

# Contents

|   |           |
|---|-----------|
| <b>1 Special Relativity . . . . .</b>                           | <b>1</b>  |
| 1.1 Relativity of Motion . . . . .                              | 1         |
| 1.2 Inertial Frames . . . . .                                   | 2         |
| 1.3 Galileo Transformations . . . . .                           | 3         |
| 1.4 Velocity Addition Formula . . . . .                         | 4         |
| 1.5 Lorentz Transformations . . . . .                           | 5         |
| 1.6 Relativistic Velocity Addition Formula . . . . .            | 6         |
| 1.7 Time Dilation . . . . .                                     | 7         |
| 1.8 Derivation of the Lorentz Transformation Formulas . . . . . | 7         |
| 1.9 Important Formulas . . . . .                                | 8         |
| 1.10 Exercises . . . . .  | 9         |
| 1.11 Solutions . . . . .  | 11        |
| <b>2 Minkowski Geometry . . . . .</b>                           | <b>17</b> |
| 2.1 Units . . . . .   | 17        |
| 2.2 Space–Time Diagrams . . . . .                               | 18        |
| 2.3 Interval Between Events . . . . .                           | 19        |
| 2.4 Generalized Twin Paradox . . . . .                          | 21        |
| 2.5 More Dimensions . . . . .                                   | 24        |
| 2.6 Important Formulas . . . . .                                | 25        |
| 2.7 Exercises . . . . .   | 25        |
| 2.8 Solutions . . . . .   | 28        |
| <b>3 Non-Euclidean Geometry . . . . .</b>                       | <b>35</b> |
| 3.1 Curvilinear Coordinates . . . . .                           | 35        |
| 3.2 The Sphere . . . . .  | 37        |
| 3.3 Geodesics . . . . .   | 39        |
| 3.4 Curvature . . . . .   | 41        |
| 3.5 Other Maps of the Sphere . . . . .                          | 42        |
| 3.6 Other Geometries . . . . .                                  | 44        |
| 3.7 Exercises . . . . .   | 45        |
| 3.8 Solutions . . . . .   | 46        |

|   |     |
|---|-----|
| <b>4 Gravity . . . . .</b>                          | 49  |
| 4.1 Newton's Law of Universal Gravitation . . . . . | 49  |
| 4.2 Units . . . . .                                 | 50  |
| 4.3 Escape Velocity . . . . .                       | 50  |
| 4.4 Kepler Laws . . . . .                           | 51  |
| 4.5 Circular Orbits . . . . .                       | 52  |
| 4.6 Important Formulas . . . . .                    | 54  |
| 4.7 Exercises . . . . .                             | 54  |
| 4.8 Solutions . . . . .                             | 55  |
| <b>5 General Relativity . . . . .</b>               | 59  |
| 5.1 Equivalence Principle . . . . .                 | 59  |
| 5.2 Gravitational Redshift . . . . .                | 60  |
| 5.3 Curved Space–Time . . . . .                     | 61  |
| 5.4 Important Formulas . . . . .                    | 63  |
| 5.5 Exercises . . . . .                             | 64  |
| 5.6 Solutions . . . . .                             | 65  |
| <b>6 The Schwarzschild Solution . . . . .</b>       | 69  |
| 6.1 The Schwarzschild Solution . . . . .            | 70  |
| 6.2 Stationary Observers . . . . .                  | 71  |
| 6.3 Redshift . . . . .                              | 71  |
| 6.4 Space Curvature . . . . .                       | 72  |
| 6.5 Orbits . . . . .                                | 73  |
| 6.6 Light Rays . . . . .                            | 74  |
| 6.7 Black Holes . . . . .                           | 77  |
| 6.8 Important Formulas . . . . .                    | 80  |
| 6.9 Exercises . . . . .                             | 81  |
| 6.10 Solutions . . . . .                            | 84  |
| <b>7 Cosmology . . . . .</b>                        | 95  |
| 7.1 Redshift . . . . .                              | 95  |
| 7.2 Hubble Law . . . . .                            | 96  |
| 7.3 FLRW Models . . . . .                           | 96  |
| 7.4 Hubble Law in the FLRW Models . . . . .         | 99  |
| 7.5 Redshift in the FLRW Models . . . . .           | 100 |
| 7.6 Friedmann Equations . . . . .                   | 101 |
| 7.7 Important Formulas . . . . .                    | 103 |
| 7.8 Exercises . . . . .                             | 104 |
| 7.9 Solutions . . . . .                             | 106 |
| <b>8 Mathematics and Physics . . . . .</b>          | 115 |
| 8.1 Mathematics for General Relativity . . . . .    | 115 |
| 8.2 Modern Physics . . . . .                        | 116 |

|                          |     |
|--------------------------|-----|
| Contents                 | xi  |
| <b>Astronomical Data</b> | 119 |
| <b>Bibliography</b>      | 121 |
| <b>Index</b>             | 123 |