# STATISTICS A:

# TABLES AND GRAPHS



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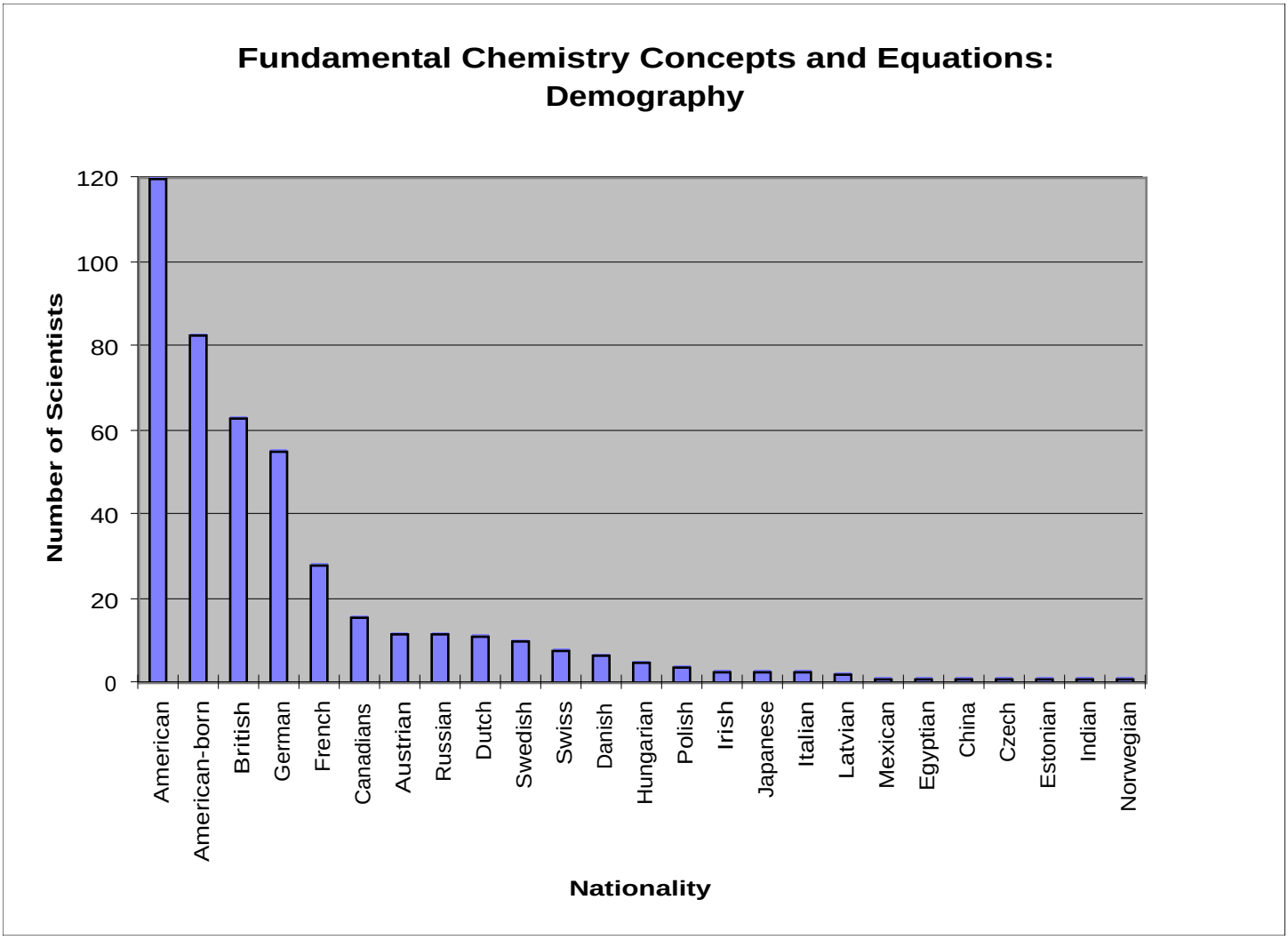
**http://www.chem.yorku.ca/NAMED/**

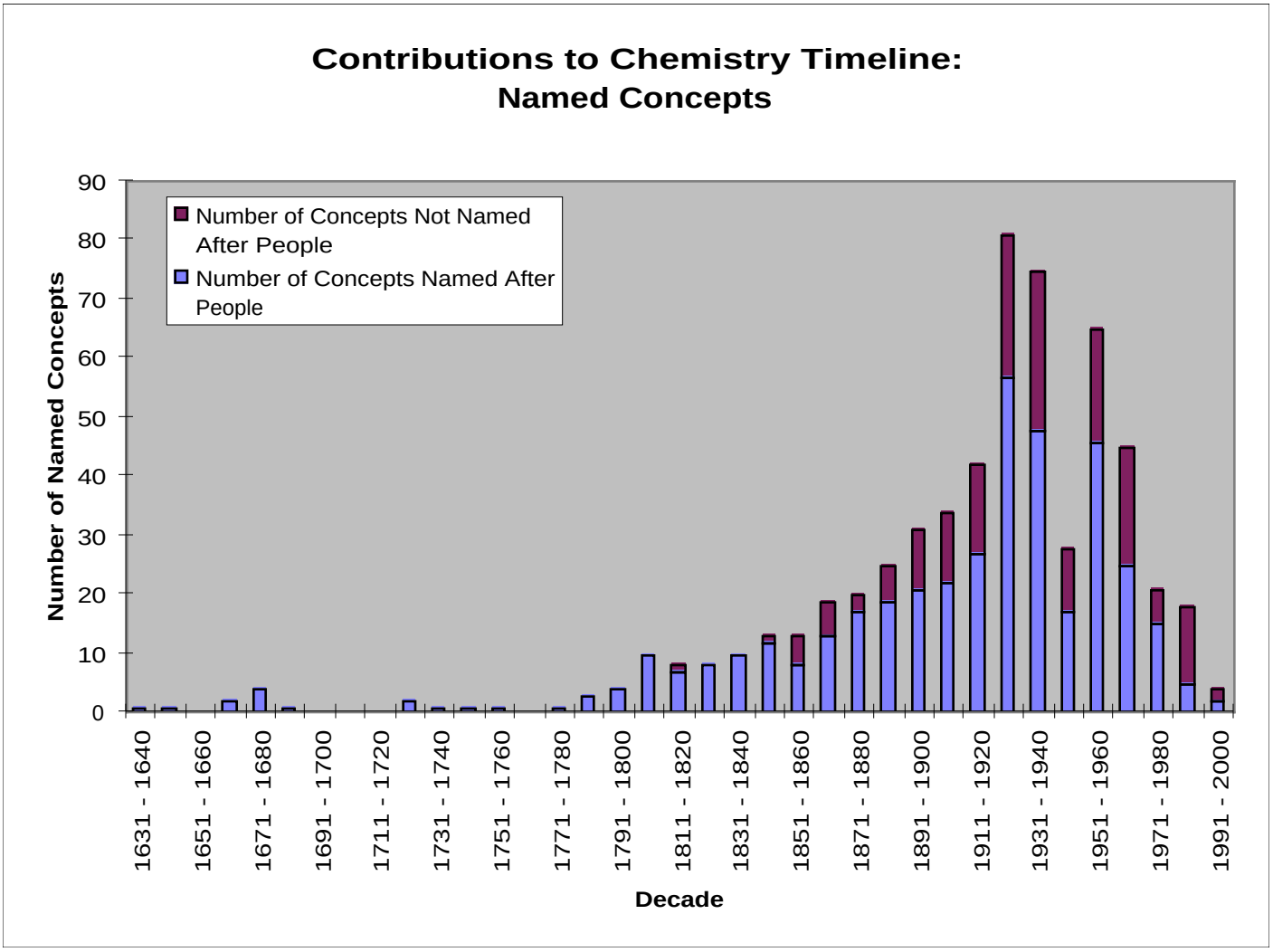
Contents:

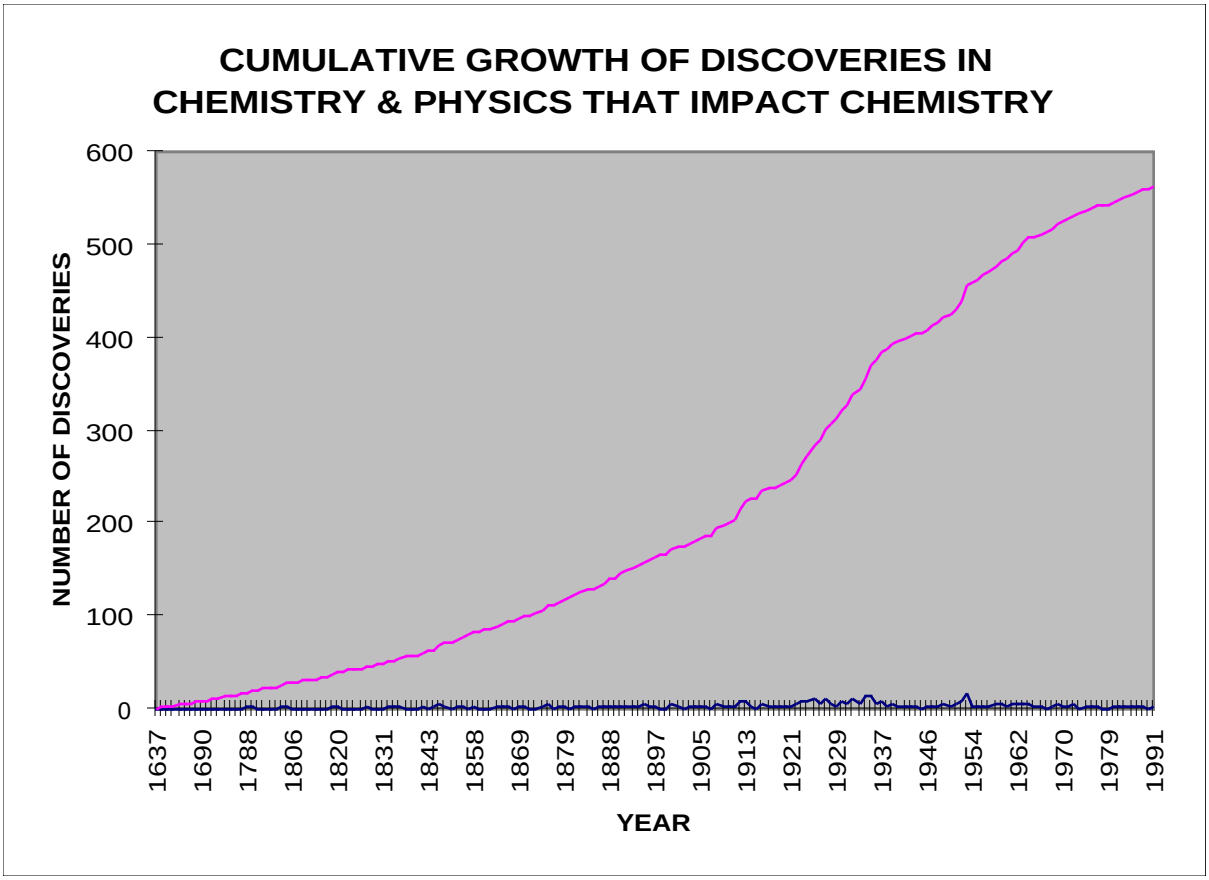
# (1) Fundamental Ideas in Chemistry

| Nationality | Number of Scientists |
|---|---|
| American | 121 |
| American-born | 84 |
| British | 63 |
| German | 55 |
| French | 28 |
| Canadians | 16 |
| Russian | 13 |
| Austrian | 12 |
| Dutch | 11 |
| Swedish | 10 |
| Swiss | 10 |
| Danish | 7 |
| Hungarian | 5 |
| Polish | 4 |
| Irish | 3 |
| Japanese | 3 |
| Italian | 3 |
| Latvian | 2 |
| Mexican | 1 |
| Egyptian | 1 |
| China | 1 |
| Czech | 2 |
| Estonian | 1 |
| Indian | 1 |
| Norwegian | 1 |
| **TOTAL** | **457** |


Fundamental Chemistry Concepts and Equations:
Demography
Number of Scientists
120
100
80
60
40
20
0
American
American-born
British
German
French
Canadians
Austrian
Russian
Dutch
Swedish
Swiss
Danish
Hungarian
Polish
Irish
Japanese
Italian
Latvian
Mexican
Egyptian
China
Czech
Estonian
Indian
Norwegian
Nationality

