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SOME SIGNIFICANT DATES IN THE HISTORY OF PHYSICS

са. 320 вс	Aristotle describes motion in terms of natural tendencies.
са. 250 вс	Archimedes discovers the principle of buoyancy.
ca. ad 150	Ptolemy refines the Earth-centered system of the world.
1543	Copernicus publishes his Sun-centered system of the world.
1575–1596	Brahe measures precise positions of the planets in the sky.
1609	Galileo first uses a telescope as an astronomical tool.
1609/1619	Kepler publishes three laws of planetary motion.
1634	Galileo advances understanding of accelerated motion.
1661	Boyle relates pressure and volume of gases at constant temperature.
1676	Roemer demonstrates that light has finite speed.
1678	Huygens develops a wave theory of light.
1687	Newton presents the theory of mechanics in his Principia.
1738	Bernoulli explains the behavior of gases in terms of molecular motions.
1747	Franklin suggests the conservation of electrical "fire" (charge).
1780	Galvani discovers "animal electricity."
1785	Coulomb precisely determines the law of electric force.
1795	Cavendish measures the gravitational constant G.
1798	Rumford argues that heat is a form of motion.
1800	Volta invents the battery.
1802	Young uses wave theory to account for interference.
1811	Avogadro suggests that, at equal temperature and pressure, all gases have equal numbers of molecules per unit volume.
1815–1820	Young and others provide evidence for the wave nature of light.
1820	Oersted discovers the magnetic effect of an electric current.
1820	Ampère establishes the law of force between current-carrying wires.
1821	Fraunhofer invents the diffraction grating.
1824	Carnot states that heat cannot be transformed wholly to work.
1831	Faraday and Henry discover electromagnetic induction.
1842–1843	Mayer and Joule suggest a general law of energy conservation.
1846	Adams and Leverrier predict the existence of the planet Neptune.
1865	Maxwell gives the electromagnetic theory of light.
1869	Mendeleev organizes the elements into a periodic table.
1877	Boltzmann relates entropy to probability.
1885	Balmer finds numerical regularity in the spectrum of hydrogen.
1887	Michelson and Morley fail to detect the ether.
1888	Hertz generates and detects radio waves.
1895	Roentgen discovers X-rays.
1896	Bequerel discovers radioactivity.
1897	Thomson identifies cathode rays as negative corpuscles (electrons).

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Metal
Metalloid
Nonmetal

Atomic masses are averaged by isotopic abundance on the Earth's surface, expressed in atomic mass units. Conventional IUPAC atomic masses are provided as recommended by G. Kaptay in *J. Min. Metall. Sect. BMetall. 48 (1) B (2012)153 159*. For radioactive elements, this is commonly the whole number nearest the most stable isotope of that element. The elements here are color coded to indicate metal, metalloid, or nonmetal. But please recognize that the heaviest elements, such as 104 and greater, are highly unstable existing only for a fraction of a second within a laboratory setting. Any metallic properties they might exhibit are not discernible.

CELEBRATING 50 YEARS OF CONCEPTUAL PHYSICS

Conceptual Physics began as a compilation of Paul Hewitt's classroom lectures at City College of San Francisco—published in 1971 by Little, Brown and Company as its first college science textbook. Successive editions testify to its success, each occurring, on average, at four-year intervals. Covers for the first three editions honored Erwin Muller's historic micrograph of atoms at the tip of a sharp needle. The fourth edition cover is the author's photo of interference colors reflected by oily water. The author's son James tossed grains of rice into a pond next to the Exploratorium to create wave interference for the photo on the fifth edition cover. Up to this point, all photos and Paul's hand-drawn illustrations were black and white. A second color was added for the sixth edition. Subsequent editions sported full-color art and photos. Not shown are the covers for editions six through nine. The sixth edition featured a blend of bubble-chamber particle tracks and flowing water, the seventh featured lightning bolts as viewed through a diffraction grating, the eighth of the aurora borealis, and the ninth of Hawaiian lava flow. Covers that are shown pick up with edition ten, of elementary particle tracks blended with sky and water, edition eleven with solar cells on the ISS, the only edition that shows humans. A close-up of solar cells on Earth is on the cover of the twelfth edition. Not indicated, are the increases in cover size from $7" \times 9"$ for the first three editions to the present $8\frac{1}{2}" \times 11"$. This array of textbook covers marks a half century of physics presented as a study of nature's rules—relevant at all times.

