# Albert einstein atomic model real world analogy

In 1905, Albert Einstein, developed his Theory of Relativity. This groundbreaking piece of work changed how we think and perceive the world around us, overturning centuries of accepted scientific thinking.My favorite analogy for the theory comes from the man himself:"When you sit with a nice girl for two hours you think it's only a minute, but when you sit on a hot stove for a minute you think it's two hours. That's relativity."- Albert EinsteinAbout the Theory ItselfTo most it may seem like a complex mathematical solution to an esoteric problem. But how well does it explain the things we see in our daily lives?First some clarification is in order. When we refer to the theory of relativity we need to be a bit clearer.The special theory of relativity states that the laws of physics are equal in the universe to a stationary or non moving object or observer. In a vacuum the speed of light is constant independent of any observers. It introduced a new framework for all of physics and proposed new concepts of space and time.But there was a problem, what about acceleration and gravity? Einstein spent the next 10 years trying to include acceleration into the theory and published his theory of general relativity in 1915. In it, he determined that massive objects cause a distortion in space-time, which is felt as gravity.These two theories can be thought of collectively as the Theory of Relativity. It helps explains the motion of the planets, the effect of gravity on light to the existence of black holes.As complex as the theory sounds it's actually surprisingly simple. First, there is no "absolute" frame of reference, hence relativity. Every time you measure an object's velocity, momentum, or passage time, it's always in relation to something else. Second, the speed of light is the constant to however measures it, whether in motion or not. Third, nothing can go faster than light.Given all that, how can we see the effects of relativity in real life? Let's find out.1. Global Positioning SystemWithout compensating for relativistic effects, a GPS unit that tells you it's, say, 0.8 km, to the next gas station would be 5 miles (8 km) off after only one day."Because an observer on the ground sees the satellites in motion relative to them, Special Relativity predicts that we should see their clocks ticking more slowly," explained researchers from Ohio State University.[Image Source: Pixabay]Why? Though not hurtling around at the speed of light, GPS satellites are going pretty fast (around 6,000 mph or 10,000 km/h). Factor in that they are sending signals to Earth's surface which is under a greater influence of the Earth's gravity. This causes a small but not imperceptible relativistic time dilation that adds about 4 microseconds each day. Add in the effects of gravity and the figure goes up to about 7 microseconds.2. All that glitters is not goldMost metals are "shiny" because most light is reflected with some absorbed and re-emitted as electrons "jump and fall" within orbitals.Gold, however, is a very heavy atom. The inner electrons are moving so fast (close to half the speed of light) that their mass increases and length shortens under the effects of the Theory of Relativity. This gives them more momentum and shorter paths.These electrons have as almost as much energy as those in the outer shells and thus wavelength absorbed and reflected are longer. This means that more light than "normal" is absorbed, which is the blue end of the spectrum.This means the light reflected from gold has less blue and violet in it giving gold its yellowish colour since this part of the spectrum is longer wavelength than blue.This is a great article if you want to know more.4. Going back to goldThe Theory of relativity doesn't just affect gold's enticing color. It also impacts on gold's ability, well inability, to react with other materials.Gold only has one electron in its outer shell (according to Bohr's naive model), which should make it highly reactive (think of calcium or lithium). As gold is such a massive or heavy atom these electrons are held closer to the nucleus. This means that the electrons are less likely to be influenced by other atoms as they are more likely to be partying with their fellow gold electrons close to the nucleus.3. ElectromagnetsElectromagnets work via relativity. When DC current flows through a single wire the conducting material is electrically neutral with no net positive or negative charge. Now lets put another identical wire next to the first.Assuming the currents are moving and same strength, in the same direction, the electrons in the first wire "see" the electrons in the second wire as motionless. From the electrons' perspective, the protons in both wires appear to be moving. Due to relativistic length contraction, they appear to be more closely spaced, so there's more positive charge per length of wire than negative charge. Since like charges repel, the two wires also repel.Reverse one of the currents in one of wires and you'll get the opposite effect and they will attract creating you electromagnet - awesome.