

The Foundations of Medical and Veterinary Virology: Discoverers and Discoveries, Inventors and Inventions, Developers and Technologies

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"If I have seen further it is by standing on the shoulders of giants."
Isaac Newton in a letter to Robert Hooke, 1676

"A great many highly creative scientists take it quite for granted that an interest in the history of science is a sign of failing powers.... The history of science does not often interest the scientist as science."
Peter Medawar, 1968

The foundation of the medical and veterinary virology/viral disease sciences predates the concept of the specificity of disease causation and is heavily dependent upon initial discoveries about bacteria and bacterial diseases. Upon a broad and venerable foundation, Louis Pasteur established the microbiologic/virologic/infectious disease sciences, first in 1857 by discovering the specificity of microbial fermentations (wine, beer, cheese), then in 1865 by extending the concept to infectious diseases of silkworms, and finally between 1877 and 1895 by extending the concept to human and animal diseases. His early infectious disease work centered on septic war wounds; he then turned to anthrax and other bacterial diseases, and lastly to rabies. In each instance, he moved quickly from studies aimed at discovering the causative agent to the development of specific intervention. In 1885, Pasteur gave the first rabies vaccine to a boy, Joseph Meister, bitten severely by a rabid dog—that day marked the opening of the modern era of infectious disease science aimed at disease prevention and control. Pasteur was joined by Robert Koch, who discovered the causative agents of tuberculosis and cholera and contributed much to the development of laboratory methods in bacteriology. Koch also worked on several diseases which others eventually showed were caused by viruses. As a result of the work of Pasteur, Koch and others, the identification of the causative agents of many important human diseases proceeded at breakneck pace around the turn of the twentieth century.

From the foundation laid by Pasteur, Koch and their colleagues, others extended the breadth and depth of the infectious disease sciences in many ways. There are many names to be remembered. The following table is an attempt to remember some of the discoverers and discoveries, inventors and inventions, and developers and technologies that were seminal in the advance of medical and veterinary virology. The listing is completely arbitrary, based only on the author's decision as to what to include and what to leave out. Several factors guided this decision: (1) The table is not limited simply to human pathogenic viruses per se; many important veterinary and zoonotic pathogens are included because they have always been part of the context in which human viruses are studied, and because it is the zoonotic and species-jumping viruses from which most of the new, emerging and re-emerging human pathogens originate. Thus, it seemed best to err on the side of inclusiveness. Further, in the era of the founding of virology there was exceptional crossover between human and veterinary virology, much more than is seen today—there is value in being reminded of this. (2) The table is not limited to the type viruses of families and genera; rather the table is extended to include as many as possible of the important and interesting pathogens that are the focus of medical and veterinary virology and comparative virology research. (3) In some instances the table includes two entries for a given virus, one from the era when the classification of an infectious agent as a virus was based solely upon its ultra-filterability, and a second from the modern era, when the virus was defined by more definitive methods. (4) The discovery/development of the great attenuated viruses used in vaccines is included, but in condensed form—a comprehensive listing here would have to include the many independently derived vaccine substrates. (5) The arboviruses proved to be a special case because of their profusion, so a selective approach was taken in order to emphasize those viruses causing major human and veterinary diseases

and the initial discoveries of viruses representing major groups. (6) The attempt to include inventors and their inventions, and developers and their technologies proved especially difficult—the crucial role of these in the advance of the virology/viral disease sciences is acknowledged, but in many cases breakthroughs derive to commercial corporations rather than individuals and credit is difficult to attribute. (7) The table fails greatly in not capturing the excitement, the romance, the “*Eureka!*” behind each entry—only a full article, or in some cases a full book, on each discovery and invention would do justice to the story behind each entry. (8) The table must be seen as a “work-in-progress”—it is meant to be used, to be modified, and changed in any way to meet the particular needs of any and all virologists. (9) The table inevitably contains errors—it is meant to be corrected by all users, preferably with communication about such errors to the author.

The table is not formally referenced. In trying to do so it was found that in many cases authors cited secondary, tertiary and lesser sources, in a daisy-chain fashion, never getting to the original publications. Because all lines in the table were not reference-able, none are referenced here.

For those who would like to further their interest in this subject, here are a few references: (1) A. P. Waterson and Lise Wilkinson’s classic book, *An Introduction To The History Of Virology* [Cambridge University Press, 1978]; (2) Frank Fenner and Adrian Gibbs’ series, *Portraits of Viruses: A History of Virology* [Karger, 1988]; (3) Alfred Grafe’s book, *A History of Experimental Virology* [Springer-Verlag, 1991]; (4) Brian Mahy and Dimitri Lvov’s book (eds.), *Concepts in Virology—From Ivanovsky to the Present* [Harwood, 1993]; (5) Hilary Koprowski and Michael Oldstone’s book, *Microbe Hunters—Then and Now* [Medi-Ed Press, 1996]; (6) Charles Calisher and Marian Horzinek’s (eds.) book, *Virology: The First 100 Years*. [Springer-Verlag, 1999]; (7) Michael Oldstone and Arnold Levine’s article, *Virology in the Next Millennium* [Cell 100:139-142, 2000]; and especially (8) Arnold Levine and Lynn Enquist’s chapter in *Fields VIROLOGY, Fifth Edition*, entitled *History of Virology* [Lippincott Williams & Wilkins, 2006].

The table is now complemented by a PowerPoint slide set containing ~700 images. It is now up on a website at UTMB, as an experiment pending its finalization. The link to the PowerPoint slide set is at the very bottom of the website page. Here is the website link:

<http://www.utmb.edu/ihii/virusimages/index.shtml>.

Note: these PowerPoint files are rather large (20-70mb) and may download slowly, according to the Internet connection, etc.

Many colleagues responded to inquiries about the table, in every case with incredible enthusiasm—it must be that this subject, the founding of virology and the viral disease sciences, really touches a common chord.¹

**Table: The Foundations of Medical and Veterinary Virology—
Discoverers and Discoveries, Inventors and Inventions,
Developers and Technologies**

Date	Discoverer(s) Inventor(s) Developer(s)	Discovery(ies) Invention(s) Technology(ies)
400 BCE	Hippocrates	father of medicine, important epidemiologic observations on many infectious diseases
1546	G Fracastoro	theory that epidemic diseases are contagious and disseminated by minute particles carried over long distances
1595- 1660	S & H Jansen, R Hooke	development of the first compound microscopes and illumination system
1660	Lord Brouncker, C Wren, R Boyle, others	founding of the Royal Society
1668	A van Leeuwenhoek	invention of a simple microscope, observation of bacteria
1690- 1907		major yellow fever epidemics in U.S. and throughout the Western hemisphere, recurring every few years
1735	C Linnaeus	development of the hierarchical classification (Classes, Orders, Genera, Species) of all organisms and the binomial nomenclature system
1762	C Bourgelat	founding of L'Ecole Nationale Vétérinaire de Lyon, the first veterinary school in the world
1765	J Morgan, B Franklin	founding of the first medical school in the United States (the University of Pennsylvania)
1765- 1775	L Spallanzani	first experiments refuting the theory of the spontaneous generation and the first growth of bacteria in culture
1774	B Jesty	vaccination against smallpox using material from cowpox lesion
1793	B Rush	descriptive account of great yellow fever epidemic in Philadelphia, 1793 (during which he treated up to 120 patients per day), and account of what is considered the first case report on dengue fever (1789, case from 1780)
1796	E Jenner	application of cowpox virus for vaccination against smallpox
1798	U.S. Public Health Service	establishment of the U.S. Public Health Service [first as the Marine Hospital Service (1798-1902), then the Public Health and Marine Hospital Service (1902-1912), and finally as the Public Health Service (1912-present)]
1835- 1870s	C Chevalier, J Purkinje, W His, C Minot, A Pfeiffer, others	development of the microtome, crucial to the development of cellular biology and cellular pathology
1835	M Schleiden, T Schwann, others	development of the concept that all organisms are composed of cells
1838>	J Snow, along with J Graunt, W Farr, L Villerme, P Panum, M Pruden, H Biggs, others	father of epidemiology
1840	F Henle	father of the germ theory, first substantial proposal that infectious agents are the cause of many diseases
1840s- 1860s	I Semmelweis, O Holmes, J Lister	development of practical methods of hygiene and antimicrobial disinfection
1857>	L Pasteur	father of microbiology
1858	C Darwin	father of evolutionary science, development of the concepts of evolutionary progression, common descent, natural selection
1858- 1867	R Virchow	father of pathology, founded the disciplines of cellular (microscopic) pathology and comparative pathology (comparison of diseases common to humans and animals)
1860s	W Henderson, R Paterson	discovery of the inclusion body of molluscum contagiosum virus
1863	A Bache, L Agassiz, B Peirce, B Gould,	founding of the U.S. National Academy of Sciences