## (2) Timeline of Ideas in Chemistry




CUMULATIVE GROWTH OF DISCOVERIES IN CHEMISTRY & PHYSICS THAT IMPACT CHEMISTRY
NUMBER OF DISCOVERIES
600
500
400
300
200
100
0
1637
1690
1788
1806
1820
1831
1843
1858
1869
1879
1888
1897
1905
1913
1921
1929
1937
1946
1954
1962
1970
1979
1991
YEAR

| FUNDAMENTAL DEVELOPMENTS BENEFICIAL TO CHEMISTRY: TIMELINE | |
|---|---|
| | |
| **YEAR** | **CONCEPT** |
| 1637 | Snell's law of refraction |
| | |
| 1644 | Torricelli barometer |
| | |
| 1662 | Boyle's law |
| 1663 | Pascal's law of pressure |
| | |
| 1672 | Newton (dispersion of light) |
| 1676 | Mariotte's law |
| 1678 | Hooke's law |
| 1679 | Fermat (refraction of light) |
| | |
| 1690 | Huygens principle |
| | |
| 1724 | Fahrenheit temperature scale |
| 1729 | Bouguer's law |
| | |
| 1738 | Bernoulli (kinetic theory of gases) |
| | |
| 1742 | Celsius temperature scale |
| | |
| 1760 | Lambert's law |
| | |
| 1775 | Lavoisier's law |
| | |
| 1787 | Charles' law |
| 1788 | Coulomb's law |
| 1788 | Blagden's law (freezing point depression) |
| | |
| 1791 | Galvani (electric current) |
| 1791 | Prevost theory of exchanges (dynamic equilibrium between cold and hot bodies) |
| 1799 | Proust's law |
| 1800 | Voltaic cell |
| | |
| 1802 | Dalton's law of partial pressures |
| 1803 | Black (discovery of latent and specific heat) |
| 1804 | Young (interference of light) |
| 1804 | Henry's law |
| 1805 | Dalton's law of multiple proportions |
| 1805 | Dalton's law of solubility of gases in liquids |
| 1806 | Grotthuss chain |
| 1807 | Young's modulus of elasticity |
| 1808 | Dalton's atomic theory |
| 1809 | Gay-Lussac's law |
| | |
| 1811 | Avogadro Law |

| | |
|---|---|
| 1812 | Mohs hardness scale |
| 1817 | Fraunhofer diffraction, lines |
| 1819 | Dulong-Petit law |
| 1820 | Ampere's law |
| 1820 | Oersted law (action of currents on magnets) |
| 1820 | Biot-Savart law |
| | |
| 1821 | Mitscherlich (law of isomorphism) |
| 1822 | Seebeck effect |
| 1822 | Fourier heat theorem |
| 1824 | Carnot cycle |
| 1826 | Fresnel (diffraction of light) |
| 1826 | Ohm's law |
| 1827 | Brownian motion |
| 1830 | Hamilton operator |
| | |
| 1831 | Neumann's law |
| 1832 | Henry (induction concept) |
| 1832 | Berzelius (isomerism concept) |
| 1833 | Graham's law |
| 1833 | Faraday law |
| 1834 | Lenz's law |
| 1834 | Clapeyron equation of state |
| 1836 | Berzelius/Ostwald (catalysis concept) |
| 1838 | Miller's law |
| 1840 | Hess' law |
| | |
| 1841 | Gauss (magnetic force measurement) |
| 1841 | Joule's law |
| 1841 | Grotthuss-Draper law |
| 1843 | Joule (mechanical equivalent of heat) |
| 1847 | Helmholtz (conservation of energy) |
| 1847 | Doppler effect |
| 1848 | Thomson abolute temperature scale (Kelvin) |
| 1848 | Pasteur separation of racemic tartrates |
| 1848 | Kelvin (absolute temperature scale) |
| 1848 | Kohlrausch current theory |
| 1848 | Bravais lattices |
| 1850 | Clausius statement of second law of thermodynamics |
| | |
| 1851 | Hofmann rule |
| 1852 | Beer-Lambert-Bouguer law |
| 1852 | Stokes' law of fluorescence |
| 1855 | Fick's first and second laws of diffusion |
| 1855 | Mohr titration |
| 1856 | Stokes law |
| 1858 | Kirchhoff's laws (electrolytes) |
| 1858 | Kirchhoff's law of heat radiation |
| | |
| 1863 | Mobius strip |

| | |
|---|---|
| 1863 | Kohlrausch relaxation |
| 1865 | Joule-Thomson coefficient |
| 1865 | Kekule structures |
| 1865 | Maxwell electromagnetic equations |
| 1865 | Mach bands |
| 1866 | Loschmidt number |
| 1868 | Angstrom length |
| 1869 | Mendeleev's periodic law |
| 1869 | Tyndall effect |
| 1869 | Massieu functions |
| 1870 | Markovnikov rule |
| 1870 | Lorenz-Lorentz formula |
| | |
| 1871 | Maxwell's thermodynamic equations |
| 1873 | van der Waals equation of state |
| 1874 | van't Hoff-Le Bel asymmetric carbon model |
| 1874 | McLeod vacuum gauge |
| 1875 | Berthelot's equation |
| 1875 | Maxwell-Boltzmann distribution |
| 1875 | Gibbs equation |
| 1875 | Gibbs free energy |
| 1875 | Gibbs phase rule |
| 1875 | Saytzeff rule |
| 1875 | Kerr electro-optic effect |
| 1876 | Viktor Meyer method |
| 1877 | Kerr magneto-optic effect |
| 1877 | Van't Hoff's law |
| 1879 | Stefan law of temperature radiation |
| 1879 | Hall effect |
| 1880 | Curie law |
| | |
| 1882 | Helmholtz equation |
| 1882 | Raoult's law |
| 1882 | Carnelley's melting point-molecular symmetry rule |
| 1883 | Reynolds number |
| 1883 | Kjeldahl method of nitrogen determination |
| 1884 | Le Chatelier's principle |
| 1884 | Van't Hoff equation |
| 1885 | Balmer series |
| 1886 | Allihn condenser |
| 1886 | Gibbs-Duhem equation |
| 1886 | Tait free path |
| 1887 | van't Hoff theory of dilute solutions |
| 1887 | Arrhenius (dissociation of ions in water) |
| 1887 | Michelson-Morley experiment |
| 1888 | Ostwald dilution law |
| 1888 | van't Hoff's law of osmosis |
| 1888 | Beckmann thermometer, Beckmann method |
| 1888 | Hofmeister series |
| 1889 | Arrhenius equation |

| | |
|---|---|
| 1889 | Nernst equation |
| 1890 | Rydberg transition |
| 1890 | Rydberg formula |
| | |
| 1891 | Fischer projections |
| 1893 | Walden inversion rule |
| 1893 | Wien's displacement law |
| 1893 | Werner (configuration of inorganic compounds) |
| 1894 | Meyer steric hindrance |
| 1895 | Roentgen ray |
| 1895 | Dewar flask |
| 1895 | Perrin (negative charges in cathode rays) |
| 1895 | Cotton effect |
| 1895 | Pulfrich's refractometer |
| 1896 | Becquerel, Curie (discovery of radioactivity) |
| 1896 | Fabry-Perot interferometer |
| 1897 | Zeeman effect |
| 1897 | Thompson (discovery of electron) |
| 1900 | Rayleigh-Jeans law |
| 1900 | Planck's equation, quanta concept |
| 1900 | Planck's radiation law |
| 1900 | Larmor precession frequency |
| 1900 | Meyer-Overton rule, hypothesis, theory, correlation |
| | |
| 1901 | Pockels effect |
| 1903 | Thomson model of atom |
| 1904 | Langevin equation |
| 1904 | Bravais-Friedel law |
| 1905 | Friedel's law of rational symmetric intercepts |
| 1905 | Curie-Weiss law |
| 1906 | Nernst heat theorem |
| 1906 | Einstein model |
| 1906 | Rosanoff-Fischer projection rules |
| 1907 | Davies condenser |
| 1908 | Friedel's law of mean indices |
| 1908 | Paschen's series |
| 1908 | Vigreux column |
| 1908 | Haber process |
| 1908 | Henderson-Hasselbalch equation |
| 1908 | Ritz principle, procedure |
| 1908 | Einstein-Smoluchowski equation |
| 1909 | Sorensen pH scale |
| 1909 | Geiger counter |
| 1910 | Hill plot |
| 1910 | Knudsen vacuum gauge |
| 1910 | Abderhalden optical method |
| | |
| 1911 | Gieger-Nuttall law |
| 1911 | Zeleny electroscope |
| 1912 | Debye model, T3 law |

| | |
|---|---|
| 1912 | Einstein law |
| 1912 | Friedrichs condenser |
| 1912 | Bragg equation |
| 1912 | Laue symmetry groups |
| 1912 | Stark-Einstein law of photochemical equivalence |
| 1912 | Debye equation |
| 1913 | Bodenstein steady state approximation |
| 1913 | Michaelis-Menten equation |
| 1913 | Moseley's law |
| 1913 | Bohr model of the atom |
| 1913 | Gouy-Chapman diffuse double layer |
| 1913 | Fajan's bonding rules |
| 1913 | Stark effect |
| 1913 | Millikan oil drop experiment |
| 1914 | Lyman series |
| 1914 | Rutherford scattering |
| 1916 | Sommerfeld model |
| 1916 | Lewis structures |
| 1916 | Ehrenfest adiabatic theorem |
| 1917 | Smoluchowski equation |
| 1917 | Thiele tube |
| 1918 | Madelung series |
| 1918 | Nernst radical chain |
| 1919 | Stern-Volmer plot |
| 1919 | Dufton column |
| 1920 | Dean-Stark apparatus |
| | |
| 1921 | Ehrenfest symmetry factor |
| 1921 | Bohr correspondence principle |
| 1921 | Lande g-factor |
| 1922 | Kasha-Vavilov rule |
| 1922 | Brackett series |
| 1922 | Stern-Gerlach experiment |
| 1922 | Townsend effect |
| 1923 | Auger effect, Auger electron spectroscopy |
| 1923 | Bronsted catalysis law |
| 1923 | Bronsted-Lowry acid |
| 1923 | Debye-Huckel law |
| 1923 | Lewis acid |
| 1923 | Compton effect |
| 1923 | Gaede diffusion pump |
| 1924 | Bronsted-Bjerrum equation |
| 1924 | Pauli exclusion principle |
| 1924 | Pfund series |
| 1924 | Bredt's rule |
| 1924 | Bose-Einstein statistics |
| 1924 | Hanle effect |
| 1924 | Hudson's rules |
| 1925 | Pulfrich's photometer |
| 1925 | de Broglie's law |

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|---|---|
| 1925 | Ising model |
| 1925 | Hund's rules |
| 1925 | Russell-Saunders coupling |
| 1925 | Briggs-Haldane solution to Michaelis-Menten equation |
| 1925 | Haworth formulas |
| 1925 | Paschen-Back effect |
| 1925 | Laporte rule |
| 1926 | Guggenheim method |
| 1926 | Schrodinger equation |
| 1926 | Fermi-Dirac distribution |
| 1926 | Wigner's rules |
| 1926 | Debye-Waller factor |
| 1927 | Rice-Ramsperger-Kassel (RRK) theory |
| 1927 | Born-Oppenheimer approximation |
| 1927 | Heitler-London treatment |
| 1927 | Heisenberg uncertainty principle |
| 1927 | Ehrenfest theorem |
| 1927 | Onsager limiting law |
| 1927 | Hinshelwood equation |
| 1927 | Lennard-Jones potential |
| 1928 | Gamow-Condon-Gurney law |
| 1928 | Raman spectroscopy |
| 1928 | Hartree equation |
| 1928 | Franck-Condon principle |
| 1928 | Grotrian diagrams |
| 1928 | Cori cycle |
| 1929 | Morse potential |
| 1929 | Slater determinant |
| 1930 | Slater orbital |
| 1930 | Haldane equation |
| 1930 | Haldane relationships |
| 1930 | Hickman oil diffusion pump |
| 1930 | London dispersion forces |
| 1930 | Turner-Czerny optical arrangement |
| 1930 | Mills-Nixon effect |
| | |
| 1931 | Huckel molecular orbital theory |
| 1931 | Jablonski diagram |
| 1931 | Huckel 4n + 2 rule |
| 1931 | Onsager reciprocal relations |
| 1931 | Van de Graaff electrostatic generator |
| 1931 | Pfeiffer effect |
| 1932 | Hammett acidity function |
| 1932 | Pauling electronegativity scale |
| 1932 | Wigner tunnelling correction |
| 1932 | van Vleck paramagnetism |
| 1932 | Hanes-Woolf plot |
| 1932 | Fenske equation |
| 1932 | Langmuir adsorption isotherm |
| 1932 | Langmuir equation |