[Video Source: Veritasium] 5. MercuryMercury, like gold, is a very heavy atom. As, with gold, the electrons are held closer to the nucleus (and thus have more velocity and mass than should otherwise be expected). This means that inter-atomic bonds are weak enough for Mercury to have a low melting point than other metals and thus exist in liquid state on Earth.6. Your Old TVOlder TV's contain a piece of tech called a cathode ray tube. These work by firing electrons at a phosphor surface using a big magnet. Each electron equates to a lighted pixel on the screen. These electrons travel at about 30 percent of the speed of light and relativist effects have to be compensated for when designing the shapes of the magnets.7. LightIsaac Newton proposed that there exists in absolute rest frame in the Universe. If this was true, then light shouldn't exist at all.Andrew Moore of Pomona College explained it as:"Not only would magnetism not exist but light would also not exist, because relativity requires that changes in an electromagnetic field move at a finite speed instead of instantaneously, if relativity did not enforce this requirement ... changes in electric fields would be communicated instantaneously ... instead of through electromagnetic waves, and both magnetism and light would be unnecessary."8. Your very existenceAll mass in our solar system came from a supernova before the birth of our sun. We are the children of this long dead Star and all heavier atoms are created and made within Supernovas.Supernovas occur when relativistic effects overcome quantum ones in huge stars. The outer layers of a star collapse down onto the core. This then explodes, creating elements heavier than iron. In fact, nearly all the heavy elements we are familiar with today.*(Ok we cheated a bit)From nuclear power plants to our domestic star, E=MC2 describes the phenomenon of mass and energy being interconnected and convertible to one another. Without this we'd have no nuclear power and more importantly no sunlight.SEE ALSO: One Map Explains How the Entirety of Physics is ConnectedSources Living science, John Walker, Veritasium Kinds of scientific mental experiments done by Einstein A hallmark of Albert Einstein's career was his use of visualized thought experiments (German: Gedankenexperiment[1]) as a fundamental tool for understanding physical issues and for elucidating his concepts to others. Einstein's thought experiments took diverse forms. In his youth, he mentally chased beams of light. For special relativity, he employed moving trains and flashes of lightning to explain his most penetrating insights. For general relativity, he considered a person falling off a roof, accelerating elevators, blind beetles crawling on curved surfaces and the like. In his debates with Niels Bohr on the nature of reality, he proposed imaginary devices intended to show, at least in concept, how the Heisenberg uncertainty principle might be evaded. In a profound contribution to the literature on quantum mechanics, Einstein considered two particles briefly interacting and then flying apart so that their states are correlated, anticipating the phenomenon known as quantum entanglement. Introduction See also: Thought experiment A thought experiment is a logical argument or mental model cast within the context of an imaginary (hypothetical or even counterfactual) scenario. A scientific thought experiment, in particular, may examine the implications of a theory, law, or set of principles with the aid of fictive and/or natural particulars (demons sorting molecules, cats whose lives hinge upon a radioactive disintegration, men in enclosed elevators) in an idealized environment (massless trapdoors, absence of friction). They describe experiments that, except for some specific and necessary idealizations, could conceivably be performed in the real world.[2] As opposed to physical experiments, thought experiments do not report new empirical data. They can only provide conclusions based on deductive or inductive reasoning from their starting assumptions. Thought experiments invoke particulars that are irrelevant to the generality of their conclusions. It is the invocation of these particulars that give thought experiments their experiment-like appearance. A thought experiment can always be reconstructed as a straightforward argument, without the irrelevant particulars. John D. Norton, a well-known philosopher of science, has noted that "a good thought experiment is a good argument; a bad thought experiment is a bad argument."[3] When effectively used, the irrelevant particulars that convert a straightforward argument into a thought experiment can act as "intuition pumps" that stimulate readers' ability to apply their intuitions to their understanding of a scenario.[4] Thought experiments have a long history. Perhaps the best known in the history of modern science is Galileo's demonstration that falling objects must fall at the same rate regardless of their masses. This has sometimes been taken to be an actual physical demonstration, involving his climbing up the Leaning Tower of Pisa and dropping two heavy weights off it. In fact, it was a logical demonstration described by Galileo in Discorsi e dimostrazioni matematiche (1638).[5] Einstein had a highly visual understanding of physics. His work in the patent office "stimulated [him] to see the physical ramifications of theoretical concepts." These aspects of his thinking style inspired him to fill his papers with vivid practical detail making them quite different from, say, the papers of Lorentz or Maxwell. This included his use of thought experiments.