

07/23/15 **Particles and People** rickdower@gmail.com

Year	People	Particle	Observation	Theory	Nobel Prize
ATOMS VS. CONTINUUM					
5 th cen. B.C.	Democritus	Uncuttable atoms		Atoms and vacuum	
350 B.C.	Aristotle	Earth, Water, Air, Fire, Aether		No atoms, matter continuous and space-filling.	
1644	R. Descartes	Continuum		Continuous space-filling matter	
1704	I. Newton	Atoms		Matter made of hard, massy particles	
1738	D. Bernoulli	Kinetic atoms	Gases exert pressure	Elastic collisions produce pressure.	
1745	R. Boscovic	Atoms exert forces	Solids stick together, but resist squeezing	Atoms as centers of force, $F(r)$.	
1805	J. Dalton	Chemical atoms	Constant proportions, multiple proportions	Chemical compounds are made of simple ratios of atoms.	
1834	M. Faraday	Electrical atoms	Quantity of material produced in electrolysis proportional to charge		
1866, 1877	J. C. Maxwell, L. Boltzmann, others	Kinetic atoms		Temperature measures avg. molecular kinetic energy.	
NATURAL RADIOACTIVITY, ATOMIC STRUCTURE					
1895	W. Röntgen	x-ray (photon)	Penetrating radiation, photo emulsions		1901 – 1 st Nobel Prize
1897	J. J. Thomson	Cathode rays (electrons) in atoms	m_e/q_e	Raisin pudding model of atoms	1906
1898	Marie and Pierre Curie	New elements	New radioactive elements Po, Ra. Radioactivity ionizes air.		1903 - M&P Physics; 1911 - Marie Chemistry
1899	E. Rutherford	α , β rays from uranium			

1900	P. Villard, H. Becquerel	γ radiation from radium	Photographic emulsion		1903 - Becquerel
early 1900s	Rutherford and Frederick Soddy		Radioactive atoms can transmute		1921 – Soddy - Chemistry
1903	E. Rutherford	α , β , γ rays	Order of penetrating power; $q_\alpha = +2q_e$		1908 - Chemistry
1905	A. Einstein	photon	Photoelectric effect	$E = hf$ for photon	1921
1905	A. Einstein	atoms	Brownian motion	SR; $E = mc^2$	
1908	E. Rutherford	α particles are He nuclei, $m_\alpha = 4$ u	He collected from α emitted into vacuum		
1909	J. Stark	γ -ray carries E and p			1919
1911	R. Millikan	Elementary charge	$q_e =$ 1.6×10^{-19} C	Charge quantization	1923
ATOMIC STRUCTURE, PHOTONS, COSMIC RAYS					
1911	E. Rutherford	Atomic nucleus	α scattering from thin metal foils	Nuclear model of atom	
1912	V. Hess	Cosmic rays	Cosmic rays observed in balloon flights	Origin in space, otherwise unknown	1936
1912	C. T. R. Wilson		Cloud chamber		1927
1913	N. Bohr	Atomic structure; nuclear radioactivity	H spectrum explained, H atom size from theory	1 st quantum theory of atomic structure; radioactivity from nucleus	1922
1913	H. Moseley	Nuclei with $+Z$ charge	K x-rays	Z (atomic number) from Bohr theory	
1914	J. Chadwick	nucleus	β spectrum continuous		
1916	R. Millikan	photon	Confirmation of Einstein's photoelectric theory	$E = hf$ for photon $hf = W + KE_e$, $KE_e =$ electron kinetic energy	
1919	E. Rutherford	Proton (p) discovery	H nuclei knocked from nuclei by α collision		
1920	E. Rutherford	neutron		Neutron hypothesis	
1921	J. Chadwick	α - p collisions		Strong force proposed	
1923	A. Compton	photon	x-ray scattering by electrons in metals	$E = hf = pc$ for photons	1927