	C Felton, J Henry	
1863	C Davaine	first association of a specific infectious organism with a specific disease (<i>Bacillus anthracis</i> —anthrax)
1865	G Mendel	father of genetics
1868	J-F Meischer	discovery and characterization of nucleic acids
1868	J Law	father of modern veterinary medicine in the United States
1874	W Osler	father of modern medicine, physician, clinician, pathologist, teacher, diagnostician, bibliophile, historian, classicist, essayist, and author
1876	R Koch	with Pasteur, the founder of microbiology, first incontrovertible proof that a microorganism can cause disease (<i>Bacillus anthracis</i> —anthrax)
1878	L Pasteur, R Koch, others	popularization of the germ theory of disease
1879	S Chaille	father of hygiene and health education in the United States
1880	J Michels, American Association for the Advancement of Science	publication of the journal, <i>Science</i>
1880-1897	P Manson, C Laveran, R Ross, G Grassi	discovery of the protozoan etiologic agents of malaria, filariasis and trypanosomiasis, and their arthropod transmission cycles—keys to the discovery of the first human virus, yellow fever virus, and its transmission by mosquitoes
1883>	E Metchnikoff, J Bordet, P Ehrlich, Shiga Kiyoshi, E von Behring	founding of immunology, hematology and chemotherapy
1884	J Henle, R Koch, F Loeffler, C Chamberland	Henle-Koch postulates, criteria for proof of causation
1884	C Chamberland	development of the Chamberland-Pasteur unglazed porcelain ultra-filter and the autoclave
1885	L Pasteur, E Roux	development of rabies vaccine
1886	A Mayer	development of the concept of transmissibility of tobacco mosaic disease and the earliest concept of filterable virus
1887	J Buist, E Cowdry	discovery of the elementary bodies of vaccinia and variola viruses
1887	J Kinyoun	establishment of the National Institute of Allergy and Infectious Diseases, first as the Laboratory of Hygiene of the Marine Hospital Service, then of the U.S. Public Health Service, and in 1955 as the National Institute of Allergy and Infectious Diseases of the National Institutes of Health
1888	Institut Pasteur	founding of the Institut Pasteur at 15 rue du Docteur-Roux, Paris
1888>	F Loeffler, P Roux, A Yersin, E von Behring	discovery of microbial toxins and antitoxins
1892	G Sternberg	discovery of virus neutralization (vaccinia virus)
1892	D Ivanovsky ²	discovery of tobacco mosaic virus
1893	T Smith, C Curtice, F Kilborne, D Salmon	the first proof of arthropod transmission of disease (agent: <i>Babesia bigemina</i> ; tick vector: <i>Boophilus annulatus</i>)—a key to the discovery of the first human virus, yellow fever virus, and its transmission by mosquitoes
1893	G Sternberg	founding of Walter Reed Army Institute of Research
1895-1929	J Bordet, Bedson, J Bland	discovery of complement and development of the complement-fixation diagnostic test
1898	M Beijerinck ²	discovery of tobacco mosaic virus
1898	F Loeffler, P Frosch ²	discovery of foot-and-mouth disease virus (the first virus, the first vertebrate virus, the first picornavirus)
1898	G Sanarelli	discovery of myxoma virus (the first poxvirus)
1881-1898	C Finlay	initial experiments on the mode of transmission of yellow fever virus
1898	H Rose Carter	discovery of the extrinsic incubation period in the mosquito vector of yellow fever virus
1899	P Manson	father of tropical medicine
1899	W Sedgwick, W Welch, H Conn, T Smith, F Novy, E Jordan, E Smith, J Carroll, others	founding of the American Society for Microbiology (then the Society of American Bacteriologists)
1900	W Reed, J Carroll, A Agramonte, J Lazear,	discovery of yellow fever virus (the first human virus, the first arbovirus,

	C Finlay	the first flavivirus) and its transmission cycle
1900	J M'Fadyean, T Edgington, A Theiler	discovery of African horse sickness virus (the first orbivirus)
1900	H. de Vries, C Correns, E von Tschermak	founding of genetics, and rediscovery of Mendel's work
1901	J Rockefeller, W Welch, T Prudden, L Holt, C Herter, H Biggs, T Smith, S Flexner	founding of the Rockefeller Institute for Medical Research (1901), Rockefeller Institute(1958), Rockefeller University (1958)
1901	E Centanni, E Savonuzzi, A Lode, J Gruber	discovery of fowl plague virus (avian influenza virus, the first orthomyxovirus)
1902	A Aujeszky	discovery of pseudorabies virus (the first herpesvirus)
1902	A Borrel	discovery of sheeppox virus
1902	M Nicolle, M Adil-Bey	discovery of rinderpest virus (the first morbillivirus)
1902-1906	J Spruell, A Theiler	discovery of bluetongue viruses
1903	M Dorset, E De Schweinitz	discovery of classical swine fever virus (hog cholera virus, the first pestivirus)
1903	A Negri	discovery of the rabies inclusion body—Negri body
1903	M Remlinger, Riffat-Bay, A di Vestea	discovery of rabies virus (the first rhabdovirus)
1903	A Tiselius	development of electrophoresis
1904	H Vallée, H Carré	discovery of equine infectious anemia virus (the first retrovirus)
1904	W Gorgas	control of yellow fever, allowing construction of the Panama Canal
1905	H Carré, P Laidlaw, G Dunkin	discovery of canine distemper virus
1906	P-L Simond, E Marchoux	first suggestion of transovarial transmission of a virus in its mosquito vector (yellow fever virus, <i>Aedes aegypti</i>)
1907	R Harrison	development of the first cell cultures (nerve fibers from frog embryo tissues)
1907	P Ashburn, C Craig	discovery of dengue viruses
1908	V Ellermann, O Bang	discovery of avian leukemia virus (the first leukemia virus)
1909	K Landsteiner, E Popper	discovery of poliovirus (the first enterovirus)
1909	C Levaditi, K Landsteiner	discovery of poliovirus in non-nervous system tissues
1909	R Doerr, K Franz, S Taussig	discovery of sandfly (phlebotomus) fever viruses (the first phleboviruses)
1910>	T Morgan	discovery of the nature and role of the chromosome, and the use of <i>Drosophila</i> in genetics research
1911	J Goldberger, J Anderson	discovery of measles virus
1911	P Rous, J Beard	discovery of Rous sarcoma virus (first solid tumor virus)
1911-1934	G von Hevesey, R Schoenheimer, D Rittenberg	development of radioisotopic labeling
1912>	A Carrel, M Burrows, W&M Lewis, H&M Maitland, C Levaditi, H Eagle, G Gey, T Puck, R Hamm, J Enders, T Weller, F Robbins, others	development of many cell and tissue culture methods
1913	E Steinhardt, C Israeli, R Lambert	cultivation of the first virus in tissue culture (vaccinia virus on pieces of rabbit cornea)
1913>	W Sawyer, T Rivers, F Horsfall, M Theiler, R Shope, others	founding of the Rockefeller Foundation (1913) and its international research programs
1914-1938	A Hess, Y Hiro, S Tasaka	discovery of rubella virus (the only rubivirus)
1915-2004	American Public Health Association	publication of the book, <i>Control of Communicable Diseases Manual</i> , to date 18 editions
1917-1919	F Twort, F d'Herelle	discovery of bacteriophages
1917	R Montgomery	discovery of Nairobi sheep disease virus (the first nairovirus, the first tick-borne virus)
1918-		influenza pandemic, 40-100 million deaths worldwide

