Title: ***Relativity: The Special and the General Theory, 100th Anniversary edition***
Author: A. Einstein (with commentary by editors H. Gutfreund and J. Renn)
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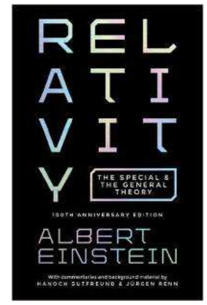


The year 2015 marked the 100th anniversary of when Albert Einstein first published his theory of general relativity in 1915. Ten years before that, in 1905, he published his theory of special relativity, and in 1917 he published a "popular account" of his two theories in a booklet called ***Relativity: The Special and the General Theory***. The ***100th Anniversary edition*** reviewed here includes the original English translation of Einstein's 1917 booklet and material he added later as well as contemporary interpretations of his theories and other interesting details, which I describe below. Einstein originally wrote his booklet in German (but did not publish in Germany until 1954) and it was translated to English by Robert Lawson in 1920.

Einstein starts out by discussing Euclidean geometry, which is the plane geometry we studied in school and which is based on the concepts of a point, line and plane. Euclidean geometry uses a small number of *assumptions* (axioms, or "truths") from which *propositions* or theorems of geometry are proved. Einstein spends some time discussing the meaning of "truths" and questioning how we know these axioms to be really true. Euclid's geometry works well in every-day experience, but Einstein warns the reader that it requires refinement by his general relativity theory, which he explains in the second part of his booklet. There he shows that Euclidean geometry is a limiting case of general relativity. I found it interesting that the first thing Einstein mentions in his booklet is Euclidean geometry but he does not take it up again until the middle and then returns to it again at the end.

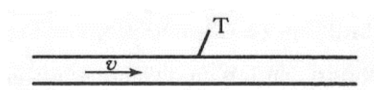
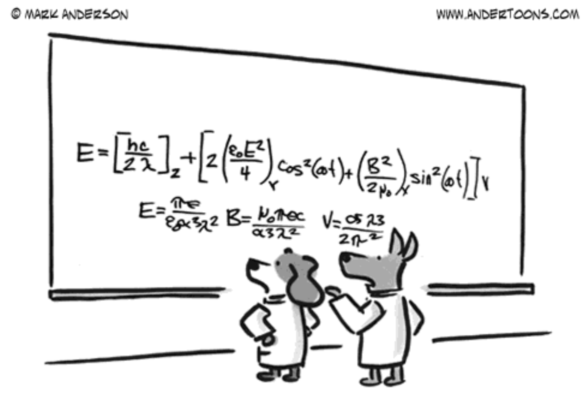


FIG. 3

Einstein's descriptions include several thought experiments and examples involving a moving train and adjacent embankment and only four simple illustrations (one illustration is shown right). He discusses several simple algebraic equations including the Lorentz and Galilei transformations but says nothing of the differential field equations and tensors of his field theories (thankfully, that level of mathematics is unnecessary in a "popular account"). His appendices, which he added after the original booklet was published, discuss various ways the theories were proved correct during his lifetime. However, the appendices only mention that positive results were achieved in certain experiments and, unfortunately, do not discuss how his theories predicted the results or how the experiments proved them. Perhaps these details were beyond the scope of a "popular account" or he felt they required a level of mathematics beyond the target audience's capabilities.

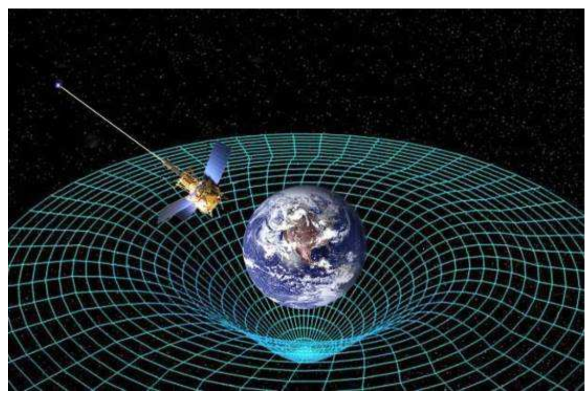
The theories of special and general relativity cover a wide range and have had a huge effect on science, particularly astrophysics where masses and speeds can be very high. *Special relativity* says the same laws of physics (results of calculations) apply to observers even though they may be moving in constant relative motion and have different views of an event. An important assumption of special relativity is that the speed of light in a vacuum is constant, even if the observer or the light source is moving. Special relativity specifies the relationship between energy and mass with the famous equation $E = mc^2$, where E is energy, m is mass, and c is the speed of light in a vacuum.

