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"Current Comments"

Citation Classics. 3. Articles from the Physical Sciences Published in the 1930s.

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Recently we listed highly-cited life-sciences articles from the 1930s. Here is the corresponding list for the physical sciences.

The 49 articles on the list were published in 20 different journals. The journals are listed alphabetically in Figure 1. Figure 1 shows also the number of articles each journal published. The 1975 'impact' for each journal is included. Four journals published more than half the items: *Journal of Chemical Physics* (9): *Physical Review* (8); *Journal of the American Chemical Society* (6); and *Zeitschrift für Physik* (3). Seven journals produced two articles each--the remaining nine, one each. Two of these are mathematics journals, but clearly the subject involved here is mathematical physics (articles 46 and 49). All but two of the journals (*Physikalische Zeitschrift der Sowjetunion* and *Zeitschrift für Technische Physik*) are still being published. As indicated in Figure 1, a few have changed titles. *Science* and *Nature* are notable by their absence from this list and the previous list for life sciences.

The 49 articles are listed in Figure 2 alphabetically by first author. Each was cited more than 150 times during the period 1961-1975. On the average they were cited about 375 times each during those 15 years. And, on the average, they continue to be cited about 30 times a year.

There is something about these lists of classics that I haven't stressed before. I have called these classics "highly cited articles." In fact it is more accurate to call them "*still* highly cited articles." These articles were published in the 1930s. Most were surely cited heavily in the 1930s and 40s and 50s. Counts given in Figure 2 are for the years 1961-1975 *only*. By then, all the papers were already twenty to thirty years old.

We're restricted in our citation counting to the period 1961-1975 because it was in 1961 that we began to process information for the *Science Citation Index®* (*SCI®*) data base. Thus this list of articles can't include many articles that may have been heavily cited in the 1930s and 40s and 50s, but are no longer cited.

A	B	Journal
1	1.226	Ann. Mathematics
2	0.358	Annalen der Physik
1	1.493	Chem. Berichte
2	3.291	Ind. Eng. Chem. Anal. Ed. (Analyt. Chemistry)
6	4.383	J. Amer. Chem. Soc.
9	2.918	J. Chem. Physics
1	1.830	J. Chem. Society
1	0.229	J. Inst. Metals London
1	0.426	J. Pharmacie Chimie (Ann. Pharm. Fr.)
2	1.861	J. Physique Radium (J. Physique)
2	0.969	Physica
8	2.684	Physical Review
2	--	Phys. Zschr. Sowjetunion (disc.)
1	0.397	Proc. Cambridge Phil. Soc.
2	2.215	Proc. Roy. Soc. Lond. A Math.
1	21.500	Revs. Modern Physics
1	0.217	Trans. Amer. Inst. Chem. Eng. (Chem. Eng. Progr.)
2	1.812	Trans. Faraday Soc. (J. Chem. Soc. Faraday)
3	1.340	Zschr. Physik
1	--	Zschr. Techn. Physik (disc.)

Figure 1. Journals that published the articles listed in Figure 2. **A** = number of articles listed. **B** = journal's impact factor. (Titles in parentheses are present titles of the journals); *disc.* indicates journal has been discontinued.)

Such articles reached their citation peaks sometime before 1961, and then dropped below the citation level of ten times a year--the criterion we use in selecting articles for our 'highly-cited' file.

We are dealing here with a list of articles that have a particular citation pattern in common. Other articles--significant but of shorter citation life--had a different citation history. Our fifteen years of data, as unique as it is, doesn't encompass their records. This study reinforces a conclusion we reached sometime ago. Only when ISI® has compiled citation indexes for the decades before the 1960s--as we hope to do--will we be able to do a satisfactory job of identifying the other types of citation classics and their distinct citation patterns. Then we will be better able to interpret their historical significance.

