

Preface

In the early 1900s, three events took place that dramatically changed the course of modern physics. In 1905 Albert Einstein formulated the Special Theory of Relativity. Then, in 1915, he developed the General Theory of Relativity, and around 1925 quantum mechanics took its present form. Since then, physics has progressed rapidly. Beginning in 1930, quantum mechanics and special relativity were united into what is known as the relativistic quantum field theory. This merger was very rewarding in that it provides, at the least, partial explanation of the laws and interactions governing elementary particle physics.

Among the four types of forces (strong, electromagnetic, weak, and gravitational) known today, gravity is perhaps the strangest. Weak though it is, gravity dominates the other three forces over cosmic distances. Any cosmology must be founded on a logically secure theory of gravitation.

The first three forces could be explained through particle interactions taking place in the flat space-time of special relativity. However, gravity defies such an explanation. In order to describe the mysterious force known as gravity, Einstein in 1915 was compelled to generalize the ideas of his special relativity, and he eventually connected gravity with the geometry of space-time. In other words, Einstein's General Theory of Relativity is a relativistic theory of gravitation.

For a long time, Einstein's Theory of General Relativity occupied an isolated position within the domain of general physics. This was attributable in part to the mathematical framework of the theory, which is based on Riemannian geometry, a kind of geometry not needed in most other physical applications. The extreme difficulty in devising suitable experiments that might verify the theory and the growth of more fertile fields of investigation, such as atomic and nuclear physics as well as the study of elementary particles, also contributed to the isolation of the theory.

However, Einstein's Theory of General Relativity is now enjoying renewed interest. This is due partly to the development of new technological capabilities that opened up previously inaccessible avenues for the experimental verification of general relativity and partly to the conjecture of some theoretical physicists that the fundamental difficulties confronting quantum field theory may find their resolution in a suitable combination of the two disciplines. The discovery of extremely

compact celestial objects—neutron stars and black holes, for instance—provided the final turning point. The study of these objects demanded the application of Einstein's Theory of General Relativity. Today, physics and astronomy have joined forces to form the discipline called relativistic astrophysics. Einstein's Theory of General Relativity is also essential to modern cosmology, since the overall space-time structure is intimately related to the gravitational field. In the past decade interest in cosmology and general relativity has grown considerably.

Today, there is increased demand for undergraduate courses in relativity and cosmology. There are many advanced books on the Theory of General Relativity and cosmology for the specialist, and many elementary expositions for the lay reader. But there is a gap at the undergraduate level. This book is an attempt to fill the gap. We will try to make available to the student a working acquaintance with the concepts and fundamental ideas in general relativity and modern cosmology. For the modes of calculation we choose the old-fashioned tensor calculus for pedagogical reasons. Most undergraduates have not been exposed to the many new formalisms developed in general relativity. Hopefully after reading this book, the student can continue delving more deeply into particular aspects or topics in general relativity and cosmology that interest him or her.

This book evolved from a set of lecture notes for a course that I have taught over the past 10 years. I am making the assumption that the student has been exposed to a calculus-based course in general physics and a course in calculus (including the handling of differentiations of field equations). Some exposure to tensor analysis would be helpful but is not necessary; this subject is covered in the text.

The student will find that in the derivations of equations, a generous amount of detail has been given. However, to ensure that the student does not lose sight of the development underway, some of the more lengthy and tedious algebraic manipulations have been omitted.

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