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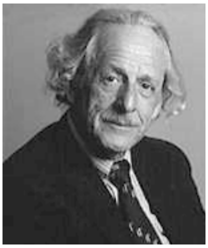

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The Most-Cited Papers of All Time, *SCI* 1945-1988. Part 4. The Papers Ranked 301-400

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The fourth group of most-cited articles in the 1945-1988 *Science Citation Index* ® is listed, together with citation updates for 1989 and 1990. Eleven Nobel laureates appear as authors, bringing the total so far to 45. The *Journal of Biological Chemistry* published the most papers in this list (10), and leads overall with 53 of the top 400.

Through the four installments of this analysis covered to date, we have discussed the 300 most-cited papers of all time—looking at papers with instantaneous impacts, Nobel laureates as authors, the journals in which the papers appeared, delayed recognition, and perennial papers (those that have been highly cited year after year).

Introduction

I am often surprised to encounter readers who are unaware that the *Science Citation Index* ® (*SCI* ®) covers the literature from 1945 to 1964, especially when you consider how important this period was to the development of science as we know it today. In this period, science conquered polio, took man into space, and developed the field of molecular biology; computing, communications, and transportation technologies brought the world closer together; and, science began in earnest to wrest the secrets of the physical universe from the void. And, it is for this reason that, several years ago, we established a special project to produce citation indexes for these years.[1,2] Knowledge from this golden age of science is extremely useful in tracking the developments of ideas during this 20-year period and using them to build the science of tomorrow.

As a means to draw attention to the importance of these indexes, we compiled a list of the most-cited papers published from 1945 to 1988. From these efforts, we have produced this series of essays for *Current Contents*.[3-6]

In the pages that follow, we have provided some of the basic analyses characteristic of these studies, such as the contributions of Nobel Prize winners, the impact of important journals, and the various paths papers may take to end up among the most cited of all time.

There is good reason to question whether or not we should lump together material covering such a long period of time. After all, the number of papers published today is, probably, an order of magnitude greater than it was in 1945. Therefore, we should expect the number of citation superstars from these earlier papers to be lower than that for more recent papers. As a matter of fact, this is characteristic of much primordial work—that important papers suffer the fate of citation obliteration. As I have discussed in previous essays,[7] citation obliteration is a phenomenon where a key development becomes so standard within a field that researchers take it for granted and cease to cite the work.

Therefore, by way of commentary, rather than a précis of selected papers, we will concentrate our efforts on updating the list and allow you, the reader, to interpret the significance in the context of your work.

Table 1. Bibliography of the fourth 100 most-cited papers, *SCI* ® 1945-1988. Papers are arranged alphabetically. A=1945-1988 citations. B=1945-1988 rank. C=average number of annual citations, 1945-1988. D=1989 citations. E=1990 citations. An asterisk (*) indicates that the paper was the subject of a *Citation Classic* ® commentary. The issue, year, and edition of the commentary follow the bibliographic reference.

A	B	C	D	E	Bibliographic Data
1,618	391	70	113	113	**Ames B N.** Assay of inorganic phosphate, total phosphate and phosphatases. *Meth. Enzymology* 8:115-8, 1966.
1,768	330	63	56	45	***Aminoff D.** Methods for the quantitative estimation of *N*-acetylneuraminic acid and their application to hydrolysates of sialomucoids. *Biochem. J.* 81:384-92, 1961. (26/80/LS)
1,700	356	85	35	24	**Avrameas S & Ternynck T.** The cross-linking of proteins with glutaraldehyde and its use for the preparation of immunoadsorbents. *Immunochemistry* 6:53-66, 1969.
1,686	359	62	34	39	***Barka T & Anderson P J.** Histochemical methods for acid phosphatase using hexazonium pararosanilin as coupler. *J. Histochem. Cytochem.* 10:741-53, 1962. (8/78)
1,770	329	295	311	323	***Barre-Sinoussi F, Chermann J-C, Rey F, Nugeyre M T, Chamaret S, Gruest J, Dauguet C, Axler-Blin C, Vezinet-Brun F, Rouzioux C, Rozenbaum W & Montagnier L.** Isolation of a T-lymphotropic retrovirus from a patient at risk for acquired immune deficiency syndrome (AIDS). *Science* 220:868-71, 1983. (8/87/LS)
1,787	320	44	69	60	**Benesi H A & Hildebrand J H.** A spectrophotometric investigation of the interaction of iodine with aromatic hydrocarbons. *J. Amer. Chem. Soc.* 71:2703-7, 1949.
1,726	346	101	6	67	**Black J W, Duncan W A M, Durant C J, Ganellin C R & Parsons E M.** Definition and antagonism of histamine H_2-receptors. *Nature* 236:385-90, 1972.
1,812	50	314	9	6	**Boas N F.** Method for the determination of hexosamines in tissues. *J. Biol. Chem.* 204:553-63, 1953.
1,758	335	41	28	19	***Bowden K, Heilbron I M, Jones E R H & Weedon B C L.** Researches on acetylenic compounds. Part I. The preparation of acetylenic ketones by oxidation of acetylenic carbinols and glycols. *J. Chem. Soc.* (London) 1946:39-45. (20/79/PC&ES)
1,771	327	111	96	87	**Brazeau P, Vale W, Burgus R, Ling N, Butcher M, Rivier J & Guillemin R.** Hypothalamic polypeptide that inhibits the secretion of immunoreactive pituitary growth hormone. *Science* 179:77-9, 1973.
1,615	394	202	265	271	**Breathnach R & Chambon P.** Organization and expression of eucaryotic split genes coding for proteins. *Annu. Rev. Biochem.* 50:349-83, 1981.
1,610	397	41	18	20	**Brecher G & Cronkite E P.** Morphology and enumeration of human blood platelets. *J. Appl. Physiol.* 3:365-77, 1950.
1,743	338	47	3	0	***Bush I E.** Methods of paper chromatography of steroids applicable to the study of steroids in mammalian blood and tissues. *Biochem. J.* 50:370-8, 1952. (3/84/LS)
1,712	353	78	46	48	***Chen R F.** Removal of fatty acids from serum albumin by charcoal treatment. *J. Biol. Chem.* 242:173-81, 1967. (13/82/LS)
1,764	332	196	97	72	***Cheung W Y.** Calmodulin plays a pivotal role in cellular regulation. *Science* 207:19-27, 1980. (49/83/LS)
1,788	319	69	47	46	***Cleland W W.** The kinetics of enzyme-catalyzed reactions with two or more substrates or products. I. Nomenclature and rate equations. *Biochim. Biophys. Acta* 67:104-37, 1963. (28/77)
1,718	349	72	19	11	**Clementi E.** Ab initio computations in atoms and molecules. *IBM J. Res. Develop.* 9:2-19, 1965.
1,772	326	118	157	141	**Clementi E & Roetti C.** Roothaan-Hartree-Fock atomic wavefunctions. *At. Data Nucl. Data Tables* 14:177-478, 1974.
1,771	327	87	72	51	***Clewell D B & Helinski D R.** Supercoiled circular DNA-protein complex in *Escherichia coli*: purification and induced conversion to an open circular DNA form. *Proc. Nat. Acad. Sci. USA* 62:1159-66, 1969. (8/83/LS)
1,824	311	107	116	82	**Cohen S N, Chang A C Y & Hsu L.** Nonchromosomal antibiotic resistance in bacteria: genetic transformation of *Escherichia coli* by R-factor DNA. *Proc. Nat. Acad. Sci. USA* 69:2110-4, 1972.
1,658	375	38	97	69	***Cole K S & Cole R H.** Dispersion and absorption in dielectrics. I. Alternating current characteristics. *J. Chem. Phys.* 9:341-51, 1941. (3/80/PC&ES)
1,817	313	79	43	22	***de Duve C & Wattiaux R.** Functions of lysosomes. *Annu. Rev. Physiol.* 28:435-92, 1966. (7/85/LS)