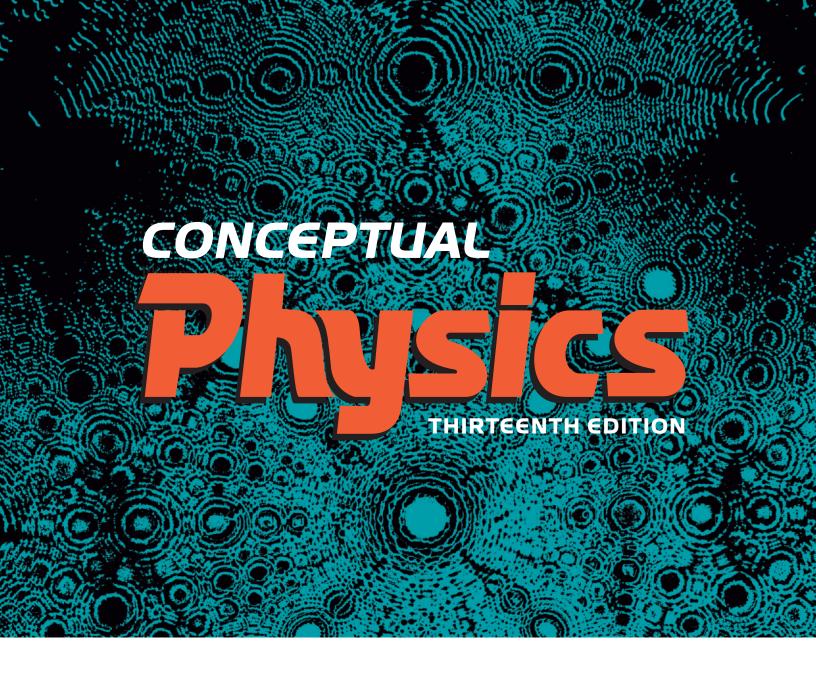


1900	Planck introduces the quantum idea.
1905	Einstein introduces the light corpuscle (photon) concept.
1905	Einstein advances the special theory of relativity.
1911	Rutherford reveals the nuclear atom.
1913	Bohr gives a quantum theory of the hydrogen atom.
1915	Einstein advances the general theory of relativity.
1923	Compton's experiments confirm the existence of the photon.
1924	de Broglie advances the wave theory of matter.
1925	Goudsmit and Uhlenbeck establish the spin of the electron.
1925	Pauli states the exclusion principle.
1926	Schrödinger develops the wave theory of quantum mechanics.
1927	Heisenberg proposes the uncertainty principle.
1928	Dirac blends relativity and quantum mechanics in a theory of the electron.
1929	Hubble discovers the expanding universe.
1932	Anderson discovers antimatter in the form of the positron.
1932	Chadwick discovers the neutron.
1934	Fermi proposes a theory of the annihilation and creation of matter.
1938	Meitner and Frisch interpret results of Hahn and Strassmann as nuclear fission.
1939	Bohr and Wheeler give a detailed theory of nuclear fission.
1942	Fermi builds and operates the first nuclear reactor.
1945	Oppenheimer's Los Alamos team creates a nuclear explosion.
1947	Bardeen, Brattain, and Shockley develop the transistor.
1956	Reines and Cowan identify the antineutrino.
1957	Feynman and Gell-Mann explain weak interactions with a "left-handed" neutrino.
1960	Maiman invents the laser.
1965	Penzias and Wilson discover background radiation in the universe left over from the Big Bang.
1967	Bell and Hewish discover pulsars, which are neutron stars.
1969	Gell-Mann suggests quarks as the building blocks of nucleons.
1977	Lederman and his team discover the bottom quark.
1981	Binning and Rohrer invent the scanning tunneling microscope.
1987	Bednorz and Müller discover high-temperature superconductivity.
1995	Cornell and Wieman create a "Bose–Einstein condensate" at 20 billionths of a degree.
1998	Perlmutter, Schmidt, and Riess discover the accelerated expansion of the universe.
2000	
2000	Pogge and Martini provide evidence for supermassive black holes in other galaxies.
2000	Fermilab group identifies the tau neutrino, the last member of the lepton particle group.
2003	Scientists studying radiation in space put the age of the universe at 13.7 billion years.
2004	Geim and Novoselov discover graphene, a one-atom-thick form of carbon.
2005	Gerald Gabrielse measures the magnetism of the electron to 1 part in a trillion. U.S.–Russian team identifies elements number 116 and 118.
2006	
2012	CERN laboratory announces the discovery of the long-sought Higgs boson.
2015	LIGO team detects gravitational waves from coalescing black holes.
2018	Jarillo-Herrero discovers superconductivity in graphene.
2019	Event Horizon Telescope obtains first image of a supermassive black hole.
2020	The catalog of exoplanets (planets orbiting other stars) grows to more than 4,330.

