

APPENDIX A

Astronomical data

Body	Mass/kg	Radius/m	Orbit radius/m (average)	Orbital period
Sun	1.99×10^{30}	6.96×10^8	–	–
Moon	7.35×10^{22}	1.74×10^6	3.84×10^8	27.3 days
Mercury	3.30×10^{23}	2.44×10^6	5.79×10^{10}	88.0 days
Venus	4.87×10^{24}	6.05×10^6	1.08×10^{11}	224.7 days
Earth	5.98×10^{24}	6.38×10^6	1.50×10^{11}	365.3 days
Mars	6.42×10^{23}	3.40×10^6	2.28×10^{11}	687.0 days
Jupiter	1.90×10^{27}	6.91×10^7	7.78×10^{11}	11.86 yr
Saturn	5.69×10^{26}	6.03×10^7	1.43×10^{12}	29.42 yr
Uranus	8.66×10^{25}	2.56×10^7	2.88×10^{12}	83.75 yr
Neptune	1.03×10^{26}	2.48×10^7	4.50×10^{12}	163.7 yr
Pluto*	1.5×10^{22}	1.15×10^6	5.92×10^{12}	248.0 yr

Luminosity of the sun

$L = 3.9 \times 10^{26} \text{ W}$

Distance to nearest star (Proxima Centauri)

$4 \times 10^{16} \text{ m}$ (approx. 4.3 ly)

Diameter of the Milky Way

10^{21} m (approx. 100 000 ly)

Mass of the Milky Way

$4 \times 10^{41} \text{ kg}$

Distance to nearest galaxy (Andromeda)

$2 \times 10^{22} \text{ m}$ (approx. 2.3 million ly)

*Pluto has recently been downgraded into a new category of ‘dwarf planet’ (see Option D, Astrophysics).

APPENDIX B

Nobel prize winners in physics

No awards were made in years not listed.

2013: The prize was awarded jointly to François Englert and Peter W. Higgs “for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”

2012: The prize was awarded jointly to Serge Haroche and David J. Wineland “for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems”

2011: Half the prize was awarded to Saul Perlmutter, and the other half jointly to Brian P. Schmidt and Adam G. Riess “for the discovery of the accelerating expansion of the Universe through observations of distant supernovae”

2010: The prize was awarded jointly to Andre Geim and Konstantin Novoselov “for groundbreaking experiments regarding the two-dimensional material graphene”

2009: Half the prize was awarded to Charles Kuen Kao “for groundbreaking achievements concerning the transmission of light in fibers for optical communication” and the other half jointly to Willard S. Boyle and George E. Smith “for the invention of an imaging semiconductor circuit – the CCD sensor”

2008: Half the prize was awarded to Yoichiro Nambu “for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics” and the other half jointly Makoto Kobayashi and Toshihide Maskawa “for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature”

2007: The prize was awarded jointly to Albert Fert and Peter Grünberg “for the discovery of Giant Magnetoresistance”

2006: The prize was awarded jointly to John C. Mather and George F. Smoot (both USA) for their discovery of the black-body form and anisotropy of the cosmic microwave background radiation.

2005: Half the prize was awarded to Roy J. Glauber (USA) for his contribution to the quantum theory of optical coherence, and the other half was awarded jointly to John L. Hall (USA) and Theodor W. Hänsch (Germany) for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique.

2004: The prize was awarded jointly to D.J. Gross, H. D. Politzer and F. Wilczek (all USA) for their discovery of asymptotic freedom in quantum chromodynamics.



2003: The prize was awarded jointly to Alexei Abrikosov (Russia and USA), Vitaly Ginzburg (Russia) and Anthony Leggett (UK and USA) for pioneering contributions to the theory of superconductors and superfluids.

2002: Half the prize was awarded jointly to Raymond Davis Jr (USA) and Masatoshi Koshiba (Japan), and the other half was awarded to Riccardo Gianconi (USA) for pioneering contributions to astrophysics, particularly for the detection of cosmic neutrinos.