A	B	C	D	E	Bibliographic Data
1,837	301	153	374	399	***Dewar M J S & Thiel W.** Ground states of molecules. 38. The MNDO method. Approximations and parameters. *J. Amer. Chem. Soc.* 99:4899-907, 1977. (14/85/ET&AS; 14/85/PC&ES)
1,707	355	47	17	14	**Dische Z & Shettles L B.** A specific color reaction of methylpentoses and a spectrophotometric micromethod for their determination. *J. Biol. Chem.* 175:595-603, 1948.
1,809	315	101	81	60	**Ditchfield R, Hehre W J & Pople J A.** Self-consistent molecular-orbital methods. IX. An extended Gaussian-type basis for molecular-orbital studies of organic molecules. *J. Chem. Phys.* 54:724-8, 1971.
1,661	374	66	49	47	**Dittmer J C & Lester R L.** A simple, specific spray for the detection of phospholipids on thin-layer chromatograms. *J. Lipid Res.* 5:126-7, 1964.
1,641	382	78	53	63	***Doyle P A & Turner P S.** Relativistic Hartree-Fock X-ray and electron scattering factors. *Acta Crystallogr. A—Cryst. Phys.* 24:390-7, 1968. (29/80/ET&AS)
1,711	354	78	52	43	***Druckrey H, Preussmann R, Ivankovic S & Schmahl D.** Organotrope carcinogene Wirkungen bei 65 verschiedenen N-Nitroso-Verbindungen an BD-Ratten (Organotropic carcinogenic effects of 65 different N-nitroso-compounds on BD-rats). *Z. Krebsforsch.* 69:103-201, 1967. (17/81/LS)
1,784	321	53	128	120	**Dunnett C W.** A multiple comparison procedure for comparing several treatments with a control. *J. Amer. Statist. Assn.* 50:1096-1121, 1955.
1,632	387	37	12	16	**Elson L A & Morgan W T J.** A colorimetric method for the determination of glucosamine and chondrosamine. *Biochem. J.* 27:1824-8, 1933.
1,745	336	159	210	161	***Ey P L, Prowse S J & Jenkin C R.** Isolation of pure IgG_1, IgG_{2a} and IgG_{2b} immunoglobulins from mouse serum using protein A-sepharose. *Immunochemistry* 15:429-36, 1978. (12/89/LS)
1,715	351	72	27	24	**Fahey J L & McKelvey E M.** Quantitative determination of serum immunoglobulins in antibody-agar plates. *J. Immunol.* 94:84-90, 1965.
1,667	373	39	10	9	**Folin O & Ciocalteu V.** On tyrosine and tryptophane determinations in proteins. *J. Biol. Chem.* 73:627-50, 1927.
1,837	301	102	153	148	**Geary W J.** The use of conductivity measurements in organic solvents for the characterisation of coordination compounds. *Coord. Chem. Rev.* 7:81-122, 1971.
1,679	365	70	101	95	***Gehan E A.** A generalized Wilcoxon test for comparing arbitrarily singly-censored samples. *Biometrika* 52:203-23, 1965. (39/79/LS)
1,732	344	64	8	7	**Gell-Mann M.** Symmetries of baryons and mesons. *Phys. Rev.* 125:1067-84, 1962.
1,767	331	74	64	73	**Giles K W & Myers A.** An improved diphenylamine method for the estimation of deoxyribonucleic acid. *Nature* 206:93, 1965.
1,658	375	38	24	8	**Good C A, Kramer H & Somogyi M.** The determination of glycogen. *J. Biol. Chem.* 100:485-91, 1933.
1,644	380	38	22	19	**Goodwin T W & Morton R A.** The spectrophotometric determination of tyrosine and tryptophan in proteins. *Biochem. J.* 40:628-32, 1946.
1,681	363	140	128	137	**Gordon T, Castelli W P, Hjortland M C, Kannel W B & Dawber T R.** High density lipoprotein as a protective factor against coronary heart disease. *Amer. J. Med.* 62:707-14, 1977.
1,650	379	49	69	56	***Hammond G S.** A correlation of reaction rates. *J. Amer. Chem. Soc.* 77:334-40, 1955. (34/85/ET&AS; 34/85/PC&ES)
1,779	324	71	1	1	***Hanson H P, Herman F, Lea J D & Skillman S.** HFS atomic scattering factors. *Acta Crystallogr.* 17:1040-4, 1964. (30/77)
1,672	370	119	85	81	***Helenius A & Simons K.** Solubilization of membranes by detergents. *Biochim. Biophys. Acta* 415:29-79, 1975. (22/85/LS)
1,608	399	50	43	39	***Huggett A S G & Nixon D A.** Use of glucose oxidase, peroxidase, and o-dianisidine in determination of blood and urinary glucose. *Lancet* 2:368-70, 1957. (21/81/CP)
1,612	396	58	1	2	**Karnovsky M J.** Simple methods for "staining with lead" at high pH in electron microscopy. *J. Biophys. Biochem. Cytol.* 11:729-32, 1961.
1,617	392	62	61	47	**Karplus M.** Letter to editor. (Vicinal proton coupling in nuclear magnetic resonance.) *J. Amer. Chem. Soc.* 85:2870-1, 1963.
1,675	369	168	186	181	**Kebabian J W & Calne D B.** Multiple receptors for dopamine. *Nature* 277:93-6, 1979.
1,628	389	37	10	7	**King E J.** The colorimetric determination of phosphorus. *Biochem. J.* 26:292-7, 1932.
1,633	386	102	184	147	***Kosterlitz J M & Thouless D J.** Ordering, metastability and phase transitions in two-dimensional systems. *J. Phys. C—Solid State Phys.* 6:1181-203, 1973. (In press.)