1919		
1918-1952	A Breinl, J Cleland, E French	discovery of Murray Valley encephalitis virus
1919	A Löwenstein	discovery of herpes simplex virus
1920s	G Ramon	development of the use of formaldehyde to inactivate virus for vaccines and toxins for toxoids, the means for measuring vaccine potency, and the first adjuvants
1921	R Montgomery	discovery of African swine fever virus (the only asfarvirus)
1923	T Svedberg	development of the ultracentrifuge
1925	S Lewis	publication of the inspiring book, <i>Arrowsmith</i>
1925>	F Sabin	discoveries of the role of the monocyte and other white blood cells in defense against viral (and bacterial) infections
1925-1952	K Kundratitz, H Ruska, T Weller, M Stoddard	discovery of varicella-zoster virus—chickenpox and zoster
1926	W Cotton, P Olitsky, J Traum, H Schoening	discovery of vesicular stomatitis viruses
1926	F Kraneveld, T Doyle	discovery of Newcastle disease virus
1926	P de Kruif	publication of the book, <i>Microbe Hunters</i> , translated into 18 languages
1927	T Rivers	publication of paper differentiating bacteria from viruses, establishing virology as a field distinct from bacteriology, and the beginning of clinical virology
1928	W Sawyer, T Rivers, F Horsfall, M Theiler, R Shope, others	founding of the Rockefeller Foundation Virus Laboratory (RFVL)
1928	F Griffith	discovery of transformation in bacteria, a foundation of molecular genetics
1928>	R Lancefield, E Lennette, others	founding of viral disease diagnostics
1928	T Rivers (ed)	publication of the first major virology book, <i>Filterable Viruses</i>
1928	J Verge, N Christoforoni	discovery of feline panleukopenia virus (the first parvovirus)
1928	A Stokes, J Bauer, N Hudson, J Laigret	transmission of yellow fever virus to rhesus macaque
1929	S Nicolau, I Galloway	discovery of Borna virus (the only bornavirus)
1930	R Green, N Ziegler, others	discovery of infectious canine hepatitis virus (the first adenovirus)
1930	M Theiler, J Furth, C Armstrong	development of the mouse as an experimental animal for research on viruses
1930	K Meyer, C Haring, B Howitt	discovery of western equine encephalitis virus (the first alphavirus)
1931	W Eford, C Andrewes	use of graded collodion membranes to determine virion size
1931	R Shope	discovery of swine influenza virus (the first Influenzavirus)
1931	A Woodruff, E Goodpasture, M Burnet, H Cox	development of embryonated hen's eggs as host for viruses
1931	R Daubney, J Hudson, P Garnham	discovery of Rift Valley fever virus
1931	G Kärber	development of the Spearman-Kärber method for estimating fifty percent endpoints
1932	C Little, J Bittner, Staff of Jackson Memorial Laboratory	discovery of mouse mammary tumor virus (Bittner virus)
1932	F Gay, A Sabin, M Holden, W Wright	discovery of B virus
1933	W Smith, C Andrewes, P Laidlaw	discovery of human influenza viruses
1933	R Shope, P Rous, J Beard	discovery of rabbit papillomavirus (the first papillomavirus)
1933	E Ruska, M Knoll	invention of the electron microscope
1933	R Muckenfuss, C Armstrong, H McCordock, L Webster, G Fite	discovery of St. Louis encephalitis virus
1933	F Soper, H Penna, R Shannon, L Whitman, J Boshell-Manrique	discovery of the jungle cycle of yellow fever virus involving <i>Haemagogus</i> species in the Americas and as <i>Aedes</i> species in Africa
1933-1954	W Dimmock, P Edwards, E Doll, J Kintner	discovery of equid herpesvirus 1 (EHV-1; equine abortion virus) and equid herpesvirus 4 (EHV-4; equine rhinopneumonitis virus)

1934	C Johnson, E Goodpasture	discovery of mumps virus
1934	A Beckman	development of the electronic pH meter
1934	M Merrill, C Lacaillade, C Ten Broeck	discovery of eastern equine encephalitis virus
1934	M Hayashi, S Kasahara, R Kawamura, T Taniguchi	discovery of Japanese encephalitis virus
1935	W Stanley	purification and crystallization of tobacco mosaic virus
1935	M Theiler	development of yellow fever vaccine
1935	H Zinsser	publication of the inspiring book, <i>Rats, Lice and History</i>
1936	F Bawden, N Pirie	discovery that tobacco mosaic virus is comprised of nucleoprotein and that the nucleic acid is RNA
1936	J CuilleCuillé, P-L Chelle	transmission of scrapie to normal sheep by cell-free material from diseased sheep
1936	C Armstrong, T Rivers, E Traub	discovery of lymphocytic choriomeningitis virus (the first arenavirus)
1936	T Dobzhansky	publication of the book <i>Genetics and the Origin of Species</i> , seminal in the development of concepts in evolutionary genetics
1936	P Rous, J Beard	induction of carcinomas in other species by rabbit papillomavirus
1936	J Traub	discovery of vesicular exanthema virus of swine (the first calicivirus)
1937	F Beaudette, C Hudson	discovery of avian infectious bronchitis virus (the first coronavirus)
1937	M Theiler	demonstration of persistent CNS infection (Theiler's virus)
1937	T Rivers	criteria for proof of viral disease causation: the Henle-Koch postulates revisited
1937	L Zilber, M Chumakov, N Seitlenok, E Levkovich	discovery of tick-borne encephalitis virus (Russian spring summer encephalitis virus)
1937	E Wollman, E Wollman	discovery of the eclipse period in virus infection (bacteriophage)
1938	L Reed, H Muench	development of the Reed-Muench method for estimating fifty percent endpoints
1938	V Kubes, F Rios, C Beck, P Wyckoff	discovery of Venezuelan equine encephalitis virus
1938	R Doerr, C Hallauer (eds)	publication of the major virology book, <i>Handbuch der Virusforschung-erste Halfte</i>
1938	B von Borries, H Ruska, E Ruska	first electron micrograph of a virus (ectromelia virus)
1939	R Doerr, C Hallauer	first international virology journal, <i>Archiv für die gesamte Virusforschung</i> (now <i>Archives of Virology</i>)
1939	J Hillier, A Prebus	development of first electron microscope in North America at the University of Toronto
1940	K Smithburn, T Hughes, A Burke, J Paul	discovery of West Nile virus
1940	E Mayr	proposal of the widely used definition of species used in systematics
1940s	B McClintock	development of the concept of transposable elements, transposons
1941	G Hirst	discovery of virus hemagglutination, hemagglutination-inhibition, receptor destroying enzyme (neuraminidase) (influenza virus)
1941	N Gregg	discovery of rubella virus congenital abnormalities
1941	W Hammon, W Reeves, colleagues	quantitative study of natural history of arboviruses in vector arthropods (St. Louis encephalitis virus, <i>Culex tarsalis</i>)
1941	A Beckman	development of the spectrophotometer (the Beckman DU)
1941	T Anderson	discovery of the variety of bacteriophage morphologies and invention of critical point drying of specimens for electron microscopy
1942	C Huang	development of the quantitative virus neutralization assay (WEE virus and pH color change endpoint)
1942	J Mountain, others	founding of the U.S. Centers for Disease Control and Prevention, first as the Office of National Defense Malaria Control Activities (1942), then the Office of Malaria Control in War Areas (1942), then the Communicable Disease Center (1946), then the National Center for Disease Control (1967), then the Center for Disease Control (1970), then the Centers for Disease