For the reasons cited above some of the most important work done in the physical sciences during the 1930s is not included. The culmination of significant work in nuclear, high energy, and particle physics took place at that time. Some examples are Chadwick's discovery of the neutron (1932); the Cockroft-Walton description of artificial disintegration of the nucleus (1932); Anderson's discovery of the positron (1933); Fermi's theory of beta-decay (1934); Yukawa's theory of the meson (1935); Bohr's compound nucleus model (1936); the discovery of fission (1939). Keep in mind, however, that the relevant articles are still cited frequently, though not frequently enough to have gotten on this list. In many instances, however, the work had by 1961 become so fundamental and integral a part of modern physics, that such individual articles no longer needed to be cited. By then, indeed, much of the re-

search was explained or even assumed in even secondary-school textbooks. This progression has been called the obliteration phenomenon.[2]

Inspite of all these 'limitations' of such 'classics' lists, there can be no doubt about the significance of the articles that have been selected. Eleven of the 49 articles were authored or coauthored by future Nobel prize winners: Bethe (article 6), 1967 award in physics; Goeppert-Mayer (16), 1963 award in physics; Landau (28 and 29), 1962 award in physics; Onsager (34, 35, and 36), 1968 award in chemistry; Wigner (7, 44, 45, and 46), 1963 award in physics. In scanning for Nobel prize winners you may, as I did, do a double take at articles 37 and 38 by Perrin. These two articles on Brownian motion by Francois Perrin are on the same subject whose study won his father, Jean-Baptiste Perrin, a Nobel award in 1926.

There are other names among the authors that may be equally familiar, even among non-physicists: Edward Teller of the Jahn-Teller effect (articles 8, 21 and 29); Fowler of Fowler's photoemission equation formulation (14); London of the Heitler-London theorem and the London-van der Waals attraction (31); Hückel of the Hückel rule (20), and Van Vlech of the Brooks-Van Vlech model (43). Hardly less notable will be Bernal (article 5), Eyring (12), Mott (33), and Slater (39 and 40). With some reflected pride I also point out the name of L.P. Hammett (article 18). I worked for Professor Hammett during my brief career as a laboratory chemist. I even coauthored a paper with him and my cousin, Sid Bernhard.[3] They were very generous to a lowly lab assistant.

The first ten articles on the list are fairly representative of its character as a whole. Only two (6 and 7) deal with physics. The rest are chemistry papers--but chemistry papers that show application of physical research into atomic and molecular structure. The quantum theory, for example, had been developed before the 30s. Much of the work represented by the list of papers in Figure 2 is basically the application of quantum mechanics and phase change to specific applications and specific problems, especially those of materials and their properties. As such, the list of articles will be of more interest to chemists than to physicists, despite the more frequent occurrence of the word *physics* in the titles of journals from which the articles come.

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1. Garfield E. Citation classics. 2. Life sciences articles from the 1930s. *Current Contents®* (*CC®*) No. 43, 25 October 1976, p. 5-10.
2. ————. The 'obliteration phenomenon' in science, and the advantage of being obliterated. *CC* No. 51/52, 22 December 1975, p. 5-7.
3. **Bernhard S A, Garfield E & Hammett L P.** Specific effects in acid catalysis by ion exchange resins. 3. Some observations on the effect of polyvalent cations. *J. Amer. Chem. Soc.* 76:991-92, 1954.

Figure 2. Articles in the physical sciences published in the 1930s and highly cited in the period 1961-1975. A = item number. B = times cited 1961-1975. C = times cited 1975-1976.