A	B	C	D	E	Bibliographic Data
1,835	306	44	52	40	**Kunitz M.** Crystalline soybean trypsin inhibitor. II. General properties. *J. Gen. Physiol.* 30:291-310, 1947.
1,617	392	74	85	79	***Lacy P E & Kostianovsky M.** Method for the isolation of intact islets of Langerhans from the rat pancreas. *Diabetes* 16:35-9, 1967. (8/81/LS)
1,773	325	104	114	94	***Laurell C-B.** Electroimmuno assay. *Scand. J. Clin. Lab. Invest.* 29(Supp. 124):21-37, 1972. (48/90/CM; 48/90/LS)
1,782	323	52	69	51	**Lennox E S.** Transduction of linked genetic characters of the host by bacteriophage P1. *Virology* 1:190-206, 1955.
1,737	340	40	27	25	***Lowry O H & Lopez J A.** The determination of inorganic phosphate in the presence of labile phosphate esters. *J. Biol. Chem.* 162:421-8, 1946. (31/81/LS)
1,734	342	96	55	46	**Maizel J V.** Polyacrylamide gel electrophoresis of viral proteins. *Meth. Virology* 5:179-246, 1971.
1,641	382	57	4	1	**Mandell J D & Hershey A D.** A fractionating column for analysis of nucleic acids. *Anal. Biochem.* 1:66-77, 1960.
1,717	350	115	71	57	**March S C, Parikh I & Cuatrecasas P.** A simplified method for cyanogen bromide activation of agarose for affinity chromatography. *Anal. Biochem.* 60:149-52, 1974.
1,678	367	153	287	255	**Markwell M A K, Haas S M, Bieber L L & Tolbert N E.** A modification of the Lowry procedure to simplify protein determination in membrane and lipoprotein samples. *Anal. Biochem.* 87:206-10, 1978.
1,835	306	46	23	20	**Martin J B & Doty D M.** Determination of inorganic phosphate. *Anal. Chem.* 21:965-7, 1949.
1,821	312	59	68	60	**McFarlane A S.** Efficient trace-labelling of proteins with iodine. *Nature* 182:53, 1958.
1,627	390	78	64	61	**McMillan W L.** Transition temperature of strong-coupled superconductors. *Phys. Rev.* 167:331-44, 1968.
1,721	348	215	201	164	***Messing J, Crea R & Seeburg P H.** A system for shotgun DNA sequencing. *Nucl. Acid. Res.* 9:309-21, 1981. (In press.)
1,668	372	46	184	238	**Metropolis N, Rosenbluth A W, Rosenbluth M N, Teller A H & Teller E.** Equation of state calculations by fast computing machines. *J. Chem. Phys.* 21:1087-92, 1953.
1,836	305	131	95	86	***Michell R H.** Inositol phospholipids and cell surface receptor function. *Biochim. Biophys. Acta* 415:81-147, 1975. (50/88/CM)
1,642	381	37	58	47	***Miles A A, Misra S S & Irwin J O.** The estimation of the bactericidal power of the blood. *J. Hyg.* 38:732-49, 1938. (37/79/LS)
1,681	363	120	87	85	***Miller G J & Miller N E.** Plasma-high-density-lipoprotein concentration and development of ischaemic heart-disease. *Lancet* 1:16-9, 1975. (15/81/LS)
1,688	358	73	25	38	***Mitchell P.** Chemiosmotic coupling in oxidative and photosynthetic phosphorylation. *Biol. Rev. Cambridge Phil. Soc.* 41:445-502, 1966. (16/78)
1,833	308	73	40	46	***Mollenhauer H H.** Plastic embedding mixtures for use in electron microscopy. *Stain Technol.* 39:111-4, 1964. (27/87/LS)
1,636	384	68	78	61	**Mori H.** Transport, collective motion, and Brownian motion. *Prog. Theor. Phys. Kyoto* 33:423-55, 1965.
1,652	377	45	33	27	**Mulliken R S.** Molecular compounds and their spectra. II. *J. Amer. Chem. Soc.* 74:811-24, 1952.
1,832	309	76	200	169	***Nelder J A & Mead R.** A simplex method for function minimization. *Comput. J.* 7:308-13, 1965. (15/79/ET&AS)
1,609	398	89	63	67	**Neville D M.** Molecular weight determination of protein-dodecyl sulfate complexes by gel electrophoresis in a discontinuous buffer system. *J. Biol. Chem.* 246:6328-34, 1971.
1,837	301	54	10	5	**Nilsson S G.** Binding states of individual nucleons in strongly deformed nuclei. *Mat. Fys. Medd. Dan. Vid. Selsk.* 29:3-68, 1955.
1,678	366	80	39	37	***Niswender G D, Midgley A R, Monroe S E & Reichert L E.** Radioimmunoassay for rat luteinizing hormone with antiovine LH serum and ovine LH-^{131}I. *Proc. Soc. Exp. Biol. Med.* 128:807-11, 1968. (44/80/LS)
1,761	334	84	211	290	**North A C T, Phillips D C & Mathews F S.** A semi-empirical method of absorption correction. *Acta. Crystallogr. A—Cryst. Phys.* 24:351-9, 1968.
1,764	332	71	99	102	**Omura T & Sato R.** The carbon monoxide-binding pigment of liver microsomes. II. Solubilization, purification, and properties. *J. Biol. Chem.* 239:2379-85, 1964.
1,800	317	41	62	79	**Onsager L.** Electric moments of molecules in liquids. *J. Amer. Chem. Soc.* 58:1486-93, 1936.
1,671	371	46	35	12	**Ouchterlony O.** Antigen-antibody reactions in gels. *Acta Pathol. Microbiol. Scand.* 32:231-40, 1953.

