

Appendix F Historical Timeline

- 600 B.C. The Ancient Greek philosopher and mathematician Thales discovers that by rubbing amber (“ἤλεκτρον” or “elektron”) with a piece of fur, he could attract feathers to the amber. The phenomenon was probably known well before Thales.
- 60 B.C. The Roman philosopher Lucretius discusses magnetism in his famous work On the Nature of Things (Latin: De Rerum Natura). Among other things, he attributes the attraction of iron to a loadstone as due to a stream of atoms given off by the magnet.
- 1000 Ibn al-Haytham writes the The Book of Optics.
- 1269 Petrus Peregrinus writes Epistola de magnete.
- 1581 Robert Norman presents the dip needle in The Newe Attractive.
- 1600 William Gilbert publishes On the Magnet, which introduced Peregrinus’s work to modern Europe.
- 1632 Galileo publishes Dialogue Concerning the Two Chief World Systems: Ptolemy and Copernicus, with the principle of relativity.
- 1665 Robert Hooke publishes Micrographia, which reports observations of microscopic objects and suggests that light is a wave.
- 1676 Ole Rømer measures the speed of light, in astronomical units, by observing the Galilean moons of Jupiter.
- 1687 Isaac Newton publishes Philosophiæ Naturalis Principia Mathematica.
- 1690 Christiaan Huygens publishes Traité de la Lumière.
- 1704 Isaac Newton publishes the first edition of Opticks.
- 1725 James Bradley and Samuel Molyneux discover the *aberration of starlight*, a shift in the positions of stars due to the earth’s motion. This supported Newton’s particle model of light.
- 1745 Pieter van Musschenbroek invents the Leyden jar
- 1754 Benjamin Franklin publishes the first edition of Experiments and Observations on Electricity.
- 1757 Leonhard Euler publishes the continuity equation.
- 1776 The American revolution.
- 1785 Charles Coulomb publishes Mémoires des Académie des Sciences, which includes what is now known as Coulomb’s law.

- 1789 The French Revolution begins.
- 1791 Luigi Galvani makes a dead frog's legs twitch with electricity.
- 1792 France declares war on Austria.
- 1799 Napoleon Bonaparte takes power in France.
- 1799 Simon-Pierre Laplace publishes his equation in the context of celestial mechanics.
- 1800 Alessandro Volta invents the voltaic pile.
- 1800 William Nicholson, Anthony Carlisle, and William Cruickshank separate hydrogen and oxygen from water using electric current.
- 1804 Thomas Young publishes his double-slit experiment.
- 1811 Étienne-Louis Malus discovers polarization of reflected sunlight, and publishes "Théorie de la Double Réfraction."
- 1812 Siméon Denis Poisson translates Lagrange's gravitational scalar potential to the electrostatic scalar potential.
- 1813 Carl Friedrich Gauss re-expresses Newton's law of gravity in terms of the mass enclosed by an arbitrary closed surface. The resulting mathematical statement is now known as Gauss's law of gravity.
- 1814 David Brewster explains polarization off of a reflective surface.
- 1817 Augustin-Jean Fresnel proposes that light is a transverse wave.
- 1819 André-Marie Ampère demonstrates parallel, current-carrying wires attracting, or repelling, when current flows in the same, or opposite, direction.
- 1819 François Arago observes the Poisson spot.
- 1819 Hans Christian Ørsted discovers that an electric current twists a compass needle, and maps the direction of the magnetic field.
- 1820 Jean-Baptiste Biot and Felix Savart make the first careful quantitative measurements of forces between magnets and current carrying wires. In the process, they discover the law of Laplace.
- 1821 André-Marie Ampère and Félix Savary discover the Biot-Savart law.
- 1822 Joseph Fourier publishes The Analytical Theory of Heat.
- 1828 George Green publishes a paper that introduces the term potential in the contexts of gravity, electricity, and magnetism.
- 1830 Joseph Henry discovers electromagnetic induction.

