Richard feynman pdf books

Chances are, if you are not in the field of science, or if you don't work at a bookstore or library, you might not be familiar with the works of Richard Feynman. Feynman was a rock star in his field, an American theoretical physicist known for his work in the path integral formulation of quantum mechanics, the theory of quantum electrodynamics, the physics of the superfluidity of supercooled liquid helium, and more. He even developed a widely used pictorial representation scheme for the mathematical expressions explaining subatomic particles, which later became known as Feynman diagrams. For his contributions to science, he was awarded the Nobel Prize in Physics in 1965. Feynman also worked on the development of the atomic bomb, and was a member of the panel that investigated the Space Shuttle Challenger disaster. He has been credited with pioneering the field of quantum computing and introducing the concept of nanotechnology. He led quite an amazing life! Now, if you are not a theoretical physicist, quantum electrodynamics, the physics of the superfluidity, and those other things I just talked about probably sound pretty confusing to you. I know that I couldn't explain them! But that's why Feynman was a rock star: he took his brilliant work and broke it down into layman's terms in several books that everyone can enjoy. With such an amazing career, Feynman had a lot of knowledge to share with the world. And whether you're a theoretical physicist, a student, or just curious about Feynman and his work, these Richard Feynman books will give you a broad overview of the man and his work. Liberty Hardy is a Book Riot senior contributing editor and velocireader in the great state of Maine, where she reads 500-600 books a year and lives with her three cats, who hate to read. *Source: Wikipedia If you only have time to read one Feynman book, make it this one. 'Surely You're Joking, Mr Feynman!' is as close as you'll come to an audience with the man himself.Transcribed and edited by Ralph Leighton, Feynman's stories of safecracking, drawing nudes and playing the bongos are interspersed with his life in science.The title comes from a misunderstanding of etiquette at a college tea party – airs and graces being a particular Feynman bugbear.Surely You're Joking Mr Feynman (£10.99, Vintage) 2Richard Feynman wasn't a writer, so this collection of short pieces edited by Jeffrey Robbins consists mostly of transcribed talks and interviews.It is, however, a complete joy, showcasing his extraordinary curiosity in everything from the future of computers to pseudoscience and even religion.Also included are his report on the Shuttle Challenger disaster and the seminal talk, 'There's plenty of room at the bottom', which anticipated the nanotechnology revolution.Watch the BBC Horizon special 1981: The Pleasure of Finding Things Out where Professor Richard Feynman of Caltech talks about his life and career.3In 1964, Feynman presented the Messenger Lectures at Cornell University. This is a record of those talks, in which he outlines some of the fundamentals of physics.Apparently with the aid of very few lecture notes, Feynman explained gravity, mathematical laws, symmetry, probability and more to a packed theatre.There are a handful of diagrams and very few equations, making this his most accessible book on physics.4The second volume of recollections edited by Ralph Leighton centres on Feynman's time on the committee that investigated the Shuttle Challenger disaster.It reveals the shockingly poor communication between the engineers who built the Shuttle and NASA management, culminating in Feynman's demonstration on live TV.The poignant title of this book comes from Feynman's first wife, who died of tuberculosis.5QED is short for the theory of quantum electrodynamics, which describes how light and matter interact, and it won Feynman the Nobel Prize in 1965.Feynman was a gifted teacher able to convey his irreverent enthusiasm for science to the layman, but you'll probably find it hard going if you've never studied any physics.Follow Science Focus on Twitter, Facebook, Instagram and Flipboard American theoretical physicist (1918–1988) "Feynman" redirects here. For other uses, see Feynman (disambiguation). Richard FeynmanFeynman c. 1965BornRichard Phillips Feynman(1918-05-11)May 11, 1918New York City, U.S.DiedFebruary 15, 1988(1988-02-15) (aged 69)Los Angeles, California, U.S.Resting placeMountain View Cemetery and Mausoleum, Altadena, California, U.S.Other namesDickThe OrganizationAlma materMassachusetts Institute of Technology (S.B.)Princeton University (Ph.D.)Known for See list Manhattan Project Acoustic wave equation Bethe–Feynman formula Feynman checkerboard Feynman diagrams Feynman gauge Feynman–Kac formula Feynman parametrization Feynman point Feynman propagator Feynman slash notation Feynman sprinkler Hellmann–Feynman theorem Heaviside–Feynman formula V−A theory Brownian ratchet Feynman–Stueckelberg interpretation Nanotechnology One-electron universe Parton Path integral formulation Playing the bongos Quantum cellular automata Quantum computing Quantum dissipation Quantum electrodynamics Quantum hydrodynamics Quantum logic gates Quantum turbulence Reversible computing Rogers Commission Shot noise Synthetic molecular motor The Feynman Lectures on Physics Universal quantum simulator Vortex ring model Wheeler–Feynman absorber theory Variational perturbation theory Spouse(s)Arline Greenbaum (m. 1941; died 1945) Mary Louise Bell (m. 1952–1956) Gweneth Howarth (m. 1960)Children2Awards Albert Einstein Award (1954) E. O. Lawrence Award (1962) Nobel Prize in Physics (1965) Foreign Member of the Royal Society (1965) Oersted Medal (1972) National Medal of Science (1979) Scientific careerFieldsTheoretical physicsInstitutionsCornell UniversityCalifornia Institute of TechnologyThesisThe Principle of Least Action in Quantum Mechanics (1942)Doctoral advisorJohn Archibald WheelerDoctoral students James M. Bardeen Laurie Mark Brown Thomas Curtright Albert Hibbs Giovanni Rossi Lomanitz George Zweig Other notable students Robert Barro W. Daniel Hillis Douglas D. Osheroff Paul Steinhardt Peter Shor Stephen Wolfram Signature Richard Phillips Feynman (/ˈfaɪnmən/; May 11, 1918 – February 15, 1988) was an American theoretical physicist, known for his work in the path integral formulation of quantum mechanics, the theory of quantum electrodynamics, the physics of the superfluidity of supercooled liquid helium, as well as his work in particle physics for which he proposed the parton model. For contributions to the development of quantum electrodynamics, Feynman received the Nobel Prize in Physics in 1965 jointly with Julian Schwinger and Shin'ichirō Tomonaga. Feynman developed a widely used pictorial representation scheme for the mathematical expressions describing the behavior of subatomic particles, which later became known as Feynman diagrams. During his lifetime, Feynman became one of the best-known scientists in the world. In a 1999 poll of 130 leading physicists worldwide by the British journal Physics World he was ranked the seventh-greatest physicist of all time.