A	B	C	D	E	Bibliographic Data
1,742	339	124	105	92	**Palade G.** Intracellular aspects of the process of protein synthesis. *Science* 189:347-58, 1975.
1,694	357	47	32	47	**Pople J A.** Electron interaction in unsaturated hydrocarbons. *Trans. Faraday Soc.* 49:1375-85, 1953.
342	54	20	20	16	***Poulik M D.** Starch gel in electrophoresis in a discontinuous system of buffers. *Nature* 180:1477-9, 1957. (15/84/LS)
1,615	394	77	65	62	**Reid R V.** Local phenomenological nucleon-nucleon potentials. *Ann. Phys. N. Y.* 50:411-48, 1968.
1,686	359	169	124	121	**Rosenberg M & Court D.** Regulatory sequences involved in the promotion and termination of RNA transcription. *Annu. Rev. Genet.* 13:319-53, 1979.
1,805	316	201	330	281	**Sanger F, Coulson A R, Barrell B G, Smith A J H & Roe B A.** Cloning in single-stranded bacteriophage as an aid to rapid DNA sequencing. *J. Mol. Biol.* 143:161-78, 1980.
1,635	385	65	140	144	**Savitzky A & Golay M J E.** Smoothing and differentiation of data by simplified least squares procedures. *Anal. Chem.* 36:1627-39, 1964.
1,784	321	46	8	6	**Schneider W C & Hogeboom G H.** Intracellular distribution enzymes. V. Further studies on the distribution of cytochrome *c* in rat liver homogenates. *J. Biol. Chem.* 183:123-8, 1950.
1,745	336	40	25	29	**Slater J C.** Atomic shielding constants. *Phys. Rev.* 36:57-64, 1930.
1,685	362	56	4	1	**Smithies O.** An improved procedure for starch-gel electrophoresis: further variations in the serum proteins of normal individuals. *Biochem. J.* 71:585-7, 1959.
1,727	345	144	186	197	***Sokoloff L, Reivich M, Kennedy C, Des Rosiers M H, Patlak C S, Pettigrew K D, Sakurada O & Shinohara M.** The $[^{14}C]$deoxyglucose method for the measurement of local cerebral glucose utilization: theory, procedure, and normal values in the conscious and anesthetized albino rat. *J. Neurochem.* 28:897-916, 1977. (27/89/CM; 27/89/LS)
1,608	399	73	76	76	**Sottocasa G L, Kuylenstierna B, Ernster L & Bergstrand A.** An electron-transport system associated with the outer membrane of liver mitochondria. *J. Cell Biol.* 32:415-38, 1967.
1,713	352	156	193	214	**Spitzer R L, Endicott J & Robins E.** Research diagnostic criteria. *Arch. Gen. Psychiat.* 35:773-82, 1978.
1,685	361	99	71	68	***Steiner A L, Parker C W & Kipnis D M.** Radioimmunoassay for cyclic nucleotides. I. Preparation of antibodies and iodinated cyclic nucleotides. *J. Biol. Chem.* 247:1106-13, 1972. (38/85/LS)
1,837	301	102	65	65	**Ungerstedt U.** Stereotaxic mapping of the monoamine pathways in the rat brain. *Acta Physiol. Scand.* (Supp. 367):1-48, 1971.
1,793	318	47	41	36	***Ussing H H & Zerahn K.** Active transport of sodium as the source of electric current in the short-circuited isolated frog skin. *Acta Physiol. Scand.* 23:110-27, 1951. (35/81/LS)
1,735	341	193	354	356	**Wallenstein S, Zucker C L & Fleiss J L.** Some statistical methods useful in circulation research. *Circ. Res.* 47:1-9, 1980.
1,676	368	99	42	35	**Weber K, Pringle J R & Osborn M.** Measurement of molecular weights by electrophoresis on SDS-acrylamide gel. *Meth. Enzymology* 26:3-27, 1972.
1,629	388	44	65	40	**Westphal O, Luderitz O & Bister F.** Uber die Extraktion von Bakterien mit Phenol/Wasser (Extraction of bacteria with phenol/water). *Z. Naturforsch. Sect. B* 7:148-55, 1952.
1,724	347	78	14	15	***Woods K R & Wang K-T.** Separation of dansyl-amino acids by polyamide layer chromatography. *Biochim. Biophys. Acta* 133:369-70, 1967. (35/84/LS)
1,651	378	49	31	25	**Yemm E W & Cocking E C.** The determination of amino-acids with ninhydrin. *Analyst* 80:209-14, 1955.
1,832	310	51	37	51	***Zlatkis A, Zak B & Boyle A J.** A new method for the direct determination of serum cholesterol. *J. Lab. Clin. Med.* 41:486-92, 1953. (12/81/LS)

Most-Cited Papers: The "Fourth 100"

Table 1 lists the papers ranked from 301 to 400, based on citation totals from 1945 to 1988, in alphabetical order by the primary author's last name. The columns that precede the bibliographic data include total citations 1945-1988, rank, average annual citations 1945 to 1988, and 1989 and 1990 citations, respectively.

The authors of 38 of these 100 papers have written *Citation Classic* ® commentaries on the listed works. These are indicated by asterisks. The *Current Contents* ® (*CC* ®) reference for each commentary follows in parentheses. Inclusive of this in-

Table 2. Chronological distribution of the fourth 100 most-cited papers from the *SCI* ®, 1945-1988. Data in parentheses are cumulated through the top 400 most-cited papers identified to date.

Decade	Number of Papers	Total Cites	Average Citations Per Year	Average 1988 Cites
1920s	1 (4)	1,667 (23,926)	38 (136)	6 (102)
1930s	6 (15)	10,105 (48,330)	38 (79)	29 (57)
1940s	8 (37)	13,961 (119,353)	42 (76)	39 (92)
1950s	20 (86)	34,440 (470,895)	49 (162)	47 (236)
1960s	33 (142)	56,151 (460,113)	72 (132)	68 (123)
1970s	26 (91)	45,106 (358,309)	119 (268)	142 (446)
1980s	6 (25)	10,410 (62,898)	214 (376)	285 (663)
Total	100 (400)	171,840 (1,543,924)	82 (175)	88 (246)

stallment, 173 of the 400 most-cited papers have been featured as *Citation Classics*.

Table 2 provides a chronological distribution of the fourth 100 most-cited papers and, in parentheses, the data accumulated through the top 400, inclusive. The decade with the most papers and largest number of accumulated citations is the 1960s. Not surprisingly, since they have climbed the list in so few years, papers published in the 1980s have the highest annual citation average as well as 1990 citedness. So far among the 400 papers, not one was published in 1942, and only three from 1941 and two from 1943 made the list. Whether this reflects an overall decline in publications in wartime is not certain.

