Einstein's take on his much-celebrated theories

Relativity
The Special and the General Theory

Albert Einstein
100th anniversary ed.
Princeton U. Press, 2015. $26.95
(320 pp.). ISBN 978-0-691-16633-9

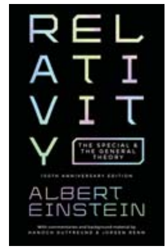
Reviewed by Nelson Christensen

A century ago, Albert Einstein published his description of general relativity. A decade before that, he presented special relativity. The public was curious to know more about those theories, so Einstein commenced work on a book that explained special and general relativity. It was a huge success. The first version was published in German in 1917, and it has been reprinted in many other languages and editions over the years. The first English version, titled *Relativity: The Special and the General Theory*, was published in 1920. Einstein updated the book a few times, adding material to the appendix section when new experimental results supported general relativity.

To mark the centennial of general relativity, the 1961 English translation by Robert W. Lawson has been republished as *Relativity: The Special and the General Theory*, 100th anniversary edition. This new offering was edited by Hanoch Gutfreund and Jürgen Renn, who have included much background information that adds historical context to the text. (The article by Renn and Michel Janssen on page 30 of this issue traces Einstein's path to his field equations.)

The description of special relativity in Einstein's book is pleasurable and easy to read. I can imagine students in my special relativity course reading Einstein's description and taking away a better understanding of the subject. As to whether the general public can understand the work, I think Einstein's own recommendation says it best: "The work presumes a standard of education corresponding to that of a university matriculation examination, and, despite the shortness of the book, a fair amount of patience and force of will on the part of the reader." That recommendation still holds true, in my opinion.

Einstein goes through the classic comparisons of measurements made by an observer on a train moving at a constant velocity and another at rest on an embankment next to the train tracks. Given the coordinate systems of those two observers, Einstein derives, among other things, time dilation, length contraction, and the Lorentz transformations. All the derivations are gentle and intuitive. I immensely enjoyed Einstein's insight in this part of the book. More difficult derivations and technical explanations are left to an appendix, but even those would be easily understood by undergraduate physics students.



The general relativity section of the book was also fun to read. I especially enjoyed Einstein's own words describing the difference between spacetime and coordinates, "which have not the least direct physical significance." He also provides a clear introduction to the consequences of curved space; I expect that description will give some much-needed intuition to those encountering non-Euclidean geometry for the first time.

I teach general relativity and conduct research in the field, so I have the necessary background to be able to sit back and enjoy the well-written and insightful text. However, I do not think the general relativity section will be easy for people who have not previously spent some time thinking about the subject. In the introduction to the 1921 Polish translation of *Relativity*, philosopher Maksymilian Tytus Huber noted that it "is not *popular* in the usual sense, but rather, as someone said jokingly, *popular with physicists*." The general relativity section of Einstein's book will certainly be popular with physicists.

Among the gems that were added to the post-1917 editions is a nice summary of Arthur Eddington's 1919 measurement of the deflection of light by the Sun's gravitational field. It is also enjoyable to hear directly from Einstein about the evolution in his cosmological understanding of the universe. Alexander Friedmann's solutions in general relativity convinced Einstein that an expanding universe was possible and that he could discard his "cosmological term." Einstein also writes positively about Edwin Hubble's observations, which confirmed that the universe was expanding, but he expressed reservations about the implied age of the universe—10^9 years—which Einstein recognized as being too young. Such considerations, written in Einstein's own words, are fascinating to read.

In a few areas Einstein's descriptions run counter to our modern interpretation of special and general relativity. We will forgive the author for those rare and minor missteps. The reader will recognize that over the past century special and general relativity have survived stringent tests.

Editors Gutfreund and Renn provide a good historical introduction to Einstein's book, explaining how it came into being and how it became hugely popular after the splash made by Eddington's observations. They summarize the book's numerous publications in a section that also includes descriptions of Einstein's interactions with scientists from around the world.

Most physicists should enjoy this book; so, too, should educated members of the public with sufficient "patience and force of will." Einstein is to be commended for his successful physical theories and also for his pleasant descriptions of them.