[1] He assisted in the development of the atomic bomb during World War II and became known to a wide public in the 1980s as a member of the Rogers Commission, the panel that investigated the Space Shuttle Challenger disaster. Along with his work in theoretical physics, Feynman has been credited with pioneering the field of quantum computing and introducing the concept of nanotechnology. He held the Richard C. Tolman professorship in theoretical physics at the California Institute of Technology. Feynman was a keen popularizer of physics through both books and lectures, including a 1959 talk on top-down nanotechnology called There's Plenty of Room at the Bottom and the three-volume publication of his undergraduate lectures, The Feynman Lectures on Physics. Feynman also became known through his autobiographical books Surely You're Joking, Mr. Feynman! and What Do You Care What Other People Think?, and books written about him such as Tuva or Bust! by Ralph Leighton and the biography Genius: The Life and Science of Richard Feynman by James Gleick. Early life Feynman was born on May 11, 1918, in Queens, New York City,[2] to Lucille née Phillips, a homemaker, and Melville Arthur Feynman, a sales manager[4] originally from Minsk in Belarus[5] (then part of the Russian Empire). His family was Jewish.[3][4] Feynman was a late talker, and did not speak until after his third birthday. As an adult he spoke with a New York accent[6][7] strong enough to be perceived as an affectation or exaggeration,[8][9] so much so that his friends Wolfgang Pauli and Hans Bethe once commented that Feynman spoke like a "bum".[8] The young Feynman was heavily influenced by his father, who encouraged him to ask questions to challenge orthodox thinking, and who was always ready to teach Feynman something new. From his mother, he gained the sense of humor that he had throughout his life. As a child, he had a talent for engineering,[10] maintained an experimental laboratory in his home, and delighted in repairing radios. This radio repairing was probably the first job Feynman had, and during this time he showed early signs of an aptitude for his later career in theoretical physics, when he would analyze the issues theoretically and arrive at the solutions.[11] When he was in grade school, he created a home burglar alarm system while his parents were out for the day running errands.[12] When Richard was five, his mother gave birth to a younger brother, Henry Phillips, who died at age four weeks.[13] Four years later, Richard's sister Joan was born and the family moved to Far Rockaway, Queens.[4] Though separated by nine years, Joan and Richard were close, and they both shared a curiosity about the world.[14] Though their mother thought women lacked the capacity to understand such things, Richard encouraged Joan's interest in astronomy, and Joan eventually became an astrophysicist.[15] Religion Feynman's parents were both from Jewish families[4] but not religious, and by his youth, Feynman described himself as an "avowed atheist".[16][17] Many years later, in a letter to Tina Levitan, declining a request for information for her book on Jewish Nobel Prize winners, he stated, "To select, for approbation the peculiar elements that come from some supposedly Jewish heredity is to open the door to all kinds of nonsense on racial theory", adding, "at thirteen I was not only converted to other religious views but I also stopped believing that the Jewish people are in any way 'the chosen people'".[18] Later in his life, during a visit to the Jewish Theological Seminary, he encountered the Talmud for the first time. He saw that it contained the original text in a little square on the page, and surrounding it were commentaries written over time by different people. In this way the Talmud had evolved, and everything that was discussed was carefully recorded. Despite being impressed, Feynman was disappointed with the lack of interest for nature and the outside world expressed by the rabbis, who cared about only those questions which arise from the Talmud.[19] Education Feynman attended Far Rockaway High School, which was also attended by fellow Nobel laureates Burton Richter and Baruch Samuel Blumberg.[20] Upon starting high school, Feynman was quickly promoted to a higher math class. An IQ test administered in high school estimated his IQ at 125—high but "merely respectable", according to biographer James Gleick.[21][22] His sister Joan, who scored one point higher, later jokingly claimed to an interviewer that she was smarter. Years later he declined to join Mensa International, saying that his IQ was too low.[23] When Feynman was 15, he taught himself trigonometry, advanced algebra, infinite series, analytic geometry, and both differential and integral calculus.[24] Before entering college, he was experimenting with mathematical topics such as the half-derivative using his own notation.[25] He created special symbols for logarithm, sine, cosine and tangent functions so they did not look like three variables multiplied together, and for the derivative, to remove the temptation of canceling out the d's (d/dx).[26][27] A member of the Arista Honor Society, in his last year in high school he won the New York University Math Championship.[28] His habit of direct characterization sometimes rattled more conventional thinkers; for example, one of his questions, when learning feline anatomy, was "Do you have a map of the cat?" (referring to an anatomical chart).[29] Feynman applied to Columbia University but was not accepted because of their quota for the number of Jews admitted.[4] Instead, he attended the Massachusetts Institute of Technology, where he joined the Pi Lambda Phi fraternity.[30] Although he originally majored in mathematics, he later switched to electrical engineering, as he considered mathematics to be too abstract. Noticing that he "had gone too far," he then switched to physics, which he claimed was "somewhere in between".[31] As an undergraduate, he published two papers in the Physical Review.[29] One of these, which was co-written with Manuel Vallarta, was entitled "The Scattering of Cosmic Rays by the Stars of a Galaxy".[32] Vallarta let his student in on a secret of mentor-protégé publishing: the senior scientist's name comes first. Feynman had his revenge a few years later, when Heisenberg concluded an entire book on cosmic rays with the phrase: "such an effect is not to be expected according to Vallarta and Feynman". When they next met, Feynman asked gleefully whether Vallarta had seen Heisenberg's book. Vallarta knew why Feynman was grinning. "Yes," he replied. "You're the last word in cosmic rays."[33] The other was his senior thesis, on "Forces in Molecules",[34] based on a topic assigned by John C. Slater, who was sufficiently impressed by the paper to have it published. Today, its main result is known as the Hellmann–Feynman theorem.[35] In 1939, Feynman received a bachelor's degree[36] and was named a Putnam Fellow.[37] He attained a perfect score on the graduate school entrance exams to Princeton University in physics—an unprecedented feat—and an outstanding score in mathematics, but did poorly on the history and English portions. The head of the physics department there, Henry D. Smyth, had another concern, writing to Philip M. Morse to ask: "Is Feynman Jewish? We have no definite rule against Jews but have to keep their proportion in our department reasonably small because of the difficulty of placing them."[38] Morse conceded that Feynman was indeed Jewish, but reassured Smyth that Feynman's "physiognomy and manner, however, show no trace of this characteristic".[38] Attendees at Feynman's first seminar, which was on the classical version of the Wheeler–Feynman absorber theory, included Albert Einstein, Wolfgang Pauli, and John von Neumann. Pauli made the prescient comment that the theory would be extremely difficult to quantize, and Einstein said that one might try to apply this method to gravity in general relativity,[39] which Sir Fred Hoyle and Jayant Narlikar did much later as the Hoyle–Narlikar theory of gravity.