Papers from the 1980s: "Bullets"

Keep in mind that if our starting database were 1945 to 1990, instead of 1945 to 1988, there would be many changes in ranking, especially with the papers from recent years. Only six papers in Table 1 were published in the 1980s, each averaging 200 or more citations per year—the only ones in this list to do so. Even among those papers ranked 201-300, only papers published in the 1980s were cited at this rate. However, 65 of the pre-1980 papers in the top 200 averaged more than 200 cites per year.

If you add columns D and E to column A, the transient nature of these rankings becomes apparent. Consider, for example, the papers by B.N. Ames, E. Clementi, and M.J.S. Dewar—over the last two years, all have been cited far above their listed averages.

"Bullets" typically start off strong and quickly accelerate. A good example is the most recently published paper in the table. It also is the first AIDS paper to make our most-cited listing. The citations to this 1983 article from the Montagnier group in Paris concerned the isolation of a T-lymphotropic retrovirus from a patient at risk for AIDS. Coauthored by Francoise Barre-Sinoussi and colleagues, Pasteur Institute, citations to this paper jumped from 27 in 1983 to 146 in 1984. Between 1983 and 1988, the paper was cited 1,770 times, averaging nearly 300 per year, with a high point of 435 in 1987 (see Figure 1).

As they noted in their *Citation Classic* commentary:

> [The] idea that our viral isolate was a new retrovirus that might be the cause of the disease was not very well accepted until it was confirmed one year later by other laboratories.... Thus, this paper is highly cited because it provided evidence for the role of a new human retrovirus in AIDS.[8]

This paper is one of four 1980s articles in Table 1 that have been highlighted in previous essays identifying papers highly cited within two years of publication.[9,10] Others include a description of multicellular split-gene coding for proteins (R. Breathnach),[11] a method for "shotgun" DNA sequencing (J. Messing),[11] and a review of calmodulin in cellular regulation (W.Y. Cheung).[12] Figure 1 illustrates the citation records of the 1980s publications from this study.

Table 3. Nobel Prize winners with papers ranked between 301 and 400 in the *SCI* ®, 1945-1988. A=Nobelists, listed alphabetically. B=year and prize. C=affiliation.

A	B	C
James W. Black	1988/Physiology or Medicine	Smith, Kline and French Laboratories
Stanley N. Cohen	1986/Physiology or Medicine	Stanford University School of Medicine
Christian de Duve	1974/Physiology or Medicine	Rockefeller University
Murray Gell-Mann	1969/Physics	California Institute of Technology
Roger Guillemin	1977/Physiology or Medicine	Salk Institute
Alfred D. Hershey	1969/Physiology or Medicine	Carnegie Institution of Washington
Peter Mitchell	1978/Chemistry	Glynn Research Laboratory
Robert S. Mulliken	1966/Chemistry	University of Chicago
Lars Onsager	1968/Chemistry	Yale University
George E. Palade	1974/Physiology or Medicine	Yale University
Frederick Sanger	1958 & 1980/Chemistry	Medical Research Council Laboratory of Molecular Biology

We should note here that one of the most cited of the other pioneering AIDS papers, by Robert Gallo and colleagues,[13] also the subject of a *Citation Classic* commentary,[14] had been cited 1,496 times through the end of 1988, falling just short of the cutoff for the top 400.

In his *Classic* commentary on this 1984 paper, Gallo discussed the detection of the HTLV-III virus and the subsequent citation impact of the papers published by his group.

> The first published detection of the virus was from a patient with lymph-node enlargement, but tests of sera originally showed less than 20 percent of AIDS patients had antibodies to LAV. No doubt this was due to insufficient virus production. We found and described 48 isolates of HTLV-III (now generically HIV) from patients with AIDS and at risk; none of the 115 nonrisk healthy people yielded such isolates. We think the 1984 *Science* papers are frequently cited because it was the first time anyone stated that they knew the cause of AIDS.[14]

An article in the *New Scientist*,[15] by Alison Rawling, Sydney University, Australia, analyzes the citation trends for the Gallo and the Barre-Sinoussi papers. She notes that, after the very public contest for priority in the discovery of the AIDS virus between the two groups, the scientific community has increasingly cited the Barre-Sinoussi paper as the primordial paper on HIV. Without drawing a direct conclusion, she indicates that this may be a conscious choice by the scientific community to disregard the formal settlement of

Figure 1. Citation records for 1980s papers ranked between 301 and 400.

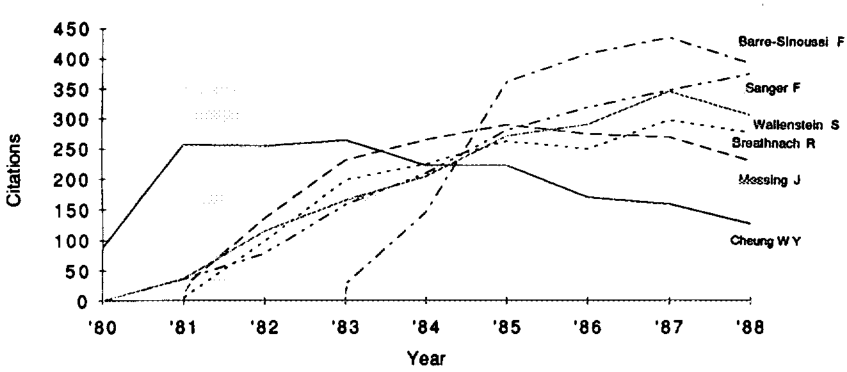


Table 4. The journals that published the fourth group of most-cited *SCI* ® papers, 1945-1988. A=title, with first year of publication in parentheses. B=number of most-cited articles appearing in the journal.