The special theory embraced the concept of 4-dimensional space-time. Also included in special relativity are the changes in length and time associated with a body and an observer that are moving with respect to each other. These are calculated with the Lorentz transformation and are called *velocity contraction* and *velocity time dilation* (these effects are similar but separate from those caused by gravity, which are discussed in the next paragraph). The theory is *special* because it only applies to observers in inertial (nonaccelerating) reference frames; that is, coordinate systems that are moving with constant velocity with respect to each other or at rest; for example, a train moving at a constant speed with respect to the embankment – as in the examples used by Einstein.



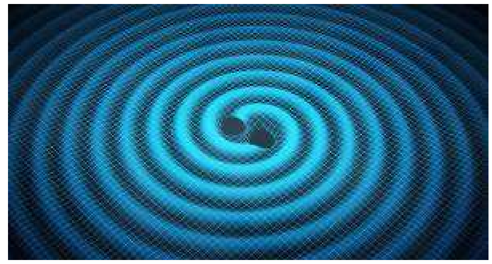
"There it is. You forgot to convert to dog years."

General relativity expands on the concept that space and time are inexorably connected and that any coordinate system is a continuum of space-time. It explains that gravity distorts space-time (image right courtesy NASA). Further, gravity is a field similar in some ways to electromagnetic fields except that bodies moving under the influence of gravity experience acceleration that does not depend on the material or physical state of the body. This was demonstrated on television in 1971 when astronaut David Scott of Apollo 15 dropped a hammer and feather together on the Moon and they reached the surface at the same time.



The general theory applies to observers who may be accelerating and reduces to the special theory when the observers are moving with constant linear motion or at rest. Solutions to Einstein's gravity field equations have yielded many predictions such as the bending of light rays by a gravitational field and the precession of planetary and stellar orbits. General relativity also predicts that length and time are affected by a gravitational field, called *gravitational contraction* and *gravitational time dilation*. In the presence of a gravitational field, the length of an object is shortened and a clock runs slower with respect to an outside observer. The farther the object or clock is from a massive body or the smaller the gravitational field, the smaller are these effects. All of these effects are extremely small on everyday scales but become significant in the vicinities of very large masses and when relative speeds are a significant fraction of the speed of light. Gravity exerts its influence everywhere in the universe even so-called "empty space".

Einstein's theories initially were popular with mathematicians and philosophers but not noticed by physicists. That changed overnight when A.S. Eddington and other astronomers observed a solar eclipse in May 1919 and photographed stars that otherwise would have been invisible because of bright sunlight. General relativity predicts that the starlight would be deflected and the position of these stars would appear shifted. The results published by Eddington supported Einstein's theory, and physicists quickly took notice. However, it was later determined that Eddington's instruments did not have the needed precision and to top it off he cooked his data to favor Einstein's theory. Nevertheless, a number of modern experiments have since shown within the limits of observation that light is, in fact, deflected by the gravitational field around a body as predicted by Einstein's theory. The accuracies of early measurements of other effects predicted by relativity also have been questioned but many, many modern measurements have put to rest most lingering doubts about Einstein's theories.



Another recently proved solution to Einstein's field equations indicates the existence of gravitational waves that could be caused by, for example, the merger of massive objects such as two black holes (image right courtesy NASA). The Laser Interferometer Gravitational-wave observatory (LIGO) located in Louisiana, and Washington USA detected such a wave for the first time on 15 September 2015 (and announced in February 2016), thus confirming yet another aspect of Einstein's theory of general relativity. However, even though Einstein evidently thought and lectured about gravitational waves, he did not write about them in his booklet.

About 168 pages of the 100th anniversary edition are the translation of Einstein's original booklet and the appendices he added later. Altogether, Einstein's booklet has three parts, 32 short sections and five appendices. Some sections consist of only one page. Part I covers special relativity, Part II covers general relativity and Part III briefly covers Einstein's considerations on the universe as a whole. The short sections allow the reader to ponder the material being presented without becoming bogged down by long, dense technical discussions. However, the writing style of the English translation dates to 1920 and is typical of British writers at the time. Compared to modern style it can be somewhat convoluted.

A very helpful 60 page **Reading Companion** section immediately follows Einstein's original work. It is a series of thirteen commentaries added to the 100th anniversary edition by the editors. It discusses the basic concepts and interpretations of Einstein's two theories by direct reference to his numbered sections. Also included are about 40 pages of descriptions and interesting discussions of the original booklet's translations to many other languages.

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$$

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}$$

It should be clear by now that Einstein's famous theories are about geometry and gravity. To start understanding them, the reader needs a working knowledge of inertial and accelerated reference frames, Galilean system of coordinates and Galilean reference bodies (Einstein uses the spelling Galileian), Gaussian coordinates, Minkowski's four dimensional space, Newtonian mechanics, Euclidean space and Euclidean geometry, Lorentz transformation, and many other similar topics. I found the **Reading Companion** section to be essential because the editors explain these concepts in contemporary terms. As I read the companion I often said to myself "Okay, now I get it."