[40][41] Feynman received a Ph.D. from Princeton in 1942; his thesis advisor was John Archibald Wheeler.[42] In his doctoral thesis entitled "The Principle of Least Action in Quantum Mechanics",[43] Feynman applied the principle of stationary action to problems of quantum mechanics, inspired by a desire to quantize the Wheeler–Feynman absorber theory of electrodynamics, and laid the groundwork for the path integral formulation and Feynman diagrams.[44] A key insight was that positrons behaved like electrons moving backwards in time.[44] James Gleick wrote: This was Richard Feynman nearing the crest of his powers. At twenty-three ... there was no physicist on earth who could match his exuberant command over the native materials of theoretical science. It was not just a facility at mathematics (though it had become clear ... that the mathematical machinery emerging from the Wheeler collaboration was beyond Wheeler's own ability). Feynman seemed to possess a frightening ease with the substance behind the equations, like Einstein at the same age, like the Soviet physicist Lev Landau—but few others.[42] One of the conditions of Feynman's scholarship to Princeton was that he could not be married; nevertheless, he continued to see his high school sweetheart, Arline Greenbaum, and was determined to marry her once he had been awarded his Ph.D. despite the knowledge that she was seriously ill with tuberculosis. This was an incurable disease at the time, and she was not expected to live more than two years. On June 29, 1942, they took the ferry to Staten Island, where they were married in the city office. The ceremony was attended by neither family nor friends and was witnessed by a pair of strangers. Feynman could kiss Arline only on the cheek. After the ceremony he took her to Deborah Hospital, where he visited her on weekends.[45][46] Manhattan Project Feynman (center) with Robert Oppenheimer (right) relaxing at a Los Alamos social function during the Manhattan Project Feynman's ID badge In 1941, with World War II raging in Europe but the United States not yet at war, Feynman spent the summer working on ballistics problems at the Frankford Arsenal in Pennsylvania.[47][48] After the attack on Pearl Harbor brought the United States into the war, Feynman was recruited by Robert R. Wilson, who was working on means to produce enriched uranium for use in an atomic bomb, as part of what would become the Manhattan Project.[49][50] At the time, Feynman had not earned a graduate degree.[51] Wilson's team at Princeton was working on a device called an isotron, intended to electromagnetically separate uranium-235 from uranium-238. This was done in a quite different manner from that used by the calutron that was under development by a team under Wilson's former mentor, Ernest O. Lawrence, at the Radiation Laboratory of the University of California. On paper, the isotron was many times more efficient than the calutron, but Feynman and Paul Olum struggled to determine whether or not it was practical. Ultimately, on Lawrence's recommendation, the isotron project was abandoned.[52] At this juncture, in early 1943, Robert Oppenheimer was establishing the Los Alamos Laboratory, a secret laboratory on a mesa in New Mexico where atomic bombs would be designed and built. An offer was made to the Princeton team to be redeployed there. "Like a bunch of professional soldiers," Wilson later recalled, "we signed up, en masse, to go to Los Alamos."[53] Like many other young physicists, Feynman soon fell under the spell of the charismatic Oppenheimer, who telephoned Feynman long distance from Chicago to inform him that he had found a sanatorium in Albuquerque, New Mexico for Arline. They were among the first to depart for New Mexico, leaving on a train on March 28, 1943. The railroad supplied Arline with a wheelchair, and Feynman paid extra for a private room for her. There they spent their wedding anniversary.[54] At Los Alamos, Feynman was assigned to Hans Bethe's Theoretical (T) Division,[55] and impressed Bethe enough to be made a group leader.[56] He and Bethe developed the Bethe–Feynman formula for calculating the yield of a fission bomb, which built upon previous work by Robert Serber.[57] As a junior physicist, he was not central to the project. He administered the computation group of human computers in the theoretical division. With Stanley Frankel and Nicholas Metropolis, he assisted in establishing a system for using IBM punched cards for computation.[58] He invented a new method of computing logarithms that he later used on the Connection Machine.[59][60] An avid drummer, Feynman figured out how to get the machine to click in musical rhythms.[61] Other work at Los Alamos included calculating neutron equations for the Los Alamos "Water Boiler", a small nuclear reactor, to measure how close an assembly of fissile material was to criticality.[62] On completing this work, Feynman was sent to the Clinton Engineer Works in Oak Ridge, Tennessee, where the Manhattan Project had its uranium enrichment facilities. He aided the engineers there in devising safety procedures for material storage so that criticality accidents could be avoided, especially when enriched uranium came into contact with water, which acted as a neutron moderator. He insisted on giving the rank and file a lecture on nuclear physics so that they would realize the dangers.[63] He explained that while any amount of unenriched uranium could be safely stored, the enriched uranium had to be carefully handled. He developed a series of safety recommendations for the various grades of enrichments.[64] He was told that if the people at Oak Ridge gave him any difficulty with his proposals, he was to inform them that Los Alamos "could not be responsible for their safety otherwise".[65] At the 1946 colloquium on the "Super" at the Los Alamos Laboratory. Feynman is in the second row, fourth from left, next to Oppenheimer Returning to Los Alamos, Feynman was put in charge of the group responsible for the theoretical work and calculations on the proposed uranium hydride bomb, which ultimately proved to be infeasible.[56][66] He was sought out by physicist Niels Bohr for one-on-one discussions. He later discovered the reason: most of the other physicists were too much in awe of Bohr to argue with him. Feynman had no such inhibitions, vigorously pointing out anything he considered to be flawed in Bohr's thinking. He said he felt as much respect for Bohr as anyone else, but once anyone got him talking about physics, he would become so focused he forgot about social niceties. Perhaps because of this, Bohr never warmed to Feynman.[67][68] At Los Alamos, which was isolated for security, Feynman amused himself by investigating the combination locks on the cabinets and desks of physicists. He often found that they left the lock combinations on the factory settings, wrote the combinations down, or used easily guessable combinations like dates.[69] He found one cabinet's combination by trying numbers he thought a physicist might use (it proved to be 27–18–28 after the base of natural logarithms, e = 2.71828 ...), and found that the three filing cabinets where a colleague kept research notes all had the same combination. He left notes in the cabinets as a prank, spooking his colleague, Frederic de Hoffmann, into thinking a spy had gained access to them.[70] Feynman's $380 (equivalent to $6,000 in 2021) monthly salary was about half the amount needed for his modest living expenses and Arline's medical bills, and they were forced to dip into her $3,300 (equivalent to $52,000 in 2021) in savings.