2001: The prize was awarded jointly to Eric Cornell (USA), Wolfgang Ketterle (Germany) and Carl Wieman (USA) for the achievement of Bose–Einstein condensation in dilute alkali gases and for early fundamental studies of the properties of the condensates.

2000: Half the prize was awarded jointly to Zhores I. Alferov (Russia) and Herbert Kroemer (USA) for developing semiconductor heterostructures used in high-speed and optoelectronics, and the other half was awarded to Jack St. Clair Kilby (USA) for his part in the invention of the integrated circuit.

1999: The prize was awarded jointly to Gerardus 't Hooft and Martinus J. G. Veltman (both Netherlands) for elucidating the quantum structure of electroweak interactions in physics.

1998: The prize was awarded jointly to Robert B. Laughlin (USA), Horst L. Stormer (Germany) and Daniel C. Tsui (USA) for their discovery of a new form of quantum fluid with fractionally charged excitations.

1997: The prize was awarded jointly to Steven Chu (USA), Claude Cohen-Tannoudji (France) and William D. Phillips (USA) for development of methods to cool and trap atoms with laser light.

1996: The prize was awarded jointly to David M. Lee, Douglas D. Osheroff and Robert C. Richardson (all USA) for their discovery of superfluidity in helium-3.

1995: The prize was awarded for pioneering experimental contributions to lepton physics, with half to Martin L. Perl (USA) for the discovery of the tau lepton, and the other half to Frederick Reines (USA) for the detection of the neutrino.

1994: The prize was awarded jointly to Bertram N. Brockhouse (Canada) and Clifford G. Shull (USA) for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter: Brockhouse for the development of neutron spectroscopy, and Shull for the development of the neutron diffraction technique.

1993: The prize was awarded jointly to Russell A. Hulse and Joseph H. Taylor Jr (both USA) for the discovery of a new type of pulsar – a discovery that has opened up new possibilities for the study of gravitation.

1992: Georges Charpak (France) for his invention and development of particle detectors, in particular the multiwire proportional chamber.

1991: Pierre-Gilles de Gennes (France) for discovering that methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter, in particular to liquid crystals and polymers.

1990: The prize was awarded jointly to Jerome I. Friedman, Henry W. Kendall (both USA) and Richard E. Taylor (Canada) for their pioneering investigations concerning deep inelastic scattering of electrons on protons and bound neutrons, which have been of essential importance for the development of the quark model in particle physics.

1989: Half of the prize was awarded to Norman F. Ramsey (USA) for the invention of the separated oscillatory fields method and its use in the hydrogen maser and other atomic clocks, and the other half was awarded jointly to Hans G. Dehmelt (USA) and Wolfgang Paul (Germany) for the development of the ion trap technique.

1988: The prize was awarded jointly to Leon M. Lederman, Melvin Schwartz and Jack Steinberger (all USA) for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino.

1987: The prize was awarded jointly to J. Georg Bednorz (Germany) and K. Alexander Müller (Switzerland) for their important breakthrough in the discovery of superconductivity in ceramic materials.

1986: Half of the prize was awarded to Ernst Ruska (Germany) for his fundamental work in electron optics and for the design of the first electron microscope, and the other half was awarded jointly to Gerd Binnig (Germany) and Heinrich Rohrer (Switzerland) for their design of the scanning tunnelling microscope.

1985: Klaus von Klitzing (Germany) for the discovery of the quantized Hall effect.

1984: The prize was awarded jointly to Carlo Rubbia (Italy) and Simon van der Meer (Netherlands) for their decisive contributions to the large project that led to the discovery of the field particles W and Z, communicators of the weak interaction.

1983: The prize was divided equally between Subrahmanyan Chandrasekhar (USA) for his theoretical studies of the physical processes of importance to the structure and evolution of the stars, and William A. Fowler (USA) for his theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe.

