EVENTS IN SCIENCE, MATHEMATICS, AND TECHNOLOGY — VERSION 3.0

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Classical Mechanics

-260 Archimedes mathematically works out the principle of the lever and discovers the principle of buoyancy
60 Hero of Alexandria writes *Metrica*, *Mechanics*, and *Pneumatics*
1490 Leonardo da Vinci describes capillary action
1581 Galileo Galilei notices the timekeeping property of the pendulum
1589 Galileo Galilei uses balls rolling on inclined planes to show that different weights fall with the same acceleration
1638 Galileo Galilei publishes *Dialogues Concerning Two New Sciences*
1658 Christian Huygens experimentally discovers that balls placed anywhere inside an inverted cycloid reach the lowest point of the cycloid in the same time and thereby experimentally shows that the cycloid is the isochrone
1668 John Wallis suggests the law of conservation of momentum
1687 Isaac Newton publishes his *Principia Mathematica*
1690 James Bernoulli shows that the cycloid is the solution to the isochrone problem
1691 Johann Bernoulli shows that a chain freely suspended from two points will form a catenary
1691 James Bernoulli shows that the catenary curve has the lowest center of gravity that any chain hung from two fixed points can have
1696 Johann Bernoulli shows that the cycloid is the solution to the brachistochrone problem
1714 Brook Taylor derives the fundamental frequency of a stretched vibrating string in terms of its tension and mass per unit length by solving an ordinary differential equation
1733 Daniel Bernoulli derives the fundamental frequency and harmonics of a hanging chain by solving an ordinary differential equation
1734 Daniel Bernoulli solves the ordinary differental equation for the vibrations of an elastic bar clamped at one end
1738 Daniel Bernoulli examines fluid flow in *Hydrodynamica*
1739 Leonhard Euler solves the ordinary differential equation for a forced harmonic oscillator and notices the resonance phenomenon
1742 Colin Maclaurin discovers his uniformly rotating self-gravitating spheroids
1747 Pierre-Louis Moreau de Maupertuis applies minimum principles to mechanics
1759 Leonhard Euler solves the partial differential equation for the vibration of a rectangular drum
1764 Leonhard Euler examines the partial differential equation for the vibration of a circular drum and finds one of the Bessel function solutions
1788 Joseph Lagrange presents Lagrange's equations of motion in *Mécanique Analytique*
1789 Antoine Lavoisier states the law of conservation of mass
1821 William Hamilton begins his analysis of Hamilton's characteristic function
1834 Carl Jacobi discovers his uniformly rotating self-gravitating ellipsoids
1834 John Russell observes a nondecaying solitary water wave in the Union Canal near Edinburgh and uses a water tank to study the dependence of solitary water wave velocities on wave amplitude and water depth
1835 William Hamilton states Hamilton's canonical equations of motion
1835 Gaspard de Coriolis examines motion on a spinning surface deduces the Coriolis effect
1842 Christian Doppler examines the Doppler shift of sound
1847 Hermann Helmholtz formally states the law of conservation of energy
1851 Jean-Bernard Foucault shows the Earth's rotation with a huge pendulum
1902 James Jeans finds the length scale required for gravitational pertrubatations to grow in a static nearly homogeneous medium
1994 Zhihong Xia proves that a system of three bodies moving under the influence of gravity is not integrable and is chaotic

Electromagnetism and Classical Optics

130 Claudius Ptolemaeus tabulates angles of refraction for several media
1269 Pèlerin de Maricourt describes magnetic poles and remarks on the nonexistence of isolated magnetic poles
1305 Dietrich von Freiberg uses crystalline spheres and flasks filled with water to study the reflection and refraction in raindrops that leads to primary and secondary rainbows
1604 Johannes Kepler describes how the eye focuses light
1611 Marko Dominis discusses the rainbow in *De Radiis Visus et Lucis*
1611 Johannes Kepler discovers total internal reflection, a small angle refraction law, and thin lens optics
1621 Willebrord Snell states his law of refraction
1637 René Descartes quantitatively derives the angles at which primary and secondary rainbows are seen with respect to the angle of the Sun's elevation
1657 Pierre de Fermat introduces the principle of least time into optics
1678 Christian Huygens states his principle of wavefront sources
1704 Isaac Newton publishes *Opticks*
1728 James Bradley discovers the aberration of starlight and uses it to determine that the speed of light is about 283,000 km/s
1752 Benjamin Franklin shows that lightning is electricity
1767 Joseph Priestly proposes an electrical inverse-square law
1785 Charles Coulomb introduces the inverse-square law of electrostatics
1786 Luigi Galvani discovers 'animal electricity' and postulates that animal bodies are storehouses of electricity
1800 William Herschel discovers infrared radiation from the Sun
1801 Johann Ritter discovers ultraviolet radiation from the Sun
1801 Thomas Young demonstrates the wave nature of light and the principle of interference
1808 Étienne Malus discovers polarization by reflection
1809 Étienne Malus publishes the law of Malus which predicts the light intensity transmitted by two polarizing sheets
1811 François Arago discovers that some quartz crystals will continuously rotate the electric vector of light
1816 David Brewster discovers stress birefringence
1818 Siméon Poisson predicts the Poisson bright spot at the center of the shadow of a circular opaque obstacle
1818 François Arago verifies the existence of the Poisson bright spot
1820 Hans Oersted notices that a current in a wire can deflect a compass needle
1825 Augustin Fresnel phenomenologically explains optical activity by introducing circular birefringence
1826 Simon Ohm states his law of electrical resistance
1831 Michael Faraday states his law of induction
1833 Heinrich Lenz states that an induced current in a closed conducting loop will appear in such a direction that it opposes the change that produced it
1845 Michael Faraday discovers that light propagation in a material can be influenced by external magnetic fields
1849 Armand Fizeau and Jean-Bernard Foucault measure the speed of light to be about 298,000 km/s
1852 George Stokes defines the Stokes parameters of polarization
1864 James Clerk Maxwell publishes his papers on a dynamical theory of the electromagnetic field
1871 Lord Rayleigh discusses the blue sky law and sunsets
1873 James Clerk Maxwell states that light is an electromagnetic phenomenon
1875 John Kerr discovers the electrically induced birefringence of some liquids
1888 Heinrich Hertz discovers radio waves
1895 Wilhelm Röntgen discovers X-rays
1896 Arnold Sommerfeld solves the half-plane diffraction problem
1956 R. Hanbury-Brown and R.Q. Twiss complete the correlation interferometer

Thermodynamics, Statistical Mechanics, and Random Processes

1761 Joseph Black discovers that ice absorbs heat without changing temperature when melting
1798 Count Rumford has the idea that heat is a form of energy
1822 Joseph Fourier formally introduces the use of dimensions for physical quantities in his *Theorie Analytique de la Chaleur*
1824 Sadi Carnot scientifically analyzes the efficiency of steam engines
1827 Robert Brown discovers the Brownian motion of pollen and dye particles in water
1834 Benoit-Pierre Clapeyron presents a formulation of the second law of thermodynamics
1843 James Joule experimentally finds the mechanical equivalent of heat

1848 Lord Kelvin discovers the absolute zero point of temperature
1852 James Joule and Lord Kelvin demonstrate that a rapidly expanding gas cools
1859 James Clerk Maxwell discovers the distribution law of molecular velocities
1870 Rudolph Clausius proves the scalar virial theorem
1872 Ludwig Boltzmann states the Boltzmann equation for the temporal development of distribution functions in phase space
1874 Lord Kelvin formally states the second law of thermodynamics
1876 Josiah Gibbs begins a two-year long series of papers which discusses phase equilibria, the free energy as the driving force behind chemical reactions, and chemical thermodynamics in general
1879 Josef Stefan observes that the total radiant flux from a blackbody is proportional to the fourth power of its temperature
1884 Ludwig Boltzmann derives the Stefan-Boltzmann blackbody radiant flux law from thermodynamic considerations
1888 Henri-Louis Le Châtelier states that the response of a chemical system perturbed from equilbrium will be to counteract the perturbation
1893 Wilhelm Wien discovers the displacement law for a blackbody's maximum specific intensity
1905 Albert Einstein mathematically analyzes the Brownian motion
1906 Walther Nernst presents a formulation of the third law of thermodynamics
1910 Albert Einstein and Marian Smoluchowski find the Einstein-Smoluchowski formula for the attenuation coefficient due to density fluctuations in a gas
1916 Sydney Chapman and David Enskog systematically develop a kinetic theory of gases
1919 James Jeans discovers that the dynamical constants of motion determine the distribution function for a system of particles
1920 Meghnad Saha states the Saha ionization equilibrium equation
1923 Pieter Debye and Erich Hückel publish a statistical treatment of the dissociation of electrolytes
1928 J.B. Johnson discovers Johnson noise in a resistor
1928 Harry Nyquist derives the fluctuation-dissipation relationship for a resistor to explain Johnson noise
1942 J.L. Doob states his theorem on Gaussian-Markoff processes
1957 A.S. Kompaneets derives his Compton scattering Fokker-Planck equation

States of Matter and Phase Transitions

1895 Pierre Curie discovers that induced magnetization is proportional to magnetic field strength
1911 Heike Kammerlingh Onnes discovers superconductivity
1912 Pieter Debye derives the T-cubed law for the low temperature heat capacity of a nonmetallic solid
1925 Ernst Ising presents the solution to the one-dimensional Ising model and models ferromagnetism as a cooperative spin phenomenon
1933 Walter Meissner and R. Ochsenfeld discover perfect superconducting diamagnetism
1942 Hannes Alfvén predicts magnetohydrodynamic waves in plasmas
1944 Lars Onsager publishes the exact solution to the two-dimensional Ising model
1957 John Bardeen, Leon Cooper, and Robert Schrieffer develop the BCS theory of superconductivity
1958 Rudolf Mössbauer finds the Mössbauer crystal recoil effect
1972 Douglas Osheroff, Robert Richardson, and David Lee discover that helium-3 can become a superfluid
1974 Kenneth Wilson develops the renormalization group technique for treating phase transitions
1987 Alex Müller and Georg Bednorz discover high critical temperature ceramic superconductors

Quantum Mechanics, Molecular Physics, Atomic Physics, Nuclear Physics, and Particle Physics

