

# 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 differential 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 perturbations 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 Pelerin 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

- 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 equilibrium 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 Kamerlingh 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 Mendeleev 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 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 paraffin

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 Rethford measure the Lamb-Rethford 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  $J/\psi$  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

- 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 Nordström 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-Nordström 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 Lemaitre 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 Lemaitre 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

- 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 Shethman 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

- 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 Reifeinstein, William Cocks, 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 Zytow present a detailed analysis of Thorne-Zytow 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 Fabricius 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 Pigott 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 Kirchhoff 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

- 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 Rømer 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 Opik 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

- 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 aperture 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 1* 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 1* and *Viking 2* 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



- 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 Oro 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  $\phi$ X174 — 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 Buckminsterfullerene molecule and deduce its structure
- 1990 Wolfgang Krätschmer, Lowell Lamb, Konstantinos Fotiropoulos, and Donald Huffman discover that Buckminsterfullerene 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-Nafis 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 anesthesia
- 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 diphtheria 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 chemotherapeutic cure for sleeping sickness
- 1921 Edward Mellanby discovers vitamin D and shows that its absence causes rickets

## 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  $\pi$  to two decimal places using inscribed and circumscribed 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 K'eng-Chih compute  $\pi$  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  $\pi$  to sixteen decimal places using inscribed and circumscribed 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  $\pi$  to twenty decimal places using inscribed and circumscribed 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  $\pi$  and computes  $\pi$  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 Wantzel 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  $\pi$  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

- 1914 Srinivasa Ramanujan publishes *Modular Equations and Approximations to  $\pi$*
- 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  $\pi$  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  $\pi$  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  $\pi$  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

- 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  $\text{\TeX}$
- 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 Kamerlingh Onnes liquifies helium

#### **Rocket and Missile Technology**

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