1982: Kenneth G. Wilson (USA) for his theory for critical phenomena in connection with phase transitions.

1981: Half the prize was awarded jointly to Nicolaas Bloembergen and Arthur L. Schawlow (both USA) for their contribution to the development of laser spectroscopy, and the other half was awarded to Kai M. Siegbahn (Sweden) for his contribution to the development of high-resolution electron spectroscopy.

1980: The prize was divided equally between James W. Cronin and Val L. Fitch (both USA) for the discovery of violations of fundamental symmetry principles in the decay of neutral K-mesons.



1979: The prize was divided equally between Sheldon L. Glashow (USA), Abdus Salam (Pakistan) and Steven Weinberg (USA) for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, among other things, the prediction of the weak neutral current.

1978: Half the prize was awarded to Pyotr Leonidovich Kapitsa (USSR) for his basic inventions and discoveries in the area of low-temperature physics, and the other half was divided equally between Arno A. Penzias and Robert W. Wilson (both USA) for their discovery of cosmic microwave background radiation.

1977: The prize was divided equally between Philip W. Anderson (USA), Sir Nevill F. Mott (UK) and John H. van Vleck (USA) for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems.

1976: The prize was divided equally between Burton Richter and Samuel C. C. Ting (both USA) for their pioneering work in the discovery of a heavy elementary particle of a new kind.

1975: The prize was awarded jointly to Aage Bohr, Ben Mottelson (both Denmark) and James Rainwater (USA) for the discovery of the connection between collective motion and particle motion in atomic nuclei, and the development of the theory of the structure of the atomic nucleus based on this connection.

1974: The prize was awarded jointly to Sir Martin Ryle and Antony Hewish (both UK) for their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars.

1973: Half the prize was equally shared between Leo Esaki (Japan) and Ivar Giaever (USA) for their experimental discoveries regarding tunnelling phenomena in semiconductors and superconductors, respectively, and the other half was awarded to Brian D. Josephson (UK) for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena that are generally known as the Josephson effects.

1972: The prize was awarded jointly to John Bardeen, Leon N. Cooper and J. Robert Schrieffer (all USA) for their jointly developed theory of superconductivity, usually called the BCS theory.

1971: Dennis Gabor (UK) for his invention and development of the holographic method.

1970: The prize was divided equally between Hannes Alfvén (Sweden) for fundamental work and discoveries in magneto-hydrodynamics with fruitful applications in different parts of plasma physics, and Louis Néel (France) for fundamental work and discoveries concerning antiferromagnetism and ferromagnetism, which have led to important applications in solid state physics.

1969: Murray Gell-Mann (USA) for his contributions and discoveries concerning the classification of elementary particles and their interactions.

1968: Luis W. Alvarez (USA) for his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using a hydrogen bubble chamber and data analysis.

1967: Hans Albrecht Bethe (USA) for his contributions to the theory of nuclear reactions, especially his discoveries concerning energy production in stars.

1966: Alfred Kastler (France) for the discovery and development of optical methods for studying hertzian resonances in atoms.

1965: The prize was awarded jointly to Sin-Itiro Tomonaga (Japan), Julian Schwinger and Richard P. Feynman (both USA) for their fundamental work in quantum electrodynamics, with far-reaching consequences for the physics of elementary particles.

1964: Half the prize was awarded to Charles H. Townes (USA) and the other half was awarded jointly to Nicolay Gennadiyevich Basov and Aleksandr Mikhailovich Prokhorov (both USSR) for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser–laser principle.

1963: Half the prize was awarded to Eugene P. Wigner (USA) for his contributions to the theory of the atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles, and the other half was awarded jointly to Maria Goeppert-Mayer (USA) and J. Hans D. Jensen (Germany) for their discoveries concerning nuclear shell structure.

1962: Lev Davidovich Landau (USSR) for his pioneering theories for condensed matter, especially liquid helium.