-440 Democritus speculates about fundamental indivisible particles—calls them 'atoms'
1766 Henry Cavendish discovers and studies hydrogen
1778 Carl Scheele and Antoine Lavoisier discover that air is composed mostly of nitrogen and oxygen
1781 Joseph Priestly creates water by igniting hydrogen and oxygen
1800 William Nicholson and Anthony Carlisle use electrolysis to separate water into hydrogen and oxygen
1803 John Dalton introduces atomic ideas into chemistry and states that matter is composed of atoms of different weights
1811 Amedeo Avogadro claims that equal volumes of gases should contain equal numbers of molecules
1832 Michael Faraday states his laws of electrolysis
1871 Dmitri Mendeleyev systematically examines the periodic table and predicts the existence of gallium, scandium, and germanium
1873 Johannes van der Waals introduces the idea of weak attractive forces between molecules
1885 Johann Balmer finds a mathematical expression for observed hydrogen line wavelengths
1887 Heinrich Hertz discovers the photoelectric effect
1894 Lord Rayleigh and William Ramsay discover argon by spectroscopically analyzing the gas left over after nitrogen and oxygen are removed from air
1895 William Ramsay discovers terrestrial helium by spectroscopically analyzing gas produced by decaying uranium
1896 Antoine Becquerel discovers the radioactivity of uranium
1896 Pieter Zeeman studies the splitting of sodium D lines when sodium is held in a flame between strong magnetic poles
1897 Joseph Thomson discovers the electron
1898 William Ramsay and Morris Travers discover neon, krypton, and xenon
1898 Marie Curie shows that thorium is radioactive and hypothesizes that radioactive emanations come from single atoms
1898 Marie Curie and Pierre Curie isolate and study radium and polonium
1899 Ernest Rutherford discovers that uranium radiation is composed of positively charged alpha particles and negatively charged beta particles
1900 Paul Villard discovers gamma-rays while studying uranium decay
1900 Johannes Rydberg refines the expression for observed hydrogen line wavelengths
1900 Max Planck states his quantum hypothesis and blackbody radiation law
1902 Philipp Lenard observes that maximum photoelectron energies are independent of illuminating intensity but depend on frequency
1902 Theodor Svedberg suggests that fluctuations in molecular bombardment cause the Brownian motion
1905 Albert Einstein explains the photoelectric effect
1906 Charles Barkla discovers that each element has a characteristic X-ray and that the degree of penetration of these X-rays is related to the atomic weight of the element
1909 Hans Geiger and Ernest Marsden discover large angle deflections of alpha particles by thin metal foils
1909 Ernest Rutherford and Thomas Royds demonstrate that alpha particles are doubly ionized helium atoms
1911 Ernest Rutherford explains the Geiger-Marsden experiment by invoking a nuclear atom model and derives the Rutherford cross section
1912 Max von Laue suggests using lattice solids to diffract X-rays
1912 Walter Friedrich and Paul Knipping diffract X-rays in zinc blende
1913 William Bragg and Lawrence Bragg work out the Bragg condition for strong X-ray reflection
1913 Henry Moseley shows that nuclear charge is the real basis for numbering the elements
1913 Niels Bohr presents his quantum model of the atom
1913 Robert Millikan measures the fundamental unit of electric charge
1913 Johannes Stark demonstrates that strong electric fields will split the Balmer spectral line series of hydrogen
1914 James Franck and Gustav Hertz observe atomic excitation
1914 Ernest Rutherford suggests that the positively charged atomic nucleus contains protons
1915 Arnold Sommerfeld develops a modified Bohr atomic model with elliptic orbits to explain relativistic fine structure
1916 Gilbert Lewis and Irving Langmuir formulate an electron shell model of chemical bonding
1917 Albert Einstein introduces the idea of stimulated radiation emission
1921 Alfred Landé introduces the Lande g-factor
1922 Arthur Compton studies X-ray photon scattering by electrons
1922 Otto Stern and Walter Gerlach show 'space quantization'
1923 Louis de Broglie suggests that electrons may have wavelike properties
1924 Wolfgang Pauli states the quantum exclusion principle
1924 John Lennard-Jones proposes a semiempirical interatomic force law
1924 Satyendra Bose and Albert Einstein introduce Bose-Einstein statistics
1925 George Uhlenbeck and Samuel Goudsmit postulate electron spin
1925 Pierre Auger discovers the Auger autoionization process
1925 Werner Heisenberg, Max Born, and Pascual Jordan formulate quantum matrix mechanics
1926 Erwin Schrödinger states his nonrelativistic quantum wave equation and formulates quantum wave mechanics
1926 Erwin Schrödinger proves that the wave and matrix formulations of quantum theory are mathematically equivalent
1926 Oskar Klein and Walter Gordon state their relativistic quantum wave equation

1926 Enrico Fermi discovers the spin-statistics connection
1926 Paul Dirac introduces Fermi-Dirac statistics
1927 Clinton Davission, Lester Germer, and George Thomson confirm the wavelike nature of electrons
1927 Werner Heisenberg states the quantum uncertainty principle
1927 Max Born interprets the probabilistic nature of wavefunctions
1928 Chandrasekhara Raman studies optical photon scattering by electrons
1928 Paul Dirac states his relativistic electron quantum wave equation
1928 Charles G. Darwin and Walter Gordon solve the Dirac equation for a Coulomb potential
1929 Oskar Klein discovers the Klein paradox
1929 Oskar Klein and Y. Nishina derive the Klein-Nishina cross section for high energy photon scattering by electrons
1929 N.F. Mott derives the Mott cross section for the Coulomb scattering of relativistic electrons
1930 Paul Dirac introduces electron hole theory
1930 Erwin Schrödinger predicts the *zitterbewegung* motion
1930 Fritz London explains van der Waals forces as due to the interacting fluctuating dipole moments between molecules
1931 John Lennard-Jones proposes the Lennard-Jones interatomic potential
1931 Irène Joliot-Curie and Frédéric Joliot-Curie observe but misinterpret neutron scattering in parafin
1931 Wolfgang Pauli puts forth the neutrino hypothesis to explain the apparent violation of energy conservation in beta decay
1931 Linus Pauling discovers resonance bonding and uses it to explain the high stability of symmetric planar molecules
1931 Paul Dirac shows that charge conservation can be explained if magnetic monopoles exist
1931 Harold Urey discovers deuterium using evaporation concentration techniques and spectroscopy
1932 John Cockcroft and Thomas Walton split lithium and boron nuclei using proton bombardment
1932 James Chadwick discovers the neutron
1932 Werner Heisenberg presents the proton-neutron model of the nucleus and uses it to explain isotopes
1932 Carl Anderson discovers the positron
1933 Max Delbrück suggests that quantum effects will cause photons to be scattered by an external electric field
1934 Irène Joliot-Curie and Frédéric Joliot-Curie bombard aluminum atoms with alpha particles to create artificially radioactive phosphorus-30
1934 Leo Szilard realizes that nuclear chain reactions may be possible
1934 Enrico Fermi formulates his theory of beta decay
1934 Lev Landau tells Edward Teller that nonlinear molecules may have vibrational modes which remove the degeneracy of an orbitally degenerate state
1934 Enrico Fermi suggests bombarding uranium atoms with neutrons to make a 93 proton element
1934 Pavel Čerenkov reports that light is emitted by relativistic particles traveling in a nonscintillating liquid
1935 Hideki Yukawa presents a theory of strong interactions and predicts mesons
1935 Albert Einstein, Boris Podolsky, and Nathan Rosen put forth the EPR paradox
1935 Niels Bohr presents his analysis of the EPR paradox
1936 Eugene Wigner develops the theory of neutron absorption by atomic nuclei
1936 Hans Jahn and Edward Teller present their systematic study of the symmetry types for which the Jahn-Teller effect is expected
1937 H. Hellmann finds the Hellmann-Feynman theorem
1937 Seth Neddermeyer, Carl Anderson, J.C. Street, and E.C. Stevenson discover muons using cloud chamber measurements of cosmic rays
1939 Richard Feynman finds the Hellmann-Feynman theorem
1939 Otto Hahn, Fritz Strassman and Lise Meitner bombard uranium salts with thermal neutrons and discover barium among the reaction products
1939 Lise Meitner and Otto Frisch determine that nuclear fission is taking place in the Hahn-Strassman-Meitner experiments
1942 Enrico Fermi makes the first controlled nuclear chain reaction
1942 Ernst Stückelberg introduces the propagator to positron theory and interprets positrons as negative energy electrons moving backwards through spacetime
1943 Sin-Itiro Tomonaga publishes his paper on the basic physical principles of quantum electrodynamics
1947 Willis Lamb and Robert Retheford measure the Lamb-Retheford shift
1947 Cecil Powell, C.M.G. Lattes, and G.P.S. Occhialini discover the pi-meson by studying cosmic ray tracks
1947 Richard Feynman presents his propagator approach to quantum electrodynamics
1948 Hendrik Casimir predicts a rudimentary attractive Casimir force on a parallel plate capacitor
1951 Martin Deutsch discovers positronium
1953 R. Wilson observes Delbrück scattering of 1.33 MeV gamma-rays by the electric fields of lead nuclei
1954 Chen Yang and Robert Mills investigate a theory of hadronic isospin by demanding local gauge invariance under isotopic spin space rotations—first non-Abelian gauge theory
1955 Owen Chamberlain, Emilio Segrè, Clyde Wiegand, and Thomas Ypsilantis discover the antiproton
1956 Frederick Reines and Clyde Cowan detect antineutrinos
1956 Chen Yang and Tsung Lee propose parity violation by the weak force
1956 Chien Shiung Wu discovers parity violation by the weak force in decaying cobalt
1957 Gerhart Lüders proves the CPT theorem
1957 Richard Feynman, Murray Gell-Mann, Robert Marshak, and Ennackel Sudarshan propose a V-A Lagrangian for weak interactions
1958 Marcus Sparnaay experimentally confirms the Casimir effect
1959 Yakir Aharonov and David Bohm predict the Aharonov-Bohm effect
1960 R.G. Chambers experimentally confirms the Aharonov-Bohm effect
1961 Murray Gell-Mann and Yuval Ne'eman discover the Eightfold Way patterns—SU(3) group
1961 Jeffery Goldstone considers the breaking of global phase symmetry
1962 Leon Lederman shows that the electron neutrino is distinct from the muon neutrino
1963 Murray Gell-Mann and George Zweig propose the quark/aces model
1964 Peter Higgs considers the breaking of local phase symmetry
1964 J.S. Bell shows that all local hidden variable theories must satisfy Bell's inequality
1964 Val Fitch and James Cronin observe CP violation by the weak force in the decay of K mesons
1967 Steven Weinberg puts forth his electroweak model of leptons
1969 J.C. Clauser, M. Horne, A. Shimony, and R. Holt propose a polarization correlation test of Bell's inequality
1970 Sheldon Glashow, John Iliopoulos, and Luciano Maiani propose the charm quark
1971 Gerard 't Hooft shows that the Glashow-Salam-Weinberg electroweak model can be renormalized
1972 S. Freedman and J.C. Clauser perform the first polarization correlation test of Bell's inequality
1973 David Politzer proposes the asymptotic freedom of quarks
1974 Burton Richter and Samuel Ting discover the J/ψ meson implying the existence of the charm quark
1975 Martin Perl discovers the tauon
1977 S.W. Herb finds the upsilon resonance implying the existence of the beauty quark
1982 A. Aspect, J. Dalibard, and G. Roger perform a polarization correlation test of Bell's inequality that rules out conspiratorial polarizer communication
1983 Carlo Rubbia, Simon van der Meer, and the CERN UA-1 collaboration find the $W^{\pm}$ and Z^0 intermediate vector bosons
1989 The Z^0 intermediate vector boson resonance width indicates three quark-lepton generations

Particle Physics Technology

1896 Charles Wilson discovers that energetic particles produce droplet tracks in supersaturated gases
1908 Hans Geiger and Ernest Rutherford invent the Geiger counter
1911 Charles Wilson finishes a sophisticated cloud chamber
1934 Ernest Lawrence and Stan Livingston invent the cyclotron
1945 Edwin McMillan devises a synchrotron
1952 Donald Glaser develops the bubble chamber
1968 Georges Charpak and Roger Bouclier build the first multiwire proportional mode particle detection chamber

Gravitational Physics and Relativity

1640 Ismael Bullialdus suggests an inverse-square gravitational force law
1665 Isaac Newton deduces the inverse-square gravitational force law from the 'falling' of the Moon