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written and illustrated by

Paul G. Hewitt

City College of San Francisco



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1 About Science

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Conceptual Physics Photo Album

onceptual Physics is a very personal book, reflected in its many photographs of family, along with friends and colleagues worldwide. Many of these people are identified in chapter-opening photos, and, with some exceptions, I'll not repeat their names here. Family and friends whose photos are Part Openers, however, are listed. The book opens on page 1 with great-nephew Evan Suchocki sitting on my lap pondering life's opportunities with his pet chick.

Part One opens on page 23 with little Ian Evans, son of teacher friends Bart and Jill Evans. Part Two opens on page 237 with little Georgia Hernandez, my delightful great-great-niece. Part Three opens on page 325 with four-year-old Francesco Ming Giovannuzzi, grandson of friend Tsing Bardin, page 280. Part Four opens on page 405 with Abby Dijamco, daughter of my last CCSF teaching assistant, dentist Stella Dijamco. In Part Five on page 461 is my great-great-nephew Richard Hernandez, older brother to Georgia. Part Six opens on page 549 with my granddaughter Gracie Hewitt at age four. Part Seven opens with another granddaughter, Kara Mae Hurrell, as a four-year-old tot in a pot on page 687. Part Eight opens on page 751 with young London Dixon, the daughter of my physician's medical assistant, April Dixon.

The two friends most influential in my transition from a life of sign painting to a life of physics are Burl Grey, page 33, and Jacque Fresco, pages 152, 153. For success as an author I credit my friend and physics mentor, Ken Ford, pages 426, 752, to whom previous editions have been dedicated. Longtime best friend Huey Johnson, known as Dan, page 384, has also been personally influential.

Family photos include my first wife, Millie, on page 350. My eldest daughter is Jean Hurrell, page 261, and with her children Marie and Kara Mae on page 499, and both granddaughters shown separately on pages 67 and 102. Jean's husband Phil tinkers with electricity on page 488. My son Paul is with his daughter Grace, page 84, and doing some thermodynamics on page 389. Gracie plays music on page 446 and further speculates about science on page 549.

Son Paul's former wife Ludmila is shown with Polaroids on page 636, and their son Alex skateboards on pages 104, 170. My daughter Leslie at age 16 is on page 249, a colorized photo that has been a trademark of *Conceptual Physics* since the third edition. Since then Leslie has been my earth-science coauthor of the *Conceptual Physical Science* textbooks. A more recent photo with her husband Bob Abrams, page 550. Their children, Megan and Emily, are on pages 349 and 210. A grand slam grandchildren photo is on page 579. My late son James is on page 171 with his best friend Robert Baruffaldi, also his cousin. Other photos of James are on pages 450 and 613. James left me my first grandson, Manuel, pages 268, 331, 436.

Millie's relatives include nephew Mike Luna, page 232. Grand-niece Angela Hendricks, page 656, is a teacher and amateur photographer who graciously supplied photos of her cousins Georgia Hernandez and her older brother Richard Hernandez on pages 294, 321, 426, 446 and 461, and her own child Hudson, page 294. Hudson also appears with his dad Jake Hendricks on page 97. Grand-niece Alejuandra Luna leans on Newton's third law, page 102. Great nephew Isaac Jones uses a sparkler, page 329, as his dad Terrence used back in the sixth and seventh editions. Terrence Jones is now on page 326.

A year after Millie's passing in 2004, I married my friend of many years, Lillian Lee. Lillian has wonderfully assisted me in all steps of textbook production, including ancillaries. Of the many photos of Lil throughout this edition, I'll mention two favorites: One with her pet bird Sneezlee on page 580, and the photo with me illustrating the essence of Newton's third law—you cannot touch without being touched on page 92. Lillian's dad, Wai Tsan Lee, shows magnetic induction on page 517, and mom, Siu Bik Lee, making excellent use of solar energy on page 360 and with solar images on page 611. Lillian's niece Serena Sinn excels in sports, page 126. Lil's nephew Erik Wong with his sister Allison nicely illustrate thermodynamics on page 395.