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|---|---|
| 1933 | Koopmans theorem |
| 1933 | Bell equation |
| 1933 | Hellmann-Feynmann theorem |
| 1933 | Kapustinskii equation |
| 1934 | Patterson functions |
| 1934 | Szilard-Chalmers effect |
| 1934 | Badger rules and equation |
| 1934 | Lineweaver-Burk plot |
| 1934 | Kirkwood-Onsager equation |
| 1934 | Moller-Plesset single point energy calculation |
| 1934 | Renner-Teller effect |
| 1934 | Chadwick (discovery of neutron) |
| 1934 | Cherenkov effect, radiation |
| 1934 | Mulliken-Jaffe electronegativity scale |
| 1935 | Müller-Müller-Rodloff biradical rule |
| 1935 | Teller-Redlich product rule |
| 1935 | Baker-Nathan effect |
| 1935 | Eyring equation |
| 1935 | Hammett equation |
| 1935 | Eyring transition state theory |
| 1935 | Kreb's cycle |
| 1935 | London equations |
| 1935 | London equations (superconductivity) |
| 1936 | Gross-Butler equation |
| 1936 | Bell-Evans-Polanyi principle |
| 1936 | Jahn-Teller effect |
| 1936 | Gamow-Teller selection rule |
| 1936 | Gray unit of radiation |
| 1937 | Penning vacuum gauge |
| 1937 | Krebs cycle |
| 1937 | Fiegl spot tests |
| 1937 | Langmuir-Blodgett film |
| 1938 | Evans-Polanyi relation |
| 1938 | BET (Brunauer-Emmett-Teller) method |
| 1939 | Zucker-Hammett hypothesis |
| 1939 | Evans principle |
| 1939 | Weibull distribution |
| 1940 | Pauli principle |
| | |
| 1941 | Fieser-Woodward rules |
| 1941 | Stockmayer potential |
| 1942 | Eadie plot |
| 1942 | Flory-Huggins theory |
| 1942 | Wheland intermediate |
| 1944 | Pirani vacuum gauge |
| 1945 | Pitzer ring strain |
| 1946 | Bloch equations |
| 1947 | Bigeleisen-Wolfsberg equation |
| 1947 | Bigeleisen-Goepper-Mayer heavy atom approximation |
| 1948 | Jones effect |

| | |
|---|---|
| 1948 | Grunwald-Winstein equation |
| 1948 | Pake pattern |
| 1949 | Forster cycle |
| 1949 | Scatchard plot |
| 1950 | Feynman diagrams |
| 1950 | Hahn spin echoes |
| 1950 | Kasha's rule |
| 1950 | Lowdin orthogonalization |
| | |
| 1951 | Hartree-Fock-Roothaan theory |
| 1951 | Cahn-Ingold-Prelog rules |
| 1951 | Rice-Ramsperger-Kassel-Marcus (RRKM) theory |
| 1951 | Davydov splitting/exciton theory |
| 1951 | Dewar-Chatt-Duncanson model |
| 1952 | Fukui frontier molecular orbital theory |
| 1952 | Taft equation |
| 1952 | Dewar PMO method |
| 1952 | Entner-Doudoroff pathway |
| 1953 | PPP theory (Pariser-Parr-Pople) |
| 1953 | Prelog's rules |
| 1953 | Doering-Zeiss intermediate |
| 1953 | Dexter excitation transfer |
| 1953 | Frost polygon |
| 1953 | Leffler hypothesis |
| 1953 | Swain-Scott equation |
| 1953 | Nuclear Overhauser effect |
| 1953 | Walsh diagrams |
| 1953 | Shoolery rule |
| 1953 | Humphreys series |
| 1953 | Watson-Crick base pairing in DNA |
| 1953 | Mossbauer spectroscopy |
| 1954 | Curtin-Hammett principle |
| 1954 | Carr-Purcell experiment |
| 1954 | Ramachandran triple helix (collagen) |
| 1955 | Hammond postulate |
| 1955 | Newman projection |
| 1955 | Winstein-Holness equation |
| 1955 | Mulliken population analysis |
| 1956 | Edwards equation |
| 1956 | Marcus equation |
| 1956 | King-Altman method |
| 1956 | Calvin cycle |
| 1957 | BCS (Bardeen-Cooper-Schrieffer) theory of superconductivity |
| 1957 | Gillespie-Nyholm model |
| 1957 | Zimmerman-Traxler transition state |
| 1957 | Allred-Rochow electronegativity scale |
| 1958 | Kosower Z-values |
| 1958 | Dirac bracket notation |
| 1958 | Swain-Schaad equation |
| 1959 | Hofstee plot |

| | |
|---|---|
| 1959 | Yukawa-Tsuno equation |
| 1959 | Karplus equation |
| 1959 | Cram's rule |
| 1959 | CPK space filling models (Corey-Pauling-Koltun) |
| 1960 | Alder rule |
| 1960 | Berry pseudorotation |
| 1960 | Wanzlich equilibrium |
| | |
| 1961 | Marcus-Hush relationship |
| 1961 | Schenck sensitization mechanism |
| 1961 | Westheimer principle |
| 1961 | Dreiding molecular model |
| 1962 | Hartmann-Hahn experiment |
| 1962 | Method of Wong and Hanes |
| 1963 | Schachtschneider method of vibrational frequency calculations |
| 1963 | Dimroth-Reichardt parameter |
| 1963 | Pearson's HSAB principle |
| 1963 | Cleland rules |
| 1963 | Hoogsteen base pairing |
| 1963 | Meutterties rule |
| 1963 | Ramachandran plot |
| 1963 | Birks scheme for excimer fluorescence |
| 1964 | Eigen curve |
| 1965 | Woodward-Hoffmann rules |
| 1966 | Bunnett-Olsen equations |
| 1966 | Volkenstein-Goldstein method |
| 1966 | Dunitz angle |
| 1966 | Hammond-Herkstroeter plot |
| 1966 | Feynman ratchet and pawl |
| 1967 | Verlet algorithm in reaction dynamics |
| 1968 | Swain-Lupton equation |
| 1968 | El-Sayed's rule |
| 1969 | Kaptein-Closs rules |
| 1969 | Benson's additivity rules |
| 1969 | Edward-Lemieux effect (anomeric effect) |
| 1969 | Hansch constant |
| 1969 | Chauvin-Herisson mechanism |
| 1970 | More O'Ferrall-Jencks diagram |
| 1970 | Rehm-Weller equation |
| | |
| 1972 | Ritchie equation |
| 1972 | Kaptein's rules |
| 1972 | Koppel-Palm solvent parameters |
| 1974 | Cornish-Bowden plot |
| 1975 | Redfield sequence |
| 1975 | Sanger method of DNA sequencing |
| 1975 | Southern blot |
| 1975 | Tolman cone angle |
| 1975 | Bordwell carbon acidity scale in polar non-hydrogen-bond solvents |
| 1976 | Kamlet-Taft solvent parameters |

| | |
|---|---|
| 1976 | Davydov splitting |
| 1976 | Baldwin's rules |
| 1977 | Kaptein-Closs rules |
| 1977 | Jencks' clock |
| 1977 | Maxam-Gilbert method of DNA sequencing |
| 1977 | Topliss decision tree |
| 1978 | Cox-Yates acidity function |
| | |
| 1985 | Albery-Siebrand model |
| 1985 | Maehr stereochemical descriptors |
| 1988 | Boyd-Edgecombe electronegativity parameters |
| 1988 | Becke-Lee-Yang-Parr method |
| 1990 | Lever ligand electrochemical parameters |
| | |
| 1991 | ZINDO (Zerner-INDO) method |
| 1997 | Lipinski rule of 5 |
| | |
| 2001 | Little effect |

## (3) Concepts in Chemistry Not Named After People

| YEAR | CONCEPTS NOT NAMED AFTER PEOPLE | SCIENTISTS |
|---|---|---|
| 1819 | Discovery of optical rotation of plane polarized light | Biot, J.B. |
| 1832 | Concept that green parts of plants absorb carbon dioxide so that light energy is transformed into chemical energy | Dutrochet, R.H. |
| 1848 | stereochemistry | Pasteur, L./van't Hoff, J.H./Le Bel, J.A. |
| 1850 | laws of chemical kinetics | van't Hoff, J.H./Wilhelmy, L.F. |
| 1852 | concept of valence | Frankand, Sir E. |
| 1855 | actinometry | Bunsen, R./Roscoe, H. |
| 1858 | tetravalent nature of carbon | Couper, A.S./Kekuke, A. |
| 1858 | Distinction between atoms and molecules | Cannizzaro, S. |
| 1859 | Spectra of gases | Plücker, J./Hittorf, W. |
| | | |
| 1860 | atomic spectra | Kirchhoff, G.; Hartley, W.N.; Bunsen, R. |
| 1861 | forerunner of modern structural formula | Loschmidt, J. |
| 1866 | phosphorescence | Sidot, T. |
| 1867 | law of mass action | Waage. P./Guldberg, C./Harcourt, A.V./Esson, W. |
| 1867 | Doubling of reaction rate with a 10 degree increment in temperature | Harcourt, A.V. |
| 1868 | origin of colour | Graebe, C./Liebermann, C./Witt, O.N./Armstrong, H.E. |

| | | |
|---|---|---|
| 1874 | Aromatic substitution | Koerner, W. |
| 1875 | Isomer enumeration | Cayley, A./<br>Crum Brown, A. |
| 1877 | tautomerism | Laar, C./Butlerov, A./Baeyer, A./Wislicenus, J./Meyer, K.H./Knorr, L./Nef, J.U./Michael, A. |
| 1879 | ultraviolet spectroscopy | Hartley, W.N./Huntington, A.K. |
| 1880 | Discovery of isomorphism and polymorphism in crystals | Mallard, F.E. |
| 1880 | Oxidation numbers | Johnson, O.C. |
| | | |
| 1883 | catalysis | Ostwald, W. |
| 1887 | ionization theory | Arrhenius, S. |
| 1888 | law of osmotic pressure | van't Hoff, J.H. |
| 1888 | Discovery of liquid crystals | Reinitzer, F. |
| 1890 | chair and boat ring conformations | Sachse, H./Mohr, E. |
| 1890 | Stereoisomerism (existence of stereoisomers) | Meyer, V./<br>Auwers, K./Eiloart, A. |
| | | |
| 1891 | Discovery of cyclodextrins | Villiers, A./Schardinger, F. |
| 1894 | co-ordination numbers in inorganic compounds | Werner, A. |
| 1894 | steric effect | Meyer, V. |
| 1896 | Active transport of solutes against concentration gradient | Overton, C.E. |
| 1897 | cell-free fermentation | Buchner, E. |
| 1897 | discovery of electron | Thomson, J.J. |
| 1898 | colloids | Zsigmondy, R./Svedberg, T. |
| 1899 | reaction intermediates concept (carbocations) | Stieglitz, J./Norris, J.F. |
| 1900 | disintegration of the elements | Rutherford, E. |
| 1900 | quantum concept | Planck, M. |
| | | |
| 1901 | blackbody radiation | Planck, M. |
| 1902 | protein and peptide structure | Fischer, E. |
| 1903 | use of enzymes to catalyze simple organic reactions | Acree, S.F./Kastle, J.H./Loevenhart, A.S./Cornforth, J.W./Prelog, V. |
| 1904 | Transmutation of the elements | Brooks, H. |
| 1905 | infrared spectroscopy | Coblentz, W.W. |
| 1905 | photoelectric effect | Einstein, A. |
| 1905 | Isotope concept | Soddy, F. |
| 1906 | chromatography | Tswett, M. |
| 1908 | liquification of helium | Kamerlingh-Onnes, H. |
| 1909 | alpha particles | Rutherford, E. |
| 1910 | directing groups in aromatic chemistry | Holleman, A.F. |
| 1910 | discovery of sedimentation equilibrium | Perrin, J.B. |