[71] On weekends he borrowed a car from his friend Klaus Fuchs to drive to Albuquerque to see Arline.[72][73] Asked who at Los Alamos was most likely to be a spy, Fuchs mentioned Feynman's safe-cracking and frequent trips to Albuquerque;[72] Fuchs himself later confessed to spying for the Soviet Union.[74] The FBI would compile a bulky file on Feynman,[75] particularly in view of Feynman's Q clearance.[76] Informed that Arline was dying, Feynman drove to Albuquerque and sat with her for hours until she died on June 16, 1945.[77] He then immersed himself in work on the project and was present at the Trinity nuclear test. Feynman claimed to be the only person to see the explosion without the very dark glasses or welder's lenses provided, reasoning that it was safe to look through a truck windshield, as it would screen out the harmful ultraviolet radiation. The immense brightness of the explosion made him duck to the truck's floor, where he saw a temporary "purple splotch" afterimage.[78] Cornell Feynman nominally held an appointment at the University of Wisconsin–Madison as an assistant professor of physics, but was on unpaid leave during his involvement in the Manhattan Project.[79] In 1945, he received a letter from Dean Mark Ingraham of the College of Letters and Science requesting his return to the university to teach in the coming academic year. His appointment was not extended when he did not commit to returning. In a talk given there several years later, Feynman quipped, "It's great to be back at the only university that ever had the good sense to fire me."[80] As early as October 30, 1943, Bethe had written to the chairman of the physics department of his university, Cornell, to recommend that Feynman be hired. On February 28, 1944, this was endorsed by Robert Bacher,[81] also from Cornell,[82] and one of the most senior scientists at Los Alamos.[83] This led to an offer being made in August 1944, which Feynman accepted. Oppenheimer had also hoped to recruit Feynman to the University of California, but the head of the physics department, Raymond T. Birge, was reluctant. He made Feynman an offer in May 1945, but Feynman turned it down. Cornell matched its salary offer of $3,900 per annum.[81] Feynman became one of the first of the Los Alamos Laboratory's group leaders to depart, leaving for Ithaca, New York, in October 1945.[84] Because Feynman was no longer working at the Los Alamos Laboratory, he was no longer exempt from the draft. At his induction physical, Army psychiatrists diagnosed Feynman as suffering from a mental illness and the Army gave him a 4-F exemption on mental grounds.[85][86] His father died suddenly on October 8, 1946, and Feynman suffered from depression.[87] On October 17, 1946, he wrote a letter to Arline, expressing his deep love and heartbreak. The letter was sealed and only opened after his death. "Please excuse my not mailing this," the letter concluded, "but I don't know your new address."[88] Unable to focus on research problems, Feynman began tackling physics problems, not for utility, but for self-satisfaction.[87] One of these involved analyzing the physics of a twirling, nutating dish as it is moving through the air, inspired by an incident in the cafeteria at Cornell when someone tossed a dinner plate in the air.[89] He read the work of Sir William Rowan Hamilton on quaternions, and tried unsuccessfully to use them to formulate a relativistic theory of electrons. His work during this period, which used equations of rotation to express various spinning speeds, ultimately proved important to his Nobel Prize-winning work, yet because he felt burned out and had turned his attention to less immediately practical problems, he was surprised by the offers of professorships from other renowned universities, including the Institute for Advanced Study, the University of California, Los Angeles, and the University of California, Berkeley.[87] Feynman diagram of electron/positron annihilation Feynman was not the only frustrated theoretical physicist in the early post-war years. Quantum electrodynamics suffered from infinite integrals in perturbation theory. These were clear mathematical flaws in the theory, which Feynman and Wheeler had tried, unsuccessfully, to work around.[90] "Theoreticians", noted Murray Gell-Mann, "were in disgrace."[91] In June 1947, leading American physicists met at the Shelter Island Conference. For Feynman, it was his "first big conference with big men ... I had never gone to one like this one in peacetime."[92] The problems plaguing quantum electrodynamics were discussed, but the theoreticians were completely overshadowed by the achievements of the experimentalists, who reported the discovery of the Lamb shift, the measurement of the magnetic moment of the electron, and Robert Marshak's two-meson hypothesis.[93] Bethe took the lead from the work of Hans Kramers, and derived a renormalized non-relativistic quantum equation for the Lamb shift. The next step was to create a relativistic version. Feynman thought that he could do this, but when he went back to Bethe with his solution, it did not converge.[94] Feynman carefully worked through the problem again, applying the path integral formulation that he had used in his thesis. Like Bethe, he made the integral finite by applying a cut-off term. The result corresponded to Bethe's version.[95][96] Feynman presented his work to his peers at the Pocono Conference in 1948. It did not go well. Julian Schwinger gave a long presentation of his work in quantum electrodynamics, and Feynman then offered his version, entitled "Alternative Formulation of Quantum Electrodynamics". The unfamiliar Feynman diagrams, used for the first time, puzzled the audience. Feynman failed to get his point across, and Paul Dirac, Edward Teller and Niels Bohr all raised objections.[97][98] To Freeman Dyson, one thing at least was clear: Shin'ichirō Tomonaga, Schwinger and Feynman understood what they were talking about even if no one else did, but had not published anything. He was convinced that Feynman's formulation was easier to understand, and ultimately managed to convince Oppenheimer that this was the case.[99] Dyson published a paper in 1949, which added new rules to Feynman's that told how to implement renormalization.[100] Feynman was prompted to publish his ideas in the Physical Review in a series of papers over three years.[101] His 1948 papers on "A Relativistic Cut-Off for Classical Electrodynamics" attempted to explain what he had been unable to get across at Pocono.[102] His 1949 paper on "The Theory of Positrons" addressed the Schrödinger equation and Dirac equation, and introduced what is now called the Feynman propagator.[103] Finally, in papers on the "Mathematical Formulation of the Quantum Theory of Electromagnetic Interaction" in 1950 and "An Operator Calculus Having Applications in Quantum Electrodynamics" in 1951, he developed the mathematical basis of his ideas, derived familiar formulae and advanced new ones.[104] While papers by others initially cited Schwinger, papers citing Feynman and employing Feynman diagrams appeared in 1950, and soon became prevalent.[105] Students learned and used the powerful new tool that Feynman had created. Computer programs were later written to evaluate Feynman diagrams, enabling physicists to use quantum field theory to make high-precision predictions.[106] Marc Kac adapted Feynman's technique of summing over possible histories of a particle to the study of parabolic partial differential equations, yielding what is now known as the Feynman–Kac formula, the use of which extends beyond physics to many applications of stochastic processes.