1923	L. de Broglie	matter waves		$\lambda = h/p$	1929
1924	S. Bose, A. Einstein	spin 1 particles		Bose-Einstein statistics	
1925	G. Uhlenbeck, S. Goudsmit	electron spin	electron spin	electron spin	
1925	W. Pauli	spin 1/2 particles		Pauli exclusion principle	1945
1925-1927	W. Heisenberg, E. Schrödinger, Max Born	atoms		Quantum theory of atomic structure	1933 – E. S. 1954 – M.B.
1926	E. Fermi, P.A. M. Dirac	spin 1/2 particles		Fermi-Dirac statistics	
1927	W. Heisenberg			Uncertainty principle	1932
1927, 1928	C. Davisson, G. P. Thomson	electron	electron diffraction	Electron wave properties	1937
1928	P. A. M. Dirac			Relativistic quantum theory, antimatter	1933
1928	G. Gamow	α -decay		α -decay tunneling	
1930	W. Pauli	neutrino (ν_e) proposed		Energy conservation in β decay	

PARTICLE ACCELERATORS, PARTICLE DISCOVERIES

1931	E. Lawrence		Cyclotron to accelerate protons		1939
1931	R. Van de Graaff		Electrostatic accelerator		
1932	J. Cockcroft, E. Walton		Accelerator; nuclear transmutation via accelerated p^+		1951
1932-1933	C. Anderson	positron (e^+) discovered	Cosmic ray positron track in cloud chamber		1936
1932	J. Chadwick	neutron (n) discovered	Collisions with H and N atoms		1935
1932	H. Urey	deuteron discovered	D spectrum vs. H spectrum		1934 - Chemistry
1932	W. Heisenberg	nucleus		Nucleus composed of p^+ and n^0 ; isotopic spin	
1933	P. M. S. Blackett		Counter-controlled cloud chambers		1948
1934	P. Čerenkov		Čerenkov effect observed	Čerenkov. effect explained	1958

1934	E. Fermi	neutrino (ν_e)		Neutrino named and incorporated in field theory for β -decay	1938- neutron induced radio-activity
1935	H. Yukawa	pion (π^+ , π^-)		Strong force field theory; pion predicted	1949
1937	S. Neddermeyer, C. Anderson	muon (μ^+ , μ^-)	Cosmic ray muon tracks in cloud chamber		
1938	E. Stückleberg	baryons		Baryon number conservation	
1940	E. Williams	muon	muon decay observed		
1942	B. Rossi	muon	$\tau_\mu = 2.3 \pm 0.3 \mu\text{s}$		
1944	L. Leprince-Ringuet	K^+ meson	1 st evidence		
1946-1947	G. Rochester, C. Butler	kaon (K^0), strange particle	Decay tracks observed in cloud chamber		
1947	C. Powell	pion (π^+ , π^-)	Pion tracks in nuclear emulsions		1950
1947	G. Rochester, C. Butler	kaon (K^+ , K^-), strange particles	Tracks in cloud chamber		
1948	R. Oppenheimer, H. Lewis, S. Wouthuysen	pion (π^0)		π^0 existence predicted	
1949	R. Bjorkland, et al.	pion (π^0)	synchrocyclotron (LBL) observation of coincident γ rays from π^0 decay		
1943; 1948; 1948	S. Tomonaga, J. Schwinger, R. Feynman			Quantum Electrodynamics (QED)	1965
1950	J. Robson	neutron	1 st observation of $n^0 \rightarrow p^+ + e^- + \nu$		
1951	R. Armenteros, et al.	Λ^0 , K^0	1 st evidence for Λ^0 , K^0		
1952	H. Anderson, et al.	Δ^{++} resonance			
1952	A. Pais	Strange particles		Associated production hypothesis	
1952	1 st proton synchrotron	K and Λ hyperons	3 GeV Brookhaven Cosmotron	Associated production observed	