Photos of my siblings begin with my sister Marjorie, author and theologian emerita at Claremont School of Theology in Claremont, California, illustrating reflection on page 596. Marjorie's daughter, occupational therapist Cathy Candler, page 157, and her son Garth Orr, page 260. Marjorie's daughter Joan Lucas's two children, SpaceX engineer Mike Lucas, page 772, and lawyer Alexandra Lucas, page 550. Marjorie's multitalented son, John Suchocki, page 366, the creator of Conceptual Academy, a chemistry professor and author, and my coauthor of the Conceptual Physical Science and Conceptual Integrated Science textbooks; he's also a singer-songwriter known as John Andrew strumming his guitar, pages 406, 533. The group listening to music, page 454, is of John and Tracy's Hawaii long-ago wedding party. My brother Dave and his wife Barbara pump water on page 309. Their electrician son Davey is on page 505, and the

yum photos of solar cells, page 360, and the GPS unit, page 782, is courtesy of their daughter Dotty Jean Allen. My youngest brother Steve and his daughter Gretchen are shown on page 100. Steve's son, Navy pilot Travis is on page 176, and Steve's teacher daughter Stephanie on pages 619 and 782.

Photos of City College of San Francisco physicsinstructor friends open several chapters and are named there. Others include Diana Lininger Markham, pages 152, 182. Fred Cauthen, pages 146, 540. Norman Whitlatch, page 454. Dave Wall, page 550. Roger King, pages 354, 688. Jill Evans, pages, 64, 140, and 488, and Chelcie Liu, page 44.

Suppliers of physics equipment are friends David and Christine Vernier of Vernier Software, page 126, Paul Stokstad of PASCO, page 152, and Peter Rea of Arbor Scientific, page 215.

The following people are personal American friends in order of appearance: Judith Brand, whose skillful edits grace this entire edition, page 2. David Vasquez, pages 2, 143. Will Maynez, pages 24, 116, 341, and 504. Sue Johnson, Huey Johnson's wife, p 44. Lab Manual author Dean Baird, pages 44, 45, 366, 557, 562, and 583. Paul Doherty, pages 84, 85, 550. David Kagan, pages 84, 688. Howie Brand from college days, pages 104, 384. David Manning, pages 120, 177, 304, and his daughter Brady, page 59. Bob Miner, page 129, his wife Ana, page 24, and Ana's daughter Estefania, page 368. Tenny Lim, page 133, draws her bow, a photo that has appeared in every book since the sixth edition. Tenny again on pages 184, 185. Young Andrea Wu, page 150. Marshall Ellenstein, pages 158, 302, 622, 623. Alexei Cogan, page 169. Alan Davis with son William, page 184, and William again, page 512, and a photo taken by his mom Fe, page 589. Chuck Stone, page 213. John Hubisz, page 260. Ray Serway, page 280. Evan Jones, page 304. Fred Myers, pages 304, 305, 512, 592, 712. Helen Yan, pages 346, 347, 622. Dennis McNelis, page 353, and his grandson Myles Dooley, page 423. Exploratorium physicist Ron Hipschman on pages 184, 366, 367, 373, 644. Childhood best friend Paul Ryan is on page 378. Huey and Sue Johnson's grandson Bay Johnson, page 452. Ryan Patterson, page 436. Elan Lavie, page 462. Kirby Perchbacher, pages 286 and 462. Karen Jo Matsler, pages 542 and 592. Bruce Novak, page 554, and his mom Greta Novak on page 302. Charlie Spiegel, page 559. Suzanne Lyons and children Simone and Tristan, page 572. Carlos Vasquez, page 572. Jeff Wetherhold, page 572. Bree Barnett Dreyfuss, page 622. Phil Wolf, page 666. Brad Huff, page 692. Stanley Micklavzina, page 704, Walter Steiger, page 717. Brenda Skoczelas, page 752. Mike and Jane Jukes, pages 780 and 796.