1961: The prize was divided equally between Robert Hofstadter (USA) for his pioneering studies of electron scattering in atomic nuclei and for his thereby achieved discoveries concerning the structure of the nucleons, and Rudolf Ludwig Mössbauer (Germany) for his researches concerning the resonance absorption of gamma radiation and his discovery in this connection of the effect which bears his name.

1960: Donald A. Glaser (USA) for the invention of the bubble chamber.

1959: The prize was awarded jointly to Emilio Gino Segre and Owen Chamberlain (both USA) for their discovery of the antiproton.

1958: The prize was awarded jointly to Pavel Alekseyevich Cherenkov, Il'ja Mikhailovich Frank and Igor Yevgenyevich Tamm (all USSR) for the discovery and the interpretation of the Cherenkov effect.

1957: The prize was awarded jointly to Chen Ning Yang and Tsung-Dao Lee (both China) for their penetrating investigation of the so-called parity laws, which has led to important discoveries regarding the elementary particles.

1956: The prize was awarded jointly, one-third each, to William Shockley, John Bardeen and Walter Houser Brattain (all USA) for their researches on semiconductors and their discovery of the transistor effect.



1955: The prize was divided equally between Willis Eugene Lamb (USA) for his discoveries concerning the fine structure of the hydrogen spectrum and Polykarp Kusch (USA) for his precision determination of the magnetic moment of the electron.

1954: The prize was divided equally between Max Born (UK) for his fundamental research in quantum mechanics, especially for his statistical interpretation of the wavefunction, and Walther Bothe (Germany) for the coincidence method and his discoveries made using this method.

1953: Frits (Frederik) Zernike (Netherlands) for his demonstration of the phase contrast method, especially for his invention of the phase contrast microscope.

1952: The prize was awarded jointly to Felix Bloch and Edward Mills Purcell (both USA) for their development of new methods for nuclear magnetic precision measurements and discoveries made using these methods.

1951: The prize was awarded jointly to Sir John Douglas Cockcroft (UK) and Ernest Thomas Sinton Walton (Ireland) for their pioneering work on the transmutation of atomic nuclei by artificially accelerated atomic particles.

1950: Cecil Frank Powell (UK) for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method.

1949: Hideki Yukawa (Japan) for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces.

1948: Lord Patrick Maynard Stuart Blackett (UK) for his development of the Wilson cloud chamber method, and his discoveries using this method in the fields of nuclear physics and cosmic radiation.

1947: Sir Edward Victor Appleton (UK) for his investigations of the physics of the upper atmosphere, especially for the discovery of the so-called Appleton layer.

1946: Percy Williams Bridgman (USA) for the invention of an apparatus to produce extremely high pressures, and for the discoveries he made using this apparatus in the field of high-pressure physics.

1945: Wolfgang Pauli (Austria) for the discovery of the exclusion principle, also called the Pauli principle.

1944: Isidor Isaac Rabi (USA) for his resonance method for recording the magnetic properties of atomic nuclei.

1943: Otto Stern (USA) for his contribution to the development of the molecular ray method and his discovery of the magnetic moment of the proton.

1939: Ernest Orlando Lawrence (USA) for the invention and development of the cyclotron and for results obtained with it, especially with regard to artificial radioactive elements.

1938: Enrico Fermi (Italy) for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons.

1937: The prize was awarded jointly to Clinton Joseph Davisson (USA) and Sir George Paget Thomson (UK) for their experimental discovery of the diffraction of electrons by crystals.

1936: The prize was divided equally between Victor Franz Hess (Austria) for his discovery of cosmic radiation, and Carl David Anderson (USA) for his discovery of the positron.

1935: Sir James Chadwick (UK) for the discovery of the neutron.

1933: The prize was awarded jointly to Erwin Schrödinger (Austria) and Paul Adrien Maurice Dirac (UK) for the discovery of new productive forms of atomic theory.