- 1831 David Brewster publishes A Treatise on Optics.
- 1831 Michael Faraday discovers electromagnetic induction (independently of Henry).
- 1834 Emil Lenz discovers that the induced current in a moving conductor is always in the direction opposite its velocity.
- 1838 Queen Victoria is coroneted.
- 1839 Joseph Henry publishes Contributions to Electricity and Magnetism.
- 1839 Michael Faraday publishes Experimental Researches in Electricity.
- 1840 Carl Friedrich Gauss and Wilhelm Weber publish an atlas of geomagnetism.
- 1840 Samuel Morse patents the telegraph and his code.
- 1842 Christian Doppler discovers the relationship among the emitted and received wavelengths, the wave speed in the medium, and the relative velocity of the source and detector.
- 1845 Franz Ernst Neumann introduces the vector potential.
- 1845 Michael Faraday discovers that, under the influence of a magnetic field parallel to the propagation direction, the polarization angle of light rotates when it passes through certain media. This is the first direct evidence that light is an electromagnetic phenomenon.
- 1846 Michael Faraday writes an intriguing, and nuanced, letter speculating on the nature of light as an electromagnetic wave.
- 1847 Georg Ohm publishes what became known as Ohm's Law.
- 1847 William Thomson finds the vector potential of a small magnet.
- 1848 Wilhelm Weber publishes his action at a distance theory.
- 1849 Hippolyte Fizeau measures the speed of light using a rotating toothed wheel and a mirror placed 8 km away.
- 1850 Gustav Kirchhoff expresses Ohm's Law in the modern form.
- 1851 Hippolyte Fizeau conducts his running water experiment, apparently confirming Fresnel's aether drag hypothesis.
- 1854 William Thomson derives Stokes's theorem of vector calculus.
- 1856 Rudolf Kohlrausch and Wilhelm Weber show that the ratio of electrostatic to electromagnetic units, c , numerically equals the speed of light.

- 1857 Gustav Kirchhoff and Wilhelm Weber model electricity in a telegraph wire as a wave with a speed close to the speed of light.
- 1858 The first transatlantic telegraph functions for three weeks.
- 1861 James Clerk Maxwell applies Gauss's law to electricity.
- 1861 James Clerk Maxwell derives the Maxwell-Ampère law.
- 1862 Léon Foucault measures the speed of light using a mirror rotating at 48,000 rpm, a tuning fork, and a train whistle.
- 1866 William Thomson oversees the operation of the first stable transatlantic telegraph cable.
- 1867 Ludvig Lorenz introduces a mathematical addendum to Weber's action at a distance theory, which we now call the Lorenz gauge.
- 1871 George Airy attempts, but fails, to measure the relative velocity of the earth and aether using a water-filled telescope.
- 1873 James Clerk Maxwell publishes A Treatise on Electricity and Magnetism.
- 1879 Edwin Hall discovers that usually negative, rather than positive, charge, predominantly flows through wires.
- 1880 Oliver Heaviside patents the coaxial cable.
- 1881 Albert Michelson presents his first paper where he fails to measure the aether wind.
- 1881 Heinrich Hertz confirms Maxwell's theory experimentally by generating and detecting radio waves.
- 1881 Hermann von Helmholtz argues that electricity is comprised of many tiny discrete particles.
- 1881 J.J. Thomson attempts to derive the magnetic force on a moving charged particle, but is off by a factor of two.
- 1883 Oliver Heaviside explains Ohm's Law with a fluid model.
- 1883 Horace Lamb derives the skin depth for a spherical conductor.
- 1883 Osborne Reynolds investigates the onset of turbulence.
- 1884 John Henry Poynting investigates the energy flow by electromagnetic fields in wires and telegraph cables.
- 1889 George FitzGerald points out that lengths foreshorten in the direction of motion, but not sideways, anticipating both so-called Lorentz-FitzGerald contraction and the Lorentz-FitzGerald transformations.