		Control (1980), finally the Centers for Disease Control and Prevention (1992)
1942>	A Coons, colleagues	development of immunofluorescence
1943-1948	W Earle, K Sanford	development of the L cell line and clone L929 cell line (subcutaneous connective tissue, mouse; one of the first cell lines to be established in continuous culture; clone L929 was the first cloned cell line to be established)
1943	U.S. Army, Camp Detrick	development of military high-containment virology laboratories
1944	K Smithburn, A Hadow	discovery of Semliki Forest virus
1944	O Avery, C MacLeod, M McCarty	identification of DNA as the material of inheritance
1944	E Schrödinger	publication of seminal book, <i>What is Life?</i> – a motivation for many scientists, leading to the rise of molecular biology
1945-1953	M Delbrück, S Luria, A Hershey, S Benzer, G Stent	founding of the "Phage School" at the Cold Spring Harbor Laboratory, with "branches" at the California Institute of Technology and the University of California Berkeley
1945>	T Francis, G Hirst, F Davenport, T Eickhoff, G Meiklejohn, E Kilbourne	development of inactivated influenza vaccines
1945-1956	M Chumakov, G Courtois, colleagues	discovery of Crimean-Congo hemorrhagic fever virus (the first nairovirus)
1946	M Delbrück	discovery of genetic recombination (bacteriophage)
1946	K Smithburn, A Hadow, A Mahaffy	discovery of Bunyamwera virus (the first bunyavirus)
1946	J Steele	founder of the field of veterinary public health
1947	F Fenner	experimentation with ectromelia virus in mice and the beginning of viral pathogenesis research
1947-1955	M Burnet, A Gottschalk, E Klenk	discovery of virus receptors
1947-2007	C Clifton, S Raffel	publication of <i>Annual Review of Microbiology</i> , 60 volumes
1947	A Beckman	development of the Spinco Model E Analytical Ultracentrifuge
1947	Mettler Instruments AG	development of the first single-pan precision analytical balance
1948	World Health Organization	establishment of the World Health Organization
1948	G Dalldorf, G Sickles	discovery of Coxsackieviruses
1948	K Sanford	culture of single animal cells
1948-1965	T Rivers, F Horsfall, I Tamm	publication of book, <i>Viral and Rickettsial Infections of Man</i> (eventually four editions)
1948-1995	American Public Health Association, E Lennette, N Schmidt	publication of book, <i>Diagnostic Procedures for Virus and Rickettsial Diseases</i> , Seven Editions
1949	A Beckman	development of the Spinco Model L preparative ultracentrifuge
1949	J Enders, T Weller, F Robbins	development of cell culture methodology for polio, measles and other vaccines, neutralization of poliovirus with immune sera, and demonstration of attenuation of poliovirus neurovirulence with repetitive passage
1949	A Lwoff, L Siminovitch, N Kjeldgaard	discovery of lysogeny and induction (bacteriophage)
1950	L Florio, M Miller, E Mugrage	discovery of Colorado tick fever virus (the first coltivirus)
1950-1960s	M Delbrück, A Hershey, S Luria	discovery of mechanisms of virus replication and genetic variation
1950-1960s	C Mims	development of immunofluorescence in viral pathogenesis research
1951	G Gey	establishment of the HeLa cell line (human cervical adenocarcinoma; named for patient <u>Henrietta Lacks</u>)
1951	L Gross	discovery that murine leukemias and lymphomas caused by viruses are transmitted through the embryo
1951	E Lederberg	discovery of bacteriophage λ

1951	UNIVAC 1 and Ferranti Mark I	development of the first commercial electronic digital computers
1951-1960	L Pauling, J Kendrew, M Perutz	discovery of the structure of proteins using X-ray crystallography
1952	A Hershey, M Chase	biological proof of DNA as the material of inheritance
1952	W Stanley	establishment of the Virus Laboratory at the University of California Berkeley
1952	J Lederberg, N Zinder	discovery of transduction: transfer of genetic information between bacteria by viruses
1952	K Maramorosch	demonstration that some viruses can replicate in both plants and insects
1952	R Dulbecco	development of virus quantification by plaque assay
1953	W Rowe	discovery of human adenoviruses
1953	J Watson, F Crick, M Wilkins, R Franklin	discovery of the structure of DNA
1953	J Murphy, F Bang	discovery of virus release by budding at the cell surface
1953	N Ishida, N Kuroya	discovery of Sendai virus (parainfluenza virus 1)
1953	S Stewart, L Gross, B Eddy	discovery of polyoma virus (the first polyomavirus)
1953	W Plowright	discovery of bovine malignant catarrhal fever virus
1953	S Luria	publication of the major book, <i>General Virology</i>
1953	R Billingham, P Medawar, L Brent, F Fenner, M Burnet, R Owens	discovery of immunologic tolerance in virus infections
1953	K Smith	publication of the first major virology review series, <i>Advances in Virus Research</i>
1953-1959	A Sabin	discovery of orthoreoviruses (the first reoviruses)
1954	R Dulbecco, P Vogt	development of the concept of the "one-step virus growth curve," "latent period," "burst size," etc. (WEE virus)
1954	J Salk, J Youngner, T Francis	development of inactivated polio vaccine
1954	M Smith	discovery of murine cytomegalovirus
1954	B Sigurdsson	development of the concept of slow viruses (maedi-visna virus, scrapie prion)
1954	G Takatsy	development of microtiter plate technology
1955	G Hirst, L Black, S Luria	publication of the journal, <i>Virology</i>
1955-1962	W Joklik	seminal studies in viral genetics: recombination and reactivation (vaccinia virus)
1955>	F Brown	seminal studies on the chemical structure, replication, diagnosis and vaccinology of foot-and-mouth disease viruses
1955	R Taylor, T Hurlbut, T Work, J Kingston, T Frothingham	discovery of Sindbis virus
1955	M Minsky	development of confocal microscopy
1955	H Fraenkel-Conrat, R Williams	reconstitution of tobacco mosaic virus from its protein and nucleic acid
1955	S Benzer	definition of a gene (cis-trans test)
1955	W Schäfer	discovery that fowl plague virus is an influenza virus, and likely zoonotic
1956	J Morris, R Chanock, colleagues	discovery of respiratory syncytial virus (the first pneumovirus)
1956	W Pelon, W Mogabgab, W Price	discovery of human rhinoviruses and numerical nomenclature system
1956	C Friend	discovery of Friend murine erythroblastosis virus
1956	A Gierer, G Schramm, H Fraenkel-Conrat, B Singer	discovery of the infectivity of viral RNA (tobacco mosaic virus)
1956	S Madin, C York, D McKercher	discovery of infectious bovine rhinotracheitis virus
1956	R Ross	discovery of chikungunya virus
1956	R Chanock	discovery of human parainfluenza viruses
1956	M Smith, W Rowe, T Weller	discovery of human cytomegalovirus
1956>	W Plowright	development of rinderpest vaccine