[107] To Schwinger, however, the Feynman diagram was "pedagogy, not physics".[108] By 1949, Feynman was becoming restless at Cornell. He never settled into a particular house or apartment, living in guest houses or student residences, or with married friends "until these arrangements became sexually volatile".[109] He liked to date undergraduates, hire prostitutes, and sleep with the wives of friends.[110] He was not fond of Ithaca's cold winter weather, and pined for a warmer climate.[111] Above all, at Cornell, he was always in the shadow of Hans Bethe.[109] Despite all of this, Feynman looked back favorably on the Telluride House, where he resided for a large period of his Cornell career. In an interview, he described the House as "a group of boys that have been specially selected because of their scholarship, because of their cleverness or whatever it is, to be given free board and lodging and so on, because of their brains". He enjoyed the house's convenience and said that "it's there that I did the fundamental work" for which he won the Nobel Prize.[112][113] Caltech years Personal and political life Feynman spent several weeks in Rio de Janeiro in July 1949.[114] That year, the Soviet Union detonated its first atomic bomb, generating concerns about espionage.[115] Fuchs was arrested as a Soviet spy in 1950 and the FBI questioned Bethe about Feynman's loyalty.[116] Physicist David Bohm was arrested on December 4, 1950[117] and emigrated to Brazil in October 1951.[118] Because of the fears of a nuclear war, a girlfriend told Feynman that he should also consider moving to South America.[115] He had a sabbatical coming for 1951–52,[119] and elected to spend it in Brazil, where he gave courses at the Centro Brasileiro de Pesquisas Físicas. In Brazil, Feynman was impressed with samba music, and learned to play the frigideira,[120] a metal percussion instrument based on a frying pan ("frigideira [pt]").[121] He was an enthusiastic amateur player of bongo and conga drums and often played them in the pit orchestra in musicals.[122][123] He spent time in Rio with his friend Bohm, but Bohm could not convince Feynman to investigate Bohm's ideas on physics.[124] Feynman did not return to Cornell. Bacher, who had been instrumental in bringing Feynman to Cornell, had lured him to the California Institute of Technology (Caltech). Part of the deal was that he could spend his first year on sabbatical in Brazil.[125][109] He had become smitten by Mary Louise Bell from Neodesha, Kansas. They had met in a cafeteria in Cornell, where she had studied the history of Mexican art and textiles. She later followed him to Caltech, where he gave a lecture. While he was in Brazil, she taught classes on the history of furniture and interiors at Michigan State University. He proposed to her by mail from Rio de Janeiro, and they married in Boise, Idaho, on June 28, 1952, shortly after he returned. They frequently quarreled and she was frightened by his violent temper. Their politics were different; although he registered and voted as a Republican, she was more conservative, and her opinion on the 1954 Oppenheimer security hearing ("Where there's smoke there's fire") offended him. They separated on May 20, 1956. An interlocutory decree of divorce was entered on June 19, 1956, on the grounds of "extreme cruelty". The divorce became final on May 5, 1958.[126][127] He begins working calculus problems in his head as soon as he awakens. He did calculus while driving in his car, while sitting in the living room, and while lying in bed at night. Mary Louise Bell, divorce complaint[128] In the wake of the 1957 Sputnik crisis, the U.S. government's interest in science rose for a time. Feynman was considered for a seat on the President's Science Advisory Committee, but was not appointed. At this time, the FBI interviewed a woman close to Feynman, possibly his ex-wife Bell, who sent a written statement to J. Edgar Hoover on August 8, 1958:I do not know—but I believe that Richard Feynman is either a Communist or very strongly pro-Communist—and as such is a very definite security risk. This man is, in my opinion, an extremely complex and dangerous person, a very dangerous person to have in a position of public trust ... In matters of intrigue Richard Feynman is, I believe immensely clever—indeed a genius—and he is, I further believe, completely ruthless, unhampered by morals, ethics, or religion—and will stop at absolutely nothing to achieve his ends.[127] The U.S. government nevertheless sent Feynman to Geneva for the September 1958 Atoms for Peace Conference. On the beach at Lake Geneva, he met Gweneth Howarth, who was from Ripponden, Yorkshire, and working in Switzerland as an au pair. Feynman's love life had been turbulent since his divorce; his previous girlfriend had walked off with his Albert Einstein Award medal and, on the advice of an earlier girlfriend, had feigned pregnancy and extorted him into paying for an abortion, then used the money to buy furniture. When Feynman found that Howarth was being paid only $25 a month, he offered her $20 a week to be his live-in maid. Feynman knew that this sort of behavior was illegal under the Mann Act, so he had a friend, Matthew Sands, act as her sponsor. Howarth pointed out that she already had two boyfriends, but decided to take Feynman up on his offer, and arrived in Altadena, California, in June 1959. She made a point of dating other men, but Feynman proposed in early 1960. They were married on September 24, 1960, at the Huntington Hotel in Pasadena. They had a son, Carl, in 1962, and adopted a daughter, Michelle, in 1968.[129][130] Besides their home in Altadena, they had a beach house in Baja California, purchased with the money from Feynman's Nobel Prize.[131] Feynman tried marijuana and ketamine at John Lilly's sensory deprivation tanks, as a way of studying consciousness.[132][133] He gave up alcohol when he began to show vague, early signs of alcoholism, as he did not want to do anything that could damage his brain. Despite his curiosity about hallucinations, he was reluctant to experiment with LSD.[134] There had been protests over his alleged sexism in 1968, and again in 1972, but there is no evidence he discriminated against women.[135][136] Feynman recalled protesters entering a hall and picketing a lecture he was about to make in San Francisco, calling him a "sexist pig". Seeing the protesters, as Feynman later recalled the incident, he addressed institutional sexism by saying that "women do indeed suffer prejudice and discrimination in physics".[137] Physics At Caltech, Feynman investigated the physics of the superfluidity of supercooled liquid helium, where helium seems to display a complete lack of viscosity when flowing. Feynman provided a quantum-mechanical explanation for the Soviet physicist Lev Landau's theory of superfluidity.[138] Applying the Schrödinger equation to the question showed that the superfluid was displaying quantum mechanical behavior observable on a macroscopic scale. This helped with the problem of superconductivity, but the solution eluded Feynman.[139] It was solved with the BCS theory of superconductivity, proposed by John Bardeen, Leon Neil Cooper, and John Robert Schrieffer in 1957.[138] Richard Feynman at the Robert Treat Paine Estate in Waltham, Massachusetts, in 1984 Feynman, inspired by a desire to quantize the Wheeler–Feynman absorber theory of electrodynamics, laid the groundwork for the path integral formulation and Feynman diagrams.