[6]:26–27,121–127 Special relativity Pursuing a beam of light See also: Einstein's views on the aether Late in life, Einstein recalled ...a paradox upon which I had already hit at the age of sixteen: If I pursue a beam of light with the velocity c (velocity of light in a vacuum), I should observe such a beam of light as an electromagnetic field at rest though spatially oscillating. There seems to be no such thing, however, neither on the basis of experience nor according to Maxwell's equations. From the very beginning it appeared to me intuitively clear that, judged from the standpoint of such an observer, everything would have to happen according to the same laws as for an observer who, relative to the earth, was at rest. For how should the first observer know or be able to determine, that he is in a state of fast uniform motion? One sees in this paradox the germ of the special relativity theory is already contained in[7][p 1]:52–53 Einstein's recollections of his youthful musings are widely cited because of the hints they provide of his later great discovery. However, Norton has noted that Einstein's reminiscences were probably colored by a half-century of hindsight. Norton lists several problems with Einstein's recounting, both historical and scientific:[7] 1. At 16 years old and a student at the Gymnasium in Aarau, Einstein would have had the thought experiment in late 1895 to early 1896. But various sources note that Einstein did not learn Maxwell's theory until 1898, in university.[7][8] 2. A 19th century aether theorist would have had no difficulties with the thought experiment. Einstein's statement, "...there seems to be no such thing...on the basis of experience," would not have counted as an objection, but would have represented a mere statement of fact, since no one had ever traveled at such speeds. 3. An aether theorist would have regarded "...nor according to Maxwell's equations" as simply representing a misunderstanding on Einstein's part. Unfettered by any notion that the speed of light represents a cosmic limit, the aether theorist would simply have set velocity equal to c, noted that yes indeed, the light would appear to be frozen, and then thought no more of it.[7] Rather than the thought experiment being at all incompatible with aether theories (which it is not), the youthful Einstein appears to have reacted to the scenario out of an intuitive sense of wrongness. He felt that the laws of optics should obey the principle of relativity. As he grew older, his early thought experiment acquired deeper levels of significance: Einstein felt that Maxwell's equations should be the same for all observers in inertial motion. From Maxwell's equations, one can deduce a single speed of light, and there is nothing in this computation that depends on an observer's speed. Einstein sensed a conflict between Newtonian mechanics and the constant speed of light determined by Maxwell's equations.[6]:114–115 Regardless of the historical and scientific issues described above, Einstein's early thought experiment was part of the repertoire of test cases that he used to check on the viability of physical theories. Norton suggests that the real importance of the thought experiment was that it provided a powerful objection to emission theories of light, which Einstein had worked on for several years prior to 1905.[7][8][9] Magnet and conductor See also: Moving magnet and conductor problem In the very first paragraph of Einstein's seminal 1905 work introducing special relativity, he writes: It is well known that Maxwell's electrodynamics—as usually understood at present—when applied to moving bodies, leads to asymmetries that do not seem to attach to the phenomena. Let us recall, for example, the electrodynamic interaction between a magnet and a conductor. The observable phenomenon here depends only on the relative motion of conductor and magnet, while according to the customary conception the two cases, in which, respectively, either the one or the other of the two bodies is the one in motion, are to be strictly differentiated from each other. For if the magnet is in motion and the conductor is at rest, there arises in the surroundings of the magnet an electric field endowed with a certain energy value that produces a current in the places where parts of the conductor are located. But if the magnet is at rest and the conductor is in motion, no electric field arises in the surroundings of the magnet, while in the conductor an electromotive force will arise, to which in itself there does not correspond any energy, but which, provided that the relative motion in the two cases considered is the same, gives rise to electrical currents that have the same magnitude and the same course as those produced by the electric forces in the first-mentioned case.[p 2] Magnet and conductor thought experiment This opening paragraph recounts well-known experimental results obtained by Michael Faraday in 1831. The experiments describe what appeared to be two different phenomena: the motional EMF generated when a wire moves through a magnetic field (see Lorentz force), and the transformer EMF generated by a changing magnetic field (due to the Maxwell–Faraday equation).[9][10][11]:135–157 James Clerk Maxwell himself drew attention to this fact in his 1861 paper On Physical Lines of Force. In the latter half of Part II of that paper, Maxwell gave a separate physical explanation for each of the two phenomena.[p 3] Although Einstein calls the asymmetry "well-known", there is no evidence that any of Einstein's contemporaries considered the distinction between motional EMF and transformer EMF to be in any way odd or pointing to a lack of understanding of the underlying physics. Maxwell, for instance, had repeatedly discussed Faraday's laws of induction, stressing that the magnitude and direction of the induced current was a function only of the relative motion of the magnet and the conductor, without being bothered by the clear distinction between conductor-in-motion and magnet-in-motion in the underlying theoretical treatment.