| | | |
|---|---|---|
| 1911 | atomic nucleus | Rutherford, E. |
| 1911 | Discovery of optical activity in co-ordination compounds | Werner, A./King, V.L. |
| 1912 | x-ray diffraction | Laue, M./Bragg, W.L./Bragg, W.H. |
| 1912 | chemical high pressure methods | Bergius, F./Bosch, C. |
| 1913 | group displacement law | Fajans, K.; Soddy, F. |
| 1913 | radiotracers | Paneth, F./Hevesy, G. |
| 1914 | superconductivity at low temperatures | Kamerlingh-Onnes, H. |
| 1914 | potential energy surfaces | Marcelin, R. |
| 1914 | Experimental verification of tetrahedral asymmetry at carbon | Fischer, E. |
| 1915 | pH indicators | Lubs, H.A./Clark, W.M./Acree, S.F. |
| 1915 | Dipole moment | Debye, P. |
| 1916 | covalent bonding | Lewis, G.N. |
| 1916 | octet rule | Lewis, G.N./Langmuir, I. |
| 1916 | kinetics of adsorption | Langmuir, I. |
| 1917 | mutorotations | Hudson, C.S. |
| 1918 | mass spectrometry | Aston, F.W. |
| 1919 | concept of isosteres | Langmuir, I.; Mulliken, R.; Hund, F. |
| 1920 | hydrogen bonding | Latimer, W.H./Rodebush, W.H./Huggins, M.L. |
| 1920 | Rule of alternating polarities | Lapworth,A. |
| | | |
| 1921 | electrophilicity-nucleophilicity | Fry, H.S./Bronsted, J.N./Lowry, T.M./Lapworth, A./Lewis, G.N. |
| 1922 | combustion and explosives | Hinshelwood, C.N./Semenov, N.N. |
| 1922 | polymer chemistry | Staudinger, H. |
| 1922 | Asymmetric molecule without asymmetric carbon atoms | Christie, G.H./Kenner, J. |
| 1923 | inductive effect | Lewis, G.N./Ingold, C.K./Lowry, T.M. |
| 1923 | vectorial analysis of net dipole moment | Thomson, J.J. |
| 1923 | Connection between SN2 mechanism and Waldon inversion rule | Phillips, H./Kenyon, J. |
| 1924 | electron configuration (aufbau principle) | Bohr, N. |
| 1924 | linear free energy relationships | Bronsted, J.N./Pedersen, K./Hammett, L.P. |
| 1924 | mesomeric (resonance) effect | Lucas, H.J./Arndt, F./Ingold, C.K. |
| 1924 | Concept of isobestic point | Thiel, A./Prideaux, E.B.R. |
| 1925 | synthesis of radioactive elements | Joliot, F./Joliot-Curie, I. |
| 1925 | crystal lattice energy | Mayer, J.E.; Lennard-Jones, J.E. |

| | | |
|---|---|---|
| 1926 | crystallization of enzymes | Sumner, J.B. |
| 1926 | electron spin | Uhlenbeck, G./ Goudsmit, S.A. |
| 1926 | Electronic theory of organic chemistry | Robinson, R./Ingold, C.K. |
| 1927 | solvolysis | Ward, A.M./Hammett, L.P. |
| 1927 | wave nature of electron | Davisson, C.J./Germer, L.H. |
| 1927 | discovery of cytochromes | Keilin, D. |
| 1928 | electron diffraction by crystals | Davisson, C.J./Thomson, G.P. |
| 1928 | quantum theory of electron | Dirac, P.A.M. |
| 1929 | concept of conformation | Haworth, W.N. |
| 1929 | discovery of parahydrogen | Harteck, P. |
| 1930 | electrostatic (field) effect | London, F. |
| 1930 | microanalytical methods for organic substances | Pregl, F. |
| 1930 | development of the cyclotron | Lawrence, E.O. |
| 1930 | partition functions | Giauque, W.; Eyring, H.; Halford; Eidenhoff |
| | | |
| 1932 | discovery of deuterium | Urey, H.C. |
| 1932 | protecting groups in organic synthesis | Bergmann, M. |
| 1932 | discovery of neutron | Chadwick, J. |
| 1933 | absolute zero measurements | Giauque, W.F. |
| 1933 | atropisomerism | Kuhn, R. |
| 1933 | Whole number rule for isotopes | Aston, F.W. |
| 1933 | Three-point model for molecular chiral recognition | Easson, E.H./Stedman, E./Ogston, A.G. |
| 1934 | hyperconjugation | Wheland, G.W. |
| 1934 | SN1/SN2 | Ingold, C.K./Hughes, E.D. |
| 1934 | synthesis of new radioactive elements using slow neutrons | Fermi, E. |
| 1934 | phase contrast microscopy | Zernike, F. |
| 1935 | ion exchange resins | Adams, B.A./Holmes, E.L. |
| 1935 | substituent effect | Hammett, L.P. |
| 1935 | isotopic exchange | Urey, H.C. |
| 1935 | isotopic labelling experiment | Urey, H.C./Ingold, C.K./Rittenberg, D./Schoenheimer, R. |
| 1935 | nuclear fission | Hahn, O./Meitner, L. |
| 1935 | Dipole moment measurements to elucidate stereochemistry | Jensen, K.A. |
| 1935 | Concept of resonance hybrids | Bury, C.R. |
| 1936 | isotope effect | Reitz, O. |
| 1936 | discovery of rotational barrier in ethane | Pitzer, K.S. |
| 1937 | chain mechanism (concept of chain transfer and vinyl polymerization kinetics) | Flory, P.J. |
| 1937 | crossover experiment | Hurd, C.D. |
| 1937 | acidity function | Hammett, L.P. |
| 1937 | condensed matter physics | Landau, L.D. |
| 1937 | Peroxide effect | Kharash, M.S./Mayo, F.R. |

| | | |
|---|---|---|
| 1938 | principle of least motion | Rice, F.O./Teller, E. |
| 1939 | anchimeric assistance | Winstein, S. |
| 1939 | energy production from ATP by enzyme catalysis | Engelhardt, V.A. |
| 1939 | Effect of resonance on electronic transitions | Pauling, L./ Lewis, G.N./Calvin, M. |
| 1939 | Electrode kinetics | Eyring, H./Laidler, K.J. |
| 1940 | Heterogeneous catalysis | Eyring, H./Laidler, K.J. |
| 1940 | Solvent effects in kinetics | Eyring, H./Laidler, K.J. |
| 1940 | common ion effect | Ingold, C.K. |
| 1940 | normal salt effect | Ingold, C.K./Winstein, S. |
| 1940 | concept of complementariness in biological macromolecules | Pauling, L. |
| 1940 | Stopped flow technique | Chance, B./Gibson, Q.H. |
| | | |
| 1941 | A1 and A2 mechanisms | Ingold, C.K. |
| 1941 | liquid-liquid and gas-liquid chromatography | Martin, A.J.P./Synge, R.L.M. |
| 1941 | discovery of carbon-14 | Kamen, M. |
| 1944 | B-strain (bond) | Brown, H.C. |
| 1944 | discovery of streptomycin | Schatz, A./Waksman, S.E. |
| 1944 | DNA as source of heredity | Avery, O.T. |
| 1945 | F-strain (force) | Brown, H.C. |
| 1946 | nuclear magnetic resonance | Purcell, E.M./Bloch, F. |
| 1946 | chain reacting atomic pile | Fermi, E. |
| 1947 | electron spin resonance | Zavoiskii, E.K. |
| 1948 | hybridization in chemical bonding | Pauling, L. |
| 1948 | E1/E2 eliminations | Ingold, C.K./Hughes, E.D. |
| 1949 | thin layer chromatography | Meinhard, J.E./Hall, N.F./Keller, C.J./Kirchner, J.K./Miller, J.M. |
| 1949 | time resolved spectroscopy and kinetics | Norrish, R.G.W./Porter, G./Eigen, M. |
| 1949 | nuclear shell model | Goeppert-Mayer, M. |
| | | |
| 1950 | DNA base complementarity | Chargaff, E. |
| 1950 | I-strain (internal) | Brown, H.C. |
| 1951 | protein structures (alpha-helix; beta-sheet; kinks) | Pauling, L./Corey, R.B. |
| 1951 | Verification of absolute configuration of tartaric acid (verification of Fischer's assignments) | Bijvoet, B.M. |
| 1952 | asymmetric induction | Cram, D.J. |
| 1952 | conformation in organic synthesis | Barton, D.H.R./Hassel, O. |
| 1952 | frontier molecular orbital theory | Fukui, K. |
| 1952 | intimate and solvent separated ion pairs | Cram, D.J./Winstein, S. |
| 1952 | radio carbon dating | Libby, W.F. |
| 1953 | Pulse radiolysis | Gray, L.H./Boag, J.W. |
| 1953 | NMR lineshape analysis and coalescence phenomena | Gutowsky, H.S. |
| 1953 | Prebiotic synthesis of amino acids | Miller, S.L./Urey, H.C. |
| 1953 | Interpretation of pH rate profiles as straight line segments | Dixon, M. |

| | | |
|---|---|---|
| 1953 | Enzyme inhibition plots | Dixon, M. |
| 1954 | special salt effect | Winstein, S. |
| 1954 | Matrix isolation spectrscopy | Pimentel, G.C./Porter, G. |
| 1957 | connection between structure and function of proteins | Anfinsen, C.B. |
| 1957 | electron microscopy | Ruska, E./Siegbahn, K. |
| 1958 | discovery of recombinant DNA | Berg, P. |
| 1958 | electrophoresis | Tiselius, A. |
| 1959 | discovery of metallocenes | Wilkinson, G./Fischer, E.O. |
| 1959 | Temperature jump (T-jump) technique | Eigen, M. |
| | | |
| 1961 | chemiosmotic theory | Mitchell, P. |
| 1961 | octant rule | Djerassi, C./ Woodward, R.B. |
| 1962 | Alpha effect nucleophiles | Edwards, J.O./ Pearson, R.G. |
| 1962 | Photoaffinity labelling | Thornton, E.R./ Westheimer, F.H. |
| 1962 | noble gas compounds (XePtF6) | Bartlett, N. |
| 1962 | non-equilibrium thermodynamics | Prigogine, I. |
| 1962 | RNA codons for protein synthesis | Boyer, P. |
| 1962 | Electron capture detector | Lovelock, J.E. |
| 1962 | Discovery of hydrated electron | Boag, J.W. |
| 1962 | Pulse radiolysis | Dorfman, L.M. |
| 1963 | valence shell electron pair repulsion theory (VSEPR) | Gillespie, R.J. |
| 1964 | QSAR (quantitative structure-activity relationship) | Hansch, C. |
| 1964 | fractionation factor theory | Kresge, A.J./Gold, V. |
| 1964 | retrosynthetic analysis | Corey, E,J. |
| 1964 | density functional theory | Parr, R.G./Yang, W./Kohn, W./Becke, A./Lee, C. |
| 1964 | dye lasers | Schaefer, F.P. |
| 1965 | Discovery of organometallic complexes of dinitrogen | Allen, A.D./Senoff, C.V. |
| 1966 | Delayed excimer fluorescence | Birks, J.B. |
| 1967 | molecular mechanics calculations | Allinger, N.L. |
| 1967 | Enzyme-substrate Pn nomenclature | Schechter, I. |
| 1968 | polarography | Heyrovsky, M. |
| 1968 | scaling laws | de Gennes, P.G. |
| 1969 | laser spectroscopy | Bloembergen, N./Schawlow, A.L. |
| 1969 | principle of microscopic reversibility | Ingold, C.K. |
| 1969 | Pump-probe technique | Buettner, A.V./Snavely, B.B./Peterson, O.G. |
| | | |
| 1970 | SNR1 mechanism | Bunnett, J.F. |
| 1970 | Factor analysis method | Malinowski, E.R. |
| 1971 | discovery of transfer-RNA | Altman, S./Cech, T.R. |
| 1971 | host-guest chemistry | Cram, D.J./Lehn, J.M./Pedersen, C.J. |
| 1972 | gauche effect | Wolfe, S. |

| | | |
|---|---|---|
| 1972 | 16- and 18-electron rule for organometallic complexes | Tolman, C.A. |
| 1973 | Application of Marcus theory to proton transfer reactions | Kresge, A.J. |
| 1978 | Probe technique to observe invisible transients | Scaiano, J.C. |
| 1978 | Captodative effect | Viehe, H.G. |
| 1979 | ligand field theory | Ballhausen, C.J. |
| 1979 | 3D QSAR analysis | Marshall, G.R. |
| | | |
| 1981 | scanning tunnelling microscopy | Binnig, G./Rohrer, H. |
| 1981 | atoms in molecules (AIM) | Bader, R.F.W. |
| 1981 | Two laser-two colour experiment | Bernstein, R.B./ Smalley, R.E./ Rentzepis, P.M./ Scaiano, J.C. |
| 1982 | proton inventory technique | Schowen, R.L. |
| 1982 | site-directed mutagenesis | Smith, M. |
| 1984 | reactivity-selectivity principle | Giese, B. |
| 1984 | Discovery of organometallic complexes of dihydrogen | Kubas, G.J./Ryan, R.R./Swanson, B.I./Vergamini, P.J./Wasserman, H.J. |
| 1985 | principle of non-perfect synchronization | Bernasconi, C.F. |
| 1985 | discovery of c60 | Kroto, H.W./Smalley, R.E./Curl, R.F. |
| 1986 | general valence bond theory | Goddard (III), W.A. |
| 1986 | atomic force microscopy | Binnig, G./Gerber, C./Quate, C.F. |
| 1986 | Combinatorial chemistry | Furka, A. |
| 1986 | polymerase chain reaction (PCR) method | Mullis, K.B. |
| 1988 | Comparative molecular field analysis (CoMFA) | Cramer, R.D. (III) |
| 1988 | Variable Marcus intrinsic barriers for deprotonation of carbon acids | Bunting, J.W./ Stefanidis, D. |
| | | |
| 1991 | Atom economy reaction metric | Trost, B. |
| 1992 | Environmental impact factor reaction metric | Sheldon, R.A. |
| 1993 | Laser drop experiment | Banks, J.T./Scaiano, J.C. |
| 1999 | No-barrier multi-dimensional Marcus theory | Guthrie, J.P. |
| | | |
| 2002 | First observation of distinct steps in SN1 reaction | Mayr, H. |