A	B	C	Bibliographic Data
1.	227	45	**Åkerlöf G.** Dielectric constants of some organic solvent-water mixtures at various temperatures. *J. Amer. Chem. Soc.* **54**:4125-39, **1932.**
2.	272	42	**Avrami M.** Kinetics of phase change. 1. General theory. *J. Chem. Phys.* 7:1103-12, **1939.**
3.	219	35	**Becker R & Doring W.** Kinetische Behandlung der Keimbildung in übersättigen Dämpfen (Kinetic treatment of nucleus formation in supersaturated steams). *Ann. Physik* **24**:719-52, **1935.**
4.	347	34	**Bergmann M & Zervas L.** Ueber ein allgemeines Verfahren der Peptidsynthese (A general method for peptide synthesis). *Chem. Berichte* **65**:1192-1201, **1932.**
5.	412	44	**Bernal J D & Fowler R H.** A theory of water and ionic solution, with particular reference to hydrogen and hydroyl ions. *J. Chem. Phys.* 1:515-48, **1933.**
6.	545	91	**Bethe H.** Zur Theorie des Durchgangs schneller Korpuskularstrahlen durch Materie (On the theory of the passage of corpuscular rays through matter). *Ann. Physik* 5:325-400, **1930.**
7.	303	30	**Bouckaert L P, Smoluchowski R & Wigner E.** Theory of Brillouin zones and symmetry properties of wave functions in crystals. *Physical Review* **50**:58-67, **1936.**
8.	1008	164	**Brunauer S, Emmett P H & Teller E.** Absorption of gases in multimolecular layers. *J. Amer. Chem. Soc.* **60**:309; **1938.**
9.	219	27	**Bunn C W.** The crystal structure of long-chain normal paraffin hydrocarbons; the 'shape' of the $=CH_2$ group. *Trans. Faraday Soc.* **34**:482-91, **1939.**
10.	227	41	**Davies C W.** The extent of dissociation of salts in water. 8. An equation for the mean ionic activity coefficient of an electrolyte in water, and a revision of the dissociation constants of some sulphates. *J. Chem. Soc.* 2093-98, **1938.**
11.	305	67	**Dunham J L.** The energy levels of a rotating vibrator. *Physical Review* **41**:721-31, **1932.**
12.	222	37	**Eyring H.** Viscosity, plasticity, and diffusion as examples of absolute reaction rates. *J. Chem. Phys.* 4:283-91, **1936.**
13.	194	21	**Fleury P F & Langues J.** Sur le dosage de l'acide periodique en presence de l'acide iodique (Determination of periodic acid in the presence of iodic acid). *J. Pharmacie Chimie* **17**:107-13, **1933.**
14.	165	33	**Fowler R H.** The analysis of photoelectric sensitivity curves for clean metals at various temperatures. *Physical Review* **38**:45-56, **1931.**

15. 259 40 **Fuchs K.** The conductivity of thin metallic films according to the electron theory of metals.
Proc. Cambridge Phil. Soc. **34**:100-08, **1938.**

16. 214 19 **Goeppert-Mayer M & Sklar A L.** Calculations of the lower excited levels of benzene. *J. Chem. Phys.* **6**:645-52, **1938.**

17. 195 40 **Hamaker H C.** The London-van-der-Waals attraction between spherical particles. *Physica* **4**:1058-72, **1937.**

18. 281 30 **Hammett L P & Deyrup A J.** A series of simple basic indicators. I. The acidity functions of mixtures of sulfuric and perchloric acid with water. *J. Amer. Chem. Soc.* **54**:2721-39, **1932.**

19. 207 28 **Higbie R.** The rate of absorption of a pure gas into a still liquid during short periods of exposure.
Trans. Amer. Inst. Chem. Engrs. **31**:365-89, **1935.**

20. 292 28 **Huckel E.** Quantentheoretische Beiträge zum Benzolproblem. 1. Die Elektronenkonfiguration des Benzols und verwandter Verbindungen (The quantum theory and the problem of benzene. 1. Electronic configuration of benzene and related compounds). *Zschr. Physik* **70**:204-86, **1931.**

21. 384 53 **Jahn H A & Teller E.** Stability of polyatomic molecules in degenerate electronic states. I. Orbital degeneracy.
Proc. R. Soc. London A Math. **161**:220-35, **1937.**

22. 273 49 **Kielland J.** Individual activity coefficient of ions in aqueous solutions. *J. Amer. Chem. Soc.* **59**:1675-78, **1937.**

23. 242 55 **Kirkwood J G.** The dielectric polarization of polar liquids.
J. Chem. Phys. **7**:911-19, **1939.**

24. 170 32 **Kirkwood J G.** Theory of solutions of molecules containing widely separated charges with special application to zwitterions.
J. Chem. Phys. **2**:351-61, **1934.**

25. 176 19 **Kirkwood J G & Westheimer F H.** The electrostatic influence of substituents on the dissociation constants of organic acids. 1.
J. Chem. Phys. **6**:506-12, **1938.**

26. 688 260 **Koopmans T.** Ueber die Zuordnung von Wellenfunktionen und Eigenwerten zu den einzelnen Elektronen eines Atoms (Relation of wave functions and eigen values to electrons of an atom). *Physica* **1**:104-13, **1934.**