[11]:135–138 Yet Einstein's reflection on this experiment represented the decisive moment in his long and tortuous path to special relativity. Although the equations describing the two scenarios are entirely different, there is no measurement that can distinguish whether the magnet is moving, the conductor is moving, or both.[10] In a 1920 review on the Fundamental Ideas and Methods of the Theory of Relativity (unpublished), Einstein related how disturbing he found this asymmetry: The idea that these two cases should essentially be different was unbearable to me. According to my conviction, the difference between the two could only lie in the choice of the point of view, but not in a real difference .[p 4]:20 Einstein needed to extend the relativity of motion that he perceived between magnet and conductor in the above thought experiment to a full theory. For years, however, he did not know how this might be done. The exact path that Einstein took to resolve this issue is unknown. We do know, however, that Einstein spent several years pursuing an emission theory of light, encountering difficulties that eventually led him to give up the attempt.[10] Gradually I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts. The longer and more desperately I tried, the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results.[p 1]:49 That decision ultimately led to his development of special relativity as a theory founded on two postulates of which he could be sure.[10] Expressed in contemporary physics vocabulary, his postulates were as follows:[note 1] 1. The laws of physics take the same form in all inertial frames. 2. In any given inertial frame, the velocity of light c is the same whether the light be emitted by a body at rest or by a body in uniform motion. [Emphasis added by editor][12]:140–141 Einstein's wording of the second postulate was one with which nearly all theorists of his day could agree. His wording is a far more intuitive form of the second postulate than the stronger version frequently encountered in popular writings and college textbooks.[13][note 2] Trains, embankments, and lightning flashes See also: Relativity of simultaneity The topic of how Einstein arrived at special relativity has been a fascinating one to many scholars: A lowly, twenty-six year old patent officer (third class), largely self-taught in physics[note 3] and completely divorced from mainstream research, nevertheless in the year 1905 produced four extraordinary works (Annus Mirabilis papers), only one of which (his paper on Brownian motion) appeared related to anything that he had ever published before.[8] Einstein's paper, On the Electrodynamics of Moving Bodies, is a polished work that bears few traces of its gestation. Documentary evidence concerning the development of the ideas that went into it consist of, quite literally, only two sentences in a handful of preserved early letters, and various later historical remarks by Einstein himself, some of them known only second-hand and at times contradictory.[8] Train and embankment thought experiment In regards to the relativity of simultaneity, Einstein's 1905 paper develops the concept vividly by carefully considering the basics of how time may be disseminated through the exchange of signals between clocks.[16] In his popular work, Relativity: The Special and the General Theory, Einstein translates the formal presentation of his paper into a thought experiment using a train, a railway embankment, and lightning flashes. The essence of the thought experiment is as follows: Observer M stands on an embankment, while observer M' rides on a rapidly traveling train. At the precise moment that M and M' coincide in their positions, lightning strikes points A and B equidistant from M and M'. Light from these two flashes reach M at the same time, from which M concludes that the bolts were synchronous. The combination of Einstein's first and second postulates implies that, despite the rapid motion of the train relative to the embankment, M' measures exactly the same speed of light as does M. Since M' was equidistant from A and B when lightning struck, the fact that M' receives light from B before light from A means that to M', the bolts were not synchronous. Instead, the bolt at B struck first.[p 5]:29–31 [note 4] A routine supposition among historians of science is that, in accordance with the analysis given in his 1905 special relativity paper and in his popular writings, Einstein discovered the relativity of simultaneity by thinking about how clocks could be synchronized by light signals.[16] The Einstein synchronization convention was originally developed by telegraphers in the middle 19th century. The dissemination of precise time was an increasingly important topic during this period. Trains needed accurate time to schedule use of track, cartographers needed accurate time to determine longitude, while astronomers and surveyors dared to consider the worldwide dissemination of time to accuracies of thousandths of a second.[17]:132–144,183–187 Following this line of argument, Einstein's position in the patent office, where he specialized in evaluating electromagnetic and electromechanical patents, would have exposed him to the latest developments in time technology, which would have guided him in his thoughts towards understanding the relativity of simultaneity.[17]:243–263 However, all of the above is supposition. In later recollections, when Einstein was asked about what inspired him to develop special relativity, he would mention his riding a light beam and his magnet and conductor thought experiments. He would also mention the importance of the Fizeau experiment and the observation of stellar aberration. "They were enough", he said.[18] He never mentioned thought experiments about clocks and their synchronization.