1953	A. Bonetti, et al.	Σ^+ , Σ^- hyperons	Nuclear emulsions		
1953	F. Reines, C. Cowan	detection of anti- ν_e	anti- $\nu_e p \rightarrow n e^+$		1995
1953	C. Anderson, E. Cowan, et al.	cascade particle, Ξ^-	Cloud chamber		
1953	D. Glaser		Invented bubble chamber		1960
1954	CERN begun			Conseil Européen pour la Recherche Nucléaire	
1954	Proton synchrotron		6.2 GeV Berkeley Bevatron	Designed to produce antiprotons	
1955	O. Chamberlain, E. Segrè, et al.	antiproton, <i>i.e.</i> p^-	Measured speed for known p		1959
1956	B. Cork, et al.	anti-n	1 st evidence for anti-neutron		
1956	T. D. Lee, C. N. Yang			Nonconservation of parity possible	1957
1956	M. Gell-Mann	Σ^0 , Ξ^0		Particles predicted	
1957	R. Plano, <i>et al.</i>	Σ^0	Existence shown		
1957	C. S. Wu		Nonconservation of parity found		
1957	K. Nishijima	leptons		Lepton family # conservation	
1958	D. Prowse, M. Baldo-Ceolin	anti- Λ	1 st evidence for anti- Λ		
1959	CERN		Proton synchrotron reaches 24 GeV	Strong focusing 100 m radius machine	
1959	S. Fukui, S. Miamoto		Spark chamber described		
1959	L. Alvarez, et al.	Ξ^0 - 1 st evidence	Alvarez developed liquid H ₂ bubble chamber from 1954		1968
1959	B. Pontecorvo	ν_μ , ν_e		ν_μ proposed different from ν_e	
1960	Brookhaven		30 GeV AGS proton synchrotron		
1960	J. Button, et al.	anti- Σ^0	1 st evidence anti- Σ^0		
1960	W. Kang-Chang	anti- Σ^-	1 st evidence anti- Σ^-		
1961	A. Salam, J. Ward			Gauge theory	
1961	S. Glashow	Z^0		Neutral weak boson theory	1979
1961	J. Button, <i>et al.</i>	anti- Λ^0	1 st evidence anti- Λ^0		
1961	M. Gell-Mann			Eight-Fold Way	

1962	H. Brown, <i>et al.</i>	Ξ^+ (i.e. anti- Ξ)	1 st evidence Ξ^+		
1962	L. Lederman, J. Steinberger, M. Schwartz	ν_μ	ν_μ demonstrated with spark chambers	2 nd lepton family	1988
1962	M. Gell-Mann	Ω^-		Ω^- predicted	
1964	M. Gell-Mann	quarks		u, d, s quarks proposed	1969
1964	G. Zweig	aces (quarks)		Aces proposed as baryon constituents	
1964	P. Higgs	Higgs particle		Higgs particle proposed	
1964	J. Bjorken, S. Glashow	Charm particle		Charmed fermion proposed	
1964	N. Samios, et al.	Ω^-	Ω^- detected at Brookhaven	Confirmed Gell- Mann's prediction	
1964	J. Cronin, V. Fitch	K^0	1 st evidence for CP violation		1980
1964	O. Greenberg	quarks, gluons		Color quantum #	
1964	M. Han, Y. Nambu	quark, gluon		Color quantum #	
1964	A. Salam	W^\pm		W mass estimate	1979
1967	S. Weinberg	W, Z		W, Z mass estimates	1979
1967	SLAC		3 km e- accelerator at 20GeV	Stanford Linear Accelerator Center	
1968	G. Charpak, et al.			Multiwire proportional counter	1992
1969	J. Friedman, H. Kendall, R. Taylor	quarks	Deep inelastic e- scattering from p at SLAC	Partons in protons	1990
1969	R. Feynman	parton		Parton model of proton, neutron	
1970	S. Glashow	charmed quark		Proposal for charmed quark	1979 for electro weak
1971	G. 't Hooft	quarks, gluons		QCD	
1972	G. 't Hooft, M. Veltman	quarks, gluons		QCD renormalization	1999
1972	Fermilab		200 GeV proton synchrotron	1 km radius	
1973	F. Hasert, et al.	Z^0	Weak neutral current observed	Confirmed electroweak theory	
1973	D. Gross, F. Wilczek	quarks, gluons		QCD	2004