27. 247 45 **Kubelka P & Munk F.** Reflection characteristics of paints.
Zschr. Techn. Physik **12**:593-601, **1931.**

28. 162 18 **Landau L & Lifshitz E.** On the theory of the dispersion of magnetic permeability in ferromagnetic bodies.
Phys. Zschr. Sowjetunion **8**:153-69, **1935.**

29. 200 31 **Landau L & Teller E.** Theory of sound dispersion.
Phys. Zschr. Sowjetunion **10**:34-43, **1936.**

30. 4633 640 **Lineweaver H & Burk D.** The determination of enzyme dissociation constants. *J. Am. Chem. Soc.* **56**:658-66, **1934.**

31. 164 23 **London F.** Zur Theorie und Systematik der Molekularkräfte (On the theory and systematics of molecular forces). *Zschr. Physik* **63**:245-79, **1930.**

32. 199 23 **Margenau H.** Van-der-Waals forces. *Revs. Modern Physics* **11**:1-35, **1939.**

33. 187 24 **Mott N F & Littleton M J.** Conduction in polar crystals. 1. Electrolytic conduction in solid salts. *Trans. Faraday Soc.* **34**:485-99, **1938.**

34. 606 101 **Onsager, L.** Electric moments of molecules in liquids. *J. Amer. Chem. Soc.* **58**:1486, **1936.**

35. 330 59 **Onsager L.** Reciprocal relations in irreversible processes. 1. *Physical Review* **37**:405-26, **1931.**

36. 268 47 **Onsager L.** Reciprocal relations in irreversible processes. II. *Physical Review* **38**:2265-79, **1931.**

37. 245 46 **Perrin F.** Mouvement Brownien d'un ellipsoide. I. Dispersion dielectrique pour des molecules ellipsoidales (Brownian movement of ellipsoids. I. Dielectric dispersion for ellipsoidal molecules). *J. Physique Radium* **5**:497-511, **1934.**

38. 218 32 **Perrin F.** Mouvement Brownien d'un ellipsoide. II. Rotation libre de depolarisation des fluorescences; translation et diffusion de molecules ellipsoidales (Brownian movement of an ellipsoid. II. Free rotation in depolarization of fluorescence; transfer and diffusion of ellipsoid molecules). *J. Physique Radium* **7**:1-11, **1936.**

39. 772 99 **Slater J C.** Atomic shielding constants. *Physical Review* **36**:57-64, **1930.**

40. 151 25 **Slater J C.** Wave functions in a periodic potential. *Physical Review* **51**:846-51, **1937.**

41. 199 32 **Taylor G I.** Plastic strain in metals. *J. Inst. Metals London* **62**:307-24, **1938.**

42. 202 27 **Thiele E W.** Relation between catalytic activity and size of particle. *Ind. Eng. Chem. Anal. Ed.* **31**:916-20, **1939.**

43. 167 18 **Van Vleck J H.** The Jahn-Teller effect and crystalline stark splitting for clusters of the form XY_6. *J. Chem. Physics* **7**:72-84, **1939.**

44. 164 25 **Weisskopf V & Wigner E.** Berechnung der naturlichen Linienbreite auf Grund der Diracschen Lichttheorie (Calculation of natural band width according to Dirac's theory of light). *Zschr. Physik* **63**:54-73, **1930.**

45. 232 50 **Wigner E.** On the quantum correction for thermodynamic equilibrium. *Physical Review* **40**:749-59, **1932.**

46. 386 44 **Wigner E P.** On unity representations of the inhomogenous Lorentz group. *Ann Math.* **40**:149-204, **1939.**

47. 199 22 **Willard H H.** Volumetric method for determination of fluorine. *Ind. Eng. Chem. Anal. Ed.* **5**:7-10, **1933.**

48. 314 25 **Wilson E B.** A method for obtaining the expanded secular equation for the vibration frequencies of a molecule. *J. Chem. Phys.* **7**:1047-52, **1939.**

49. 176 58 **Zener C.** Non-adibatic crossing of energy levels. *Proc. R. Soc. London A Math* **137**:696-702, **1932.**