[44] With Murray Gell-Mann, Feynman developed a model of weak decay, which showed that the current coupling in the process is a combination of vector and axial currents (an example of weak decay is the decay of a neutron into an electron, a proton, and an antineutrino). Although E. C. George Sudarshan and Robert Marshak developed the theory nearly simultaneously, Feynman's collaboration with Murray Gell-Mann was seen as seminal because the weak interaction was neatly described by the vector and axial currents. It thus combined the 1933 beta decay theory of Enrico Fermi with an explanation of parity violation.[140] Feynman attempted an explanation, called the parton model, of the strong interactions governing nucleon scattering. The parton model emerged as a complement to the quark model developed by Gell-Mann. The relationship between the two models was murky; Gell-Mann referred to Feynman's partons derisively as "put-ons". In the mid-1960s, physicists believed that quarks were just a bookkeeping device for symmetry numbers, not real particles; the statistics of the omega-minus particle, if it were interpreted as three identical strange quarks bound together, seemed impossible if quarks were real.[141][142] The SLAC National Accelerator Laboratory deep inelastic scattering experiments of the late 1960s showed that nucleons (protons and neutrons) contained point-like particles that scattered electrons. It was natural to identify these with quarks, but Feynman's parton model attempted to interpret the experimental data in a way that did not introduce additional hypotheses. For example, the data showed that some 45% of the energy momentum was carried by electrically neutral particles in the nucleon. These electrically neutral particles are now seen to be the gluons that carry the forces between the quarks, and their three-valued color quantum number solves the omega-minus problem. Feynman did not dispute the quark model; for example, when the fifth quark was discovered in 1977, Feynman immediately pointed out to his students that the discovery implied the existence of a sixth quark, which was discovered in the decade after his death.[141][143] After the success of quantum electrodynamics, Feynman turned to quantum gravity. By analogy with the photon, which has spin 1, he investigated the consequences of a free massless spin 2 field and derived the Einstein field equation of general relativity, but little more. The computational device that Feynman discovered then for gravity, "ghosts", which are "particles" in the interior of his diagrams that have the "wrong" connection between spin and statistics, have proved invaluable in explaining the quantum particle behavior of the Yang–Mills theories, for example, quantum chromodynamics and the electro-weak theory.[144] He did work on all four of the forces of nature: electromagnetic, the weak force, the strong force and gravity. John and Mary Gribbin state in their book on Feynman that "Nobody else has made such influential contributions to the investigation of all four of the interactions".[145] Partly as a way to bring publicity to progress in physics, Feynman offered $1,000 prizes for two of his challenges in nanotechnology; one was claimed by William McLellan and the other by Tom Newman.[146] Feynman was also interested in the relationship between physics and computation. He was also one of the first scientists to conceive the possibility of quantum computers.[147][148][149] In the 1980s he began to spend his summers working at Thinking Machines Corporation, helping to build some of the first parallel supercomputers and considering the construction of quantum computers.[150][151] In 1984–1986, he developed a variational method for the approximate calculation of path integrals, which has led to a powerful method of converting divergent perturbation expansions into convergent strong-coupling expansions (variational perturbation theory) and, as a consequence, to the most accurate determination[152] of critical exponents measured in satellite experiments.[153] At Caltech, he once chalked "What I cannot create I do not understand" on his blackboard.[154] Pedagogy In the early 1960s, Feynman acceded to a request to "spruce up" the teaching of undergraduates at Caltech. After three years devoted to the task, he produced a series of lectures that later became The Feynman Lectures on Physics. Accounts vary about how successful the original lectures were. Feynman's own preface, written just after an exam on which the students did poorly, was somewhat pessimistic. His colleagues David L. Goodstein and Gerry Neugebauer said later that the intended audience of first-year students found the material intimidating while older students and faculty found it inspirational, so the lecture hall remained full even as the first-year students dropped away. In contrast, physicist Matthew Sands recalled the student attendance as being typical for a large lecture course.[155] Converting the lectures into books occupied Sands and Robert B. Leighton as part-time co-authors for several years. Feynman suggested that the cover have a picture of a drum with mathematical diagrams about vibrations drawn upon it, in order to illustrate the application of mathematics to understanding the world. Instead, the publishers gave the books plain red covers, though they included a picture of him playing drums in the foreword.[156] Even though the books were not adopted by universities as textbooks, they continue to sell well because they provide a deep understanding of physics.[157] Many of his lectures and miscellaneous talks were turned into other books, including The Character of Physical Law, QED: The Strange Theory of Light and Matter, Statistical Mechanics, Lectures on Gravitation, and the Feynman Lectures on Computation.[158] Feynman wrote about his experiences teaching physics undergraduates in Brazil. The students' studying habits and the Portuguese language textbooks were so devoid of any context or applications for their information that, in Feynman's opinion, the students were not learning physics at all. At the end of the year, Feynman was invited to give a lecture on his teaching experiences, and he agreed to do so, provided he could speak frankly, which he did.[159][160] Feynman opposed rote learning or unthinking memorization and other teaching methods that emphasized form over function. Clear thinking and clear presentation were fundamental prerequisites for his attention. It could be perilous even to approach him unprepared, and he did not forget fools and pretenders.[161] In 1964, he served on the California State Curriculum Commission, which was responsible for approving textbooks to be used by schools in California. He was not impressed with what he found.[162] Many of the mathematics texts covered subjects of use only to pure mathematicians as part of the "New Math". Elementary students were taught about sets, but:It will perhaps surprise most people who have studied these textbooks to discover that the symbol ∪ or ∩ representing union and intersection of sets and the special use of the brackets { } and so forth, all the elaborate notation for sets that is given in these books, almost never appear in any writings in theoretical physics, in engineering, in business arithmetic, computer design, or other places where mathematics is being used. I see no need or reason for this all to be explained or to be taught in school. It is not a useful way to express one's self. It is not a cogent and simple way. It is claimed to be precise, but precise for what purpose?