1684 Isaac Newton proves that planets moving under an inverse-square force law will obey Kepler's laws
1686 Isaac Newton uses a fixed length pendulum with weights of varying composition to test the weak equivalence principle to 1 part in 1000
1798 Henry Cavendish measures the gravitational constant
1845 Urbain Leverrier observes a 35" per century excess precession of Mercury's orbit
1876 William Clifford suggests that the motion of matter may be due to changes in the geometry of space
1882 Simon Newcomb observes a 43" per century excess precession of Mercury's orbit
1887 Albert Michelson and Edward Morley do not detect the ether drift
1889 Roland von Eötvös uses a torsion fiber balance to test the weak equivalence principle to 1 part in one billion
1893 Ernst Mach states Mach's principle—first constructive attack on the idea of Newtonian absolute space
1905 Albert Einstein completes his theory of special relativity and states the law of mass-energy conservation
1907 Albert Einstein introduces the principle of equivalence of gravitation and inertia and uses it to predict the gravitational redshift
1907 Albert Einstein deduces the gravitational dilation of time
1912 Albert Einstein realizes that spacetime is curved and that tidal gravity is a manifestation of that curvature
1915 Albert Einstein completes his theory of general relativity
1915 Albert Einstein shows that the excess precession of Mercury is a consequence of general relativity
1916 Albert Einstein shows that the field equations of general relativity admit wavelike solutions
1918 J. Lense and Hans Thirring find the gravitomagnetic precession of gyroscopes in the equations of general relativity
1919 Arthur Eddington leads a solar eclipse expedition which claims to detect gravitational deflection of light by the Sun
1921 T. Kaluza demonstrates that a five-dimensional version of Einstein's equations unifies gravitation and electromagnetism
1937 Fritz Zwicky states that galaxies could act as gravitational lenses
1937 Albert Einstein, Leopold Infeld, and Banesh Hoffman show that the geodesic equations of general relativity can be deduced from its field equations
1957 John Wheeler discusses the breakdown of classical general relativity near singularities and the need for quantum gravity
1960 Robert Pound and Glen Rebka test the gravitational redshift predicted by the equivalence principle to approximately 1%
1962 Robert Dicke, Peter Roll, and R. Krotkov use a torsion fiber balance to test the weak equivalence principle to 2 parts in 100 billion
1964 Irwin Shapiro predicts a gravitational time delay of radiation travel as a test of general relativity
1965 Joseph Weber puts the first Weber bar gravitational wave detector into operation
1968 Irwin Shapiro presents the first detection of the Shapiro delay
1968 Kenneth Nordtvedt studies a possible violation of the weak equivalence principle for self-gravitating bodies and proposes a new test of the weak equivalence principle based on observing the relative motion of the Earth and Moon in the Sun's gravitational field
1976 Robert Vessot and Martin Levine use a hydrogen maser clock on a Scout D rocket to test the gravitational redshift predicted by the equivalence principle to approximately 0.007%
1979 Dennis Walsh, Robert Carswell, and Ray Weymann discover the gravitationally lensed quasar Q0957+561
1982 Joseph Taylor and Joel Weisberg show that the rate of energy loss from the binary pulsar PSR1913+16 agrees with that predicted by the general relativistic quadrupole formula to within 5%

Black Hole Physics

1783 John Michell discusses classical bodies which have escape velocities greater than the speed of light
1795 Pierre Laplace discusses classical bodies which have escape velocities greater than the speed of light
1916 Karl Schwarzschild solves the Einstein vacuum field equations for uncharged spherically symmetric systems
1918 Hans Reissner and Gunnar Nordstrøm solve the Einstein-Maxwell field equations for charged spherically symmetric systems
1923 George Birkhoff proves that the Schwarzschild spacetime geometry is the unique spherically symmetric solution of the Einstein vacuum field equations
1939 Robert Oppenheimer and Hartland Snyder calculate the collapse of a pressure-free homogeneous fluid sphere and find that it cuts itself off from communication with the rest of the universe
1958 David Finkelstein discovers the Finkelstein reference frame for the Schwarzschild geometry
1960 John Graves and Dieter Brill discover that the Reissner-Nordstrøm solution describes a charged black hole
1963 Roy Kerr solves the Einstein vacuum field equations for uncharged rotating systems
1964 Roger Penrose proves that an imploding star will necessarily produce a singularity once it has formed an event horizon
1965 Robert Boyer, Richard Lindquist, Brandon Carter and Roger Penrose discover that the Kerr solution describes a spinning black hole
1965 Ted Newman, Eugene Couch, K. Chinnapared, Albert Exton, A. Prakash, and Robert Torrence solve the Einstein-Maxwell field equations for charged rotating systems
1967 Werner Israel proves that a non-spinning black hole must be precisely spherical
1968 Brandon Carter uses Hamilton-Jacobi theory to derive first-order equations of motion for a charged particle moving in the external fields of a Kerr-Newman black hole
1969 Roger Penrose discusses the Penrose process for the extraction of the spin energy from a Kerr black hole
1969 Roger Penrose proposes the cosmic censorship hypothesis
1971 Identification of Cygnus X-1/HDE 226868 as a binary black hole candidate system
1971 Bill Press realizes that black holes can pulsate
1971 Stephen Hawking points out that primordial black holes might have been created in the Big Bang
1972 Kip Thorne proposes the hoop conjecture
1972 Saul Teukolsky derives a set of perturbation equations for rapidly spinning black holes
1972 Stephen Hawking proves that the area of a classical black hole's event horizon cannot decrease
1972 James Bardeen, Brandon Carter, and Stephen Hawking propose four laws of black hole mechanics in analogy with the laws of thermodynamics
1972 Jacob Bekenstein suggests that black holes have an entropy proportional to their surface area due to information loss effects
1974 Stephen Hawking applies quantum field theory to black hole spacetimes and shows that black holes will radiate particles with a blackbody spectrum which can cause black hole evaporation
1977 Roger Blandford and Roman Znajek develop a process to extract rotational energy from a spinning black hole using magnetic fields that thread the hole
1986 Werner Israel shows that it is impossible to destroy a black hole by spinning it up faster than its maximum allowed rate
1987 Bernard Whiting gives a formal proof that black holes cannot be torn apart by their pulsations
1989 Identification of GS2023+338/V404 Cygni as a binary black hole candidate system

Cosmology

1576 Thomas Digges modifies the Copernican system by removing its outer edge and replacing the edge with a star filled unbounded space
1610 Johannes Kepler uses the dark night sky to argue for a finite universe
1720 Edmund Halley puts forth an early form of Olbers' paradox
1744 Jean-Phillipe de Cheseaux puts forth an early form of Olbers' paradox
1826 Heinrich Olbers puts forth Olbers' paradox
1917 Willem de Sitter derives an isotropic static cosmology with a cosmological constant as well as an empty expanding cosmology with a cosmological constant
1922 Vesto Slipher summarizes his findings on the spiral nebulae's systematic redshifts
1922 Alexander Friedmann finds a solution to the Einstein field equations which suggests a general expansion of space
1927 Georges-Henri Lemaître discusses the creation event of an expanding universe governed by the Einstein field equations
1928 Harold Robertson briefly mentions that Vesto Slipher's redshift measurements combined with brightness measurements of the same galaxies indicate a redshift-distance relation
1929 Edwin Hubble demonstrates the linear redshift-distance relation and thus shows the expansion of the universe
1933 Edward Milne names and formalizes the cosmological principle
1934 Georges-Henri Lemaître interprets the cosmological constant as due to a 'vacuum' energy with an unusual perfect fluid equation of state
1938 Paul Dirac presents a cosmological theory where the gravitational constant decreases slowly so that the age of the universe divided by the atomic light-crossing time always equals the ratio of the electric force to the gravitational force between a proton and electron
1948 Ralph Alpher, Hans Bethe, and George Gamow examine element synthesis in a rapidly expanding and cooling universe and suggest that the elements were produced by rapid neutron capture
1948 Hermann Bondi, Thomas Gold, and Fred Hoyle propose steady state cosmologies based on the perfect cosmological principle
1951 William McCrea shows that the steady state C-field can be accommodated within general relativity by interpreting it as a contribution to the energy-momentum tensor with an unusual equation of state

1961 Robert Dicke argues that carbon-based life can only arise when the Dirac large numbers hypothesis is true because this is when burning stars exist—first use of the weak anthropic principle
1963 Fred Hoyle and Jayant Narlikar show that the steady state theory can explain the isotropy of the universe because deviations from isotropy and homogeneity exponentially decay in time
1964 Fred Hoyle and Roger Tayler point out that the primordial helium abundance depends on the number of neutrinos
1965 Martin Rees and Dennis Sciama analyze quasar source count data and discover that the quasar density increases with redshift
1965 Edward Harrison resolves Olbers' paradox by noting the finite lifetime of stars
1966 Stephen Hawking and George Ellis show that any plausible general relativistic cosmology is singular
1966 Jim Peebles shows that the hot Big Bang predicts the correct helium abundance
1967 Andrey Sakharov presents the requirements for a baryon-antibaryon asymmetry in the universe
1967 John Bahcall, Wal Sargent, and Maarten Schmidt measure the fine-structure splitting of spectral lines in 3C191 and thereby show that the fine-structure constant does not vary significantly with time
1968 Brandon Carter speculates that perhaps the fundamental constants of nature must lie within a restricted range to allow the emergence of life—first use of the strong anthropic principle
1969 Charles Misner formally presents the Big Bang horizon problem
1969 Robert Dicke formally presents the Big Bang flatness problem
1973 Edward Tryon proposes that the universe may be a large scale quantum mechanical vacuum fluctuation where positive mass-energy is balanced by negative gravitational potential energy
1974 Robert Wagoner, William Fowler, and Fred Hoyle show that the hot Big Bang predicts the correct deuterium and lithium abundances
1976 A.I. Shlyakhter uses samarium ratios from the prehistoric natural fission reactor in Gabon to show that some laws of physics have remained unchanged for over two billion years
1977 Gary Steigman, David Schramm, and James Gunn examine the relation between the primordial helium abundance and number of neutrinos and claim that at most five lepton families can exist
1980 Alan Guth proposes the inflationary Big Bang universe as a possible solution to the horizon and flatness problems

Cosmic Microwave Background Astronomy

1934 Richard Tolman shows that blackbody radiation in an expanding universe cools but remains thermal
1941 Andrew McKellar uses the excitation of CN doublet lines to measure that the 'effective temperature of space' is about 2.3 K
1948 George Gamow, Ralph Alpher, and Robert Herman predict that a Big Bang universe will have a blackbody cosmic microwave background with temperature about 5 K
1955 Tigran Shmaonov finds excess microwave emission with a temperature of roughly 3 K
1964 A.G. Doroshkevich and Igor Novikov write an unnoticed paper suggesting microwave searches for the blackbody radiation predicted by Gamow, Alpher, and Herman
1965 Arno Penzias, Robert Wilson, Bernie Burke, Robert Dicke, and James Peebles discover the cosmic microwave background radiation
1966 Rainer Sachs and Arthur Wolfe theoretically predict microwave background fluctuation amplitudes created by gravitational potential variations between observers and the last scattering surface
1968 Martin Rees and Dennis Sciama theoretically predict microwave background fluctuation amplitudes created by photons traversing time-dependent potential wells
1969 Rashid Sunyaev and Yakov Zel'dovich study the inverse Compton scattering of microwave background photons by hot electrons
1990 The COBE satellite shows that the microwave background has a nearly perfect blackbody spectrum and thereby strongly constrains the density of the intergalactic medium
1992 The COBE satellite discovers anisotropy in the cosmic microwave background