1956	W Coulter	development of first high-throughput flow cytometer
1956-1966	C Hartsough, J Gorham, J Henson, R Leader, G Padgett, F Dixon	discovery of Aleutian disease of mink virus and its relationship to immunologically mediated glomerulonephritis and myeloma
1957	M Burnet, D Talmadge	discovery of clonal selection as the central mechanism in the immune response
1957	A Isaacs, J Lindenmann	discovery of interferons
1957	T Work, F Rodriguez, P Bhatt	discovery of Kyasanur Forest disease virus
1957	H Fraenkel-Conrat, R Williams	first in vitro assembly of a virus (tobacco mosaic virus)
1957	E Doll, J Bryans, W McCollum	discovery of equine arteritis virus (the first arterivirus)
1957	K Lee, J Gillespie, N Underdahl, others	discovery of bovine virus diarrhea virus
1957>	J Enders, M Hilleman, A Gershon, S Katz, S Plotkin, M Takahashi, others	development of vaccines against measles, mumps, rubella, Marek's disease, hepatitis A, hepatitis B, varicella-zoster, adenoviruses
1962>	R Webster	discovery of the link between avian and human influenza viruses and development of the concept that that pandemic virus strains arise via reassortment of genes of various human and non-human strains
1958	M Meselson, F Stahl	discovery of the semi-conservative mode of replication of DNA
1958	E Berger, J Melnick	publication of virology review series, <i>Progress in Medical Virology</i>
1958	R Kissling, R Goldwasser	development of rabies immunofluorescence diagnostics
1958>	A Parodi, D Greenway, H Rugiero, I Pirotsky, J Zuccarini, E Molinelli, J Maizstegui, others	discovery of Junin virus, the etiologic agent of Argentine hemorrhagic fever, and development of an attenuated live-virus vaccine
1958	D Burkitt	description of Burkitt's lymphoma in African children
1958>	S Krugman	separation of two forms of hepatitis (HBV, HAV) in seminal studies of the natural history of viral hepatitis at the Willowbrook State School
1958	K Åström, E Richardson, J Cavanaugh, G Zu Rhein, B Padgett, D Walker, M Bouteille, L Horta-Barbosa	discovery of progressive multifocal leukoencephalopathy (JC, SV40 viruses—polyomaviruses)
1959	J Gowans	discovery of lymphocyte circulation
1959	A Sabin, H Cox, H Koprowski	development of attenuated live-virus polio vaccine
1959	L Kilham	discovery of murine parvoviruses
1959	S Brenner, R Horne	invention of negative stain electron microscopy
1959	R Porter, G Edelman, A Nisonoff	discovery of the structure and molecular function of antibodies
1959	R Sinsheimer	discovery that a virus may have a single stranded DNA genome (bacteriophage ØX174)
1959	R Yalow, S Berson	development of radioimmunoassays (RIAs)
1959	A Kornberg, S Ochoa	discovery of the mechanisms in the biological synthesis of DNA and RNA
1959-1962	A Shubladze, K Chzhu-Shan, K Schneewis, W Dowdle	differentiation of herpes simplex viruses 1 and 2
1960	Digital Equipment Corporation	development of the first minicomputer
1960	B Sweet, M Hilleman	discovery of simian virus 40 (SV40)
1960	V Riley, K Rowson, colleagues	discovery of lactate-dehydrogenase elevating virus
1960	W Thompson, B Kalfayan, R Anslow	discovery of La Crosse virus
1960-1970s	G Palade, A Claude, K Porter, C de Duve	description of the fine structure and biochemistry of cellular organelles
1960-1970s	F Dixon, W Weigle, M Oldstone, J Feldman, J Vazquez, R Lerner, others	founding of immunopathology, and the role of viruses in immune complex diseases
1960s>	J Casals, D Clarke, R Shope, R Tesh, J Digoutte, O and C Causey, R Taylor, S Buckley, C Calisher, F Murphy, D Bishop, T Monath, J Dalrymple, B Beaty, C Schmaljohn, many others	discovery, serological grouping and characterization of many arthropod-borne alphaviruses, flaviviruses, bunyaviruses, rhabdoviruses and orbiviruses
1960s	C Mims, R Johnson, N Nathanson, R Blanden, B Fields, M Oldstone, A Haase,	founding of the modern era of viral pathogenesis research

	D Griffin, F Murphy, others	
1960s	R Merrifield	development of solid phase synthesis technology (polypeptides, oligonucleotides, etc.)
1961	F Jacob, J Monod, A Lwoff, S Brenner, F Gros, M Meselson	discovery of messenger RNA, the operon theory, and genetic regulatory mechanisms for control of the synthesis of proteins
1961	J Miller	discovery of the role of the thymus in cellular immunity
1961	I Macpherson, M Stoker	development of BHK-21 cell line
1961	F Crick, S Brenner, J Griffith, L Orgel, L Barnett, R Watts-Tobin	discovery of the triplet coding of DNA (bacteriophage)
1961	U.S. Centers for Disease Control and Prevention	publication of CDC's Morbidity and Mortality Weekly Report (then U.S. Communicable Disease Center)
1961-1966	M Nirenberg, H Khorana, R Holley, S Ochoa, J Matthaei, colleagues	deciphering of the genetic code
1962	Y Yasumura, Y Kawakita	establishment of the Vero cell line (African green monkey kidney epithelial cell, named from "Verda Reno" meaning "green" and "truth" in Esperanto)
1962	A Chovnick, R Dulbecco, J Cairns, G Hirst, A Lwoff, H Rubin, M Stoker	Cold Spring Harbor Symposium on Quantitative Biology: <i>Basic Mechanisms in Animal Virus Biology</i>
1962	A Lwoff, R Horne, P Tournier	first comprehensive classification of the viruses based on virion characteristics
1962	L Kraft	discovery of mouse hepatitis virus (lethal intestinal virus of infant mice)
1962	D Caspar, A Klug	discovery of the principles of icosahedral virus structure
1962	P Gomatos, I Tamm	discovery of double-stranded RNA in a virus (reovirus)
1962	A Cosgrove, H Lasher	discovery of infectious bursal disease virus (the first birnavirus)
1962	F Rauscher	discovery of the first virus-induced lymphoid leukemia in mice
1962	J Trentin, Y Yabe, G Taylor	discovery of induction of tumors in hamsters by human adenoviruses
1963	W Downs, C Anderson, L Spence, others	discovery of Tacaribe virus
1964	M Epstein, B Achong, Y Barr	discovery of Epstein-Barr virus and its association with Burkitt's lymphoma
1964	W Jarrett	discovery of feline leukemia virus
1965	K Johnson, N Wiebenga, R McKenzie, P Webb, others	discovery of Machupo virus, the etiologic agent of Bolivian hemorrhagic fever
1965	J Casals, H Hoogstraal, K Johnson, A Shelokov, N Wiebenga, T Work	initial viral disease scientific exchange between U.S. and U.S.S.R. – on hemorrhagic fevers in Eurasia
1965	D Tyrrell, M Bynoe, J Almeida, D Hamre, J Procknow	discovery of human coronaviruses (B814 and 229E)
1965	M Bouteille, T Chen, L Horta-Barbosa, J Sever, others	discovery of subacute sclerosing panencephalitis (measles virus)
1965	R Atchison, J Melnick, colleagues	discovery of adeno-associated viruses
1965	R Valentine, H Pereria, E Norrby	discovery of adenovirus structural elements (penton fibers, etc.)
1965>	B Roizman	seminal studies of the molecular structure and replication and the cell biology of herpes simplex virus
1965-1978	S Kasakura, L Lowenstein, J Gordon, L Maclean, K Smith	discovery and characterization of the first interleukin, IL-2
1966	C Gajdusek, C Gibbs, W Hadlow, M Alpers	transmission of the etiologic agent of kuru (the kuru prion), to non-human primates
1966	National Library of Medicine	development of Medline
1966	P Wildy, F Fenner, R Matthews, others	founding of the International Committee on Nomenclature of Viruses (now the International Committee on Taxonomy of Viruses) ³
1966	H Meyer, P Parkman	development of rubella vaccine
1966>	P Bhatt, R Jacoby, H Morse, A New, others	development of diagnostic virology of laboratory rodents
1966>	M Studdert	seminal studies of equine viruses (herpesviruses, rhinoviruses, others)
1967	B Blumberg, H Alter, A Prince, others	discovery of Australia antigen, hepatitis B virus and the etiology of post-