[163] In April 1966, Feynman delivered an address to the National Science Teachers Association, in which he suggested how students could be made to think like scientists, be open-minded, curious, and especially, to doubt. In the course of the lecture, he gave a definition of science, which he said came about by several stages. The evolution of intelligent life on planet Earth—creatures such as cats that play and learn from experience. The evolution of humans, who came to use language to pass knowledge from one individual to the next, so that the knowledge was not lost when an individual died. Unfortunately, incorrect knowledge could be passed down as well as correct knowledge, so another step was needed. Galileo and others started doubting the truth of what was passed down and to investigate ab initio, from experience, what the true situation was—this was science.[164] In 1974, Feynman delivered the Caltech commencement address on the topic of cargo cult science, which has the semblance of science, but is only pseudoscience due to a lack of "a kind of scientific integrity, a principle of scientific thought that corresponds to a kind of utter honesty" on the part of the scientist. He instructed the graduating class that "The first principle is that you must not fool yourself—and you are the easiest person to fool. So you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists. You just have to be honest in a conventional way after that."[165] Feynman served as doctoral advisor to 30 students.[166] In 1977, Feynman supported his colleague Jenijoy La Belle, who had been hired as Caltech's first female professor in 1969, and filed suit with the Equal Employment Opportunity Commission after she was refused tenure in 1974. The EEOC ruled against Caltech in 1977, adding that La Belle had been paid less than male colleagues. La Belle finally received tenure in 1979. Many of Feynman's colleagues were surprised that he took her side, but he had gotten to know La Belle and liked and admired her.[135][167] Surely You're Joking, Mr. Feynman! Main article: Surely You're Joking, Mr. Feynman! In the 1960s, Feynman began thinking of writing an autobiography, and he began granting interviews to historians. In the 1980s, working with Ralph Leighton (Robert Leighton's son), he recorded chapters on audio tape that Ralph transcribed. The book was published in 1985 as Surely You're Joking, Mr. Feynman! and became a best-seller.[168] Gell-Mann was upset by Feynman's account in the book of the weak interaction work, and threatened to sue, resulting in a correction being inserted in later editions.[169] This incident was just the latest provocation in decades of bad feeling between the two scientists. Gell-Mann often expressed frustration at the attention Feynman received;[170] he remarked: "[Feynman] was a great scientist, but he spent a great deal of his effort generating anecdotes about himself."[171] Feynman has been criticized for a chapter in the book entitled "You Just Ask Them", where he describes how he learned to seduce women at a bar he went to in the summer of 1946. A mentor taught him to ask a woman if she would sleep with him before buying her anything. He describes seeing women at the bar as "bitches" in his thoughts, and tells a story of how he told a woman named Ann that she was "worse than a whore" after Ann persuaded him to buy her sandwiches by telling him he could eat them at her place, but then, after he bought them, saying they actually could not eat together because another man was coming over. Later on that same evening, Ann returned to the bar to take Feynman to her place.[172][173][174][175][176] Feynman states at the end of the chapter that this behaviour was not typical of him: "So it worked even with an ordinary girl! But no matter how effective the lesson was, I never really used it after that. I didn't enjoy doing it that way. But it was interesting to know that things worked much differently from how I was brought up."[177] Challenger disaster Main article: Space Shuttle Challenger disaster The 1986 Space Shuttle Challenger disaster Feynman played an important role on the Presidential Rogers Commission, which investigated the 1986 Challenger disaster. He had been reluctant to participate, but was persuaded by advice from his wife.[178] Feynman clashed several times with commission chairman William P. Rogers. During a break in one hearing, Rogers told commission member Neil Armstrong, "Feynman is becoming a pain in the ass."[179] During a televised hearing, Feynman demonstrated that the material used in the shuttle's O-rings became less resilient in cold weather by compressing a sample of the material in a clamp and immersing it in ice-cold water.[180] The commission ultimately determined that the disaster was caused by the primary O-ring not properly sealing in unusually cold weather at Cape Canaveral.[181] Feynman devoted the latter half of his 1988 book What Do You Care What Other People Think? to his experience on the Rogers Commission, straying from his usual convention of brief, light-hearted anecdotes to deliver an extended and sober narrative. Feynman's account reveals a disconnect between NASA's engineers and executives that was far more striking than he expected. His interviews of NASA's high-ranking managers revealed startling misunderstandings of elementary concepts. For instance, NASA managers claimed that there was a 1 in 100,000 probability of a catastrophic failure aboard the Shuttle, but Feynman discovered that NASA's own engineers estimated the probability of a catastrophe at closer to 1 in 200. He concluded that NASA management's estimate of the reliability of the Space Shuttle was unrealistic, and he was particularly angered that NASA used it to recruit Christa McAuliffe into the Teacher-in-Space program. He warned in his appendix to the commission's report (which was included only after he threatened not to sign the report), "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled."[182] Recognition and awards The first public recognition of Feynman's work came in 1954, when Lewis Strauss, the chairman of the Atomic Energy Commission (AEC) notified him that he had won the Albert Einstein Award, which was worth $15,000 and came with a gold medal. Because of Strauss's actions in stripping Oppenheimer of his security clearance, Feynman was reluctant to accept the award, but Isidor Isaac Rabi cautioned him: "You should never turn a man's generosity as a sword against him. Any virtue that a man has, even if he has many vices, should not be used as a tool against him."[183] It was followed by the AEC's Ernest Orlando Lawrence Award in 1962.[184] Schwinger, Tomonaga and Feynman shared the 1965 Nobel Prize in Physics "for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles".[185] He was elected a Foreign Member of the Royal Society in 1965,[3][186] received the Oersted Medal in 1972,[187] and the National Medal of Science in 1979.[188] He was elected a Member of the National Academy of Sciences, but ultimately resigned[189][190] and is no longer listed by them.[191] Death In 1978, Feynman sought medical treatment for abdominal pains and was diagnosed with liposarcoma, a rare form of cancer. Surgeons removed a "very large" tumor that had crushed one kidney and his spleen. Further operations were performed in October 1986 and October 1987.[192] He was again hospitalized at the UCLA Medical Center on February 3, 1988. A ruptured duodenal ulcer caused kidney failure, and he declined to undergo the dialysis that might have prolonged his life for a few months. Watched over by his wife Gweneth, sister Joan, and cousin Frances Lewine, he died on February 15, 1988, at age 69.