Other Background Radiation Fields

1912 Victor Hess discovers that the ionization of air increases with altitude indicating the existence of cosmic radiation
1956 Herbert Friedman detects evidence for extrasolar X-rays
1962 Riccardo Giacconi, Herbert Gursky, Frank Paolini, and Bruno Rossi formally discover the X-ray background

Galaxies, Clusters of Galaxies, and Large Scale Structure

1521 Ferdinand Magellan observes the Magellanic Clouds during his circumnavigating expedition
1750 Thomas Wright discusses galaxies and the shape of the Milky Way
1845 Lord Rosse discovers a nebula with a distinct spiral shape
1918 Harlow Shapley demonstrates that globular clusters surround our galaxy like a halo and are not centered on the Earth
1920 Harlow Shapely and Heber Curtis debate whether or not the spiral nebulae lie within the Milky Way
1923 Edwin Hubble resolves the Shapely-Curtis debate by finding Cepheids in Andromeda
1926 Edwin Hubble discovers planetary nebula type spectra in NGC 1068, NGC 4051 and NGC 4151
1932 Karl Jansky discovers radio noise from the center of the Milky Way
1933 Fritz Zwicky applies the virial theorem to the Coma cluster and obtains evidence for unseen mass
1936 Edwin Hubble introduces the spiral, barred spiral, elliptical, and irregular galaxy classifications
1939 Grote Reber discovers the radio source Cygnus A
1943 Carl Seyfert identifies six spiral galaxies (NGC 1068, NGC 1275, NGC 3516, NGC 4051, NGC 4151, NGC 7469) with unusually broad emission lines
1949 John Bolton, Gordon Stanley and Bruce Slee identify NGC 4486 (M87) and NGC 5128 as extragalactic radio sources
1951 William Morgan discovers the Orion and Perseus arms of the Milky Way
1953 R.C. Jennison and M.K. Das Gupta discover that the radio waves from galaxies are often produced by giant lobes
1953 Gérard de Vaucouleurs discovers that the galaxies within approximately 200 million light years of the Virgo cluster are confined to a giant supercluster disk
1954 Walter Baade and Rudolph Minkowski identify the extragalactic optical counterpart of the radio source Cygnus A
1959 Geoffrey Burbidge estimates the amount of energy in a radio lobe
1960 Thomas Matthews determines the radio position of 3C48 to within 5"
1960 Allan Sandage optically studies 3C48 and observes an unusual blue quasi stellar object
1962 Cyril Hazard, M.B. Mackey, and A.J. Shimmins use lunar occultations to determine a precise position for 3C273 and deduce that it is a double source
1963 Maarten Schmidt identifies the redshifted Balmer lines from the quasar 3C273
1964 Yakov Zel'dovich and Edwin Salpeter speculate that supermassive black holes power quasars and radio galaxies
1969 Donald Lynden-Bell proposes that giant black holes with accretion discs reside in the nuclei of galaxies
1973 Jeremiah Ostriker and James Peebles discover that the amount of visible matter in the disks of typical spiral galaxies is not enough for Newtonian gravitation to keep the disks from flying apart or drastically changing shape
1974 B.L. Fanaroff and J.M. Riley distinguish between edge-darkened (FR I) and edge-brightened (FR II) radio sources
1976 Sandra Faber and Robert Jackson discover the Faber-Jackson relation between the luminosity of an elliptical galaxy and the velocity dispersion in its center
1977 Brent Tully and Richard Fisher discover the Tully-Fisher relation between the luminosity of an isolated spiral galaxy and the velocity of the flat part of its rotation curve
1978 Steve Gregory and Laird Thompson describe the Coma supercluster
1978 Vera Rubin, Kent Ford, N. Thonnard, and Albert Bosma measure the rotation curves of several spiral galaxies and find significant deviations from what is predicted by the Newtonian gravitation of visible stars
1981 Robert Kirshner, August Oemler, Paul Schechter, and Stephen Shectman find evidence for a giant void in Boötes with a diameter of approximately 100 million light years
1985 Robert Antonucci and J. Miller discover that the Seyfert II galaxy NGC 1068 has broad lines which can only be seen in polarized reflected light
1986 Amos Yahil, David Walker, and Michael Rowan-Robinson find that the direction of the IRAS galaxy density dipole agrees with the direction of the cosmic microwave background temperature dipole
1987 David Burstein, Roger Davies, Alan Dressler, Sandra Faber, Donald Lynden-Bell, R.J. Terlevich, and Gary Wegner claim that a large group of galaxies within about 200 million light years of the Milky Way are moving together towards 'The Great Attractor'
1990 Michael Rowan-Robinson and Tom Broadhurst discover that the IRAS galaxy F10214+4724 is the brightest known object in the universe

The Interstellar Medium and Intergalactic Medium

1848 Lord Rosse studies M1 and names it the Crab Nebula
1864 William Huggins studies the spectrum of the Orion Nebula and shows that it is a cloud of gas
1927 Ira Bowen explains unidentified spectral lines from space as forbidden transition lines
1930 Robert Trumpler discovers absorption by interstellar dust by comparing the angular sizes and brightnesses of globular clusters
1944 Hendrik van de Hulst predicts the 21 cm hyperfine line of neutral interstellar hydrogen
1951 H.I. Ewen and Edward Purcell observe the 21 cm hyperfine line of neutral interstellar hydrogen
1953 I.S. Shklovsky proposes that synchrotron radiation is the source of the radio and optical continuum emission from the Crab Nebula
1956 Lyman Spitzer predicts coronal gas around the Milky Way
1964 Herbert Friedman measures the angular size of the Crab Nebula using the Moon as an occulting disk
1965 James Gunn and Bruce Peterson use observations of the relatively low absorption of the blue component of the Lyman-alpha line from 3C9 to strongly constrain the density and ionization state of the intergalactic medium
1969 Lewis Snyder, David Buhl, Ben Zuckerman, and Patrick Palmer find interstellar formaldehyde
1970 Arno Penzias and Robert Wilson find interstellar carbon monoxide
1970 George Carruthers observes molecular hydrogen in space
1977 Christopher McKee and Jeremiah Ostriker propose a three component theory of the interstellar medium

White Dwarfs, Neutron Stars, and Supernovae

1054 Chinese and American Indian astronomers observe the Crab supernova explosion
1572 Tycho Brahe discovers his supernova in Cassiopeia
1604 Johannes Kepler's supernova in Serpens is observed
1862 Alvan Clark observes Sirius B
1866 William Huggins studies the spectrum of a nova and discovers that it is surrounded by a cloud of hydrogen
1914 Walter Adams determines an incredibly high density for Sirius B
1926 Ralph Fowler uses Fermi-Dirac statistics to explain white dwarf stars
1930 Subrahmanyan Chandrasekhar discovers the white dwarf maximum mass limit
1933 Fritz Zwicky and Walter Baade propose the neutron star idea and suggest that supernovae might be created by the collapse of normal stars to neutron stars—they also point out that such events can explain the cosmic ray background
1937 Lev Landau proposes a neutron core model for stellar energy generation
1939 Robert Oppenheimer and George Volkoff calculate the first neutron star models and show that there is a maximum mass for neutron stars
1942 J.J.L. Duyvendak, Nicholas Mayall, and Jan Oort deduce that the Crab Nebula is a remnant of the 1054 supernova observed by Chinese astronomers
1958 Evry Schatzman, Kent Harrison, Masami Wakano, and John Wheeler show that white dwarfs are unstable to inverse beta decay
1962 Riccardo Giacconi, Herbert Gursky, Frank Paolini, and Bruno Rossi discover Sco X-1
1967 Jocelyn Bell and Anthony Hewish discover radio pulses from the pulsar PSR 1919+21
1967 J.R. Harries, Ken McCracken, R.J. Francey, and A.G. Fenton discover the first X-ray transient (Cen X-2)
1968 Thomas Gold proposes that pulsars are rotating neutron stars
1969 David Staelin, Ed Reifenstein, William Cocke, Mike Disney, and Donald Taylor discover the Crab Nebula pulsar thus connecting supernovae, neutron stars, and pulsars
1971 Riccardo Giacconi, Herbert Gursky, Ed Kellogg, R. Levinson, E. Schreier, and H. Tananbaum discover 4.8 second X-ray pulsations from Cen X-3
1974 Russell Hulse and Joseph Taylor discover the binary pulsar PSR1913+16
1977 Kip Thorne and Anna Żytkow present a detailed analysis of Thorne-Żytkow objects
1982 D.C. Backer, Shrinivas Kulkarni, Carl Heiles, M.M. Davis, and Miller Goss discover the millisecond pulsar PSR1937+214
1985 Michiel van der Klis, Fred Jansen, Jan van Paradijs, Edward van den Heuvel, Walter Lewin, Joachim Trümper and Mirek Sztajno discover 30 Hz quasi-periodic oscillations in GX 5-1
1987 Ian Shelton discovers supernova 1987A in the Large Magellanic Cloud

Stellar Astronomy

-134 Hipparchus creates the magnitude scale of stellar apparent luminosities
1596 David Fabricus notices that Mira's brightness varies
1672 Geminiano Montanari notices that Algol's brightness varies
1686 Gottfried Kirch notices that Chi Cygni's brightness varies
1718 Edmund Halley discovers stellar proper motions by comparing his astrometric measurements with those of the Greeks
1782 John Goodricke notices that the brightness variations of Algol are periodic and proposes that it is partially eclipsed by a body moving around it
1784 Edward Piggot discovers the first Cepheid variable star
1838 Thomas Henderson, Friedrich Struve, and Friedrich Bessel measure stellar parallaxes
1844 Friedrich Bessel explains the wobbling motions of Sirius and Procyon by suggesting that these stars have dark companions
1906 Arthur Eddington begins his statistical study of stellar motions
1908 Henrietta Leavitt discovers the Cepheid period-luminosity relation
1910 Ejnar Hertzsprung and Henry Russell study the relation between magnitudes and spectral types of stars
1924 Arthur Eddington develops the main-sequence mass-luminosity relationship
1929 George Gamow proposes hydrogen fusion as the energy source for stars
1938 Hans Bethe and Carl von Weizsäcker detail the proton-proton chain and CNO cycle in stars
1939 Rupert Wildt realizes the importance of the negative hydrogen ion for stellar opacity
1952 Walter Baade distinguishes between Cepheid I and Cepheid II variable stars
1953 Fred Hoyle predicts a carbon-12 resonance to allow stellar triple alpha reactions at reasonable stellar interior temperatures
1955 John Crawford resolves the Algol paradox by proposing binary star mass exchange
1961 Chushiro Hayashi publishes his work on the Hayashi track of fully convective stars
1963 Fred Hoyle and William Fowler conceive the idea of supermassive stars
1964 Subrahmanyan Chandrasekhar and Richard Feynman develop a general relativistic theory of stellar pulsations and show that supermassive stars are subject to a general relativistic instability
1967 Gerry Neugebauer and Eric Becklin discover the Becklin-Neugebauer object at 10 microns