		transfusion hepatitis (the first hepadnavirus)
1967	J Kates, B McAuslan	discovery of DNA-dependent RNA polymerase in a virion (vaccinia virus)
1967	W Siegert, R Slenczka, G Martini, R Kissling, R Robinson, F Murphy, others	discovery of Marburg virus (the first filovirus)
1967	U.S. Centers for Disease Control and Prevention	development of civilian high-containment virology laboratories (then U.S. Communicable Disease Center)
1967	B van der Westhuizen, Y Inaba, Y Tanaka, colleagues	discovery of bovine ephemeral fever virus
1967	R Wagner, L Kozloff, N Salzman	publication of the journal, <i>Journal of Virology</i>
1967	C Kaplan, P Wildy	publication of the journal, <i>Journal of General Virology</i>
1967	J Maizel, U Laemmli	development of SDS polyacrylamide gel electrophoresis of proteins
1967-1969	A Churchhill, P Biggs, B Bermester	discovery of Marek's disease virus (herpesvirus) and development of vaccine
1968	M Ptashne, W Gilbert	identification of repressor genes (bacteriophage, lac operon)
1968	Congressman J Fogarty	founding of the John E. Fogarty International Center for Advanced Study in the Health Sciences at the National Institutes of Health
1968	J Kates, B McAuslan, A Shatkin, J Sipe	discovery of RNA-dependent RNA polymerase in a virion (reovirus)
1968	U.S. Advanced Research Projects Agency	development of the Internet
1968	W and G Henle	association of Epstein-Barr virus with mononucleosis
1968	L Hayflick	development of human diploid cell strains (WI-1 through WI-38)
1968	H-W Doerr	publication of virology review series, <i>Monographs in Virology</i>
1968	S Gard, C Hallauer, K Meyer	publication of virology review series, <i>Virology Monographs</i>
1968	P Wildy, J Melnick, N Oker-Blom, V Zhdanov	the First International Congress for Virology ³
1968	T Kelly, W Arber, H Smith, K Wilcox, D Nathans, K Danna	discovery and characterization of first restriction endonucleases, cleaving DNA only at specific sites
1968>	P Vogt, H Hanafusa, C Moscovici, W Okazaki, B Burmester, others	discoveries elaborating the molecular biology of avian retroviruses
1969	R Huebner, G Todaro	development of the viral oncogene hypothesis
1969	S Buckley, J Casals-Ariet	discovery of Lassa virus
1969	C Mebus, N Underdahl, M Rhodes, M Twiehaus	discovery of bovine rotavirus (the first rotavirus)
1969	M Crichton	publication of book, <i>The Andromeda Strain</i> , viral science fiction
1970	I Page, W McDermott, I Bennett, C Child, J Comroe, C MacLeod, J Murtaugh, D Wilbur, R Glaser, J Hogness, D Fredrickson, J Shannon, D Hamburg	founding of the Institute of Medicine (IOM) of the U.S. National Academy of Sciences
1970	D Baltimore, A Huang	discovery of RNA-dependent RNA polymerase in an enveloped RNA virion (vesicular stomatitis virus)
1970	H Temin, D Baltimore	discovery of the reverse transcriptase of retroviruses
1970-1973	W Plowright, R Tesh, D Watts	transovarial transmission of viruses by arthropods (African swine fever virus by ticks, vesicular stomatitis Indiana by sandflies and La Crosse virus by mosquitoes)
1970s>	P Halonen, others	development of modern rapid clinical diagnostic methods
1970s	S Kalter, R Heberling	development of non-human primate virology
1970s-1980s	G Hitchings, G Elion, R Whitley, L Corey, others	development of "rational" drug design" and the antiviral chemotherapeutic, acyclovir, for treatment of herpesvirus infections
1971	P Doherty, R Zinkernagel	discovery of how the cellular immune system recognizes virus-infected cells
1971	P Perlmann, E Engvall, A Schuurs, B van Weemen	invention of enzyme immunoassays—EIAs and ELISAs
1971	T Diener	discovery of viroids (infectious naked RNA molecules)
1971	D Baltimore	Baltimore system of virus classification based on replicative path to

		mRNA
1971-1982>	G Baer, M Abelseh, M Debbie, G Winkler, F Steck, A Wandeler, others	development of the concept, strategy and programs for oral vaccination of wildlife against rabies
1971>	B Achong, M Epstein, P Luciw, W Heneine, D Neumann-Haefelin, T Folks, others	discovery and characterization of simian foamy virus infection in humans
1971>	M Horzinek	seminal studies of veterinary viruses (bovine, equine, feline viruses)
1972	R Tomlinson	development of e-mail
1972	A Kapikian, colleagues	discovery of Norwalk virus (the first human calicivirus)
1972	P Berg, H Boyer	development of the first recombinant-DNA molecules
1973	S Cohen, H Boyer	development of the technology for manipulation of recombinant DNA molecules, the start of genetic engineering
1973	R Bishop, G Davidson, I Holmes, T Flewett, A Kapikian, others	discovery of human rotaviruses
1973	A Hellman, M Oxman, R Pollack	Asilomar conference and proceedings: <i>Biohazards in Biological Research</i>
1973	S Feinstone, A Kapikian, R Purcell	discovery of hepatitis A virus
1973	J Sambrook, colleagues	development of agarose gel electrophoresis of DNA and use of staining with ethidium bromide
1973	D Nathans	completion of the restriction enzyme map of a viral genome (SV40 virus)
1974	G Köhler, C Milstein	development of monoclonal antibodies
1974	F Blattner, P Leder, L Enquist, K Murray, T Maniatis, others	development of phage λ as a viral vector for recombinant DNA technology
1974	T Torsvik, I Dundas, A Wais, others	discovery of viruses of Archaea, many with exceptional morphologies
1974	H zur Hausen	discovery of the association between human papillomavirus infection and cervical cancer
1974-1982	I Tischer, H Gelderblom	discovery of porcine circovirus (the first circovirus)
1975	P Berg, D Baltimore, S Brenner, R Roblin III, M Singer	Asilomar <i>International Conference on Recombinant DNA Molecules, 1975</i>
1975	P Sharp, L Chow, R Roberts, T Broker	discovery of RNA splicing and split genes (adenovirus)
1975	Y Cossart, A Field, A Cant, D Widdows	discovery of parvovirus B-19 and its association with aplastic crisis in hemolytic anemia
1975	C Madeley, B Cosgrove, T Lee, J Kurtz	discovery of human astrovirus 1 (the first astrovirus)
1975	B Blumberg, B Larouze, W London, B Werner, J Hesser, I Millman, G Saimot, M Payet	discovery of the relationship of hepatitis B virus with hepatocellular carcinoma
1975	B Moss, A Shatkin	discovery that messenger RNA contains a specific nucleotide 5' cap for correct processing during translation (vaccinia, reovirus)
1975	E Southern	development of southern blotting
1976	K Johnson, P Webb, J Lange, F Murphy, S Pattyn, W Jacob, G Van der Groen, P Piot, E Bowen, G Platt, G Lloyd, A Baskerville, colleagues	discovery of Ebola virus
1976	J Bishop, H Varmus	discovery of the cellular origin of retroviral oncogenes
1976	A Evans	special criteria for proof of viral disease causation: the Henle-Koch postulates revisited again
1976	R Rott, C Scholtissek	development of the concept that an optimum constellation of genes determines pathogenicity (influenza viruses)
1976-1977	W Fiers, F Sanger colleagues	first complete sequencing of viral genomes (bacteriophages MS2 and Φ X174)
1977	D Henderson, F Fenner, I Arita, many others	global eradication of smallpox
1977	A Maxam, W Gilbert, F Sanger, colleagues	development of the technology for rapid sequencing of DNA (chain termination (dideoxy) method, and partial cleavage of end-labeled DNA method)