[16] The routine analyses of the Fizeau experiment and of stellar aberration, that treat light as Newtonian corpuscles, do not require relativity. But problems arise if one considers light as waves traveling through an aether, which are resolved by applying the relativity of simultaneity. It is entirely possible, therefore, that Einstein arrived at special relativity through a different path than that commonly assumed, through Einstein's examination of Fizeau's experiment and stellar aberration.[16] We therefore do not know just how important clock synchronization and the train and embankment thought experiment were to Einstein's development of the concept of the relativity of simultaneity. We do know, however, that the train and embankment thought experiment was the preferred means whereby he chose to teach this concept to the general public.[p 5]:29–31 Relativistic center-of-mass theorem See also: Mass–energy equivalence Einstein proposed the equivalence of mass and energy in his final Annus Mirabilis paper.[p 6] Over the next several decades, the understanding of energy and its relationship with momentum were further developed by Einstein and other physicists including Max Planck, Gilbert N. Lewis, Richard C. Tolman, Max von Laue (who in 1911 gave a comprehensive proof of M0 = E0/c2 from the stress–energy tensor[19]), and Paul Dirac (whose investigations of negative solutions in his 1928 formulation of the energy–momentum relation led to the 1930 prediction of the existence of antimatter[20]). Poincaré's center-of-mass paradox (as reinterpreted by Einstein) Einstein's relativistic center-of-mass theorem of 1906 is a case in point.[p 7] In 1900, Henri Poincaré had noted a paradox in modern physics as it was then understood: When he applied well-known results of Maxwell's equations to the equality of action and reaction,[p 8] he could describe a cyclic process which would result in creation of a reactionless drive, i.e. a device which could displace its center of mass without the exhaust of a propellant, in violation of the conservation of momentum. Poincaré resolved this paradox by imagining electromagnetic energy to be a fluid having a given density, which is created and destroyed with a given momentum as energy is absorbed and emitted. The motions of this fluid would oppose displacement of the center of mass in such fashion as to preserve the conservation of momentum. Einstein demonstrated that Poincaré's artifice was superfluous. Rather, he argued that mass-energy equivalence was a necessary and sufficient condition to resolve the paradox. In his demonstration, Einstein provided a derivation of mass-energy equivalence that was distinct from his original derivation. Einstein began by recasting Poincaré's abstract mathematical argument into the form of a thought experiment: Einstein considered (a) an initially stationary, closed, hollow cylinder free-floating in space, of mass M {\displaystyle M} and length L {\displaystyle L} , (b) with some sort of arrangement for sending a quantity of radiative energy (a burst of photons) E {\displaystyle E} from the left to the right. The radiation has momentum E / c . {\displaystyle E/c.} Since the total momentum of the system is zero, the cylinder recoils with a speed v = − E / ( M c ) . {\displaystyle v=-E/(Mc).} (c) The radiation hits the other end of the cylinder in time Δ t = L / c , {\displaystyle \Delta t=L/c,} (assuming v h.} 5. General relativity informs us that while the two clocks run at the same rate, a flash of light emitted by one... — light from the lower clock arrives at the upper clock... — {\displaystyle \Delta \nu =\nu \cdot 2\ gh/c^2} ... the mass of which ... M {\displaystyle M} ... {\displaystyle t_{0},} the emission time of the photon. 6. Hence, c 2 Δ m t = Δ E Δ t > h , {\displaystyle c^{2}\Delta m\Delta t=\Delta E\Delta t>h.} The accuracy with which the energy of the photon is emitted ... precision with which its moment of emission can be measured, following the Heisenberg uncertainty principle. After finding his last attempt at finding a loophole around the uncertainty principle refuted, Einstein quit trying to search for inconsistencies in quantum mechanics. Instead, he shifted his focus to the other aspects of quantum mechanics with which he was uncomfortable, focusing on his critique of action at a distance. His next paper on quantum mechanics foreshadowed his later paper on the EPR paradox.[12]:448 Einstein was gracious in his defeat. The following September, Einstein nominated Heisenberg and Schroedinger for the Nobel Prize, stating, "I am convinced that this theory undoubtedly contains a part of the ultimate truth."[12]:448 EPR Paradox See also: EPR paradox and Quantum entanglement Both Bohr and Einstein were subtle men. Einstein tried very hard to show that quantum mechanics was inconsistent; Bohr, however, was always able to counter his arguments. But in his final attack Einstein pointed to something so deep, so counterintuitive, so troubling, and yet so exciting, that at the beginning of the twenty-first century it has returned to fascinate theoretical physicists. Bohr's only answer to Einstein's last great discovery—the discovery of entanglement—was to ignore it.—Leonard Susskind[45] Einstein's fundamental dispute with quantum mechanics was not about whether God rolled dice, whether the uncertainty principle allowed simultaneous measurement of position and momentum, or even whether quantum mechanics was complete. It was about reality. Does a physical reality exist independent of our ability to observe it? To Bohr and his followers, such questions were meaningless. All that we can know are the results of measurements and observations. It makes no sense to speculate about an ultimate reality that exists beyond our perceptions.