Solar Astronomy

1613 Galileo Galilei uses sunspot observations to demonstrate the rotation of the Sun
1619 Johannes Kepler postulates a solar wind to explain the direction of comet tails
1802 William Wollaston observes dark lines in the solar spectrum
1814 Joseph Fraunhofer systematically studies the dark lines in the solar spectrum
1834 Hermann Helmholtz proposes gravitational contraction as the energy source for the Sun
1843 Heinrich Schwabe announces his discovery of the sunspot cycle and estimates its period to be about ten years
1852 Edward Sabine shows that sunspot number is correlated with geomagnetic field variations
1859 Richard Carrington discovers solar flares
1859 Richard Carrington suspects a physical connection between a major solar flare and enhanced magnetic activity on the Earth some hours thereafter
1860 Gustav Kirchoff and Robert Bunsen discover that each element has its own distinct set of spectral lines and use this fact to explain the solar dark lines
1861 F.G.W. Spörer discovers the variation of sunspot latitudes during a solar cycle
1863 Richard Carrington discovers the differential nature of solar rotation
1868 Pierre-Jules-César Janssen and Norman Lockyer discover an unidentified yellow line in solar prominence spectra and suggest it comes from a new element which they name 'helium'
1893 Edward Maunder discovers the 1645–1715 Maunder sunspot minimum
1904 Edward Maunder plots the first sunspot 'butterfly diagram'
1906 Karl Schwarzschild explains solar limb darkening
1908 George Hale discovers the Zeeman splitting of spectral lines from sunspots
1942 J.S. Hey detects solar radio waves

1949 Herbert Friedman detects solar X-rays
1960 Robert Leighton, Robert Noyes, and George Simon discover solar five-minute oscillations by observing the Doppler shifts of solar dark lines
1961 H. Babcock proposes the magnetic coiling sunspot theory
1970 Roger Ulrich, John Leibacher, and Robert Stein deduce from theoretical solar models that the interior of the Sun could act as a resonant acoustic cavity
1975 Franz-Ludwig Deubner makes the first accurate measurements of the period and horizontal wavelength of the five-minute solar oscillations

Solar System Astronomy

-2136 Chinese astronomers record a solar eclipse
-586 Thales of Miletus predicts a solar eclipse
-350 Aristotle argues for a spherical Earth using lunar eclipses and other observations
-280 Aristarchus uses the size of the Earth's shadow on the Moon to estimate that the Moon's radius is one-third that of the Earth
-200 Eratosthenes uses shadows to determine that the radius of the Earth is roughly 6,400 km
-150 Hipparchus uses parallax to determine that the distance to the Moon is roughly 380,000 km
-134 Hipparchus discovers the precession of the equinoxes
1512 Nicholas Copernicus first states his heliocentric theory in *Commentariolus*
1543 Nicholas Copernicus shows that his heliocentric theory simplifies planetary motion tables in *De Revolutionibus de Orbium Coelestium*
1577 Tycho Brahe uses parallax to prove that comets are distant entities and not atmospheric phenomena
1609 Johannes Kepler states his first two empirical laws of planetary motion
1610 Galileo Galilei discovers Callisto, Europa, Ganymede, and Io
1610 Galileo Galilei sees Saturn's rings but does not recognize that they are rings
1619 Johannes Kepler states his third empirical law of planetary motion
1655 Giovanni Cassini discovers Jupiter's great red spot
1656 Christian Huygens identifies Saturn's rings as rings and discovers Titan and the Orion Nebula
1665 Giovanni Cassini determines the rotational speeds of Jupiter, Mars, and Venus
1672 Giovanni Cassini discovers Rhea
1672 Jean Richer and Giovanni Cassini measure the astronomical unit to be about 138,370,000 km
1675 Ole Römer uses the orbital mechanics of Jupiter's moons to estimate that the speed of light is about 227,000 km/s
1705 Edmund Halley publicly predicts the periodicity of Halley's comet and computes its expected path of return in 1758
1715 Edmund Halley calculates the shadow path of a solar eclipse
1716 Edmund Halley suggests a high-precision measurement of the Sun-Earth distance by timing the transit of Venus
1758 Johann Palitzsch observes the return of Halley's comet
1766 Johann Titius finds the Titius-Bode rule for planetary distances
1772 Johann Bode publicizes the Titius-Bode rule for planetary distances
1781 William Herschel discovers Uranus during a telescopic survey of the northern sky
1796 Pierre Laplace states his nebular hypothesis for the formation of the solar system from a spinning nebula of gas and dust
1801 Giuseppe Piazzi discovers the asteroid Ceres
1802 Heinrich Olbers discovers the asteroid Pallas
1821 Alexis Bouvard detects irregularities in the orbit of Uranus
1825 Pierre Laplace completes his study of gravitation, the stability of the solar system, tides, the precession of the equinoxes, the libration of the Moon, and Saturn's rings in *Mécanique Céleste*
1843 John Adams predicts the existence and location of Neptune from irregularities in the orbit of Uranus
1846 Urbain Leverrier predicts the existence and location of Neptune from irregularities in the orbit of Uranus
1846 Johann Galle discovers Neptune
1846 William Lassell discovers Triton
1849 Edouard Roche finds the limiting radius of tidal destruction and tidal creation for a body held together only by its self gravity and uses it to explain why Saturn's rings do not condense into a satellite
1856 James Clerk Maxwell demonstrates that a solid ring around Saturn would be torn apart by gravitational forces and argues that Saturn's rings consist of a multitude of tiny satellites
1866 Giovanni Schiaparelli realizes that meteor streams occur when the Earth passes through the orbit of a comet that has left debris along its path
1906 Max Wolf discovers the Trojan asteroid Achilles
1930 Clyde Tombaugh discovers Pluto
1930 Seth Nicholson measures the surface temperature of the Moon
1932 Ernst Öpik suggests the idea of a cloud of comets which is stable against stellar perturbations
1950 Jan Oort deduces the existence of the Oort cloud by studying the semi-major axis distribution of 19 comets
1950 Fred Whipple outlines the 'dirty snowball' model of the cometary nucleus which describes it as a mixture of ices and meteoritic dust
1951 Gerard Kuiper argues for an annular reservoir of comets between 40–100 astronomical units from the Sun
1977 James Elliot discovers the rings of Uranus during a stellar occultation experiment on the Kuiper Airborne Observatory
1978 James Christy discovers Charon
1978 Peter Goldreich and Scott Tremaine present a Boltzmann equation model of planetary-ring dynamics for indestructible spherical ring particles that do not self-gravitate and find a stability requirement relation between ring optical depth and particle normal restitution coefficient
1988 Martin Duncan, Thomas Quinn, and Scott Tremaine demonstrate that short-period comets come primarily from the Kuiper Belt and not the Oort cloud

Astronomical Maps, Catalogs, and Surveys

-134 Hipparchus makes a detailed star map
1678 Edmund Halley publishes a catalog of 341 southern stars—first systematic southern sky survey
1771 Charles Messier publishes his first list of nebulae
1864 John Herschel publishes the *General Catalog* of nebulae and star clusters
1890 John Dreyer publishes the *New General Catalog* of nebulae and star clusters
1956 Completion of the Palomar sky survey with the Palomar 48-inch Schmidt optical reflecting telescope
1958 George Abell makes a catalog of rich galaxy clusters in the northern sky
1962 A.S. Bennett publishes the *Revised 3C Catalog* of 328 radio sources
1965 Gerry Neugebauer and Robert Leighton begin a 2.2 micron sky survey with a 1.6-meter telescope on Mount Wilson
1993 Start of the 20 cm VLA FIRST survey

Telescopes, Observatories, and Observing Technology

1608 Hans Lippershey tries to patent an optical refracting telescope
1609 Galileo Galilei builds his first optical refracting telescope
1641 William Gascoigne invents telescope cross hairs
1661 James Gregory proposes an optical reflecting telescope
1668 Isaac Newton constructs the first optical reflecting telescope
1733 Chester Moor Hall invents the achromatic lens refracting telescope
1758 John Dolland reinvents the achromatic lens
1789 William Herschel finishes a 49-inch optical reflecting telescope—located in Slough, England
1840 J.W. Draper invents astronomical photography and photographs the Moon
1845 Lord Rosse finishes the Birr Castle 72-inch optical reflecting telescope—located in Parsonstown, Ireland
1872 Henry Draper invents astronomical spectral photography and photographs the spectrum of Vega
1890 Albert Michelson proposes the stellar interferometer
1892 George Hale finishes a spectroheliograph—allows the Sun to be photographed in the light of one element only
1897 Alvan Clark finishes the Yerkes 40-inch optical refracting telescope—located in Williams Bay, Wisconsin
1917 Mount Wilson 100-inch optical reflecting telescope begins operation—located in Mount Wilson, California
1930 Bernard-Ferdinand Lyot invents the coronagraph
1930 Karl Jansky builds a 30-meter long rotating aerial radio telescope

1933 Bernard-Ferdinand Lyot invents the Lyot filter
1934 Bernhard Schmidt finishes the first 14-inch Schmidt optical reflecting telescope
1936 Palomar 18-inch Schmidt optical reflecting telescope begins operation—located in Palomar, California
1937 Grote Reber builds a 31-foot radio telescope
1946 Herbert Friedman and his team launch the first astronomical instrument (a solar ultraviolet spectrograph) above the Earth's atmosphere on a captured German V-2 rocket
1947 Bernard Lovell and his group complete the Jodrell Bank 218-foot non-steerable radio telescope
1949 Palomar 48-inch Schmidt optical reflecting telescope begins operation—located in Palomar, California
1949 Palomar 200-inch optical reflecting telescope begins regular operation—located in Palomar, California
1957 Bernard Lovell and his group complete the Jodrell Bank 250-foot steerable radio telescope
1957 Peter Scheuer publishes his $P(D)$ method for obtaining source counts of spatially unresolved sources
1960 Martin Ryle tests Earth rotation aperature synthesis
1960 Owens Valley 27-meter radio telescopes begin operation—located in Big Pine, California
1963 Arecibo 300-meter radio telescope begins operation—located in Arecibo, Puerto Rico
1964 Ryle 1-mile radio interferometer begins operation—located in Cambridge, England
1965 Owens Valley 40-meter radio telescope begins operation—located in Big Pine, California
1967 First VLBI images—183 km baseline
1969 Observations start at Big Bear Solar Observatory—located in Big Bear, California
1970 Cerro Tololo 158-inch optical reflecting telescope begins operation—located in Cerro Tololo, Chile
1970 Kitt Peak National Observatory 158-inch optical reflecting telescope begins operation—located near Tucson, Arizona
1974 Anglo-Australian 153-inch optical reflecting telescope begins operation—located in Siding Springs, Australia
1975 Gerald Smith, Frederick Landauer, and James Janesick use a CCD to observe Uranus—first astronomical CCD observation
1978 Multiple Mirror 176-inch equivalent optical/infrared reflecting telescope begins operation—located in Amado, Arizona
1979 UKIRT 150-inch infrared reflecting telescope begins operation—located at Mauna Kea, Hawaii
1979 Canada-France-Hawaii 140-inch optical reflecting telescope begins operation—located at Mauna Kea, Hawaii
1980 Completion of construction of the VLA—located in Socorro, New Mexico
1993 Keck 10-meter optical/infrared reflecting telescope begins operation—located at Mauna Kea, Hawaii