The physics community is global. International friends in order of appearance: My protégé Einstein Dhayal (India), pages 2, 530. Cedric and Anne Linder (Sweden), pages 24, 25. Carl Angell (Norway), page 44. Derek Muller (Canada), pages 104, 105. Peter Hopkinson (Canada), pages 122, 592. Bilal Gunes (Turkey), page 152. Ed van den Berg (Netherlands), page 184, and his wife Daday, page 488. Tomas Brage (Sweden), page 184, and with Barbara Brage, page 384. Ole Anton and Aage Mellem (Norway), page 326. Anette Zetterberg (Sweden), page 326, and husband P. O. page 384, with son Johan on page 304. Johan's wife Sara Bloomberg on page 282. Z. Tugba Kahyaoglu (Turkey), pages 462, 530. Mona El Tawil-Nassar (Egypt), page 480. David Housden (New Zealand), page 502. Roger Rasool (Australia), pages 704 and 716.

These are photographs of people very dear to me, which makes *Conceptual Physics* all the more a labor of love.

To the Student

You know you can't enjoy a game unless you know its rules; whether it's a ball game, a computer game, or simply a party game. Likewise, you can't fully appreciate your surroundings until you understand the rules of nature. Physics is the study of these rules, which show how everything in nature is beautifully connected. So the main reason to study physics is to enhance the way you see the physical world. You'll see the mathematical structure of physics in frequent equations, but more than being recipes for computation, you'll see the equations as guides to thinking.



I enjoy physics, and you will too — because you'll understand it. If you get hooked and take a follow-up course, then you can focus on mathematical problems. Go for comprehension of concepts now, and if computation follows, it will be with understanding. Enjoy your physics!

PAUL G. HEWIT

To the Instructor

he sequence of chapters in this Thirteenth Edition is identical to that in the previous edition. Personality profiles continue with every chapter, highlighting a scientist, teacher, or historical figure who complements the chapter material. Each chapter begins with a photo montage of educators, and sometimes their students, who bring life to the learning of physics.

As in the previous edition, Chapter 1, "About Science," begins your course on a high note with coverage of early measurements of the Earth and distances to the Moon and the Sun. New to this edition is how an extension of Eratosthenes' measurements to calculating distances between far-apart schools. And also, a way that students can measure the distance to the Moon with a pea.

Part One, "Mechanics," begins with Chapter 2, which, as in the previous edition, presents a brief historical overview of Aristotle and Galileo, progressing to Newton's first law and to mechanical equilibrium. Force vectors are introduced, primarily for forces that are parallel to one another. Vectors are extended to velocity in the following Chapter 3, and Chapter 5 treats both force and velocity vectors and their components. Vector treatment is gradual, and, understandable.

Chapter 3, "Linear Motion," is the only chapter in Part One that is devoid of physics laws. Kinematics has no laws, only definitions, mainly for *speed*, *velocity*, and *acceleration*—likely the least exciting concepts that your course has to offer. Too often kinematics becomes a pedagogical "black hole" of instruction—too much time for too little physics. Being more math than physics, the kinematics equations can appear to the student as the most intimidating in the book. Although the experienced eye doesn't see them as such, this is how *students* first see them:

$$\mathbf{s} = \mathbf{s}_0 + \delta \mathbf{i}$$
$$\mathbf{s} = \mathbf{s}_0 \mathbf{i} + \frac{1}{2} \delta \mathbf{i}^2$$
$$\mathbf{s}^2 = \mathbf{s}_0^2 + 2\delta \mathbf{s}$$
$$\mathbf{s}_a = \frac{1}{2}(\mathbf{s}_0 + \mathbf{s})$$

If you wish to reduce class size, display these equations on the first day and announce that class effort for much of the term will be on making sense of them. Don't we do much the same with the standard symbols?

Ask any college graduate two questions: What is the acceleration of an object in free fall? What keeps Earth's interior hot? You'll see what their education focused on because many more will correctly answer the first question than the second. Traditionally, physics courses have been top-heavy in kinematics with little or no coverage of modern physics. Radioactive decay almost never gets the attention given to falling bodies. So my recommendation is to pass quickly through Chapter 3, making the distinction between velocity and acceleration, and then to move on to Chapter 4, "Newton's Second Law of Motion," where the concepts of velocity and acceleration find their application.

Chapter 5 continues with Newton's third law. Many third-law examples via vectors and their components should bring clarity to this commonly misunderstood law of motion. More on vectors is found in Appendix D and especially in the *Practice Book*.