[6]:460–461 Einstein's beliefs had evolved over the years from those that he had held when he was young, when, as a logical positivist heavily influenced by his reading of David Hume and Ernst Mach, he had rejected such unobservable concepts as absolute time and space. Einstein believed:[6]:460–461 1. A reality exists independent of our ability to observe it. 2. Objects are located at distinct points in spacetime and have their own independent, real existence. In other words, he believed in separability and locality. 3. Although at a superficial level, quantum events may appear random, at some ultimate level, strict causality underlies all processes in nature. EPR paradox thought experiment. (top) The total wave function of a particle pair spreads from the collision point. (bottom) Observation of one particle collapses the wave function. Einstein considered that realism and localism were fundamental underpinnings of physics. After leaving Nazi Germany and settling in Princeton at the Institute for Advanced Study, Einstein began writing up a thought experiment that he had been mulling over since attending a lecture by Léon Rosenfeld in 1933. Since the paper was to be in English, Einstein enlisted the help of the 46-year-old Boris Podolsky, a fellow who had moved to the institute from Caltech; he also enlisted the help of the 26-year-old Nathan Rosen, also at the institute, who did much of the math.[note 18] The result of their collaboration was the four page EPR paper, which in its title asked the question Can Quantum-Mechanical Description of Physical Reality be Considered Complete?[6]:448–450 [p 22] After seeing the paper in print, Einstein found himself unhappy with the result. His clear conceptual visualization had been buried under layers of mathematical formalism.[6]:448–450 Einstein's thought experiment involved two particles that have collided or which have been created in such a way that they have properties which are correlated. The total wave function for the pair links the positions of the particles as well as their linear momenta.[6]:450–453 [40] The figure depicts the spreading of the wave function from the collision point. However, observation of the position of the first particle allows us to determine precisely the position of the second particle no matter how far the pair have separated. Likewise, measuring the momentum of the first particle allows us to determine precisely the momentum of the second particle. "In accordance with our criterion for reality, in the first case we must consider the quantity P as being an element of reality, in the second case the quantity Q is an element of reality."[p 22] Einstein concluded that the second particle, which we have never directly observed, must have at any moment a position that is real and a momentum that is real. Quantum mechanics does not account for these features of reality. Therefore, quantum mechanics is not complete.[6]:451 It is known, from the uncertainty principle, that position and momentum cannot be measured at the same time. But even though their values can only be determined in distinct contexts of measurement, can they both be definite at the same time? Einstein concluded that the answer must be yes.[40] The only alternative, claimed Einstein, would be to assert that measuring the first particle instantaneously affected the reality of the position and momentum of the second particle.[6]:451 "No reasonable definition of reality could be expected to permit this."[p 22] Bohr was stunned when he read Einstein's paper and spent more than six weeks framing his response, which he gave exactly the same title as the EPR paper.[p 26] The EPR paper forced Bohr to make a major revision in his understanding of complementarity in the Copenhagen interpretation of quantum mechanics.[40] Prior to EPR, Bohr had maintained that disturbance caused by the act of observation was the physical explanation for quantum uncertainty. In the EPR thought experiment, however, Bohr had to admit that "there is no question of a mechanical disturbance of the system under investigation." On the other hand, he noted that the two particles were one system described by one quantum function. Furthermore, the EPR paper did nothing to dispel the uncertainty principle.[12]:454–457 [note 19] Later commentators have questioned the strength and coherence of Bohr's response. As a practical matter, however, physicists for the most part did not pay much attention to the debate between Bohr and Einstein, since the opposing views did not affect one's ability to apply quantum mechanics to practical problems, but only affected one's interpretation of the quantum formalism. If they thought about the problem at all, most working physicists tended to follow Bohr's leadership.[40][47][48] So stood the situation for nearly 30 years. Then, in 1964, John Stewart Bell made the groundbreaking discovery that Einstein's local realist world view made experimentally verifiable predictions that would be in conflict with those of quantum mechanics. Bell's discovery shifted the Einstein–Bohr debate from philosophy to the realm of experimental physics. Bell's theorem showed that, for any local realist formalism, there exist limits on the predicted correlations between pairs of particles in an experimental realization of the EPR thought experiment. In 1972, the first experimental tests were carried out. Successive experiments improved the accuracy of observation and closed loopholes. To date, it is virtually certain that local realist theories have been falsified.