Artificial Satellites and Space Probes

1957 *Sputnik I* is launched—first orbiting satellite
1962 *Mariner 2* is the first mission to Venus
1965 *Mariner 4* sends the first clear pictures of Mars
1966 *Luna 10* becomes the first spacecraft to orbit the Moon
1967 *Venera 4* sends the first data from below the clouds of Venus
1967 The OSO-3 gamma-ray satellite discovers gamma-ray emission from the plane of the Milky Way
1970 Launch of *Uhuru*—first dedicated X-ray satellite
1972 Launch of the *Copernicus* ultraviolet satellite
1974 *Mariner 10* passes by and photographs Mercury
1974 Launch of the *Ariel V* X-ray satellite
1975 *Venera 9* returns the first pictures of the surface of Venus
1976 *Viking I* and *Viking II* land on Mars
1976 The *Vela* and ANS X-ray satellites discover X-ray bursts
1976 The OSO-8 X-ray satellite shows that X-ray bursts have blackbody spectra
1977 Launch of the HEAO-1 X-ray satellite
1978 Launch of the *International Ultraviolet Explorer* satellite
1978 Launch of the *Einstein* X-ray satellite (HEAO-2)—first X-ray photographs of astronomical objects
1979 Launch of the *Hakucho* X-ray satellite (ASTRO-A)
1979 Launch of the *Ariel VI* cosmic-ray and X-ray satellite
1979 *Voyager 1* and *Voyager 2* send back images of Jupiter and its system
1980 *Voyager 1* sends back images of Saturn and its system
1980 Launch of the *Solar Maximum Mission* satellite
1981 *Voyager 2* sends back images of Saturn and its system
1983 Launch of the EXOSAT X-ray satellite
1983 Launch of the *Tenma* X-ray satellite (ASTRO-B)
1983 Launch of the IRAS satellite
1986 *Voyager 2* sends back images of Uranus and its system
1987 Launch of the *Ginga* X-ray satellite (ASTRO-C)
1989 *Voyager 2* sends back images of Neptune and its system
1989 Launch of the *Granat* gamma-ray and X-ray satellite
1989 Launch of the *Hipparcos* satellite
1989 Launch of the COBE satellite
1990 Launch of the *Hubble Space Telescope*
1990 Launch of the ROSAT X-ray satellite—first imaging X-ray sky survey
1990 First observations made with *Astro-1* (BBXRT, HUT, UIT, WUPPE)
1991 Launch of the *Compton Gamma-Ray Observatory* satellite
1993 Launch of the *Asca* X-ray satellite (ASTRO-D)

Biology and Organic Chemistry

-320 Theophrastus begins the systematic study of botany
1658 Jan Swammerdam observes red blood cells under a microscope
1663 Robert Hooke sees cells in cork using a microscope
1668 Francesco Redi disproves theories of the spontaneous generation of maggots in putrefying matter
1676 Anton van Leeuwenhoek observes protozoa and calls them 'animalcules'
1677 Anton van Leeuwenhoek observes spermatazoa
1683 Anton van Leeuwenhoek observes bacteria
1765 Lazzaro Spallanzani disproves many theories of the spontaneous generation of cellular life
1771 Joseph Priestly discovers that plants convert carbon dioxide into oxygen
1798 Thomas Malthus discusses human population growth and food production in *An Essay on the Principle of Population*
1801 Jean Lamarck begins the detailed study of invertebrate taxonomy
1809 Jean Lamarck proposes an inheritance of acquired characteristics theory of evolution
1817 Pierre-Joseph Pelletier and Joseph-Bienaimé Caventou isolate chlorophyll
1828 Karl von Baer discovers the eggs of mammals
1828 Friedrich Wöhler synthesizes urea—first synthesis of an organic compound
1836 Theodor Schwann discovers pepsin in extracts from the stomach lining—first isolation of an animal enzyme
1837 Theodor Schwann shows that heating air will prevent it from causing putrefaction
1838 Matthias Schleiden discovers that all living plant tissue is composed of cells
1839 Theodor Schwann discovers that all living animal tissue is composed of cells
1856 Louis Pasteur states that microorganisms produce fermentation
1858 Charles R. Darwin and Alfred Wallace independently propose natural selection theories of evolution
1858 Rudolf Virchow proposes that cells can only arise from pre-existing cells
1862 Louis Pasteur convincingly disproves the spontaneous generation of cellular life
1865 Gregor Mendel presents his experiments on the crossbreeding of pea plants and postulates dominant and recessive factors
1865 August Kekulé realizes that benzene is composed of carbon and hydrogen atoms in a hexagonal ring
1869 Friedrich Miescher discovers nucleic acids in the nuclei of cells
1874 Jacobus van't Hoff and Joseph-Achille Le Bel advance a three-dimensional stereochemical representation of organic molecules and propose a tetrahedral carbon atom
1876 Oskar Hertwig and Hermann Fol show that fertilized eggs possess both male and female nuclei
1884 Emil Fischer begins his detailed analysis of the compositions and structures of sugars

1898 Martinus Beijerinck uses filtering experiments to show that tobacco mosaic disease is caused by something smaller than a bacteria which he names a virus
1906 Mikhail Tsvett discovers the chromatography technique for organic compound separation
1907 Ivan Pavlov demonstrates conditioned responses with salivating dogs
1907 Emil Fischer artificially synthesizes peptide amino acid chains and thereby shows that amino acids in proteins are connected by amino group-acid group bonds
1911 Thomas Morgan proposes that Mendelian factors are arranged in a line on chromosomes
1926 James Sumner shows that the urease enzyme is a protein
1928 Otto Diels and Kurt Alder discover the Diels-Alder cycloaddition reaction for forming ring molecules
1929 Phoebus Levene discovers the sugar deoxyribose in nucleic acids
1929 Edward Doisy and Adolf Butenandt independently discover estrone
1930 John Northrop shows that the pepsin enzyme is a protein
1931 Adolf Butenandt discovers androsterone
1932 Hans Krebs discovers the urea cycle
1933 Tadeus Reichstein artificially synthesizes vitamin C—first vitamin synthesis
1935 Rudolf Schoenheimer uses hydrogen-2 as a tracer to examine the fat storage system of rats
1935 Wendell Stanley crystallizes the tobacco mosaic virus
1935 Konrad Lorenz describes the imprinting behavior of young birds
1937 Theodosius Dobzhansky links evolution and genetic mutation in *Genetics and the Origin of Species*
1938 A living coelacanth is found off the coast of southern Africa
1940 Donald Griffin and Robert Galambos announce their discovery of sonar echolocation by bats
1942 Max Delbrück and Salvador Luria demonstrate that bacterial resistance to virus infection is caused by random mutation and not adaptive change
1943 Erwin Schrödinger delivers the *What is Life?* lectures at Trinity College, Dublin
1944 Oswald Avery, C.M. McLeod and M. McCarty show that DNA carries the genetic code in pneumococci bacteria
1944 Robert Woodward and William von Eggers Doering synthesize quinine
1948 Erwin Chargaff shows that in DNA the number of guanine units equals the number of cytosine units and the number of adenine units equals the number of thymine units
1948 John von Neumann discusses the logical separability of biological metabolism and replication
1951 Robert Woodward synthesizes cholesterol and cortisone
1952 Alfred Hershey and Martha Chase use radioactive tracers to show that DNA is the genetic material in bacteriophage viruses
1952 Fred Sanger, Hans Tuppy, and Ted Thompson complete their chromatographic analysis of the insulin amino acid sequence
1952 Rosalind Franklin uses X-ray diffraction to study the structure of DNA and suggests that its sugar-phosphate backbone is on its outside
1953 James Watson and Francis Crick propose a double helix structure for DNA
1953 Max Perutz and John Kendrew determine the structure of hemoglobin using X-ray diffraction studies
1953 Stanley Miller shows that amino acids can be formed when simulated lightning is passed through vessels containing water, methane, ammonia, and hydrogen
1955 Severo Ochoa discovers RNA polymerase enzymes
1955 Arthur Kornberg discovers DNA polymerase enzymes
1960 Juan Oró finds that concentrated solutions of ammonium cyanide in water can produce the nucleotide organic base adenine
1960 Robert Woodward synthesizes chlorophyll
1967 John Gurden uses nuclear transplantation to clone a clawed frog—first cloning of a vertebrate
1968 Fred Sanger uses radioactive phosphorous as a tracer to chromatographically decipher a 120 base long RNA sequence
1970 Hamilton Smith and Daniel Nathans discover DNA restriction enzymes
1970 Howard Temin and David Baltimore independently discover reverse transcriptase enzymes
1972 Robert Woodward synthesizes vitamin B-12
1972 Stephen Jay Gould and Niles Eldredge propose punctuated equilibrium effects in evolution
1974 Manfred Eigen and Manfred Sumper show that mixtures of nucleotide monomers and RNA-replicase will give rise to RNA molecules which replicate, mutate, and evolve
1974 Leslie Orgel shows that RNA can replicate without RNA-replicase and that zinc aids this replication
1977 John Corliss, Jack Dymond, Louis Gordon, John Edmond, Richard von Herzen, Robert Ballard, Kenneth Green, David Williams, Arnold Bainbridge, Kathy Crane, and Tjeerd van Andel discover chemosynthetically based animal communities located around submarine thermal springs on the Galápagos Rift
1977 Walter Gilbert and Allan Maxam present a rapid gene sequencing technique which uses cloning, base destroying chemicals, and gel electrophoresis
1977 Fred Sanger and Alan Coulson present a rapid gene sequencing technique which uses dideoxynucleotides and gel electrophoresis
1978 Fred Sanger presents the 5,386 base sequence for the virus ϕX174 — first sequencing of an entire genome
1983 Kary Mullis invents the polymerase chain reaction
1984 Alec Jeffreys devises a DNA fingerprinting method
1985 Harry Kroto, J.R. Heath, S.C. O'Brien, R.F. Curl, and Richard Smalley discover the unusual stability of the carbon-60 Buckminsterfullerine molecule and deduce its structure
1990 Wolfgang Krätschmer, Lowell Lamb, Konstantinos Fostiropoulos, and Donald Huffman discover that Buckminsterfullerine can be separated from soot because it is soluble in benzene

Medicine and Medical Technology

-420 Hippocrates begins the scientific study of medicine by maintaining that diseases have natural causes
-280 Herophilus studies the nervous system and distinguishes between sensory nerves and motor nerves
-250 Erasistratus studies the brain and distinguishes between the cerebrum and cerebellum
50 Pedanius Dioscorides describes the medical applications of plants in *De Materia Medica*
180 Galen studies the connection between paralysis and severance of the spinal cord
1242 Ibn an-Nafīs suggests that the right and left ventricles of the heart are separate and describes the lesser circulation of blood
1249 Roger Bacon writes about convex lens eyeglasses for treating farsightedness
1403 Venice implements a quarantine against the Black Death
1451 Nicholas of Cusa invents concave lens spectacles to treat nearsightedness
1543 Andreas Vesalius publishes *De Fabrica Corporis Humani* which corrects Greek medical errors and revolutionizes medicine
1546 Gerolamo Fracastoro proposes that epidemic diseases are caused by transferable seedlike entities
1553 Miguel Serveto describes the lesser circulation of blood through the lungs
1559 Realdo Colombo describes the lesser circulation of blood through the lungs in detail
1603 Girolamo Fabrici studies leg veins and notices that they have valves which only allow blood to flow toward the heart
1628 William Harvey explains the vein-artery system and structure of the heart in *De Motu Cordis et Sanguinis*
1701 Giacomo Pylarini gives the first smallpox inoculations
1747 James Lind discovers that citrus fruits prevent scurvy
1763 Claudius Aymand performs the first successful appendectomy
1796 Edward Jenner develops a smallpox vaccination method
1800 Humphry Davy announces the anaesthetic properties of nitrous oxide
1816 Rene Laennec invents the stethoscope
1842 Crawford Long performs the first surgical operation using anasthesia
1847 Ignaz Semmelweis studies and prevents the transmission of puerperal fever
1870 Louis Pasteur and Robert Koch establish the germ theory of disease
1881 Louis Pasteur develops an anthrax vaccine
1882 Louis Pasteur develops a rabies vaccine
1890 Emil von Behring discovers antitoxins and uses them to develop tetanus and diptheria vaccines
1906 Frederick Hopkins suggests the existence of vitamins and suggests that a lack of vitamins causes scurvy and rickets
1907 Paul Ehrlich develops a chemotheraputic cure for sleeping sickness
1921 Edward Mellanby discovers vitamin D and shows that its absence causes rickets
1928 Alexander Fleming discovers penicillin
1932 Gerhard Domagk develops a chemotheraputic cure for streptococcus