The back dust cover of the "special" 100th anniversary edition has glowing reviews written recently by a number of academics around the English-speaking world. I wonder how many actually read the book. I believe the 100th anniversary edition book needs to be read at least twice to obtain maximum benefit from it. The first time through, the reader can get a feel for the progression of Einstein's explanations, become lost by them and then find clarification in the reading companion. The second time through, the reader does not so easily get lost. I purposefully read this book the second time at a much slower pace and, for me, the second time through was much clearer.

Readers who feel they are stumbling while trying to understand the concepts of relativity should remember that Einstein struggled for many years with highly focused work to formulate his theories (10 years from special to general alone). He did not follow a straight course and made many mistakes along the way, sometimes having to eat crow and correct earlier work. Einstein freely acknowledged that he borrowed technical concepts from many others, including H. Lorentz and H. Minkowski. It is interesting to read Einstein's account of how he used the work of many others. Einstein's association and collaboration with mathematician M. Grossmann was essential to his development of the general theory; in fact, Grossmann probably was more responsible. Einstein said his general theory grew out of electrodynamics and optics, thus indicating his heavy reliance on J.C. Maxwell and others. It was Einstein's special theory that dispelled the long-thought concept that electromagnetic waves required a medium (ether, also spelled aether and æther) to propagate similar to soundwaves in an atmosphere of air or plasma.

Einstein had a phenomenal ability to think and that helped him to use these other original concepts to build his theories. Therefore, one should not expect to fully understand Einstein after only a few days of casual reading. Einstein says in his original preface that "*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.*" I have seen earlier editions of Einstein's booklet advertised with the subtitle "*A Clear Explanation that Anyone Can Understand*", a claim that is far from true and conflicts with Einstein's own warning.

At the end of his booklet Einstein said his theories may or may not stand the test of time, implying that he felt they might be limited cases of a larger, more general theory yet to be discovered. Also at the end, Einstein said that quantum theory has questionable utility and that one should pursue relativistic field theory "*to the end*" before accepting the idea that statistics rule reality. So far, both Einstein's theories and quantum theory have stood up to the test of time.

Readers do not have to purchase a paper copy of this book if interested only in the English translation of Einstein's original work. Various editions are in the public domain and PDF versions of them may be freely downloaded from the internet. Readers with only a casual desire to learn about the theories of relativity probably will be disappointed by Einstein's "popular account" unless, as Einstein said, they have "*... a fair amount of patience and force of will ....*"

In conclusion, it can be fun to read Einstein's translated booklet. However, we must realize there is nothing that says a great thinker also must be a great writer or teacher of thinking any more than a great musician also must be a great music teacher. There are much better explanations of relativity than Einstein's. Most editions of Einstein's original ***Relativity: The Special and the General Theory*** include an introduction or, as with the 100th anniversary edition, a **Reading Companion**, that explain what Einstein was trying to say. The introduction by Nigel Calder in the edition published by Penguin Books in 2006 [Calder] is particularly lucid and it appears *before* Einstein's work, thus providing an interpretive primer before Einstein's primer.

Another example of what I think is a better book is the one by another great scientist and relativity expert Max Born titled ***Einstein's Theory of Relativity*** [Born]. Born's book is altogether original and does not include Einstein's booklet. It was originally published in English in 1924 but completely rewritten by Born and two collaborators for Dover Publications in 1962. It still is available from Dover. Born's book is over twice the length of Einstein's booklet and much better illustrated. Some readers may not be interested in Born's book, however, because it freely uses algebra to explain concepts. However, Born deliberately avoids the mathematician's representations of field equations – differential and integral calculus.

Readers who wish to avoid math altogether but still learn about relativity can find very clear explanations on the website *Einstein Online* by the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) [Planck]. This site uses a more modern context with spacecraft instead of a train for explaining relativity, movement and frames of reference. Obviously, the context changes nothing about the theories themselves. The original papers of A. Einstein in which he published the theories of relativity may be viewed at Princeton University [Princeton].

References:

[Born] Born, M., Einstein's Theory of Relativity, Dover Publications, 1962

[Calder] Calder, N., Albert Einstein, Relativity: The Special and General Theory, Penguin Books, 2006, available here: http://selfdefinition.org/science/25-greatest-science-books-of-all-time/08.%20Albert%20Einstein%20-%20Relativity%20-%20The%20Special%20and%20General%20Theory%20(1916)%20-%20Translated%20by%20Robert%20W.%20Lawson%20(1920)%20-%20Penguin%20Classics%20(2006).pdf

[Planck] Einstein Online at http://www.einstein-online.info/

[Princeton] Collected papers of Albert Einstein at http://einsteinpapers.press.princeton.edu/

Reviewer - Whitham Reeve is a contributing editor for the SARA journal, *Radio Astronomy*. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and has lived in Anchorage, Alaska his entire life.