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Book review

Gravity: Newtonian, Post-Newtonian, Relativistic

Eric Poisson and Clifford M Will

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In his 2010 review of the second edition of Schutz's *A First Course in General Relativity*, Eric Poisson wrote: 'while the 1970s was the decade of Weinberg and Misner, Thorne and Wheeler, and while the 1980s was the decade of Schutz and Wald, the 2000s was clearly the decade of Hartle and Carroll […]. At the dawn of this new decade, I look forward to see what fresh pedagogical insights will be produced next, and who will be revealed as the winners of the 2010s.' I am very happy to report that we have found a winner!

This new textbook by Poisson and Will is a much-needed, self-contained presentation of gravitational physics appropriate for graduate-level courses. This book deserves a spot on the bookshelf of anyone with an interest in gravitational physics, next to the classic textbooks quoted above. Unlike those standard references, Poisson and Will focus on weak-field, slow-motion systems, gravitational-wave theory and experimental tests of Einstein's general relativity. Their book leads the reader to the edge of current research using an elegant, self-consistent, modern notation. The choice of topics and the organization of the material are exceptional, and the writing is outstandingly clear. Following the example of Misner, Thorne and Wheeler, the book makes extensive use of 'boxes' to clarify technical issues and to provide historical context with interesting anecdotes (e.g. on the famous quadrupole formula controversy).

The core of the book is chapters 6–9, where the authors work out post-Minkowskian and post-Newtonian theory using the Landau–Lifshitz formulation of the Einstein field equations. This material is largely based on the DIRE (direct integration of the relaxed Einstein equations) approach developed by Will and collaborators. To my knowledge, no existing textbook covers this topic at a comparable level of competence, clarity and detail. So far, students and researchers working on post-Newtonian theory had only one option: studying the original research papers or some of the excellent (but highly technical) reviews, such as Blanchet's 'Living review' article (2014 *Living Rev. Relativity* **17** 2). *Gravity* fills this gap admirably.

The book assumes no prior knowledge of general relativity. In my opinion, the first three chapters alone are well worth the price of admission. Chapter 1 presents the foundations of Newtonian gravity in a style reminiscent of Jackson's *Classical Electrodynamics*. Along the way, the authors introduce the mathematics of symmetric trace-free tensors, which is used extensively in gravitational-wave theory. Chapter 2 deals with the equilibrium structure of spherical and rotating bodies and with their perturbations. The core material of this chapter is based on the classic monographs by Chandrasekhar (*An Introduction to the Study of Stellar Structure* and *Ellipsoidal Figures of Equilibrium*), and on Kopal's not-so-well-known books on close binary systems and on the theory of deformed bodies, but the authors reformulate the whole theory in a self-consistent, modern notation that is very useful as an introduction to current research. Finally, chapter 3 presents a remarkably clear exposition of Kepler's problem and its perturbations. The authors cover topics such as the method of osculating orbital elements, the Kozai mechanism, and perturbations of two-body motion due to oblateness, tidal interactions and the presence of additional bodies. The material is presented with a balance between pedagogical care and mathematical rigor that I haven't seen anywhere else. This first part of the book is relevant and useful even to astrophysicists and physicists with no interest in general relativity.

Chapter 4 is a review of special-relativistic kinematics, hydrodynamics and electrodynamics that serves mainly to establish notation and conventions for later chapters. Chapter 5 is a concise but self-contained introduction to general relativity. It differs from standard textbook treatments in several aspects: 1) it begins with a pedagogical discussion of equivalence principles as the experimental foundation for the idea of 'gravity as curved spacetime'; 2) it includes a detailed description of Fermi and Riemann normal coordinates and their physical meaning; 3) it presents a very clear treatment of linearized theory and its limitations—this part follows a nice set of lectures on gravitational waves by Flanagan and Hughes (gr-qc/0501041); 4) the discussion of the Schwarzschild spacetime focuses mostly on the role of different coordinate systems (with particular attention to harmonic coordinates, in preparation for later chapters on post-Minkowskian and post-Newtonian theory), and there is no discussion at all of the Reissner–Nordström and Kerr spacetimes.