A	B
J. Biol. Chem. (1905)	10
Biochem. J. (1906)	6
J. Amer. Chem. Soc. (1879)	6
Nature (1869)	5
Biochim. Biophys. Acta (1947)	4
Science (1880)	4
Anal. Biochem. (1960)	3
J. Chem. Phys. (1931)	3
Phys. Rev. (1893)	3
Acta Crystallogr. A—Cryst. Phys. (1968)	2
Acta Physiol. Scand. (1940)	2
Anal. Chem. (1929)	2
Immunochemistry (1964)	2
Lancet (1823)	2
Meth. Enzymology (1955)	2
Proc. Nat. Acad. Sci. USA (1915)	2
Acta Crystallogr. (1948)	1
Acta Pathol. Microbiol. Scand. (1924)	1
Amer. J. Med. (1946)	1
Analyst (1877)	1
Ann. Phys. N. Y. (1957)	1
Annu. Rev. Biochem. (1932)	1
Annu. Rev. Genet. (1967)	1
Annu. Rev. Physiol. (1939)	1
Arch. Gen. Psychiat. (1959)	1
At. Data Nucl. Data Tables (1969)	1
Biol. Rev. Cambridge Phil. Soc. (1936)	1
Biometrika (1901)	1
Circ. Res. (1953)	1
Comput. J. (1958)	1
Coord. Chem. Rev. (1966)	1
Diabetes (1952)	1
IBM J. Res. Develop. (1957)	1
J. Amer. Statist. Assn. (1888)	1
J. Appl. Physiol. (1948)	1
J. Biophys. Biochem. Cytol. (1955)	1
J. Cell Biol. (1962)	1
J. Chem. Soc. (London) (1849)	1
J. Gen. Physiol. (1918)	1
J. Histochem. Cytochem. (1953)	1
J. Hyg. (1901)	1
J. Immunol. (1916)	1
J. Lab. Clin. Med. (1915)	1
J. Lipid Res. (1959)	1
J. Mol. Biol. (1959)	1
J. Neurochem. (1956)	1
J. Phys. C—Solid State Phys. (1968)	1
Mat. Fys. Medd. Dan. Vid. Selsk. (1917)	1
Meth. Virology (1967)	1
Nucl. Acid. Res. (1974)	1
Proc. Soc. Exp. Biol. Med. (1903)	1
Prog. Theor. Phys. (1946)	1
Scand. J. Clin. Lab. Invest. (1949)	1
Stain Technol. (1926)	1
Trans. Faraday Soc. (1905)	1
Virology (1955)	1
Z. Krebsforsch. (1903)	1
Z. Naturforsch. Sect. B. (1947)	1

the dispute—a settlement which states that the two groups jointly share the discovery.

Nobel Laureates

Eleven Nobel laureates authored papers in Table 1, bringing our total to 45 Nobelists who have authored 66 of the top 400 papers. Table 3 lists the 11 laureates with papers ranked between 301 and 400, the years and categories in which they received their awards, and their affiliations, as listed on their papers.

Journals of the *SCI* Top 400

Table 4 presents the 58 journals that published the papers covered in this segment of the series. As expected, the *Journal of Biological Chemistry* (*JBC*) leads with 10 papers, bringing its cumulative total to 53. And for the third time, the second highest total comes from the *Biochemical Journal*, which has 6 articles here and 24 overall.

Among the 400 most-cited articles listed to date, three were published in French and five in German. In the previous three lists, review journals did not show up. In this listing, the *Annual Reviews* series—in *Biochemistry, Genetics*, and *Physiology*—appear for the first time.

Journals publishing at least five articles among the *SCI* Top 400 are shown in Table 5. These 19 journals account for 237 papers, or 59 percent of the total. Interestingly, five of them—*Nature*, *Journal of the American Chemical Society*, *Science*, *Physical Review*, and *Journal of Experimental Medicine*—were first published in the 19th century. In contrast, three started in 1960 or later.

"Shooting Stars" and Obliteration

Eleven papers in Table 1 can be classified as shooting stars. These papers accumulate citations quickly and, often, just as quickly, drop off with long citation "tails." For example, a typical case history is the 1959 methods paper on a procedure for determining serum proteins in normal individuals, by O. Smithies, Connaught Medical Research Laboratories, Toronto, Ontario, Canada. In 1966, seven years after publication in the *Biochemical Journal*, annual citations to the article peaked at 286 then declined to double digits three years later. From 1979 on, it has fewer than 16 cites annually, with only a single citation in 1990. Cumulative through 1988, the paper has 1,685 citations, with an annual average of 56. Figure 2 gives a graphic representation of this paper's history.

In a recent conversation with *CC*, Smithies characterized this as an evolution of this type of paper—highly cited when it was the first, best method and, eventually, replaced by papers detailing newer, often simpler methods. In this case, Smithies 1959 paper was replaced by the work of U.K. Laemmli[16] and B.J. Davis,[17] numbers two and seven in this series.[3,4]

The fact that this paper was superseded by subsequent procedures does not in any way dim the importance of this work. In recognition of his efforts in gel electrophoresis, Smithies received the 1990 Gairdner Foundation award.

Most of the shooting star papers parallel the Smithies publication history. They average from 47 to 96 citations a year then fall off within two to seven years after their high points.

Table 5. Journals that published five or more of the top 400 most-cited *SCI*® papers, 1945-1988. A=title, with first year of publication in parentheses. B=number of most-cited papers appearing in the journal.

A	B
J. Biol. Chem. (1905)	53
Biochem. J. (1906)	24
Nature (1869)	18
Anal. Biochem. (1960)	14
J. Chem. Phys. (1931)	14
J. Mol. Biol. (1959)	13
Proc. Nat. Acad. Sci. USA (1915)	13
J. Amer. Chem. Soc. (1879)	11
Science (1880)	10
Phys. Rev. (1893)	9
J. Cell Biol. (1962)	8
J. Histochem. Cytochem. (1953)	8
Meth. Enzymology (1955)	8
Anal. Chem. (1929)	7
Biochim. Biophys. Acta (1947)	6
J. Exp. Med. (1896)	6
Acta Crystallogr. (1948)	5
Acta Crystallogr. A—Cryst. Phys. (1968)	5
J. Immunol. (1916)	5

Two of the papers are from the 1950s, eight from the 1960s, and one from the 1970s. Whether we can attach any significance to the high percentage of shooting star papers from the 1960s is doubtful. However, Leon M. Lederman, winner of the 1988 Nobel Prize for physics, characterized this as the golden age of science. His 1962 paper exemplifies how primordial references eventually decline and are absorbed into the common wisdom. This paper, coauthored with, among others, Melvin Schwartz and

Figure 2. Citation history of O. Smithies "Shooting Star" paper.