- 1889 Oliver Heaviside derives the correct expression for the magnetic force acting on a moving charge.
- 1895 Guglielmo Marconi sends the first radio signal over 1.5 km.
- 1895 Pierre Curie publishes his thesis on magnetization.
- 1897 J.J. Thomson discovers the electron.
- 1897 Pieter Zeeman observes the splitting of a spectral line when the material was placed in a strong magnetic field.
- 1898 Alfred-Marie Liénard introduces the *retarded potentials*, which are the potentials due to an electric charge undergoing arbitrary motion.
- 1900 Emil Wiechert also derives the Liénard-Wiechert potentials.
- 1901 Queen Victoria dies.
- 1904 Henri Poincaré delivers “The Present and the Future of Mathematical Physics” at the St. Louis world’s fair.
- 1905 Albert Einstein publishes “Concerning a Heuristic Point of View Toward the Emission and Transformation of Light.”
- 1905 Albert Einstein publishes “On the Electrodynamics of Moving Bodies.”
- 1906 Albert Einstein correctly derives the Planck distribution, despite his use of classical Boltzmann statistics.
- 1909 Hans Geiger and Ernest Marsden carry out the gold foil experiment, which demonstrates that atoms are made up of mostly empty space with a dense positively charged nucleus at the center.
- 1911 Ernest Rutherford proposes his planetary model of the atom.
- 1911 Kamerlingh Onnes discovers superconductivity.
- 1911 Robert Millikan, Ernest Rutherford, and others independently measure the elementary charge.
- 1913 Niels Bohr combines Rutherford’s planetary model with Planck’s energy quanta to fashion a workable model of the hydrogen atom, where electrons only orbit in particular stationary orbits.
- 1915 Albert Einstein and Wander J. de Haas measure the angular momentum associated with magnetization.
- 1916 Robert Millikan directly determines Planck’s constant using the photoelectric effect, verifying Einstein’s concept of light quanta.

- 1915 Samuel Barnett shows that spinning ferromagnetic materials become magnetized.
- 1918 John Stewart and Maurice Pate measure the electron gyromagnetic ratio to be twice what is predicted classically.
- 1922 Otto Stern and Walter Gerlach measure the quantized magnetic moment of an electron.
- 1923 Arthur Compton scatters x-rays off of the loosely bound electrons in a carbon target, showing that the photon exists.
- 1924 Louis de Broglie postulates that all particles have an associated wavelength related to their momentum.
- 1924 Satyendra Nath Bose derives Planck's spectrum without *ad hoc* classical assumptions, introducing Bose-Einstein statistics.
- 1927 Clint Davisson and Lester Germer observe diffraction peaks in a beam of electrons scattered from a sliced nickel crystal.
- 1927 George Thomson observes electron diffraction by scattering electrons off of gold foil.
- 1927 Paul Dirac quantizes the electromagnetic field.
- 1928 Paul Dirac unites quantum mechanics and special relativity, which results in a single particle theory of the electron and the famous equation that bears Dirac's name.
- 1928 Werner Heisenberg explains the energetics of the alignment of electron spins in ferromagnetic materials.
- 1931 Robert van de Graaff invents his electrostatic generator.
- 1933 Walther Meissner and Robert Ochsenfeld find that magnetic fields do not penetrate superconductors.
- 1935 Fritz and Heinz London develop acceleration theory to account for superconductivity.
- 1935 John Cunningham McLennan opens an international conference on superconductivity in London.
- 1935 Lev Landau and Evgeny Lifshitz explain magnetic domain structure in ferromagnetic materials.
- 1938 Jack Allen and Don Misener, and independently Pyotr Kapitza, discover superfluidity in cold helium.
- 1940 Wolfgang Pauli proves the *spin-statistics theorem*, which asserts that spin one-half particles obey Fermi-Dirac statistics, and therefore obey the Pauli exclusion principle.
- 1952 John Bardeen, Leon N. Cooper, and J. Robert Schrieffer develop a quantum model of superconductivity.

- 1959 Yakir Aharonov and David Bohm show that in quantum mechanics the potentials are more fundamental than the fields.
- 1962 Thomas Kuhn writes The Structure of Scientific Revolutions.
- 1965 Gordon Moore, publishes “Cramming More Components onto Integrated Circuits.”