Tensor	96
4.8.1	Inverse Metric	97
4.8.2	Metric Determinant.	101
4.9	The Levi-Civita Symbol and Tensor Densities	101
4.9.1	Properties of the Levi-Civita Symbol in Four Dimensions	104
4.9.2	Volume Element	106
4.10	Conclusion.	107
	References	110
5	Tensors in Minkowski Spacetime	111
5.1	Introduction	111
5.2	Vectors and Tensors in Minkowski Spacetime	111
5.3	The Minkowski Metric	112
5.4	Scalar Product and Length of a Vector in Minkowski Spacetime	117
5.5	Raising and Lowering Tensor Indices	120
5.5.1	Working with Tensors in Minkowski Spacetime.	122

5.6	Causal Nature of 4-Vectors	123
5.7	Hypersurfaces	128
5.8	Gauss' Theorem	129
5.9	Conclusion.	131
	References	135
6	Relativistic Mechanics	137
6.1	Introduction	137
6.1.1	Massive Particles	138
6.2	Relativistic Dynamics of Massive Particles	141
6.2.1	Relativistic Energy	144
6.2.2	Pair Production and Annihilation	146
6.2.3	★Positron Emission Tomography	147
6.3	The Relativistic Force	148
6.3.1	The Relativistic 4-Force	148
6.3.2	The Relativistic 3-Force	150
6.3.3	Relativistic Kinetic Energy	152
6.3.4	Motion with Constant Acceleration.	155
6.3.5	★Particle Accelerators	158
6.4	Angular Momentum of a Particle	161
6.5	Particle Systems	162
6.6	Conservation of Mass-Energy	163
6.6.1	Nuclear Fusion.	165
6.6.2	Nuclear Fission	166
6.7	Conclusion.	167
	References	169
7	Relativistic Optics.	171
7.1	Introduction	171
7.2	Relativistic Optics: Null Rays	171
7.3	The Drag Effect	175
7.4	The Doppler Effect.	176
7.5	Aberration	179
7.6	Relativistic Beaming.	182
7.6.1	★Synchrotron Light Imaging	184
7.7	Visual Appearance of Extended Objects	185
7.8	Conclusion.	188
	References	189
8	Measurements in Minkowski Spacetime	191
8.1	Introduction	191
8.2	Energy of a Particle Measured by an Observer.	191
8.3	Frequency Measured by an Observer	192
8.4	A More Systematic Treatment of Measurement	193

8.5	The 3+1 Splitting	195
8.6	Conclusion.	198
9	Matter in Minkowski Spacetime	201
9.1	Introduction	201
9.2	The Energy-Momentum Tensor	201
9.3	Covariant Conservation	203
9.4	*Energy Conditions	206
9.5	Angular Momentum	208
9.6	Perfect Fluids.	209
9.6.1	Equation of Motion of the Perfect Fluid	211
9.7	The Scalar Field.	214
9.8	The Electromagnetic Field.	217
9.9	Conclusion.	223
	References	227
10	*Special Relativity in Arbitrary Coordinates.	229
10.1	Introduction	229
10.2	The Covariant Derivative	230
10.2.1	Computing Covariant Derivatives.	232
10.3	Spacetime Curves and Covariant Derivative	234
10.3.1	Geodesics	234
10.4	Physics in Minkowski Spacetime Revisited	236
10.4.1	Mechanics	237
10.4.2	Optics	237
10.4.3	General Matter Distributions	238
10.4.4	Perfect Fluids.	238
10.4.5	The Maxwell Field	238
10.5	Conclusions	240
	References	242
	Appendix	243
	Solutions to Selected Problems.	245
	Index	301

Special Relativity

Faraoni, V.

2013, XVIII, 304 p. 51 illus., Softcover

ISBN: 978-3-319-01106-6