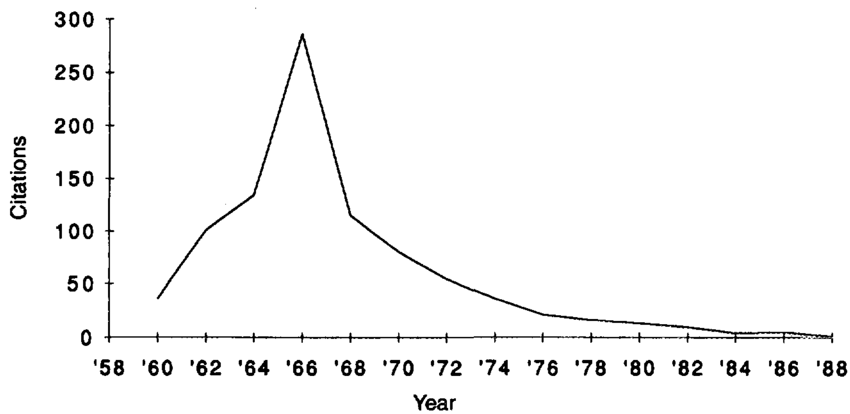
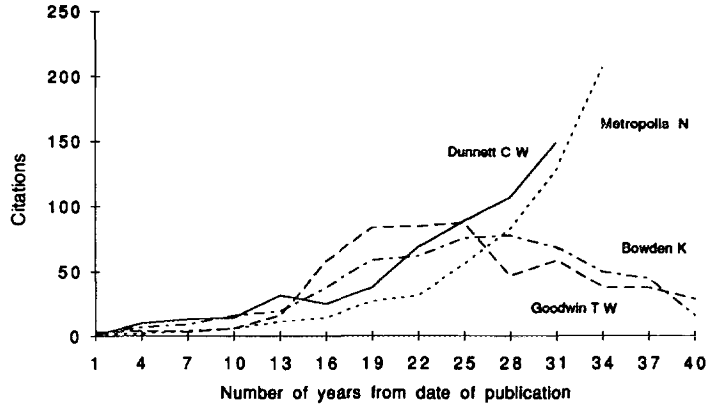


Figure 3. Citation records of papers showing delayed recognition.



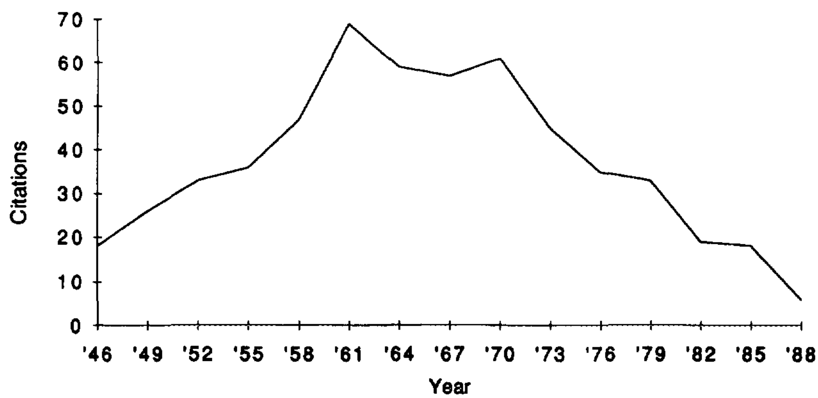
Jack Steinberger, with whom Lederman shared the Nobel Prize, developed a method for detecting neutrinos.[18,19] Its citation impact peaked the year following publication, then eventually became "obliterated."

Delayed Recognition or Application

Four papers in Table 1 deserve scrutiny as candidates for delayed recognition, or—as mentioned in previous installments of this study—cases for delayed application.[4-6] These publications are characterized by a very slow initial citation accumulation, followed by a jump to a comparatively high level of citations. In these examples, the time from obscurity to high citedness ranges up to more than three decades. Two of the papers—spectrophotometric determinations of tyrosine and tryptophan, and the preparation of acetylenic ketones—were published in 1946. Another came out in 1953, describing a general method for calculating equations for nuclear particle interactions. The fourth paper was published in 1955 and outlines a procedure using mathematical equations for comparing experimental results with a control or standard. Figure 3 shows the year-by-year figures of citations for these papers.

In his *Classic* commentary on his paper from this group, K. Bowden discusses the reasons for the delayed recognition of this work:

Figure 4. Graph of citations to the O. Folin & V. Ciocalteu "Perennial" paper.



> This [synthesis of acetylenic ketones] proved to be an elegant method and gave rise to the term "the Jones reagent" when it was found applicable to the oxidation of a variety of compounds.[20]

The 1953 paper, in the *Journal of Chemical Physics*, on calculations by fast computing machines, deserves to be singled out. Published by Nicholas Metropolis and colleagues, Los Alamos Scientific Laboratory, New Mexico, and the University of Chicago, this publication, through 1988, has garnered nearly 1,700 citations, an average of 46 per year. Three interesting points: the paper has not yet peaked (its highest annual citation count was 238 in 1990); one of the coauthors is Edward Teller—at the University of Chicago when the paper was written—who, along with mathematician Stanislaw Ulam, developed the thermonuclear hydrogen bomb; and, one of the Los Alamos coauthors was Teller's wife, Augusta H. Teller.

Perennials

More than 25 papers from the late 1920s through the 1960s have been referenced fairly steadily through the decades. We call these papers "perennials." The oldest paper listed is the classic by Otto Folin and Vintila Ciocalteu, Harvard Medical School, Boston, Massachusetts. It was published in 1927 in the *JBC*. This is the fifth *JBC* paper that dates from the 1920s or early 1930s. The citation record of this methods paper indicates that, between 1945 and 1960, it averaged 34 citations annually. In 1961, it reached a peak of 69. Since then, the number of works citing it gradually declined, with only nine in 1990. Other perennials have similar citation "biographies." Figure 4 illustrates this paper's year-by-year citation record.

Methods papers also characterize the group of 1930s perennials. These cover the determination of glucosanine and chondrasamine (L.A. Elson), glycogen (C.A. Good), phosphorus (E.J. King), electric moments of molecules in liquids (L. Onsager), atomic shielding constants (J.C. Slater), and the estimation of the bactericidal power of blood (A.A. Miles).

A *Classic* commentary on this last paper, by Ashley A. Miles, London Hospital Medical College, England, touches on the reasons for the paper's longevity.

> I suspect, from the references I have come across, that the paper is most commonly cited for the description of the surface-viable count for bacteria.... From the scientific literature I have subsequently read, the bactericidal method and the statistical considerations in determining the significance of differences in killing rates appear, like the mule, to have nothing to show in the way of offspring; though as far as my own work is concerned, they are coming home to roost in some current work on the bactericidal power of macrophage populations. The surface-viable count evidently—and gratifyingly—lives on.[21]

The 1940s-vintage publications highlight spectrophotometry: for the determination of methylpentoses (Z. Dische) and the interaction of iodine with hydrocarbons (H.A. Benesi). Other topics include descriptions of the general properties of soybean trypsin inhibitor (M. Kunitz), dispersion and absorption of dielectrics (nonconductors of electrical current) when exposed to alternating current (K.S. Cole), and the determination of inorganic phosphate in the presence of unstable phosphate esters (O.H. Lowry).