[49] So Einstein was wrong. But after decades of relative neglect, the EPR paper has been recognized as prescient, since it identified the phenomenon of quantum entanglement. It has several times been the case that Einstein's "mistakes" have foreshadowed and provoked major shifts in scientific research. Such, for instance, has been the case with his proposal of the cosmological constant, which Einstein considered his greatest blunder, but which currently is being actively investigated for its possible role in the accelerating expansion of the universe. In his Princeton years, Einstein was virtually shunned as he pursued the unified field theory. Nowadays, innumerable physicists pursue Einstein's dream for a "theory of everything."[50] The EPR paper did not prove quantum mechanics to be incorrect. What it did prove was that quantum mechanics, with its "spooky action at a distance," is completely incompatible with commonsense understanding.[51] Furthermore, the effect predicted by the EPR paper, quantum entanglement, has inspired approaches to quantum mechanics different from the Copenhagen interpretation, and has been at the forefront of major technological advances in quantum computing, quantum encryption, and quantum information theory.[52] Notes ^ Einstein's original expression of these postulates was as follows: "1. The laws governing the changes of the state of any physical system do not depend on which one of two coordinate systems in uniform translational motion relative to each other these changes of the state are referred to. 2. Each ray of light moves in the coordinate system "at rest" with the definite velocity V independent of whether this ray of light is emitted by a body at rest or a body in motion."[p 2] ^ One popular textbook expresses the second postulate as, "The speed of light in free space has the same value c in all directions and in all inertial reference frames."[14] ^ Einstein was very disappointed in the physics curriculum at the Zurich Polytechnic, which was geared towards the training of future engineers rather than treating physics as a discipline in its own right. It did not cover cutting-edge research that Einstein considered of fundamental importance. Professor Weber, for instance, "simply ignored anything since Helmholtz". Although basic kinetic theory of gases was taught, Einstein had to learn deeper aspects of the subject by studying the recently published books of Boltzmann. The new electromagnetic field theory was ignored. Einstein read works by Hertz, Drude (through which he picked up Maxwell's theory), and Lorentz on his own. In other words, it was only through his self-study (and cutting a lot of classes) that Einstein kept himself in tune with the mainstream of physics research.[15]:55–63 ^ Other than that M' witnesses the bolt at B striking before the bolt at A, details of what M' observes are not often considered. An animation of a modified train-and-embankment thought experiment and its inverse is available here. ^ As with several other of Einstein's thought experiments, his conservation of energy argument has, over the years, become much embellished by subsequent writers so that current recountings of his argument are sometimes almost unrecognizable. Schutz, for instance, added a tall drop tower and a photonic mass-energy converter to Einstein's basic construct.[25]:118–126 ^ The old quantum theory refers to a mixed collection of heuristic corrections to classical mechanics which predate modern quantum mechanics. The elements of the theory are now understood to be semi-classical approximations to modern quantum mechanical treatments. ^ The 1819 observation of the Arago spot (a bright point at the center of a circular object's shadow due to diffraction), Foucault's 1850 differential measurements of the speed of light in air versus water,[35] and above all, the success of Maxwell's equations in explaining virtually all known electromagnetic phenomena were considered to have proven the wave nature of light as opposed to a corpuscular theory. "Einstein, a virtual unknown [in 1905] who was contradicting the wave theory of light, had hardly more credibility than a crackpot..."[33]:79 ^ This statement is only exactly true for perfect crystals. Imperfect crystals, amorphous bodies, etc. retain disorder which does not freeze out at absolute zero. ^ Unlike Einstein's hypothesis of light quanta, his quantum theory of solid bodies gained rapid acceptance, largely due to the support of the well-known physical chemist Walther Nernst.[15]:153–154 ^ Planck's derivation required that hypothetical "resonators" in the walls of a cavity take on equally spaced states of definite energy, with intermediate energies being forbidden. Use of equally spaced energy levels allowed Planck to calculate the sum of an infinite series. In reality, atomic energy levels are not equally spaced, and Planck's derivation breaks down.[37] ^ Bose claimed that both Planck's and Einstein's methods of deriving the law relied on a previously derived classical result, Wien's distribution law, for the factor 8π2/c2, which was "a most unsatisfactory point in all derivations." Einstein privately corrected Bose on this point, showing that he was wrong in believing that Wien's distribution law presupposed classical wave theory. ^ When asked about whether he understood the fundamental implications of his counting method, Bose replied with great candor: "I had no idea that what I had done was really novel.... I was not a statistician to the extent of really knowing that I was doing something which was really different from what Boltzmann would have done, from Boltzmann statistics."