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Introduction to General Relativity, Black Holes, and Cosmology

Yvonne Choquet-Bruhat
Oxford U. Press, 2015. $99.95
(279 pp.). ISBN 978-0-19-966645-4

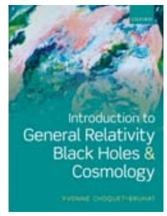
Yvonne Choquet-Bruhat is a giant of mathematical general relativity. In 1952 she proved a groundbreaking theorem on the existence of solutions to the Einstein field equations. Since then she has obtained many results in general relativity, partial differential equations, classical field theory, and fluid dynamics. Now in her nineties, she shows no signs of slowing down, and even finds time to write textbooks.

Her latest, *Introduction to General Relativity, Black Holes, and Cosmology*, consists of two parts: "Fundamentals" and "Advanced Topics." Unlike other areas of physics, general relativity needs the mathematics of differential geometry, so Choquet-Bruhat starts with that subject and explains manifolds, tensor fields, metrics, connections, and curvature. After introducing those tools, she moves on to the flat metric of special relativity, the curved metrics of general relativity, and the Einstein field equations, which relate the curvature of spacetime to the energy density of matter.

The main applications of general relativity are to the physics of black holes and to cosmology, and the author next turns to those topics. Nonrotating black holes—indeed, the exteriors of all nonrotating spherical objects—are described by the Schwarzschild metric. Using that metric, Choquet-Bruhat presents calculations of some of the effects used to test general relativity: the gravitational bending of light, the precession of the perihelion of Mercury, and the redshift of light in a gravitational field. She also discusses rotating black holes, which are described by the Kerr metric. In the last chapter in the "Fundamentals" section, she covers cosmology; she introduces the symmetries of cosmological metrics and shows how the Einstein field equations yield equations relating the expansion of the universe to the types of matter and energy that it contains.

The "Advanced Topics" section is primarily focused on the Cauchy problem for the Einstein field equations, both without matter and with various types of matter. For a given set of equations of motion, the Cauchy problem is the task of proving that, given a choice of initial data, a unique solution of the equations exists and that the solution depends continuously on the data. In the process of solving the Cauchy problem, one finds the true degrees of freedom of the theory by finding what initial data one is allowed to specify. For example, Maxwell's equations without charges or currents include equations of motion for the electric and magnetic fields. However, the electric and magnetic fields cannot be chosen arbitrarily; they must have zero divergence.

In general relativity, the initial data are the metric of space and a geometric quantity called the extrinsic curvature—essentially, the derivative with respect to time of the space metric. Those fields also cannot be chosen arbitrarily; rather, they should satisfy a set of nonlinear constraint equations. Any sensible physical theory must have equations of motion for which the task of the Cauchy problem is successfully completed, so one can regard the mathematicians' work in that area as checking the physical sensibleness of each proposed theory. That work is more important than ever these days, when new theories are frequently proposed and specified with no more than an expression for the theory's Lagrangian.



The word "introduction" in the title of the book suggests that it would be an ideal first book in general relativity—and so it is, if the reader is a mathematician. For such a reader, the book provides an elementary introduction to the physics of general relativity and a beautiful exposition of how that physics relates to the differential geometry of spacetime and to the hyperbolic nonlinear partial differential equations that describe the evolution of the gravitational field. However, I would not recommend it as a first book in general relativity for a physicist.

Most physics students first learning general relativity are somewhat put off by the amount of new mathematics that needs to be learned, and the problem is not likely to be alleviated when the material is presented from the point of view of mathematics—even when, as in the present case, the author has a deep understanding of both physics and mathematics. Nonetheless, for a reader who already knows some general relativity, Choquet-Bruhat's book is an ideal introduction to the mathematical approach. Nowadays, research in general relativity is done by members in both physics departments and mathematics departments. Without a bridge between those two groups, such as the one provided by this book, there is a danger that they will lack a common language and will end up talking past each other.