1973	H. D. Politzer	quarks, gluons		QCD	2004
1973	S. Weinberg	quarks, gluons		QCD	
1974	Samuel Ting, et al.	J/ψ , c quark, antiquark	J/ψ observed at Brookhaven	Surprise	1976
1974	Burton Richter, et al.	J/ψ	J/ψ obs. at SLAC, charm-anticharm	Surprise	1976
1975	E. Cazzoli, et al.	$\Sigma_c(2455)^{++}$, Λ_c^+	1 st evidence for charmed baryons		
1975	M. Perl, et al.	τ	1 st evidence for τ lepton at SLAC	3 rd generation lepton	1995
1975	G. Hanson, et al.	quark jets	1 st evidence for quark jets		
1976	Fermilab		Main Ring reaches 500 GeV		
1976	CERN		SPS reaches 400 GeV	Super Proton Synchrotron (SPS)	
1976	G. Goldhaber, et al.	D^0	1 st evidence for D^0 charmed meson		
1976	I. Perizzi, et al.	D^+ , D^-	1 st evidence for D^+ , D^- charmed mesons		
1976	Knapp, et al.	anti- Λ_c^-	1 st evidence for anti- Λ_c^- charmed antibaryon		
1977	R. Brandelik, et al.	$D_{S^*}^+$, D^{*+}_S , D^{*-}_S	1 st evidence for strange charmed mesons		
1977	L. Lederman's team; S. Herb, et al.	Υ , b – anti-b quarks	1 st evidence for bottom meson at Fermilab	3 rd generation quark	
1979	D. Barber, et al.	gluon jets	1 st evidence for gluon jets		
1981	CERN		SPS colliding 270 GeV p^+ and p^-		
1981	C. Bebek, et al.	B meson	1 st evidence for B meson		
1981	M. Basile, et al.	Λ_b	1 st evidence for bottom baryon	3 rd generation quark	
1983	Fermilab		Tevatron superconducting magnets, 1TeV p		
1983	S. Biagi, et al.	$\Xi_c(2460)^+$	1 st evidence for charmed strange baryon Ξ_c^+		

1983	UA1; C. Rubbia, S. van der Meer	W^+, W^-, Z^0	1 st evidence for W^+, W^-, Z^0	Confirmed electroweak theory	1984
1985	S. Biagi, et al.	Ω_c	1 st evidence for ssc charmed baryon		
1985	Fermilab		Tevatron colliding 800 GeV $p^+ p^-$		
1986	L. Voyvodic, et al.	$\Sigma_c(2455)^0$	1 st evidence for $\Sigma_c(2455)^0$		
1989	CERN		LEP collides 50 GeV $e^- e^+$ in 27 km ring	Large Electron Positron collider	
1989	CLEO; P. Avery, et al.	$\Xi_c(2460)^0$, anti- $\Xi_c(2460)^0$	1 st evidence for these charmed strange baryons		
1991	UA1; C. Albajar, et al.	Λ_b	1 st <u>observation</u> of bottom baryon		
1992	HERA at DESY		Hadron Electron Ring Accelerator	More evidence for partons in protons	
1993	ALEPH; D. Buskulic, et al.	B_s	1 st measurement of B_s meson mass		
1994	CDF; F. Abe, et al.	top quark	1 st <u>evidence</u> of top quark	3 rd generation quark	
1995	CDF; F. Abe, et al.	top quark	<u>Observation</u> of top quark	3 rd generation quark	
1995	D0; A. Abachi, et al.	top quark	<u>Observation</u> of top quark	3 rd generation quark	
2000	Fermilab DONUT	ν_τ	1 st evidence for ν_τ in photographic emulsions	3 rd generation lepton	
2007	D0, CDF collaborations	Ξ_{b^-}	Quark from each generation: d, s, b		
2010	CERN LHC CMS, ATLAS, ALICE, LHCb		Large Hadron Collider starts - 3.5 Tev protons		
2012	CERN LHC	Higgs Boson announced	4 July ATLAS, CMS - discovery of Higgs boson at 125 GeV	Missing piece of Standard Model confirmed	2013 P. Higgs, F. Englert,
2014, 2015	CERN LHC, LHCb	$Z(4430)$, $P^+(4380)$ announced	Z (u-bar, d, c, c-bar), P (u, u, d, c, c-bar) particles		

Note on text colors:

Blue items indicate particle theories.

Green items indicate detector technology.

Red items indicate particle accelerators.