1952	Jonas Salk develops the first polio vaccine

Pure and Applied Mathematics

-1700	Egyptian mathematicians employ primitive fractions
-530	Pythagoras studies propositional geometry and vibrating lyre strings
-370	Eudoxus states the method of exhaustion for area determination
-350	Aristotle discusses logical reasoning in *Organon*
-300	Euclid studies geometry as an axiomatic system in *Elements* and states the law of reflection in *Catoptrics*
-260	Archimedes computes π to two decimal places using inscribed and cirumscribed polygons and computes the area under a parabolic segment
-200	Apollonius writes *On Conic Sections* and names the ellipse, parabola, and hyperbola
250	Diophantus writes *Arithmetica*, the first systematic treatise on algebra
450	Tsu Ch'ung-Chih and Tsu Kêng-Chih compute π to six decimal places
550	Hindu mathematicians give zero a numeral representation in a positional notation system
1202	Leonardo Fibonacci demonstrates the utility of Arabic numerals in his *Book of the Abacus*
1424	Ghiyāth al-Kāshī computes π to sixteen decimal places using inscribed and cirumscribed polygons
1520	Scipione Ferro develops a method for solving cubic equations
1535	Niccolò Tartaglia develops a method for solving cubic equations
1540	Lodovico Ferrari solves the quartic equation
1596	Ludolf van Ceulen computes π to twenty decimal places using inscribed and cirumscribed polygons
1614	John Napier discusses Napierian logarithms in *Mirifici Logarithmorum Canonis Descriptio*
1617	Henry Briggs discusses decimal logarithms in *Logarithmorum Chilias Prima*
1619	René Descartes discovers analytical geometry
1629	Pierre de Fermat develops a rudimentary differential calculus
1634	G.P. de Roberval shows that the area under a cycloid is three times the area of its generating circle
1637	Pierre de Fermat claims to have proven Fermat's Last Theorem in his copy of Diophantus' *Arithmetica*
1654	Blaise Pascal and Pierre de Fermat create the theory of probability
1655	John Wallis writes *Arithmetica Infinitorum*
1658	Christopher Wren shows that the length of a cycloid is four times the diameter of its generating circle
1665	Isaac Newton invents his calculus
1668	Nicholas Mercator and William Brouncker discover an infinite series for the logarithm while attempting to calculate the area under a hyperbolic segment
1671	James Gregory discovers the series expansion for the inverse-tangent function
1673	Gottfried Leibniz invents his calculus
1675	Isaac Newton invents an algorithm for the computation of functional roots
1691	Gottfried Leibniz discovers the technique of separation of variables for ordinary differential equations
1693	Edmund Halley prepares the first mortality tables statistically relating death rate to age
1696	Guillaume de L'Hôpital states his rule for the examination of indeterminate forms
1706	John Machin develops a quickly converging inverse-tangent series for π and computes π to 100 decimal places
1712	Brook Taylor develops Taylor series'
1722	Abraham De Moivre states De Moivre's theorem
1724	Abraham De Moivre studies mortality statistics and the foundation of the theory of annuities in *Annuities on Lives*
1730	James Stirling publishes *The Differential Method*
1733	Geralamo Saccheri studies what geometry would be like if Euclid's fifth postulate were false
1734	Leonhard Euler introduces the integrating factor technique for solving first order ordinary differential equations
1736	Leonhard Euler solves the Koenigsberg bridge problem
1739	Leonhard Euler solves the general homogeneous linear ordinary differential equation with constant coefficients
1742	Christian Goldbach conjectures that every even number greater than two can be expressed as the sum of two primes
1744	Leonhard Euler shows the existence of transcendental numbers
1748	Maria Agnesi discusses analysis in *Instituzioni Analitiche ad Uso della Gioventu Italiana*
1761	Thomas Bayes proves Bayes' theorem
1796	Karl Gauss presents a method for constructing a heptadecagon using only a compass and straightedge and also shows that only polygons with certain numbers of sides can be constructed
1797	Caspar Wessel associates vectors with complex numbers and studies complex number operations in geometrical terms
1799	Karl Gauss proves that every polynomial equation has a solution among the complex numbers
1806	Jean-Robert Argand associates vectors with complex numbers and studies complex number operations in geometrical terms
1807	Joseph Fourier first announces his discoveries about the trigonometric decomposition of functions
1811	Karl Gauss discusses the meaning of integrals with complex limits and briefly examines the dependence of such integrals on the chosen path of integration
1815	Siméon Poisson carries out integrations along paths in the complex plane
1817	Bernard Bolzano presents Bolzano's theorem—a continuous function which is negative at one point and positive at another point must be zero for at least one point in between
1824	Niels Abel partially proves that the general quintic or higher equations do not have algebraic solutions
1822	Augustin-Louis Cauchy presents the Cauchy integral theorem for integration around the boundary of a rectangle
1825	Augustin-Louis Cauchy presents the Cauchy integral theorem for general integration paths—he assumes the function being integrated has a continuous derivative
1825	Augustin-Louis Cauchy introduces the theory of residues
1825	Peter Dirichlet and Adrien Legendre prove Fermat's Last Theorem for n=5
1828	George Green proves Green's theorem
1829	Nikolai Lobachevski publishes his work on hyperbolic non-Euclidean geometry
1832	Évariste Galois presents a general condition for the solvability of algebraic equations
1832	Peter Dirichlet proves Fermat's Last Theorem for n=14
1837	Pierre Wantsel proves that doubling the cube and trisecting the angle are impossible with only a compass and straightedge
1841	Karl Weierstrass discovers but does not publish the Laurent expansion theorem
1843	Pierre-Alphonse Laurent discovers and presents the Laurent expansion theorem
1843	William Hamilton discovers the calculus of quaternions and deduces that they are non-commutative
1847	George Boole formalizes symbolic logic in *The Mathematical Analysis of Logic*
1849	George Stokes shows that solitary waves can arise from a combination of periodic waves
1850	Alexandre Puiseux distinguishes between poles and branch points and introduces the concept of essential singular points
1850	George Stokes proves Stokes' theorem
1854	Bernhard Riemann introduces Riemannian geometry
1854	Arthur Cayley shows that quaternions can be used to represent rotations in four-dimensional space
1858	August Möbius invents the Möbius strip
1870	Felix Klein constructs an analytic geometry for Lobachevski's geometry thereby establishing its self-consistency and the logical independence of Euclid's fifth postulate
1873	Charles Hermite proves that e is transcendental
1878	Charles Hermite solves the general quintic equation by means of elliptic and modular functions
1873	Georg Frobenius presents his method for finding series solutions to linear differential equations with regular singular points
1882	Ferdinand Lindeman proves that π is transcendental and that the circle cannot be squared with a compass and straightedge
1882	Felix Klein invents the Klein bottle
1895	Diederik Korteweg and Gustav de Vries derive the KdV equation to describe the development of long solitary water waves in a canal of rectangular cross section
1896	Jacques Hadamard and Charles de La Vallée-Poussin independently prove the prime number theorem
1899	David Hilbert presents a set of self-consistent geometric axioms in *Foundations of Geometry*
1900	David Hilbert states his list of 23 problems which show where further mathematical work is needed
1901	Élie Cartan develops the exterior derivative
1903	C. Runge presents a fast Fourier transform algorithm
1908	Ernst Zermelo axiomatizes set theory
1912	L.E.J. Brouwer presents the Brouwer fixed-point theorem

1914 Srinivasa Ramanujan publishes *Modular Equations and Approximations to* π
1928 John von Neumann begins devising the principles of game theory and proves the minimax theorem
1930 Casimir Kuratowski shows that the three cottage problem has no solution
1931 Kurt Gödel shows that mathematical systems are not fully self-contained
1933 Karol Borsuk and Stanislaw Ulam present the Borsuk-Ulam antipodal-point theorem
1942 G.C. Danielson and Cornelius Lanczos develop a fast Fourier transform algorithm
1943 Kenneth Levenberg proposes a method for nonlinear least squares fitting
1948 John von Neumann mathematically studies self-reproducing machines
1949 John von Neumann computes π to 2,037 decimal places using ENIAC
1950 Stanislaw Ulam and John von Neumann present cellular automata dynamical systems
1953 Nicholas Metropolis introduces the idea of thermodynamic simulated annealing algorithms
1955 Enrico Fermi, John Pasta, and Stanislaw Ulam numerically study a nonlinear spring model of heat conduction and discover solitary wave type behavior
1960 C.A.R. Hoare invents the quicksort algorithm
1960 Irving Reed and Gustave Solomon present the Reed-Solomon error-correcting code
1961 Daniel Shanks and John Wrench compute π to 100,000 decimal places using an inverse-tangent identity and an IBM-7090 computer
1962 Donald Marquardt proposes the Levenberg-Marquardt nonlinear least squares fitting algorithm
1963 Martin Kruskal and Norman Zabusky analytically study the Fermi-Pasta-Ulam heat conduction problem in the continuum limit and find that the KdV equation governs this system
1965 Martin Kruskal and Norman Zabusky numerically study colliding solitary waves in plasmas and find that they do not disperse after collisions
1965 James Cooley and John Tukey present an influential fast Fourier transform algorithm
1966 E.J. Putzer presents two methods for computing the exponential of a matrix in terms of a polynomial in that matrix
1976 Kenneth Appel and Wolfgang Haken use a computer to solve the four-color problem
1983 Gerd Faltings proves the Mordell Conjecture and thereby shows that there are only finitely many whole number solutions for each exponent of Fermat's Last Theorem
1985 Louis de Branges proves the Bieberbach Conjecture
1987 Yasumasa Kanada, David Bailey, Jonathan Borwein, and Peter Borwein use iterative modular equation approximations to elliptic integrals and a NEC SX-2 supercomputer to compute π to 134 million decimal places
1993 Andrew Wiles proves part of the Taniyama-Shimura Conjecture and thereby proves Fermat's Last Theorem