The largest number of perennials in Table 1 was published in the 1950s. These 12 papers represent a wide range of topics: studies on amino acids (E.W. Yemm), proteins (A.S. McFarlane), bacteria extraction (O. Westphal), the distribution of enzymes (W.C. Schneider), molecular compounds (R.S. Mulliken), genetic linkage (E.S. Lennox), electron interaction in hydrocarbons (J. A. Pople), the transport of sodium in epithelial tissue (H.H. Ussing), determination of hexosamines in tissues (N.F. Boas), chemical reaction rates (G.S. Hammond), blood in urinary glucose (A.S.G. Huggett), and, finally, blood platelet counts (G. Brecher).

Conclusion

There are trends that stand out in these essays. Among them: Nobel Prize winners have participated as authors on one out of every six of the top 400 papers; high-impact journals dominate the publication of these most-cited papers, with 13 journals accounting for more than half of these papers (203 of 400); and, while the "shooting stars" of the group are the papers from the 1980s, having an impact immediate enough to make this listing, there continue to be "perennial" papers that have been cited steadily for decades.

Obviously, the essays describing the top 400 papers, 1945 to 1988, are really a "snapshot" of the *SCI* data at the end of 1988. You can see by the 1989 and 1990 data in Table 1 that the rankings of many of these papers have been dramatically altered already. This is a reflection of both the rapidly changing dynamics of science and the extraordinary growth of the literature and exemplifies what is so exciting about science.

REFERENCES

1. **Garfield E.** The 1955-1964 *Science Citation Index* cumulation—a major new bibliographic tool for historians of science and all others who need precise information retrieval for the age of space and molecular biology. *Current Contents* (5):5-8, 31 January 1983. (Reprinted in: *Essays of an information scientist.* Philadelphia: ISI Press, 1984. Vol. 6. p. 27-30.)
2. ---------. The new 1945-1954 *SCI* cumulation provides unique access to the crucial postwar decade of scientific and technological achievement. *Current Contents* (27):3-10, 4 July 1988. (Reprinted in: *Ibid.*, 1990. Vol. 11. p. 219-26.)
3. ---------. The most-cited papers of all time, *SCI* 1945-1988. Part 1A. The *SCI* top 100—will the Lowry method ever be obliterated? *Current Contents* (7):3-14, 12 February 1990.
4. ---------. The most-cited papers of all time, *SCI* 1945-1988. Part 1B. Superstars new to the *SCI* top 100. *Current Contents* (8):3-13, 19 February 1990.
5. ---------. The most-cited papers of all time, *SCI* 1945-1988. Part 2. The second 100 *Citation Classics*. *Current Contents* (26):5-17, 25 June 1990.
6. ---------. The most-cited papers of all time, *SCI* 1945-1988. Part 3. Another 100 from the *Citation Classics* hall of fame. *Current Contents* (34):3-13, 20 August 1990.
7. ---------. The 'obliteration phenomenon' in science—and the advantage of being obliterated! *Current Contents* (51/52):5-7, 22 December 1975. (Reprinted in: *Op. cit.*, 1977. Vol. 2. p. 396-8.)
8. **Barre-Sinoussi F, Chermann J-C & Montagnier L.** Citation Classic. Commentary on *Science* 220:868-71, 1983. *Current Contents/Life Sciences* 30(8):18, 23 February 1987.
9. **Garfield E.** The 1983 articles most cited in 1983 and 1984. 1. Life sciences. *Current Contents* (47):3-18, 25 November 1985. (Reprinted in: *Op. cit.*, 1986. Vol. 8. p. 444-59.)
10. ---------. The 1983 articles most cited in the *SSCI*, 1983-1985. Part 1. Fifty-three papers highlight studies of law, nuclear winter, and eating disorders. *Current Contents* (43):3-11, 26 October 1987. (Reprinted in: *Ibid.*, 1989. Vol. 10. p. 310-8.)
11. ---------. The 1981 articles most cited in 1981 and 1982. 1. Life sciences. *Current Contents* (38):5-15, 19 September 1983. (Reprinted in: *Ibid.*, 1984. Vol. 6. p. 301-11.)
12. ---------. The 1980 articles most cited in 1980 and 1981. 1. Life sciences. *Current Contents* (10):5-15, 7 March 1983. (Reprinted in: *Ibid.* p. 63-73.)
13. **Gallo R C, Salahuddin S Z, Poppovic M, Shearer G M, Kaplan M, Haynes B F, Palker T J, Redfield R, Oleske J, Safai B, White G, Foster P & Markham P D.** Frequent detection and isolation of cytopathic retroviruses (HTLV-III) from patients with AIDS and at risk for AIDS. *Science* 224:500-3, 1984.
14. **Gallo R C.** Citation Classic. Commentary on *Science* 224:500-3, 1984. *Current Contents/Life Sciences* 31(15):16, 11 April 1988.
15. **Rawling A.** Montagnier, Gallo or both? *New Sci.* 127(1735):74-5, 22 September 1990.
16. **Laemmli U K.** Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature* 227:680-5, 1970.
17. **Davis B J.** Disc electrophoresis—II. Method and application to human serum proteins. *Ann. NY Acad. Sci.* 121:404-27, 1964.
18. **Garfield E.** The 1988 Nobel Prize in physics: Melvin Schwartz, Leon Lederman, Jack Steinberger, and the story of two neutrinos. *Current Contents* (32):3-9, 7 August 1989.
19. **Danby G, Gaillard J M, Goulianos K, Lederman L M, Mistry N, Schwartz M & Steinberger J.** Observation of high-energy neutrino reactions and the existence of two kinds of neutrinos. *Phys. Rev. Lett.* 9:36-44, 1962.
20. **Bowden K.** Citation Classic. Commentary on *J. Chem Soc.* (London) 1946:39-45. (Thackray A, comp.) *Contemporary classics in physical, chemical, and earth sciences.* Philadelphia: ISI Press, 1986. p. 208.
21. **Miles A A.** Citation Classic. Commentary on *J. Hygiene* 38:732-49, 1938. (Barrett J T, ed.) *Contemporary classics in the life sciences. Volume 1: cell biology.* Philadelphia: ISI Press, 1986. p. 122.