1977	M Rizzetto, J Gerin, M Canese, colleagues	discovery of hepatitis delta virus (the only deltavirus)
1977>	C Woese	recasting of <i>The Tree of Life</i> , phylogeny based on mRNA gene sequences
1978	H Lee, P Lee, K Johnson	discovery of Hantaan virus, the etiologic agent of hemorrhagic fever with renal syndrome, Korean hemorrhagic fever
1978	L Carmichael, M Appel	discovery of canine parvovirus (CPV-2)
1978	C Parrish	molecular characterization, structure and phylogeny of canine parvovirus
1978	D Botstein	discovery of restriction-fragment-length polymorphisms (RFLPs), yeast, bacteriophage, humans
1978	A Waterson, L Wilkinson	publication of the book, <i>An Introduction to the History of Virology</i>
1978	R Swanson, H Boyer	founding of Genentech, the first biotech company listed on the NY Stock Exchange
1978-1985	S Harrison, M Rossman, N Olson, R Kuhn, T Baker, J Hogle, M Chow, R Rueckert, J Johnson	determination of the atomic structure of a plant virus (tomato bushy stunt virus) and vertebrate viruses (poliovirus, rhinovirus)
1979	L Enquist, M Madden, P Schiop-Stanley, G Vande Woude	development of the technology for cloning viral DNA fragments into phage λ vector (herpes simplex virus)
1979	S Halstead	discovery of the role of immune enhancement in the pathogenesis of dengue hemorrhagic fever and dengue shock syndrome
1980	R Gallo, B Poiesz, M Yoshida, I Miyoshi, Y Hinuma, colleagues	discovery of human T lymphotropic viruses 1 and 2, the first unequivocal human cancer viruses to be identified
1980	E Williams, S Young	discovery that chronic wasting disease of deer and elk is a spongiform encephalopathy and caused by a prion
1980s	S Altman, T Cech	discovery of the catalytic properties of RNA, the ribozyme concept
1981	U.S. Centers for Disease Control and Prevention, Morbidity and Mortality Weekly Report (MMWR)	publication of reports of <i>Pneumocystis carinii</i> pneumonia in five previously healthy young men in Los Angeles, and an unusual number of cases of Kaposi sarcoma in gay men—AIDS
1981	V Racaniello, D Baltimore	development of the first infectious recombinant clone of an animal virus (poliovirus)
1981	G Binnig, H Rohrer	development of the scanning tunneling microscope
1981	D Wiley, J Skehel, I Wilson, others	discovery of the structure of the influenza virus hemagglutinin
1981	G Stark, W Burnette, R Reiser, H Towbin	invention of western blotting—electrophoretic transfer of proteins from polyacrylamide gels to nitrocellulose sheets and detection with antibody
1981	W Joklik, H Ginsberg, others	founding of the American Society for Virology
1982	S Prusiner	development of the concept of the prion and the etiologic role of prions in spongiform encephalopathies
1982	W Goad	development of GenBank
1982	M Oldstone, Y Sinha, P Lampert, colleagues	development of the concept of virus-induced alterations in cellular homeostasis and luxury functions of infected cells
1982-1997	G Woode, D Reed, M Weiss, F Steck, M Horzinek, M Koopmans, R Glass, R Guerrant, colleagues	discovery of bovine, equine and human toroviruses
1983	F Barre-Sinoussi, J Chermann, L Montagnier, R Gallo, others	discovery of human immunodeficiency virus 1 (HIV1)
1983	M Balayan, colleagues	discovery of hepatitis E virus (the only hepevirus)
1983	M Carruthers, M Matteucci, M Hunkapiller, Applied Biosystems Inc	development of commercial DNA synthesizer technology
1983	A Murray, J Szostack	development of the yeast artificial chromosome—vector to clone large DNA fragments
1984	B Mahy, R Compans	publication of the journal, <i>Virus Research</i>
1984	M Hilleman, others, Merck Sharp & Dohme Inc	development of the first recombinant vaccine for humans (hepatitis B vaccine made in yeast)
1985	K Mullis, colleagues, Cetus, Perkin-Elmer	invention of the polymerase chain reaction (PCR)
1985>	B Fields, others	publication of <i>Fields Virology</i> , now five editions

1985	bioMérieux, Bio-Rad Genetic Systems, Abbott	development of the first FDA approved HIV antibody tests (EIAs)
1985	N Letvin, R Desrosiers	discovery of simian immunodeficiency virus
1985	F Barin, F Clavel, M Essex, P Kanki, F Brun-Vézinet, others	discovery of human immunodeficiency virus 2 (HIV2)
1985	A Jeffreys	development of DNA fingerprinting (detection of single nucleotide polymorphisms (SNPs) to identify genetic variation)
1985	C Richardson	discovery of bovine spongiform encephalopathy in the United Kingdom
1986	S Kit	development of the first recombinant DNA vaccine for animals (pseudorabies virus, TK-deletion mutant)
1986	R Gallo	discovery of human herpesvirus 6A
1986	N Pedersen, E Ho, M Brown, J Yamamoto	discovery of feline immunodeficiency virus
1987	M St. Clair, S Broder, H Mitsuya, M Fischl, D Richman, Burroughs Wellcome Co, others	development of the first anti-HIV drug approved by the FDA (AZT-zidovudine)
1987	L Hood, A Marion, S Eletr, Applied Biosystems Inc	development of commercial DNA sequencing technology
1987	M Capecchi, M Evans, O Smithies	development of knockout and other genetically manipulated mice
1987>	M Estes	seminal studies of human gastroenteritis viruses (noroviruses, rotaviruses)
1988	C Lopez, P Pellett, K Yamanishi, T Kurata, colleagues	discovery of human herpesvirus 6B and its association with exanthem subitum
1988	National Library of Medicine	founding of the National Center for Biotechnology Information (NCBI) and the creation of public databases and systems for their use
1988>	M Eigen, C Biebricher, J Holland, E Domingo, E Koonin, A Gibbs, L Villarreal, J de la Torre, R Adino, S Weaver, others	development of modern concepts of the origin of viruses, virus evolution and quasispecies
1988>	A Osterhaus, colleagues	discovery of phocine distemper virus, marine mammal morbilliviruses
1989	M Houghton, Q-L Choo, G Kuo, D Bradley, H Alter, colleagues	discovery of hepatitis C virus
1989	T Brock	discovery of Taq polymerase
1989	S Fodor, I Herskowitz, M Schena, R Davies, P Brown, Affymax Research Institute	development of microarray technology
1989	M van Regenmortel	definition of virus species
1990	U.S. National Institutes of Health, U.S. Department of Energy, others	launching of the Human Genome Project
1990	N Frenkel	discovery of human herpesvirus 7
1991	T Berners-Lee	development of the World Wide Web (WWW)
1991	C Venter, H Smith, colleagues (TIGR)	invention of shotgun cloning methods
1991	G Reyes, J Kim, Genelabs Incorporated	development of SISPA (sequence-independent single primer amplification)
1991	R Salas, N de Manzione, R Tesh, R Rico-Hesse, R Shope, colleagues	discovery of Guanarito virus and its association with Venezuelan hemorrhagic fever
1992	J Smith, C Rupprecht, others	development of rabies genotyping and mapping geographic and temporal distribution of virus variants in support of wildlife rabies control programs
1992>	J Lederberg, S Morse, R Shope, S Oaks, M Hamburg, M Smolinski, others	development of the concept of <i>New, Emerging and Re-emerging Infectious Diseases</i> , the basis for rebuilding infectious disease research
1993	N Lisitsyn, N Lisitsyn, M Wigler	development of representational difference analysis (RDA)
1993	S Nichol, C Peters, P Rollin, T Ksiazek, colleagues	discovery of Sin Nombre virus and its association with hantavirus pulmonary syndrome
1993	S Falkow	molecular criteria for proof of viral disease causation: the Henle-Koch postulates revisited again
1994	Y Chang, P Moore	discovery of human herpesvirus 8—Kaposi sarcoma herpesvirus
1994	M Schnell, T Mebatsion, K-K Conzelmann	development of reverse genetics for negative-strand RNA viruses, infectious virus derived from cloned cDNA (rabies virus)