# (4) Concepts in Physical Organic Chemistry

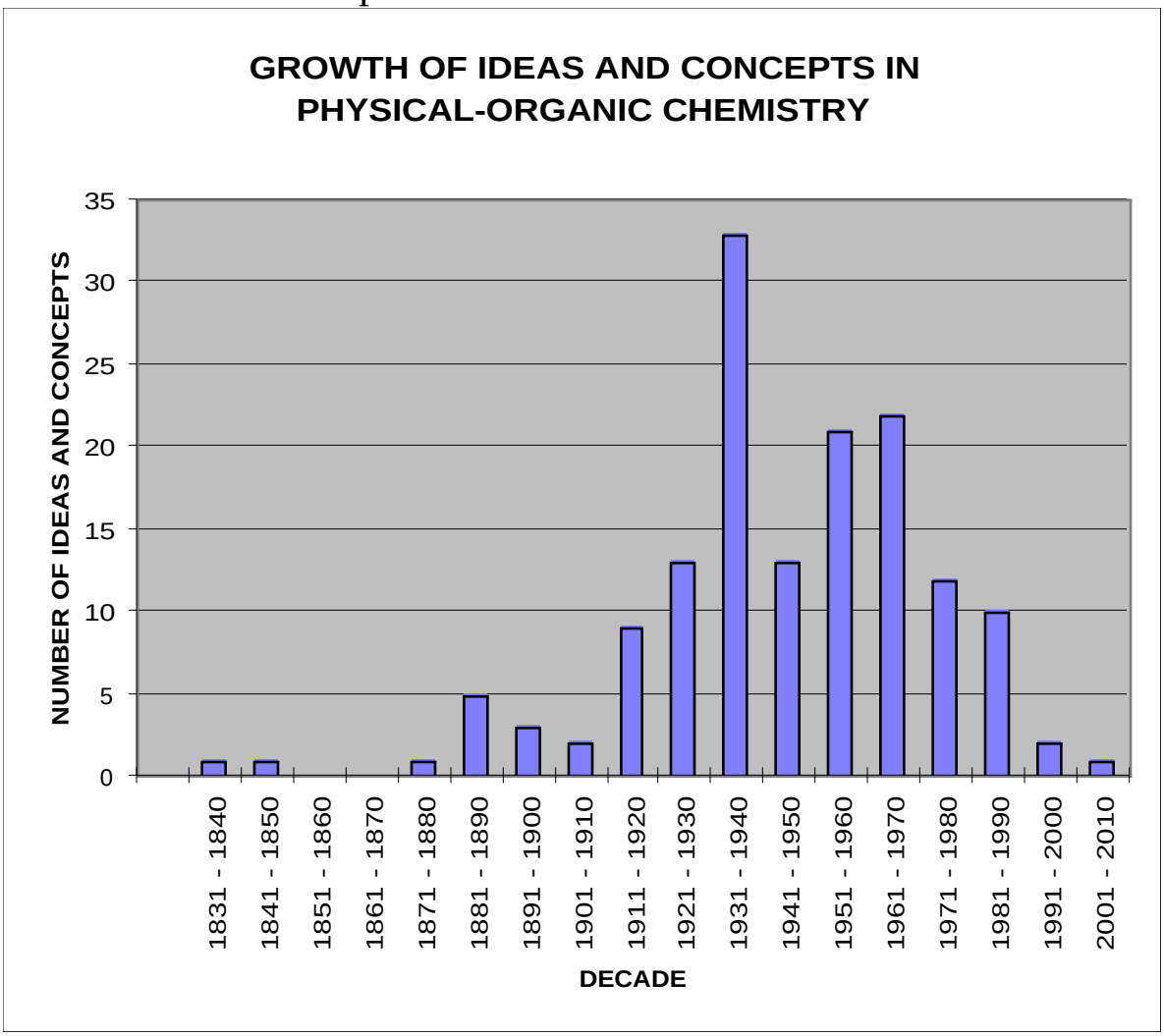
| | **CHRONOLOGY OF CONCEPTS IN PHYSICAL-ORGANIC CHEMISTRY** |
|---|---|
| **YEAR** | **CONCEPT (SCIENTISTS)** |
| 1836 | Berzelius-Ostwald catalysis concept |
| 1850 | laws of chemical kinetics (van't Hoff, J.H./Wilhelmy, L.F.) |
| 1877 | tautomerism (Laar, C./Butlerov, A./Baeyer, A./Wislicenus, J./Meyer, K.H./Knorr, L./Nef, J.U./Michael, A.) |
| 1883 | catalysis (Ostwald, W.) |
| 1884 | Le Chatelier's principle |
| 1887 | ionization theory (Arrhenius, S.) |
| 1889 | Arrhenius equation |
| 1890 | chair and boat ring conformations (Sachse, H./Mohr, E.) |
| 1893 | Walden inversion rule |
| 1894 | steric effect (Meyer, V.) |
| 1899 | reaction intermediates concept (carbocations) (Stieglitz, J./Norris, J.F.) |
| 1907 | Acree-Curtin-Hammett principle |
| 1910 | directing groups in aromatic chemistry (Holleman, A.F.) |
| 1910 | Hill plot |
| 1913 | Bodenstein steady state approximation |
| **1913** | **Michaelis-Menten equation** |
| 1914 | potential energy surfaces (Marcelin, R.) |
| 1915 | pH indicators (Lubs, H.A./Clark, W.M./Acree, S.F.) |
| 1916 | covalent bonding (Lewis, G.N.) |
| 1916 | octet rule (Lewis, G.N./Langmuir, I.) |
| 1918 | Nernst radical chain |
| 1919 | Stern-Volmer plot |
| 1920 | hydrogen bonding (Latimer, W.H./Rodebush, W.H./Huggins, M.L.) |
| 1921 | electrophilicity-nucleophilicity (Fry, H.S./Bronsted, J.N./Lowry, T.M./Lapworth, A./Lewis, G.N.) |
| 1923 | Lewis acid |
| 1923 | inductive effect (Lewis, G.N./Ingold, C.K./Lowry, T.M.) |
| 1923 | Bronsted catalysis law |
| 1923 | Bronsted-Lowry acid |
| 1924 | linear free energy relationships (Bronsted, J.N./Pedersen, K./Hammett, L.P.) |
| 1924 | mesomeric (resonance) effect (Lucas, H.J./Arndt, F./Ingold, C.K.) |
| 1926 | Guggenheim method |
| 1926 | Concept of partial charges in chemical structures (Ingold, C.K./ Ingold, E.H.) |
| 1926 | Electronic theory of organic chemistry (Robinson, R./Ingold, C.K.) |
| 1927 | Born-Oppenheimer approximation |
| 1927 | solvolysis (Ward, A.M./Hammett, L.P.) |
| 1930 | electrostatic (field) effect (London, F.) |
| 1930 | Mills-Nixon effect |
| 1932 | Hammett acidity function |
| 1932 | Pauling electronegativity scale |

| | |
|---|---|
| 1932 | Hanes-Woolf plot |
| 1933 | Bell equation |
| 1933 | Peroxide effect (Kharasch, M.S./Mayo, F.R.) |
| 1934 | hyperconjugation (Wheland, G.W.) |
| 1934 | SN1/SN2 (Ingold, C.K./Hughes, E.D.) |
| 1934 | Lineweaver-Burk plot |
| 1935 | Baker-Nathan effect |
| 1935 | Eyring equation |
| 1935 | Hammett equation |
| 1935 | Eyring transition state theory |
| 1935 | substituent effect (Hammett, L.P.) |
| 1935 | isotopic exchange (Urey, H.C.) |
| 1935 | isotopic labelling experiment (Urey, H.C./Ingold, C.K./ Rittenberg, D./Schoenheimer, R.) |
| 1935 | Müller-Müller-Rodloff biradical rule |
| 1936 | Gross-Butler equation |
| 1936 | Bell-Evans-Polanyi principle |
| 1936 | isotope effect (Reitz, O.) |
| 1937 | crossover experiment (Hurd, C.D.) |
| 1937 | acidity function (Hammett, L.P.) |
| 1938 | principle of least motion (Rice, F.O./Teller, E.) |
| 1939 | Zucker-Hammett hypothesis |
| **1939** | **anchimeric assistance (Winstein, S.)** |
| **1939** | **Electrode kinetics (Eyring, H./Laidler, K.J.)** |
| 1940 | common ion effect (Ingold, C.K.) |
| **1940** | **normal salt effect (Ingold, C.K./Winstein, S.)** |
| 1940 | Stopped-flow technique (Chance, B./Gibson, Q.H.) |
| **1940** | **Heterogeneous catalysis (Eyring, H./Laidler, K.J.)** |
| **1940** | **Solvent effects in kinetics (Eyring, H./Laidler, K.J.)** |
| 1941 | A1 and A2 mechanisms (Ingold, C.K.) |
| 1942 | Wheland intermediate |
| 1945 | Pitzer ring strain |
| 1947 | Bigeleisen-Wolfsberg equation |
| 1948 | Grunwald-Winstein equation |
| 1948 | hybridization in chemical bonding (Pauling, L.) |
| 1948 | E1/E2 eliminations (Ingold, C.K./Hughes, E.D.) |
| 1948 | "push-pull" mechanism (Swain, C.G.) |
| 1949 | time resolved spectroscopy and kinetics (Norrish, R.G.W./Porter,G./ Eigen, M.) |
| 1949 | Scatchard plot |
| **1949** | **Kinetics of urea-urease enzyme system (Laidler, K.J.)** |
| 1952 | Taft equation |
| 1952 | conformation in organic synthesis (Barton, D.H.R./Hassel, O.) |
| **1952** | **intimate and solvent separated ion pairs (Cram, D.J./Winstein, S.)** |
| 1953 | Doering-Zeiss intermediate |
| 1953 | Leffler hypothesis |
| 1953 | Swain-Scott equation |
| 1953 | NMR lineshape analysis and coalescence phenomena (Gutowsky, H.S.) |
| 1954 | Curtin-Hammett principle |
| **1954** | **special salt effect (Winstein, S.)** |

| | |
|---|---|
| 1954 | Matrix isolation spectroscopy (Pimentel, G.C./Porter, G.) |
| 1955 | Hammond postulate |
| **1955** | **Winstein-Holness equation** |
| 1956 | Edwards equation |
| 1956 | Marcus equation |
| 1956 | King-Altman method |
| **1957** | **Gillespie-Nyholm model** |
| 1958 | Swain-Schaad equation |
| 1958 | Kosower Z-values |
| 1959 | Corey-Pauling-Koltun space filling models |
| 1959 | Temperature jump (T-jump) technique (Eigen, M.) |
| 1961 | Westheimer principle |
| 1962 | Discovery of hydrated electron (Hart, E.J./Boag, J.W.) |
| **1962** | **Pulse radiolysis technique (Dorfman, L.M.)** |
| 1963 | Pearson's HSAB principle |
| 1963 | Cleland rules |
| 1963 | Muetterties rule |
| **1963** | **valence shell electron pair repulsion theory (VSEPR) (Gillespie, R.J.)** |
| 1964 | Eigen curve |
| **1964** | **fractionation factor theory (Kresge, A.J./Gold, V.)** |
| **1964** | **density functional theory (Parr, R.G./Yang, W./Kohn, W./Becke, A./Lee, C.)** |
| 1965 | Woodward-Hoffmann rules |
| 1966 | Bunnett-Olsen equations |
| 1967 | molecular mechanics calculations (Allinger, N.L.) |
| 1968 | Swain-Lupton equation |
| **1968** | **magic or super acid (Gillespie, R.J./Olah, G.A.)** |
| **1969** | **Edward-Lemieux effect (anomeric effect)** |
| 1969 | Hansch constant |
| 1969 | principle of microscopic reversibility (Ingold, C.K.) |
| 1970 | More O'Ferrall-Jencks diagram |
| 1970 | SNR1 mechanism (Bunnett, J.F.) |
| 1970 | Factor analysis method (Malinowski, E.R.) |
| 1971 | host-guest chemistry (Cram, D.J./Lehn, J.M./Pedersen, C.J.) |
| 1972 | Ritchie equation |
| 1972 | Koppel-Palm solvent parameters |
| **1972** | **gauche effect (Wolfe, S.)** |
| 1975 | Three phase test for reaction intermediates (Rebek, J.) |
| 1975 | Bordwell carbon acidity scale in polar non-hydrogen-bond solvents |
| 1976 | Kamlet-Taft solvent parameters |
| 1976 | Baldwin's rules |
| 1977 | Kaptein-Closs rules |
| 1977 | Jencks' clock |
| 1977 | Concept of philicity of singlet carbenes (Moss, R.A.) |
| **1977** | **Probe technique to observe spectroscopically “invisible” transients (Scaiano, J.C.)** |
| **1978** | **Cox-Yates acidity function** |
| 1978 | Captodative effect (Viehe, H.G.) |
| **1981** | **atoms in molecules (AIM) (Bader, R.F.W.)** |
| 1981 | Keeffe-Jencks equations |

| | |
|---|---|
| 1982 | proton inventory technique (Schowen, R.L.) |
| 1984 | reactivity-selectivity principle (Giese, B.) |
| 1985 | principle of non-perfect synchronization (Bernasconi, C.F.) |
| 1986 | general valence bond theory (Goddard (III), W.A.) |
| **1988** | **Boyd-Edgecombe electronegativity parameters** |
| **1988** | **Variable Marcus intrinsic barrier for deprotonation of carbon acids (Bunting, J.W./Stefanidis, D.)** |
| **1990** | **Lever ligand electrochemical parameters** |
| **1999** | **No-barrier multi-dimensional Marcus theory (Guthrie, J.P.)** |
| 2002 | First observation of distinct steps in SN1 reaction (Mayr, H.) |

Bolded entries correspond to those with Canadian connections.