As anticipated, the material becomes significantly more technical—and more suitable for an advanced graduate course—in chapters 6 and 7, where post-Minkowskian theory is formulated in the DIRE formalism and then developed up to second post-Minkowskian order. Chapters 8 and 9 cover post-Newtonian theory, including a review of conceptual issues in the 'classical' formulation of the theory developed by Chandrasekhar, a rigorous discussion of coordinate transformations and post-Newtonian hydrodynamics, and a detailed (and time-consuming) derivation of the equations of motion for spinning bodies that at times becomes, in Poisson and Will's own words, 'exhausting (both for the reader and the authors)'. Personally I would not recommend covering this material in a graduate course (unless one has very special students!), but the fact that these calculations are finally collected in a standard reference is remarkable.

My favorite part of the book is probably chapter 10, which is dedicated to experimental applications of post-Newtonian theory. Here, Poisson and Will discuss the solutions of the post-Newtonian two-body problem using the formalism introduced by Damour and Deruelle. Then they study the motion of light in post-Newtonian gravity (including gravitational lensing and the Shapiro time delay), and they discuss applications of post-Newtonian gravity in pulsar timing, timekeeping and navigation, as well as frame-dragging effects and their experimental verifications. This material is the foundation for modern applications (and tests) of general relativity, and it is great to have it all collected in a single place.

Chapters 11 and 12 introduce gravitational-wave theory. These two chapters may well be the clearest and most comprehensive coverage of this topic in any textbook to date. The first sections of these chapters (namely, 11.1–11.2 and 12.1–12.4) can be used for a one-semester introduction to this topic, somewhat similar to—but much more detailed and advanced than—the corresponding treatment in Schutz's book. The remainder of these chapters work out gravitational waveforms up to 1.5PN order, and discuss in detail the effects of radiation reaction. The material is covered with remarkable clarity, building heavily on analogies with electromagnetism.

The last chapter of the book is an introduction to alternative theories of gravity (with a special focus on scalar-tensor gravity) and to their experimental tests within the parametrized post-Newtonian formalism developed by Nordtvedt and Will. This chapter is a more pedagogical and up-to-date version of material from Will's classic book *Theory and Experiment in Gravitational Physics*. It serves as an excellent introduction to the subject of experimental tests of general relativity, that ideally should be followed by a reading of Will's more detailed 'Living review' article (2014 *Living Rev. Relativity* **17** 4).

Gravity is very likely to become the standard reference for students and researchers working on post-Newtonian theory, the experimental verifications of general relativity, binary systems and gravitational radiation. I was lucky to have early access to various draft versions of the text. I found almost no typos, even in these early drafts, which is truly remarkable for a work of this length and complexity. The final book weighs in at almost 800 pages. The typesetting is excellent, and the hardcover edition that I reviewed is well built. There are more than 100 exercises, some of which are easy, and some of which are hard enough to warrant a research paper (cf arXiv:1308.0394). Fortunately, a solution manual is in the making.

I managed to cover most of the book (excluding chapters 2, 8, 9 and 13) in a one-semester course on advanced general relativity at the University of Mississippi, but this was a tour de force for both the instructor and the students. In hindsight, I would recommend using the book for a two-semester course. The most significant—and deliberate—omission with respect to books like Misner, Thorne and Wheeler or Wald is a modern, comprehensive treatment of black holes, neutron stars and cosmology. However, the material covered here is so brilliant that I would recommend this book over the above references for a graduate course in general relativity and gravitational waves. The text can be complemented with selected topics from the many excellent textbooks on compact objects and cosmology, such as Shapiro and Teukolsky's *Black Holes, White Dwarfs and Neutron Stars*, Stergioulas and Friedman's *Rotating Relativistic Stars*, Frolov and Zelnikov's *Introduction to Black Hole Physics*, Chandrasekhar's *The Mathematical Theory of Black Holes* and Weinberg's *Cosmology*.

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