Geology

1620 Francis Bacon notices the jigsaw fit of the opposite shores of the Atlantic Ocean
1701 Edmund Halley suggests using the salinity and evaporation of the Mediterranean to determine the age of the Earth
1837 Louis Agassiz begins his glaciation studies which eventually demonstrate that the Earth has had at least one Ice Age
1862 Lord Kelvin attempts to find the age of the Earth by examining its cooling time and estimates that the Earth is between 20–400 million years old
1903 George Darwin and John Joly claim that radioactivity is partially responsible for the Earth's heat
1907 Bertram Boltwood proposes that the amount of lead in uranium and thorium ores might be used to determine the Earth's age and crudely dates some rocks to have ages between 410–2200 million years
1912 Alfred Wegener proposes that all the continents once formed a single landmass called Pangaea that broke apart via continental drift
1913 Albert Michelson measures tides in the solid body of the Earth
1935 Charles Richter invents a logarithmic scale to measure the intensity of earthquakes
1953 Maurice Ewing and Bruce Heezen discover the Great Global Rift running along the Mid-Oceanic Ridge
1960 Harry Hess proposes that new sea floor might be created at mid-ocean rifts and destroyed at deep sea trenches
1963 F.J. Vine and D.H. Matthews explain the stripes of magnetized rocks with alternating magnetic polarities running parallel to mid-ocean ridges as due to sea floor spreading and the periodic geomagnetic field reversals

Geography, Meteorology, Paleontology, Science Philosophy, and Science Publishing

25 Pomponius Mela formalizes the climatic zone system
1569 Gerardus Mercator issues the first Mercator projection map
1620 Francis Bacon analyzes the scientific method in his *Great Instauration of Learning*
1686 Edmund Halley presents a systematic study of the trade winds and monsoons and identifies solar heating as the cause of atmospheric motions
1686 Edmund Halley establishes the relationship between barometric pressure and height above sea level
1716 Edmund Halley suggests that aurorae are caused by 'magnetic effluvia' moving along the Earth's magnetic field lines
1822 Gideon Mantell discovers the fossilized skeleton of an iguanodon dinosaur
1869 Joseph Lockyer starts the scientific journal *Nature*
1909 Discovery of the Burgess Shale Cambrian fossil site
1920 Andrew Douglass proposes dendrochronology dating
1920 Milutin Milankovich proposes that long term climatic cycles may be due to changes in the eccentricity of the Earth's orbit and changes in the Earth's obliquity
1947 Willard Libby introduces carbon-14 dating
1949 Edward Murphy states his law
1974 Donald Johanson and Tom Gray discover a 3.5 million-year-old female hominid fossil that is 40% complete and name it 'Lucy'
1980 Luis Alvarez, Walter Alvarez, Frank Asaro, and Helen Michel propose that a giant comet or asteroid may have struck the Earth approximately 65 million years ago thereby causing massive extinctions and enriching the iridium in the K-T layer
1984 Hou Xianguang discovers the Chengjiang Cambrian fossil site

Agriculture and Food Technology

-1800 Fermentation of dough, grain, and fruit juices is discovered
600 The moldboard plow is invented in eastern Europe
850 Coffee is invented in Arabia
1300 Arnau de Villanova develops alcohol distillation

Clothing and Textiles Technology

1733 John Kay patents the flying shuttle loom
1764 James Hargreaves invents the spinning jenny
1794 Eli Whitney patents the cotton gin
1801 Joseph-Marie Jacquard invents the Jacquard punched card loom
1856 William Perkin invents the first synthetic dye

Motor and Engine Technology

1698 Thomas Savery builds a steam-powered water pump for pumping water out of mines
1712 Thomas Newcomen builds a piston-and-cylinder steam-powered water pump for pumping water out of mines
1769 James Watt patents his first improved steam engine
1821 Michael Faraday builds an electricity-powered motor
1876 Nikolaus Otto designs a four-stroke internal-combustion engine
1888 Nikola Tesla patents the induction motor

Transportation Technology

-3500 Wheeled carts are invented
-3500 River boats are invented
-2000 Horses are tamed and used for transport
770 Iron horseshoes come into common use
1492 Leonardo da Vinci describes a flying machine

1662 Blaise Pascal invents a horse-drawn public bus which has a regular route, schedule, and fare system
1740 Jacques de Vaucanson demonstrates his clockwork powered carriage
1783 Joseph Montgolfier and Étienne Montgolfier launch the first hot air balloons
1801 Richard Trevithick builds a prototype steam powered railroad locomotive
1807 Isaac de Rivas makes a hydrogen gas powered vehicle
1814 George Stephenson builds the first practical steam powered railroad locomotive
1862 Jean Lenoir makes a gasoline-engine automobile
1868 George Westinghouse invents the compressed air locomotive brake
1900 Ferdinand von Zeppelin builds the first successful dirigible
1903 Orville Wright and Wilbur Wright fly the first motor-driven airplane
1908 Henry Ford develops the assembly line method of automobile manufacturing
1947 First supersonic flight
1969 First manned mission to the Moon
1981 First flight of the space shuttle

Underwater Technology

1716 Edmund Halley builds a diving bell
1801 Robert Fulton builds the first submarine
1819 Augustus Siebe invents a diving suit which receives air pumped down from the surface
1934 Charles Beebe dives to 3,028 feet using a bathysphere
1943 Jacques-Yves Cousteau makes the first dive with a compressed-air aqualung

Communication Technology

-3500 The Sumerians develop cuneiform writing and the Egyptians develop hieroglyphic writing
-1500 The Phoenicians develop an alphabet
-170 Parchment is discovered in Pergamum
105 Tsai Lun invents paper
350 The Chinese develop a method for printing pages using symbols carved on a wooden block
1450 The Chinese develop wooden block movable type printing
1454 Johannes Gutenberg finishes a printing press with metal movable type
1793 Claude Chappe establishes the first long-distance semaphore telegraph line
1831 Joseph Henry proposes and builds an electric telegraph
1835 Samuel Morse develops the Morse code
1843 Samuel Morse builds the first long distance electric telegraph line
1876 Alexander Graham Bell and Thomas Watson exhibit an electric telephone
1877 Thomas Edison patents the phonograph
1889 Almon Strowger patents the direct dial telephone
1901 Guglielmo Marconi transmits radio signals from Cornwall to Newfoundland
1925 John Baird transmits the first television signal
1958 Chester Carlson presents the first photocopier suitable for office use
1966 Charles Kao realizes that silica-based waveguides offer a practical way to transmit light via total internal reflection
1973 Akira Hasegawa and Fred Tappert propose the use of solitary waves to carry information in optical fibers
1977 Donald Knuth begins work on $\TeX$
1980 Linn Mollenauer, Rogers Stollen, and James Gordon demonstrate that solitary waves can be propagated through optical fibers
1991 Anders Olsson transmits solitary waves through an optical fiber with a data rate of 32 billion bits per second

Photography Technology

1826 Joseph Niépce takes the first permanent photograph
1891 Thomas Edison patents the 'kinetoscopic camera'
1973 Fairchild Semiconductor releases the first large image forming CCD chip—100 rows and 100 columns

Calculator and Computer Technology

1617 John Napier discusses the Napier's bones calculating method in *Rabdologia*
1622 William Oughtred invents the slide rule
1623 Wilhelm Schickard builds his 6-digit 'Calculating Clock' that can add and subtract
1645 Blaise Pascal completes his 5-digit 'Pascaline' that can add
1930 Vannevar Bush builds a partly electronic computer capable of solving differential equations
1946 Presper Eckert and John Mauchly announce ENIAC, the first practical entirely electronic computer
1948 William Shockley, Walter Brattain, and John Bardeen invent the transistor
1950 Alan Turing proposes the 'Turing test' criterion for an intelligent machine
1951 Presper Eckert and John Mauchly finish UNIVAC I, the first mass-produced electronic computer
1971 Texas Instruments releases the first easily portable electronic calculator
1977 Apple Computer releases the Apple II personal computer

Time Measurement Technology

-270 Ctesibius builds a popular water clock
-46 Julius Caesar and Sosigenes develop a solar calendar with leap years
1502 Peter Henlein builds the first pocketwatch
1582 Pope Gregory XIII, Aloysius Lilius, and Christopher Clavius introduce a Gregorian calendar with an improved leap year system
1656 Christian Huygens builds the first accurate pendulum clock
1737 John Harrison presents the first stable nautical chronometer, thereby allowing for precise longitude determination while at sea
1928 Joseph Horton and Warren Morrison build the first quartz crystal oscillator clock
1946 Felix Bloch and Edward Purcell develop nuclear magnetic resonance
1949 Harold Lyons develops an atomic clock based on the quantum mechanical vibrations of the ammonia molecule

Temperature and Pressure Measurement Technology

1592 Galileo Galilei builds a crude thermometer using the contraction of air to draw water up a tube
1643 Evangelista Torricelli invents the mercury barometer
1714 Gabriel Fahrenheit invents the mercury in glass thermometer
1864 Antoine Becquerel suggests an optical pyrometer
1892 Henri-Louis Le Châtelier builds the first optical pyrometer

Microscope Technology

1590 Zacharias Janssen invents the microscope
1674 Anton van Leeuwenhoek invents the compound microscope
1932 Ernst Ruska builds the first electron microscope

Low Temperature Technology

1891 Z.F. Wroblewski condenses experimentally useful quantities of liquid air
1892 James Dewar invents the vacuum-insulated, silver-plated glass Dewar
1908 Heike Kammerlingh Onnes liquifies helium

Rocket and Missile Technology

1926 Robert Goddard launches the first liquid fuel rocket
1944 Wernher von Braun and Walter Dornberger launch the first V2 rocket

1958 Launch of the first ICBM

Materials Technology

-4000 Copper metallurgy is invented and copper is used for ornamentation
-3000 Bronze is used for weapons and armor
-1500 The Hittites develop crude iron metallurgy
-1200 Invention of steel when iron and charcoal are combined properly
700 Porcelain is invented in China
1839 Charles Goodyear invents vulcanized rubber
1909 Leo Baekeland presents the Bakelite hard thermosetting plastic
1931 Julius Nieuwland develops the synthetic rubber neoprene
1931 Wallace Carothers develops nylon
1953 Karl Ziegler discovers metallic catalysts which greatly improve the strength of polyethylene polymers

Lighting Technology

-3000 Candles are invented
1815 Humphry Davy invents the miner's safety lamp
1879 Thomas Edison patents the carbon-thread incandescent lamp

General Technology

-7000 Pottery is invented
-700 Invention of aqueducts
-640 Invention of coins
-400 Catapults are invented in Syracuse
-150 Hipparchus invents the astrolabe
-100 Glass-blowing is discovered in Syria
700 Windmills are invented in Persia
1050 Crossbows are invented in France
1249 Roger Bacon states formulas for gunpowder
1346 Cannon come into wide use
1480 Martin Behaim introduces the nautical astrolabe
1480 Leonardo da Vinci describes a workable parachute
1645 Otto von Guericke builds the first vacuum pump
1731 John Hadley invents the sextant
1800 Alessandro Volta announces his invention of the electric battery
1823 William Sturgeon invents the electromagnet
1840 Justus von Liebig invents artificial fertilizer
1867 Alfred Nobel patents dynamite
1880 John Milne invents the seismograph
1885 William Stanley invents the alternating current transformer
1903 Konstantin Tsiolkovsky begins a series of papers discussing the use of rocketry to reach outer space, space suits, and colonization of the solar system
1917 Paul Langevin develops a sonar echolocation system
1925 Theodor Svedberg develops the ultra-centrifuge, thereby revolutionizing the determination of molecular weights
1935 Robert Watson-Watt devises a microwave radar
1945 First nuclear fission bomb exploded at the Trinity test site, about sixty miles northwest of Alamogordo, New Mexico
1952 First thermonuclear fusion bomb exploded
1952 Wernher von Braun discusses the technical details of a manned exploration of Mars in *The Mars Project*
1953 Charles Townes makes the first maser
1954 Construction of the first nuclear power reactor
1960 Theodore Maiman makes the first laser