## (5) Laboratory Apparatus

| Nationality | Number of Chemists |
|---|---|
| German | 22 |
| British | 9 |
| French | 5 |
| American | 5 |

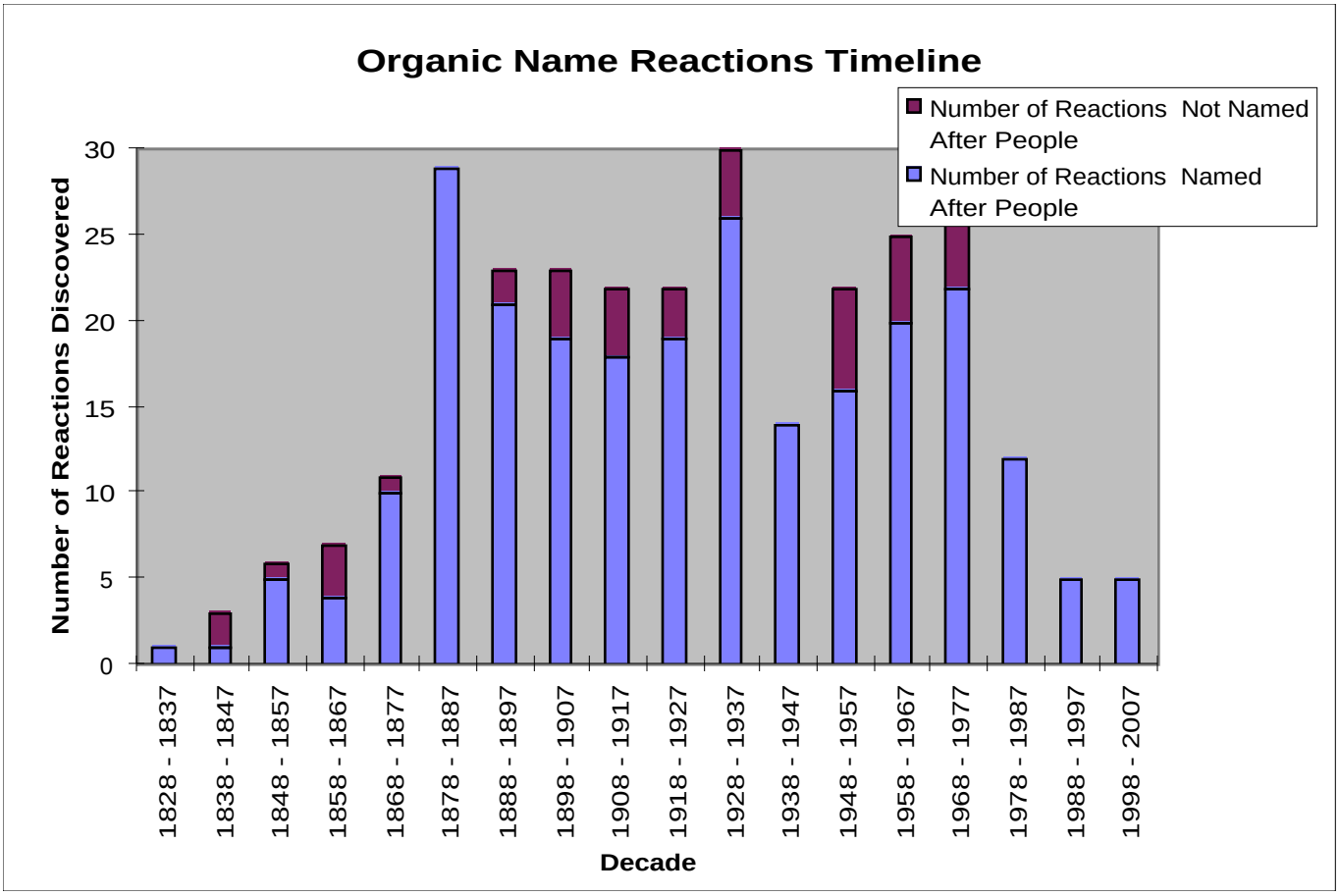
| | |
|---|---|
| Italian | 2 |
| Swiss | 2 |
| Swedish | 1 |
| Canadian | 1 |
| Polish | 1 |
| Danish | 1 |
| Dutch | 1 |
| | **51** |

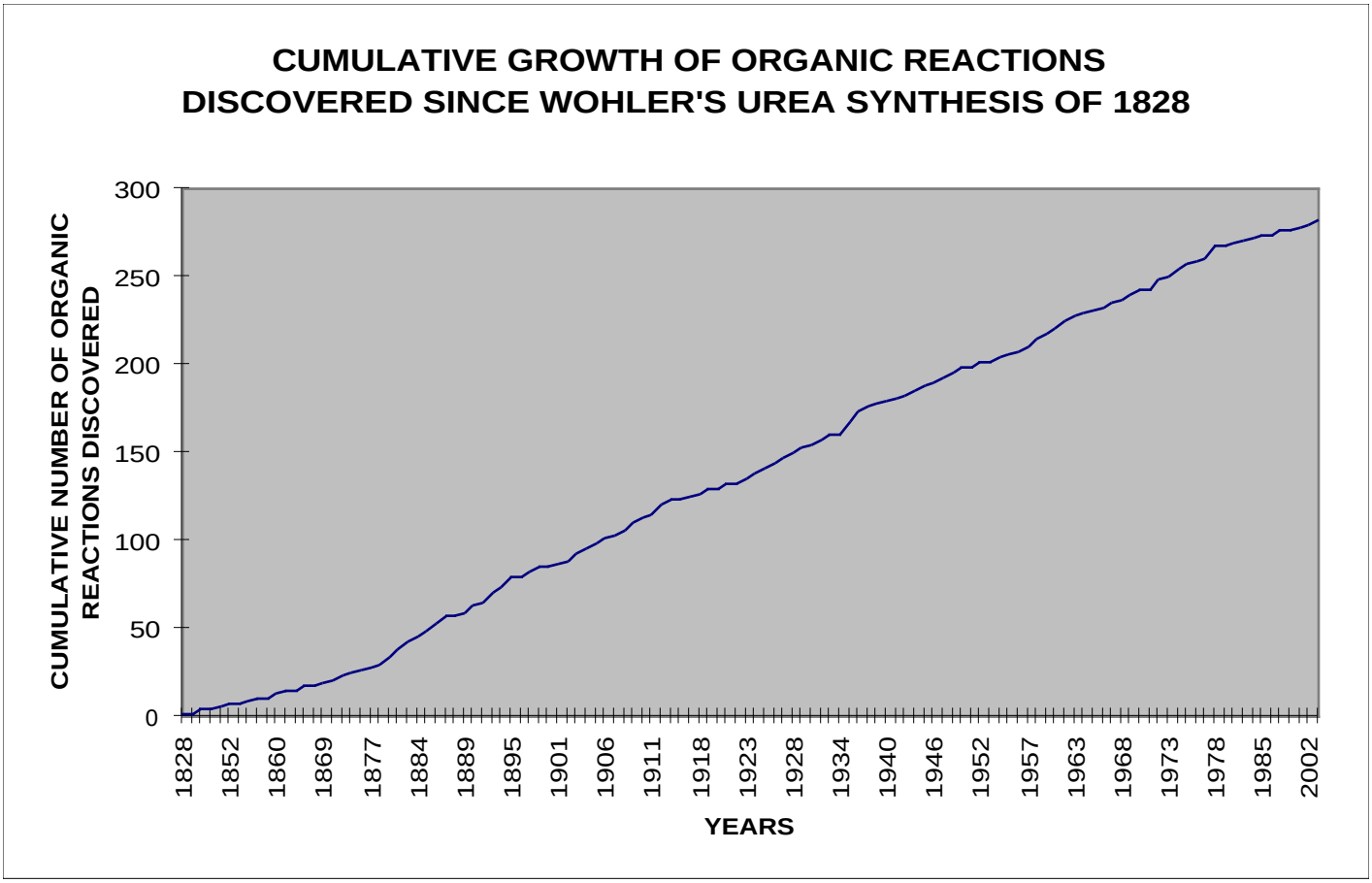
| **Year** | **Laboratory Apparatus** |
|---|---|
| 1724 | Fahrenheit temperature scale |
| 1742 | Celsius temperature scale |
| 1823 | Dobereiner lamp |
| 1836 | Daniell cell |
| 1844 | Kipp gas generator |
| 1874 | McLeod vacuum gauge |
| 1876 | Viktor Meyer tube |
| 1879 | Gooch crucible |
| 1879 | Soxhlet extractor |
| 1886 | Allihn condenser |
| 1888 | Kjeldahl flask |
| 1888 | Beckmann thermometer |
| 1888 | Hirsch funnel |
| 1888 | Büchner funnel |
| 1895 | Pulfrich refractometer |
| 1900 | Parr calorimeter bomb |
| 1901 | Schott glass |
| 1905 | Dewar flask |
| 1907 | Davies double surface condenser |
| 1908 | Geiger counter |
| 1908 | Vigreux column |
| 1910 | Knudsen vacuum gauge |
| 1910 | Abderhalden drying pistol |
| 1911 | Ketene lamp |
| 1912 | Friedrichs condenser |
| 1913 | Schlenk flask |
| 1914 | Raschig rings |
| 1917 | Thiele tube |
| 1919 | Dufton column |
| 1919 | Friedrichs filter funnel |
| 1920 | Dean-Stark apparatus |
| 1924 | Widmer column |
| 1924 | Parnas apparatus |
| 1925 | Pulfrich photometer |
| 1932 | Fenske rings |
| 1932 | Gaede oil diffusion pump |
| 1936 | Hershberg stirrer |
| 1936 | Stedman column |
| 1937 | Penning vacuum gauge |
| 1944 | Pirani vacuum gauge |

| | |
|---|---|
| 1948 | Holzman column |
| 1956 | Beckman pH meter |
| 1963 | Lessing rings |
| | |
| | Bunsen burner |
| | Claisen adapter |
| | Claisen flask |
| | Dimroth condenser |
| | Dixon gauze rings |
| | Erlenmeyer flask |
| | Griffin beaker |
| | Hempel column |
| | Hempel pipet |
| | Liebig condenser |
| | Mariotte bottle |
| | Pasteur pipet |
| | Perkin triangle |
| | Vernier calipers |
| | West condenser |
| | Zimmerli vacuum gauge |

## (6) Named Organic Reactions

| **Nationality** | **Number of Chemists** |
|---|---|
| German | 114 |
| American | 63 |
| American-born | 48 |
| British | 30 |
| Russian | 19 |
| French | 16 |
| Swiss | 11 |
| Japanese | 8 |
| Italian | 5 |
| Canadian | 4 |
| Belgian | 5 |
| Czech | 4 |
| Austrian | 4 |
| Australian | 2 |
| Ukrainian | 2 |
| Swedish | 2 |
| Hungarian | 2 |
| Polish | 2 |
| Dutch | 2 |
| Romanian | 1 |
| **TOTAL** | **342** |