The French have a saying, "*L'appétit vient en mangeant*"; roughly translated, it means, "Eating a little makes you hungry for more." *Introduction to General Relativity, Black Holes, and Cosmology* necessarily has an abbreviated treatment of some topics, often with the statement that the topic is "outside the scope of this book." In particular, the reader might be left hungry for more details on the astrophysics of black holes, the history of the early universe and its relation to particle physics, the ongoing search for gravitational waves, and the efforts to find a quantum theory of gravity. On the mathematical side, the reader might want to know more about singularity theorems, global existence and stability theorems, and black hole uniqueness theorems. However, the author has wisely chosen to write a short book that gives a taste of the subject. *Bon appétit*.

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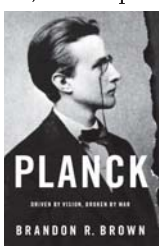
Planck

Driven by Vision, Broken by War

Brandon R. Brown
Oxford U. Press, 2015. $29.95
(258 pp.). ISBN 978-0-19-021947-5

Among physicists, Max Planck is a household name. He is immortalized, of course, by the fundamental constant named after him, and also by the Planck radiation curve, Planck units, the Max Planck Society, and the *Planck* space observatory. With *Planck: Driven by Vision, Broken by War*, University of San Francisco physics professor Brandon Brown has written a captivating biography that covers Planck's main contributions to science and, with greater emphasis, his personal and intellectual life.



The book is organized into 16 chapters, each devoted to a particular month in the period from April 1943 to May 1945, plus a coda. However, it is much more than an account of Planck's troubled life during the last part of World War II. Brown occasionally deviates from the chronological chapter arrangement to go back and forth in time and skillfully paint a full picture of Planck's life. It is an unusual structure, but it works very well.

Planck faced many moral dilemmas as the doyen of German physicists in a troubled era. Those dilemmas are discussed in John Heilbron's acclaimed biography, *The Dilemmas of an Upright Man* (University of California Press, 1986). Although he makes much use of Heilbron's book, Brown offers a different perspective and adds new material and insights.

Following Planck's life from his birth in 1858 in Kiel, Germany, to his last year in Göttingen in 1947 after the fall of the Third Reich, Brown provides a vivid narrative of German science and culture during that most dramatic period in Europe's history. Planck's life was rich in rewards but also had more than its share of tragedy. His oldest son, Karl, was killed in the 1916 battle of Verdun, and his youngest child, Erwin, accused of conspiring against Adolf Hitler, was tortured and executed by the Gestapo in 1945. Brown writes movingly of that cruel episode and how the 86-year-old physicist tried in vain to prevent it.

Much like Heilbron, Brown discusses Planck's problematic role in the Third Reich, including his fruitless meeting with Hitler in May 1933. Brown's treatment is balanced and empathetic. Although the patriotic Planck had no sympathy for National Socialism, he did follow the party line by dismissing the Jewish staff at the Kaiser Wilhelm Society, saluting the swastika flag, praising the Führer in official speeches, and generally advocating an appeasement policy. As Brown points out, Planck "stood with his Fatherland, no matter its warts and crimes." With balance and empathy, without passing judgment, he leaves no doubt that the period under Hitler's rule damaged Planck's reputation as an "upright, honorable character," as Max Born characterized him in a 1920 letter to Albert Einstein.

Although Planck is the book's main character, Brown devotes considerable space to some of the scientists with whom he interacted, and to Einstein in particular. Although very different personalities, the two physicists admired one another and remained on friendly terms even after Germany had become the Third Reich. Brown deals in some detail with their relationship and describes Einstein's scientific theories as much as he describes Planck's. Another Jewish physicist who plays an important part in the book is Lise Meitner, who served for a period as Planck's assistant and over the years received much support from him. Meitner, who held the old theoretical physicist in great reverence, described him in 1958 as having "an unusually pure disposition and inner rectitude, which corresponded to his outer simplicity and lack of pretension."

Well-researched and informative as the book is, it does contain a few errors or questionable statements. For example, Brown exaggerates the significance of anti-atomism in the 1890s when he writes that Planck was one of the few German physicists accepting the reality of atoms. In his account of Einstein's 1905 paper on light quanta, he wrongly presents it as a paper on the photoelectric effect and incorrectly indicates that Einstein's argument proceeds from Planck's radiation law, which Einstein,