1994	T Lisieux Moraes Coimbra, E Nassar, F Pinheiro, A Travassos da Rosa, R Rico-Hesse, J LeDuc, P Jahrling, colleagues	discovery of Sabiá virus and its association with Brazilian hemorrhagic fever
1995	K Murray, P Hooper, A Hyatt, colleagues	discovery of Hendra virus and its reservoir host fruit bats
1995	R Preston	publication of the influential book, <i>The Hot Zone</i>
1996	R Will, J Ironside, J Collinge, colleagues	discovery that bovine spongiform encephalopathy prion is the cause of variant Creutzfeldt-Jakob disease in humans
1996	D Fredricks, D Relman	development of sequence-based identification of microbial pathogens: the Henle-Koch postulates revisited again
1996	M Hirsch, D Ho, T Merigan, S Hammer, others	development of HAART treatment for AIDS
1996	L Diatchenko, Y-F Luat, A Campbell, P Siebert, colleagues	development of suppression subtractive hybridization [SSH]
1997	National Center for Biotechnology Information	development of PubMed
1997	T Nishizawa, H Okamoto, colleagues	discovery of torque teno virus (TTV) (anellovirus) and its association with acute hepatitis
1998	A Fire, C Mello	discovery of RNA interference (RNAi, RNA silencing by dsRNA)
1998	L Page, S Brin	development of Google
1999	K Chua, S Lam, W Bellini, T Ksiazek, B Eaton, colleagues	discovery of Nipah virus
2001	B van den Hoogen, A Osterhaus, colleagues	discovery of human metapneumovirus
2001	International Human Genome Project: U.S. Department of Energy, U.S. National Institutes of Health, (F Collins, others; National Human Genome Research Institute (NHGRI), The Wellcome Trust), and Celera Genomics (C Venter, others)	completion and publication of draft version of the 2.9-billion base pair (bp) consensus sequence of the euchromatic portion of the human genome
2001>		anthrax bioterrorism events, beginnings of development of large-scale biodefense research and response programs
2002-2006	I Frazer, J Zhou, S-J Ghim, A Jenson, R Schlegel, R Kirnbauer, D Lowy, J Schiller, R Reichman, W Bonnez, R Rose, Sanofi Pasteur, Merck Sharp & Dohme, GlaxoSmithKline	development of papillomavirus vaccine (cervical cancer)
2002>	E Norrby	series of papers describing the awarding of the Nobel Prizes pertinent to virology
2003	C Urbani, J Peiris, S Lai, L Poon, G Drosten, K Stöhr, A Osterhaus, T Ksiazek, D Erdman, C Goldsmith, S Zaki, J DeRisi, many others	discovery of SARS coronavirus
2003	D Raoult, J-M Claverie	discovery of mimivirus, from amoebae, the largest virus known
2005	J Taubenberger, P Palese, T Tumpey, A Garcia-Sastre, others	1918 influenza virus genome sequenced and the virus reconstructed
2005	R Mahieux, A Gessain	discovery of human T lymphotropic viruses 3 and 4
2005	C Rice, F Chisari, T Wakita	manipulation of virus and cells for the first in vitro hepatitis C virus culture system
2005	J Rothberg, 454 Life Sciences	development of very rapid, very high throughput sequencing (pyrosequencing)
2005	European Centre for Disease Prevention and Control	founding of European Centre for Disease Prevention and Control (ECDC)
2006	T Allander	discovery of human bocavirus (parvovirus)
2008-2015	WHO Global Polio Eradication Initiative	planned global eradication of poliomyelitis

Endnotes:**¹ Colleagues who responded to inquiries about the table:**

Garry Adams; Larry Anderson; Pertti Arstila; Lorne Babiuk; Alan Barrett; Barry Beaty; Kenneth Berns; Carol Blair; Aaron Brault; Mike Bray; Michael Buchmeier; Donald Burke; Christopher Burrell; Charles Calisher; Leland Carmichael; Purnell Choppin; Richard Compans; Robert Couch; Andrew Davison; Anthony Della-Porta; James DeMartini; Bryan Eaton; Joseph Esposito; Mary Estes; Thomas Folks; Frank Fenner; Donald Ganem; Hans Gelderblom; Adrian Gibbs; Paul Gibbs; Harry Greenberg; Diane Griffin; Ronald Hedrick; Stephen Higgs; Martin Hirsch; John Holland; Kathryn Holmes; Marian Horzinek; Colin Howard; Peter Howley; Peter Jahrling; Karl Johnson; Richard Johnson; Bill Joklik; Hans-Dieter Klenk; Thomas Ksiazek; Takeshi Kurata; Michael Lairmore; Robert Lamb; Howard Lipton; Paul Luciw; John Mackenzie; James MacLachlan; Brian Mahy; Peter McMinn; Cedric Mims; Edward Mocarski; Thomas Monath; Neal Nathanson; Erling Norrby; Michael Oldstone; Ab Osterhaus; Mark Pallansch; Colin Parrish; Niels Pedersen; C.J. Peters; Craig Pringle; Charles Rice; Harriet Robinson; Bernard Roizman; David Rowlands; Linda Saif; Connie Schmaljohn; Ralph Smith; Samuel Speck; Ellen Strauss; James Strauss; Michael Studdert; Robert Tesh; Guido van der Groen; Marc van Regenmortel; Luis Villarreal; David Walker; Scott Weaver; Robert Webster; Richard Whitley; Washington Winn; Dawn Wooley; Martine Work; William Wunner; Sherif Zaki.

² Who discovered the first virus?

“Although all historical accounts of the beginnings of virology refer to the work of Ivanovsky, Beijerinck, and Loeffler and Frosch (working with Koch), there is disagreement among various authors about who should be credited with the discovery that viruses were a new type of infectious agent. This is an interesting debate since it concerns the question of what is a scientific discovery. Although Ivanovsky was clearly the first one to show that the agent causing tobacco mosaic disease passed through a bacteria-retaining filter, all his publications show that he did not grasp the significance of his observation. He actually believed that the filter he used might have had fine cracks and that small spores of a microbe might have passed through the filter. More than 10 years after his initial observations he remained convinced that he was dealing with a bacterium rather than with a new type of infectious agent. Beijerinck on the other hand, realized he was dealing with something different from a microbe but he thought that the virus was an infectious liquid and not a corpuscular particle. Only Loeffler and Frosch correctly concluded that the virus causing foot-and-mouth disease was a small particle that passed through a Chamberland filter, but was stopped by a fine-grain Kitasato filter. The debate about who should be considered the founder of virology may be settled only if it is accepted that, in order to make a discovery, it is not sufficient to make a novel observation (i.e. the filterability of an infectious agent) but that, in addition, it is also necessary to interpret the observation correctly. Good science does not consist only in making new observations or collecting new data but it requires also unbiased, imaginative thinking which enables the scientist to arrive at the correct interpretation of his experimental findings. Loeffler and Frosch’s interpretation of their filtration experiments came the closest to the modern concept of a virus and so they should be acknowledged as the founders of virology.” From M.H.V. van Regenmortel, 2006.

³ History of the International Congresses for Virology and the International Committee on Taxonomy of Viruses

International Congress for Virology	Place and Year of Congress	Chair(s) of Congress	International Committee on Taxonomy of Viruses Report	President of ICTV & Editor(s) of Report
First Congress	Helsinki, 1968	P Wildy, J Melnick, N Oker-Blom, V Zhdanov	First Report, 1971	P Wildy
Second Congress	Budapest, 1971	J Melnick, P Wildy, N Oker-Blom		
Third Congress	Madrid, 1975	P Wildy, J Melnick, N Oker-Blom	Second Report, 1976	F Fenner
Fourth Congress	Hague, 1978	P Wildy, J van der Want, E Norrby, J Melnick	Third Report, 1979	R Mathews
Fifth Congress	Strasbourg, 1981	J van der Want	Fourth Report, 1982	R Mathews
Sixth Congress	Sendai, 1984	F Murphy	Fifth Report, 1991	R Francki, C Fauquet, D Knudson, F Brown
Seventh Congress	Edmonton, 1987	E Norrby		
Eighth Congress	Berlin, 1990	M van Regenmortel		
Ninth Congress	Glasgow, 1993	B Mahy	Sixth Report, 1995	F Murphy, C Fauquet, D Bishop, S Ghabrial, A Jarvis, G Martelli, M Mayo, M Summers
Tenth Congress	Jerusalem, 1996	R Pettersson		
Eleventh Congress	Sydney, 1999	J Almond		
Twelfth Congress	Paris, 2002	R Compans	Seventh Report, 2000	M van Regenmortel, C Fauquet, D Bishop, E Carstens, M Estes, S Lemon, J Maniloff, M Mayo, D McGeoch, C Pringle, R Wickner
Thirteenth Congress	San Francisco, 2005	H Klenk	Eighth Report, 2005	L Ball, C Fauquet, M Mayo, J Maniloff, U Desselberger
Fourteenth Congress	Istanbul, 2008	G Smith		