[193] When Feynman was nearing death, he asked his friend and colleague Danny Hillis why Hillis appeared so sad. Hillis replied that he thought Feynman was going to die soon. Feynman said that this sometimes bothered him, too, adding, when you get to be as old as he was, and have told so many stories to so many people, even when he was dead he would not be completely gone.[194] Near the end of his life, Feynman attempted to visit the Tuvan Autonomous Soviet Socialist Republic (ASSR) in the Soviet Union, a dream thwarted by Cold War bureaucratic issues. The letter from the Soviet government authorizing the trip was not received until the day after he died. His daughter Michelle later made the journey.[195] His burial was at Mountain View Cemetery and Mausoleum in Altadena, California.[196] His last words were: "I'd hate to die twice. It's so boring."[195] Popular legacy See also: List of things named after Richard Feynman Aspects of Feynman's life have been portrayed in various media. Feynman was portrayed by Matthew Broderick in the 1996 biopic Infinity.[197] Actor Alan Alda commissioned playwright Peter Parnell to write a two-character play about a fictional day in the life of Feynman set two years before Feynman's death. The play, QED, premiered at the Mark Taper Forum in Los Angeles in 2001 and was later presented at the Vivian Beaumont Theater on Broadway, with both presentations starring Alda as Richard Feynman.[198] Real Time Opera premiered its opera Feynman at the Norfolk (CT) Chamber Music Festival in June 2005.[199] In 2011, Feynman was the subject of a biographical graphic novel entitled simply Feynman, written by Jim Ottaviani and illustrated by Leland Myrick.[200] In 2013, Feynman's role on the Rogers Commission was dramatised by the BBC in The Challenger (US title: The Challenger Disaster), with William Hurt playing Feynman.[201][202][203] In 2016, Oscar Isaac performed a public reading of Feynman's 1946 love letter to the late Arline.[204] Feynman is commemorated in various ways. On May 4, 2005, the United States Postal Service issued the "American Scientists" commemorative set of four 37-cent self-adhesive stamps in several configurations. The scientists depicted were Richard Feynman, John von Neumann, Barbara McClintock, and Josiah Willard Gibbs. Feynman's stamp, sepia-toned, features a photograph of a 30-something Feynman and eight small Feynman diagrams.[205] The stamps were designed by Victor Stabin under the artistic direction of Carl T. Herrman.[206][207][208] The main building for the Computing Division at Fermilab is named the "Feynman Computing Center" in his honor.[209] Two photographs of Feynman were used in Apple Inc.'s "Think Different" advertising campaign, which launched in 1997.[210][211] Sheldon Cooper, a fictional theoretical physicist from the television series The Big Bang Theory, is a Feynman fan who has emulated him on various occasions, once by playing the bongo drums.[212] On January 27, 2016, Bill Gates wrote an article "The Best Teacher I Never Had" describing Feynman's talents as a teacher which inspired Gates to create Project Tuva to place the videos of Feynman's Messenger Lectures, The Character of Physical Law, on a website for public viewing. In 2015 Gates made a video on why he thought Feynman was special. The video was made for the 50th anniversary of Feynman's 1965 Nobel Prize, in response to Caltech's request for thoughts on Feynman.[213] At CERN, home of the Large Hadron Collider, a street on the Meyrin site is named "Route Feynman" after the physicist. Bibliography Selected scientific works Feynman, Richard P. (1942). Laurie M. Brown (ed.). The Principle of Least Action in Quantum Mechanics. PhD Dissertation, Princeton University. World Scientific (with title "Feynman's Thesis: a New Approach to Quantum Theory") (published 2005). ISBN 978-981-256-380-4. Wheeler, John A.; Feynman, Richard P. (1945). "Interaction with the Absorber as the Mechanism of Radiation". Reviews of Modern Physics. 17 (2–3): 157–181. Bibcode:1945RvMP...17..157W. doi:10.1103/RevModPhys.17.157. Feynman, Richard P. (1946). A Theorem and its Application to Finite Tampers. Los Alamos Scientific Laboratory, Atomic Energy Commission. doi:10.2172/4341197. OSTI 4341197. Feynman, Richard P.; Welton, T. A. (1946). 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The work has endured and is useful to this day. They were edited and supplemented in 2005 with Feynman's Tips on Physics: A Problem-Solving Supplement to the Feynman Lectures on Physics by Michael Gottlieb and Ralph Leighton (Robert Leighton's son), with support from Kip Thorne and other physicists. Feynman, Richard P.; Leighton, Robert B.; Sands, Matthew (2005) [1970]. The Feynman Lectures on Physics: The Definitive and Extended Edition (2nd ed.). Addison Wesley. ISBN 0-8053-9045-6. Includes Feynman's Tips on Physics (with Michael Gottlieb and Ralph Leighton), which includes four previously unreleased lectures on problem solving, exercises by Robert Leighton and Rochus Vogt, and a historical essay by Matthew Sands. Three volumes; originally published as separate volumes in 1964 and 1966. Feynman, Richard P. (1961). Theory of Fundamental Processes. Addison Wesley. ISBN 0-8053-2507-7. Feynman, Richard P. (1962). Quantum Electrodynamics. Addison Wesley. ISBN 978-0-8053-2501-0. 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Audio and video recordings Safecracker Suite (a collection of drum pieces interspersed with Feynman telling anecdotes) Los Alamos From Below (audio, talk given by Feynman at Santa Barbara on February 6, 1975) The Feynman Lectures on Physics: The Complete Audio Collection, selections from which were also released as Six Easy Pieces and Six Not So Easy Pieces Samples of Feynman's drumming, chanting and speech are included in the songs "Tuva Groove (Bolur Daa-Bol, Bolbas Daa-Bol)" and "Kargyraa Rap (Dürgen Chugaa)" on the album Back Tuva Future, The Adventure Continues by Kongar-ool Ondar. The hidden track on this album also includes excerpts from lectures without musical background. The Messenger Lectures, given at Cornell in 1964, in which he explains basic topics in physics;[215] adapted into the book The Character of Physical Law Take the world from another point of view [videorecording] / with Richard Feynman; Films for the Hu (1972) The Douglas Robb Memorial Lectures, four public lectures of which the four chapters of the book QED: The Strange Theory of Light and Matter are transcripts. (1979) The Pleasure of Finding Things Out, BBC Horizon episode (1981) (not to be confused with the later published book of the same title) Richard Feynman: Fun to Imagine Collection, BBC Archive of six short films of Feynman talking in a style that is accessible to all about the physics behind common to all experiences. (1983) Elementary Particles and the Laws of Physics (1986) Tiny Machines: The Feynman Talk on Nanotechnology (video, 1984) Computers From the Inside Out (video) Quantum Mechanical View of Reality: Workshop at Esalen (video, 1983) Idiosyncratic Thinking Workshop (video, 1985) Bits and Pieces—From Richard's Life and Times (video, 1988) Strangeness Minus Three (video, BBC Horizon 1964) No Ordinary Genius (video, Cristopher Sykes Documentary) Richard Feynman—The Best Mind Since Einstein (video, Documentary) The Motion of Planets Around the Sun (audio, sometimes titled "Feynman's Lost Lecture") Nature of Matter (audio) Notes ^ "Everybody called him Dick." – Freeman DysonQuote from June 1998 interview with Silvan "Sam" Schweber] Archived September 25, 2019, at the Wayback Machine, posted at

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