Organic Name Reactions Timeline
Number of Reactions Not Named After People
Number of Reactions Named After People
Number of Reactions Discovered
0
5
10
15
20
25
30
1828 - 1837
1838 - 1847
1848 - 1857
1858 - 1867
1868 - 1877
1878 - 1887
1888 - 1897
1898 - 1907
1908 - 1917
1918 - 1927
1928 - 1937
1938 - 1947
1948 - 1957
1958 - 1967
1968 - 1977
1978 - 1987
1988 - 1997
1998 - 2007
Decade




| Year | Named Reactions |
|---|---|
| | |
| 1828 | Wohler urea synthesis |
| 1836 | Marsh arsenic test |
| 1838 | Aldol condensation (Kane, R.); Benzilic acid rearrangement (Liebig, J.) |
| 1849 | Fehling |
| 1850 | Strecker amino acid synthesis |
| 1852 | Williamson ether synthesis |
| 1853 | Cannizzaro |
| 1855 | Wurtz |
| 1856 | Aromatic nitration (Kopp, H.) |
| 1858 | Griess diazotization |
| 1860 | Kolbe-Schmitt; pinacol rearrangement (Fittig, R.) |
| 1862 | Aromatic halogenation (Muller, H./Schramm, J./Seelig, E./Scheufelen, A.) |
| 1863 | Benzidine rearrangement (Hofmann, A.W.) |
| 1864 | Wurtz-Fittig, Schiff base |
| 1868 | Perkin reaction |
| 1869 | Glaser coupling |
| 1870 | Perkin rearrangement |
| 1871 | Hofmann-Martius rearrangement, von Richter, aromatic sulphonation (Meyer, V.) |
| 1872 | Lossen rearrangement, Beilstein |
| 1876 | Reimer-Tiemann |
| 1877 | Friedel-Crafts acylation and alkylation |

| | |
|---|---|
| 1880 | Skraup, Wallach |
| 1881 | Claisen-Schmidt, Hell-Volhard-Zelinsky, Hofmann elimination, Etard, Ciamician pyridine synthesis from pyrrole |
| 1882 | Friedlander, Hantzsch pyridine synthesis, Tollens test, Radziszewski |
| 1883 | Doebner-Miller, Fischer indole synthesis, Hofmann-Loffler-Freytag, von Pechmann |
| 1884 | Schotten-Baumann, Sandmeyer, Elbs |
| 1885 | Kiliani-Fischer, Paal-Knorr, Leuckart |
| 1886 | Beckmann rearrangement, Knorr, Fischer-Hepp rearrangement, Jaffe's reaction, Janovsky reaction |
| 1887 | Claisen condensation, Gabriel, Michael addition, Reformatskii |
| 1888 | Japp-Klingemann |
| 1889 | Liebermann-Burchard method or reaction |
| 1890 | Curtius, Gatterman, Menshutkin, Hinsberg test |
| 1891 | Tiemann rearrangement |
| 1893 | Bischler-Napieralski, Fenton, Ruff-Fenton degradation, Stobbe condensation, Wohl degradation, Biginelli |
| 1894 | Bamberger rearrangement, Frisch-Buttenberg-Wiechell, Dieckmann, Nef |
| 1895 | Delepine, Fischer esterification, Henry, oxidation of olefins with permanganate (Wagner, G.), Lobry de Bruyn-van Eckenstein transformation |
| 1897 | Gatterman-Koch |
| 1898 | Arbuzov-Michaelis, Knoevenagel condensation |
| 1899 | Baeyer-Villager oxidation, Chugaev, Wagner-Meerwein rearrangement |
| 1900 | Grignard |
| 1901 | Ciamician photodisproportionation |
| 1902 | Orton rearrangement |
| 1903 | Bouveault-Blanc, Tiffeneau-Demjanov rearrangement; Benzoin condensation (Lapworth, A.J.), Lapworth |
| 1904 | Bucherer, Darzens, Thorpe, Ullmann |
| 1905 | Eschweiler-Clarke, Harries ozonolysis; Acyloin condensation (Bouveault, L.) |
| 1906 | Tischenko; Zincke reaction; Chichibabin pyridine condensation |
| 1907 | Malonic ester synthesis (Perkin, W.H. Jr.), hemiacetals/hemiketals formation (Jackson, C.L.) |
| 1908 | Fries rearrangement, esterification with diazomethane (Herzig, J./Wegschneidler, R./Bouveault, L.), acyl rearrangement (Auwers, K. von/Fischer, Emil) |
| 1909 | Paterno-Buchi, Willgerodt, Prilezhaev, Benedict test |
| 1910 | Pummerer rearrangement, Finkelstein; Acetoacetic ester synthesis (Simonsen, J.L.) |
| 1911 | Wolff-Kishner reduction; Pictet-Spengler isoquinoline synthesis, Abderhalden ninhydrin |
| 1912 | Barbier-Wieland, Claisen rearrangement, Maillard, Mannich, Wolff rearrangement; Allylic rearrangement (Claisen, L.) |
| 1913 | Clemmensen reduction, Favorskii rearrangement |
| 1914 | Chichibabin pyridine amination |
| 1915 | Houben-Hoesch |
| 1918 | Rosenmund reduction, Weerman degradation |
| 1919 | Meisenheimer, Staudinger, Prins |
| 1920 | Vinyl ether rearrangement (Adams, R.) |
| 1921 | Dienone-phenol rearrangement (von Auwers, K.), Passerini |

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|---|---|
| 1922 | Meyer-Schuster rearrangement |
| 1923 | Fischer-Tropsch process, Nametkin rearrangement |
| 1924 | Bachmann-Gomberg; Zemplen's saponification, acetals/ketals formation (Skrabal, A.) |
| 1925 | Chapman rearrangement, Meerwein-Pondorff-Verley, Stephen reduction |
| 1926 | Neber, Rupe rearrangement, Zemplen degradation of sugars |
| 1927 | Vilsmeier-Haack-Arnold, Schiemann, Polonovski |
| 1928 | Diels-Alder, Stevens rearrangement, Dakin-West reaction |
| 1929 | Neuberg degradation, Nenitzescu indole synthesis, Nesmeyanov's diazo method |
| 1930 | Lucas test, Schoenberg rearrangement, Schoenberg reaction |
| 1931 | Criegee, haloform reaction (Fuson, R.C.) |
| 1932 | Haworth phenanthrene synthesis; Bergmann-Zervas Cbz method |
| 1933 | Helferich method; Prevost reaction; epoxide rearrangement (Paul, R./Tiffeneau, M.) |
| 1934 | Nieuwland enyne synthesis |
| 1935 | Arndt-Eistert synthesis, Robinson annulation, Smiles rearrangement, Wenker synthesis, Lohmann transphorphorylation; cyclopropanation with diazomethane (Fischer, Hans), hydrogenolysis of benzyl ethers (Adkins, H.) |
| 1936 | Hooker oxidation, McFadyen-Stevens rearrangement, Norrish Type I/II, Nenitzescu reductive acylation |
| 1937 | Hammick, Sommelet-Hauser, Oppenauer oxidation |
| 1939 | Meerwein arylation, Marschalk |
| 1940 | Ramberg-Backland, Cope rearrangement |
| 1941 | Dakin |
| 1942 | Borodin-Hunsdiecker, Wittig rearrangement |
| 1944 | Birch reduction, Bartlett-Condon-Schneider, Criegee rearrangement |
| 1945 | Kharasch cyclization, Sanger reaction |
| 1946 | Jones oxidation, Nazarov cyclization |
| 1948 | Ritter, LAH reduction of methyl esters (Karrer, P./Bachmann, W.E.) |
| 1949 | Cope elimination, Cornforth rearrangement, LAH reduction of ketones |
| 1950 | Edman degradation, Wessely oxidation, oxymercuration of olefins (Brook, A.G./Wright, G.F.) |
| 1951 | Borohydride reduction (Wolfrom, M.L./Woodward, R.B.) |
| 1952 | Bamford-Stevens, Benkeser reduction, Macdonald coupling |
| 1953 | Sarett procedure |
| 1954 | Eglinton, Stork enamine synthesis, Wittig reaction |
| 1955 | Grob fragmentation, Fischer-Hafner reaction |
| 1956 | Lemieux-Johnson oxidation; Hydroboration (Brown, H.C.) |
| 1957 | Cadiot-Chodkeivicz, aniline synthesis via arynes (Bunnett, J.F./Roberts, J.D.) |
| 1958 | Brook rearrangement, Horner-Emmons, Simmons-Smith cyclopropanation, Asinger |
| 1959 | McLafferty rearrangement, Wacker, Nenitzescu synthesis of pyrylium salts |
| 1960 | Barton, Martynoff rearrangement, Wawzonek-Yeakey rearrangement, pyrolysis of sulfoxides (DePuy, C.H./Cram, D.J.) |
| 1961 | Wharton, Wadsworth-Emmons, diimide reduction (Corey, E.J./van Tamelen, E.E.), 1,3-dipolar additions (Huisgen, R.) |
| 1963 | Corey-Winter, Merrifield solid phase synthesis, Pfitzner-Moffatt oxidation |
| 1964 | tosylhydrazone reduction (Caglioti, L.) |
| 1965 | Graham, Kochi |

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|---|---|
| 1966 | sulfenate-sulfoxide rearrangement (Mislow, K.), Newman-Kwart rearrangement |
| 1967 | Kemp, Shapiro, Regitz diazo group transfer, Eschenmoser fragmentation |
| 1968 | Peterson oxidation, Weiss |
| 1969 | Di-pi-methane rearrangement (Zimmerman), Meyers aldehyde synthesis, Schlosser modification of Wittig |
| 1970 | Mitsunobu, dehalogenation with nBu3SnH |
| 1971 | Nicholas reaction |
| 1972 | Corey-Kim, Heck, Borch reduction, Bergman cyclization, Claisen-Ireland, TMS enolate rearrangement (Ireland, R.E.), Kinugasa |
| 1973 | Julia synthesis, Pauson-Khand |
| 1974 | McMurry, Mukaiyama aldol, Danishefsky, vinylogous Wolff rearrangement (Smith, A.B. III) |
| 1975 | Ugi condensation, Dotz, Barton-McCombie, Sharpless oxyamination |
| 1976 | Stetter |
| 1977 | Hosomi-Sukarai, Negishi coupling |
| 1978 | Stille coupling, Swern oxidation, Murahashi, Still-Wittig, Tebbe olefination, Vorbrueggen coupling |
| 1979 | Suzuki coupling |
| 1980 | Sharpless epoxidation |
| 1983 | Dess-Martin oxidation, Nozaki |
| 1982 | Mukaiyama-Michael |
| 1985 | Noyori |
| 1988 | Grieco condensation |
| 1989 | Sharpless-Jacobsen hydroxylation, Kulinkovich |
| 1990 | Jacobsen epoxidation |
| | |
| 1997 | Petasis condensation |
| 1998 | Uemura oxidation |
| | |
| 2002 | Stahl oxidative amination |
| 2002 | Liebeskind-Srogl coupling |
| 2003 | Jacobs oxidative coupling, Stoltz oxidative etherification |
| | |

## Timeline of Discovery of Organic Reactions

| **Decade** | **Number of Reactions Named After People** | **Number of Reactions Not Named After People** |
|---|---|---|
| 1828 - 1837 | 1 | 0 |
| 1838 - 1847 | 1 | 2 |
| 1848 - 1857 | 5 | 1 |
| 1858 - 1867 | 4 | 3 |
| 1868 - 1877 | 10 | 1 |
| 1878 - 1887 | 29 | 0 |
| 1888 - 1897 | 21 | 2 |

| | | |
|---|---|---|
| 1898 - 1907 | 20 | 4 |
| 1908 - 1917 | 19 | 4 |
| 1918 - 1927 | 19 | 3 |
| 1928 - 1937 | 28 | 4 |
| 1938 - 1947 | 14 | 0 |
| 1948 - 1957 | 16 | 6 |
| 1958 - 1967 | 22 | 5 |
| 1968 - 1977 | 22 | 4 |
| 1978 - 1987 | 12 | 0 |
| 1988 - 1997 | 5 | 0 |
| 1998 - 2007 | 5 | 0 |
| **TOTAL** | **253** | **39** |