1932: Werner Heisenberg (Germany) for the creation of quantum mechanics, the application of which has, among other things, led to the discovery of the allotropic forms of hydrogen.

1930: Sir Chandrasekhara Venkata Raman (India) for his work on the scattering of light and for the discovery of the effect named after him.

1929: Prince Louis-Victor de Broglie (France) for his discovery of the wave nature of electrons.

1928: Sir Owen Willans Richardson (UK) for his work on the thermionic phenomenon, and especially for the discovery of the law named after him.

1927: The prize was divided equally between Arthur H. Compton (USA) for his discovery of the effect named after him, and Charles Thomson Rees Wilson (USA) for his method of making the paths of electrically charged particles visible by condensation of vapour.

1926: Jean B. Perrin (France) for his work on the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium.

1925: The prize was awarded jointly to James Franck and Gustav Hertz (Germany) for their discovery of the laws governing the impact of an electron upon an atom.

1924: Karl Manne Georg Siegbahn (Sweden) for his discoveries and research in the field of X-ray spectroscopy.

1923: Robert Andrews Millikan (USA) for his work on the elementary charge of electricity and on the photoelectric effect.

1922: Niels Bohr (Denmark) for his services in the investigation of the structure of atoms and of the radiation emanating from them.

1921: Albert Einstein (Germany) for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect.

1920: Charles Edouard Guillaume (Switzerland) in recognition of the service he has rendered to precision measurements in physics by his discovery of anomalies in nickel–steel alloys.

1919: Johannes Stark (Germany) for his discovery of the Doppler effect in canal rays and the splitting of spectral lines in electric fields.

1918: Max Karl Ernst Ludwig Planck (Germany) in recognition of the services he rendered to the advancement of physics by his discovery of energy quanta.



1917: Charles Glover Barkla (UK) for his discovery of the characteristic Röntgen radiation of the elements.

1915: The prize was awarded jointly to Sir William Henry Bragg and Sir William Lawrence Bragg (both UK) for their services in the analysis of crystal structure by means of X-rays.

1914: Max von Laue (Germany) for his discovery of the diffraction of X-rays by crystals.

1913: Heike Kamerlingh-Onnes (Netherlands) for his investigations on the properties of matter at low temperatures, which led, among other things, to the production of liquid helium.

1912: Nils Gustaf Dalén (Sweden) for his invention of automatic regulators for use in conjunction with gas accumulators for illuminating lighthouses and buoys.

1911: Wilhelm Wien (Germany) for his discoveries regarding the laws governing the radiation of heat.

1910: Johannes Diderik van der Waals (Netherlands) for his work on the equation of state for gases and liquids.

1909: The prize was awarded jointly to Guglielmo Marconi (Italy) and Carl Ferdinand Braun (Germany) in recognition of their contributions to the development of wireless telegraphy.

1908: Gabriel Lippmann (France) for his method of reproducing colours photographically based on the phenomenon of interference.

1907: Albert Abraham Michelson (USA) for his optical precision instruments and the spectroscopic and metrological investigations carried out with their aid.

1906: Sir Joseph John Thomson (UK) in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases.

1905: Philipp Eduard Anton Lenard (Netherlands) for his work on cathode rays.

1904: Lord John William Strutt Rayleigh (UK) for his investigations of the densities of the most important gases and for his discovery of argon in connection with these studies.

1903: Half the prize was awarded to A. Henri Becquerel (France) in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity, and the other half was awarded jointly to Pierre and Marie Curie (France) in recognition of the extraordinary services they rendered by their joint researches on the radiation phenomena discovered by Henri Becquerel.

1902: The prize was awarded jointly to Hendrik A. Lorentz and Pieter Zeeman (both Netherlands) in recognition of the extraordinary service they rendered by their researches into the influence of magnetism upon radiation phenomena.

1901: Wilhelm K. Röntgen (Germany) in recognition of the extraordinary services he rendered by the discovery of the remarkable rays subsequently named after him.