[33]:223 ^ In his Nobel lecture, Born gave Einstein full credit for having been the source of his idea: "...we missed the correct approach. This was left to Schrödinger, and I immediately took up his method since it held promise of leading to an interpretation of the ψ-function. Again an idea of Einstein's gave me the lead. He had tried to make the duality of particles - light quanta or photons - and waves comprehensible by interpreting the square of the optical wave amplitudes as probability density for the occurrence of photons. This concept could at once be carried over to the ψ-function: ψ2 ought to represent the probability density for electrons (or other particles)."[p 21] ^ Although Einstein's post-1925 scientific efforts were dominated by his abortive work on unified field theory, he still produced a number of major publications. In addition to the EPR paper, these include his introduction of the concept of wormholes,[p 23] his prediction of gravitational lensing,[p 24] and a paper that established that gravitational waves are possible (correcting an older publication that had reached the opposite conclusion).[p 25] ^ In his 1909 lecture, Einstein noted that for a wavelength of 0.5μ and a black body temperature of 1700K, the particulate term would be about 6.5×107 times larger than the wave term.[p 19] ^ Even after Compton's results, a handful of physicists continued to reject the photon. Chief among these were Bohr, Kramer and Slater, who in January 1924 published their "BKS" proposal which made drastic suggestions on how light and matter might interact. At the time of the BKS proposal, there had not yet been experimental proof of energy-momentum conservation or causality at the microlevel, so that the possibility existed that energy-momentum conservation and causality held true only as a statistical average. Using Einstein's 1916 radiation theory as a starting point, the BKS proposal suggested that continuous absorption of X-rays by an atom would increase the probability that the atom would emit an electron, but the actual electron emission would be acausal. Associated with each atom was a "virtual radiation field" that determined an electron's emission probability. The BKS proposal met with a subdued reaction by the majority of physicists. Experimental rejection was not long in coming. (1) Bothe and Geiger developed counter coincidence techniques which established that, in the Compton experiment, secondary photons and their associated knock-out electrons were produced simultaneously; (2) Compton and Simon established that the scattering angles between individual secondary photons and their associated knock-out electrons satisfied the energy-momentum conservation law.[12]:416–422 ^ Frictional damping adds heat (and therefore mass-energy) to the system, but it can be demonstrated that errors due to this effect, which was not considered by Bohr, are within an acceptable range.[44] ^ Fölsing, in his otherwise reliable biography of Einstein, suggests that Rosen actually originated the ideas in the EPR paper.[15]:696 This claim is contradicted by statements made by Rosenfeld: "'What would you say of the following situation?' he asked me [following a seminar by Rosenfeld in Brussels in 1933 that Einstein attended]. 'Suppose two particles are set in motion towards each other with the same, very large momentum, and that they interact with each other for a very short time when they pass at known positions. Consider now an observer who gets hold of one of the particles, far away from the region of interaction, and measures its momentum; then, from the conditions of the experiment, he will obviously be able to deduce the momentum of the other particle. If, however, he chooses to measure the position of the first particle, he will be able to tell where the other particle is. This is a perfectly correct and straightforward deduction from the principles of quantum mechanics; but is it not very paradoxical? How can the final state of the second particle be influenced by a measurement performed on the first, after all physical interaction has ceased between them?'"[46] ^ Bohr claimed that a measurement on one particle does involve "an influence on the very conditions which define the possible types of predictions regarding the future behavior of [the other particle]."[p 26] Arthur Fine noted that "The meaning of this claim is not at all clear," and indeed, "it is difficult to know whether a coherent response can be attributed to Bohr reliably that would derail EPR."[40] 

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Poincaré enthalten sind2, werde ich mich doch der Übersichtlichkeit halber nicht auf jene Arbeit stützen. {{cite journal}}: External link in |trans-title= (help) ^ Poincaré, H. (1900). "La théorie de Lorentz et le principe de réaction" [The Theory of Lorentz and The Principle of Reaction]. Archives Néerlandaises des Sciences Exactes et Naturelles (in French). 5: 252–278. {{cite journal}}: External link in |trans-title= (help) ^ a b Einstein, Albert (1907). "Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen" [On the relativity principle and the conclusions drawn from it] (PDF). Jahrbuch der Radioaktivität und Elektronik. 4: 411–462. Retrieved 2 August 2015. ^ a b Einstein, Albert (1990). "On the relativity principle and the conclusions drawn from it". In Stachel, John; Cassidy, David C; Renn, Jürgen; et al. (eds.). The Collected Papers of Albert Einstein, Volume 2: The Swiss Years: Writings, 1900-1909. Princeton: Princeton University Press. p. 252. 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