## (7) Named Reagents, Catalysts, and Compounds

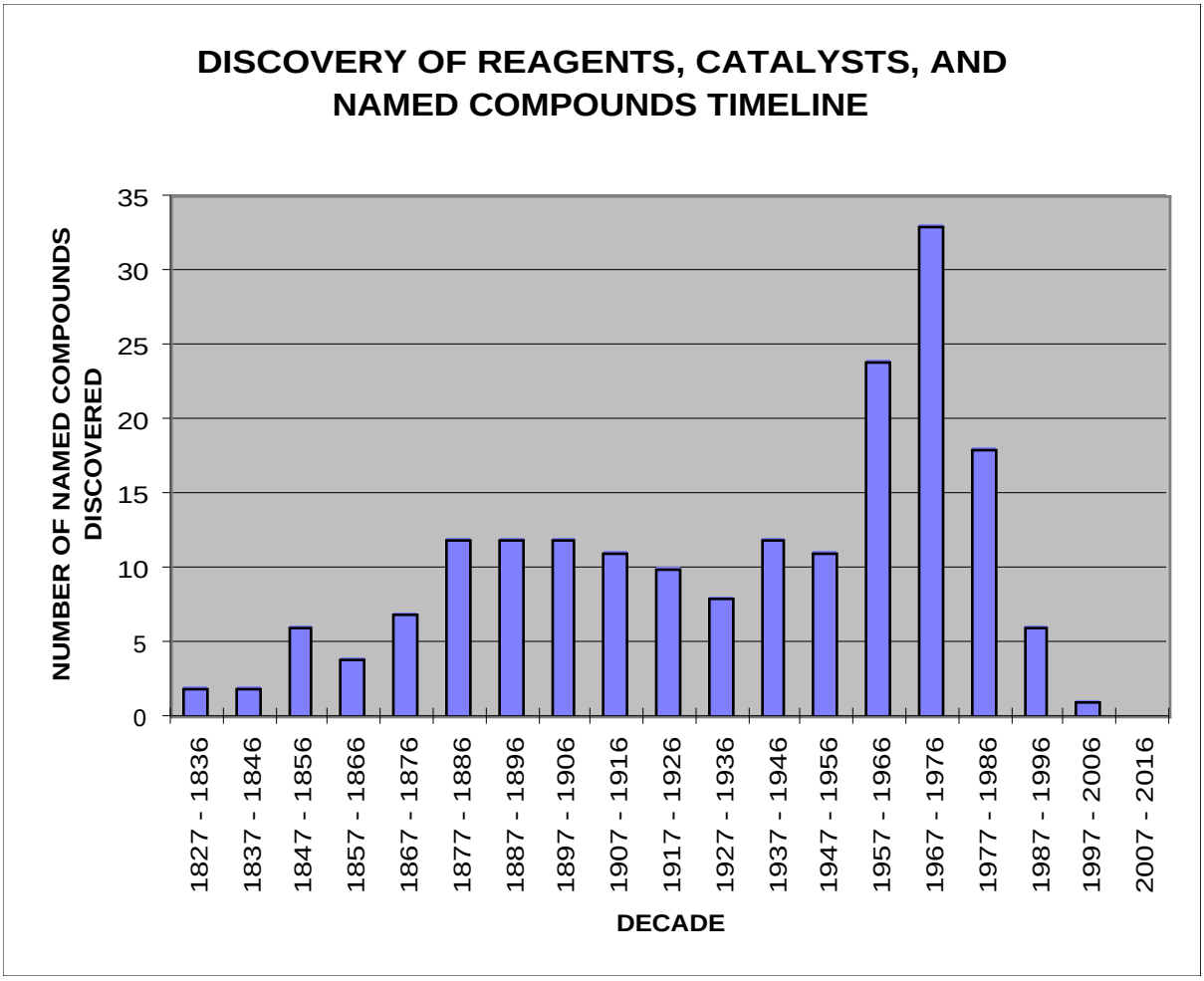
| YEAR | REAGENT/CATALYST DISCOVERED |
|---|---|
| 1658 | Glauber's salt |
| 1672 | Rochelle/Seignette salt |
| 1789 | Eau-de-Javelle |
| 1822 | Gmelin's salt |
| 1825 | Eau de Labarraque |
| 1827 | Zeise's dimer |
| 1827 | Zeise's salt |
| 1844 | Peyrone's salt |
| 1845 | Fremy's salt |
| 1849 | Fehling solution |
| 1850 | Laurent's acid |
| 1851 | Piria's acid |
| 1851 | Sobrerol |
| 1851 | Sobrerone |
| 1855 | Mohr's salt |
| 1856 | Nessler reagent |
| 1857 | Schweizer's reagent |
| 1863 | Reinecke salt |
| 1864 | Schiff's base |
| 1867 | Martius yellow |
| 1867 | Dewar benzene |
| 1869 | Ladenburg benzene |
| 1875 | Cleve's alpha acid |
| 1876 | Lauth's violet |
| 1876 | Ebert and Merz acids |
| 1876 | Michler's ketone |
| 1878 | Cleve's delta acid |
| 1879 | Meldola's blue |
| 1879 | Michler's hydride/base |
| 1879 | Würster's dyes (blue and red) |
| 1880 | Wallach intermediate |
| 1880 | Nevile and Winther's acid |
| 1880 | Ringer's solution |

| | |
|---|---|
| 1882 | Tollens reagent |
| 1882 | Broenner's acid |
| 1883 | Bindschedler's green |
| 1886 | Cleve's gamma acid |
| 1886 | Janovsky's complex |
| 1887 | Reformatskii reagent |
| 1887 | Troeger's base |
| 1887 | Cleve's beta acid |
| 1888 | Forsling's acid |
| 1891 | Armstong and Wynne's acid |
| 1893 | Fenton reagent |
| 1893 | Tobias acid |
| 1893 | Hagemann's ester |
| 1894 | Jaffe's base |
| 1895 | Freund's acid |
| 1896 | Piloty's acid |
| 1896 | Angeli's salt |
| 1897 | Wurster's reagent |
| 1898 | Caro's acid |
| 1899 | Muthmann's liquid |
| 1900 | Meisenheimer complex |
| 1900 | Thiele reagent |
| 1900 | Gomberg radical |
| 1900 | Grignard reagent |
| 1901 | Kiliani reagent |
| 1904 | Kunig's salt |
| 1904 | Schardinger sugars |
| 1904 | Thiele's hydrocarbon (biradical) |
| 1905 | Staudinger's ketene |
| 1906 | Harden and Young's ester |
| 1907 | Willstatter imines |
| 1907 | Pope's complex |
| 1907 | Chichibabin hydrocarbon (biradical) |
| 1908 | Meldrum's acid |
| 1909 | Benedict's solution |
| 1910 | Ruhemann's purple |
| 1910 | Niementowski's dye |
| 1913 | Meerwein ester |
| 1914 | Evans blue |
| 1915 | Schlenk-Brauns biradical |
| 1916 | Lewis structures |
| 1917 | Mannich's bases |
| 1919 | Claisen's alkali |
| 1921 | Rosenmund catalyst |
| 1922 | Adam's catalyst |
| 1923 | Broensted catalyst |
| 1924 | Fieser's solution |
| 1924 | Markush structures |
| 1925 | Lewisite |
| 1925 | Neuberg ester |

| | |
|---|---|
| 1926 | Banfield-Kenyon radical |
| 1927 | Raney nickel |
| 1927 | Vilsmeier reagent |
| 1927 | Gibbs reagent |
| 1933 | Raybin’s reagent |
| 1934 | Schoenberg's reagent |
| 1935 | Karl Fischer reagent |
| 1935 | Kohler's ketone |
| 1936 | Gilman reagents |
| 1937 | Meerwein salt |
| 1937 | Reichstein substance G |
| 1937 | Cori ester |
| 1938 | Sheibley's reagent |
| 1939 | Bratton-Marshall reagent |
| 1941 | proton sponge |
| 1941 | Müller's hydrocarbon (biradical) |
| 1942 | Wheland intermediate |
| 1942 | Tsuda reagent |
| 1943 | Lazier catalyst |
| 1943 | Girard reagent P |
| 1943 | Girard reagent T |
| 1945 | Sanger's reagent |
| 1946 | Jones reagent |
| 1947 | Heyns catalyst |
| 1950 | Wieland-Miescher ketone |
| 1950 | Adkins catalyst |
| 1950 | Edman's reagent |
| 1951 | ferrocene |
| 1952 | Lindlar's catalyst |
| 1953 | Nazarov's reagent |
| 1953 | Sarett reagent |
| 1954 | Wittig reagent |
| 1955 | Zeigler-Natta catalyst |
| 1955 | Lemieux-von Rudloff reagent |
| 1957 | Koelsch radical |
| 1957 | Coppinger's radical |
| 1958 | Simmons-Smith reagent |
| 1958 | Hunig's base |
| 1958 | Lemieux-Johnson reagent |
| 1959 | Ellman's reagent |
| 1959 | Nenitzescu's dimer |
| 1960 | Nishimura catalyst |
| 1960 | Gold's reagent |
| 1960 | Tuppy's maleimide |
| 1961 | Payne's reagent |
| 1961 | Snatzke's reagent |
| 1961 | Woodward's reagent |
| 1961 | Sawicki’s reagent |
| 1962 | Cornforth reagent |
| 1962 | Vaska compound |

| | |
|---|---|
| 1963 | Pfitzner-Moffatt reagent |
| 1963 | Merrifield resin |
| 1964 | Fischer carbene |
| 1964 | Nenitzescu's dichloride |
| 1964 | Koshland reagent number 1, 3 |
| 1965 | Wilkinson's catalyst |
| 1965 | Koshland reagent number 2 |
| 1965 | Petitt complex |
| 1967 | Mosher's acid |
| 1967 | Mosher esters |
| 1967 | Mosher amides |
| 1967 | Mosher's acid chloride |
| 1968 | Lawesson's reagent |
| 1968 | Bredereck's reagent |
| 1968 | Burgess reagent |
| 1968 | Collin's reagent |
| 1968 | Fetizon's reagent |
| 1968 | Karstedt catalyst |
| 1968 | Cleland reagent |
| 1969 | Mitsunobu reagent |
| 1969 | Creutz-Taube complex |
| 1969 | Magic acid (Olah, G.A.) |
| 1969 | Walborsky reagent |
| 1971 | Seyferth-Gilbert reagent |
| 1971 | Viehe's salt |
| 1971 | Eschenmoser's salt |
| 1971 | Martin sulfurane dehydrating agent |
| 1971 | Rondeau's reagent |
| 1972 | Collman's reagent |
| 1972 | Corey-Kim reagent |
| 1972 | Lalancette's reagent |
| 1972 | Nenitzescu's hydrocarbon |
| 1973 | Olah's reagent |
| 1973 | Pearlman's catalyst |
| 1973 | Eaton reagent |
| 1973 | Wang resin |
| 1974 | McMurry's reagent |
| 1974 | Schwartz's reagent |
| 1975 | Moore's ketene |
| 1975 | Mukaiyama's reagent |
| 1975 | Bates reagent |
| 1975 | Nysted reagent |
| 1977 | Crabtree's catalyst |
| 1978 | Swern reagent |
| 1978 | Tebbe reagent |
| 1978 | Meyers reagent |
| 1979 | Midland's reagent |
| 1979 | Noyori reagent |
| 1981 | Kemp's triacid |
| 1981 | Evans auxiliary |

| | |
|---|---|
| 1981 | Weinreb amide |
| 1982 | Koser's reagent |
| 1982 | Davy reagent methyl |
| 1983 | Reichardt's dye |
| 1983 | Barton ester |
| 1983 | Belleau reagent |
| 1984 | Marfey’s reagent |
| 1985 | Appel's reagent |
| 1986 | Vedejs reagent |
| 1986 | Williams glycinate |
| 1986 | Van Boom’s reagent |
| 1987 | Hendrickson's reagent |
| 1989 | Brown's reagent |
| 1990 | Oppolzer's auxiliary |
| 1991 | Jacobsen's catalyst |
| 1992 | Petasis reagent |
| 1999 | Grubbs ruthenium catalyst |
| | Adam's reagent |
| | Adamite |
| | Adamsite |
| | Aldrin |
| | Andresen's acid |
| | Badische acid |
| | Bayer's acids |
| | Corey aldehyde |
| | Corey lactone |
| | Corey's reagent |
| | Dahl's acid I |
| | Dahl's acid II |
| | Dahl's acid III |
| | Dieldrin |
| | Ehrlich's reagent |
| | Fieser's reagent |
| | Kalle's salt |
| | Koch's acid |
| | Marignac's salt |
| | Reichstein's substance S |
| | Schaeffer's acids |
| | Schollkopf's acid |


DISCOVERY OF REAGENTS, CATALYSTS, AND NAMED COMPOUNDS TIMELINE
NUMBER OF NAMED COMPOUNDS DISCOVERED
0
5
10
15
20
25
30
35
1827 - 1836
1837 - 1846
1847 - 1856
1857 - 1866
1867 - 1876
1877 - 1886
1887 - 1896
1897 - 1906
1907 - 1916
1917 - 1926
1927 - 1936
1937 - 1946
1947 - 1956
1957 - 1966
1967 - 1976
1977 - 1986
1987 - 1996
1997 - 2006
2007 - 2016
DECADE